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Decarbonization of maritime transport: to be or not to be?[1]

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Abstract International shipping is at a crossroads as regards decarbonization. The Paris climate change agreement in 2015 (COP21) was hailed by many as a most significant achievement. Others were less enthusiastic, and more recently American President Trump decided to take the U.S. out of the agreement. Four years earlier, the International Maritime Organization (IMO) had adopted the most sweeping piece of regulation pertaining to maritime greenhouse gas (GHG) reduction, in the name of the Energy Efficiency Design Index (EEDI). In addition, one year after COP21, the IMO adopted a mandatory data collection system for fuel consumption of ships and agreed on an initial strategy and roadmap on the reduction of GHG emissions from ships. This paper takes a critical look at the above and other recent developments and focuses on the challenges faced by the industry if a path to significant CO_2 reductions is to be successful. Difficulties and opportunities are identified, and the paper conjectures that the main obstacles are neither technical nor economic, but political.

Keywords: *emissions reduction, green shipping, decarbonization of shipping, CO_2 emissions from ships.*

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[1] Forthcoming in *Maritime Economics and Logistics.*

Introduction

International shipping is at a crossroads as regards decarbonization. The COP21 climate change agreement in Paris in 2015 was hailed by many as a most significant achievement. Others were not equally enthusiastic. The decision of American president Trump to steer the United States away from COP21 is the most recent of a series of developments on climate change. This particular decision has caused disappointment or even consternation to the broad spectrum of nations that endorsed the Paris agreement and has injected a new dose of uncertainty as to what may happen to climate change. Irrespective of the U.S. path, the COP21 agreement upheld the non-inclusion of international shipping (as well as aviation) within its mandate, something that has received mixed reviews by the international community. The rationale for the non-inclusion has been that action in these two sectors is within the mandate of the International Maritime Organization (IMO), for international shipping, and of the International Civil Aviation Organization (ICAO) for aviation. Some industry circles think this is correct, however environmental groups perceive this as a sign of inability or unwillingness to act and are not happy about it.

Before Paris, the most sweeping piece of regulation pertaining to maritime GHG emissions reduction was the adoption of the so-called Energy Efficiency Design Index (EEDI) by the IMO. This was agreed upon at the 62nd session of IMO's Marine Environment Protection Committee (MEPC 62) in July 2011. This was a no-consensus decision, as adoption was put to a vote in which a group of developing countries (such as China, India, Brazil, Saudi Arabia, South Africa and others) were firmly against the agreement. During the same session, the Ship Energy Efficiency Management Plan (SEEMP) was also adopted.

2011 was also the year the EU adopted the new Transport White Paper (EU, 2011), which targets drastic reductions in GHG emissions from all modes of transport in the EU by 2050. An aggregate 60% reduction vis-à-vis 1990 levels is stipulated. The target for maritime transport GHG emissions reduction is 40% and if possible 50%. Such targets are highly ambitious because the stipulated reductions are non-trivial. In addition, for the shipping sector (as will be further explained below) no credible pathway to reach such reductions is currently visible. So even though a detailed implementation plan has also been proposed in the White Paper, at least for maritime transport it is not immediately clear how or if the above reduction targets can be realized.

There have also been some setbacks. For instance, the discussion on a possible adoption of Market Based Measures (MBMs) for GHGs, initiated in 2010 at the IMO and entailing a comprehensive review of some 11 MBM proposals, was finally suspended in 2013. Relevant discussion was re-channelled toward a system for Monitoring, Reporting, and Verification (MRV) of CO_2 emissions, as will also be explained later.

Progress after COP21 was equally mixed. At the IMO, a roadmap was agreed in October 2016. The roadmap foresees the adoption of an *initial strategy* in 2018 to meet the targets of COP21, which entered into force in November 2016. The strategy will be validated by actual emission figures gathered through the IMO's *fuel data collection system* as of 2019. This will then lead to a final agreement on targets and measures, including an implementation plan, by 2023. On the more controversial side, perhaps the most significant development has been the February 2017 vote of the European Parliament (EP) to include shipping into the EU Emissions Trading Scheme (ETS) as of 2023, in case no global agreement is reached by 2021, and the subsequent (November 2017) alignment of the EU process with that of the IMO. The EP vote had raised extensive voices of protest from industry circles such as ECSA (European Community Shipowners Associations), ICS (International Chamber of Shipping) and many national shipowner associations. The shipping industry is concerned that an EU ETS may create significant distortions and obstacles for efficient trade, may not be compatible with the IMO roadmap, and in fact may not be a good instrument for reducing GHG emissions.

The above and other related recent developments beg the question, where does international shipping currently stand as regards decarbonization? This paper takes a critical view by discussing recent developments and by focusing on some of the challenges faced by the industry if a path to significant CO_2 reductions is to be successful. Difficulties and opportunities are identified, and the paper conjectures that the main obstacles are neither technical nor economic, but political.

The rest of the paper is organized as follows. The section that follows discusses the EEDI track as regards decarbonization, which is to date the only mandatory track. Then the next section focuses on MBMs, the second track that has been followed but later suspended. The final section comments on the way ahead.

The EEDI track

Basics

The regulatory approach to reduce maritime GHG emissions has evolved along two tracks: (a) the EEDI track, and (b) the MBM track. These tracks have evolved in parallel, in the sense that they have been discussed at the IMO by and large separately and with little or no interaction with one another. We note however that some MBM proposals embed EEDI in their formulation, so in a strict sense the two tracks are not really parallel.

The so called Energy Efficiency Design Index (EEDI), adopted by the IMO in 2011 as an amendment of MARPOL's Annex VI (IMO, 2012), is thus far the most important (and in fact thus far the only mandatory) regulatory instrument for maritime GHG emissions reduction. EEDI basically aims to induce changes *at the technological level* that would bring about GHG reduction in the world fleet.

For a specific ship of 400 GRT and above, and built as of 1/1/2013, its EEDI is computed by the following formula:

$$\frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right) + \left(\left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}**\right)}{f_i \cdot f_c \cdot Capacity \cdot f_w \cdot V_{ref}} \quad (1)$$

We need not explain all these symbols here. The numerator in (1) is the total CO_2 emissions produced by the ship and is a function of all power generated by the ship (main engine and auxiliaries). The denominator is a product of the ship's capacity (usually deadweight) and its 'reference speed', defined as the speed corresponding to 75% of

Maximum Continuous Rating (MCR), the maximum power of the ship's main engine. The units of EEDI are grams of CO_2 per tonne mile.

The EEDI of a specific ship, also known as *attained EEDI*, as computed above, is to be compared with the so-called *EEDI (reference line)*, which is only a function of ship type and DWT (deadweight) and is defined as follows:

$$\text{EEDI (reference line)} = a\text{DWT}^{-c} \qquad (2)$$

In (2), *a* and *c* are positive coefficients which have been determined by regression from the world fleet database, and have been finalized for each major ship type after a long debate within the IMO. They are presented in Table 1 below.

Table 1. EEDI reference line parameters a and c for various ship types

Ship type	a	c
Bulk carrier	961.79	0.477
Gas carrier	1120.00	0.456
Tanker	1218.80	0.488
Container ship	174.22	0.201
General cargo ship	107.48	0.216
Reefer	227.01	0.244
Combination carrier	1219.0	0.488

Source: IMO (2012)

For a given ship, the requirement for EEDI compliance is that the attained EEDI value should be equal to, or less than, the so-called *required EEDI* value. The required EEDI value is proportional to the value of EEDI (reference line), as defined in (2), and the requirement can be written as follows:

$$\text{Attained EEDI} \leq \text{Required EEDI} = (1\text{-X}/100)\ a\text{DWT}^{-c} \qquad (3)$$

where X is a *reduction factor* ranging from 0% to 30% as explained below.

The *rationale* for factor X seems to be the wish of IMO policy makers to see newer ships becoming more energy efficient in the future, and therefore have a lower EEDI, than ships of similar type and size built earlier. To do so, the specified values of X are X=0% for ships built from 2013-2015, X=10% for ships built from 2016-2020, X=20% for ships built from 2020-2025 and X=30% for ships built from 2025-2030. One can see that X gradually increases from 0% to 30%, therefore the upper bound for the attained EEDI in (3) is gradually reduced as we move towards 2025. This means that the requirement for EEDI compliance becomes more stringent in the years ahead.

The horsepower limit deficiency

Let us now compare the formula for EEDI, equation (1), and the requirement for EEDI compliance, inequality (3). In (1), the traditional assumption, which comes from marine hydrodynamics, is that the ship engine's MCR, which is in the numerator of (1), grows to the cube of speed, V^3, where V is the reference speed that appears in the denominator of (1). This means that EEDI grows like V^2. In (3), speed does not enter the formula at all. It is straightforward to check that this combination is tantamount to imposing an upper bound on speed, corresponding to 75% MCR, and this would translate to an upper bound on MCR itself. Thus, in the quest of EEDI compliance, one would run the risk to see the construction of underpowered ships, which would be less safe to navigate and which, in their attempt to go faster or just maintain speed in bad weather, would emit disproportionately more CO_2.

Perhaps more important, this might also shift the focus of action from designing the best possible hull forms, engines or propellers, which is the intended aim of EEDI, to the easy solution: just reduce speed at the design level, or equivalently, MCR. This means that any bad or totally inefficient design could be made acceptable with the easy way out: a reduction in 'design speed' (and horsepower). Note that such a reduction would be required to be more steep as we move to the various phases of EEDI implementation (reduction factor X going from 0% in 2013 to 30% in 2025). The existence of the above easy way out can hardly serve as an incentive for more efficient future ship designs.

Additional possible side-effects might include (a) adding more ships to match transport demand, with a potential risk to maritime safety due to increased ship traffic; (b) increasing cargo inventory costs due to delayed delivery; (c) increasing freight rates due to a reduction in ton-miles; (d) reduced manoeuvrability and thus navigational safety; and (e) inducing reverse modal shifts to land-based modes (mainly road), something that would increase overall GHG emissions (elaboration on these points is beyond the scope of this paper. For a discussion of potential problems associated with EEDI, see Devanney (2011) and Krüger (2011), among others).

Alternative EEDI formulations

As a way to alleviate the above deficiency, one could try looking at various alternative formulations that introduce speed to the EEDI (reference line) formula, namely functions of the form:

EEDI (reference line) = $a(DWT/V)^{-c}$, or
EEDI (reference line) = $a(DWT/V^2)^{-c}$, or finally
EEDI (reference line) = $aDWT^{-c}V^{-d}$,

where again V is the reference speed that corresponds to 75% of MCR and a, c and d are coefficients determined by regression. The use of alternative formulations that incorporate speed in the reference line formula was proposed by some IMO delegations, but not further considered. In fact this author and his colleagues looked at the above three alternatives, but none proved much better than the current formula. By contrast, a fourth alternative was tried upon and proved more promising, as explained below.

Consider modifying the formula for EEDI (reference line) as follows:

Alternate formula: EEDI (reference line) = $aDWT^{-c}V^k$, with k=2 or 3. (4)

That is, one multiplies the right-hand side of the current inequality (3) by the square or the cube of the reference speed V. The formula for EEDI remains unchanged. As before, coefficients a and c are determined by regression. These coefficients will be different in the alternate formula from what they are in the current (standard) one.

The rationale for such a proposal is simple. As mentioned earlier, if the numerator of EEDI grows like V^3 and the denominator grows like V, EEDI will grow like V^2. If EEDI (reference line) is independent of speed, to obtain an EEDI at or below the reference line would mean that an upper bound should be placed on V, with all the repercussions discussed earlier. One way to overcome this problem is to try to redefine EEDI (reference line) as being proportional to V^2. A similar rationale pertains in case the numerator of EEDI grows like V^4, which may be the case for faster ships, such as containerships.

We note here that the idea of using the square of speed to alleviate potential deficiencies in the EEDI is not new. Already (former) German classification society Germanischer Lloyd had suggested a function of the square of the ship's Froude number (which is proportional to speed) to be included in the denominator of the EEDI formula for high speed craft (Köpke and Sames, 2009). Here, something similar is considered, but the EEDI formula is kept intact, and V^2 (or V^3) is included in the reference line formula.

To test the alternate formula, this author and his colleagues performed a set of regression analyses for bulk carriers, tankers and containerships, using the Lloyds Register Fairplay Sea-Web™ database. As in the standard regressions, outliers more than 2 standard deviations have been removed. The results are shown in Table 2 below.

Table 2. Regression results for EEDI (reference line)

Ref. line	**Reference**	**Bulk carriers**	**Tankers**	**Containerships**
Standard eq. (2)	IMO (2011a)	$961.79DWT^{-0.477}$ ($R^2 = 0.93$)	$1,218.80DWT^{-0.488}$ ($R^2 = 0.96$)	$186.52DWT^{-0.200}$ ($R^2 = 0.62$)
Modified eq. (4), k=2	IMO (2010a)	$10.913DWT^{-0.555}V^2$ ($R^2 = 0.91$)	$19.164DWT^{-0.599}V^2$ ($R^2 = 0.96$)	$12.74DWT^{-0.534}V^2$ ($R^2 = 0.92$)
Modified eq. (4), k=3	This paper	$1.1712DWT^{-0.594}V^3$ ($R^2 = 0.89$)	$2.3366DWT^{-0.652}V^3$ ($R^2 = 0.95$)	$3.5918DWT^{-0.707}V^3$ ($R^2 = 0.93$)

The k=2 regressions were reported in IMO document (IMO 2010a) but thus far they have not been published. The k=3 regressions appear here for the first time.

An interesting observation from Table 2 is the very high correlation coefficient (R^2) for containerships (0.92 and 0.93), much higher than the equivalent coefficient in the standard reference line (0.62, rather poor). There is no easy explanation of this result, other than the conjecture that for containerships the modified EEDI formulation is better tailored to the data. The correlation coefficients for the other two ship types are of the same order of magnitude as those of the standard reference line. Figure 1 shows the k=2 case for containerships.

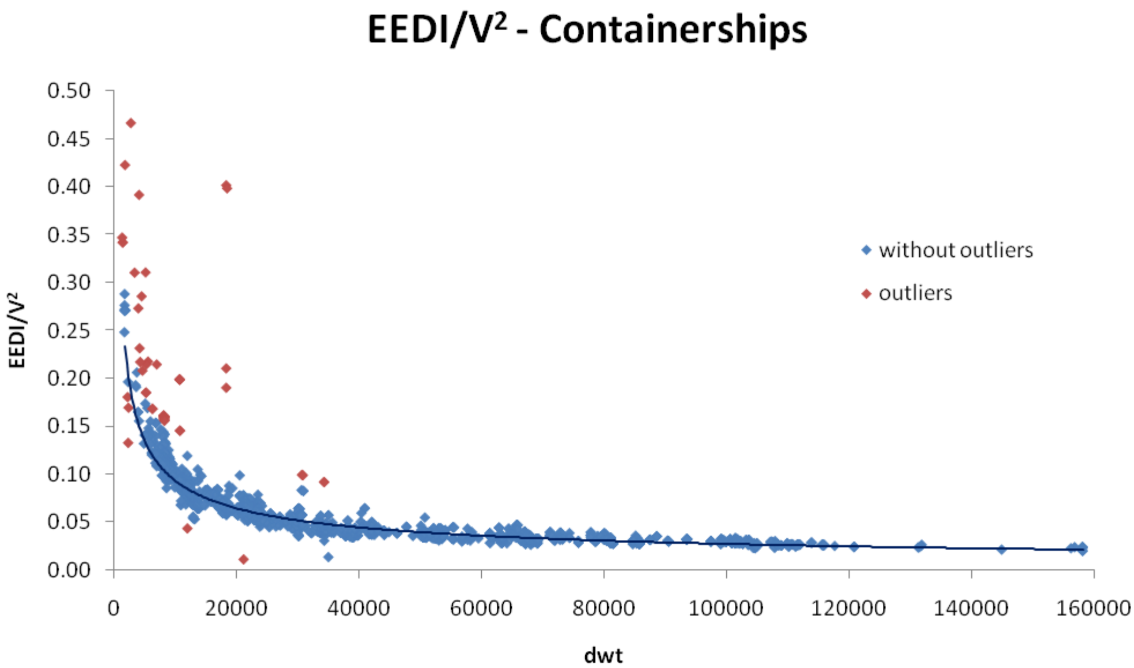

Figure 1. Modified EEDI regression for containerships (k=2)

However, the alternate formula's most important advantage over the official one lies not so much in its very good R^2, but in the significant alleviation (or even elimination) of the MCR limit effect. The extent of this would depend on the exact functional dependency between MCR and V. If this is cubic, as is the standard accepted assumption, the MCR limit effect will be essentially eliminated. If the exponent is higher than 3, as may conceivably be the case for containerships, MCR reduction will still be an alternative, but one could not use speed to the same extent as before.

The V^2 alternative was proposed to the IMO about a year before EEDI was eventually finalized (IMO, 2010a). But after some discussion, the proposal was rejected. The stated reason was that *"the power reduction option, together with technological innovations, should be retained to ship owners and ship designers as a measure to improve energy efficiency of ships"* (IMO, 2010c). In this author's opinion, the real reason of the rejection was that opening a discussion for what seemed like a radical change in the EEDI formulation would detract from the finalization of EEDI which was very pressing. In other words, political expediency to close EEDI took precedence over a technical discussion on possible EEDI alternatives that might conceivably alleviate some of the problems associated with it.

The V^3 alternative (also shown in Table 2) never reached the IMO. However, one can see a very high (or even higher) R^2 for containerships in that case as well. Such an alternative might make sense in case fuel consumption grows, e.g. to the fourth power of speed, situation which is more likely to be the case for containerships, and which can probably explain the high R^2.

Why would these results, which are admittedly dated, be relevant several years later? It turns out that the horsepower deficiency has been recognized at the IMO. Since 2011, a serious discussion has ensued, both within MEPC and MSC (IMO's Maritime Safety Committee) on how to reconcile EEDI compliance with the minimum safe power requirement (see for instance IMO (2011c), among many other documents). But the approach for such a reconciliation does not involve modifying the EEDI formulation. Having seen recent documents submitted to the IMO (see for instance IMO (2017a)), in our opinion an impasse cannot be ruled out. The impasse revolves around the dilemma between (a) seriously downgrading the requirements for ships, so as to be able to safely navigate in adverse weather conditions, and (b) admitting that the whole EEDI formulation needs to be radically modified. The latter is already the case for Ro-Ro vessels. For these, the EEDI formulation is more complex, as some coefficients in the EEDI formula are not constant. The EEDI for this type of vessel is thus currently under reconsideration by the IMO, as some industry stakeholders have reported problems with the current formulation.

Based on the above, and given that the baseline for the required EEDI is gradually being reduced in the years ahead (X in (3) going from 0% to 30%), it will be increasingly challenging for a ship to be EEDI compliant and have adequate minimum safe power at the same time, unless of course the EEDI guidelines are modified. An exception would be if there is a quantum leap in improving energy efficiency in the foreseeable future, but this does not seem likely to occur.

From EEDI to EVDI

Ship energy efficiency vetting schemes such the Existing Vessel Design Index (EVDI) promoted by the Carbon War Room and RightShip are based on the EEDI concept. EVDI is supposed to aid charterers choose an energy efficient ship. The formula for EVDI is the same as that of EEDI, the difference being that EVDI is applied to all ships, existing and future, whereas EEDI is to be applied only to ships built from 2013 on.

A central assumption of proponents of such schemes -and in fact the whole philosophy of the EVDI scheme is based on that assumption- is that owners of ships on time- or bareboat charter may have little or no incentive to adopt measures for the reduction of fuel consumption (and hence emissions) of their ships, since the fuel is paid for by the charterers and not by themselves. In such a case, the EVDI scheme comes in and assists charterers in their selection of a fuel efficient ship.

However, the above assumption is incorrect. When a ship is on time charter, the ship's consumption at various speeds is clearly described in the charter agreement. The ship's capacity, and consumption are evaluated by the charterer before the contract is signed. A ship with a higher consumption at a given speed will receive a lower charter rate than a ship with a better consumption curve. If during the charter the ship does not fulfil the agreement terms regarding fuel consumption, the charterer will lodge a claim on the ship and deduct monies accordingly as compensation for his contractual loss. 'Speed claims' are common and they may end in arbitration or in court. Thus the owner of a ship on time charter has every incentive to economize on fuel consumption while on time charter.

The use of EEDI for ships built prior to 1/1/2013 has not been allowed by the IMO, and there has been a long discussion justifying that decision. The *rationale* for such a decision was that EEDI, being a design index, should not have retroactive applicability. But EVDI is applicable universally to the whole fleet, even to ships built prior to 2013.

EVDI, like EEDI, is calculated assuming a basic design speed for the vessel. As in EEDI, this is the speed corresponding to 75% of the ship's MCR. The typical assumption is that such design speed is the one recorded and displayed in world fleet databases, which are available commercially. Yet, this may not be the case, as in some cases the design speed recorded in such databases (for instance, IHS Fairplay) is reported to be *at the 100% MCR level*. When the aforementioned regression analyses on EEDI were performed, we called the developer of the commercial fleet database that was used and asked who had provided the broad set of ship particulars that is in the database. The answer was that shipowners were the main source of such information, and this included design speed. As there is no independent verification of such information, inaccuracies in the value of the design speed can translate into inaccuracies in the computed value of EEDI, and, by extension, EVDI. In IMO (2011d) it was reported that even identical sister ships built by the same yard in the same period as part of a series program have EEDIs varying between 8% and 10%, the sole reason being different entries for the design speed recorded in the fleet databases. Such inaccuracies in the data also translate into EVDI, whose scope is broader than EEDI's.

But even in the hypothetical case of perfect information on the assumed value of the 75% MCR speed, commercial ships do not necessarily trade at that speed, or at any other predetermined speed. Whoever pays for the fuel (owner or charterer) will select an appropriate speed which is a function of basically two factors: fuel price and freight rate. High fuel prices and/or low freight rates will induce slower speeds and hence lower fuel consumption. Conversely, low fuel prices and/or high freight rates will induce ships to speed up. Slow steaming, a much prevalent practice these days, may involve speeds drastically lower than the 75% MCR speed, and the corresponding reduction in fuel consumption will be even higher. This basic behavior cannot be captured by the EVDI index, therefore rankings according to this index may give a distorted picture of the actual comparison of two vessels in real market and operating conditions.

Based on all of the above, and in our opinion, the concept of EEDI, which is at this point in time the only mandatory instrument to reduce GHG emissions from ships, even though formulated and implemented with the noblest of intentions, suffers from some basic deficiencies. These will have to be resolved if one is to see a credible dent on GHG emissions in the future. However, how or if these deficiencies will be resolved seems pretty much open at this point in time.

The MBM track

Basics

Let us now turn to the second most important instrument that the IMO has considered in order to curb GHG emissions. This has been the class of Market Based Measures (or MBMs). By and large, and following the 'compartmentalization' process that is prevalent in many of these discussions at the IMO and other fora, the MBM track has run in parallel to (and has been independent of) the EEDI track, even though there have been cross-linkages between the two, as some MBM proposals embedded EEDI into their formulation.

In 2010, an IMO Expert Group, appointed by the IMO Secretary General, and chaired by none other than the (then) Chairman of the MEPC, was tasked to evaluate as many as 11 separate MBM proposals, submitted by various member states and other organizations. Members of the Expert Group were nominated by IMO member states and observer organizations. This author was a member of the group. The range of expertise in the group was broad, ranging from experts on various 'technical' issues (such as for instance emissions modelling, cost estimation, economic impact assessment, legal language formulation, and others) to people of 'political' orientation. For instance, the ambassador of an IMO member state to the UK was a member of the group. Such a diversity had both pros and cons. On the positive side, looking at the subject from various angles and by people of diverse background was definitely a plus. However, political considerations hampered a speedy closure of this work, and ultimately did not help as regards its final outcome.

All MBM proposals described schemes that would target GHG reductions through either *in-sector* emissions reductions from shipping, or *out-of-sector* emissions reductions via the collection of funds and the spending of such funds to reduce emissions outside the maritime sector (for instance, building a wind farm in New Zealand or a solar farm in Indonesia). By making shipowners pay for their ships' CO_2 emissions, an MBM is an instrument that can implement the 'polluter pays' principle. In that sense, it may help internalize the external costs of these emissions.

The IMO formulated a list of criteria for the evaluation of the MBM proposals, including environmental effectiveness, practical feasibility, administrative burden, compatibility with existing legal frameworks and others.

The following MBM proposals were submitted to the IMO and these could be classed into the following categories:

- The so-called International GHG Fund proposal (submitted by Cyprus, Denmark, Nigeria and the International Parcel Tanker Association-IPTA). Even though its proposers avoided the use of the words 'levy' or 'tax' and used the word 'contribution', this MBM was essentially a levy on fuel.
- Four distinct Emissions Trading Scheme (ETS) proposals (submitted separately by Norway, UK, France, and Germany).
- Three distinct hybrid proposals, all embedding EEDI in their formulations: the Ship Efficiency and Credit Trading (SECT) proposal (submitted by the USA), the Leveraged Incentive Scheme (LIS) proposal (submitted by Japan) and the Vessel Efficiency Scheme (VES) proposal (submitted by the World Shipping Council-WSC)
- The so called Port-Based proposal (submitted by Jamaica)
- The so called Rebate Mechanism proposal (submitted by the International Union for the Conservation of Nature- IUCN)
- The Bahamas proposal, the basic version of which was essentially a 'do-nothing' proposal.

The MBM Expert Group met in several sessions and produced a 300-page report (IMO, 2010b) with a detailed analysis of the 11 MBM proposals, including a discussion of alternative scenarios as regards fuel prices, projected emissions growth, and other parameters. The group's modeling effort, which also involved the work of external consultants, was to develop and apply a model to make quantitative estimates of emissions reductions, revenues generated, costs and other attributes of each MBM proposal.

Marginal Abatement Costs

The results of the modeling exercise critically hinged upon the input data that was used, plus the multitude of modeling assumptions that were made. A central role in the analysis was played by the so-called *Marginal Abatement Cost* (MAC) curves. The MAC of a specific CO_2 reduction measure, such as a specific technology or other, is defined as the ratio of the net cost to implement that measure, divided by the amount of CO_2 it can avert (for a definition see Eide et al, 2011, among others). Its unit of measurement is dollars per tonne of CO_2 averted. In turn, *a MAC curve* is the curve defined by the MACs of all conceivable measures that can reduce CO_2 and rank-ordered by increasing order of MAC. It is clear that if the MAC of a specific measure is negative, the shipowner would profit from implementing it and there would be no need to mandate the measure, making this a potential win-win proposition. If on the other hand a measure has a positive MAC, it would have to be mandated to be implemented, as it would imply a net cost to the ship owner.

Figure 2 shows a sample of such MAC curves, taken from the IMO Expert Group report on MBMs (IMO, 2010b) and produced by (former) Norwegian classification society Det Norske Veritas (DNV), who was commissioned by the IMO for the task. To do so, DNV used a model developed in-house.

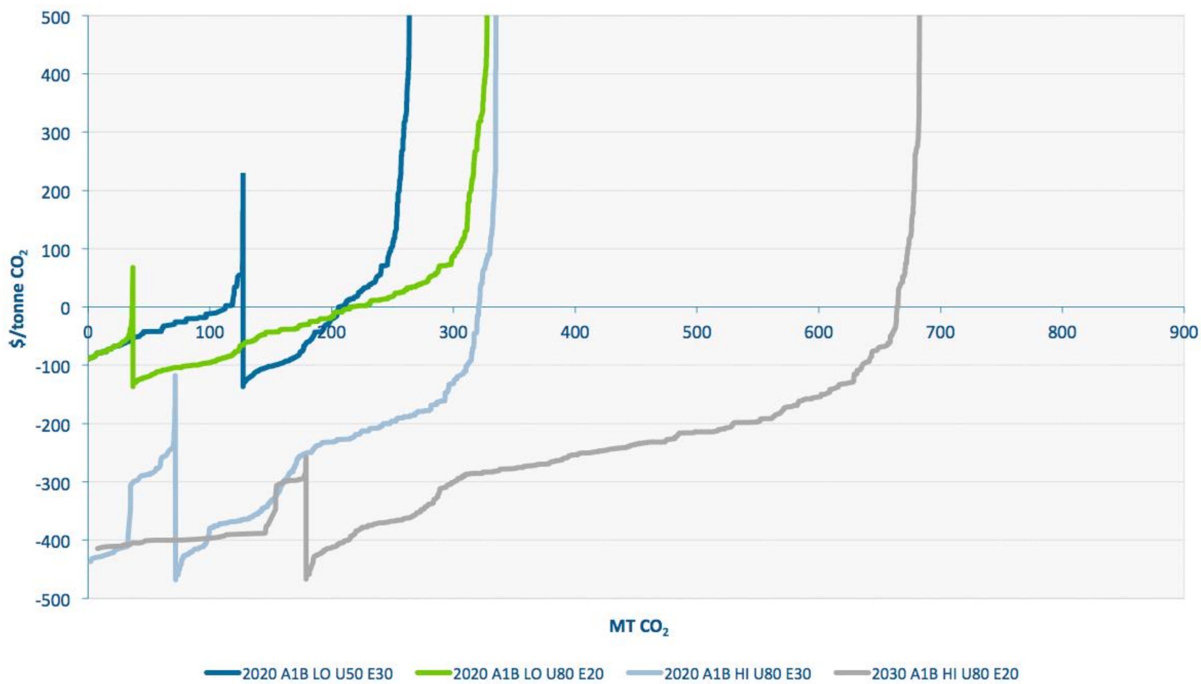

Figure 2. Sample MAC curves by DNV. Source: IMO (2010b).

One can observe from Figure 2 that some of the MAC curves are not monotonic, meaning that some measures may take precedence over other measures even though their MAC is higher. Irrespective of this, it turned out that these MAC curves were plagued by serious deficiencies.

A basic deficiency was that the MAC model, together with all of its relevant data, were unavailable to scrutiny by the IMO Expert Group, due to confidentiality clauses. This contradicted a fundamental principle of scientific research: if models used by policy-makers are not made available for scrutiny by the experts or anybody else (remaining virtually a black box), then obviously the correctness of their results cannot be confirmed. In that sense, this author expressed strong reservations on all the numerical results of this exercise. By and large, such reservations were ignored.

Other deficiencies of the approach were: (i) no interdependencies among relevant technologies were considered, (ii) among the various measures to reduce emissions, ‘speed reduction’ was also included, even though speed reduction is not an independent measure but a *logistical response* to an MBM, and (iii) no second order effects, that is, the effect of speed and fuel consumption reduction as a result of the MBM, were considered. At least as a result of these deficiencies, the whole analysis of the Expert Group on MBMs (IMO, 2010b) was seriously questionable.

Anyway, and even though some group members, including this author, pressed for the contrary, the group’s report contained no recommendation on any specific MBM proposal that could be chosen. The report did not even contain *a short list* of MBMs, keeping all of them on the table. It would thus seem that the political concerns of not displeasing any of the MBM proposers prevailed over the need to move on and close the subject. In fact, discussion on MBMs at the IMO level after 2010 was not very productive. The period to July 2011 focused on the adoption of EEDI, and not much was done on MBMs. The period immediately after the adoption of EEDI focused on practical matters involving its implementation and again there was little discussion on MBMs. A proposal by Greece in 2012 (who had submitted no MBM proposal of its own) for the IMO to decide on a short-list of MBMs (essentially a bunker levy and ETS) was rejected. All MBMs continued to be on the table, with the exception of the one by the Bahamas, which was withdrawn. Again, the decision to keep all MBMs on the table and displease none of the proposers might look like a politically correct decision, but one that ultimately proved counter-productive.

Indeed, and in addition to the almost complete lack of consensus among the MBM proposers (except for those promoting ETS who had a common position), the same group of developing countries (China, India, Brazil, Saudi Arabia, et al.) were as much against any MBM as they were against EEDI, particularly after they lost the EEDI vote in 2011. Their main objection was mainly on the ground that MBMs were not compatible with the principle of *Common But Differentiated Responsibilities and Respective Capabilities (CBDR-RC).*

Suspension of the MBM discussion

If one could just single out *one* factor that has been a serious obstacle for *any* progress on the GHG front since Kyoto in 1992, this is definitely CBDR-RC (or simply CBDR, as it was known earlier). This has been the main political argument of a group of developing countries (see above) to resist GHG emissions reduction, not just for shipping but across the board, on the ground that this would impede their economic development. In that sense, the stance of these countries was that their obligation to reduce GHGs should be less stringent than that of developed countries. It is however clear that this would be incompatible to the principle that any measure for GHG reduction should be *non-discriminatory*, so as to maintain a level playing field. At least in shipping, a sector which is based on the notion of free and fair competition, this principle is of paramount importance. For a discussion of current CBDR-RC issues, not necessarily related to shipping, see, among others, Tigre (2016) and Voigt and Ferreira (2016); for *shipping*, see, among others, Wang (2010).

Another issue of political disagreement at the IMO has been the way by which funds collected by the MBM would be used for the benefit of developing countries (capacity building, technology transfer, etc). Among industrial stakeholders, the International Chamber of Shipping (ICS), BIMCO and several shipowners' associations came out against an ETS, on the ground that it would be unworkable for the shipping industry, mainly for reasons associated with the ETS administrative burden and with the less than clear connection between carbon credits, purchased at a point in time, to emissions produced later (incidentally, this is not a problem with a bunker levy, for whoever pays for the fuel will directly adjust ship speed as a result of the levy). Interestingly enough, the German and Norwegian shipowners' associations came out against ETS, even though their national maritime administrations were in favour of it.

In May of 2013, the MEPC decided to suspend discussions on MBMs. This was accompanied by a channeling of the discussion towards the subject of Monitoring, Reporting and Verification (MRV) of CO_2 emissions. Today, and more than 4 years later, the MBM discussion at the IMO remains suspended, with no visible sign of reappearance any time soon.

Enter the European Parliament

A new twist in the MBM saga came with the February 2017 vote of the European Parliament (EP) to include shipping into the EU ETS as of 2023, in case no global agreement is reached by 2021. This followed a recommendation of the EP's Environment (ENVI) Committee to that effect in December 2016. As mentioned earlier, this caused serious concern among industry stakeholders that such a *regional* MBM would create serious distortions, not to mention that it might not necessarily reduce maritime CO_2 emissions. As an example, a ship calling at Kaliningrad, Russia, might be able to avoid the EU ETS. If so, one might see *that* Baltic port establishing itself as a regional hub, creating distortions in intermodal flows and ultimately more CO_2 in the supply chain. The same may be true for African or other non-EU ports in the Mediterranean or elsewhere. We know of no analysis of such possible distortions or other side-effects.

In November 2017, and after some negotiations between the EP and the EU Council of Ministers, it was agreed to align the EU with the IMO process, and essentially refrain from taking action on ETS before seeing what the IMO intends to do on GHGs. Industry circles, concerned with the effects of an early EU ETS, welcomed this development. However, the European Commission will closely monitor the IMO process, starting from what is agreed on the initial strategy in 2018 and all the way to 2023. Whether or not this latest agreement at the EU level might put some pressure on the IMO to resume the suspended discussion on MBMs and adopt a global MBM before the EU moves on ETS is unclear at this time. And even though the ETS looks like the default scenario for the EU, if progress at the IMO is not deemed satisfactory, precisely what action the EU will take and when that action will be taken is equally unclear (for a discussion of the relevant concepts for MBMs and a description and comparison of the 11 MBM proposals to the IMO, see Psaraftis (2012, 2016)).

The way ahead

The MRV double track

After the suspension of the MBM discussion in 2013, activity shifted to the subject of Monitoring, Reporting and Verification (MRV) of CO_2 emissions. The purpose of MRV is to monitor the energy efficiency and CO_2 emissions of the world merchant fleet. In order to document and track global energy efficiency gains, data from ships must be collected and a robust data collection and reporting system must be established.

It is clear that MRV by itself can not directly lower CO_2 emissions, even though increased awareness of a ship's fuel consumption may induce the shipowner to adopt measures to reduce it. More important, MRV can be the first necessary step for subsequent measures to effectively reduce emissions. In that sense, the suspended discussion on possible MBMs can only resume whenever an efficient and effective global MRV system is established. The same is the case for any other emissions reduction measures that may be implemented at the operational level. This means that any MRV system will have to be designed with a longer term view on what will be the next step, after the MRV is established. To this author at least, it is clear that the next step will be an MBM, whose nature would actually depend very much on the nature of the MRV system that will be adopted.

A problem here is that there is not one MRV system at play, but two. One is the IMO scheme, and the other is the EU one. Indeed, and before the IMO had finalized its own discussion on MRV, the EU adopted Regulation 2015/757 on MRV (EU, 2015), the implementation of which is currently under way. The Regulation applies to vessels above 5,000 GRT of all flags conducting voyages into, out of and between EU ports and will require annual reporting of their CO_2 emissions in line with an approved monitoring plan. Actual fuel consumption for each voyage can be calculated using one of the following four alternate methods, provided that the method selected is pre-defined in the monitoring plan and, once chosen, is applied consistently: (a) bunker fuel delivery notes and periodic stocktakes of fuel tanks, (b) bunker fuel tank monitoring on board, (c) flow meters and applicable combustion processes, and (d) direct emissions measurements.

A number of certified independent MRV verifiers are expected to assess and approve the shipping companies' monitoring schemes, and also verify their subsequent reports of CO_2 emissions. Shipping companies of any flag, whose ships are expected to call at EU ports are expected to file their reporting schemes by August 31, 2017 and their MRV reports starting in 2018. In that sense, the EU MRV, even though it is a regional measure, has a global reach.

The MRV scheme used by the IMO has some key differences vis-à-vis the EU scheme. Cargo reporting is considered mandatory in the EU scheme whereas this is not the case at the IMO level. Some operators have voiced concern that such additional data required by the EU scheme may be sensitive and not so easy to disclose, not to mention that two distinct reporting systems would pose significant additional administrative burden. In addition, discrepancies between what will be agreed on a global level and any regional legislation can create distortions and a non-level playing field. It should be noted that the EU MRV Regulation has a clause that it *may* revert to the IMO scheme if the latter is deemed satisfactory. But at this point in time the two regimes are different and it is not clear if or when they will be harmonized. Moreover, when or if an MBM is eventually adopted, it is not clear how it would be able to be implemented if two different MRV systems exist. A question would be if the MBM is tailored to the global, IMO MRV, or to the regional, EU MRV. Another question is whether there would be two separate MBMs, one for each MRV system. Needless to say, if such a thing happens, things will become very cumbersome.

The IMO roadmap

The IMO roadmap, adopted in October 2016, foresees the adoption of an initial strategy in 2018 to meet the targets of the COP 21, which entered into force in November 2016. The initial strategy will be validated by actual emission figures gathered through the IMO's fuel data collection system as of 2019. This will then lead to a final agreement on targets and measures, including an implementation plan, by 2023. However, there is currently nothing in this roadmap that would mandate GHG emissions reductions. At the latest meeting of the IMO MEPC (MEPC 71), held in July 2017, a working group on reduction of GHGs from ships continued work towards developing a comprehensive IMO strategy in accordance to the roadmap (IMO, 2017b). In that sense, MEPC71 noted a draft outline for the structure of an *initial* IMO strategy on reduction of GHG emissions from ships, including, *inter alia*, a vision, the level of ambition, a list of candidate measures, barriers and supportive measures, and possible follow-up actions. However, all these are yet to be developed and no visible measures, or even targets, are yet in sight.

From a certain perspective, this situation can explain the European Parliament's rush to include shipping within the EU ETS if no global agreement is reached by 2021, two years ahead of IMO's 2023 milestone. However, the latest development at the EU level has aligned the EU approach with that of the IMO, making unlikely any rush by the IMO to adopt a global MBM before 2023 so as to pre-empt EU action on ETS earlier. In fact, we believe that there is little in the policies that are being currently pursued that would really guarantee *significant* fuel consumption (and hence GHG emissions) reductions in the years ahead. The EEDI is plagued by the problems outlined earlier. The MBM track is dead, at least for the foreseeable future, for the reasons outlined above. As this paper was being finalized, an IMO Intersessional Working Group on the reduction of GHGs from ships held a one-week meeting (October 2017), meant to make progress on the initial IMO strategy, with a view to finalize it and come up with concrete proposals by MEPC 72 (April 2018). Shipping decarbonization was also discussed at a COP23 event in Bonn (November 2017), however this event was not directly linked to the regulatory process (COP23, 2017). Substance-wise, and even though it is conceivable that an agreement can be reached in one of the forthcoming IMO meetings, the nature and level of ambition of such an agreement are pretty open at this point, and divergence of views is still very wide. In that sense, and in spite of much talk about the maritime industry's commitment toward serious GHG emissions reductions, it is fair to say that such reductions are, as things stand, only a wish at this point in time.

A simple yet risky idea

One idea that might be worth considering, but which at the present time is not on the table in any policy forum, global or regional, nor has it been adequately studied from a research viewpoint, would be to impose a *significant* bunker levy on a global level. By significant we mean not 10 or 20 USD per tonne of oil, as is being occasionally contemplated by industry, but *at least one order of magnitude higher*. This would induce both technological changes in the long run and logistical measures in the short run. In the long run, it would lead to changes in the global fleet towards vessels and technologies that are more energy efficient, more economically viable and less dependent on fossil fuels than those today. In MAC terms, it would make negative the MAC of many technologies that currently have a positive MAC, thus inducing shipowners to adopt them. In the short run, a bunker levy would lead to slow steaming, which would reduce fuel costs and emissions at the same time.

To understand the link between fuel price and technology used, a parallel to the automotive industry can be made: it is clear that the significant fuel price difference among the US on the one hand and Europe and Japan on the other (ratio of approximately 1 to 2) is reflected in a similar major difference in these countries' automobile fleet profiles, as well as GHG emissions performance, which for the US is way behind what it is in Europe and Japan (An and Sauer, 2004). There is no serious incentive to build or use fuel efficient cars if fuel prices are low, and hybrid and electric cars would have no such market penetration today were it not for the considerable state subsidies granted to them. Such subsidies are in fact MBMs, and without them we would not see either the development or the use of such technologies in the automotive sector. That this story has not yet found a parallel in the maritime sector is, at least to this author, intriguing.

A maritime bunker levy could also collect monies that could be used to achieve *out -of-sector* GHG emissions reductions. However, it would seem self- evident that out-of-sector GHG emissions reductions (or *offsets*) should only be seen as ancillary reductions, in the sense that the shipping industry would eventually have little or no control over them. As far as what the industry can influence is concerned, *in sector* reductions seem far more relevant.

How much CO_2 can be reduced by a substantial global bunker levy? Devanney (2010) estimated that with a base BFO price of USD 465/tonne, a USD 50/tonne bunker levy would achieve a 6% reduction in total Very Large Crude Carrier (VLCC) emissions over their life cycle and that for a USD 150/tonne levy the reduction would be 11.5%. Some estimates of CO_2 reductions for tankers and handymax bulk carriers, and for several bunker levy scenarios, were made in Gkonis and Psaraftis (2012) and in Kapetanis et al (2014) respectively. These estimates showed CO_2 reductions of more than 50% for a single VLCC if fuel price rises from 400 to 1,000 USD/tonne. However, the long term fleet-level impacts of substantial levies are by and large unknown.

It should be obviously realized that any move in the above direction, even at the study level, would generate strong protests from many stakeholders. For instance, and at today's fuel prices, who would possibly entertain a global bunker levy so that total fuel cost becomes 800 or 1,000 USD/tonne? Would the US administration support it, for instance? Could an appropriate legal regime be instituted on a global level? We consider the political prospects of such a measure extremely unlikely. The scheme may also have side-effects in specific segments of the market, for instance in short sea shipping higher fuel prices at sea may potentially shift cargo to land based modes, ultimately increasing GHG emissions overall. Such potential side-effects ought to be examined carefully.

Irrespective of this, and for at least the reasons outlined above, the conjecture of this paper is that, as things stand, the international scene for the decarbonization of maritime transport has been rendered way too complex and fragmented, as well as political. Unnecessary complexity and fragmentation, coupled with factors that are mostly within the political sphere, will not help a speedy resolution of the issue. In fact they will definitely hinder prospects for substantial progress in the years ahead. Conversely, a necessary condition for substantial progress on the GHG front is the removal, or at least alleviation, of such political obstacles.

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