European Commission

Decarbonisation of Shipping

Technical Study on the future of the Ship Energy Efficiency Design Index

FINAL REPORT

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ABSTRACT

This report examines the implementation of the EEDI framework and its effect on ship design and energy efficiency in general. It shows that EEDI, together with market conditions has resulted in substantial improvements in energy efficiency of ships. This has been achieved mainly with more efficient engines, hydrodynamic optimisation and significant uptake of energy saving devices, but uptake of other types of innovative technology has been limited for a number of reasons. Increasing uptake of energy saving

devices and innovative technology is not necessarily possible or desirable because different ship types and operating profiles affect the energy saving potential of these devices and technology.

EEDI broadly needs to integrate with the CII measure and any upcoming MBM and the role and form of EEDI also needs to be adapted through a period where fuel type and ship design are in transition. As such the timing and reduction rate of Phase 4 should take into account the effect of these other measures.

Some minor adjustments and changes are investigated and proposed, however larger scale changes require redrawing of the baselines.

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Le présent rapport examine la mise en œuvre de l'indice de rendement énergétique, EEDI, et son effet sur la conception des navires et de leur efficacité énergétique en général. Il y est démontré que l'EEDI, ainsi que les conditions du marché, ont permis d'améliorer considérablement l'efficacité énergétique des navires. Cela a été possible principalement par l'utilisation des moteurs plus efficaces, l'optimisation hydrodynamique et l'adoption plus significative des dispositifs d'économie d'énergie. Cependant, la mise en place de l'EEDI n'a pas permis une adoption plus répandue d'autres types de technologies innovantes. L'adoption croissante de dispositifs d'économie d'énergie et de technologies innovantes n'est pas nécessairement possible ou souhaitable, car le potentiel d'économie d'énergie possible par ces dispositifs et technologies varie selon le type de navire et le son profil d'exploitation.

L'EEDI doit globalement s'intégrer à l'indicateur d'intensité de carbone (CII) et aux mesures de type MBM à venir. Le rôle et la forme de l'EEDI doivent également être adaptés au cours de la période pendant laquelle le type de carburant et la conception des navires sont en transition. En tant que tel, le chronogramme et le taux de réduction de la phase 4 devraient tenir compte de l'effet de ces autres mesures.

Quelques ajustements et changements mineurs sont étudiés et proposés, mais des changements à plus grande échelle nécessitent une réévaluation des lignes de référence du dispositif EEDI.

EXECUTIVE SUMMARY

The Energy Efficiency Design Index (EEDI) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI (resolution MEPC.203(62)), by Parties to MARPOL Annex VI. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments. Since 1 January 2013, following an initial two year phase zero, new ship designs need to meet the reference level for their ship type and this level is broadly tightened every 5 years by 10% (although following deliberations at MEPC, Phase 3 was brought forward to 2022 for certain ship types).

The EEDI covers a number of different ship types as defined in MARPOL Annex VI, and is based on regressions of estimates of energy efficiency called EIV (Estimated index value) using data from ships built between 1998-2009, sourced from the IHS database.

The regression quality varies widely with R^2 coefficients ranging from 0.4 to over 0.9, largely dependent on the degree of similarity of the population. Ship type populations with a large degree of variation of ship design and operating speeds have poor regression characteristics, and this caused problems that the IMO has tried to solve with limited success with correction factors. There are lessons to be learnt for other regression based regulations such as CII.

It should be noted that EIV calculations based on the underlying IHS dataset is error prone and this caused significant bias for ship types with smaller populations.

Although flawed, EEDI provided a standard for describing and comparing ship efficiency where none existed before. The advent of EEDI coincided with a period of depressed shipping markets and high bunker prices – an fortuitous situation where regulation was supported by markets and collectively drove improvements in ship energy efficiency.

When comparing average AER values for specific ship sizes of pre and EEDI ships based on DCS data, there is a marked difference for bulk carriers, tanker and container ships – on average these ships are operated similarly meaning the difference is likely to consist of design and technical differences – reduction in difference for larger container ships explained by the fact that larger ships are mostly newer ships compliant with EEDI.

	Deadweight	Non-EEDI Avg. AER	EEDI Avg AER	Percentage Difference
Bulk Carriers	35000	7.42	6.45	12.99%
Bulk Carriers	81000	4.44	3.90	12.18%
Bulk Carriers	210000	2.48	2.20	11.26%
Tanker	50000	7.83	6.39	18.33%
Tanker	109000	4.96	3.94	20.52%
Tanker	300000	2.74	2.10	23.29%
Container	12000	20.23	16.93	16.29%
Container	40000	11.43	9.98	12.68%
Container	200000	5.33	4.92	7.62%

Examination of EEDI database shows that EEDI improvements follow a trend of steep improvement in the early years of implementation followed by a plateau. In fact, the best attained EEDI scores tend to be around 2015, likely before the change to ISO 15016 in 2015 which generally reduced V_{ref} for the same sea trial.

Changes in V_{ref} speed over the period 2012 to 2020 is not perceptible in bulk carrier and tankers – that is within the uncertainty of rounding to 0.5 knots, indicating that this improvement is from design improvements rather than reduction in speed. However some speed reduction is apparent in medium to large container ships, although true magnitude may be larger if compared to even older container ships.

The IMO EEDI database is ultimately of limited usefulness due to rounding of key critical values and missing data, but also numerous and significant errors – likely caused during the transfer of data from the verified EEDI technical files to the excel file. The main errors are for quantities where more than one answer is possible, e.g P_{me} power (where the most common error is to provide installed power), and deadweight for container ships (providing 70% deadweight instead of 100%), as well as numerous minor data entry errors. It is clear that verification of the data should be conducted. It should be noted that these errors do not appear to have been brought to the attention of the IMO and member states, suggesting that detailed analysis has not been carried out on the data, and calling into question the collection of data in the first place.

Since EEDI has a fixed baseline, but energy efficiency improvements are measured per ship, energy efficiency improvements are discounted – that is if a ship is 30% better than the baseline, and you add some energy saving technology which reduces the power by 5% for the same speed, the effect may only be around 3% - meaning it becomes more and more difficult to demonstrate the same rate of improvement.

Some of the correction factors which have been implemented can have very significant effects. The ice class correction factors, the general cargo ship correction factors and the roro correction f_{jroro} can have the effect of reducing EEDI by 20%. The correction for fast general cargo ships may reduce EEDI by up to 31.5% and f_{jroro} may reduce (normalise) EEDI by 60% or even more. These correction factors are on the one hand necessary to ensure a level playing field amongst a heterogeneous population of ships however they can also exhibit a significant distorting effect and there are some examples where exceptionally good attained EEDI scores have been achieved due to correction factors (in some cases erroneously applied). Note that these ships were not designed to exploit the correction factors, but simply as a result of those particular designs.

Innovative energy efficiency technologies are allocated to category (A), (B) and (C) as defined in MEPC.1 Circ.815, depending on their characteristics and the way they influence the EEDI. Category A are hydrodynamic technologies, B are technologies that save propulsion power, and C are technologies that generate electricity. Technologies in category B and C are explicitly catered for in the EEDI formula and their use should be recorded in the IMO EEDI database.

However, the IMO EEDI database shows very little uptake of innovative technology generating power (e.g. waste heat recovery) or affecting resistance/increasing power (e.g. air lubrication or wind power), in fact levels have been static over some years leading to accusations that innovative technology is not being applied to new ships. Ships with these technologies generally perform amongst the best of their immediate peers, however it also seems that ships without these innovative technologies may be designed and optimised to match or even surpass the attained EEDI achieved.

In order to understand more about uptake of innovative technology, a stakeholder survey was conducted using the online survey platform Typeform. The survey was divided into two populations with slightly different questions – a general one with around 83 responses of which 42% were shipowners representing around 3,600 ships dominated by bulk carriers, tankers and container ships and a shipyard specific one with 14 responses from major shipyards in Asia representing around 2,400 ships. Validation of the results was undertaken, comparing answers between shipyards and shipowners, and against other third-party sources, as well as checking answers with certain shipowners.

In the case of estimating uptake of innovative technologies, it became clear that there was some confusion in terminology, for example some shipowners assumed that waste heat recovery systems that produce electricity included exhaust gas boilers that do not produce electricity but use the heat for steam production or other heating uses, or that tip raked propellers included highly skewed propellers. Also the survey asked specifically about anticipated future improvements of EEDI or technical efficiency, but many answers included consideration of operational efficiency, skewing the results. In part much of this is because EEDI compliance is primarily an issue for shipyards and other stakeholders do not necessarily think about energy efficiency as framed by EEDI.

Overall the stakeholder survey revealed that all new two stroke engines are delivered derated and with corresponding slow rpm and maximised propeller diameter. Analysis of vessel performance also showed that this was likely one of the key contributors towards improved attained EEDI which also carries into AER improvements.

The survey also revealed that almost all EEDI newbuilds have some form of hydrodynamic energy efficiency technologies fitted, however the strategy for type and combination of technology varies substantially across different ship types and operating profiles. This point is critical to grasp because there is a misapprehension that lack of uptake of technologies is evidence of lack of innovation and investment, and that Phase 3 EEDI reduction rates may be achieved simply by adding more innovative technologies, when in fact this may actually be counter-productive. Actually, increasing uptake of innovative technologies will probably not improve the attained EEDI of the best in class vessels, but improve the attained EEDI of the less efficient designs towards the best in class.

A case study in point is the choice of waste heat recovery or shaft generators. While waste heat recovery does actually have the potential to produce substantial amounts of electrical power, it is dependent on the engine load and speed, and for ships which routinely operate below their design speed, electricity production from the WHRS can be erratic, leading some to prefer shaft generators instead. At the same time, the electrical power produced by a WHRS is only useful if it may be absorbed somewhere in the system, and thus for ships with low auxiliary loads at sea, WHRS is somewhat redundant.

Stakeholder engagement shows that innovative technology is often implemented but not used in EEDI calculation due to third party manufacturers of such technology being unable to warrant their savings claims and shipyards being unwilling to take on both the contractual and the compliance risk. As such, the current preferred shipyard strategy to meet future phases of EEDI tends to be based on LNG which provides certainty of compliance. This is highlighted in the stakeholder survey when considering future fuel choices. For non shipyard stakeholders, there was no clear preference on future fuel choice, while the shipyards expressed a clear preference for LNG.

In the case of minimum power, there is some uncertainty over the impact of the changes to the level 2 calculation methodology, consistent with the submissions to MEPC on this subject. For some shipyards and ship types an increase of installed power seems inevitable, while for others further reductions will be possible.

As mentioned earlier, when asked what improvements in technical design efficiency are possible within 5-7 years, excluding wind and alternative fuels, roughly a third each answered 0-5%, 5-10% and 10-15%. However those who answered 5-10% and 10-15% generally included alternative fuels and operational measures. The majority of shipyards answered 0-5%, and a slightly smaller proportion answered 5-10%.

During the course of the project, IMO agreed a set of MARPOL Annex VI amendments that put into place a mandatory carbon intensity requirement. So while EEDI is a set of design requirements evaluated at a certain fixed loading condition and engine power focussing on efficiency underway (with a token consideration of electrical load), the carbon intensity indicator (CII) considers total fuel consumption over a year, taking into account all loading conditions, operational profiles and non propulsion loads experienced through the year. Thus EEDI is really a snapshot of energy efficiency, while CII is a comprehensive if still flawed measure of energy efficiency. This changes the role of EEDI, and it means that ships which could not be fairly or effectively regulated under the EEDI regime can still be effectively regulated by the CII framework.

The first set of recommendations covers technologies already dealt with in MEPC.1 Circ.815. For air lubrication, it was recommended that methodologies for tank testing and use of in service performance needs to be developed, together with procedures for corrections during trials. For wind propulsion, there is a need for a methodology to confirm performance gains by sea trials, as well as alternatives to the use of the Global Wind Matrix. A distinction also needs to be made between modest and substantial savings from wind, with the later perhaps needing to be categorised as non-conventional propulsion and therefore exempted from EEDI because of the unintended constraints that are imposed by the EEDI calculation methodology. Such ships would still be subject to the CII framework and demonstrate the effectiveness of the wind propulsion technology.

On the matter of waste heat recovery systems, we recommend scaling back the overly generous incentive given to such systems, to be in line with other comparable technologies such as shaft generators, noting that even with such generous calculation incentives, uptake has been limited.

Regarding non-conventional propulsion, specifically regarding diesel electric propulsion, we note that calculation assumptions differ between LNG carriers and Cruise Passenger Ships, and that a static correction factor to compensate for the losses in a diesel electric system is not appropriate, and may have the perverse incentive of encouraging use of diesel electric systems where the actual efficiency improvements across the operating profile are not sufficient. There are also significant issue with changing EEDI to evaluate across an operating profile when actually the CII will be sufficient to demonstrate effectiveness. As such, given that only 0.395% of shipping emissions are due to diesel electric, we recommend that further work on diesel electric propulsion with EEDI is ceased.

A sub-category of non-conventional propulsion is termed hybrid propulsion but is not defined anywhere leading to widespread confusion on what type of propulsion this is. The origin of the term meant a mix of conventional and non-conventional propulsion, ie direct drive + PTI/Shaft motor, however some current interpretation suggests battery hybrid. We recommend that hybrid should be clearly clarified, and particularly those which make savings at non-EEDI operating point should be exempted.

Batteries can be used in a number of different modes – as peak shaving, as spinning reserve or as the main power source for all or part of a voyage. The energy saving potential of these different modes are different, and a ship may use batteries in some or all of these modes. EEDI however assumes optimal SFOC and so peak shaving may not be credited, while batteries used during manoeuvring also have no effect. And if batteries should be charged from land, there is no methodology for including this in the EEDI calculation. We considered 4 options, of which two require significant amounts of operational data to be collected. The remaining options are to back calculate savings obtained via the intended operational profile and apply this as a factor to the attained EEDI, or to have the option to exempt ships equipped with battery capacity above a certain threshold from EEDI and allow these to be regulated by the CII. It should be noted today that ships fitted with batteries do not include these details in the EEDI technical file.

On the issue of methane slip, there is a need to differentiate between engines with high and low methane slip and we propose a methodology to include methane slip in the EEDI calculation guidelines. In this methodology we use GWP_{20} of 84 meaning that the benefit of LNG is negated from around 1.1 g/kWh of methane slip. While the calculation methodology is simple to implement, the larger challenge is the need to develop a robust measurement and certification regime.

The carbon factor C_f works reasonably well in EEDI for fossil fuels that contain carbon (noting that we are using carbon as a proxy for energy efficiency, but this changes the validity of comparison when lower carbon fuels are used), but for drop in fuels with upstream carbon removals, this is not accounted for and are no different from their fossil fuel equivalents for EEDI calculation purposes. Since EEDI is a design index, there should be some technical alteration that leads to a change in energy efficiency. The use of drop in fuels (such as bio fuels) does not entail any change of technology onboard, the extent of use of drop in fuels is also not known at design stage and the EEDI framework cannot control the use of these fuels. Therefore we recommend that only tank to wake carbon factors are used. Ammonia and hydrogen will get C_f of zero, we think this is reasonable given the large investment cost of using these fuels onboard and the need to adjust the ship design to accommodate larger volumes of high risk fuels.

The dual fuel calculation methodology may need to be more seriously amended in light of the CII framework, however minor adjustments should be made to account for alternative fuels which are liquids (current text refers only to gas) and fuels with a much lower calorific value.

The feasibility of evaluating EEDI over an operating profile instead of a single point was investigated. For bulk carriers and tankers, including both ballast and summer load line draught is a possibility, however this will lead to a reduced attained EEDI overall which will be compared against the EEDI reference line which is at summer load line draught. So, changing this will require new baselines to be created. For containerships, there is a much wider range of operating profiles, draughts and speeds and there is limited potential for a relevant EEDI that is representative of the operating profile. In effect the CII regulation already deals with the full operating profile and it is not clear at this point what is the added value of implementing this in EEDI.

The weather factor f_w represents speed loss in waves but although the parameter exists in the EEDI calculation guidelines, it is not used. Calculations were carried out indicating that newer ships generally lose more speed in waves than older ships, however the standard IMO curve for f_w is too conservative and unable to make distinctions. The challenge is that f_w is in the denominator, so the greater the speed loss, the worse the attained EEDI becomes. We propose three options, to calculate EEDI with and without f_w but retain the attained $EEDI_{weather}$ for information purposes only; impose a minimum value of f_w, and revise the baselines to include f_w.

For auxiliary power, where energy saving measures are implemented such as variable frequency drives, the calculated savings should be directly deducted from the derived P_{AE} values assuming certain default savings values rather than resorting to an electric power table simply because there is too much variability in auxiliary power demand on ships. For passenger ships (cruise and ro-ro passenger) which are mandated to use an electric power table, we propose to include a new service factor of capacity kc to account for devices with variable control that never use their full rated output.

On the subject of reduction rates, ships are already highly optimised for energy efficiency, and potential for further incremental improvement of design energy efficiency is limited. This is demonstrated by the stagnation or very minor improvement of attained EEDI values year on year in the IMO EEDI database. There is of course more potential for improvement of operational energy efficiency, but this is addressed in the CII. There are only a few design solutions that are not yet widely implemented which may results in improvements of 5% or more, namely wind assist, air lubrication and alternative fuels. Of these, alternative fuels provide the most certainty in the calculation of the EEDI, however this depends on the availability of these alternative fuels. As such, we do not think it is appropriate to suggest a reduction rate for Phase 4 when the future form of the EEDI may need change to substantially in order to complement the CII framework, market based measures and LCA of fuels. We think it is better to wait until there is some feedback from the implementation of these other measures before taking a decision.

Regarding the timescale for the start of Phase 4, we note that the view of the EEDI correspondence group is for either 2027 or 2030, based on adding a 5 year block to the current start dates of Phase 3. In general, those ship types which have had their Phase 3 start date accelerated to 2022 (General Cargo ships, Cruise passenger ships, LNG carriers, Gas carriers above 15,000 dwt) are typically due to the fact that the original reference lines were incorrectly drawn, or that market conditions had altered design speeds from the average between 1998-2008 that was used as the basis for the EEDI. Otherwise the rate of improvement is no different from the other ship types with Phase 3 from 2025 onwards in terms of incremental optimisation of energy efficiency.

Hence for Phase 4 we would propose to realign the dates for all ship types in conjunction with the revision of the baselines. Our recommendation is that 2027 is too early to start Phase 4 and a later date should be considered. Due to the need for boiloff gas management, it should be assumed that LNG carriers are unable to transition to any other alternative fuels.

As has been mentioned a number of times, with the advent of the CII measure, and other measure on the way, the necessity and relevance of EEDI needs to be evaluated.

A consideration is that we are in a transition period, moving from design energy efficiency to a mix of operational energy efficiency, and then on to a transition to zero carbon alternative fuel and propulsion, and so it is prudent to evaluate whether earlier regulatory instruments are superseded by a newer framework that is just as effective or more. If so, then there should be a process to remove the earlier regulatory instruments. For now, until we have experience with the implementation and results of the CII framework, EEDI remains important, however this may change post 2026 with the setting of the reduction rates for 2027-2030.

One option is for EEDI to become energy based, that is to disallow the use of any C_f apart from that of MGO, the concept being that this will ensure a minimum level of energy efficiency, leaving the CII framework to deliver the fuel transition. The challenge with this option is that ships that use alternative fuels generally have less deadweight for the same size of vessel due to the containment and fuel handling systems compared to a conventional vessel with only liquid fuel tanks. In an EEDI calculation, this will reduce the size of the denominator while the numerator remains the same and will therefore compare unfavourably with conventionally fuelled ships.

Additionally there will be an issue regarding the relevant SFOC to be used. This could be an option for primarily dual fuel vessels where the engine is capable of using MGO. However use of this solution will require a wholesale re-evaluation of the reduction rates and for some vessels even Phase 3 reduction rates may no longer be achievable without the option of an alternative fuel.

It is however clear that any such change to the EEDI will require new baselines and a significant rewrite of the calculation guidelines.

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L’indice de conception de l’efficacité énergétique (EEDI) a été rendu obligatoire pour les navires neufs et le plan de gestion de l’efficacité énergétique des navires (SEEMP) pour tous les navires au MEPC 62 (juillet 2011) avec l’adoption d’amendements à l’annexe VI de MARPOL (résolution MEPC.203(62)), par les Parties à l’Annexe VI de MARPOL. L’EEDI exige un niveau minimal d’efficacité énergétique par kilomètre de capacité (par exemple, tonne-mille) pour différents types et segments de taille de navires. Depuis le 1er janvier 2013, après une phase zéro initiale de deux ans, les nouvelles conceptions de navires doivent respecter le niveau de référence pour leur type de navire et ce niveau est largement resserré tous les 5 ans de 10% (bien qu’à la suite des délibérations du MEPC, la phase 3 ait été avancée à 2022 pour certains types de navires).

L’EEDI couvre un certain nombre de types de navires différents tels que définis à l’annexe VI de MARPOL et est basé sur des régressions d’estimations de l’efficacité énergétique appelées EIV (valeur estimée de l’indice) à l’aide de données provenant de navires construits entre 1998 et 2009, provenant de la base de données IHS.

La qualité de la régression varie considérablement avec des coefficients^{R2} allant de 0,4 à plus de 0,9, en grande partie en fonction du degré de similitude de la population. Les populations de type navire avec un degré élevé de variation de la conception des navires et des vitesses d’exploitation ont de mauvaises caractéristiques de régression, ce qui a causé des problèmes que l’OMI a essayé de résoudre avec un succès limité avec des facteurs de correction. Il y a des leçons à tirer pour d’autres règlements fondés sur la régression, comme l’ICI.

Il convient de noter que les calculs de l’EIV basés sur l’ensemble de données IHS sous-jacent sont sujets aux erreurs, ce qui a entraîné un biais important pour les types de navires ayant des populations plus petites.

Bien qu'imparfait, l'EEDI a fourni une norme pour décrire et comparer l'efficacité des navires là où il n'en existait pas auparavant. L'avènement de l'EEDI a coïncidé avec une période de baisse des marchés du transport maritime et de prix élevés des soutes – une situation fortuite où la réglementation a été soutenue par les marchés et a collectivement conduit à des améliorations de l'efficacité énergétique des navires.

Lorsque l'on compare les valeurs moyennes de l'AER pour des tailles de navires spécifiques de navires pré et EEDI sur la base des données DCS, il existe une différence marquée pour les vraquiers, les navires-citernes et les porte-conteneurs – en moyenne, ces navires sont exploités de la même manière, ce qui signifie que la différence est susceptible de consister en des différences de conception et de technique – la réduction de la différence pour les grands porte-conteneurs s'explique par le fait que les grands navires sont pour la plupart des navires plus récents conformes à l'EEDI.

	Port en lourd	Non-EEDI Moyenne AER	EEDI Moyenne AER	Différence en pourcentage
Vraquiers	35000	7.42	6.45	12.99%
Vraquiers	81000	4.44	3.90	12.18%
Vraquiers	210000	2.48	2.20	11.26%
Pétrolier	50000	7.83	6.39	18.33%
Pétrolier	109000	4.96	3.94	20.52%
Pétrolier	300000	2.74	2.10	23.29%
Conteneur	12000	20.23	16.93	16.29%
Conteneur	40000	11.43	9.98	12.68%
Conteneur	200000	5.33	4.92	7.62%

L'examen de la base de données de l'EEDI montre que les améliorations de l'EEDI suivent une tendance à une forte amélioration au cours des premières années de mise en œuvre, suivie d'un plateau. En fait, les scores EEDI les mieux atteints ont tendance à être autour de 2015, probablement avant le passage à ISO 15016 en 2015 qui a généralement réduit Vref pour le même essai en mer.

Les changements de vitesse de Vref au cours de la période 2012-2020 ne sont pas perceptibles chez les vraquiers et les pétroliers – c'est-à-dire dans l'incertitude de l'arrondi à 0,5 nœud, ce qui indique que cette amélioration résulte d'améliorations de la conception plutôt que d'une réduction de la vitesse. Cependant, une certaine réduction de la vitesse est apparente chez les porte-conteneurs de taille moyenne à grande, bien que l'ampleur réelle puisse être plus grande si elle est comparée à des porte-conteneurs encore plus anciens.

La base de données EEDI de l'OMI est finalement d'une utilité limitée en raison de l'arrondissement des valeurs critiques clés et des données manquantes, mais aussi de nombreuses et importantes erreurs – probablement causées lors du transfert des données des fichiers techniques EEDI vérifiés vers le fichier Excel. Les principales erreurs concernent les quantités pour lesquelles plus d'une réponse est possible, par exemple la puissance Pme (où l'erreur la plus courante est de fournir la puissance installée), et le port en lourd pour les porte-conteneurs (fournissant un port en lourd de 70% au lieu de 100%), ainsi que de nombreuses erreurs mineures de saisie de données. Il est clair que la vérification des données doit être effectuée. Il convient de noter que ces erreurs ne semblent pas avoir été portées à l'attention de l'OMI et des États membres, ce qui suggère que les données n'ont pas fait l'objet d'une analyse détaillée et remet en question la collecte de données en premier lieu.

Étant donné que l'EEDI a une base de référence fixe, mais que les améliorations de l'efficacité énergétique sont mesurées par navire, les améliorations de l'efficacité énergétique sont actualisées - c'est-à-dire si un navire est 30% meilleur que la ligne de base et que vous ajoutez une technologie d'économie d'énergie qui réduit la puissance de 5% pour la même vitesse, l'effet peut seulement être d'environ 3% - ce qui signifie qu'il devient de plus en plus difficile de démontrer le même taux d'amélioration.

Certains des facteurs de correction qui ont été mis en œuvre peuvent avoir des effets très importants. Les facteurs de correction de la classe de glace, les facteurs de correction des navires de charge générale et la correction du roro fjroro peuvent avoir pour effet de réduire l'EEDI de 20%. La correction pour les navires de charge générale rapide peut réduire l'EEDI jusqu'à 31,5% et fjroro peut réduire (normaliser) l'EEDI de 60% ou même plus. Ces facteurs de correction sont d'une part nécessaires pour garantir des conditions de concurrence équitables au sein d'une population hétérogène de navires, mais ils peuvent également présenter un effet de distorsion important et il existe des exemples où des scores EEDI exceptionnellement bons ont été obtenus en raison de facteurs de correction (dans certains cas appliqués à tort). Notez que ces navires n'ont pas été conçus pour exploiter les facteurs de correction, mais simplement à la suite de ces conceptions particulières.

Afin de mieux comprendre l'adoption de technologies novatrices, un sondage auprès des intervenants a été mené à l'aide de la plateforme de sondage en ligne Typeform. L'enquête a été divisée en deux populations avec des questions légèrement différentes – une générale avec environ 83 réponses dont 42% étaient des armateurs représentant environ 3 600 navires dominés par des vraquiers, des pétroliers et des porte-conteneurs et une spécifique aux chantiers navals avec 14 réponses de grands chantiers navals en Asie représentant environ 2 400 navires. La validation des résultats a été entreprise, en comparant les réponses entre les chantiers navals et les armateurs, et avec d'autres sources tierces, ainsi qu'en vérifiant les réponses avec certains armateurs.

Dans le cas de l'estimation de l'adoption de technologies novatrices, il est apparu clairement qu'il y avait une certaine confusion dans la terminologie, par exemple certains armateurs ont supposé que les systèmes de récupération de la chaleur résiduelle qui produisent de l'électricité comprenaient des chaudières à gaz d'échappement qui ne produisent pas d'électricité mais utilisent la chaleur pour la production de vapeur ou d'autres utilisations de chauffage, ou que les hélices à pointe ratissée comprenaient des hélices fortement asymétriques. L'enquête portait également spécifiquement sur les améliorations futures prévues de l'EEDI ou de l'efficacité technique, mais de nombreuses réponses comprenaient la prise en compte de l'efficacité opérationnelle, ce qui fausse les résultats. Cela s'explique en partie par le fait que la conformité à l'EEDI est principalement un problème pour les chantiers navals et que d'autres parties prenantes ne pensent pas nécessairement à l'efficacité énergétique telle que encadrée par l'EEDI.

Dans l'ensemble, l'enquête auprès des parties prenantes a révélé que tous les nouveaux moteurs à deux temps sont livrés avec un régime lent correspondant et un diamètre d'hélice maximisé. L'analyse des performances des navires a également montré qu'il s'agissait probablement de l'un des principaux contributeurs à l'amélioration de l'EEDI atteint, ce qui se traduit également par des améliorations de la REA.

L'enquête a également révélé que presque toutes les nouvelles constructions de l'EEDI sont équipées d'une certaine forme de technologies d'efficacité énergétique hydrodynamique, mais la stratégie de type et de combinaison de technologies varie considérablement selon les types de navires et les profils d'exploitation. Ce point est essentiel à saisir parce qu'il y a une idée erronée que le manque d'adoption des technologies est la preuve d'un manque d'innovation et d'investissement, et que les taux de réduction de la phase 3 de l'EEDI peuvent être atteints simplement en ajoutant des technologies plus innovantes, alors qu'en fait cela peut en fait être contre-productif. En fait, l'adoption croissante de technologies innovantes n'améliorera probablement pas l'EEDI atteint des meilleurs navires de leur catégorie, mais améliorera l'EEDI atteint des conceptions les moins efficaces vers les meilleurs de leur catégorie.

Une étude de cas est le choix de la récupération de chaleur résiduelle ou des générateurs d'arbre. Bien que la récupération de la chaleur résiduelle ait effectivement le potentiel de produire des quantités substantielles d'énergie électrique, elle dépend de la charge et de la vitesse du moteur, et pour les navires qui fonctionnent régulièrement en dessous de leur vitesse de conception, la production d'électricité à partir du WHRS peut être erratique, ce qui conduit certains à préférer les générateurs à arbre. Dans le même temps, l'énergie électrique produite par un WHRS n'est utile que si elle peut être absorbée quelque part dans le système, et donc pour les navires ayant de faibles charges auxiliaires en mer, WHRS est quelque peu redondant.

L'engagement des parties prenantes montre que les technologies innovantes sont souvent mises en œuvre mais pas utilisées dans le calcul de l'EEDI en raison du fait que les fabricants tiers de cette technologie ne sont pas en mesure de garantir leurs demandes d'économies et que les chantiers navals ne sont pas disposés à assumer à la fois le risque contractuel et le risque de conformité. En tant que tel, la stratégie actuelle des chantiers navals privilégiés pour répondre aux phases futures de l'EEDI tend à être basée sur le GNL, ce qui offre une certitude de conformité. Ceci est mis en évidence dans le sondage auprès des intervenants lorsqu'ils examinent les choix futurs en matière de carburant. Pour les intervenants non liés aux chantiers navals, il n'y avait pas de préférence claire pour le choix futur du carburant, tandis que les chantiers navals ont exprimé une nette préférence pour le GNL.

Dans le cas de la puissance minimale, il existe une certaine incertitude quant à l'incidence des modifications apportées à la méthode de calcul de niveau 2, conformément aux observations présentées au MEPC à ce sujet. Pour certains chantiers navals et types de navires, une augmentation de la puissance installée semble inévitable, tandis que pour d'autres, d'autres réductions seront possibles.

Comme mentionné précédemment, lorsqu'on leur a demandé quelles améliorations de l'efficacité technique de la conception sont possibles d'ici 5 à 7 ans, à l'exclusion de l'énergie éolienne et des carburants de remplacement, environ un tiers a répondu 0 à 5%, 5 à 10% et 10 à 15%. Cependant, ceux qui ont répondu 5-10% et 10-15% incluaient généralement des carburants alternatifs et des mesures opérationnelles. La majorité des chantiers navals ont répondu de 0 à 5 %, et une proportion légèrement plus faible a répondu de 5 à 10 %.

Au cours du projet, l'OMI a approuvé un ensemble d'amendements à l'annexe VI de MARPOL qui mettent en place une exigence obligatoire en matière d'intensité carbone. Ainsi, alors que l'EEDI est un ensemble d'exigences de conception évaluées à une certaine condition de charge fixe et de la puissance du moteur en mettant l'accent sur l'efficacité en cours (avec une prise en compte symbolique de la charge électrique), l'indicateur d'intensité carbone (CII) prend en compte la consommation totale de carburant sur une année, en tenant compte de toutes les conditions de chargement, des profils opérationnels et des charges non propulsives rencontrées tout au long de l'année. Ainsi, l'EEDI est vraiment un instantané de l'efficacité énergétique, tandis que le CII est une mesure complète, bien que toujours imparfaite, de l'efficacité énergétique. Cela modifie le rôle de l'EEDI et signifie que les navires qui ne pourraient pas être réglementés équitablement ou efficacement dans le cadre du régime de l'EEDI peuvent toujours l'être efficacement par le cadre de la CII.

La première série de recommandations couvre les technologies déjà traitées dans mePC.1 Circ.815. En ce qui concerne la lubrification à l'air, il a été recommandé d'élaborer des méthodes d'essai en cuve et d'utilisation des performances en service, ainsi que des procédures de correction pendant les essais. Pour la propulsion éolienne, il est nécessaire de mettre en place une méthodologie pour confirmer les gains de performance par les essais en mer, ainsi que des alternatives à l'utilisation de la Global Wind Matrix. Il convient également de faire une distinction entre les économies modestes et substantielles dues à l'énergie éolienne, cette dernière devant peut-être être classée dans la catégorie des propulsions non conventionnelles et donc exemptée de l'EEDI en raison des contraintes involontaires imposées par la méthode de calcul de l'EEDI. Ces navires seraient toujours soumis au cadre de la CII et démontreraient l'efficacité de la technologie de propulsion éolienne.

En ce qui concerne les systèmes de récupération de la chaleur résiduelle, nous recommandons de réduire l'incitation trop généreuse accordée à ces systèmes, afin d'être en conformité avec d'autres technologies comparables telles que les générateurs à arbre, en notant que même avec des incitations de calcul aussi généreuses, l'adoption a été limitée.

En ce qui concerne la propulsion non conventionnelle, en particulier en ce qui concerne la propulsion diesel-électrique, nous notons que les hypothèses de calcul diffèrent entre les méthaniers et les navires de croisière à passagers, et qu'un facteur de correction statique pour compenser les pertes dans un système diesel-électrique n'est pas approprié et peut avoir l'incitation perverse d'encourager l'utilisation de systèmes diesel-électriques lorsque les améliorations réelles de l'efficacité dans l'ensemble du profil d'exploitation ne sont pas suffisantes. Il y a également un problème important avec la modification de l'EEDI à évaluer à travers un profil d'exploitation alors que l'ICI sera réellement suffisant pour démontrer l'efficacité. Ainsi, étant donné que seulement 0,395 % des émissions du transport maritime sont dues au diesel-électrique, nous recommandons que les travaux sur la propulsion diesel-électrique avec EEDI soient interrompus.

Une sous-catégorie de propulsion non conventionnelle est appelée propulsion hybride, mais n'est définie nulle part, ce qui entraîne une confusion généralisée sur le type de propulsion dont il s'agit. L'origine du terme signifiait un mélange de propulsion conventionnelle et non conventionnelle, c'est-à-dire entraînement direct + moteur PTI / arbre, mais certaines interprétations actuelles suggèrent une batterie hybride. Nous recommandons que les hybrides soient clairement clarifiés et, en particulier, ceux qui font des économies au point d'exploitation non EEDI soient exemptés.

Les batteries peuvent être utilisées dans un certain nombre de modes différents – comme rasage de pointe, comme réserve de rotation ou comme source d'alimentation principale pour tout ou partie d'un voyage. Le potentiel d'économie d'énergie de ces différents modes est différent, et un navire peut utiliser des batteries dans certains ou tous ces modes. L'EEDI suppose cependant une SFOC optimale et donc le rasage de pointe peut ne pas être crédité, tandis que les batteries utilisées lors des manœuvres n'ont également aucun effet. Et si les batteries doivent être chargées à partir de la terre, il n'y a pas de méthodologie pour l'inclure dans le calcul de l'EEDI. Nous avons envisagé 4 options, dont deux nécessitent la collecte de quantités importantes de données opérationnelles. Les autres options sont de calculer les économies obtenues via le profil opérationnel prévu et de l'appliquer comme facteur à l'EEDI atteint, ou d'avoir la possibilité d'exempter les navires équipés d'une capacité de batterie supérieure à un certain seuil de l'EEDI et de permettre que ceux-ci soient réglementés par la CII. Il convient de noter aujourd'hui que les navires équipés de batteries n'incluent pas ces détails dans le dossier technique de l'EEDI.

En ce qui concerne la question du glissement du méthane, il est nécessaire de différencier les moteurs à glissement élevé et faible du méthane et nous proposons une méthodologie pour inclure le glissement du méthane dans les directives de calcul de l'EEDI. Dans cette méthodologie, nous utilisons le GWP_{20} de 84, ce qui signifie que le bénéfice du GNL est annulé à partir d'environ 1,1 g / kWh de glissement de méthane. Bien que la méthodologie de calcul soit simple à mettre en œuvre, le plus grand défi est la nécessité d'élaborer un régime de mesure et de certification robuste.

Le facteur carbone C_f fonctionne raisonnablement bien dans l'EEDI pour les combustibles fossiles qui contiennent du carbone (notant que nous utilisons le carbone comme indicateur de l'efficacité énergétique, mais cela change la validité de la comparaison lorsque des combustibles à faible teneur en carbone sont utilisés), mais pour la baisse des carburants avec élimination du carbone en amont, cela n'est pas pris en compte et n'est pas différent de leurs équivalents combustibles fossiles aux fins du calcul de l'EEDI. Étant donné que l'EEDI est un indice de conception, il devrait y avoir une modification technique qui conduit à un changement dans l'efficacité énergétique. L'utilisation de la baisse des carburants (tels que les biocarburants) n'entraîne aucun changement de technologie à bord, l'ampleur de l'utilisation de la baisse des carburants n'est pas non plus connue au stade de la conception et le cadre de l'EEDI ne peut pas contrôler l'utilisation de ces carburants. Par conséquent, nous recommandons que seuls les facteurs de carbone du réservoir pour réveiller soient utilisés. L'ammoniac et l'hydrogène obtiendront un C_f de zéro, nous pensons que c'est raisonnable compte tenu du coût d'investissement élevé de l'utilisation de ces carburants à bord et de la nécessité d'ajuster la conception du navire pour accueillir de plus grands volumes de carburants à haut risque.

La méthode de calcul des bicarburants devra peut-être être modifiée plus sérieusement à la lumière du cadre de la CII, mais des ajustements mineurs devraient être apportés pour tenir compte des carburants alternatifs qui sont des liquides (le texte actuel ne fait référence qu'au gaz) et des carburants ayant un pouvoir calorifique beaucoup plus faible.

La faisabilité de l'évaluation de l'EEDI sur un profil d'exploitation au lieu d'un point unique a été étudiée. Pour les vraquiers et les pétroliers, il est possible d'inclure à la fois le ballast et le tirant d'eau de la ligne de chargement d'été, mais cela entraînera une réduction de l'EEDI atteint dans l'ensemble, qui sera comparée à la ligne de référence de l'EEDI qui est à l'état de tirant d'eau de la ligne de charge d'été. Donc, pour changer cela, il faudra créer de nouvelles lignes de base. Pour les porte-conteneurs, il existe un éventail beaucoup plus large de profils d'exploitation, de tirant d'eau et de vitesses et le potentiel d'un EEDI pertinent représentatif du profil d'exploitation est limité. En effet, le règlement CII traite déjà du profil opérationnel complet et il n'est pas clair à ce stade quelle est la valeur ajoutée de sa mise en œuvre dans l'EEDI.

Le facteur météorologique f w représente$_{la}$ perte de vitesse dans les vagues, mais bien que le paramètre existe dans les directives de calcul EEDI, il n'est pas utilisé. Des calculs ont été effectués indiquant que les navires plus récents perdent généralement plus de vitesse dans les vagues que les navires plus anciens, mais la courbe standard de l'OMI pour f_w est trop conservatrice et incapable de faire des distinctions. Le défi est que f_w est dans le dénominateur, donc plus la perte de vitesse est importante, plus l'EEDI atteint devient mauvais. Nous proposons trois options, pour calculer l'EEDI avec et sans f_w mais conserver les$_{\text{conditions météorologiques}}$ EEDI atteintes à titre d'information seulement; imposer une valeur minimale de f_w, et réviser les lignes de base pourinclure f_w.

Pour la puissance auxiliaire, lorsque des mesures d'économie d'énergie sont mises en œuvre, telles que des entraînements à fréquence variable, les économies calculées doivent être directement déduites des valeurs P_{AE} dérivées en supposant certaines valeurs d'économies par défaut plutôt que de recourir à un tableau de puissance électrique simplement parce qu'il y a trop de variabilité dans la demande de puissance auxiliaire sur les navires. Pour les navires à passagers (croisière et passagers rouliers) qui sont tenus d'utiliser un tableau de puissance électrique, nous proposons d'inclure un nouveau facteur de service de capacité kc pour tenir compte des appareils à commande variable qui n'utilisent jamais leur pleine puissance nominale.

En ce qui concerne les taux de réduction, les navires sont déjà hautement optimisés pour l'efficacité énergétique et le potentiel d'amélioration progressive de l'efficacité énergétique de la conception est limité. Ceci est démontré par la stagnation ou l'amélioration très mineure des valeurs EEDI atteintes d'année en année dans la base de données EEDI de l'OMI. Il y a bien sûr plus de potentiel d'amélioration de l'efficacité énergétique opérationnelle, mais cette question est abordée dans l'ICI. Il n'y a que quelques solutions de conception qui ne sont pas encore largement mises en œuvre et qui peuvent entraîner des améliorations de 5% ou plus, à savoir l'assistance au vent, la lubrification de l'air et les carburants alternatifs. Parmi ceux-ci, les carburants alternatifs offrent la plus grande certitude dans le calcul de l'EEDI, mais cela dépend de la disponibilité de ces carburants alternatifs. Par conséquent, nous ne pensons pas qu'il soit approprié de suggérer un taux de réduction pour la phase 4 lorsque la forme future de l'EEDI pourrait devoir être modifiée de manière substantielle afin de compléter le cadre de l'ICI, les mesures fondées sur le marché et l'ACV des carburants. Nous pensons qu'il est préférable d'attendre qu'il y ait un retour d'information sur la mise en œuvre de ces autres mesures avant de prendre une décision.

En ce qui concerne le calendrier de début de la phase 4, nous notons que le point de vue du groupe de correspondance EEDI est pour 2027 ou 2030, basé sur l'ajout d'un bloc de 5 ans aux dates de début actuelles de la phase 3. En général, les types de navires dont la date de début de la phase 3 a été accélérée jusqu'en 2022 (navires de charge générale, navires de croisière à passagers, méthaniers, transporteurs de gaz au-dessus de 15 000 tnt) sont généralement dus au fait que les lignes de référence initiales ont été mal tracées ou que les conditions du marché ont modifié les vitesses de conception par rapport à la moyenne entre 1998 et 2008 qui a servi de base à l'EEDI. Sinon, le taux d'amélioration n'est pas différent des autres types de navires avec la phase 3 à partir de 2025 en termes d'optimisation progressive de l'efficacité énergétique.

Par conséquent, pour la phase 4, nous proposerions de réaligner les dates pour tous les types de navires en conjonction avec la révision des lignes de base. Nous recommandons que 2027 soit trop tôt pour commencer la phase 4 et qu'une date ultérieure devrait être envisagée. En raison de la nécessité de la gestion du gaz d'ébullition, il faut supposer que les méthaniers ne sont pas en mesure de passer à d'autres carburants de remplacement.

Comme cela a été mentionné à plusieurs reprises, avec l'avènement de la mesure CII et d'autres mesures en cours, la nécessité et la pertinence de l'EEDI doivent être évaluées.

Une considération est que nous sommes dans une période de transition, passant de l'efficacité énergétique de conception à une combinaison d'efficacité énergétique opérationnelle, puis à une transition vers un carburant de remplacement zéro carbone et la propulsion, et il est donc prudent d'évaluer si les instruments réglementaires antérieurs sont remplacés par un nouveau cadre qui est tout aussi efficace ou plus. Si c'est le cas, il devrait y avoir un processus pour supprimer les instruments réglementaires antérieurs. Pour l'instant, jusqu'à ce que nous ayons l'expérience de la mise en œuvre et des résultats du cadre cii, l'EEDI reste important, mais cela pourrait changer après 2026 avec la fixation des taux de réduction pour 2027-2030.

Une option consiste à ce que l'EEDI devienne basé sur l'énergie, c'est-à-dire à interdire l'utilisation de tout C_f autre que celui de MGO, le concept étant que cela garantira un niveau minimum d'efficacité énergétique, laissant le cadre CII pour assurer la transition énergétique. Le défi avec cette option est que les navires qui utilisent des carburants de remplacement ont généralement moins de port en lourd pour la même taille de navire en raison des systèmes de confinement et de manutention du carburant par rapport à un navire conventionnel avec seulement des réservoirs de carburant liquide. Dans un calcul EEDI, cela réduira la taille du dénominateur tandis que le numérateur restera le même et se comparera donc défavorablement aux navires à carburant conventionnel.

En outre, il y aura un problème concernant le SFOC pertinent à utiliser. Cela pourrait être une option pour les navires principalement bicarburant où le moteur est capable d'utiliser MGO. Cependant, l'utilisation de cette solution nécessitera une réévaluation en gros des taux de réduction et, pour certains navires, même les taux de réduction de la phase 3 pourraient ne plus être réalisables sans l'option d'un carburant de remplacement.

Il est toutefois clair qu'une telle modification de l'EEDI nécessitera de nouvelles bases de référence et une réécriture importante des lignes directrices de calcul.

1 OVERVIEW OF EEDI FRAMEWORK AND REGULATIONS

1.1 Introduction

The IMO, on their webpage dedicated to energy efficiency measures provides a succinct description of the EEDI framework as follows,

> *"The Energy Efficiency Design Index (EEDI) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI (resolution MEPC.203(62)), by Parties to MARPOL Annex VI. This was the first legally binding climate change treaty to be adopted since the Kyoto Protocol.*
>
> *The EEDI for new ships is the most important technical measure and aims at promoting the use of more energy efficient (less polluting) equipment and engines. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments. Since 1 January 2013, following an initial two year phase zero, new ship design needs to meet the reference level for their ship type.*
>
> *The level is to be tightened incrementally every five years, and so the EEDI is expected to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase. The EEDI is a non-prescriptive, performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry.*
>
> *As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions for the ship to comply with the regulations. The EEDI provides a specific figure for an individual ship design, expressed in grams of carbon dioxide (CO2) per ship's capacity-mile (the smaller the EEDI the more energy efficient ship design) and is calculated by a formula based on the technical design parameters for a given ship.*
>
> *The CO2 reduction level (grams of CO2 per tonne mile) for the first phase is set to 10% and will be tightened every five years to keep pace with technological developments of new efficiency and reduction measures. Reduction rates have been established until the period 2025 and onwards when a 30% reduction is mandated for applicable ship types calculated from a reference line representing the average efficiency for ships built between 2000 and 2010."*

The EEDI framework consists of amendments to MARPOL Annex VI, supported by a series of guidelines contained in resolutions and circulars.

This report will provide an overview of the implementation of the EEDI as follows:

- A history and description of the EEDI framework
- Definition of Key Terms
- Detailed Sector analysis
- Analysis of specific issues

1.2 MARPOL Annex VI

Maria Polakis and Jan de Kat have written a chapter on EEDI for a book on Sustainable Shipping which describes changes to MARPOL Annex VI. In view of this, we have decided to incorporate some of the text into this report in blue italics. The full reference to the book is:

Polakis, M.; Zachariadis, P.; de Kat, J. The Energy Efficiency Design Index (EEDI). In Sustainable Shipping: A Cross-Disciplinary View; Psaraftis, H.N., Ed.; Springer: Berlin/Heidelberg, Germany, 2019.

The primary changes that the new energy regulations brought to MARPOL Annex VI can be categorized as follows:

- *Amendments to existing regulations as a result of energy efficiency*
- *Introduction of new regulations specifically for energy efficiency*

1.2.1 *Amendments to Existing Regulations*

A summary of the changes are briefly described here.

Resolution MEPC.176(58)	Resolutions MEPC.203(62) & MEPC251 (66), …..
Chapter I Reg. 1 Application Reg. 2 Definitions Reg. 3 Exceptions and Exemptions Reg. 4 Equivalents	Chapter I Reg. 1 Application Reg. 2 Definitions Reg. 3 Exceptions and Exemptions Reg. 4 Equivalents
Chapter II Reg. 5 Surveys Reg. 6 Issue or endorsement of a Certificate Reg. 7 Issue of a Certificate by another Party Reg. 8 Form of Certificate Reg. 9 Duration and Validity of Certificate Reg. 10 Port State Control on Operational Requirements Reg. 11 Detection of Violations and Enforcements	Chapter II Reg. 5 Surveys Reg. 6 Issue or endorsement of a Certificate Reg. 7 Issue of a Certificate by another Party Reg. 8 Form of Certificate Reg. 9 Duration and Validity of Certificate Reg. 10 Port State Control on Operational Requirements Reg. 11 Detection of Violations and Enforcements

Figure 1 Existing Regulations/Amended Regulations Shown in Red – IMO

Regulation 2*: Introduction of definitions for "new ship" that are applicable to various Phases of EEDI regulations, "major conversion", "conventional / non-conventional propulsion" and "ship types" for which EEDI regulations apply. Since EEDI only applies to new ships and those ships that undergo major conversions beyond 1 January 2013, the exact definition of the "new ship" and "major conversion" terms were required. Additionally, terms such as "Attained EEDI" and "Required EEDI" were defined.*

Regulation 5*: Requirements were specified for surveys including an initial survey for newly built ships, a full or partial survey in case of a major conversion of existing ships, a survey for a Ship Energy Efficiency Management Plan (SEEMP) to verify its existence on* *board ship, etc. Regulation 5 states that EEDI survey and verification shall be carried out according to relevant IMO guidelines.*

Regulations 7 and 8*: The changes to these regulations deal with energy efficiency certification. For ships subject to EEDI regulations, an International Energy Efficiency (IEE) Certificate was made mandatory. The responsibility of the Flag Administration was also emphasized:*

> *"An International Energy Efficiency Certificate for the ship shall be issued after a survey in accordance with the provisions of regulation 5.4 to any ship of 400 gross tonnage and above, before that ship may engage in voyages to ports or offshore terminals under the jurisdiction of other Parties.*
>
> *The certificate shall be issued or endorsed either by the Administration or any organization duly authorized by it. In every case, the Administration assumes full responsibility for the certificate".*

Regulation 9*: The validity aspects of the IEE certificate were defined. The IEE certificate has been determined to be valid for the life of the ship unless otherwise invalidated by a major conversion or change of flag or ship withdrawal from service.*

> *"The IEE Certificate shall be valid throughout the life of the ship subject to the provisions of paragraph below:*
>
> *An IEE issued under this Annex shall cease to be valid in any of the following cases if the ship is withdrawn from service or if a new certificate is issued following major conversion of the ship; or upon transfer of the ship to the flag of another State.......",.*

Regulation 10*: This regulation specifies how compliance with the EEDI requirements is verified by Port State Control Authorities and defines the extent of the inspection scheme. At present stage, as described in MEPC Resolution 203(62), a Port State Control (PSC) inspection would be limited to verifying that a valid IEE certificate exists on board the vessel files.*

1.2.2 Introduction of New Regulations – Chapter 4

The introduction of EEDI regulations came following a series of discussions at the IMO MEPC sessions. The committee in July 2011 at its 62nd session reached a consensus to add a new Chapter 4 to MARPOL Annex VI, covering the new requirements exclusively. The consensus though was not general as a group of member states primarily consisting of developing countries were strongly opposed to the agreement.

Resolution MEPC.176(58)	Resolution MEPC.203(62)
Chapter Ⅲ Reg. 12 Ozone Depleting Substances Reg. 13 Nitrogen Oxides(NOx) Reg. 14 Sulphur Oxides(SOx) and Particular Matter Reg. 15 Volatile Organic Compounds (VOCs) Reg. 16 Shipboard Incineration Reg. 17 Reception Facilities Reg. 18 Fuel Oil Availability and Quality	Chapter Ⅲ Reg. 12 Ozone Depleting Substances Reg. 13 Nitrogen Oxides(NOx) Reg. 14 Sulphur Oxides(SOx) and Particular Matter Reg. 15 Volatile Organic Compounds(VOCs) Reg. 16 Shipboard Incineration Reg. 17 Reception Facilities Reg. 18 Fuel Oil Availability and Quality
	Chapter Ⅳ **Reg. 19 Application** **Reg. 20 Attained EEDI** **Reg. 21 Required EEDI** **Reg. 22 SEEMP** **Reg. 23 Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships**
Appendix Ⅰ~Ⅵ	Appendix Ⅰ~Ⅵ **Appendix Ⅷ Form of International Energy Efficiency(IEE) Certificate**

Figure 2 New Regulations Shown in Red – IMO

A short description of the main aspects of these new regulations is provided below.

Regulation 19: *Regulation 19 specifies the domain of application of the energy efficiency regulations. Chapter 4 of MARPOL Annex VI applies to all ships of 400 gross tonnage (GT) and above that are engaged in international voyages. It gives limited power to Administrations to waive the requirements for EEDI for a new ship contracted before January 1st 2017 up to a delivery date of 1 July 2019; subject to informing the IMO and other Parties to MARPOL Annex VI of this decision.*

The "waiver" clause came about due to significant discussions at MEPC and stressing that some ships may not be able to comply with IMO requirements whilst considered as good design ships. According to IMO sources, there has been no need for Administrations to use this option.

Regulation 20 and 21 require more detailed treatment as follows.

1.2.3 Regulation 20 - Attained EEDI

Regulation 20 refers to guidelines for how attained EEDI is to be calculated (currently MEPC.308(73)).

The EEDI formula used to calculate attained EEDI is written as follows (including amendments approved but not yet adopted at MEPC 74):

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

The relative length of this may make it difficult to read, so we have divided the formula into two parts to aid reading.

$$\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right)$$

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

A full definition of the terms may be found in the current version of the calculation guidelines – MEPC.308(73), however a summary is provided here:

C_F	Conversion factor between fuel consumption and CO2 emission
V_{ref}	Ship speed
Capacity	Capacity for bulk carriers, tankers, gas carriers, LNG carriers, ro-ro cargo ships (vehicle carriers), ro-ro cargo ships, ro-ro passenger ships, general cargo ships, refrigerated cargo carrier and combination carriers is deadweight Capacity for passenger ships and cruise passenger ships is GT Capacity for containerships is 70% of deadweight
P_{ME}	Power of main engines (generally 75% of installed main engine power)
P_{PTO}	Power of Shaft generator
P_{PTI}	Power of Shaft motor
P_{eff}	Innovative mechanical energy efficient technology for main engine
P_{AEeff}	Innovative mechanical energy efficient technology for auxiliary engine
P_{AE}	Power of auxiliary engines
SFC_{ME}	Certified specific fuel consumption for main engines
SFC_{AE}	Certified specific fuel consumption for auxilliary engines
f_j	Correction factor for ship specific design elements
f_w	Correction factor for speed reduction at sea
f_{eff}	Factor for each innovative energy efficiency technology
f_i	Capacity factor for technical/regulatory limitation on capacity
f_c	Cubic capacity correction factor
f_l	Factor for general cargo ships equipped with cranes and other cargo-related gear
f_m	Correction factor for ice-classed ships having 1A Super and 1A

At the very basic level, the EEDI formula takes fuel consumption based on a specific power at a fixed MCR of the main engine and an assumption of the fuel consumption for auxiliaries and converts this into CO2 emission. The sum of CO2 emission is then divided by the product of the capacity and speed at the main engine power used in the numerator.

It allows for innovative mechanical and electrical technologies to be credited.

However the EEDI concept requires that the attained EEDI must conform to a level set by an imperfect regression of a population of historical peers, and given that there are many ships with design features (such as ice class) that render them somewhat different from their peers, correction factors had to be developed to avoid setting disproportionate targets for such ships. When doing this, the attained EEDI value becomes disconnected from the actual CO2 emission intensity that the ship will achieve at 75% power in calm water at maximum draught and can no longer be accurately compared to similar ships for which correction factors are not used.

Attained EEDI must be calculated for each new ship, each new ship that undergoes a major conversion, or existing ships that undergo so many changes that according to the Administration's judgement are considered as a new ship. Ships may not use the same attained EEDI as a sister ship.

The Attained EEDI must be accompanied by an "EEDI Technical File" that contains the information necessary for the calculation of the attained EEDI and that shows the process of calculation which must be verified, either by the Administration or by any organization duly authorized by it.

The following ship types are currently required to comply with the Attained EEDI regulation:

Reg.	Ship Type	Definition
2.25	Bulk carrier	A ship which is intended primarily to carry dry cargo in bulk, including such types as ore carriers as defined in SOLAS chapter XII, regulation 1, but excluding combination carriers.
2.26	Gas carrier	A cargo ship, other than an LNG carrier as defined in paragraph 38 of this regulation, constructed or adapted and used for the carriage in bulk of any liquefied gas.
2.27	Tanker	An oil tanker as defined in MARPOL Annex I, regulation 1 or a chemical tanker or an NLS tanker as defined in MARPOL Annex II, regulation 1.
2.28	Container ship	A ship designed exclusively for the carriage of containers in holds and on deck.
2.29	General cargo ship	A ship with a multi-deck or single deck hull designed primarily for the carriage of general cargo. This definition excludes specialized dry cargo ships, which are not included in the calculation of reference lines for general cargo ships, namely livestock carrier, barge carrier, heavy load carrier, yacht carrier, nuclear fuel carrier.
2.30	Refrigerated cargo carrier	A ship designed exclusively for the carriage of refrigerated cargoes in holds.
2.31	Combination carrier	A ship designed to load 100% deadweight with both liquid and dry cargo in bulk.
2.32	Passenger ship	A ship which carries more than 12 passengers.
2.33	Ro-ro cargo ship (Vehicle carrier)	A multi deck roll-on-roll-off cargo ship designed for the carriage of empty cars and trucks.
2.34	Ro-ro cargo ship	A ship designed for the carriage of roll-on-roll-off cargo transportation units.
2.35	Ro-ro passenger ship	A passenger ship with roll-on-roll-off cargo spaces.
2.38	LNG carrier	A cargo ship constructed or adapted and used for the carriage in bulk of liquefied natural gas (LNG).
2.39	Cruise passenger ship	A passenger ship not having a cargo deck, designed exclusively for commercial transportation of passengers in overnight accommodations on a sea voyage.

Figure 3 MARPOL Annex VI Ship Type Definitions – Class NK

Of these ship types, EEDI is only applicable to ships with conventional propulsion i.e., engines that are either direct drive or geared. Cruise ships however are subject to EEDI regulations when fitted with non-conventional propulsion (such as diesel-electric propulsion, turbine propulsion, or hybrid propulsion systems). Liquefied natural gas (LNG) carriers need to comply when fitted with either conventional or non-conventional propulsion.

Some vessel types are not defined in the regulations. If these types do not fall under one of the 13 mandatory vessel types, then it is not mandatory for them to comply with Regulation 20 or Regulation 21.
EEDI regulations do not apply to cargo ships with ice-breaking capability but do apply to ice-strengthened ships.
Note that passenger ships are the only segment which does not have a baseline or reduction phases. In practice this means that passenger ships that are not cruise ships with non-conventional propulsion or ro-ro passenger ships must still calculate an attained EEDI and undergo verification, there is however no required EEDI.

1.2.4 Regulation 21 - Required EEDI

The required EEDI regulation is made up of 2 parts:

- A baseline or reference line of the form a x b^{-c} derived from regression of a ship population for each sector where parameters a, b and c are defined for each ship type,
- A table setting out the percentage reductions associated with each reduction phase, the associated time periods for the phases, the size cutoffs below which no requirements apply and the size thresholds below which the reduction rate should be interpolated

The full procedure for calculating baselines is found in Resolution MEPC.231(65) Guidelines for calculation of reference lines for use with EEDI and the equivalent set of guidelines for cruise passenger ships found in Resolution MEPC.233(65). An earlier version of the Guidelines used for the first batch of ships is found in Resolution MEPC.215(63).

The baselines were defined by calculating a simplified EEDI value known as EIV (estimated index value) for relevant ships found in the IHSF database delivered between 1 Jan 1999 and 1 Jan 2009:

$$Estimated\ Index\ Value = 3.1144 \cdot \frac{190 \cdot \sum_{i=1}^{NME} P_{MEi} + 215 \cdot P_{AE}}{Capacity \cdot V_{ref}}$$

A regression analysis was then run for each ship segment to derive the reference line and parameters a and c. The reduction phases are then defined with a reduction percentage relative to the reference line.

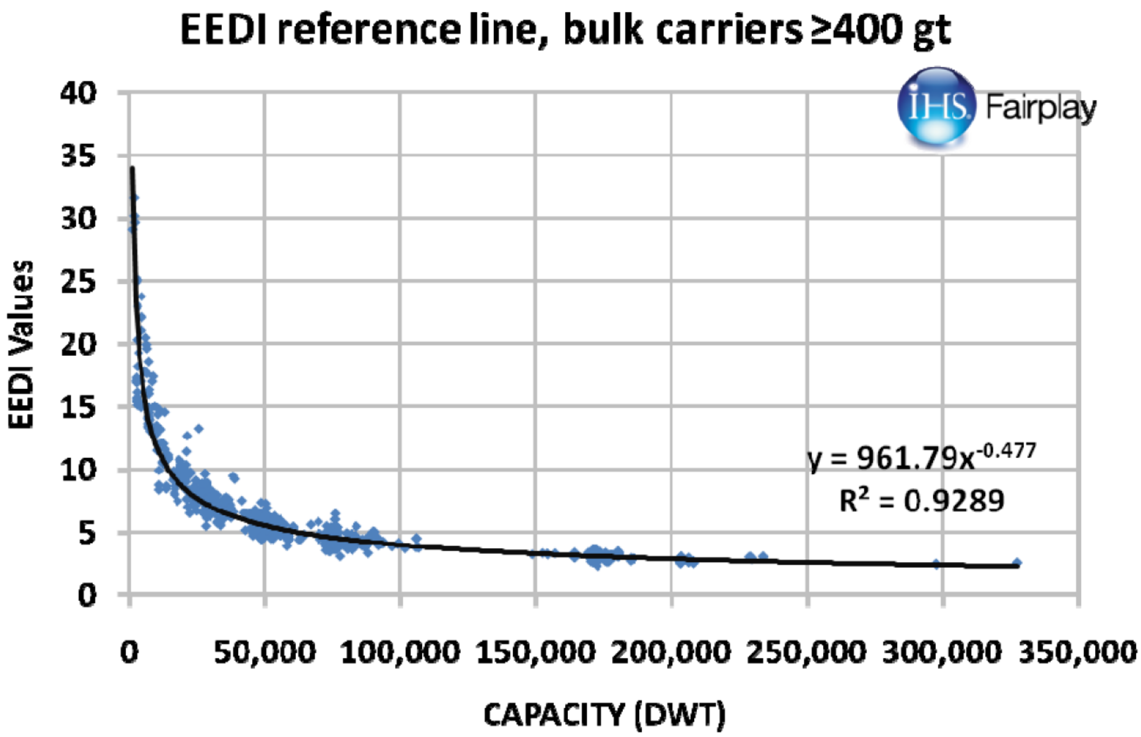


Figure 4 Bulk Carrier EEDI Reference Line MEPC 62/6/4

As can be seen from the regression for bulk carriers, the reference line roughly represents the average efficiency of the bulk carrier fleet for the dataset used. R^2 indicates that the overall fit of the line to the data is quite good and the scatter is fairly limited. What is however also evident is that the majority of the bulk carrier population is below 100,000 dwt, so larger ships are less well represented by the line – one can already make out that all ships larger than 225,000 dwt lie above the line.

However the regression is only as good as the underlying dataset and calculation assumptions. In this respect there are three aspects that need further consideration:

1. The assumption in the EIV formula of 190 g/kWh for 2 stroke engines is likely to have been an overestimate, however smaller ships would tend to use 4 stroke engines where this value would be an underestimate. Given the uncertainty and the population distribution, 190 g/kWh may have been the best compromise option. This would tend to give ships with 2-stroke engines an advantage when calculating attained EEDI, however given that this was a new regulation with far reaching implications, it would seem prudent to retain some margins, given that there was uncertainty over how quickly those ship designs above the reference line could improve
2. There was some significant discussion about the speed derived from the IHS database (MEPC 60/4/7 and 60/4/15) as to whether this was service speed at 85%-90% MCR with a sea margin or 100% MCR. Denmark's analysis in MEPC 60/4/7 for a limited sample of container ships (170) and ro-ro cargo ships (11) showed that the IHS database speed slightly overestimates the speed, which would generally mean that the EIV would be lower (better) than if the actual V_{ref} speed was used
3. The carbon factor C_f assumed in the EIV is that used for HFO – 3.114. However for attained EEDI calculations, the C_f used depends on the fuel used for testing of the engine during NOx certification, which is invariably MGO with a factor of 3.206. This means that the EIV values are around 3% lower (better) than if 3.206 was used

Taken together for the whole fleet, these 3 aspects would roughly cancel each other out, although for ships with 2 stroke engines the attained EEDI might come up slightly better than EIV (depending on SFOC), and most ships with 4 stroke engines would likely have an attained EEDI that was worse than the EIV.

On the other hand, there were some regressions where R^2 was much worse, for example:

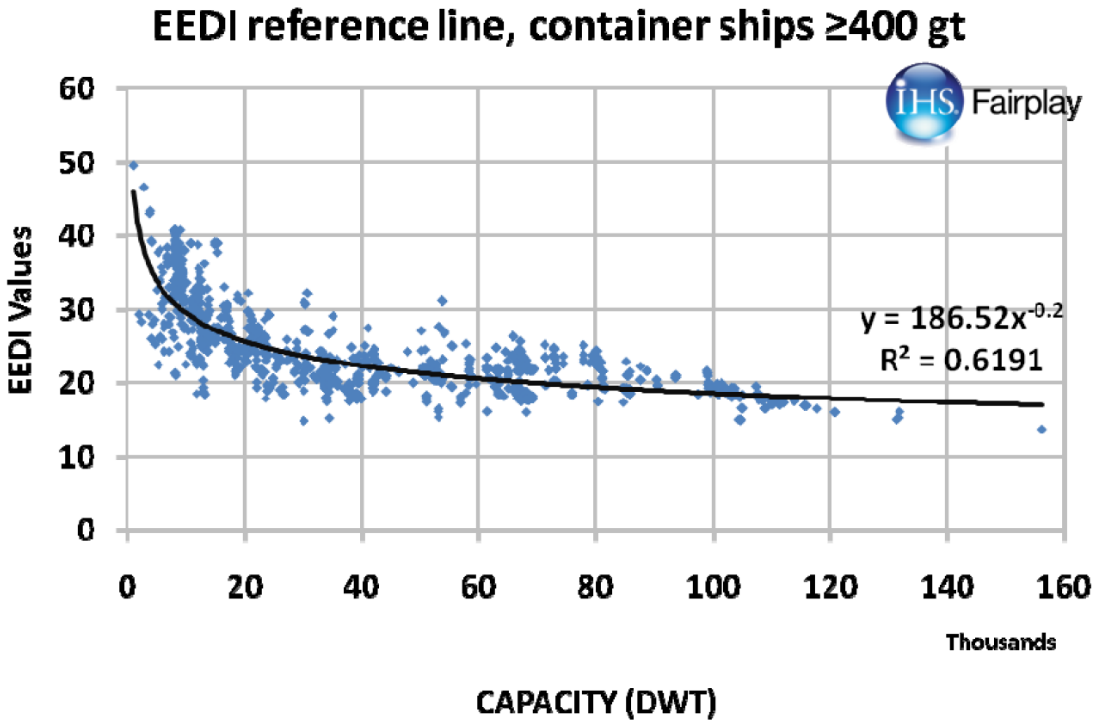


Figure 5 Container Ship EEDI Reference Line MEPC 62/6/4

In the case of container ships, a decision was made to change the calculated capacity to 70% of deadweight in order to reflect that container ships are optimised and operated at less than 100% deadweight. This means that V_{ref} is also measured at 70% of deadweight. We have not been able to find the regression result after this has been applied, however we do not think that the R^2 value was significantly increased.

One characteristic of this regression is the large degree of scatter that can be seen. Up to about 60,000 dwt there is around a ±20%-25% range, meaning that it would have been possible to already have Phase 2 (20% reduction) and even some Phase 3 (30% reduction) compliance with the original dataset for ships between 1999 and 2009.

Another characteristic is that ships between around 70,000 dwt and 100,000 dwt mostly lie above the reference line. This represents the first post-panamax sector which were high speed and high powered, and the influence of this sector skews the regression line upwards, and in part results in the very largest ships already lying below the reference line.

In some ways the scatter represents some variability of speed and operating profile, and all these issues manifest themselves in the overall situation of compliance that is seen in the container ship segment.

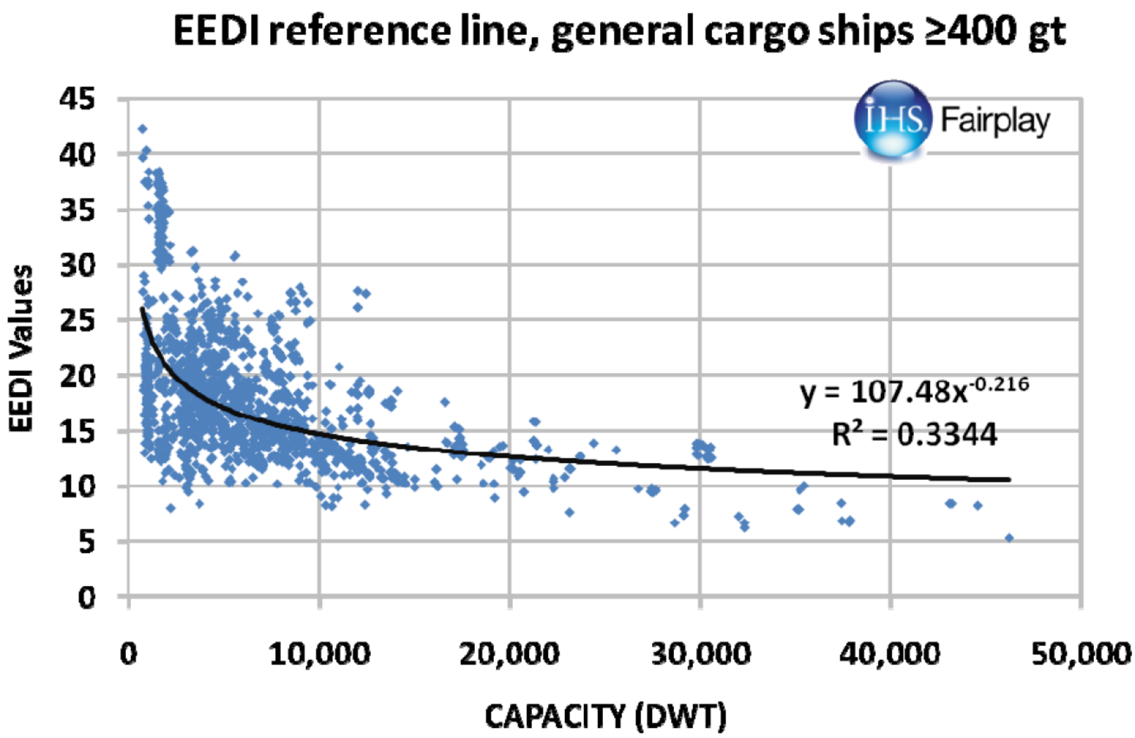


Figure 6 General Cargo Ship EEDI Reference Line MEPC 62/6/4

General cargo ships exhibit the lowest overall R^2 value amongst all the ship segments. This was improved by applying a range of correction factors, which according to MEPC 64 INF.9, application of all these correction factors to a population of general cargo ships making up the reference line improved the R^2 figure from 0.403 to 0.5553.

However the fundamental issue affecting this sector is the very large diversity of ship types, operating profile and speeds. This is reflected in the very large diversity in attained EEDI values relative to the baseline in this segment, which ranges from around 0% to over 60%

This comparison between the bulk, container ship and general cargo segments highlights that the EEDI concept of an average reference line works better for more homogenous segments (in terms of speed, ship design and operating profile) and that R^2 is somewhat correlated with the level and diversity of EEDI compliance of new ships.

This is not to say that improvements to attained EEDI values are solely down to regression characteristics, but that reference line regression does play a part, since it sets the baseline against which reduction rates and attained EEDI is calculated, and as can be seen, there are some size segments where the reference line is not an average of the population.

Reduction phases which are associated with required percentage reductions are then set out relative to the reference line, as shown below.

Ship Type	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Jan 2025 and onwards
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Gas carrier	10,000 DWT and above	0	10	20	30
	2,000 – 10,000 DWT	n/a	0-10*	0-20*	0-30*
Tanker	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Container ship	15,000 DWT and above	0	10	20	30
	10,000 – 15,000 DWT	n/a	0-10*	0-20*	0-30*

Figure 7 Extract from MEPC 62/24 Add.1 Amendments to MARPOL Annex VI

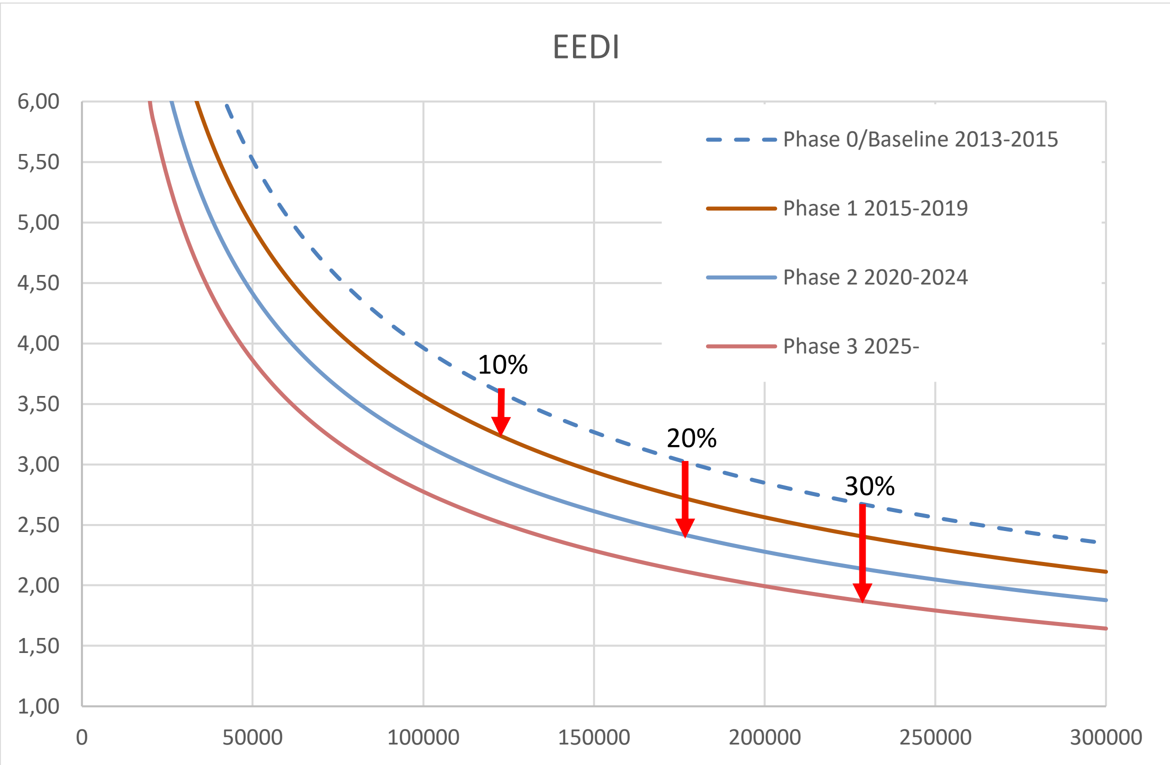


Figure 8 EEDI Reference Line and Reduction Phases

The 1st tranche of ships agreed at **MEPC 62 (2011)** comprised tankers, bulk carriers, container ships, gas carriers, refrigerated cargo carriers, general cargo ships and combination carriers. All segments have a size cutoff below which there is no required EEDI to be met, although EEDI still needs to be calculated and verified. The reduction phases were as follows:

Phase 0 (2013-2014) – 0% Reduction

Phase 1 (2015-2019) – 10% Reduction

Phase 2 (2020-2024) – 20% Reduction (15% for General cargo and reefers)

Phase 3 (2025 onwards) – 30% Reduction

All segments also have a lower threshold such that ships with capacity between the size cutoff and lower threshold should interpolate the required reduction rate.

Amendments to MARPOL Annex VI were adopted at **MEPC 66 (2014)** which included a 2nd tranche of ships which had required further analysis and fine-tuning. These included LNG Carriers (separated from Gas carriers), Ro-ro cargo ships, Ro-ro passenger ships, vehicle carriers and cruise passenger ships with non-conventional propulsion. These ships had reduction phases as follows:

Phase 1 (2015-2019) – 5% Reduction

Phase 2 (2020-2024) – 20% Reduction

Phase 3 (2025 onwards) – 30% Reduction

Phase 1 for these ships commenced on 1 September 2015 however reduction factors applies to those ships delivered on or after 1 September 2019, which is defined as a ship:

> .1 for which the building contract is placed on or after 1 September 2015; or
>
> .2 in the absence of a building contract, the keel of which is laid, or which is at a similar stage of construction, on or after 1 March 2016; or
>
> .3 the delivery of which is on or after 1 September 2019.

MARPOL Annex VI Regulation 21 includes a clause that:

> At the beginning of Phase 1 and at the midpoint of Phase 2, the Organization shall review the status of technological developments and, if proven necessary, amend the time periods, the EEDI reference line parameters for relevant ship types and reduction rates set out in this regulation.

MEPC 72 (2018) adopted amendments to MARPOL Annex VI in Resolution MEPC.301(72) which revised the EEDI reference lines of the Ro-Ro cargo and Ro-Ro Passenger segments.

As a culmination of the EEDI review process required in Regulation 21 of MARPOL Annex VI, **MEPC 74 (2019)** approved amendments to the Phase 3 time periods from 2025 to 2022 for container ships, gas carriers above 15,000 dwt, general cargo ship, LNG carriers and cruise passenger ships with non-conventional propulsion. Additionally the Phase 3 reduction rates were increased for container ships up to 50% depending on the size.

Due to issues with large bulk carriers with respect to the original reference line, the reference line parameters for bulk carriers over 279,000 dwt was also revised and approved at MEPC 74. Submissions to the IMO EEDI database were also made mandatory in the draft amendment.

Note that these amendments were meant to be adopted at MEPC 75, however due to the postponement of MEPC 75, it is not clear what the impact would be.

1.3 Key Resolutions and Circulars

MEPC 63 adopted the following resolutions:

- RESOLUTION MEPC.212(63) – 2012 GUIDELINES ON THE METHOD OF CALCULATION OF THE ATTAINED ENERGY EFFICIENCY DESIGN INDEX (EEDI) FOR NEW SHIPS
- RESOLUTION MEPC.214(63) – 2012 GUIDELINES ON SURVEY AND CERTIFICATION OF THE ENERGY EFFICIENCY DESIGN INDEX (EEDI)
- RESOLUTION MEPC.215(63) – GUIDELINES FOR CALCULATION OF REFERENCE LINES FOR USE WITH THE ENERGY EFFICIENCY DESIGN INDEX (EEDI)

Over time these have been superseded as the following table from the IMO shows.

Table 1-1 Key EEDI Resolutions and Circulars

Resolution / Circular	Title	Status	Relevant MARPOL Annex VI regulation
MEPC.254(67) and its amendments (MEPC.261(68)) MEPC.309(73)	2014 Guidelines on survey and certification of the Energy Efficiency Design Index (EEDI) Amendments to the 2014 Guidelines on Survey and Certification of the Energy Efficiency Design Index (EEDI) Consolidated text: MEPC.1 /Circ.855/Rev.2	Revokes MEPC.214(63) and MEPC.234(65)	Reg. 5
MEPC.308(73)	2018 Guidelines on the Method of calculation of the Attained Energy Efficiency Design Index (EEDI) for new ships	Supersedes MEPC.245(66) and its amendments	Reg 20.2
MEPC.1/Circ.815	2013 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI		Reg 20
MEPC.1/Circ.796	Interim Guidelines for the		Reg 20

	calculation of the coefficient f_w for decrease in ship speed in a representative sea condition for trial use		
MEPC.233(65)	2013 guidelines for calculation of reference lines for use with the Energy Efficiency Design Index (EEDI) for cruise passenger ships having non-conventional propulsion		Reg 21
MEPC.231(65)	2013 Guidelines for calculation of reference lines for use with the Energy Efficiency Design Index (EEDI)	Revokes MEPC.215(63)	Reg 21
MEPC.232(65) and its amendments (MEPC.255(67) and MEPC.262(68))	2013 Interim guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions (Consolidated text: (MEPC.1/Circ.850/Rev.2)		Reg 21.5

1.3.1 EEDI Calculation Guidelines

MEPC 66 (2014) adopted Resolution MEPC.245(66) 2014 Guidelines on the method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships which included calculation guidelines for dual fuel vessels, steam turbine or diesel propelled LNG carriers and new correction factors and definitions associated with the additional ship segments. This superseded the 2012 Guidelines found in Resolution MEPC.212(63).

MEPC 73 (2018) adopted Resolution MEPC.308(73) 2018 Guidelines on the method of calculation of the attained energy efficiency design index (EEDI) for new ships, which further refines the calculation methodology for dual fuel engines, as well as a new ice class correction

MEPC 74 (2019) adopted Resolution MEPC.322(74) as an amendment to MEPC.308(73) to include a new ice class factor f_m for ships with 1A Super and 1A.

It should be noted that these changes in calculation guidance and assumptions affects the consistency of attained EEDI values, although it is difficult to quantify the overall effect.

1.3.2 2013 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI

Since the EEDI formula includes calculation terms that allow innovative energy saving technologies to be taken into account, there needs to be some guidance on how to calculate and verify the savings from such technologies.

MEPC.1/Circ.815 categorises technologies as follows:

Category (A): Technologies that shift the power curve, which results in the change of combination of propulsion power and V_{ref} : e.g. when V_{ref} is kept constant, propulsion power will be reduced and when propulsion power is kept constant, V_{ref} will be increased

Category (B): Technologies that reduce the propulsion power, P_P, at Vref, but not generate electricity. The saved energy is counted as P_{eff}

> **Category (B-1)**: Technologies which can be used at any time during the operation and thus the availability factor (f_{eff}) should be treated as 1.00.
>
> **Category (B-2)**: Technologies which can be used at their full output only under limited condition. The setting of availability factor (f_{eff}) should be less than 1.00.

Category (C): Technologies that generate electricity. The saved energy is counted as P_{AEeff}

> **Category (C-1)**: Technologies which can be used at any time during the operation and thus the availability factor (f_{eff}) should be treated as 1.00.
> **Category (C-2)**: Technologies which can be used at their full output only under limited condition. The setting of availability factor (f_{eff}) should be less than 1.00.

(C) Emission reduction through the auxiliary power reduction by generating electricity for normal maximum sea load(P_{AEeff})

(B) Emission reduction through the propulsion power reduction (P_{eff})

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

(A) The combination of P_P and V_{ref} as reflected in the power curve (knot-kW curve)

The equation above shows how the various categories fit into the equation.

Innovative Energy Efficiency Technologies				
Reduction of Main Engine Power			Reduction of Auxiliary Power	
Category A	***Category B-1***	***Category B-2***	***Category C-1***	***Category C-2***
Cannot be separated from overall performance of the vessel	Can be treated separately from the overall performance of the vessel		Effective at all time	Depending on ambient environment
	$f_{eff} = 1$	$f_{eff} < 1$	$f_{eff} = 1$	$f_{eff} < 1$
– low friction coating – bare optimization – rudder resistance – propeller design	– hull air lubrication system (air cavity via air injection to reduce ship resistance) (can be switched off)	– wind assistance (sails, Flettner-Rotors, kites)	– waste heat recovery system (exhaust gas heat recovery and conversion to electric power)	– photovoltaic cells

Figure 9 Categorisation of Innovative Energy Efficiency Technologies MEPC.1 Circ.815

The above table summarises how the different types of innovative energy efficiency technologies are categorised. The circular also includes calculation formula and examples for each of these categories. There has been some concern from the industry that the calculation formula for wind assistance is not sufficiently robust, however this is being addressed by some research projects.

1.3.3 Minimum Power and performance in weather

It was recognised early on that in order to improve attained EEDI, engine power would likely be reduced either as a result of improved efficiencies or reduced speed.

However there is some concern that installed power on some ships, particularly those that sail at relatively slow speeds such as bulk carriers and tankers are already below historical levels of installed power, and further reductions of installed power to improve CO_2 per tonne mile efficiency may result in ships without sufficient power to safely operate in commonly experienced adverse weather and a rise in ship casualties and cargo loss.

The purpose of the Minimum Propulsion Power (MPP) requirements is to establish credible criteria that ships fulfilling EEDI requirements also have sufficient power installed to remain maneuverable under adverse conditions.

Regulation 21.5, Chapter 4 of MARPOL Annex VI clearly states that: “For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the maneuverability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization.”

At the request of the IMO, the International Association of Classification Societies (IACS) initiated the development of the guidelines referenced in the Regulation 21.5. The studies conducted by the IACS working groups served as a basis for the 2013 Interim Guidelines for Determining Minimum Propulsion Power to Maintain the Maneuverability which were further updated in 2015 and 2017.

The Guidelines are outlined in IMO MEPC.1/Circ.850/Rev.1 and currently apply to:
• Tankers
• Bulk carriers
• Combination carriers

Investigation showed that the above ship types are the most critical with respect to the sufficiency of power for maneuverability in adverse conditions. Views have been expressed by IMO member states that further consideration for other ship types should be performed at a later stage.

The applicability of the guidelines from a capacity perspective is currently limited to ships of 20,000 DWT and above. The main reason behind this restriction is that a systematic evaluation of the required standard environmental conditions for ships with deadweight less than 20,000 DWT has not yet been completed. A solid proposal is envisaged for the future, and ongoing studies in the IMO are currently addressing this issue.

The current methodologies for estimating the minimum power are based on two assessment levels.

Assessment Level 1 – Minimum Power Lines Assessment
A simple approach that involves calculation of the required minimum propulsion power as a function of ship DWT based on a regression of installed power of the existing fleet taking the form (a x Deadweight) + b.

Assessment Level 2 – Simplified Assessment

The level 2 assessment involves a more detailed investigation of the vessel's performance which also takes into account the main engine characteristics. In order to perform the Level 2 assessment the propulsive coefficients must be available, either from estimates or from model tests. This assessment
consists of two key steps:

1. Definition of the required advance speed in head wind and waves, ensuring course-keeping in all wave and wind directions.
2. Assessment whether the installed power is sufficient to achieve the above required advance speed.
3. The determination of wave added resistance through model tests in regular waves. Empirical formulae are also referenced although not directly specified.

Of the two methods, the minimum power lines are relatively easy to calculate, while this was updated in July 2015 in MEPC.1/Circ.850/Rev.1 which increases the installed power required by the minimum power lines, though with a 6 month phase in period.

Since the adoption of the 2013 guidelines, extensive research studies involved the development and validation of numerical and empirical methods for the time-average wave forces, including added resistance, and also aimed to calibrate the standard weather conditions using assessment results of existing ships with respect to the revised criteria.

Research projects SHOPERA and JASNAOE proposed a refinement to the simplified assessment, where the weather assumptions, ship response and expected degree of ship control are different from MEPC.1/Circ.850/Rev.1. These however remain proposals.

The adverse weather conditions recommended by these projects (Beaufort 8, now revised to Beaufort 9) are however felt by industry to be lower than what is typically experienced by ships at sea.

Discussions in the IMO for the Level 2 assessment are still ongoing. Research project conclusions were once again examined by the member states at MEPC 71 but were considered not mature enough to revise the 2013 Interim Guidelines for calculation of minimum propulsion power.

The IMO MEPC at its 72nd session agreed to extend the 2013 Interim Guidelines to EEDI Phase 2 and requested member states and participating bodies to continue discussions on the matter to further develop the revision to the guidelines in upcoming sessions.
In the analysis we have conducted in the bulk carrier and tanker segments, the majority of better performers do not meet the minimum power requirements as stipulated in the minimum power lines and generally apply the level 2 assessment.

Note: MEPC 76 approved changes to the Level 2 assessment methodology, and so now the SHOPERA assumptions and methodology apply from 17 June 2021 onwards as laid out in a revised circular MEPC.1/Circ.850/Rev.3

A related issue is the weather factor f_w which also has its own guidance circular MEPC.1/Circ.796. This was intended to indicate the decrease of speed in representative sea conditions, and would be a measure of the efficiency of the ship in bad weather, and thus as a means of judging between vessels optimised for calm water performance only and those optimised for representative sea conditions. However its use was never mandated and for attained EEDI calculations, f_w is assumed to be 1.

1.3.4 Reduction Phase Application Dates

While the application dates for the EEDI reduction phases appear straightforward, in reality the contract, keel laying and delivery dates may span more than one phase, and some agreed interpretations are necessary.

MEPC.1/Circ.795/Rev.4, updated at MEPC 74 contains unified interpretations to MARPOL Annex VI.

1 Definition of "new ship"

Regulation 2
Definitions

Regulation 2.23 reads as follows:

"*New ship* means a ship:

.1 for which building contract is placed on or after 1 January 2013; or

.2 in the absence of a building contract, the keel of which is laid or which is at a similar stage of construction on or after 1 July 2013; or

.3 the delivery of which is on or after 1 July 2015."

***Interpretation*:**

1.1 For the application of the definition "new ship" as specified in regulation 2.23 to each phase specified in table 1 of regulation 21, it should be interpreted as follows:

.1 the date specified in regulation 2.23.1 should be replaced with the start date of each phase;

.2 the date specified in regulation 2.23.2 should be replaced with the date six months after the start date of each phase; and

.3 the date specified in regulation 2.23.3 should, for Phase 1, 2 and 3, be replaced with the date 48 months after the start date of each phase.

1.2 With the above interpretations, the required EEDI of each phase is applied to the following new ship which falls into one of the categories defined in regulations 2.25 to 2.31 and to which chapter 4 is applicable:

.1 the required EEDI of Phase 0 is applied to the following new ship:

.1 the building contract of which is placed in Phase 0, and the delivery is before 1 January 2019; or

.2 the building contract of which is placed before Phase 0, and the delivery is on or after 1 July 2015 and before 1 January 2019; or

in the absence of a building contract:

.3 the keel of which is laid or which is at a similar stage of construction on or after 1 July 2013 and before 1 July 2015, and the delivery is before 1 January 2019; or

.4 the keel of which is laid or which is at a similar stage of construction before 1 July 2013, and the delivery is on or after 1 July 2015 and before 1 January 2019.

.2 the required EEDI of Phase 1 is applied to the following new ship:

.1 the building contract of which is placed in Phase 1, and the delivery is before 1 January 2024; or

.2 the building contract of which is placed before Phase 1, and the delivery is on or after 1 January 2019 and before 1 January 2024; or

in the absence of a building contract:

.3 the keel of which is laid or which is at a similar stage of construction on or after 1 July 2015 and before 1 July 2020, and the delivery is before 1 January 2024; or

.4 the keel of which is laid or which is at a similar stage of construction before 1 July 2015, and the delivery is on or after 1 July 2019 and before 1 January 2024.

.3 the required EEDI of Phase 2 is applied to the following new ship:

.1 the building contract of which is placed in Phase 2, and the delivery is before 1 January 2029; or

.2 the building contract of which is placed before Phase 2, and the delivery is on or after 1 January 2024 and before 1 January 2029; or

in the absence of a building contract:

.3 the keel of which is laid or which is at a similar stage of construction on or after 1 July 2020 and before 1 July 2025, and the delivery is before 1 January 2029; or

.4 the keel of which is laid or which is at a similar stage of construction before 1 July 2020, and the delivery is on or after 1 July 2024 and before 1 January 2029.

.4 the required EEDI of Phase 3 is applied to the following new ship:

.1 the building contract of which is placed in Phase 3; or

.2 in the absence of a building contract, the keel of which is laid or which is at a similar stage of construction on or after 1 July 2025; or

.3 the delivery of which is on or after 1 January 2029

1.4 IACS PR38

A joint industry working group submitted MEPC 68/3/14 and MEPC 68/INF.30 2015 Industry Guidelines on calculation and verification of the Energy Efficiency Design Index. The joint industry working group included IACS, BIMCO, CANSI, CESA, CESS, ICS, INTERCARGO, INTERTANKO, KOSHIPA, OCIMF and SAJ, ITTC, WSC, SIGTTO and INTERFERRY.

This eventually became incorporated into IACS PR38 and is amended in line with changes to MARPOL Annex VI and the Calculation guidelines.

1.5 Key Terms

Throughout this report, there are some key terms that will be used repeatedly that require definition.

- P_{ME} – this is an EEDI calculation parameter defined mostly as 75% of the installed power of the ship, though there are some modifications if a shaft generator is used in the calculation, or for LNG carriers with steam turbines or diesel electric propulsion where it is 83%. Since it is fixed for most ships, it is a useful point that may be used to compare ships fairly
- V_{ref} – this is the speed achieved by the ship at power P_{ME} in calm water at the summer load line (maximum draught) of the vessel, derived at trials under controlled conditions and verified by a flag state or recognized organisation
- Relative EEDI – this is calculated as $1-(\frac{EEDI_{Attained}}{EEDI_{Baseline}})$ and facilitates easy comparison with the reduction rates; e.g. relative EEDI of 21% just meets Phase 2. The IMO EEDI database includes a column with this value (described as Attained EEDI reduction rate relative to reference line value)
- EIV – Estimated index value is a simplified calculation of energy efficiency which was used to define the EEDI reference lines based on individual ship data found in the IHS database

$$Estimated\ Index\ Value = 3.1144 \cdot \frac{190 \cdot \sum_{i=1}^{NME} P_{MEi} + 215 \cdot P_{AE}}{Capacity \cdot V_{ref}}$$

- IHS Database – This was originally the LR Fairplay database which also administers the IMO number system and holds a significant amount of data on various ship particulars, and also forms the basis for the IMO GISIS ship particulars module

2 DATA SOURCES

At the start of the project, the consortium has in their possession the following data sources:

1. IHS Fairplay database which includes details of all ships that fall under the EEDI framework
2. IMO EEDI database from the GISIS module, version 10 March 2020, containing 5,456 ships
3. EU MRV Database 2018 version 139, with 11,843 ships
4. ABS EEDI database
5. VPS performance monitoring database, approx. 1,000 ships

Additionally Arcsilea have been carrying out work with INTERFERRY on ro-ro cargo and ro-ro passenger ships and has verified data for around 100 of each type. Although this is primarily for existing ships, there is also some data for new ships built under the EEDI framework. Arcsilea also has the original dataset used for the definition of the reference line for these sectors.

Arcsilea has also collected some EEDI data for new cruise ships including those that have been contracted and have completed tank testing, but not delivered as of April 2020.

Further sources of information include broker presentations of newbuilding designs to shipowners and the Significant Ships annual publication from the Royal Institution of Naval Architects, which in its 2019 and 2020 edition lists the energy saving technologies that have been fitted for some ships as well as the attained and required EEDI values.

2.1 IMO EEDI Database

The IMO EEDI database was established to assist with the review of the reduction phases and time periods as required in regulation 21.6 of MARPOL Annex VI:

"At the beginning of Phase 1 and at the midpoint of Phase 2, the Organization shall review the status of technological developments and, if proven necessary, amend the time periods, the EEDI reference line parameters for relevant ship types and reduction rates set out in this regulation."

MEPC submissions on this subject include MEPC 65/4/31, 66/4/13 and 66/4/29.

It was originally agreed at MEPC 66 in April 2014 to establish the database with ad hoc submissions of the following particulars:

1. Type of ship
2. Capacity of ship (GT/DWT as appropriate)
3. Year of delivery
4. Applicable Phase
5. Required EEDI
6. Attained EEDI
7. Use of innovative energy efficiency technologies (tick-box indication of whether the fourth and fifth terms of the numerator of the EEDI equation are employed)

By this stage Phase 0 was already in force. MEPC 67 INF.4 (October 2014) reported that 158 ships had been submitted including a number of ships where EEDI was applied on a voluntary basis. This increased to 454 ships in MEPC 68 INF.13, 1000 ships in MEPC 69 INF.16 and 1917 ships in MEPC 70 INF.14. In the same period, the number of IACS members submitting ships increased from 4 to 8.

MEPC 70 agreed that additional parameters should be provided from 1st April 2017:

1. Dimensional parameters – length between perpendiculars, breadth and draught
2. Ship speed V_{ref} and power of main engines P_{ME}
3. Name, outline and means/ways of performance of innovative technologies

The standard template for reporting was provided in Annex 14 of MEPC 71/17/Add.1. The database continued to increase in size as follows:

- MEPC 71 2443 ships
- MEPC 72 2769 ships – this being the first report after the expanded set of parameters were agreed
- MEPC 73 3622 ships

Some ships data were either resubmitted, or submitted late, which explains why some non-mandatory ships are provided with the additional parameters.

MEPC 73/5/5 proposed mandatory reporting of EEDI values to address the problem of there being ships that had been delivered, but not reported to the database, since reporting was voluntary. This was followed by MEPC 74/5/11 with a proposal for a draft amendment. MEPC 74 agreed draft amendments to MARPOL Annex VI Regulation 20 making submissions to the IMO EEDI database mandatory. MEPC 75 would have adopted these amendments with a provisional entry into force date of 1 September 2021.

MEPC 74/5/11 further increases the number of parameters to be reported as follows:

1. Commercial size in TEU for container ships, CEU for vehicle carriers and cubic meter for gas carriers and LNG carriers
2. Type of fuel or primary fuel
3. f_{DFgas} for ships equipped with dual fuel engines
4. Ice class
5. Short statement describing principal design elements or changes employed to achieve the attained EEDI

At the time of MEPC 74 there were 4505 ships in the database.

Submissions to the IMO contain an IMO number and the precise data used to calculate EEDI, however the IMO number is removed and all the data is rounded up as a means to preserve anonymity. In our analysis, we have found that it is possible to identify ships if cross-referenced with a ship database like IHS, particularly for segments with few ships and/or if ship particulars such as dimensions or engine power stand out from the other ships. Even if a specific ship cannot be identified, it is usually possible to narrow it down to a class of ships.

The version of the IMO EEDI database used for this report is dated 10 March 2020 and contains the following ships.

Table 2-1 IMO EEDI Database Summary (10 March 2020)

Applicable Phase	Non-mandatory	0	1	Total
Bulk carrier	161	1,629	525	**2,315**
Gas carrier	30	224	80	**334**
Tanker	204	781	719	**1,704**
Containership	141	357	250	**748**
General cargo ship	24	62	118	**204**
Refrigerated cargo carrier	-	8	13	**21**
Combination carrier	-	-	-	**-**
LNG carrier[1]	-	-	13	**13**
Ro-ro cargo ship (vehicle carrier)	6	46	17	**69**
Ro-ro cargo ship	5	10	16	**31**
Ro-ro passenger ship	-	3	5	**8**
Cruise passenger ship having non-conventional propulsion[2]	1	-	8	**9**
Total	**572**	**3,120**	**1,764**	**5,456**

2.1.1 Shortcomings of the IMO EEDI Database

Having carried out extensive analysis of the IMO database as part of this project, we have found a number of shortcomings, which may be divided into two categories:

1. Reporting or recording errors
2. Omission of key information

In the first category, we have:

- widespread confusion between installed power and P_{ME} with some smaller ship sectors having incorrect data for up to 50% of the ships. This may lead to erroneous conclusions being drawn about powering trends if the data is used for statistical analysis
- Data entry or calculation errors - required EEDI, year of delivery, draught etc. These are mostly inconsequential, however it does highlight a more general issue with a lack of quality control in the database

- Within the containership sector, some errors in reported deadweight capacity where 70% deadweight is used instead of 100%, even though the EEDI database clearly states that 100% deadweight is to be used. This error causes larger ships with better EEDI scores to be represented in a smaller size segment and makes these sectors seem capable of better efficiency than is in fact possible

In the second category we have:

- C_f (and f_{dfgas}) not recorded. For ships which are dual fuel, the C_f and f_{dfgas} parameters define carbon emission factors to be used for the calculation of EEDI and we have seen evidence that in some ship classes, similarly efficient ships are being assigned vastly different attained EEDI scores because one is calculated with LNG and the other with liquid fuel, even though engine power and speed is broadly similar. This will be addressed by the updates proposed in MEPC 74/5/11
- Ship specific and capacity correction factors not recorded. There are many correction factors involved and it is often difficult to understand if a specific efficiency level is reached due to the influence of correction factors or actual advances in efficiency
- Specific fuel oil consumption is not recorded. Thus we are not able to track changes over time due to technology improvements, or regulatory changes such as NOx tier II or III. Engine tier should also be included – both what is certified for EEDI purposes and what the engine is capable of
- Innovative technology of category A (hydrodynamic) not specified or indicated. The majority of improvements made to design efficiency have involved hydrodynamic innovative technology, larger diameter propellers and reduced rpm but we are not able to derive the extent of uptake of these likely widespread measures unlike technologies of category B and C
- Innovative technology of category B or C not consistently included or described. We are aware of ships delivered with certain types of innovative technology and yet these are not indicated. There are a number of possibilities – attained EEDI could be calculated without the innovative technology since the ship is already EEDI compliant, or the innovative technology has simply been omitted by accident. The value of P_{eff} and P_{AEeff} should also be indicated to build up a database of verified savings of improvements as the number of vessels with such technologies increases

With the current state of the IMO EEDI database, errors, omissions and correction factors mean that statistical analysis of the database to inform reduction rates and timing of future phases should be done with great care and an understanding of the limitations and specificities of the underlying data.

There are also a number of other underlying issues with the data in the database.

Ships with EEDI calculated voluntarily (denoted non-mandatory in the database) are known to have not been assessed as strictly to the guidelines as ships for which EEDI was mandatory. IACS PR 38 did not apply until 1 July 2013, after the start of Phase 0, however as we have seen, most Phase 0 ships did not start being delivered until 2015. Additionally the speed trial procedures in ISO 15016:2002 that were applied to these ships were not aligned with the EEDI requirements, and it was not until revision in April 2015 (ISO 15016:2015) that this was changed.

This means that attained EEDI of ships delivered before 2015 may have data quality issues and should be treated with caution.

3 TASK A1 GENERAL FINDINGS

3.1 Overall Vessel Findings

The regression characteristics of the EEDI reference lines often have a bearing on how the attained EEDI scores of new ships perform relative to the reduction phases. Where the regression characteristics were good, such as for bulk carriers and tankers, which exhibit a high degree of homogeneity in ship design and operating profile then attained EEDI values are likely a reasonable measure of progress in improving efficiency.

Where regression values of the reference line are poor, this indicates that both ship design and operating profile of the segment are more variable, and this generally results in attained EEDI values that exhibit wider scatter as well as over compliance. In such ship types, it is more difficult to discern whether the improvement in EEDI is down to design and technology interventions or reference line definition issues and large population variation due to wider ranges of speed.

Care must however be taken with under-represented populations in the reference line, such as the very large, or the very small, or where one size segment biases the slope of the reference line. We see this with large bulk carriers, tankers and container ships.

We find that the EEDI of sisterships may vary by up to 2-3%, and some of this may be down to the conduct of sea trials as well as the associated trial corrections applied.

One way of taking into account the natural uncertainty that stems from speed measurement, and variation in engine SFOC would be to allow for a 5% margin when evaluating ship sectors – e.g. only if a sector is consistently able to achieve 5% over a reduction rate threshold should this be considered as sufficient evidence that this reduction rate is achievable.

Some care needs to be taken for small ships, because due to the steepness of the EEDI baseline, small changes for example to deadweight and V_{ref} speed can have quite large impacts on both the attained EEDI and required EEDI.

3.1.1 Bulk Carriers

V_{ref} speeds for bulk carriers appears to be unchanged since 2013 data with the majority of ships delivered achieving 14 to 14.5 knots. At the same time we see clear evidence of reduced power for all the segments studied, and in the case studies it appears that larger propellers, extensive use of energy saving devices and improved engine SFOC are all factors in the improvement of attained EEDI in this segment.

The case studies in particular show that V_{ref} speeds are almost the same even from different shipyards.

Compliance with Phase 3 will prove to be challenging for bulk carriers, and the difficulty increases as the capacity increases. This may be a function of the regression not being representative of larger ships, but has been addressed with the revision of the reference line for deadweights larger than 279,000 tonnes. As far as we can see, all optimisation, energy saving devices and engine SFOC reduction have been utilised.

3.1.2 Gas Carriers

Gas carriers originally included LNG carriers in Phase 0, but the two were separated for Phase 1. The LNG carriers were not considered in the analysis.

Larger gas carriers appear to operate at a higher speed than the smaller gas carriers, and within the small gas carrier segment, there are further differences between ethylene carriers and LPG carriers with the ethylene carriers generally having worse attained EEDI even though it is documented that extensive optimisation has been carried out. This is a limitation of the designs being optimised for certain operating profiles. These ships are not able to meet Phase 2, and application of LNG alone would not allow these ships to meet Phase 3.

Overall the gas carrier segment is quite diverse when the results are examined more closely, and reflects operating profile and constraints. This make it difficult to identify trends, however we generally see evidence of improved attained EEDI, fairly constant speeds and small reductions in power.

Larger gas carriers appear to be able to meet Phase 3, however the smaller size segments have challenges complying. The smallest segment already exhibits difficulties in complying with Phase 1, and the evidence is that they have also carried out extensive design optimisation, fitted energy saving devices and benefitted from reduced SFOC of the main engine.

3.1.3 Tankers

While the regression characteristics of the reference line were quite good, the bulk of the population are at aframax size and below and so the reference line is biased towards the smaller ships. While we know from sector and case studies that similar design interventions have been applied across the entire fleet leading to improvements in EEDI, the largest ships generally perform worse and it will be a challenge to meet Phase 3 for VLCCs.

Aframaxes seem to perform better prior to 2015 than after, however this is most likely due to the change in the trial correction and verification methods and stricter adherence to the guidelines, in reality Aframaxes are not necessarily able to consistently meet Phase 3.

Many ships smaller than and around 50,000 dwt benefit from the chemical tanker correction factor and this is a major factor in the seemingly good performance in this size segment, with many ships meeting Phase 3.

We show that the cumulative effect of different correction factors can cause a wide variation in attained EEDI with a segment analysis.

Overall however we document that reduced rpm, larger propellers, extensive use of energy saving devices and improved engine SFOC are all factors in the improvement of attained EEDI in this segment while V_{ref} appears to be unchanged.

Tankers up to around 50,000 deadweight appear able to meet Phase 3, however many of these are aided by the chemical tanker correction factor – ships that are not able to use this correction factor may have problems meeting Phase 3, however this may prompt shipowners to choose to build to the IBC code in order to qualify for this correction factor, with no real CO2 saving. Ships larger than 50,000 dwt generally will be challenged to meet Phase 3 with the VLCCs facing the greatest difficulty.

3.1.4 Container Ships

The regression of the reference line for container ships was relatively poor with a R^2 of 0.6191 and wide scatter with some phase 3 compliance already evident from the original population of container ships between 1999-2009. Equally there are ships which are around 25-30% worse than the reference line

The 1st generation post panamax ships between around 50-100k deadweight which were very high powered and fast also further skewed the shape of the regression line, and makes the very largest ships seem more efficient than they are. This is made worse by the fact that the very largest containerships that we have today were not represented at all in the regression line.

These partly explain the overall performance of the containership sector which is somewhat separated into distinct tiers:

- Ships above 120,000 dwt seem to achieve 45% or more better than the reference line, however the range is between 45% to over 60% with the main cluster being between 45-50%
- Ships between 100,000 dwt and 120,000 dwt seem to exhibit wide scatter between 30% and over 60% better than the baseline, however mostly between 30%-50%
- Ships between 35,000 dwt and 100,000 dwt exhibit wide scatter between 5% and 55%, but with small isolated and widely separated clusters. There are very few phase 1 ships in this tier, and are mostly below 40,000 dwt
- Ships below 35,000 dwt exhibit wide scatter in a continuum between 10% and 40%

When looking at how RPM has changed there is a clear drop in RPM between 2012 and 2014 indicating a trend of reduced rpm to accommodate larger propellers, which was likely coupled with engine derating. However the majority of V_{ref} data is from 2016 onwards meaning it is not possible to come to a conclusion regarding whether speeds were reduced along with the derating.

We note that the container ship market, although well established is constantly being disrupted by external factors such as the change in crane reach facilities enabling wider vessels to be constructed, as such the design data shows that ship dimensions are not as settled as for the other major sectors.

For 12-12.5k dwt container ships, the data shows that speeds have stayed the same (around 18 knots) but with a modest reduction in power. This segment does not meet Phase 3, in fact most designs seem to straddle the Phase 2 boundary. It is likely that ships in this segment need to contend with harbour constraints leading to less than optimal hull dimensions. Phase 1 ships seem to perform much worse than earlier ships, perhaps showing the influence of the change in sea trial correction method. This is demonstrated by sister ships from the same shipyard where the 2015 ship has a relative EEDI just over 30% and the 2019 ship is just below 20%.

For 21.5-27k dwt container ships we see the gradual progression of decreasing P_{ME} power from 10,800 kW to 8,200 kW with little to no change in V_{ref} speed. The lowest powered ships meet Phase 3.

For 36.5-38k dwt container ships, there appear to be two distinct groups of ships, one designed for around 22 knots and the other designed for 19 knots. These are ships delivered around the same time. This means that it is likely they are built for the needs of specific trades and it may not be possible for the faster ships to serve their trades if their speed is reduced. However the faster ships generally only meet Phase 1 while the slower ships meet Phase 3.

For 146-154k dwt container ships, V_{ref} appears to be fairly constant between 22-23 knots, however an earlier series of ships with much better EEDI scores appear to have been built between 2014 and 2016 with waste heat recovery, but this design was not further ordered. Otherwise there is evidence of P_{ME} power being reduced by around 3,500 kW while keeping V_{ref} the same.

For 184.5-203k container ships, we have slower ships around 21 knots delivered in 2015 and 2016, then from 2017 to 2019, the top speeds appear to change from 24 knots to 23 knots, displaying a trend in speed reduction. However when the number of ships that are delivered is considered, it appears that 23 knots is the target design speed in this segment. This segment mostly has the same P_{me} and V_{ref} across the ships, however the best and worst ships exhibit a difference of around 6% in relative EEDI terms which may be due to SFOC and/or PTO arrangements.

Overall we find evidence of speed staying constant for the data provided in the IMO EEDI database, but P_{ME} has reduced in many of the segments thus indicating that energy efficiency has improved. It is however likely that speeds decreased around 2012, while the IMO EEDI database only has significant data from 2016 onwards.

Ships larger than 40,000 dwt are generally able to meet Phase 3, but we note that these ships have benefitted both from design optimisations as well as speed reductions. For some ships smaller than 40,000 dwt, meeting Phase 3 will be challenging and the scope for improvements may be limited due to the need to maintain speed for reefer cargo and port constraints impacting the overall hull dimensions.

3.1.5 General Cargo Ships

General cargo ships encompass a very wide variety of ship designs with different purposes and operating profiles. This is reflected in the very poor regression characteristic of the original population with a R^2 of 0.3344 and extremely wide scatter of the population, in the smaller segments +-50% and in the larger segments we see already ships performing 50% better than the baseline, indicating very poor fit of the data.

The solution used here was to devise specific correction factors for cargo gear and the faster general cargo ships.

We can see some improvement in energy efficiency since all ships are now below the baseline, however there is also still significant overcompliance which would be due to the regression characteristics plus some additional energy efficiency improvement. Due to this wide scatter, it is not possible to conclude on trends in speed or power.

We note that some small ships are quite draught constrained leading to poor hydrodynamic efficiency, however such ships are built to serve shallow ports and river systems and there is a limit to what can be done from a technical viewpoint. Additionally small ships are very sensitive to small variations in speed and deadweight because the reference line is very steep in this area and small changes lead to large changes in the required EEDI.

Overall many ships in this segment already meet Phase 3, however there are specific types of vessels, particularly in the smaller sizes where the performance is much poorer and where meeting Phase 3 will be a significant challenge.

3.1.6 Refrigerated Cargo Ships

There are relatively few refrigerated cargo ships in the IMO EEDI database because the sector has mostly been replaced by reefer containers. There is also a two tier market, the smaller segment which are in the frozen fish trade where vessel speed is less crucial and the larger segment trading in fruit where the speed is more critical. The smaller segment appear able to meet Phase 3, but the larger segment do not meet Phase 2 and are already considered under powered.

We note in the original regression that the smaller ships tended to perform better than the reference line.

We have an example of a Phase 3 ship where a propeller boss cap fin, twisted rudder and silicone based antifouling has been applied together with hullform optimisation for multiple draughts and speeds, giving some indication that technical means have been used to improve ship designs in this sector.

3.1.7 LNG Carriers

There are only 13 LNG carriers in the IMO database. Phase 0 LNG carriers were grouped with gas carriers and it is clear that the correction factor applied make it impossible to compare these with LNG carriers in Phase 1.

In this segment, there are 3 different propulsion technologies that utilise different calculation assumptions and we have also identified at least two ships where the C_f for MGO has been used, even though all ships in this segment use boil off LNG for propulsion.

This indicates that it is not possible to work out any trends because the attained EEDI is more influenced by the fuel used and propulsion technology than any efficiency measures. We separately explain the design measures and overall improvements that have been made in this sector since 2004 since the IMO EEDI database cannot be used to determine trends.

It is important to note that LNG carriers are already in most cases calculating EEDI using LNG as a fuel, with the reduction in C_f contributing to their good attained EEDI.

This has at least three important implications:

- Any addition of methane slip to the EEDI calculation methodology will in the short to medium term lead to a worse EEDI performance for this segment until engine or aftertreatment technology catches up

- LNG carriers are already optimised to use boil off cargo as fuel, so are not able to further improve their EEDI by switching to a lower carbon fuel (Other sectors are able in the short term to go from MGO/HFO to LNG).
- If an alternative fuel initially has some carbon in it, provision of tank volume for the alternative fuel will likely lead to a decrease in deadweight for the same size of ship due to the additional volume and weight required to carry the alternative fuel, which may also lead to a worse attained EEDI

Speed for the larger LNG carriers is relatively constant at around 19.5-20.0 knots. No conclusion may be drawn about installed power due to the different propulsion technologies (and load points) in this segment.

Although most ships in this segment meet Phase 3, the compliance is at risk depending on whether methane slip is incorporated into EEDI framework. This should not detract from the fact that the segment can evidence quite significant improvements in energy efficiency over time.

3.1.8 Vehicle Carriers

Many ships in this segment do not have a required EEDI because of the later application of the EEDI framework. It is normally possible to calculate required EEDI and therefore relative EEDI, but the ratio DWT/GT that is used to adjust the required EEDI is not provided, thus requiring identification of the ships in the IHS database to calculate this information. Our recommendation is that this ratio should be included in the EEDI database.

Vehicle carriers are highly optimised to be no longer than 200 m in order to fit existing berths, and this high degree of optimisation is reflected in the very close cluster of attained EEDI values in Figure 150. With the correction factor applied, a few ships meet phase 2 but only up to about 25% better than the baseline.

Two out of six sister ships perform extraordinarily well, meeting even phase 3, but we have reason to believe the attained EEDI values are erroneous after speaking with the shipowner.

We have reason to believe that some highly efficient eco ships have been included in this segment so current performance of the sector is considered state of the art, and yet does not meet Phase 3. We await the results of LNG powered car carriers that will be included in the next update of the EEDI database.

3.1.9 Ro-Ro Cargo and Passenger Ships

The design and operating profiles of the ro-ro segment varies more widely than any other segment, with speeds ranging from 16 to 30 knots and with many different configurations for carrying cargo and passengers. As a result the ro-ro cargo and passenger ship sectors suffered from very poor regression characteristics and introduced a series of blanket correction factors that have very large effect on the population.

These correction factors however cause the attained EEDI to misrepresent the efficiency of ships such that less efficient ships are routinely shown to be more efficient, and this both creates perverse incentives but also prevents better designs from demonstrating their efficiency.

EEDI for these two sectors needs to be reconsidered.

3 vehicle carriers were wrongly included in the ro-ro cargo ship segment, appearing to be grossly non-compliant ships.

3.1.10 Cruise Passenger Ships

The cruise passenger ship segment also includes one cruise passenger ship with conventional propulsion, and one vessel which has not yet been delivered for which the values from a sister vessel was used (which is not allowed by the EEDI framework)

This highlights the level of inconsistency that exists even at the class society level.

The cruise segment shows that the current electric power table calculation guidelines are not sufficiently prescriptive and lead to widely varying levels of auxiliary power for similar sized cruise ships. Having seen data relating to operational hotel loads across a large selection of cruise ships, the correlation between actual operational hotel load and that derived by electric power table calculation seems very poor, and therefore ships with similar levels of real world efficiency can have significantly different attained EEDI. In other words, EEDI is not representative of the efficiency of cruise ships, and therefore is not effective in driving improvements in the fleet.

We note that many of the intelligent energy saving methods which match HVAC to passenger demand for example are also not taken into account by the EPT and therefore the real world achieved improvements are not represented in the EEDI. While this ultimately might be reflected in an operational CO2 metric, these are technical solutions which are not being credited.

There are some LNG powered ships in the IMO EEDI database, however LNG is not the primary fuel and therefore the C_f used is a hybrid of LNG and MGO. We point out that this designation of primary fuel can cause the attained EEDI to vary widely, for reasons unconnected with energy efficiency and purely because the capacity of liquid fuel storage exceeded that of LNG. It should be noted that in the MRV database, these LNG ships appear to be using LNG all the time and so derivation of the Cf factor for these ships by dividing the CO2 by fuel consumption yields a figure close 2.75.

3.2 Correction Factors

Correction factors are widely used to equalise the performance of ships equipped with features that would otherwise put them at a disadvantage compared with their peers. In doing so however, these correction factors conceal the actual level of energy efficiency of these ships.

In some cases however correction factors are used to deal with the diversity of a population for which otherwise an EEDI concept would eliminate a significant number of ships.

Some correction factors affect very few ships, while others are more widely applied. The corrections range from negligible to quite large, and the distorting effect of correction factors should be reported in the interests of transparency.

3.2.1 Ice Class Correction Factors

Ice class correction factors are made up of three parts, one for engine power, one for capacity (to account for increased steelweight for ice strengthening) and one for Ice Class 1A and 1A Super fixed at 1.05. Ice class corrections were revised recently.

In the 17.5-19k DWT tanker segment, we estimated the magnitude of ice class correction factors for two 1A and one 1C vessel:

- 1A 13.6% increase in capacity and equivalent reduction in attained EEDI
- 1A 20% increase in capacity and 13% reduction in main engine power, equivalent to around a 24% reduction in attained EEDI
- 1C 5% increase in capacity and equivalent reduction in attained EEDI

In the Aframax example given in the correction factor section, the 1A vessel had a correction of 9% compared with 3% for the 1B vessel and 2% for the 1C vessel.

3.2.2 Chemical Tanker Correction Factor

The chemical tanker correction factor affects all chemical tankers and this makes up a large proportion of the total tanker fleet below 50,000 dwt. Although the correction goes up to around 18% on capacity, the average value is around 4%, although around a quarter of the sampled IHS ships have a correction value above 5%.

3.2.3 General Cargo Ships

In the General cargo ship segment, we see evidence of the combination of correction factors providing around a 20% improvement in attained EEDI to some highly powered and fast small general cargo ships, enabling them to comply with Phase 3. Without the correction factor they would not even comply with Phase 0.

Other examples show that the correction for fast general cargo ships alone accounts for about a 15-33% decrease in engine power, which is equivalent to around 14% to 31.5% on attained EEDI. An example of the crane correction factor yields a reduction in attained EEDI of 3.4%.

3.2.4 Ro-Ro Cargo and Ro-Ro Passenger Ships

F_{jRoRo} affects both Ro-Ro Cargo and Ro-Ro Passenger ships and works to reduce or normalise the main engine power of faster higher powered ships towards the segment average. It reduces main engine power on average to about 40% of the installed power (60% reduction) for Ro-Ro Cargo ships, and around 30% of the installed power for Ro-Ro passenger ships for the datasets used to establish the reference line.

F_{cRoPax} for Ro-Ro Passenger ships works to increase the deadweight capacity for ships with large superstructures, to normalise it to ships with much less superstructure since deadweight is a very imperfect measure of the capacity of such ships. For the ships used to establish the reference line, this correction factor on average increased the capacity by around 30%.

As can be observed, these two correction factors significantly distort the carbon intensity of these ship types, but also provide does not preserve the relative efficiency of ships as measured by the EIV. This means that these correction factors completely distort the overall picture and does not promote improved energy efficiency in the segments, but rather provides somewhat perverse incentives – inefficient ships are depicted as better than efficient ships and the methods for improving efficiency are based more on the manipulation of the correction factors. These should be revisited.

3.3 Specific Issues

3.3.1 Powering

It may be seen that the EEDI formula favours direct drive propulsion because it is optimised at a single point, without taking into account the operating profile for which other propulsion configurations may be more efficient.

A comparison of efficiencies at design point shows that while a diesel electric configuration might be between 86-94% efficient, the direct drive version is around 99% efficient. This however neglects the savings from such a configuration across the operating profile outside the EEDI calculation point.

3.3.2 Auxiliary Power

The auxiliary power of cargo ships is calculated as a fixed percentage of the installed power of the main engine, and consists of the required auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodation, e.g. main engine pumps, navigational systems and equipment and living on board, but excluding the power not for propulsion machinery/systems, e.g. thrusters, cargo pumps, cargo gear, ballast pumps, maintaining cargo, e.g. reefers and cargo hold fans, in the condition where the ship engaged in voyage at the speed V_{ref}.

This is 2.5% + 250 kW for installed power above 10,000 kW and 5% for ships with installed power below 10,000 kW.

This formulation does not recognise improvements and reductions to auxiliary power consumption. The effect then of shaft generators are also limited to size of P_{ae}, even if the actual auxiliary power is much higher. Conversely technologies that generate electricity such as waste heat recovery or solar panels are not similarly limited.

Passenger ships need to use an electric power table to estimate the auxiliary power, which is a modified load balance, however the we have uncovered some vastly different results for similar sized cruise passenger ships indicating that the guidelines currently do not ensure uniformity and need to be revised. The examples include similar sized ships with P_{AE} 30% higher, or 45% lower.

3.3.3 Engines

Many of the parameters used in the EEDI are closely tied to the NOx technical file. While the expectation might be that engine SFOC is tied to the engine actually installed, in fact the SFOC used is of the parent engine in the NOx technical file, which may in some cases be the engine with the best SFOC.

Note that currently Tier II SFOC figures are used in EEDI calculations for engines that are Tier III compliant, due to the worse SFOC values in Tier III mode.

For dual fuel engines, the calculation as to whether there is a primary fuel, and thus whether the most advantageous C_f factor may be used is dependent on the relative capacity of liquid and gas fuels. This leads to some strange situations where LNG carriers have been certified with a C_f of MGO, and seem inefficient when compared to peers. The use of LNG as a fuel when compared to MGO would provide around a 15% improvement to attained EEDI, which is more than 1 reduction phase.

3.3.4 Minimum Power

Most ships delivered today utilise the level 2 assessment to pass the minimum power requirements, however for the lower powered ships, there have been some problems with the time taken to pass through the barred speed range (during which increased vibration will reduce the fatigue life of the shaft).

In order to meet both the minimum power requirements and reduce the time taken to pass through the barred speed range, the propeller light running margin needs to be increased. One common way of doing this is to reduce the pitch of the propeller, however this will result in a small reduction in propulsive efficiency.

This indicates that for some vessel types we have reached the limit of what may be achieved with reducing power (due to the reduced torque of smaller engines) and further reductions will be negated by worsening propeller efficiency.

3.3.5 Operating Profiles

The operating profiles of different ship types and sizes generally indicate that ships operating profile includes a significant proportion of time operating at less than summer load draught, although engine load for most vessels apart from container vessels is more consistent. This means that efficiency improvements obtained in other parts of the operating profile may be significant, but these are not recognised by the EEDI framework.

3.3.6 Innovative Technologies

The majority of innovative technologies fall under category A – hydrodynamic or which affect the speed power relationship. These are not separately listed in the IMO EEDI database, are mostly proprietary to the shipyards and installed below the waterline and therefore go unnoticed by most.

Many of these are already widely applied – from the case studies we can see that aft ships energy saving devices are present on almost all examples.

Of the main category B technologies, air lubrication and wind assist technology show the most potential. However wind assistance is poorly served by the current IMO calculation guidelines and tends to under predict the contribution of wind. This is currently being addressed by a JIP between MARIN and ABS.

3.3.7 Energy Savings converted to EEDI

Often when we discuss energy savings, we are referring to reduction in main engine fuel consumption, primarily because for most merchant ship types, the focus on energy saving is around main engine and propulsion.

Energy savings may also be quoted as power or resistance reduction. This however does not always translate to the same reduction in EEDI terms.

To illustrate this we re-use some data from the Kamsarmax case studies found in Task A1. The Phase 0 value is 4.37.

Table 3-1 Kamsarmax Bulk Carrier Comparisons

Ship Id.	EEDI Attained	Relative to Previous	Relative to EEDI Baseline	EEDI Improvement relative to Baseline	ME MCR (kW)	ME MCR (%)
A1	4.01		7.99%		10170	0.0%
A2	3.16	21.34%	27.62%	19.63%	8000	-21.34%
A3	2.37	14.22%	37.91%	10.29%	8000 LNG	-21.34%

Ship A1 is the base vessel with an attained EEDI of 4.01 which is 7.99% better than the baseline, and therefore not meeting Phase 1.

Ship A2 reduces the power to 8000 kW which is a 21.34% reduction in engine power relative to Ship A1 which gives an EEDI attained of 3.16. This EEDI value is 27.62% better than the baseline, however the improvement in EEDI is only 19.63% relative to the baseline.

Ship A3 takes A2 and changes the fuel to LNG. Given the difference in calorific values – 2.75 and 3.206, this means A3 is 14.22% better than ship A2. However Ship A3 is 37.91% relative to the baseline, and therefore LNG has only improved the EEDI by another 10.29%.

The issue is that fuel and power savings are defined relative to peers, however EEDI and reduction rates are defined relative to a baseline. The better a ship performs, the further it will be away from the baseline, but incremental savings in fuel or power will translate to smaller savings relative to the EEDI baseline.

So in summary:

- If an ESD is fitted which reduces power by 5% with no changes to speed, the attained EEDI figure would be improved by a bit less than 5% because of the influence of aux power in the EEDI equation

- However how this influences EEDI compliance against the baseline depends on the distance from the baseline. For ships that perform very well like container ships, say 50% better than the baseline, the effect of this ESD on EEDI compliance would only be a bit less than 2.5%
- It means future phases require ships to do much more than reduction phase suggests.

3.4 EEDI Verification

3.4.1 Overview of Process

For the preliminary verification at the design stage, the following should be submitted to the verifier:

- An application for an initial survey.
- Preliminary "EEDI Technical File" containing the necessary information.
- Relevant background documents and information.

The EEDI Technical File should be developed by the submitter (ship designer or shipyard) and must include of all the data required.
Additional background documents and information necessary for the verifier include but are not limited to:

- Model Test Report complete with towing tank test results and full scale tabulated power/speed predictions for below two (I, II) loading conditions:

I. EEDI loading condition is based on maximum summer load line draft as certified in the approved Stability Booklet and applies for different vessel types as follows:

   Capacity is 100% DWT for bulk carriers, tankers, gas carriers, LNG carriers, Ro-Ro cargo ships (vehicle carriers), Ro-Ro cargo ships, Ro-Ro passenger ships, general cargo ships, refrigerated cargo carrier and combination carriers.

   Capacity is 70% DWT for containerships

   Capacity is Gross Tonnage for passenger ships and cruise passenger ships

II. Intended Sea Trial condition (vessel loading condition during sea trials if different from EEDI loading condition, which is required for final verification of EEDI)

   - Description of the tank test facility including test equipment and calibrations.
   - Lines of the model and the actual ship for the verification of the similarity of model and actual ship.
   - Lightweight of the ship and displacement table for the verification of the deadweight. This may require submission of available ship stability data for verification purposes.
   - Calculation process of the ship reference speed.
   - Reasons for exempting a tank test, if applicable.
   - Copy of the NOx Technical File and documented summary of the SFC correction for each type of engine with copy of engines' (Engine International Air Pollution Prevention) EIAPP certificate.
   - Electric Power Table (if PAE is significantly different from the value computed using the formula defined in the IMO Calculation Guidelines)

- Other specific data for specific ships: For example for ships using gas as primary fuel, the verifier may request data on gas fuel and liquid fuel tank arrangement and capacities for CF calculation purposes.

The most important element of preliminary verification is the ship's model tank test. According to the IMO guidelines IMO (2014b) :

"The speed power curve used for the preliminary verification at the design stage should be based on reliable results of tank test. A tank test for an individual ship may be omitted based on technical justifications such as availability of the results of tank tests for ships of the same type. In addition, omission of tank tests is acceptable for a ship for which sea trials will be carried under the "EEDI Condition"5, upon agreement of the ship-owner and shipbuilder and with approval of the verifier. For ensuring the quality of tank tests, the International Towing Tank Conference (ITTC) quality system should be taken into account. Model tank test should be witnessed by the verifier."

At the final EEDI verification stage, the submitter shall prepare a dedicated Sea Trial Plan in accordance with the International Organization for Standardization ISO 15016:2015 guidelines. The Sea Trial Plan will be the guiding document during the execution of the ship's commissioning trials. Adherence to the process ensures that the ship's final speed power curve and EEDI reference speed, Vref are determined accurately, this is an essential step of the final EEDI verification.

Afterward, all relevant parameters of the EEDI calculation will be re-visited and verified. Aspects that need to be considered for sea trail are elaborated further here using the IMO guidelines.

The scope of verification activities may be summarized separately for the preliminary and final stages in the lists below:

Preliminary Stage:

- Review the EEDI Technical File, check that all the input parameters are documented and justified and check that the possible omission of a tank test has been properly justified.
- Check that the ITTC procedures and quality system are implemented by the organization conducting the ship model tank tests. The verifier would audit the quality management system of the towing tank if previous experience is insufficiently demonstrated.
- Witness the tank tests according to a test plan initially agreed between the submitter and the verifier.
- Check that the work done by the tank test organization is consistent with the ITTC recommendations. In particular, the verifier will check that the power speed curves at full scale are determined in a consistent way between test condition and EEDI loading conditions.
- Issue a preliminary verification report inclusive, possibly in the form of a preliminary statement of compliance.

Final Stage:
Review the Sea Trial Plan to check that the test procedure complies with the requirements of the IMO guidelines. It should be noted that the IMO guidelines

- have endorsed the use of the ISO 15016:2015 standard for all ships trialed after September 2015.

- Survey the vessel to ascertain the ship principle and machinery characteristics conform with those in the EEDI Technical File.
- Attend the sea trial and record the main parameters to be used for the final calculation of the EEDI as discussed before.
- Review the sea trial report provided by the submitter and check that the measured power and speed have been corrected according to the ISO 15016:2015 standard.
- Perform independent speed trial analysis to verify reference ship speed V_{ref} and confirm the conversion of the speed power curve to the EEDI loading condition.
- Verify revised EEDI calculation inputs and results
- Confirm that the vessel's Attained EEDI is less that the required regulatory limit.
- Review the revised EEDI Technical File, if applicable.
- Complete relevant parts of the Record of Construction and endorse.

3.4.2 Known Problems

<u>Speed/power Prediction at Design Stage</u>

One of the common issues seen, more prominently at the earlier periods of the Regulation's implementation, is that of speed adjustment with the sea trial data analysis. This is linked to the methodology applied at design stage as well as the speed trial analysis itself.

For example, even though the ITTC Guidelines may have been followed by tank test facilities, the use of experience-based coefficients to account for scaling effects combined with other practices (e.g. situations where the speed-power curves obtained for the EEDI loading condition and sea trial condition may not necessarily apply the same calculation process) may lead to a more conservative speed/power prediction. After the trials are completed, the verified speed may likely exceed the expected prediction giving this way a benefit boost to the assigned Attained EEDI value.

The IMO has discussed the approach of standardization for experience-based correction factors to enable a more robust verification process and a more objective performance comparison between ships of same type/size.

<u>Speed Trial Plan, Conduct & Analysis</u>

At the beginning stages of EEDI regulations and up to September 2015, vessels conducting speed/power trials for EEDI would implement ISO 19019:2005 for planning, carrying out and reporting of sea trials together with ISO 15016:2002 for the analysis of the recorded data.

The scope of the above ISO standards however, was not fully aligned with the requirements of EEDI regulations and at times affected the accuracy of the resulting speed, VREF.

A joint effort between ISO WG17 and ITTC addressed the missing elements on preparation/conduct of trials and updated the sea trial data analysis methodology.

For all hulls for which EEDI speed trials are conducted on or after 1 September 2015, the updated ISO 15016:2015 applies.

Key differences between the updated and older ISO Standards are in the number of required double runs, restrictions to the prevailing environment and sea state, methodology to address the effect of current, criteria for trial displacement and trim and the implementation of the direct power method in the analysis.

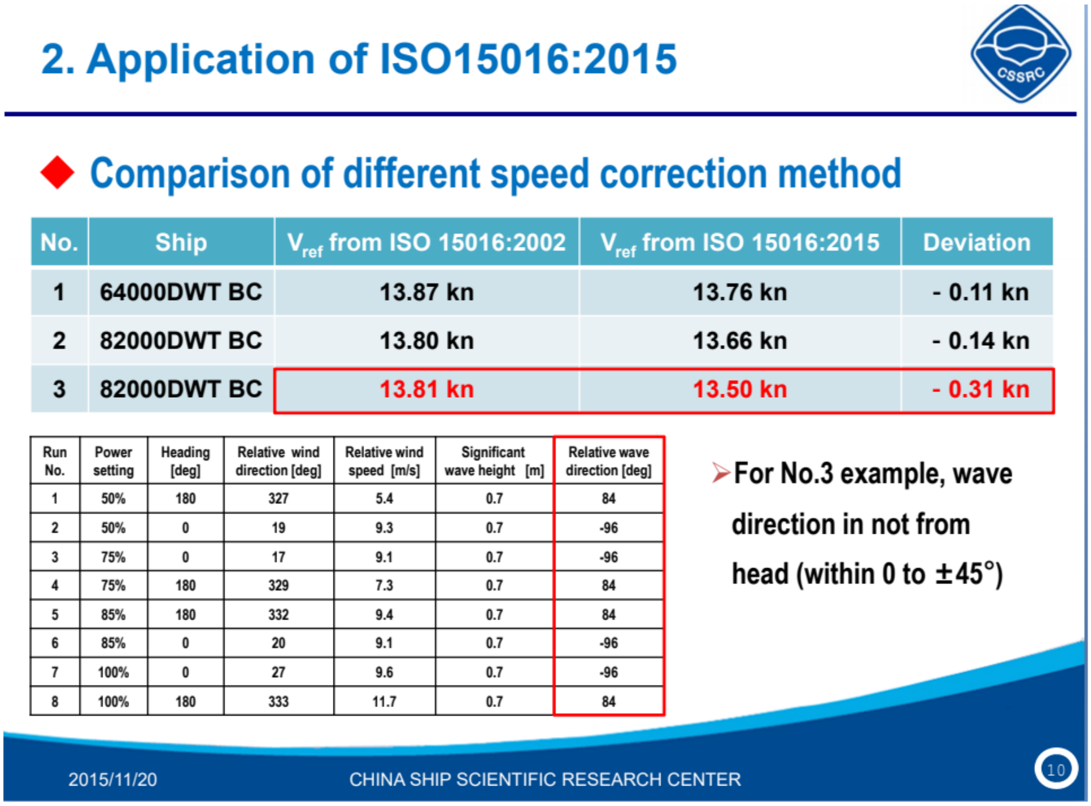


Figure 10 Comparison of Speed Trial Correction Methods (Active Shipbuilding Expert's Federation)

An example above regarding the differences between old and new trial correction methods. This may explain why sometimes certain sectors have better EEDI performance in 2015 than in later years, and in the overall assessment of EEDI performance, we should treat data points from 2015 and before with some care. For the 82,000 dwt vessel above, this difference could amount to 2-3% in EEDI relative to the baseline.

Power at Trials

Following the IMO Guidelines, speed trials for EEDI verification must be performed and evaluated according to the ISO 15016:2015 Standard. According to sec. 6.1 of this standard:

- The G-Modulus of the shaft material is to be determined from an actual shaft torsional test.
- If no certificate from a shaft torsional test is available, a G-Modulus of 82400 N/mm2 shall be used.

During the development of the ISO 15016:2015 standard, this item was discussed extensively in the working group which comprised representatives from various shipyards, owners, class societies, designers and research organizations. The value of 82,400 N/mm2 was agreed as a compromise between higher and lower values provided by the working group members.

During speed trials, the shipyard representative takes torque measurements to ascertain the main engine power at different speeds. The G-modulus of 82400 N/mm2 is to be used to derive the engine power based on the recorded torque unless other specification based on testing is provided by the shafting manufacturer. The implication here is that based on the ISO standard, a different G-Modulus needs to be derived from an actual shaft torsional test, i.e. a torque test carried out on the actual shaft. This approach may not be practicable at all times so, in order to apply a lower G-Modulus to the verification process, different methodologies have been set forth e.g., numerical calculations or torsional testing of smaller test specimens.

With a difference of shaft power by use of a lower G-Modulus being around 4% compared to that based on the 82400 N/mm2 value, an instant improvement of VREF at trial analysis will result. Therefore, the ISO group may need to expand further on their definition of torsional testing to derive the shaft G-Modulus at their next session and include possible alternative methods and acceptance criteria.

3.4.3 Submissions to IMO Database

While MARPOL Annex VI has in place detailed requirements for calculating and certifying EEDI values for new ships, a voluntary reporting mechanism of attained EEDI values of ships subject to the regulation 21 is currently in place. Under this voluntary scheme, the latest published template by IMO MEPC 71/17/Add.1 has been used by IACS members to report vessels verified by their organizations to the IMO GISIS.

However, a number of IMO members conducted a study in 2018 that identified large gaps between the IHS Fairplay datasets and IMO GISIS in terms of underreported ships. This was considered a substantial deficiency as the statistical analysis of the collected datasets is purposed to provide direction on the effectiveness of the regulations so far, drive future amendments and become the foundation to develop new requirements.

The IMO MEPC 74 agreed to introduce a new requirement under Regulation 20 of MARPOL Annex VI that would make reporting of EEDI values by the Administration or recognized organization mandatory for all vessels verified under Regulations 20 and 21 of MARPOL Annex VI. The Committee further agreed to revise the reporting template to include additional information on the fuel used in EEDI calculation together with a short description on principal design elements or changes employed to achieve the attained EEDI.

The amendment to Regulation 20 and revised reporting template as submitted in MEPC 74/5/11 by Japan et al are subject to approval by MEPC 75.

As can be seen in the analysis section, there are a number of errors that we have found in the IMO EEDI database however we are not clear if it originates from the IACS members themselves or when IMO collates the data.

Additionally we have a number of examples where ships that were fitted with innovative technologies in category A, B or C did not indicate this in the EEDI technical file, nor use the B and C technologies in the calculation of the attained EEDI, and so we believe that innovative technology is being under-reported in the IMO EEDI database.

4 INNOVATIVE TECHNOLOGY & ALTERNATIVE FUELS (TASKS B1 & D1)

There is generally some lack of clarity with regards to what constitutes innovative technology. An often-repeated assumption is that the EEDI framework was supposed to have driven the development and uptake of innovative energy efficiency technologies, and the relatively small number listed in the IMO EEDI database seems to point towards a failure of policy.

MEPC.1 Circular.815 from 2013 is the main reference for the verification of efficiency gains by innovative technologies within the EEDI framework, and categorises technologies depending on the nature of their contribution – hydrodynamic, mechanical or electrical. However, the IMO EEDI database only records mechanical and electrical technologies, and not hydrodynamic ones. The evidence from Task A1 shows that shipyards in reality focus on hydrodynamic optimisation and energy saving devices. Lack of reporting of this category of information leads to a large perception gap that ship designs have not been improved.

There are standards for the reporting of data to the IMO EEDI database, but it seems that there is a need to include procedures for reporting. More work is planned at the IMO level to include reporting guidelines into IACS PR38.

It is worth noting that while shaft generators are widespread in some sectors e.g. ro-ro passenger ships, their use on cargo ships with a single main engine has been relatively rare until recently, however engine manufacturers report an increase of such installations. Shaft generators generally work to leverage the superior SFOC characteristics of the main engine relative to the auxiliary engine, which could be as much as 50 g/kWh (165 g/kWh vs 215 g/kWh). However, these installations are not reflected in the IMO EEDI database, as there is a dedicated calculation entry in the EEDI formula outside of the innovative categories.

In reality, the concept of innovative technology is fraught with some difficulties. Sails or Flettner rotors could be seen as either new and innovative, or an evolution of old concepts updated with new technologies and materials. It is difficult to define where the innovation starts or ends.

However, Circular 815 does not attempt to define what is innovative but considers referencing any technology that has the potential to improve energy efficiency. It includes propeller design, low friction coatings, rudder resistance in category A.

The Correspondence Group on Review of EEDI has for some years maintained a table of "Information of Energy Saving Technologies" e.g. MEPC 68/INF.38 which includes hull, superstructure and propeller optimisation without invoking the term innovative.

MEPC 69 INF.8 also dispenses with the term innovative and uses instead the term technical energy efficiency measures and includes very widespread and conventional design measures such as bulbous bows. However, our familiarity with the concept of bulbous bows is also about perception since there has been proliferation of bulbous bow forms for different operating profiles and speeds.

We think that using the terms energy saving technologies or energy efficiency measures/technologies more accurately describes our subject in this report. We will use EET – energy efficiency technologies in the remainder of this report.

In contrast, the terminology alternative fuels are well recognised as anything apart from HFO and MGO.

4.1 MEPC.1 Circ.815 Categorisation of Innovative Technology

Innovative energy efficiency technologies are allocated to category (A), (B) and (C) as defined in MEPC.1 Circ.815, depending on their characteristics and the way they influence the EEDI. Furthermore, innovative energy efficiency technologies of category (B) and (C) are categorized into two sub-categories: category (B-1) and (B-2), and (C-1) and (C-2), respectively.

- Category (A): Technologies that directly influence and shift the ship speed-power curve and can change the combination of Propulsion Power (PP) and V_{ref}. For example, such technologies at constant V_{ref} can lead to a reduction of PP; or for a constant PP they could lead to an increased V_{ref}. This category covers ESDs such as pre-propeller fins, ducts, post-swirl stators, rudder fins and combinations of them along with low-friction coatings and hull/propeller/rudder optimization efforts that directly impact ship hydrodynamic performance.
- Category (B): The commonly known "5th term" technologies that reduce PP, at a V_{ref} but do not generate electricity. The saved energy is counted as P_{eff} .

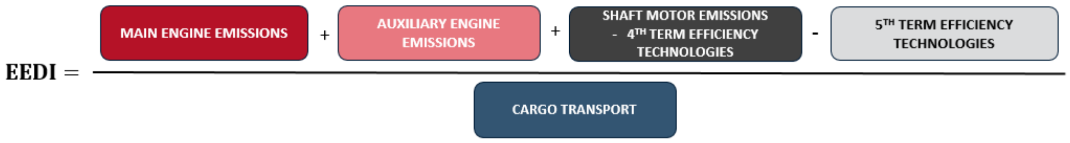
  Category (B-1): Technologies which can be used at all times during the operation (e.g. hull air lubrication) and thus the availability factor (f_{eff}) should be treated as 1.00.

  Category (B-2): Technologies which can be used at their full output only under limited conditions and periods (e.g. wind power). The setting of availability factor (f_{eff}) should be less than 1.00.

- Category (C): The commonly known "4th term" technologies that generate electricity. The saved energy is counted as P_{AEeff}

  Category (C-1): Technologies which can be used at all times during the operation (e.g. waste heat recovery) and thus the availability factor (f_{eff}) should be treated as 1.00.

  Category (C-2): Technologies which can be used at their full output only under limited condition (e.g. solar power). The setting of availability factor (f_{eff}) should be less than 1.00.



INNOVATIVE TECHNOLOGY	Category A	Category B	Category C	EFFECTED COMPONENT OF EEDI FORMULA
Hull Optimization	X			
Superstructure Optimization	X			
Propeller Optimization	X			
Podded Drives	X			
Contra Rotating Propellers	X			
Vane Wheel	X			
Ducted Propeller	X			
Pre-Swirl Device	X			
Post Swirl Device	X			
Twin Skeg	X			
Waste Heat Recovery			X	
Hybrid Propulsion				*Efficiency benefit cannot be realized within current EEDI scheme*
Fuel Cell				*Efficiency benefit cannot be realized within current EEDI scheme*
Coatings	X			
Air Lubrication		X		
LNG, Gas fuels				
Biofuels				*Efficiency benefit cannot be realized within current EEDI scheme*
Wind Propulsion		X		
Solar Power			X	
Lightweight reduction	X			
Hull vane	X			

Figure 11 Categorisation of Innovative Energy Efficiency Technologies

Generally, categories A and B work on reduction of main engine power, while category C works on reduction of auxiliary power.

Note that propulsion power P_p is defined as ΣP_{ME} (In case where shaft motor(s) are installed, $\Sigma P_{ME} + \Sigma P_{PTI(i),shaft}$, as shown in the EEDI Calculation Guidelines).

Note:

- Alternative fuels are not addressed by Circular 815, but in the C_F factor
- Technically shaft generators would fall under category C, but have a separate means of calculation within the guidelines
- Batteries are not obviously catered for since they can work in a number of different ways – peak shaving where they optimise the SFOC of an engine cannot be factored in the PAE component because the EEDI calculation already assumes optimum SFOC, and hybrid propulsion is generally excluded from the EEDI framework

4.2 Lists of EETs

There are several lists of these technologies, the one that is maintained by the EEDI Correspondence Group is MEPC.68/INF.38. We use this as a basis, and add some further ones based on our research.

Note that MEPC.68/INF.38 also includes alternative fuels, as well as fuel cells which require non-conventional propulsion to operate. These do not improve energy efficiency in the conventional sense but may be able affect the attained EEDI through a lower carbon factor.

While EEDI is termed "Energy Efficiency", the measure used is gCO2/tonne.nm and hence a ship which uses a low carbon fuel may appear to be more efficient when comparing two similar ships. However, it is possible that this ship may require more power to achieve the same speed than the ship using conventional fuel. In effect the comparison of energy efficiency is only valid if all ships use the same fuel, however this no longer holds true once fuels of different carbon factors are involved.

We consider alternative fuels in a different chapter.

The table below includes the EET name, a description of the EET effect, “Best Candidate” ship types for the EET, maturity level (orange = low TRL, green = high TRL) and category.

Table 4-1 Table of EETs

Ship design				
#	EET	Description	Best candidate	Maturity/ Category
1	Hull Optimisation	CFD and tank testing to optimise hull form	All ships	A
2	Superstructure Optimization	Wind tunnel and CFD optimisation to minimise wind resistance	All ships	A
3	Optimization of dimensions	Optimisation of length, beam, draught	All ships	A
4	Lightweight reduction	Optimisation and reduction of steel weight – mainly structural optimisation and use of high tensile steel	All ships	A
5	Hull openings optimization	Design optimization of hull openings to reduce water flow disturbance (bow/stern thrusters, sea chests)	All ships	A
6	Bow optimizations	Design of bulb design, waterline entrance, forward shoulder and transition to the turn of the bilge	Ships with high Froude numbers	A
7	Asymmetric stern	Increase propulsion efficiency by pre-swirl of the flow to the propeller and to some extent by reducing the thrust deduction	Ships with high Froude numbers	A
8	Skeg shape training edge	Design modification to direct the water evenly to the propeller	Bulk carriers, Tankers	A
9	Twin skeg	Reduction of propulsive power using twin instead of single skeg	Mainly wide beam, draught restricted ships	A

	Technologies for Hull Drag Reduction			
#	EET	Description	Best candidate	Maturity/ Category
10	Low friction coating	Hull coatings that reduce frictional resistance	Ships with low Froude number	A
11	Heating	By heating the boundary layer, the viscosity is reduced	Ships with low Froude number	A

12	Hull surface texturing	Alters the way flow velocity grows through the boundary layer and/or the way the boundary layer grows along the hull	Ships with low Froude number	A
13	Additives	High-molecule chains are released into the turbulent boundary layer	Ships with low Froude number	A

	Technologies for reduction of propulsive losses			
#	EET	Description	Best candidate	Maturity/ Category
14	Controllable pitch propellers	By setting propeller pitch better performance can be achieved at off-design conditions when the RPM are changed to match the CPP's best performance pitch setting	Ships operating at a wide range of rpm settings	A
15	Overlapping propellers / Contra-rotating propellers	Increase the propulsion efficiency by exploiting the rotational flow of the upstream propeller as a way to condition the wake in front of the downstream propeller.	All ships	A
16	Tip raked propellers (CLT)	reduces drag by weakening the vortex at the propeller tip, leading to greater efficiency	All ships	A
17	Propeller nozzle/duct	Improves propeller efficiency by changing the flow around the propeller	Ships with low Froude numbers	A
18	Grim vane wheel	Device placed behind the propeller to generate thrust. It recovers some of the rotational losses behind the propeller using it to power the turbine shaped central part of the wheel.	All ships	A
19	Pre swirl stators / Mewis ducts / Schneekluth ducts	installed in front of the propellers to improve the inflow to the propeller	All ships	A
20	Post swirl fins / stators	Devices mounted on the rudder that deflect the flow from the propeller to turn its rotational components into useful axial flow	All ships	A
21	Propeller Boss Cap Fins (PBCF)	Manage the radial distribution of the flow behind the propeller near the hub, to reduce the losses	Ships with heavily loaded propellers, e.g. containerships	A
22	Rudder bulb	Bulb design at the rudder that contributes to hub vortex	All ships	A

		recovery and improves axial efficiency		
23	Thrust fin	Fin placed on the rudder where it creates additional thrust in the rotational flow from the propeller	All ships	A
24	Twisted rudder	Asymmetric rudders with twisted leading edge that recovers the swirl energy from the slipstream	Containerships, reefers, Ro-Ro ferries, cruise ships and naval ships	A
25	Interceptor Trim Plate or Trim Wedge (e.g. hull vane)	Device attached to the stern that generates lift by directing the water flow behind propeller downwards	Ro-Ro, ferries and cruise ships	A
26	Flapping foils/wings	Biomimetic system that produces thrust by active pitching and heaving	High speed ships	A
27	Wave foils/wings	Biomimetic system that reduces motions and produces thrust as the transverse motion is provided by the ship motions	High speed ships	A
28	Ducktail waterline extension	Lengthening of the aft ship and thereby lengthening the waterline.	Ro-Ro, ferries and cruise ships	A

We are aware of a number of studies that show some significant savings being possible from reduction of lightweight which utilise composite materials. Many of these were done on passenger ships where the lightweight comprises a much larger percentage of total displacement than would be the case for cargo vessels, so the impact is larger. Another issue holding back the use of composite technology (apart from cost issues) is that the weight saving is sometimes hampered by the need to meet structural integrity requirements such as A class fire protection equivalent, resulting in substantial additional insulation requirements.

4.2.1 Category A Innovative Technology

Innovative technologies that qualify for Category A influence on the EEDI formula consist of technologies whose performance cannot be separately assessed from overall performance of the vessel. An ESD is one example that affects the vessel speed and required propulsive power.

Unconventional Propulsion and Energy Saving Devices

The effect of unconventional propulsion and ESD fittings on a vessel’s fuel efficiency has been investigated by a number of model basins worldwide. Results of experimental studies were presented in Copenhagen at the 2014 International Towing Tank Conference 27th session (ITTC, 2014)

The studies assessed the performance of unconventional propulsion and ESDs under the below key groups and summarized their results in the Conference Proceedings:

- ESDs in front of propeller such as pre-swirl ducts, wake-equalizing ducts, and flow-regulating fins. The efficiency for ships tested in towing basins was generally in the range of 3 - 5%.
- ESDs after propeller to utilize the swirling effect in the propeller slipstream, such as rudder bulb fins, post-swirl stators, and Grim Vane wheels. These applications demonstrated a benefit in the towing tank ranging between 3% for rudder fins up to 6% for the Grim Vane wheel.
- Unconventional tip shape propellers, propeller boss cap fins (PBCF) and contra-rotating propellers. The energy savings observed in the towing tank and full scale trials were 1-2% for the commonly used PBCFs, and up to 5% for new type propellers with blade tips bent forward or backward (Kappel, CLT).

Experimental assessments have been carried out in model basins in conjunction with ESD manufacturers for optimization of their designs. The procedures to obtain the propulsion improvement effect at full scale require testing and calibration by a sufficient amount of sea trial data and onboard measurements. This information, however, is in most cases proprietary to the stakeholders involved (shipyard, owner) and difficult to access.

Full Scale Evaluation of Energy Saving Devices

The prediction of power savings by ESD is of growing interest, as focus is given to meet the upcoming EEDI phases. EEDI verification is based on full scale speed-power performance which incorporates the benefit by ESDs when fitted.

The performance of various energy saving measures has been examined by manufacturers, shipyards and owners since the early implementation stages of the EEDI regulations. A suitable method to verify the efficiency gains by use of ESDs is an integral part of the process with CFD analysis playing an important role, validated through model tests and full scale sea trials.

However, further work is required for a standard process to be established given the uncertainty and differences between testing facilities, assumptions made, and methodologies applied.

4.2.2 Category B Innovative Technologies

Innovative technologies that qualify as 5th term or Category B improve the propulsive power (PP) while maintaining a constant V_{ref} without generating electricity. The two primary 5th term innovative technologies used in industry are air lubrication and wind assisted propulsion. In practice, adoption of these technologies for large bulkers and tankers has been limited.

Air Lubrication Systems

Air lubrication systems reduce the vessel skin friction to improve propulsive power. These systems are not dependent on the environmental conditions and can be deployed at any time during operation. Thus, air lubrication systems satisfy Category B-1 criteria of the EEDI formula and can be achieved through the methods below.

- Bubble Drag Reduction - This method uses bubbles to reduce the liquid density and lower the skin friction on the hull surface

- Air layer Drag Reduction (ALDR) - This system relies on injecting air bubbles that coalesce into a continuous layer of air. These devices may feature a small backward step to introduce a separation point on the fluid flow along the hull. The thickness of the air layer is thinner than the near wall region of the turbulent boundary layer
- Partial Air Cavity Drag Reduction - Taking the concept of a backward step on the hull further, a partial air cavity on the hull bottom is inflated with air. The air layer is thicker than the turbulent boundary layer on the ship hull.

Wind-Assisted Propulsion

Wind-assisted propulsion systems reduce the propulsive power required to maintain a constant speed by converting wind energy into thrust through pressure differentials. In general, wind-assisted propulsion can only be deployed when certain environmental conditions are met, which qualifies for a Category B-2 5th term technology. Wind-assisted propulsion is not a novel concept. However, the challenge for wind-assisted propulsion is more related to adapting existing technology for use on larger vessels rather than developing new technology. Four available forms of wind-assisted propulsion are described below.

- Wingsails or Rigid Sails - Rigid sails utilize the same operating principle as an aerofoil by manipulating the lift and drag forces to produce a net propulsive force.
- Square Rig Sail Systems - Flexible sail systems allow for larger surface sail areas when compared to rigid sails.
- Towing Kites - Large surface kites are connected to the vessel forecastle and deployed at higher altitudes to harness higher wind speeds.
- Flettner Rotors - Rotating columns utilize the Magnus effect to generate forward thrust creating a pressure differential. Flettner rotors can be used in lower wind speeds but require energy input to rotate the column.

Formal guidelines on the method to verify the fuel efficiency contribution of wind-assisted ship propulsion systems have not been issued by the IMO. MARIN in collaboration with ABS collaborate on a Joint Industry Project to assess the performance evaluation and regulatory compliance of ships equipped with wind-assisted propulsion.

The objectives are to:

- Establish recommended procedures to determine the performance of wind-assisted ship propulsion (WASP). This will allow for fair comparison of the different designs in the current market and enable a higher overall quality of performance predictions.
- Demonstrate that the recommended procedures through case studies
- Document challenges in existing regulation and propose new regulations catered to WASP.

Specific to tankers and bulkers, assessing the performance of WASP in a way that allows for fair comparison will help ship designers and owners better understand how these measures will affect compliance with EEDI Phase 3.

4.2.3 Category C Innovative Technologies

Electricity generating innovative technologies include waste heat recovery systems and photovoltaic (PV) solutions. Waste heat recovery technology utilizes the energy contained in the exhaust gases and converts the excess heat, gas flow and pressure into mechanical energy. ABS provides Machinery and Systems Performance analysis to evaluate the proportion of efficiency that can be recovered with consideration of complex system constraints of engine room space, safety, operation and cost of installation.

Photovoltaic technology for use in marine environments is a not-yet mature alternative to traditional marine fuels. Fortunately, the cost of PV modules has decreased while its efficiency potential appears to have increased significantly. According to IMO (2016b), solar power technology should be considered for on-board applications. However, due to the spatial requirements of PV modules and the constraints of large electric energy conversion on vessels, solar power is limited to supplementing auxiliary power plants rather than providing power exclusively.

4.3 Uptake of Innovative Technology

4.3.1 Data Source - IMO EEDI database

The IMO EEDI database contains little information about the uptake of EETs in the ship design, see table 2-3 below. This indicates 40 ships out of 5456 ships, indicating a very low uptake rate as well as a 32 out of 42 installations where the technology is categorised but not specified. There is actually a mistake in the table below where the number of bulk carriers is reported as 4 under others, but 3 under total. Hence the actual numbers should be 43 technologies and 41 ships. We note that this was not changed from the previous edition of the database which had 5015 ships in total, and the latest version of the database as of August 2021 which has 7324 ships lists the same number.

Table 4-2 List of EETs from the IMO EEDI database

Use of innovative technologies										
Ship Type	EEDI 4th term (Electrical technology)			EEDI 5th term (Mechanical technology)					Total (Technologies)	Total (Ships)
	WHR[1]	PPGS[2]	Others*	ALS[3]	Sails[4]	Flettner[5]	Kites[6]	Others*		
Bulk carrier	-	-	-	-	-	-	-	4	**3**	**3**
Gas carrier	-	-	-	-	-	-	-	-	**-**	**-**
Tanker	3	-	-	-	-	-	-	2	**5**	**5**
Containership	4	-	24	-	-	-	-	-	**28**	**28**
General cargo ship	-	-	-	-	-	-	-	-	**-**	**-**
Refrigerated cargo carrier	-	-	-	-	-	-	-	-	**-**	**-**
Combination carrier	-	-	-	-	-	-	-	-	**-**	**-**
LNG carrier	-	-	-	-	-	-	-	-	**-**	**-**
Ro-ro cargo ship (vehicle carrier)	2	-	2	2	-	-	-	-	**6**	**4**
Ro-ro cargo ship	-	-	-	-	-	-	-	-	**-**	**-**
Ro-ro passenger ship	-	-	-	-	-	-	-	-	**-**	**-**
Cruise passenger ship having non-conventional propulsion	-	-	-	-	-	-	-	-	**-**	**-**
Total	**9**	**-**	**26**	**2**	**-**	**-**	**-**	**-**	**42**	**40**

The technologies are generally specified as "other" and the improvement derived from these technologies are also not reported. This raises some questions as to the fitness of the reporting system. However, we can plot the relative EEDI improvement of ships fitted with EETs to compare with their peers.

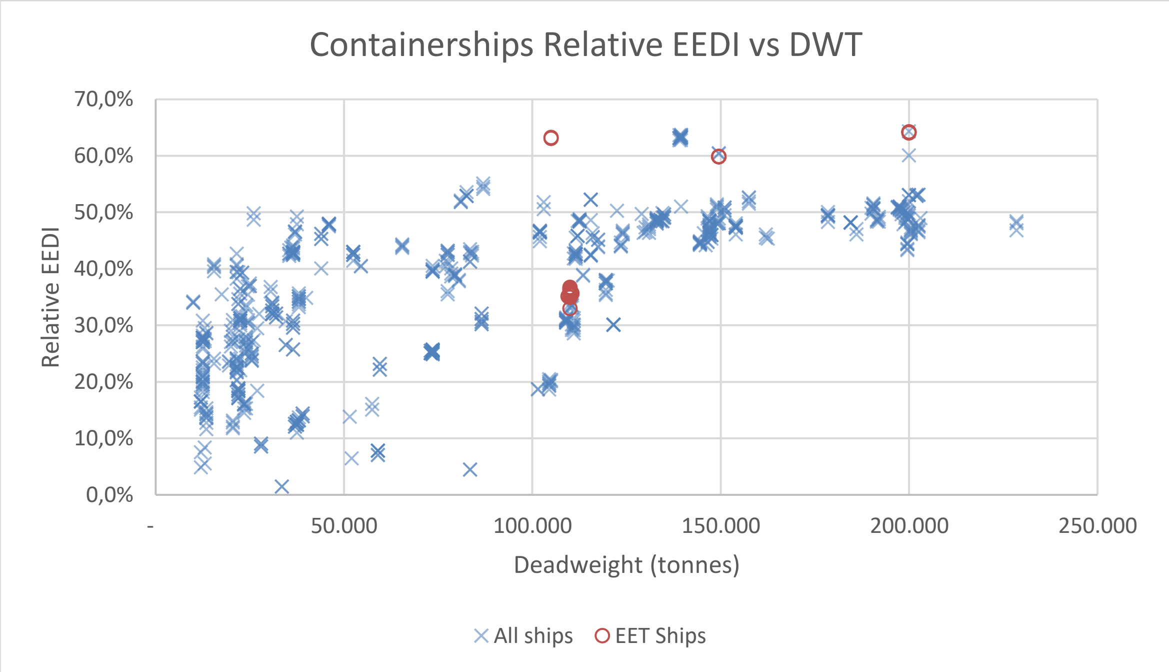


Figure 12 The relative EEDI improvement versus deadweight for vessels with EETs

As can be seen, EET ships generally perform amongst the best of their immediate peers, even for the cluster under 40% relative EEDI at 110,000 dwt. However, that cluster also shows that other optimisations can also deliver improvements (as evidenced by the slightly larger ships performing around 10% better) and efficiency needs to be considered holistically as part of ship design. For example, the ABS Energy Efficiency team carried out more than 5,000 CFD simulations to optimise a supramax bulk carrier hull form, resulting in a hull form that required 5.6% less power in design condition and 4.4% over the operating profile.

We are aware that there are instances of ships fitted with EETs which are not reported so the IMO EEDI database is not an authoritative source that may be used to estimate uptake. For example, we found some presentations slides from a shipyard group that indicated 116 installations of WHRS by end 2016 (though this may include both newbuild and retrofit). Additionally, alternative fuels and use of shaft generators are not listed.

The IMO EEDI Database was updated on 11 August 2021, and includes recently delivered Ro-Ro cargo vessels for which we have the EEDI technical file which was shared the shipowner. These series of sister vessels have solar panels, air lubrication, batteries as well as a rudder bulb. None of these are listed in the EEDI technical file, and the solar panels, air lubrication were not used in the calculation of the attained EEDI, therefore the EEDI database does not list any innovative technology for these ships.

Since the category A EETs are not listed in the IMO EEDI database it is also a challenge to estimate the effect of the EETs on EEDI improvement and for vessels where it is known what is included in the design, it is a challenge to estimate the contribution of each EET to the improvement of the EEDI. As can be seen, most lists of EETs are generally dominated by category A devices, and additionally the lists are incomplete, so estimating uptake is somewhat difficult.

4.3.2 Data Source – Manufacturers, Designers and Shipyards

A number of EETs are designed/invented by companies and customized to different vessels or included in a retrofit. The principle in the technology has then later been introduced by shipyards as part of the design of new vessels e.g. rudder bulbs, twisted fin propellers or propeller ducts.

Examples from manufacturers are listed in the below table 3-2. Where no information has been received, the table is marked with (-). According to the above paragraph the uptake does not represent the full uptake in the Industry. For ducts, fins, rudder bulbs we are aware that most shipyards have their own versions with their names e.g.: SAVER stator, SARB (Samsung Asymmetric Rudder Bulb), CMES-HVAF (hub vortex fin), CMES-PSV (pre swirl vane), CMES-WID (wake duct), SILD (Sumitomo Integrated Lammeren Duct), Hyundai thrust fin, Daewoo Pre Swirl Fin, DSME Pre-swirl stator to name a few.

Table 4-3 Example List of EET uptakes from makers and yards

Technologies for reduction of propulsive losses		
EET	Vessel Type uptake	Number of vessels
Controllable pitch propellers	Ro-Ro, ferries and cruise ships Tankers operating at a wide range of operations	-
Overlapping propellers / Contra-rotating propellers	Ro-Ro, ferries and cruise ships Bulk Carriers Tankers	- 4 2
Propeller nozzle/duct	Ro-Ro, ferries and cruise ships Vessels operating at a wide range of operations	-
Tip raked propellers	All ships	Kappel Propeller > **100** since 2005 (B&W MAN, 2020) CLT propeller > **280** since 2012 (SINMH, 2020)
Grim vane wheel	-	-
Pre swirl stators / Mewis ducts / Schneekluth ducts	Bulk carriers Tankers Container vessels	Becker Mewis duct > **1200**, since 2009 (Becker) Schneekluth duct > **1800**, since 1983 (Schneekluth, 2020) Pre Swirl - in the design/delivery of vessels from many yards, since 2005 (G.Gougoulidis et al, 2015)
Post swirl fins / stators	Bulk carriers Tankers Container vessels	in the design/delivery of vessels from many yards, since 2005 (G.Gougoulidis et al, 2015)
Propeller Boss Cap Fins	Bulk carriers Tankers Container vessels	MOL > **3400** since 1987 (MOL, 2020)
Rudder bulb	All vessels	Promas Rudder Bulb >**200**

		in the design/delivery from many yards since 2012 (G.Gougoulidis et al, 2015)
Thrust fin	All ships	in the design/delivery of vessels from many yards, since 2010 (G.Gougoulidis et al, 2015)
Twisted rudder	Containerships, reefers, Ro-Ro ferries, cruise ships and naval ships	-
Interceptor Trim Plate or Trim Wedge (e.g. hull vane)	Ro-Ro, ferries and cruise ships	-
Flapping foils/wings	High speed ships	-
Wave foils/wings	High speed ships	-
Ducktail waterline extension	Ro-Ro, ferries and cruise ships	-

Technologies for reduction of propulsion power		
EET	Vessel Type uptake	Number of vessels
Air Lubrication	All ships	> 30 installed Air Lubrication Technology (ABS, 2019) 6 vessels 23.700 TEU to MSC ordered with SHI (SHI, 2020) 12 RO/RO to Grimaldi ordered with Silverstream (Silverstream, 2020) 2 VLCCs to CMES ordered with Silverstream (Silverstream, 2020) 3 Finnlines RO/RO ordered with Silverstream (Silverstream, 2020) Framework agreement with Shell to deliver an unknown amount of installations on LNG carriers (Silverstream, 2020)
Wind power	RO/RO Ferries Tankers General Cargo	5th rotorsail technology to be installed in 2020 (Norsepower, 2020)

Technologies for generating electricity		
EET	Vessel Type uptake	Number of vessels
Waste Heat Recovery	All ships	-
Solar Panels	All ships	-

Based on the work we have carried out in the specific case studies, our estimate is that most newbuilds today would have fitted one or more EETs of category A. Ducts, fins, stators, rudder bulbs are the most common. This is corroborated by the Active Shipbuilding Expert's Federation (ASEF the association of mostly Asian shipyards) where they have slides pointing out that fuel saving improvements since 2009 have involved the application of hydrodynamic EETs.

With propellers it is more difficult to estimate, since all propellers are optimised to a certain extent. We have also seen that larger diameter propellers have been fitted to almost all ships where it is possible, together with reduced RPM main engines since around 2012/2013 onwards (see RPM figures in the Task A1 report and survey in 3.2). Again, this is corroborated by ASEF powerpoint presentations as referred to above. In addition to this, there is a further subset that have fitted tip raked propellers such as Kappel or CLT.

4.3.3 Data Source – Task D1 Survey

A section of the Task D1 survey asks for input into the uptake of various types of EETs. Only shipowner and shipyard answers are considered, because answering this accurately required detailed knowledge of what was fitted to individual ships, and even with this, we discovered errors in some of the answers.

One added caveat to this was that although we phrased the question as percentage of EEDI fleet, it is very likely that many responses were given as percentage of whole fleet including non-EEDI ships. So in reality, the percentage of the EEDI fleet fitted with various devices is likely much higher, and this is corroborated with the responses from the shipyards.

4.3.3.1 Task D1 Calculation Methodology

The survey asks what percentage of the respondent's fleet has installed a range of different technologies, and the answers are provided as multiple choice ranges as below.

Given that each respondent has a different fleet size, merely comparing total number of responses for each range may be misleading. In order to compare the impact for each technology a percentage of the technology applied is calculated on the basis of all possible unique installations.

The equipped vessels are calculated from base value of the number of vessels the stakeholders answer is based on multiplied with the factor substituted for the response:

Response	Average	Min	Max
0%	0	0	0
1% - 9%	0.05	0.01	0.09
10% - 24%	0.17	0.10	0.24
25% - 49%	0.37	0.25	0.49
50% - 74%	0.62	0.50	0.74
75% - 100%	0.87	0.75	1
Not applicable	0	0	0

So if a respondent with 50 vessels selects 10%-24% as their answer, this would translate to a minimum of 5 vessels, a maximum of 12 vessels and an average of 8-9 vessels. This may then also be compared with a respondent with 10 vessels who selected 50%-74% which translates to a minimum of 5 vessels, maximum of 7 vessels and an average of 6 vessels.

4.3.3.2 Overview of Responses

Using the calculation methodology explained above, we first provide an overview of responses to the 11 categories.

From the responses of the stakeholders, 38 (44.19%) identified as ship owner. Ship type they specialize in contains all except: Combination and General Cargo. The number of vessels they have based their answer on are 3664.

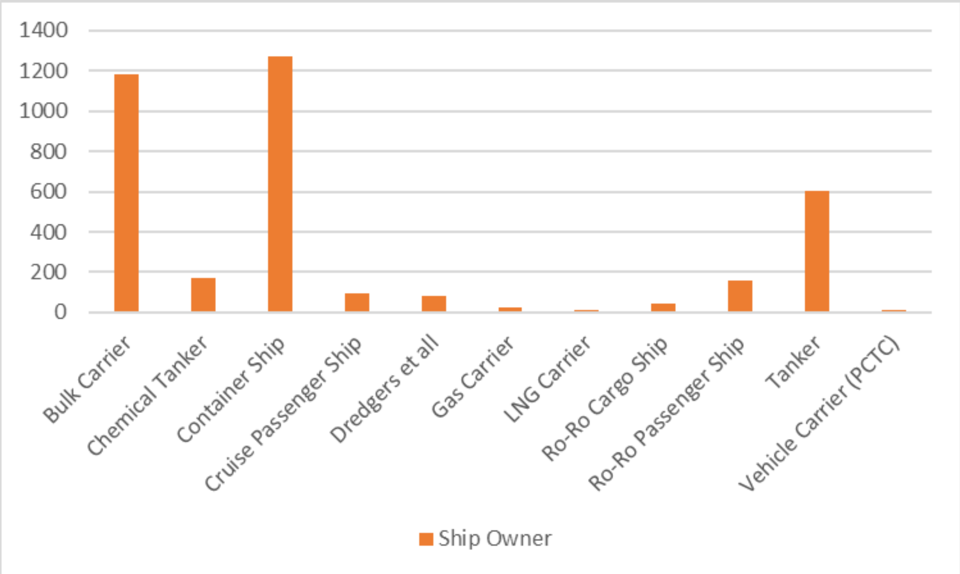


Figure 13 Ship Owner Responses – Number of ships by ship type

The responses are dominated by bulk carriers, tankers and container ships which make up the bulk of the ships in the EEDI database – 86.5% as of the database version of 3 February 2021 and the analysis of responses will focus on these ship types because they make up a statistically significant dataset.

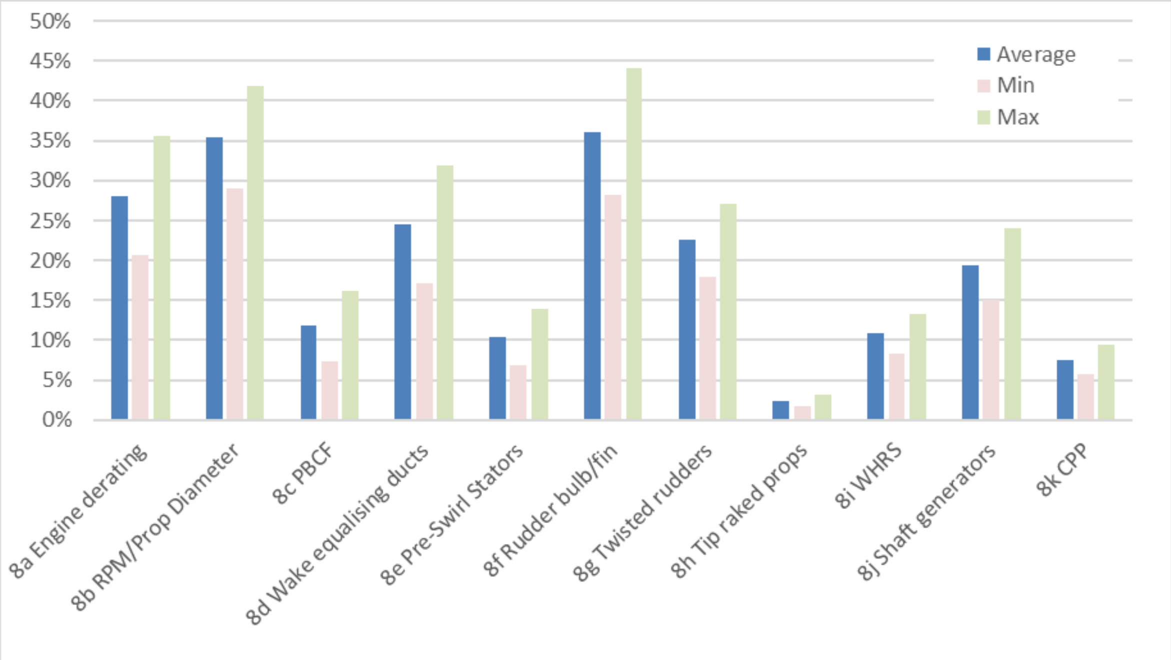


Figure 14 Equipped vessels – Ship Owner Answers

The above chart provides the overview of uptake across the different categories of technologies. Note that these categories should be considered mostly separately as it is likely that ships will have installed more than one type of technology. **Note that we do not recommend drawing conclusions from this chart alone and the subsequent sections dealing with each technology in turn should be read in conjunction with this chart.**

4.3.3.3 Propeller Boss Cap Fins

The responses to propeller boss cap fins (PBCF) indicate a much lower level of uptake compared to engine derating and low rpm/propeller diameter.

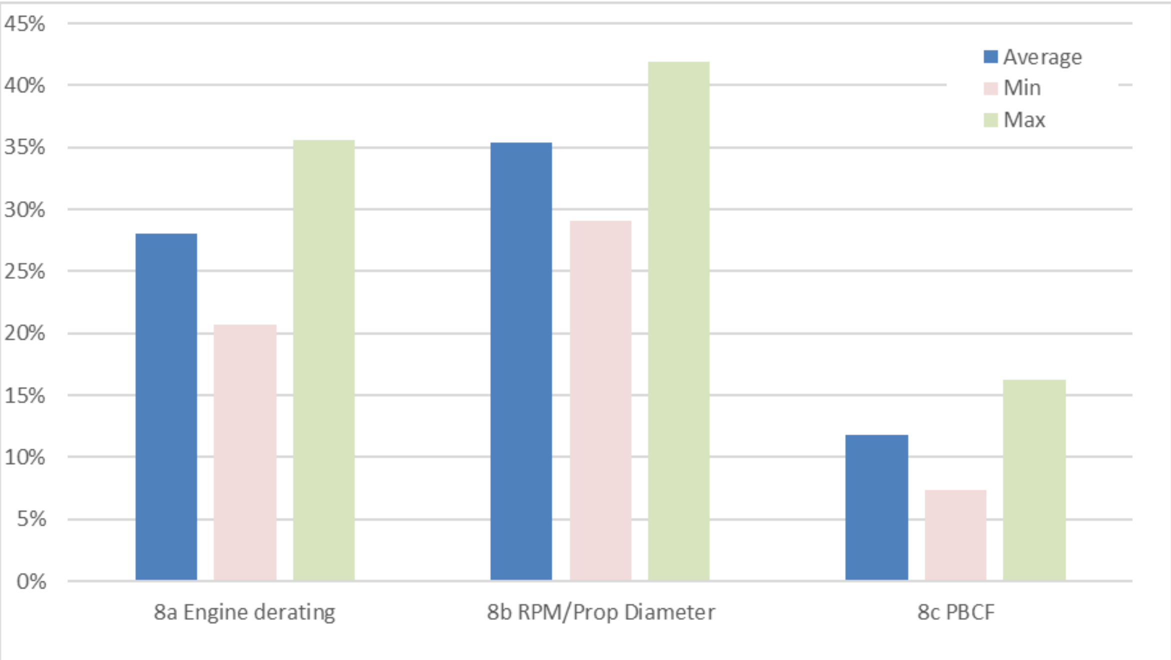


Figure 15 Ship Owners uptake of PBCF compared to derating and RPM/Prop diameter

It is likely that there is a higher level of confidence in these answers because a boss cap fin is a much more visible technology which likely has been supplied by a third party.

There are potentially a number of reasons for the low uptake:

- Propeller manufacturers who quote to supply shipyards are in a highly competitive environment and lowest cost procurement means that generally all nice to have features (such as PBCF) are stripped out
- Although manufacturers quote savings of 5-6% from the fitting of PBCF, experience from shipowners contacted individually during the survey indicate much lower levels of savings – around 1.5% for full form ships such as bulk carriers and tankers, and less than 1% for container ships (one respondent indicated privately, much less than 1%)

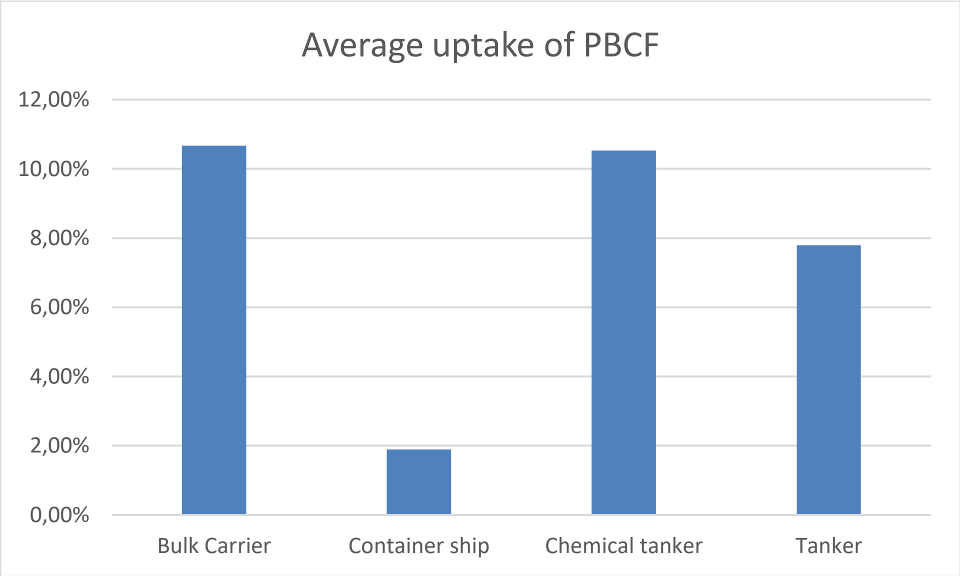


Figure 16 Shipowners Uptake of PBCF by Ship type

The above chart shows the average uptake of PBCF across a number of ship types as recorded in the survey.

The level of uptake seems to match the real savings potential when we look at individual ship types, with very low rates of installation of PBCF on containerships, where the savings are the least.

Looking further into the data, there are 3 shipowners with a very high uptake of PBCF, accounting for around 125 tankers, indicating a strong company preference.

On the other hand, PBCF seems to have found some traction in the retrofit market particularly on containerships where modifications were carried out to support sustained slower steaming, and in most cases required new propellers to be fitted, though even there it would be difficult to apportion savings between the propeller and PBCF.

4.3.3.4 Ducts, Stators, Rudder Fins & Bulbs

We group ducts, pre-swirl, rudder bulb/fin and twisted rudders together to allow for better comparison with the responses of the shipyards who have specified a particular grouping of technologies in order to keep the preferred strategies of the different shipyards anonymous.

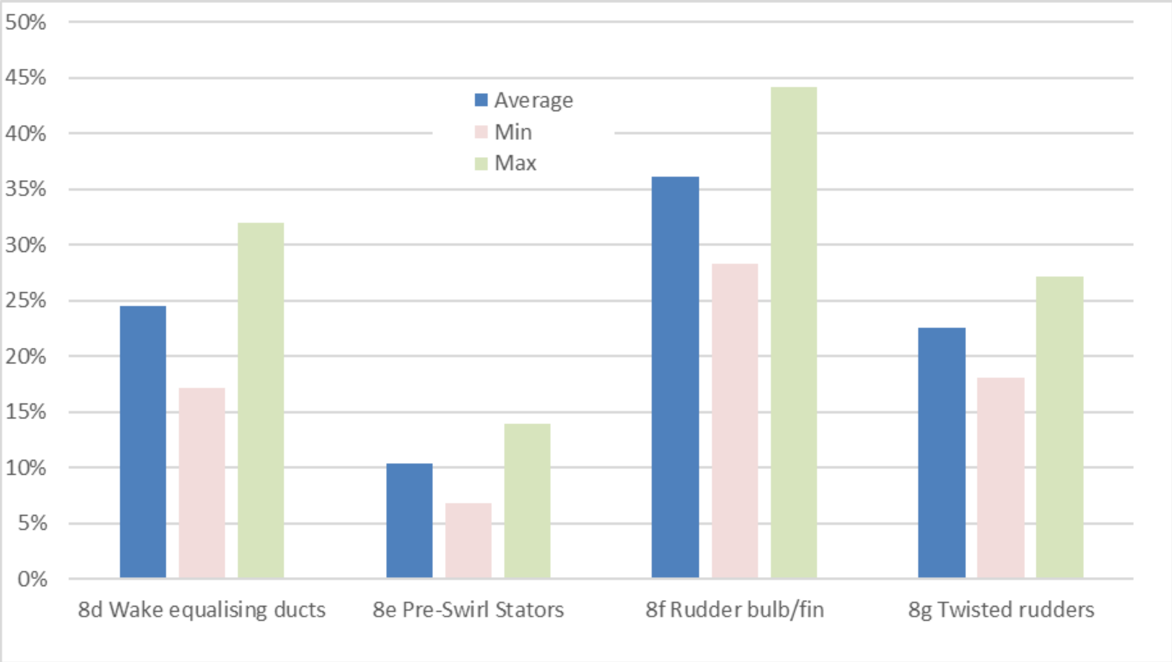


Figure 17 Ship Owners uptake of Ducts, Stators, Rudder bulbs & Twisted Rudders

Overall, pre-swirl stators seem to be less commonly used compared to ducts, rudder bulbs/fins and twisted rudders, however the Mewis duct combines pre swirl fins with a duct so this may simply be a reflection that stators are less often used independently of other devices.

It is likely that installation of devices may vary by ship type, so we examine uptake by ship type below.

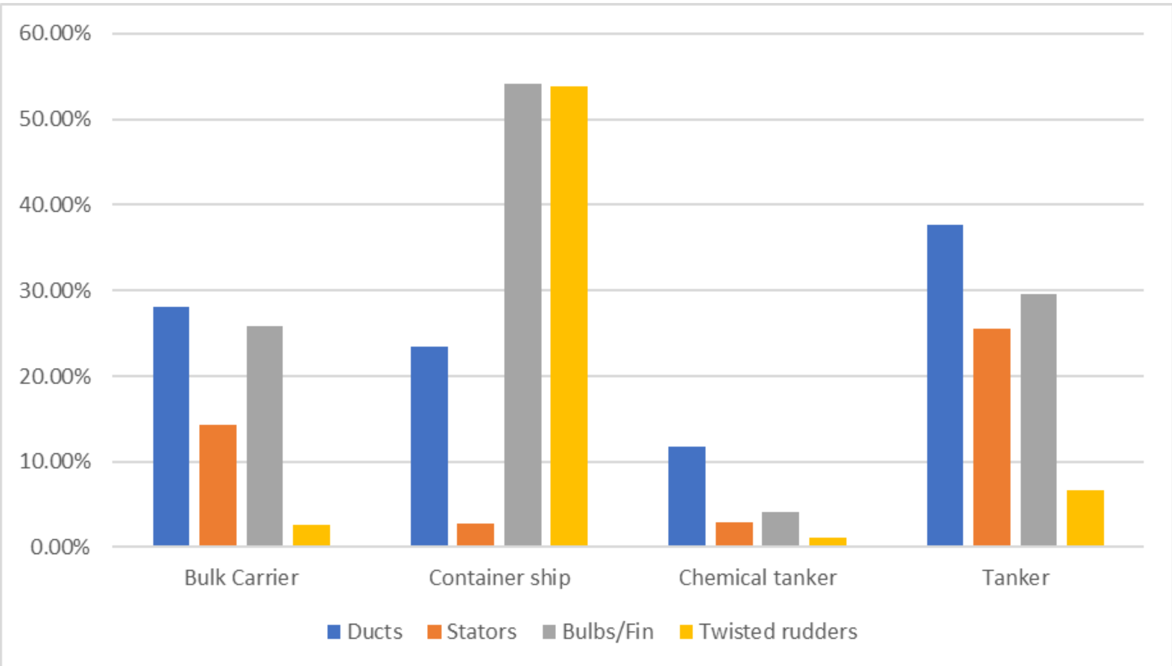


Figure 18 Uptake of ducts, stators, rudder bulbs/fins and twisted rudder by ship type

It seems clear that the design strategy for containerships differs substantially from bulk carriers and tankers when it comes to implementation of energy saving devices, with an emphasis on rudder bulbs/fins and twisted rudders and very low use of stators.

Conversely twisted rudders seem much less used on slower ships. This confirms the scientific literature that indicates that twisted rudders are generally more suited to faster ships.

Implementation of these devices on chemical tankers also seems to be at a much lower level than other ships, which may indicate substantially different strategies being used.

Overall this illustrates that lack of uptake of particular devices may simply be down to lack of suitability for certain ship types, or different design strategies being employed.

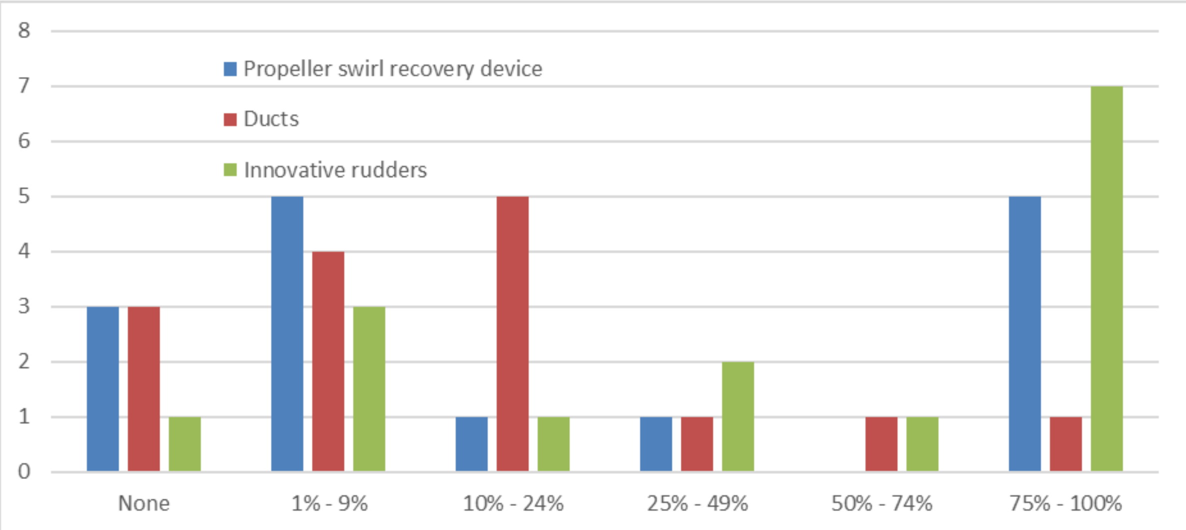


Figure 19 Shipyard responses - Uptake of propeller swirl recovery devices, ducts and innovative rudders

The shipyard responses grouped all pre and post swirl devices together and suggested that innovative rudders of all kinds should be considered rather than just twisted rudders. As such we see high uptake of innovative rudders.

In order to investigate this further, we consulted the publication RINA Significant Ships. The 2019 and 2020 editions (which covers ships delivered in 2019 and 2020) lists for most vessels the energy saving devices that are installed. A sample of 29 ships of various sizes and types is as follows:

Table 4-4 List of installed EETs derived from RINA Significant Ships 2019 and 2020

Ship Type	DWT	EET	EET	EET
Ro-ro cargo	11,288	Rudder bulb	Twisted rudder	
LPG Carrier	18,000		Mewis duct	
Ro-ro cargo	18,120	Rudder bulb	Air lubrication	Batteries
Reefer container	27,800	Rudder bulb	Twisted rudder	
Bulk carrier	34,490	Rudder bulb	Pre swirl stator	Wake fin
Container ship	37,400	Rudder bulb	Twisted rudder	
Tanker	37,836	Rudder bulb	Asymmetric stern	
Tanker	40,000	Rudder bulb		
LPG Carrier	51,312	Rudder bulb	Twisted rudder	Tip raked propeller

Bulk carrier	80,700		Mewis duct	
Bulk carrier	82,516	Rudder bulb	Duct	Hull Fin
LNG carrier	92,400	Rudder bulb	Air lubrication	
LNG carrier	93,500	Rudder bulb		
LNG carrier	93,534		Twisted rudder	PBCF
LNG carrier	93,775	Rudder bulb	PBCF	
Bulk carrier	100,449	Rudder fin	Flipper fin	
Bulk carrier	104,553		CPP	
Tanker	118,100	Rudder bulb	Pre swirl duct	Hull fin
Shuttle tanker	128,800	Rudder bulb		Batteries
Shuttle tanker	152,868		Pre swirl duct	
Container Ship	157,076	Rudder bulb	Pre swirl duct	Fin
Container ship	159,614	Rudder bulb	Mewis twisted duct	
Bulk carrier	208,600	Rudder bulb	Twisted rudder	Rudder fin
Container ship	228,600	Rudder bulb	Twisted rudder	Hull Fin
Container ship	232,700	Rudder bulb	Pre swirl stator	
Tanker	300,300	Rudder bulb	Pre swirl duct	
Bulk carrier	302,000	Rudder bulb	PBCF	
Tanker	312,499	Rudder fin	Flow control fin	PBCF
Tanker	320,500	Rudder bulb	Pre swirl duct	Hull fin

This investigation indicates that the current ESD strategy of shipyards primarily revolves around rudder bulbs, in the sample above, around 83% of ships are fitted with a rudder bulb, a further 31% are fitted with a duct and 24% are fitted with a twisted rudder.

This aligns with the answers from the shipyards which indicate that swirl recovery devices are slightly more prevalent than ducts. There is also an indication that generally twisted rudders are not paired with ducts of stators, likely reflecting different design strategies.

The above is also a strong indication that generally all new ships are fitted with energy saving devices. A check on the 2016 edition of Significant Ships indicated that rudder bulbs were already fairly common then.

The conclusion is that almost all ships today are delivered with category A EETs. Note both cases of air lubrication are not registered in the latest edition of the IMO EEDI database.

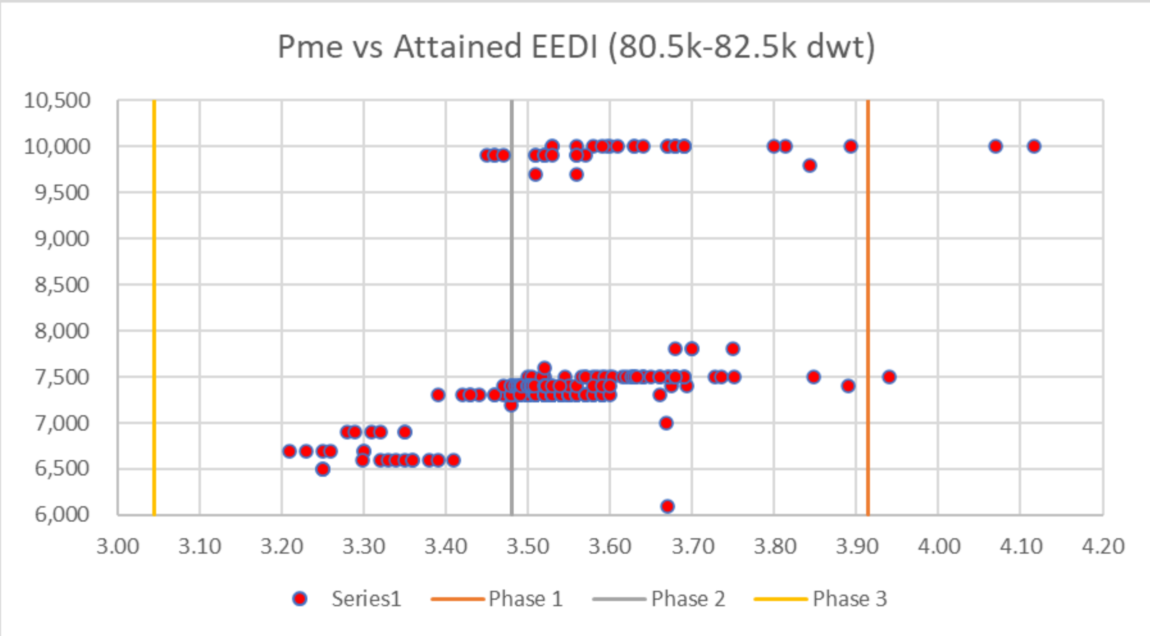


Figure 20 Kamsarmax bulk carriers P_{me} vs attained EEDI - IMO EEDI database

There is an additional point worth noting about uptake. Above is the chart of P_{ME} against Attained EEDI for Kamsarmaxes as shown in the Task A1 report. There is a widespread view that increasing uptake of energy saving devices will move all the points above to the left, hence there is this impetus to figure out the percentage improvement potential of different types of energy saving devices as well as trying to stimulate uptake of devices in order to justify larger reduction rates and EEDI Phase 4.

In reality, increasing uptake of devices which are already used will simply (in the example above) increase the proportion of ships that comply with Phase 2, since the best performing vessels (those furthest to the left) have most likely incorporated all economically viable and mature technologies.

4.3.3.5 Tip Raked Propellers

There was some confusion from respondents about this question. The question was intended to ask about uptake of tip raked propellers such as the Kappel propeller or CLT propellers, however some respondents included highly skewed propellers in this category when asked to confirm their answers, and their responses had to be edited. However we were not able to confirm the answers of all respondents and so there may be still incorrect answers to this question.

From the overview of 29 ships drawn from the Significant Ships publication, only 1 was fitted with a Kappel propeller.

According to MAN, in 2014, only 44 Kappel propellers had been fitted, and we are aware that many Kappel propellers are retrofits, the only exceptions (known to us) being a series of 6 EEDI vehicle carriers that were fitted at build.

The results of the survey indicated that between 64 to 114 ships out of 3664 ships were fitted with tip raked propellers, which is a rate of around 2%.

Feedback about the propellers seem to vary, some shipowners seem to claim significant savings, while others the benefits are not so clear, and this may account for the relatively low adoption rate.

4.3.3.6 Waste Heat Recovery and Shaft Generators

Waste heat recovery and shaft generators have been grouped together as they both try to reduce the fuel consumption for electricity production.

We are aware that there are frequent misunderstandings of the terminology waste heat recovery. Almost all ships have either an exhaust gas boiler or composite boiler (which can use both exhaust gas or burn oil to produce steam) fitted to the main engine, and to most people in shipping, this is considered waste heat recovery. We think this misunderstanding has plagued all previous surveys trying to estimate uptake of waste heat recovery and which has resulted in a significant over-estimate of WHRS uptake.

Exhaust gas boilers have been standard equipment on ships for decades, since ships need to heat their fuel (HFO), their cargo, or there is equipment that is steam driven, such as discharge pumps.

The EEDI definition of waste heat recovery is however much narrower, and only covers those installations where electricity is generated.

In the survey we specified waste heat recovery for the purposes of electricity production, however when examining the responses, it was quite clear that some had simply assumed that exhaust gas boilers were included.

Some owners have additionally fitted exhaust gas boilers to the generators such that there is steam production even when the ships are stationary, which reduces the amount of fuel that an auxiliary boiler (one that only uses fuel) needs to use. This represents a clear and measurable improvement in energy efficiency but does not lead to any improvements in EEDI. Some of these owners had also included these in their responses.

We have tried to check the answers of those with the largest purported numbers of installed WHRS in order to try and reduce the error rate however some uncertainty still remains.

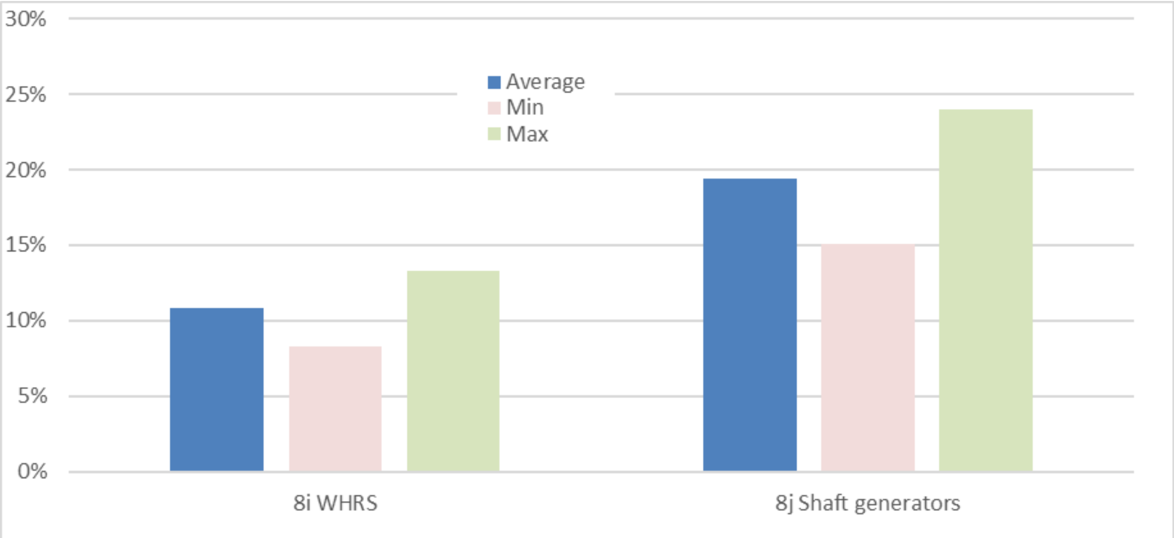


Figure 21 Ship Owners uptake of WHRS and Shaft Generators

In general for the sample responses, shaft generators are a more popular option than WHRS.

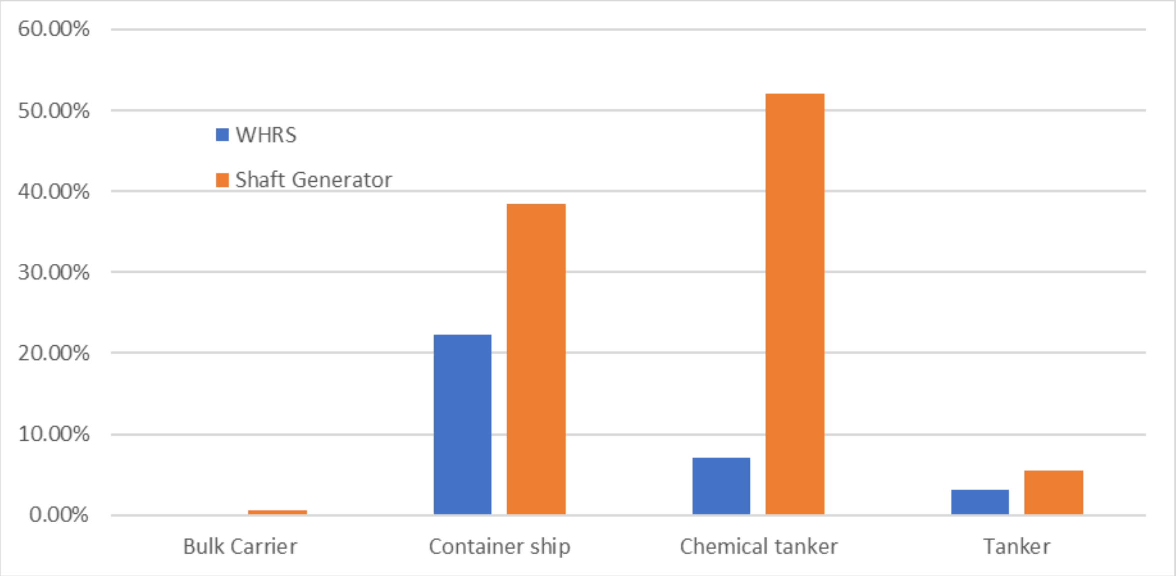


Figure 22 Ship Owner uptake of WHRS and Shaft Generators by ship type

When we break this down by ship type, ships with relatively low need for electrical power tend not to fit either WHRS or shaft generators.

Container ships with high reefer loads have the potential to maximise the benefits and thus we see higher uptake of both WHRS and shaft generators. However some shipowners have moved towards shaft generators as the power output is more consistent even at lower engine loads and slow steaming.

Chemical tankers also tend to have higher electrical loads due to the need to run nitrogen generators and electric pumps compared to conventional tankers which rely more on boilers, and this seems to explain the relatively higher rate of uptake of shaft generators.

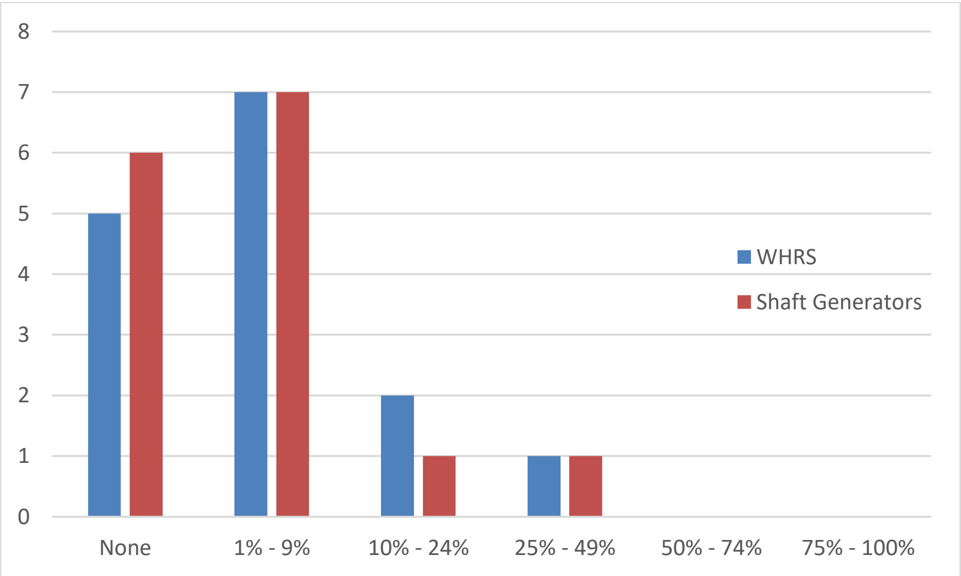


Figure 23 Shipyard Uptake of WHRS and Shaft Generators

The responses from the shipyards showed generally low uptake of both technologies at the moment. In general shaft generators have not been widely fitted with 2 stroke engines but much more prevalent on 4 stroke engines where they are also combined with CPP. However we have had indications from engine manufacturers and shipyards that interest in shaft generators is increasing, and some new designs for EEDI Phase 2 and 3 include shaft generators.

4.3.3.7 Controllable Pitch Propellers

Fixed pitch propellers are fitted to the majority of cargo vessels today, particularly those with 2 stroke engines, and so we don't expect to see large uptake of controllable pitch propellers (CPP). Segments which are able to most benefit from CPP are likely to already use them.

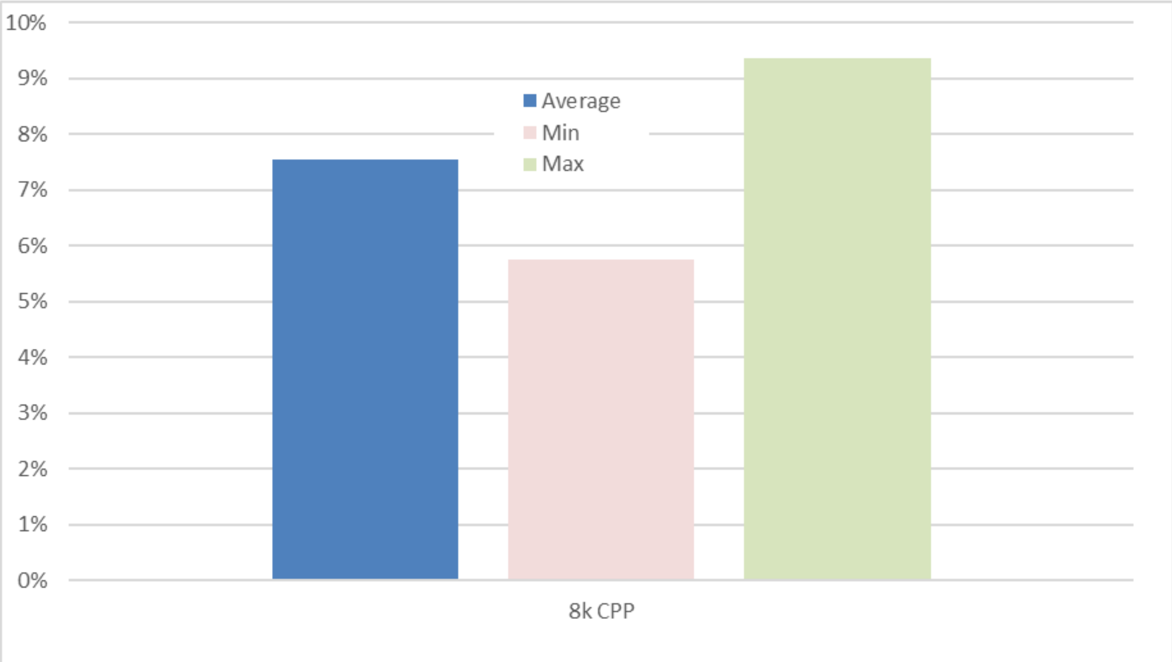


Figure 24 Ship Owners Uptake of CPP

As expected the use of CPP is fairly low overall as shown from the above stakeholder responses.

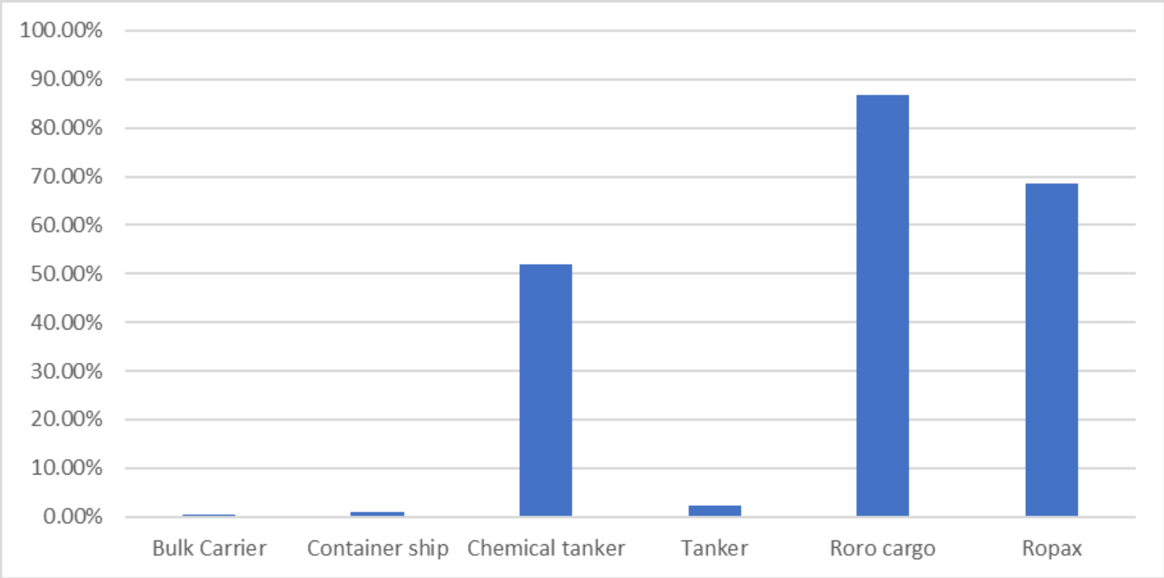


Figure 25 Ship Owners uptake of CPP by ship type

When looking at individual ship types, then it is clear that uptake for certain types of vessels is much higher than indicated by the average.

4.3.3.8 Air Lubrication and Wind Assistance

The shipyards also answered questions on uptake of air lubrication and wind assistance as follows:

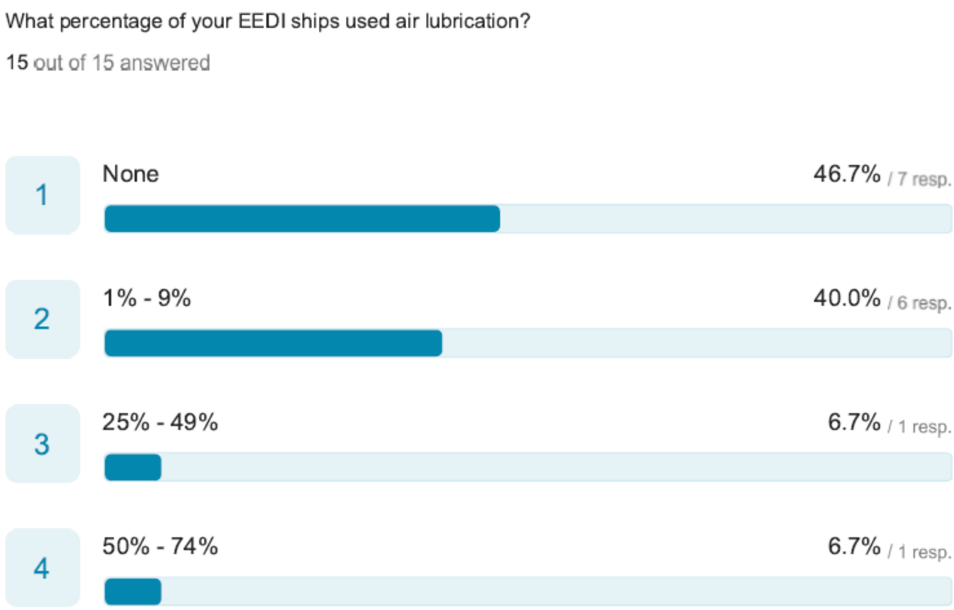


Figure 26 Uptake of Air Lubrication - Shipyard responses

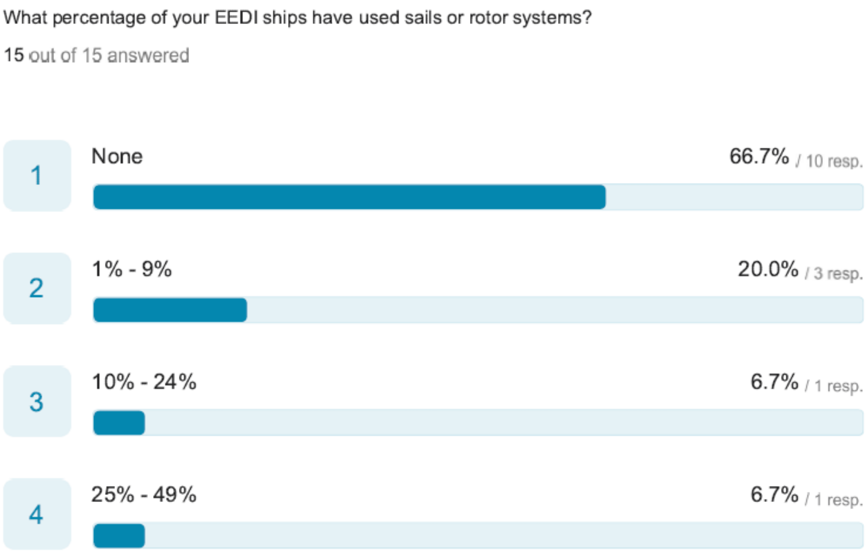


Figure 27 Uptake of Wind Propulsion

4.3.4 Data Source – MTCC Caribbean Study

In a recent study supported by EU and IMO, the MTCC Caribbean has studied the uptake of EETs in the vessels trading in the Caribbean area during the period 2017 - 2018 (MTTC Caribbean, 2020). A total of 518 vessels were included in the study and included was technology, operational and emissions control measures, see figure 3-6.

The distribution of vessels reporting to the system was as in Table 3-3.

Table 4-5 Distribution on vessels in the survey

Type of vessels	Number of vessels	Number of Port Calls
Tankers	253	575
Container ships	60	562
Bulk Carriers	66	102
Cruise Ships	54	454
General and refrigerated cargo	51	87
Car Carriers	23	51
Others	11	39
TOTAL	**518**	**1870**

The distribution of age among the vessels was as in Table 3-4.

Table 4-6 Distribution of age of the vessels in the survey

Age / Years	Number of vessels	Age / Years	Number of vessels
1-5	106	21-25	36
6-10	133	26-30	7
11-15	159	31-35	4
16-20	72	36-40	1

In the survey, the vessel operators were asked to provide the number of energy efficiency measures that they had implemented to reduce emissions. Among those were EETs as described in the previous sections, SOx reduction measures and operational measures. The latter two technologies do not relate to the EEDI but are shown here since it is a part of an overall GHG reduction strategy.

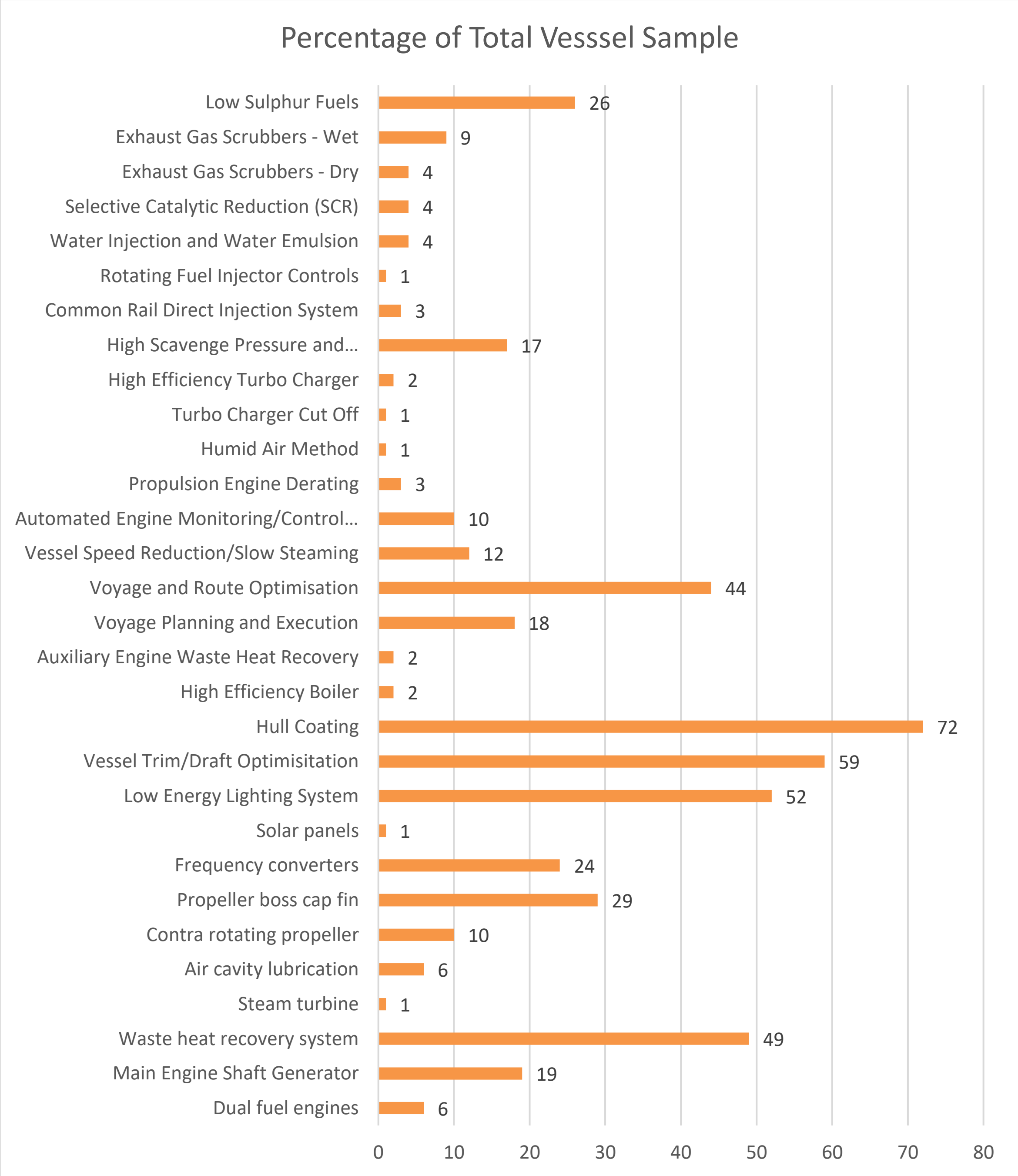


Figure 28 EET uptake in vessels trading in the Caribbean

The EETs that have the highest uptake and the ones affecting the EEDI are (low friction) hull coatings (72%) and waste heat recovery systems (49%). The details of the applications with regards to type and technology are not given fully in the report, and so for example the waste heat recovery systems may partially reflect exhaust gas boilers.

A portion (6%) of the vessels were fitted with dual fuel engines and 6% had installed air cavity lubrication. The vessel types involved were tankers, general cargo and cruise vessels. 1% did use solar panels to supplement the auxiliary power. Since the Caribbean has the environmental conditions to better exploit wind and solar technology, vessels trading in the region highlight the application for these technologies.

4.3.5 Barriers to Uptake of Innovative Technologies

We have had a number of discussions in the consortium regarding why uptake is low for certain types of technology.

In the hydrodynamic realm, within the same ship type, certain hull forms may suit certain types and combinations of EETs and not others, while a hull form from a different shipyard may favour a different type and combination of EETs.

Some technologies like controllable pitch propellers work only if an operational profile suits the strength of CPPs, while for others a FPP is a better choice. However, this is not obvious when looking purely on a statistical basis – it could be two ships of the same capacity but used with different operating profiles.

There are also some significant commercial and risk factors that need to be considered which we flesh out in the following scenarios:

- If the vessel design cannot satisfy the EEDI phase at contract time and provided the Builder can be persuaded that this technology will make through the finish line. But will a Builder rely on an external vendor to achieve compliance? Builders need to persuaded and this can happen through collaborative research, which usually needs to overcome the intellectual copyright hurdles.
- The vessel design cannot satisfy the EEDI phase requested by the Buyer (as Buyer’s extra). In such case, how will the case be resolved in a dispute?
- The Buyer wants the technology to be added at extra cost, irrespective of the EEDI. The Builder is likely to request that all extras, including additional time during construction to align with Builder’s project milestones, whilst additional trials to be at Buyer’s time and expenses after delivery has been signed off. Will the Buyer accept the Builder’s terms?
- The Builder offers the technology to be added in the vessel spec, at an extra predefined cost, but without guarantees on performance. The Builder is likely to demand a bank guarantee from the Vendor. If Vendor refuses, then it is a no-go. If Vendor accepts, then will the Buyer add it on the spec without a performance guarantee by Builder and without a life cycle cost analysis?
- The Buyer needs to be persuaded that the technology will be without bother in terms of efficient use by crew, easy to be operated by crew (crew rotate on a periodic basis), low maintenance, no safety issues at sea, available support by the vendor whenever and wherever needed during operation in future.

4.4 Trends in engines, propeller diameter and speed

As previously also described, the introduction of propulsion engines with modern technology and higher efficiency has been introduced over the recent years. The most widespread propulsion engine for larger ships is still the slow speed 2 stroke engine and introducing dual fuel capabilities, lower SFOC, electronic injection for a more efficient control of consumption and automated control systems, will keep this engine type as the main selection for ocean going ships also in the future.

With the introduction of the EEDI, the engine selection has changed towards smaller engines combined with propeller modifications and changes in the design. Further the SFOC on the modern engines have been reduced from the (IMO) reference value 190 g/kWh to a commonly obtained value around 168 g/kWh which has led to EEDI reductions of around 10%.

By studying available databases, it is possible to get and overview of these trends for bulk carriers, tankers and container vessels which are responsible for significant improvements to attained EEDI, but are not categorised as innovative technology.

4.4.1 Task D1 Survey – Engines and Propellers

From our research and discussions with stakeholders, engine derating, reduced/low rpm and maximising propeller diameter have broadly gone hand in hand and for analysis purposes we will group them together.

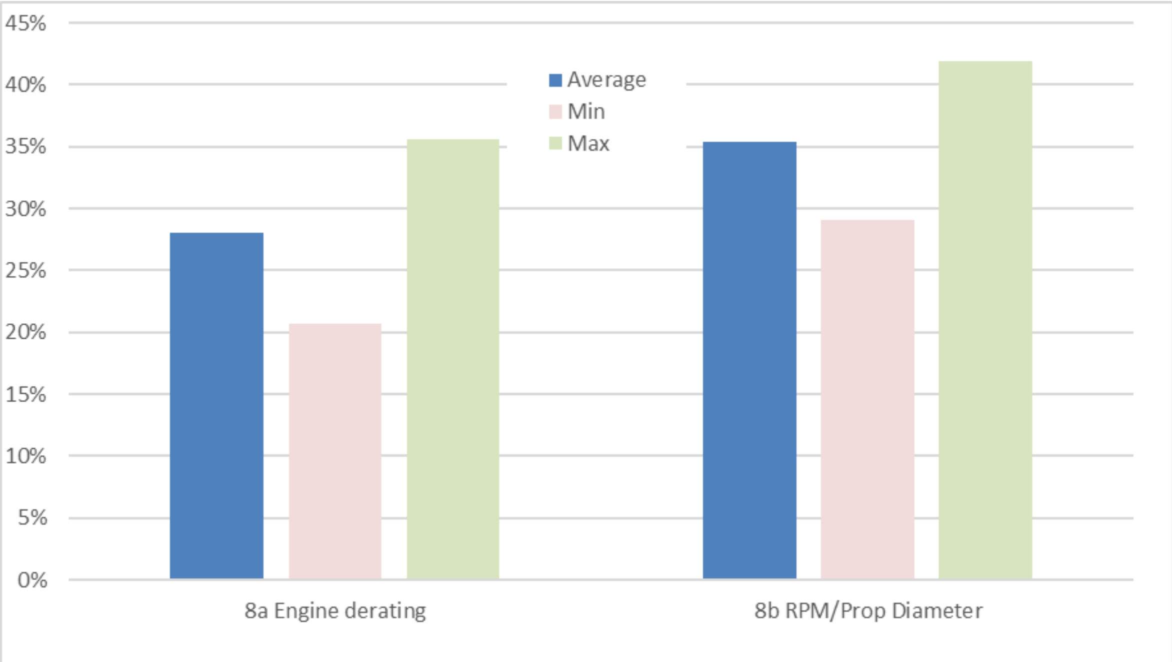


Figure 29 Ship Owners uptake of engine derating and Low RPM/Increased Prop Diameter

The results from the survey seemed unexpectedly low, so we consulted the engine manufacturer MAN which designs and licenses 2 stroke engines that power the majority of the world fleet (and holds a majority 80% market share for 2 stroke engines). MAN indicated that their licensees have been manufacturing and selling **only derated engines for a number of years now**.

In our exchanges with shipowners, there also seems to be some significant confusion about what constitutes a derated engine, and since the engines are already onboard once the owner takes delivery, many of them are under the misapprehension that their engines are not derated.

Derating does not apply to 4 stroke engines.

Given that current levels of attained EEDI are not achievable without derated engines, low rpm and larger diameter propellers, our conclusion is that all vessels that are able to use this combination already use it, that is uptake is effectively 100%.

The situation with derated engines and low rpm with larger diameter propellers is better corroborated by the shipyard responses.

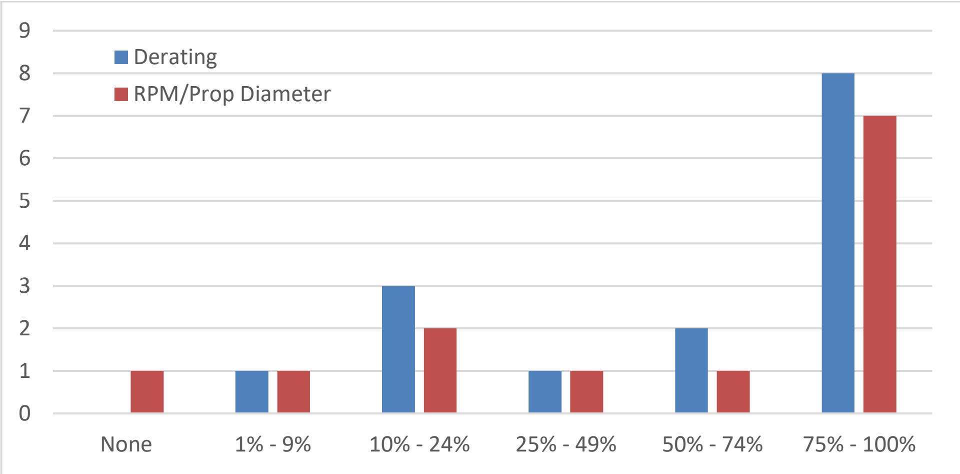


Figure 30 Shipyard Reponses - derating and RPM/Prop Diameter

The lower percentage choices were provided by shipyards that build LNG carriers (likely DFDE) and ro-ro passenger ships which use 4 stroke engines that are not derated.

4.4.2 Task D1 Survey – Shipbuilding Specifications

The survey asked what speed and associated conditions are used and how this might have changed from ships built between 1999-2008 as a means of checking how shipowner requirements may have changed in the shipbuilding contracts.

Bulk Carriers:

- 14.5 knots including 20% sea margin at design draught
- 14.5 knots at 80% MCR including 15% sea margin at 80% of summer draught
- 15 knots at 85% MCR with 15% sea margin at design draught
- Pre 2008 14.5 knots at 75% MCR with 15% sea margin at scantling draught
- Post 2008 14.0 knots at 75% MCR with 15% sea margin at scantling draught
- 14.5 knots at 85% MCR with 15% sea margin at 85% draught

For bulk carriers the design or contract condition has barely changed.

<u>**Container Ships**</u>:

- 21 knots at 85% MCR
- Required speed today is 20-22 knots, while in 2003 it was about 26 knots
- 22 knots at 85% MCR including 15% sea margin at design draught
- 2-3 knots reduced speed since 2008 but deeper design draught

For container ships there has been a marked reduction in design speed.

<u>**LNG Carriers**</u>:

- 2000 – trial speed 20.1 knots on 11.3 m draught with steam turbine at 74%
- 2005 – contract trial speed 20 knots with 15% sea margin at design draught with max propulsion power (likely DFDE)
- 2014 – 20 knots on design draught of 11.50 m at 72% MCR

For this LNG carrier owner, there have been almost no changes to the design requirements over the years since this is cargo and trade driven.

Tankers:

- 1999 service speed of 15.3 knots at 85% MCR
- 2012 minimum 14.5 knots at 75% MCR on design draught of 15m
- 2013 service speed at least 15 knots at 75% without sea margin and design draught
- 14.5 knots at 85% MCR with 15% sea margin at scantling draught
- Changed from 15 knots at 80% SMCR to 14.5 knots at 80-85% SMCR
- Changed from 16.5 knots at 85% MCR to 14.5 knots
- 14.5 knots at 85% MCR including 15% sea margin at 90% of summer draught

For tankers, there appears to be some reduction in contract speed, but it is not as significant as for containerships.

4.4.3 Bulk carriers

The following plots are extracted from vessels in the size range of 20k to 210k DWT. The blue dots are the plotted values and the red dotted line is a moving average plot.

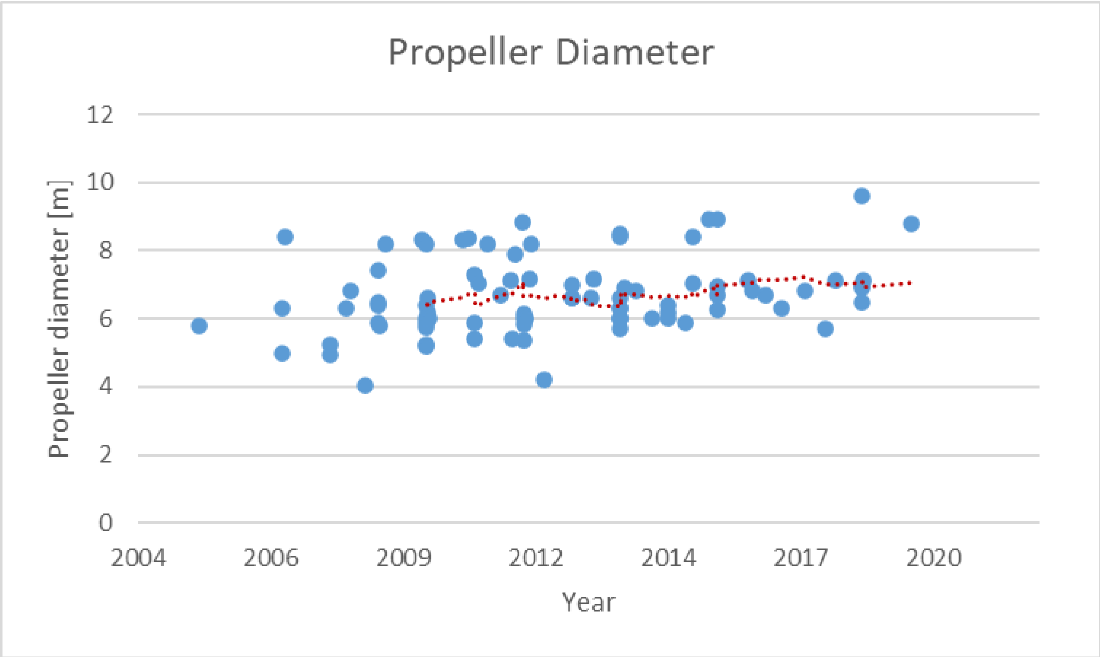


Figure 31 Propeller diameter size development from 2005 to 2020 for bulk carriers

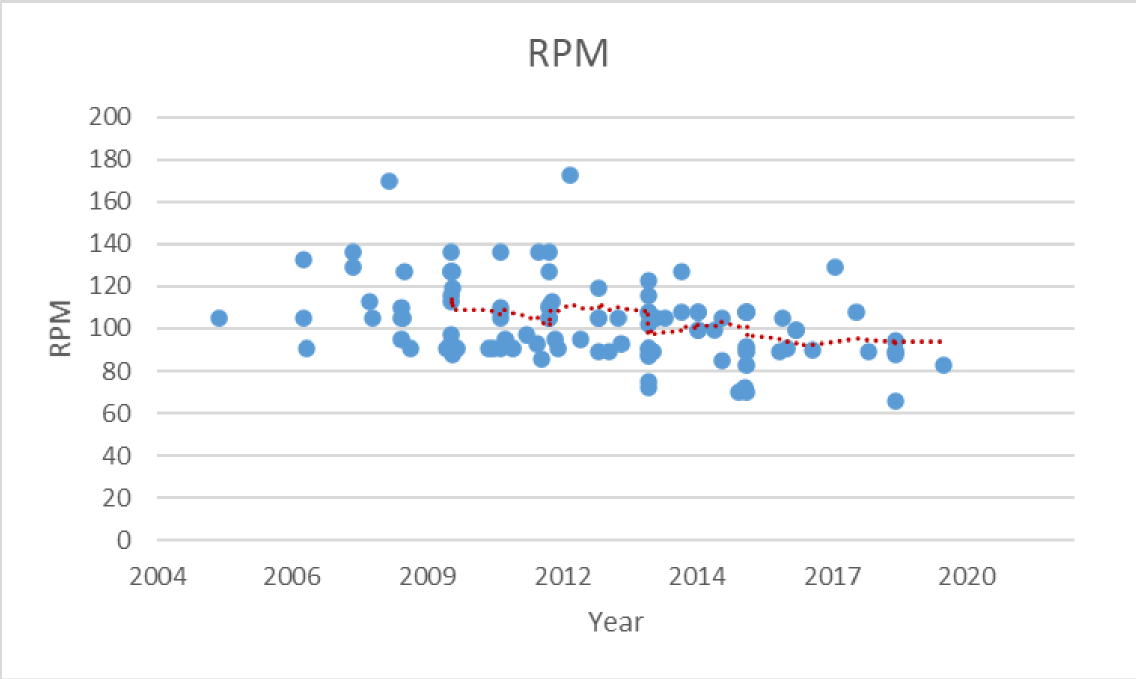


Figure 32 RPM reduction development from 2005 to 2020 for bulk carriers

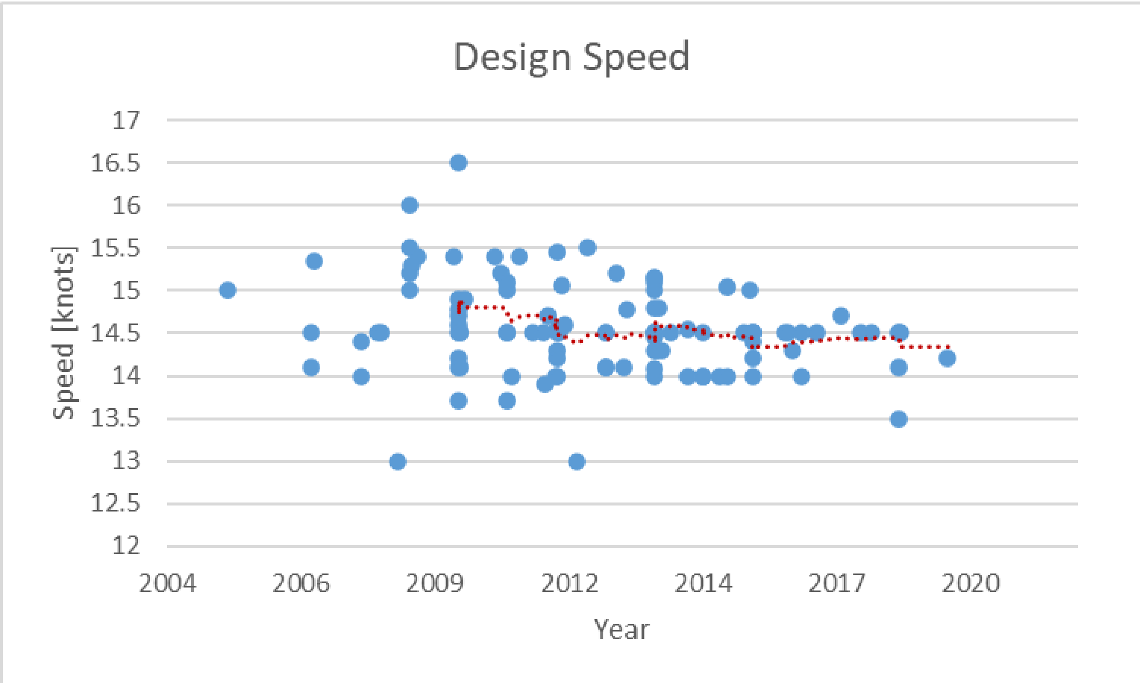


Figure 33 Design speed change from 2005 to 2020 for bulk carriers

The Propeller diameter increase is general for all vessel sizes and is in the order of 10-15%. The RPM reduction is similarly decreasing in the order of 15-20%. There is a decrease in speed up to 2012 from where the speed is constant around 14-14.5 knots.

4.4.4 Tankers

The following plots are extracted from vessels in the size range of MR to LR tankers. The blue dots are the plotted values and the red dotted line is a moving average plot.

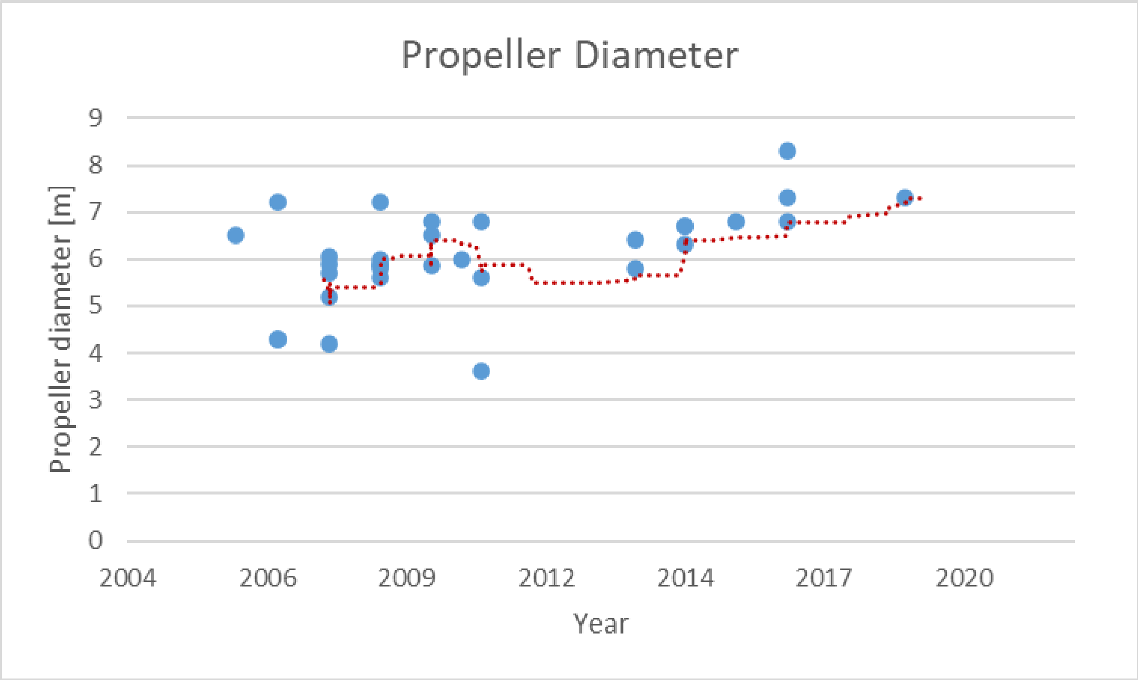


Figure 34 Propeller diameter size development from 2006 to 2020 for tankers

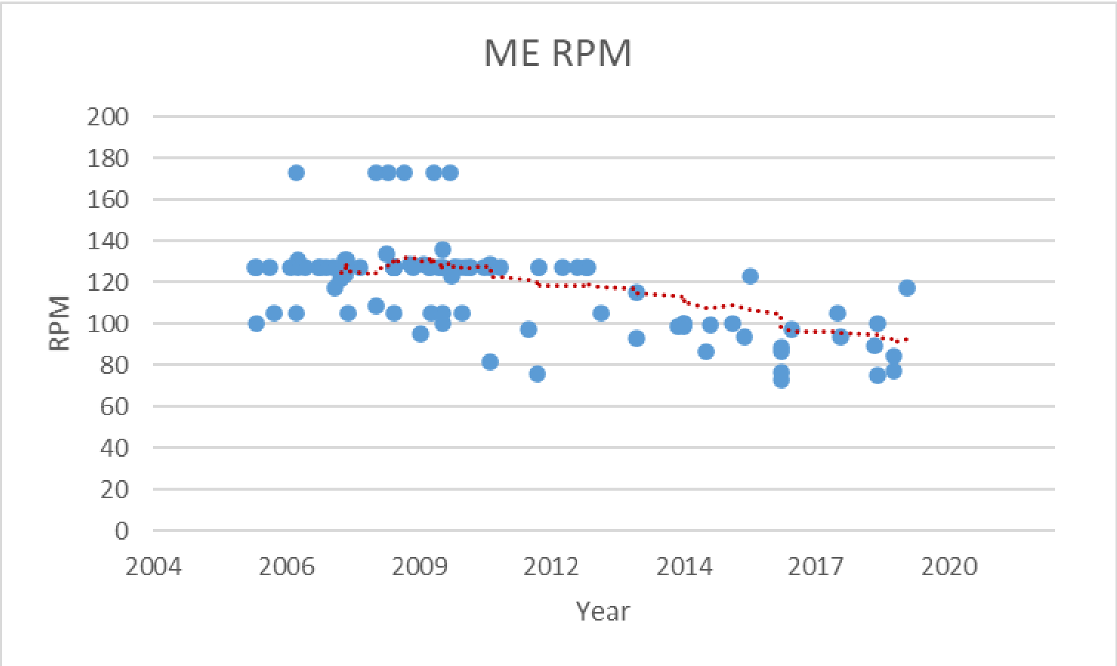


Figure 35 RPM reduction development from 2006 to 2020 for tankers

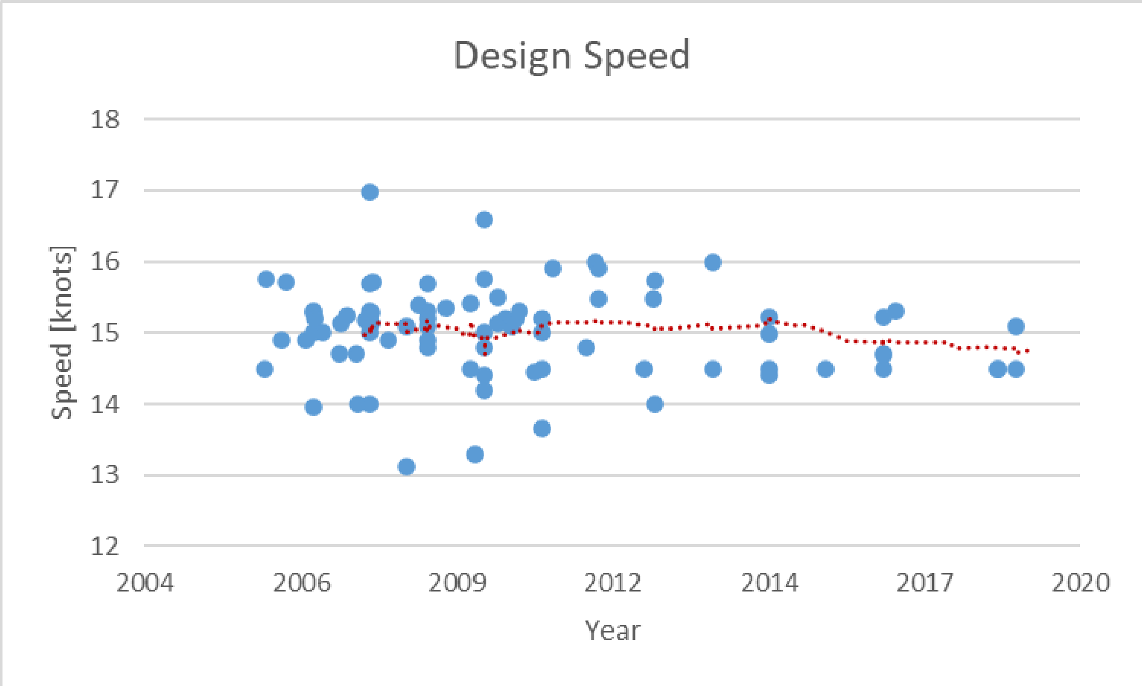


Figure 36 Design speed change from 2006 to 2020 for tankers

The Propeller diameter increase is general for all vessel sizes and is in the order of 20-25%. The RPM reduction is similarly decreasing for the MR segment in the order of 25-30% and for the LR segment in the order of 15%. There is a decrease in speed in the order of 0.5 knots from 15.0 to 14.5 knots.

For the very large Tankers (VLCCs), it seems like the efficiency gains that has been undertaken with regards to hydrodynamics has been achieved and a further reduction in power and speed does not seem possible due to safety and maintenance of seakeeping in bad weather.

4.4.5 Container ships

The following plots are extracted from vessels in the size range of 4000 to 19000 TEU. The blue dots are the plotted values and the red dotted line is a moving average plot.

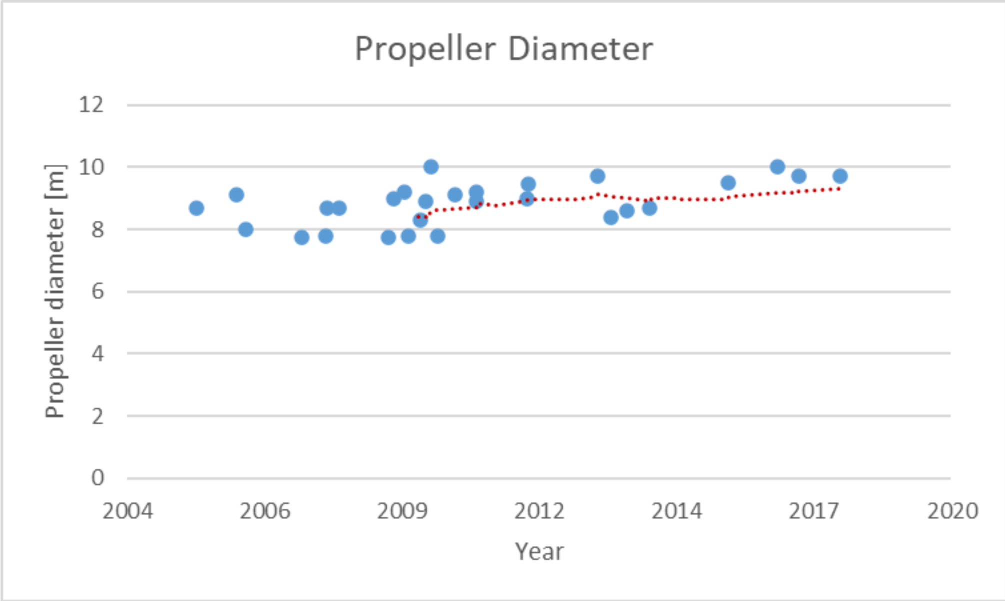


Figure 37 Propeller diameter size development from 2006 to 2020 for container ships

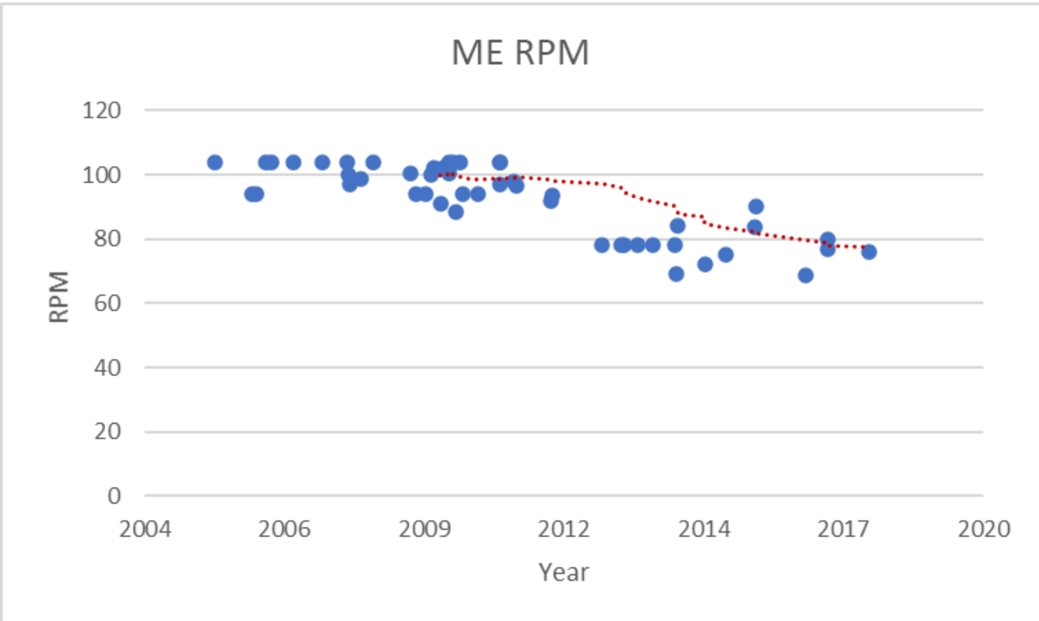


Figure 38 RPM reduction development from 2006 to 2020 for container ships

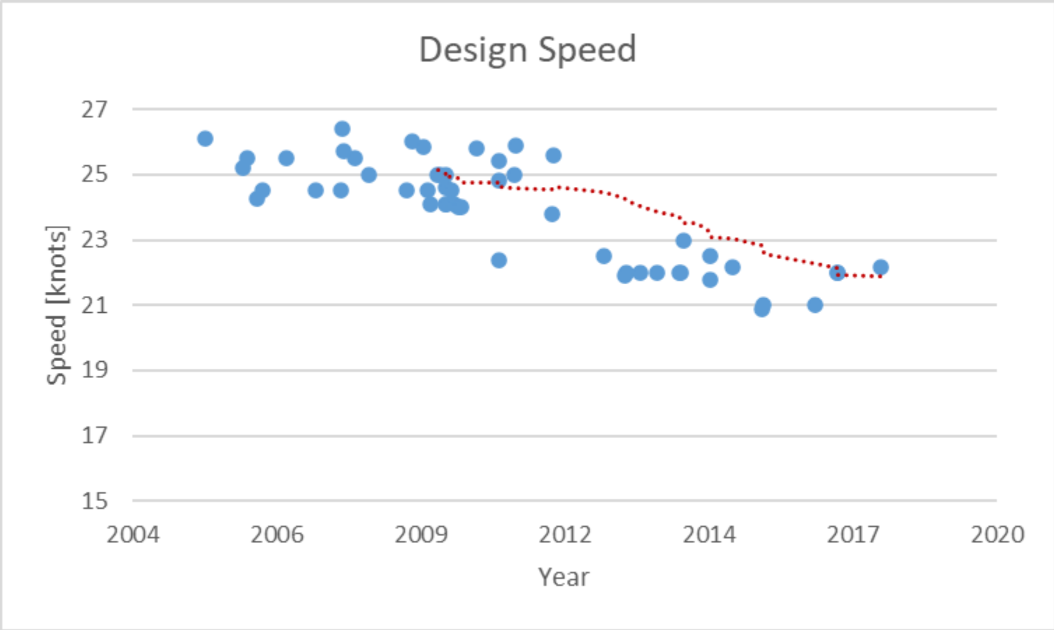


Figure 39 Design speed change from 2006 to 2020 for container ships

The Propeller diameter increase is general for all vessel sizes and is in the order of 10%. The RPM reduction is similarly decreasing 20%. There is a decrease in speed in the order of 3 knots from 25.0 to 22.0 knots.

For the smaller feeder segment (below 4000 TEU) the reduction in EEDI have been more modest. The above-mentioned changes for the large container vessels have not been possible for the smaller segment due to constraints in operation with regards to speed and size.

4.5 Effect of EETs

Effect of EETs may only be measured before and after installation, or between sister ships. A performance prediction can be applied before the installation where the performance with and without the EET to predict the savings potential. The methods used to predict the performance can either be by facility testing (model basin), by CFD simulations, by experience from previous installations or by theoretical calculations. Each method has its confidence level where facility testing and CFD are ranked the methods with the highest confidence.

A full-scale trial should be performed to verify the actual savings. It can be done by a dedicated sea trial or by in-service measurements over a longer time period. The methodology for the testing should be the same before and after the installation to ensure consistency in the results.

There is some uncertainty included in the measurements leading to the analysis. In the ISO 19030:2016-1 “Measurement of changes in hull and propeller performance”, Annex A, the uncertainty of measurements is described. The uncertainty is related to measurement equipment, frequency of measurements and period over which the measurements are acquired. The highest confidence in the results are if measurements are available with high frequency and over longer periods with similar operational conditions.

4.5.1 Estimating Impact of EETs

Combining the different technologies can lead to significant improvements to the energy efficiency. A study (ECOFYS, 2015)) shows that it is possible to save 35% on fuel only (compared to EEDI phase 0 vessels) by applying various EETs. This comes with an investment cost where high investments may bring the highest savings if properly evaluated.

However, there are also very widely differing claims being made regarding the efficiency of EETs.

A study (Bouman et al, 2017) reviewed more than 150 studies to provide a comprehensive overview of the CO2 reduction potential from both technical and operational measures. The conclusion is that there is a significant variation of estimated savings in the results, see figure 4-1. Note that not all of these measures have an effect on EEDI as they also reflect operational type measures or non-navigation type scenarios such as cold ironing in ports, however it is very helpful for visualising the very wide range of claimed savings from different technologies.

What is notable about the chart below is that hull shape and power systems/machinery has a much larger potential than most of the other solutions that we typically recognise as innovative technology

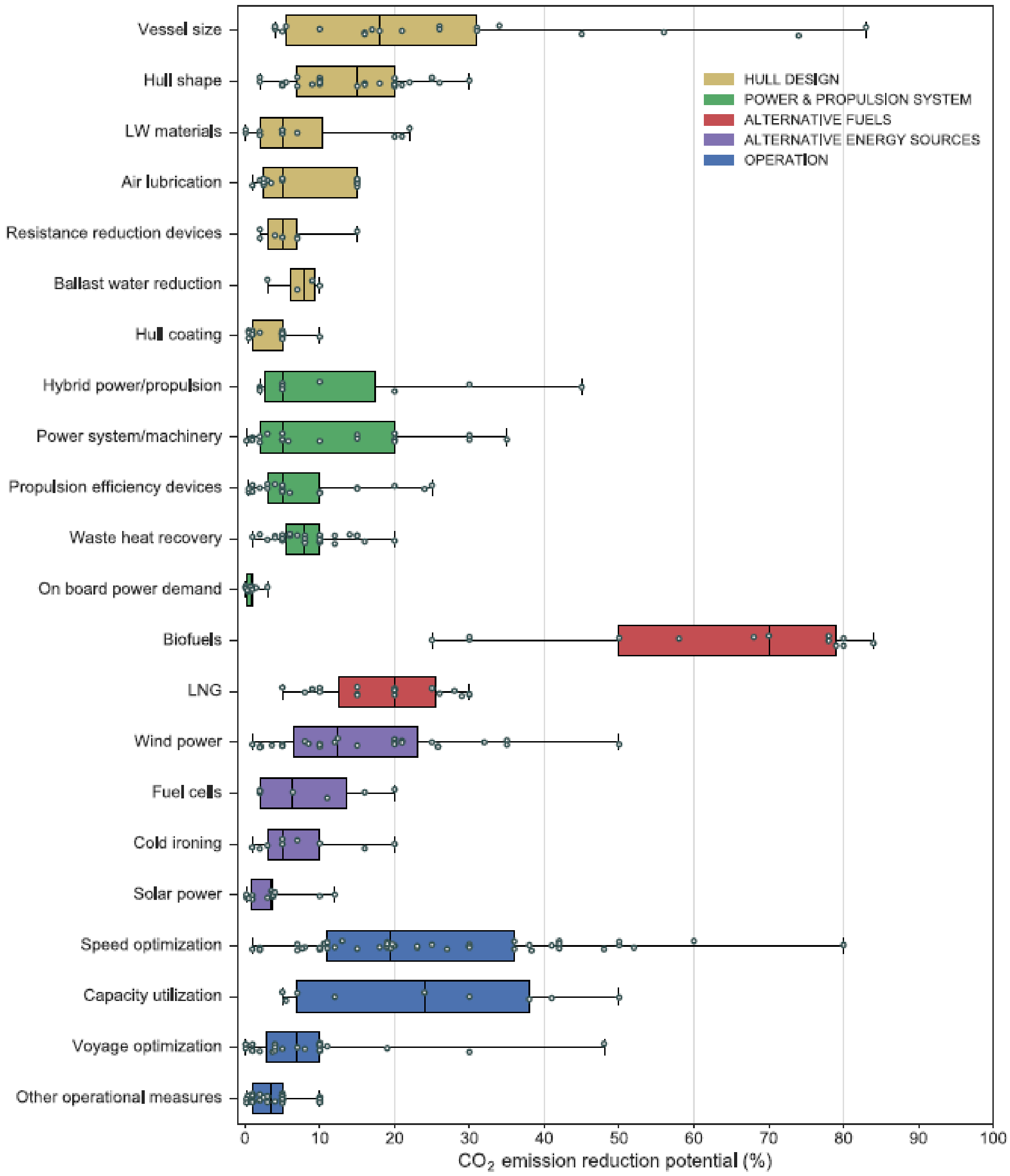


Fig. 2. CO_2 emission reduction potential from individual measures, classified in 5 main categories of measures.

Figure 40 CO2 emission reduction potential from individual measures, classified in 5 main categories of measures

Meta studies are a very instructive and useful way to survey the findings from a large number of studies, especially when the basis for the studies are very similar – e.g. in the medical domain. However, with the many studies of efficiency improvements, we find the following limitations:

- Different starting points – application of EETs to a poorly optimised ship and a well optimised ship will have largely different outcomes – to a certain extent illustrated by the wide variations shown above (e.g. speed optimization efforts). This information is often missing
- Different ship types – the effect of EETs on a bulk carrier will differ from the effect on a cruise ship or a container ship
- Different operating profiles, though this is not relevant in the EEDI context

- How fuel/CO2 savings are measured – model test, CFD, trials, and whether this involves a design point or over an operating profile

It is important to note that fuel savings do not translate directly to the same amount of EEDI improvement because EEDI also includes emissions from the auxiliary engine and may be modified by correction factors. In particular, correction factor f_j reduces the main engine power term relative to the auxiliary power, and this tends to reduce the proportional contribution to the total emissions as given by each term of the EEDI formula.

Also as mentioned in 3.3.7 Energy Savings converted to EEDI above, EEDI savings depends on how well the ship has performed relative to the EEDI baseline.

For a shipowner/operator the payback of the investments is of interest as is the validity of the actual savings promised. Further there are often other stakeholders involved in the decision process e.g. charterers who in most cases bears the fuel costs on a voyage. The maturity level of the technology and the verification of savings towards the actual vessel type and design is important to know before entering into applying EETs on existing/new vessels.

EEDI Potential Solutions

Component	Feature	Power Saving	EEDI Reduction	Technology Readiness Level (1~5)	Remark
Hull and Propulsion Efficiency	Lines Optimization	2%~5%	0.7%~1.6%	5	
	Light Weight Optimization	1%	0.3%	5	
	Energy Saving Devices	2%~5%	0.7%~1.6%	4~5	
	High Efficiency Propeller	1%~2%	0.3%~0.7%	5	
	M/E Derating	0%	0.0%	3~4	
	Low Friction Coating	6%~8%	2.0%~2.6%	2~4	
	Air Bubbling Lubrication	4%~7%	1.3%~2.3%	1~3	
	Waste Heat Recovery	3%~5%	1.0%~1.6%	3~4	
Alternative Energy	Solar Cell	2%	0.7%	2~5	
	Kite	2%~5%	0.7%~1.6%	2~3	
	Sail	2%~7%	1.0%~2.3%	3~4	
	Rotor Sail	2%~5%	1.0%~1.6%	2~3	
Alternative Fuel	LNG	0%	20%	4~5	
	Biofuel	0%	75%	2~4	Total biofuel, net Carbon emmision
	Hydrogen	0%	100%	1~3	Without considering energy generation carbon emmision
	Ammonia	0%	100%	2~4	
	Battery	0%	100%	2~3	

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Figure 41 MARIC Assessment of EEDI Solutions

The Chinese shipyards prepared the above slide for a roadshow marketing their new designs and the difference between EEDI reduction and Power saving is quite significant, as are the relatively modest power savings of most solutions.

We asked some shipowners for their views on EET savings and the consensus is described in the following table:

Table 4-7 Shipowner's Assessment of EET savings

ESD Type	Slow/Full Form Ships	Fast/Slender Ships

PBCF	1.5%	0.1% - 1.0%
Rudder Bulb	1.0%	1.0% - 2.0%
Twisted Rudder		1.0%
Mewis/Mewis Twisted	4.0%	2.5% - 3.0%

4.6 Overall Design Trends

4.6.1 Combination of EETs.

As previously described every technology by itself have a savings potential and many can have an even larger effect by combining the technologies.

In general, the newbuild vessels of vessels of today are fitted with a combination of technologies to reduce the EEDI and thereby reduce the CO2 emissions. An example in (KIM, 2012) shows a 12% reduction effect on fuel consumption on a 300k DWT VLCC. The savings are achieved by reduction in the block coefficient, optimization of the hull form, reduced RPM on the main engine combined with a larger propeller and finally, application of EETs, in this case a duct and a rudder bulb.

The vessels included in the Task A1 report are listed in the table below. The vessel were the same designs and built over the different EEDI stages.

Table 4-8 List of EETs implemented by ships in Task A1

Vessel Type	*Reduction in EEDI	Measure for reduction
VLCC	16%	11% reduction in P_{ME} Increased propeller diameter
Supramax bulk	27%	EETs in stern area and rudder Optimised propeller Lower block coefficient (Cb)
Kamsarmax bulk	31%	PBCF Rudder bulb / Rudder fins Pre swirl fins High efficiency coating Optimised propeller CPP propeller

		Dual Fuel using LNG

*Relative to EEDI reference line – there is also some influence from improvement of SFOC

In general, the reduction of EEDI is a combination of energy efficiency measures including engine/propeller modification, capacity changes and inclusion of EETs.

Looking at the specific vessel segments, the overview would be as in Table 4-2.

Table 4-9 Vessel segments and EET uptake

Vessel Type	Engine/propeller modification	Capacity change	Speed reduction	EET implementation
Bulk carriers	x			pre/post swirl fins, propeller ducts, boss cap fins, rudder fins, rudder bulbs, CLT propellers, bulbous bow modifications
Tankers	x		x	pre/post swirl fins, propeller ducts, boss cap fins, rudder fins, rudder bulbs, CLT propellers, bulbous bow modifications, WHR
Container vessels	x	x	x	pre/post swirl fins, propeller ducts, boss cap fins, rudder fins, rudder bulbs, CLT propellers, bulbous bow modifications, WHR
RO/RO & cruise	x	x		podded propulsion, rudder fins, rudder bulbs, duck tails, CLT propellers, bulbous bow modifications, WHR.

A detailed look at the specific vessel types are found in the following.

As shown in the task D1 report, a sample of 29 ships in the RINA publication Significant Ships yielded the following:

Table 4-10 List of installed EETs derived from RINA Significant Ships 2019 and 2020

Ship Type	DWT	EET	EET	EET
Ro-ro cargo	11,288	Rudder bulb	Twisted rudder	
LPG Carrier	18,000		Mewis duct	
Ro-ro cargo	18,120	Rudder bulb	Air lubrication	Batteries
Reefer container	27,800	Rudder bulb	Twisted rudder	
Bulk carrier	34,490	Rudder bulb	Pre swirl stator	Wake fin
Container ship	37,400	Rudder bulb	Twisted rudder	
Tanker	37,836	Rudder bulb	Asymmetric stern	
Tanker	40,000	Rudder bulb		
LPG Carrier	51,312	Rudder bulb	Twisted rudder	Tip raked propeller
Bulk carrier	80,700		Mewis duct	
Bulk carrier	82,516	Rudder bulb	Duct	Hull Fin
LNG carrier	92,400	Rudder bulb	Air lubrication	
LNG carrier	93,500	Rudder bulb		
LNG carrier	93,534		Twisted rudder	PBCF
LNG carrier	93,775	Rudder bulb	PBCF	
Bulk carrier	100,449	Rudder fin	Flipper fin	
Bulk carrier	104,553		CPP	
Tanker	118,100	Rudder bulb	Pre swirl duct	Hull fin
Shuttle tanker	128,800	Rudder bulb		Batteries
Shuttle tanker	152,868		Pre swirl duct	
Container Ship	157,076	Rudder bulb	Pre swirl duct	Fin
Container ship	159,614	Rudder bulb	Mewis twisted duct	
Bulk carrier	208,600	Rudder bulb	Twisted rudder	Rudder fin
Container ship	228,600	Rudder bulb	Twisted rudder	Hull Fin
Container ship	232,700	Rudder bulb	Pre swirl stator	
Tanker	300,300	Rudder bulb	Pre swirl duct	
Bulk carrier	302,000	Rudder bulb	PBCF	
Tanker	312,499	Rudder fin	Flow control fin	PBCF
Tanker	320,500	Rudder bulb	Pre swirl duct	Hull fin

It can be seen that different shipyards use different combination of EETs even for similarly sized vessels.

Not all combinations of EETs are favourable and a summary is shown in the table 4-11 below. The numbers refer to the ones in table 2-2 to 2-4. The colouring scheme is as noted in Table 4-10.

Table 4-11 Colouring scheme for Table 4-7

	Can be combined
	Can be combined in certain cases
	Should not be combined

Table 4-12 Combinations of EETs and assumed savings

		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
		CPP	CRT	CLT	Nozzle	Grim vane	Pre swirl/ Ducts	Post swirl fins	PBCF	Rudder bulb	Thrust fin	Twisted rudder	Trim wedge/ plate	Flapping foils/ wings	Wave foils/ wings	Duck tail
14	CPP	-														
15	CRT		<15%													
16	CLT			4-7%												
17	Nozzle				2-5%											
18	Grim vane					<8%										
19	Pre swirl/ Ducts						3-8%									
20	Post swirl ??							2-4%								
21	PBCF								2-5%							
22	Rudder bulb									3-8%						
23	Thrust fin										4-6%					
24	Twisted rudder											2-6%				
25	Trim wedge/ plate												<4%			
26	Flapping foils/ wings													5-5%		
27	Wave foils/ wings														5-15%	
28	Duck tail															2-6%

The combination of the ESTs and the energy efficiency cannot always be met since not all combinations are favourable. In general, the highly complicated hydrodynamic phenomena that are involved should lead to caution when quoted savings are given. As previously mentioned many of the EETs mentioned are already combined and standard on vessel new builds today.

4.6.2 Bulk carrier Design Trends

The bulk carriers are the vessels that have been the most conservative with regards to keeping dimensions and speed. The vessels are probably operating in the tightest market where the GHG rating from Rightship is an important performance parameter. The design trends are towards a reduction of the bulbous bow, increase of propeller dimensions and slower engines. Further they are fitted with all the static EETs available and useful in combinations.

Specifically, for the Category A EETs, a survey of ABS and VPS databases, show the following information for vessels built within the EEDI framework.

Table 4-13 Uptake of EETs Cat. A on bulk carriers

Bulk Carriers	Delivery date	Applicable EEDI phase	EETs Type A installations
78 vessels	2016-2019	0, 1	Pre swirl fin/stators/ducts PBCF Rudder bulb Thrust fin

An overview of the most efficient ECO designs of bulk carriers can be seen in Figure 4-2. The overview shows size ranges up to 120k DWT and includes vessels already delivered that follow the design trends mentioned above.

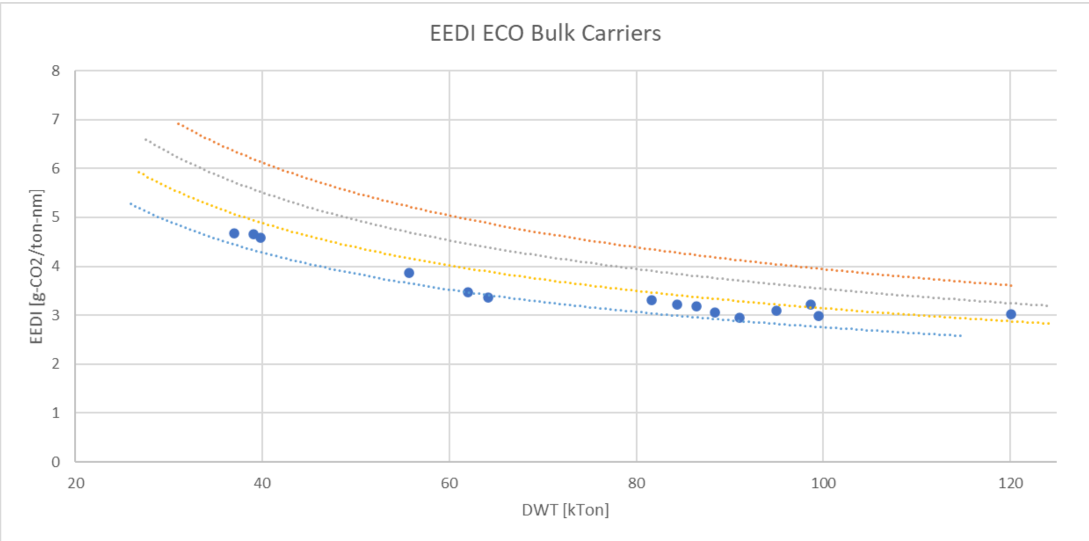

Figure 42 ECO efficient bulk carrier designs and approximate EEDIs

4.6.3 Tanker Design Trends

There have been few changes to the tankers over the EEDI years. The design speed has been reduced moderately and design changes have been on the same trends as mentioned for the bulk carriers.

An example of the changes of the EEDI for a VLCC is given in the table 4-1. Another example for an MR tanker is shown in the Section 6. The design changes for a MR tanker from the same yard is shown in Table 4-4.

Table 4-14 Example of design changes of an MR tanker

	Vessel 1	Vessel 2
Year built	2010	2019
EEDI	pre EEDI	EEDI phase 1 (EEDI = 4.58)
Design changes		
ME MCR		-20%
ME RPM (at MCR)		-33%
Propeller diam.		+20%
Cb		+5%
Additional design changes		+2% LPP / +5% $d_{scantling}$ No bulbous bow Rudder bulb High efficiency propeller

The example ship is lengthened and with a deeper draught. Further the bulbous bow is changed to be non-existing, the block coefficient is slightly increased and the engine MCR is reduced considerably.

Specifically, for the Category A EETs, a survey of ABS and VPS databases, show the following information for vessels built within the EEDI framework.

Table 4-15 Uptake of EETs Cat. A on tankers

Tankers	Delivery date	Applicable EEDI phase	EETs Type A installations
60 vessels	2016-2019	0, 1	Pre swirl fin/stators/ducts PBCF Rudder bulb Thrust fin

Table 4-16 Uptake of EETs Cat. A on LNG / Gas carriers

LNG/Gas carriers	Delivery date	Applicable EEDI phase	EETs Type A installations
19 vessels	2019-2020	1	Pre swirl

			fin/stators/ducts PBCF Rudder bulb Thrust fin

4.6.4 *Containership Design Trends*

The container vessels have for the TEU capacity > 4000 TEU met large changes towards the pre-crisis year (before 2009). The remaining designs delivered around this period were still designed to run 26 knots and many were after the delivery retrofitted with new bulbous bows and derated engines/larger propellers. Vessels delivered today are characterized by increased capacity, lower engine MCRs and therefore lower design speeds. Further all available EET technology (as for bulk carriers and tankers) are typically fitted.

As comparisons two designs are compared in Table 4-7 and 4-8.

Table 4-17 Design changes for a container vessel with 12.5 design draught

Vessel	2009	2016
design draught	**12.5m**	**12.5m**
Lpp		+15%
Breadth		+20%
Cb		+18%
MCR		-35%
RPM at MCR		-9%
Prop diam		+3%
TEU		+65%
EEDI		9.81
Vref		-20%
EETs		Rudder bulb Optimized propeller modified bulbous bow (adjusted to operational profile)

Table 4-18 Design changes for a container vessel with 14.5 design draught

Vessel	2012	2017
design draught	**14.5m**	**14.5m**
Lpp		1%

Breadth		+6%
Cb		-
MCR		-45%
RPM at MCR		-25%
Prop diam		+11%
TEU		+11%
EEDI		-50%
Vref		-8%
EETs		Rudder bulb preswirl fins/duct Optimized propeller / larger diam. modified bulbous bow (adjusted to operational profile)

The 2009 design in Table 4-4 is differing more from the vessels built today than the 2012 design in Table 4-5 due the post crisis changes in the market and the uncertainty of fuel price changes were a reality. The compared vessels did all have waste heat recovery plants installed.

Specifically, for the Type A EETs a survey of ABS and VPS databases, show the following information for vessels built within the EEDI framework.

Table 4-19 Uptake of EETs Cat. A on container vessels

Container vessels	Delivery date	Applicable EEDI phase	EETs Type A installations
26 vessels	2017-2019	1	Optimization of dimensions Controllable pitch propellers Pre swirl fin/stators/ducts PBCF Rudder bulb Thrust fin

			Twisted rudders

4.6.5 Task D1 Survey – Design Choices

One of the questions in the Task D1 survey asked about how the design of ships have been optimised.

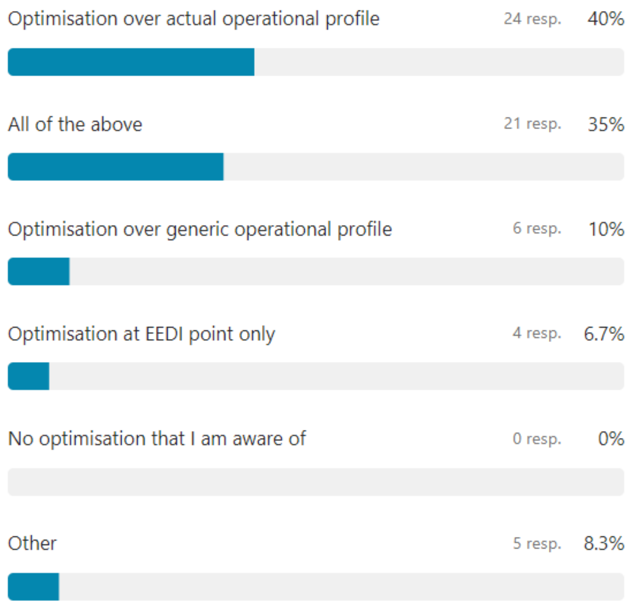

Figure 43 Ship Owners - Type of design optimisation applied

A majority indicate that the ships have been optimised over the actual operational profile, or a mix between actual, generic operational profile and EEDI point.

There were however 4 responses that indicated that optimisation was carried out at EEDI point only, which suggests either poor design practice, or challenges in meeting the required EEDI. There is of course a concern that later phases of EEDI may compel shipyards to focus optimisation on the EEDI point to the detriment of the operational profile, but this point does not appear to have been reached yet.

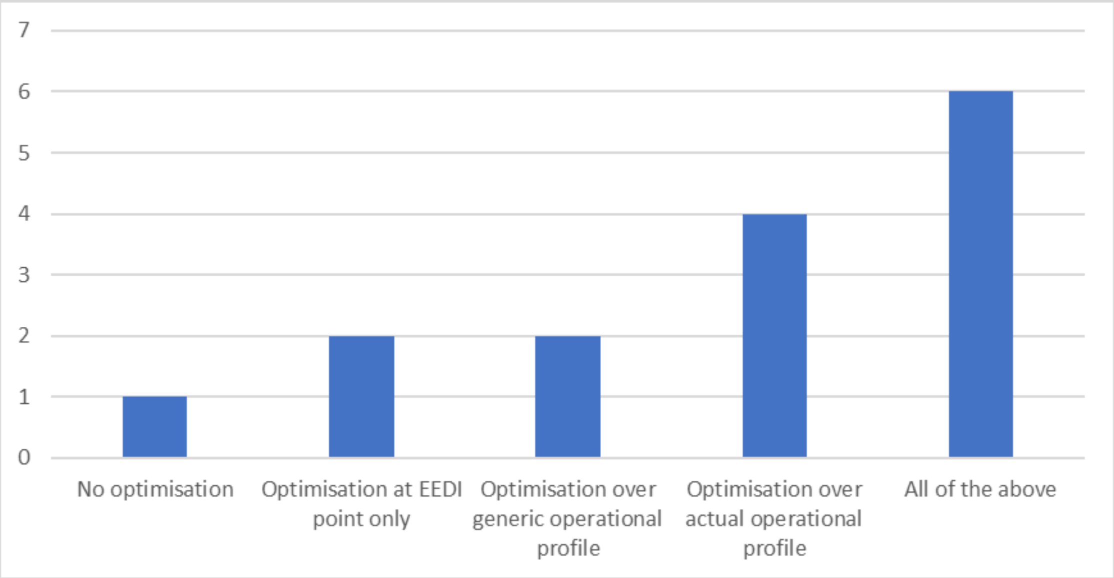

Figure 44 Shipyards - Type of design optimisation applied

The shipyards answered in a similar way to the stakeholders. The shipyards were asked an additional question regarding use of innovative hull design.

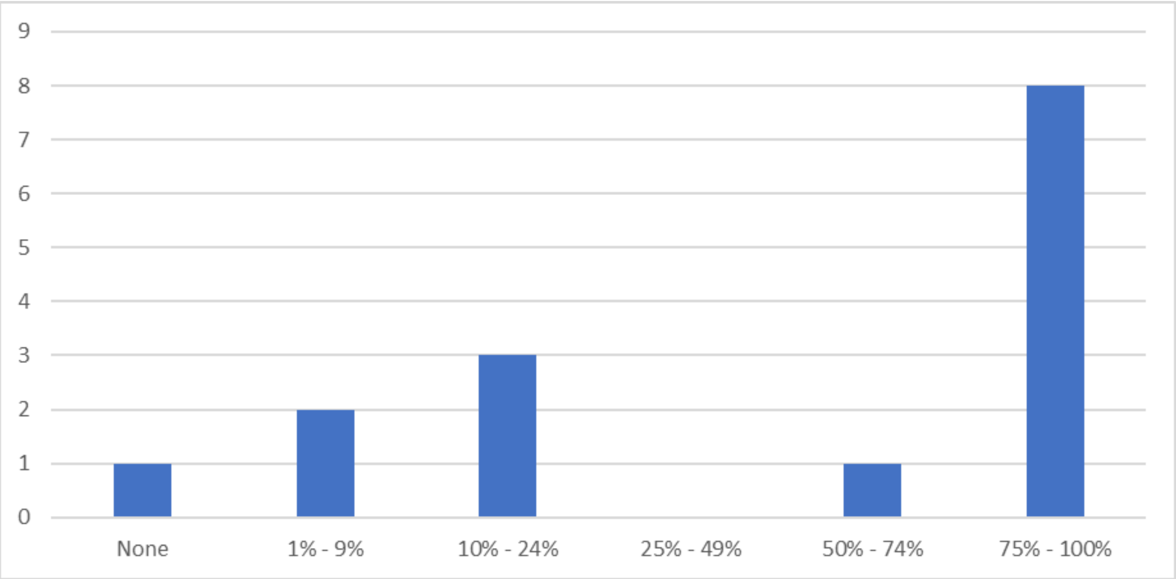

Figure 45 Shipyards – What percentage of delivered EEDI ships use of Innovative Hull Design

The question is quite subjective since there is no definition of what constitutes innovative hull design, but in the shipyard's perception, this is an area that many of them focus on.

Given all the data that was provided, we decided to make an analysis of the typical design choices for the main ship types to work out of overall design strategies differed.

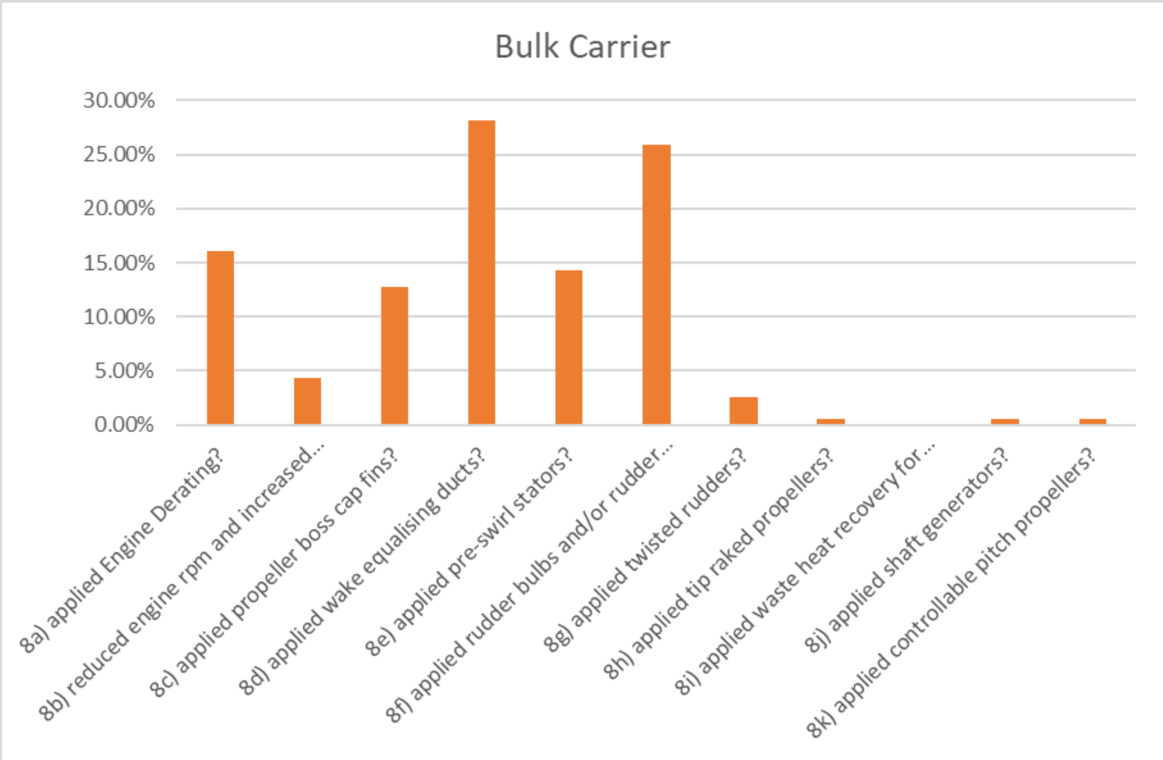

Figure 46 Bulk Carrier uptake of technologies - Ship Owner responses only

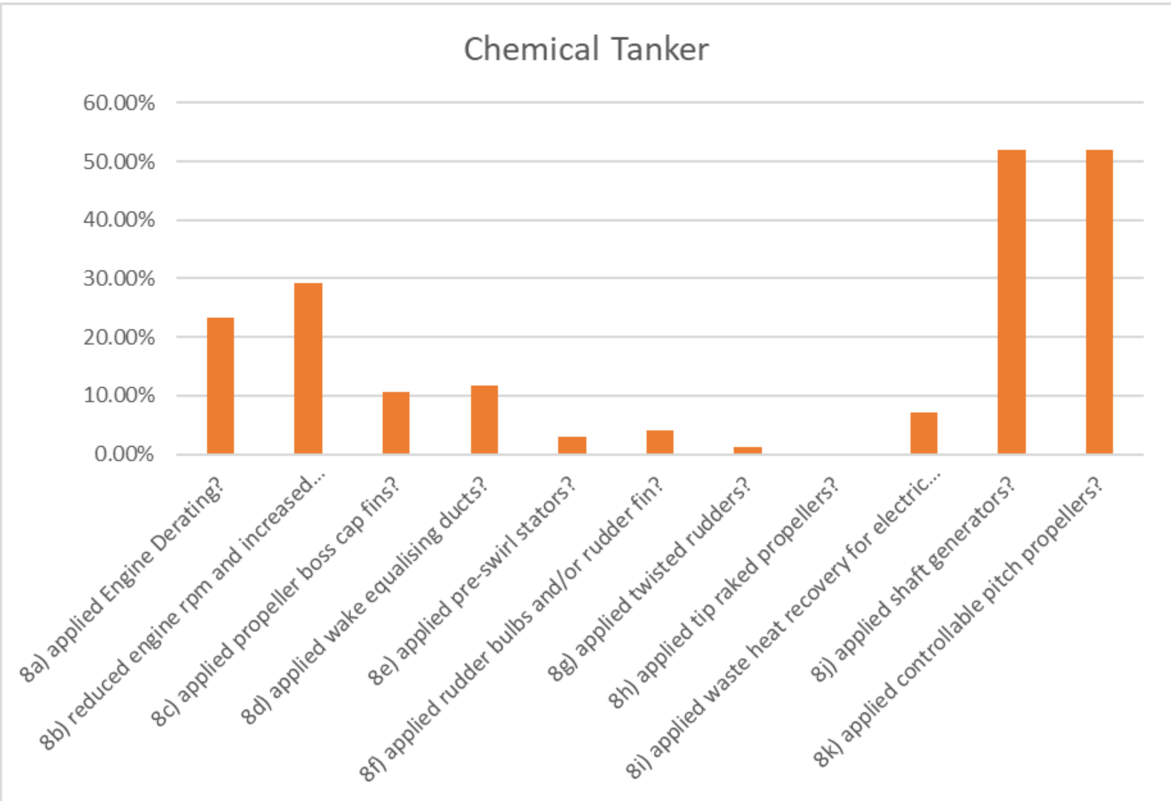

Figure 47 Chemical Tanker uptake of technologies - Ship Owner responses only

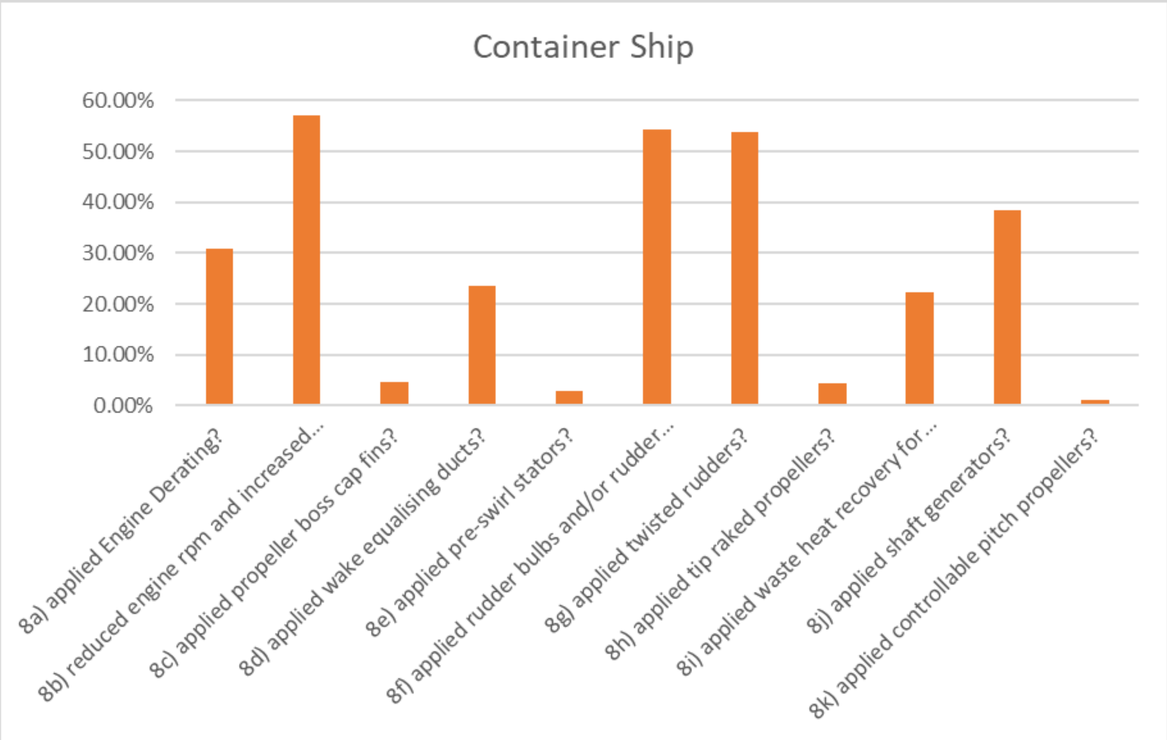

Figure 48 Containership uptake of technologies - Ship Owner responses only

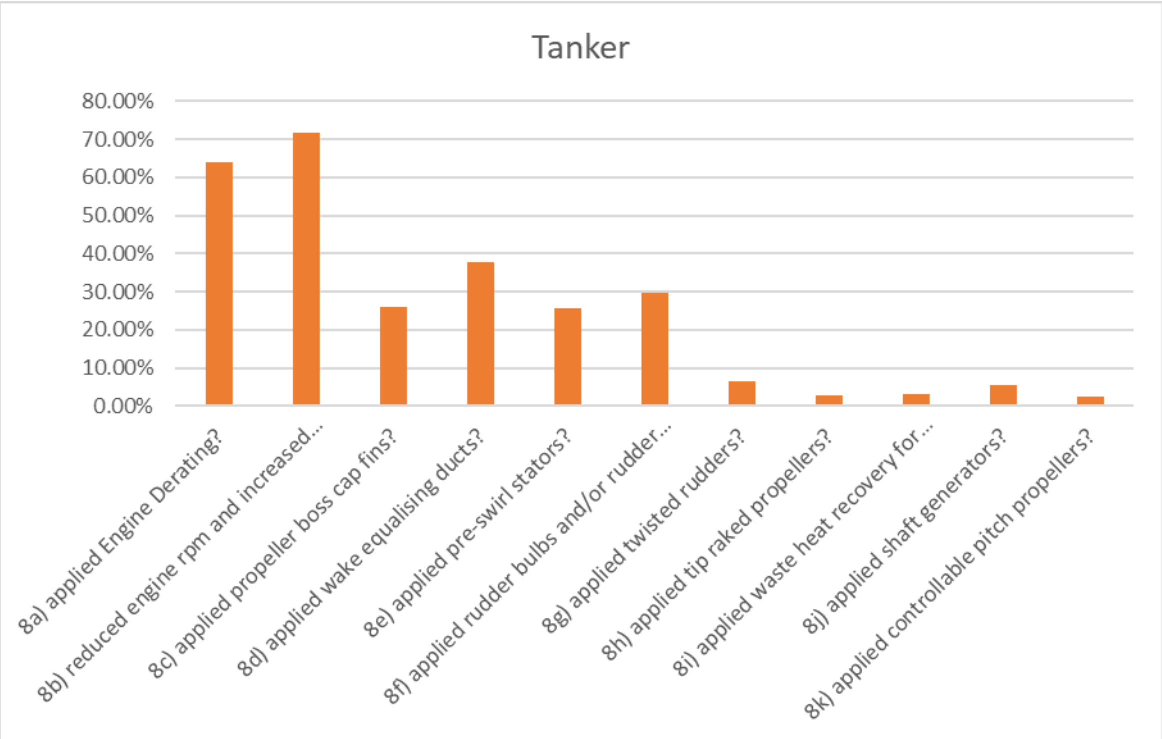

Figure 49 Tanker uptake of technologies - Ship Owner responses only

Although we provide the larger charts above to retain legibility of the text on the x axis, it is easier if all charts could be compared side by side.

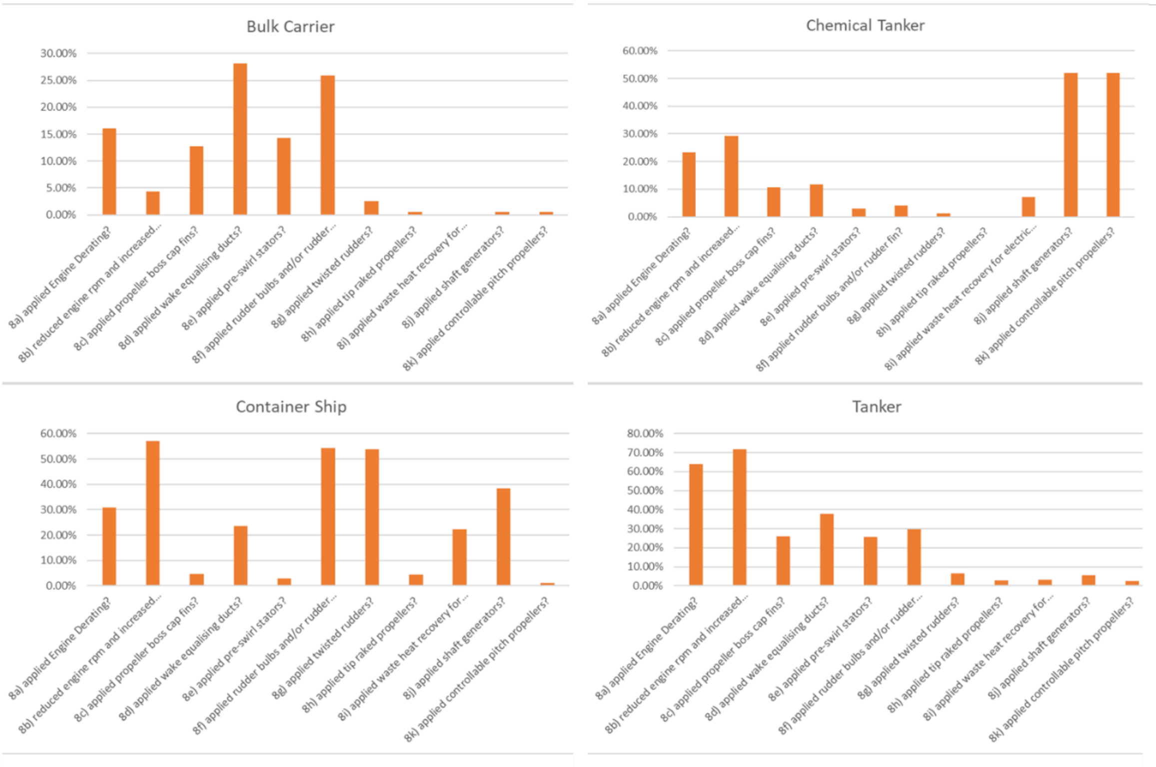

Figure 50 Ship Owner Uptake of Technologies - Bulk Carriers, Chemical Tankers, Container Ships & Tankers

Apart from the first two categories of engine derating and reduced engine rpm which should be at 100%, the remaining categories speak of a preference for different strategies that suit particular ship types better than others.

4.7 EET Conclusions

The general conclusion is that category A (hydrodynamic devices) EET uptake is very high, and that so far hull shape (optimisation) and machinery improvements have yielded better and more consistent savings than most EETs.

Electronically controlled derated engines + low rpm + larger diameter propellers has been the key development of the decade driving large step changes in attained EEDI.

Table 4-20 Comparison of Average AER of EEDI and Pre EEDI Ships - IMO DCS Data

	Deadweight	Non-EEDI Avg. AER	EEDI Avg AER	Percentage Difference
Bulk Carriers	35000	7.42	6.45	12.99%
Bulk Carriers	81000	4.44	3.90	12.18%
Bulk Carriers	210000	2.48	2.20	11.26%

Tanker	50000	7.83	6.39	18.33%
Tanker	109000	4.96	3.94	20.52%
Tanker	300000	2.74	2.10	23.29%
Container	12000	20.23	16.93	16.29%
Container	40000	11.43	9.98	12.68%
Container	200000	5.33	4.92	7.62%

This table from the Task C1 report shows that EEDI improvements also carry across to the whole operating profile, as we can see in the comparison of AER of EEDI and pre-EEDI ships.

Category A EET selection appears to be an integral part of the hydrodynamic optimisation, and different shipyards select different strategies even for vessels of the same size and type.

Contractually, shipyards take all the risk for vessel performance and integration, some shipyards do not allow owners to change the standard specification – and this results in significant challenges to get third party EETs onboard.

We have seen a number of situations where innovative technology of categories A to C have been fitted, but not recorded in the EEDI technical file or used in the calculation of the attained EEDI. The number of innovative technologies of category B and C recorded in the IMO EEDI database has also not changed for some years now and so it should be queried as to whether the IMO EEDI Database is actually fit for purpose.

Overall it seems that the current version of MEPC.1 Circ.815 may be somewhat unfavourable to certain types of wind technologies and this is one factor in the current low adoption rate of wind assist, though with the upcoming changes to the circular being proposed to MEPC 77 and the implementation of EEXI and CII, as well as the growing number of retrofit solutions and charterer interest, we may be at a tipping point for uptake of wind assist technologies.

Waste heat recovery appears to be in competition with shaft generators, and shaft generators generally have an advantage in consistency of output, size and cost. The key though is that waste heat recovery is only suitable for certain ship types and operating profiles which have high electrical loads, so there would be little point in trying to incentivise uptake of waste heat recovery.

Air lubrication appears to be fairly promising in terms of savings and also the ease with which the results may be proven, however the challenge has been the contractual terms between shipyard, ship owner and equipment supplier meaning that there are some significant obstacles to air lubrication being fitted, and if fitted, quite often they are not used in the calculation of the attained EEDI and hence not reported to the IMO EEDI database, and so we do not have a clear picture of uptake or effect across different ship types. Some of this may also be down to confidentiality concerns since there are shipyard systems, the efficacy of which the shipyards may prefer not to divulge.

Apart from containerships, designs speeds in shipbuilding specifications have hardly changed even if operational speeds have. This is confirmed by the V_{ref} values in the IMO EEDI database and the survey results from shipowners. This is likely a feature of markets with significant charterer influence, where ships are built to market expectation. Segments with more scheduled services without charterer involvement e.g. container ships and vehicle carriers have more flexibility to reduce design speeds.

Certainty and consistency of result is key for a shipyard, they must be confident that the results will comply with the regulations, but also the contractual specification, and they must have margins in place – implementing a solution that might give between 2% and 4% is high risk if the compliance gap is 3%. Hence you see that shipyards are proposing LNG solutions for Phase 3 and Phase 4 which gives certainty of compliance, as well as longevity of compliance – ie a design can be built many times over a number of years with only minor modifications and updates.

It should be noted that increasing uptake of most EETs will generally not mean an improvement of the best EET scores, since these already have implemented most EETs. Instead it may mean that more ships will reach the level of the attained EEDI of the best performers.

Bulk carriers and tankers that are subject to the minimum power requirements are in some cases not able to reduce engine power further while still complying with these minimum power requirements (and in many cases torque requirements). The approval of changes to the calculation methodology and scenarios for calculating the minimum power at MEPC 76 may in some cases lead to poorer attained EEDI for such ships.

4.8 Alternative Fuels and Power

In task B1, an overview was provided of various types of alternative fuels and power, however this was not meant to be a detailed look into the fuels, and for technical details on these fuels, there are various ABS publications that may be consulted.

4.8.1 Technology Readiness

The comparison of the different fuel types and which are the most attractive to develop further is depending on a number of factors. The composition of the fuel with regards densities of energy and volume, the production costs and storage facilities are some. A recent study from LR and UMAS (LR/UMAS, 2020) gives an overview of the techno economic considerations in an assessment of zero carbon fuels. In the study, a technology readiness level (TRL) ranking is given for the different fuel types. The zero emissions technologies are compared to a LSHFO reference ship.

The TRL estimates the maturity of technologies as per the following table:

Table 4-21 TRL Definitions

TRL 1 Basic principles observed	TRL 6 Technology demonstrated in relevant environment
TRL 2 Technology concept formulated	TRL 7 System prototype demonstration in operational environment

TRL 3 Experimental proof of concept	TRL 8 System complete and qualified
TRL 4 Technology validated in laboratory	TRL 9 Actual system proven in operational environment
TRL 5 Technology validated in relevant environment	

TRL	Bunkering			Storage onboard					Processing and conversion			Propulsion			
	Equipment	Procedures	Fuel quality standards	Structural tank	Membrane containment system	IMO type A tank	IMO type B tank	IMO type C tank	Venting system	Fuel supply system	Reformer	2-Stroke ICE	4-Stroke ICE	FC	Boiler
LSHFO ICE reference ship	9	9	9	9					9	9		9	9		9
Bio-diesel ICE	9	9	9	9					9	9		9	9		9
E-diesel ICE	9	9	9	9					9	9		9	9		9
Bio-methanol ICE	7	6	3	7					7	7		7	6		2
E-methanol ICE	7	6	3	7					7	7		7	6		2
Bio-methanol FC	7	6	3	7					7	7	3		6	7	2
E-methanol FC	7	6	3	7					7	7	3		6	7	2
Bio-LNG ICE	9	9	9		8		9	9	9	9		9	9		9
E-LNG ICE	9	9	9		8		9	9	9	9		9	9		9
Bio-LNG FC	9	9	9		8		9	9	9	9	4			7	
E-LNG FC	9	9	9		8		9	9	9	9	4			7	
E-ammonia ICE	7	2	2			7	7	7	3	7		3	2		2
NG-ammonia ICE	7	2	2			7	7	7	3	7		3	2		2
E-ammonia FC	7	2	2			7	7	7	3	7	2		2	7	2
NG-ammonia FC	7	2	2			7	7	7	3	7	2		2	7	2
E-hydrogen ICE	4	2	3				3	6	2	2		2	5		2
NG-hydrogen ICE	4	2	3				3	6	2	2		2	5		2
E-hydrogen FC	4	2	3				3	6	2	2			5	7	2
NG-hydrogen FC	4	2	3				3	6	2	2			5	7	2
Batteries	4	2	3				3	6	2	2			5	7	

Figure 51 TRL ranking for zero emissions technologies – LR/UMAS 2020

The maturity level considers Bunkering, Storage on board, Processing and conversion and finally propulsion. The table shows that the LNG solutions are the most mature, followed by biofuels and e-fuels. Even though the e-fuels are the less mature for conventional propulsion, they are on the same maturity level when considering fuel cells. A similar study by Netherlands Maritime Land and Ministry of Economic Affairs (MKC, 2020) assesses the alternative fuel for seagoing vessels. The assessment includes the TRL in 2019 and assumes a similar view for 2030 TRLs. It should be noted that TRL levels may vary depending on the assumptions, and even the very detailed TRL breakdown above may show some variation if carried out by different stakeholders.

The LR/UMAS study further includes an assessment of the fuels CO2 lifecycle emissions compared to a LSHFO reference ship. Included are the upstream, the operational and the Net CO2 emissions.

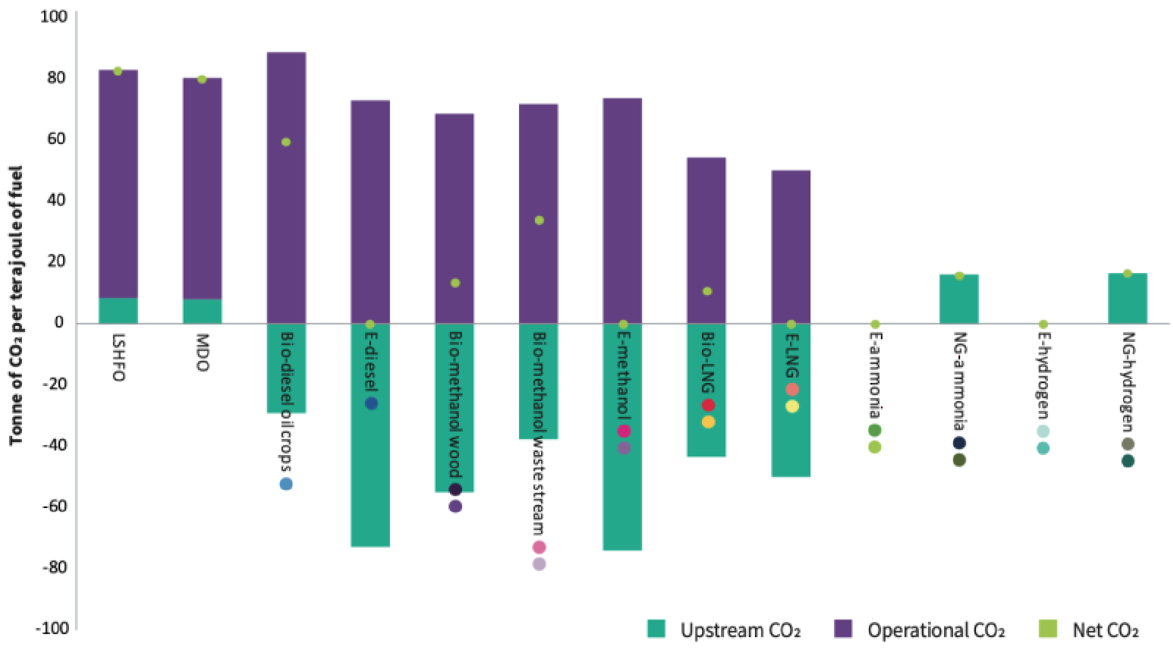

Figure 52 Upstream, operational and net CO2 emissions for each fuel LR/UMAS 2020

The best net performers are the e-fuels and in general, the lifecycle CO2 emissions are close to zero for the remaining types.

On the other hand, what is not clear when we compare CO2 emissions of fuels is the energy intensity of each of these fuel production pathways.

4.8.2 Current Uptake of Alternative Fuels

A review of the uptake of alternative fuels and other incentives to reduce GHG emissions are investigated using the Veracity (DNV-GL Veracity, 2020) platform. The information is coming from suppliers of technology, classification societies and shipyards.

The statistics includes

- Scrubber Technology
- LNG
- LNG Ready
- Methanol
- LPG
- Hydrogen

Further it includes existing vessels and vessels on order. Number of installations are as stated in Fig 53.

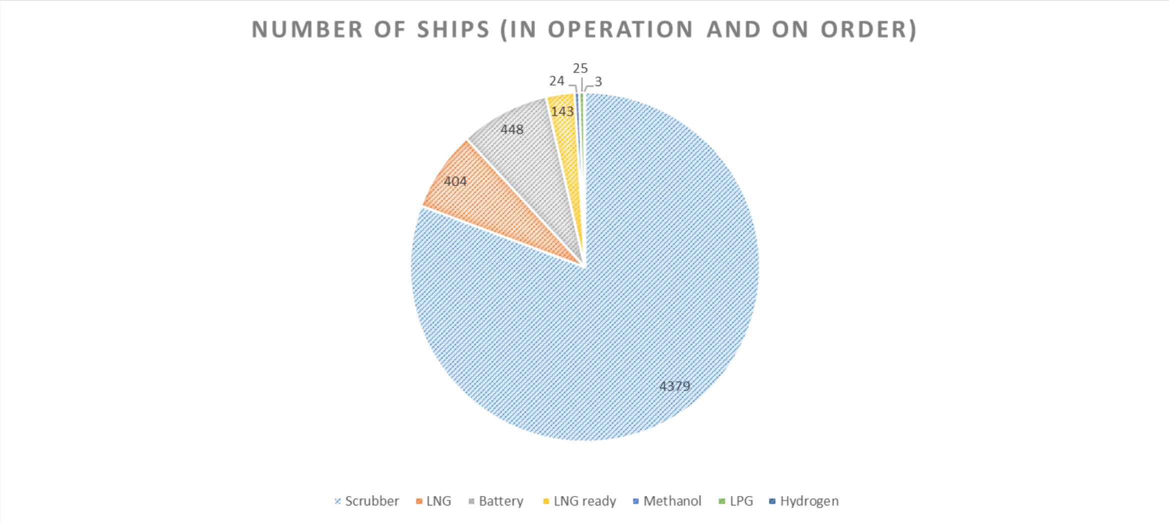

Figure 53 Number of vessels fitted with GHG emissions reduction technology (Veracity, 2020)

The distribution on ship types are shown in Fig 54.

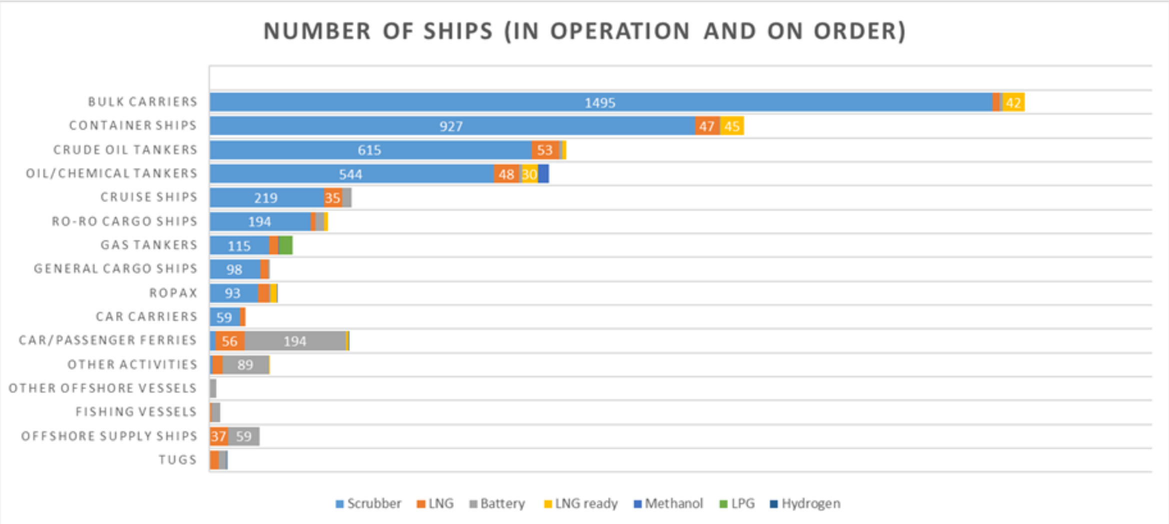

Figure 54 Technology distributed on vessel types (Veracity, 2020)

According to the information, 4379 vessels are fitted or plan to be fitted with scrubber technology to meet the 2020 sulphur cap. If this information is filtered out, the uptake of alternative fuel/technology plot will be as in figure 55:

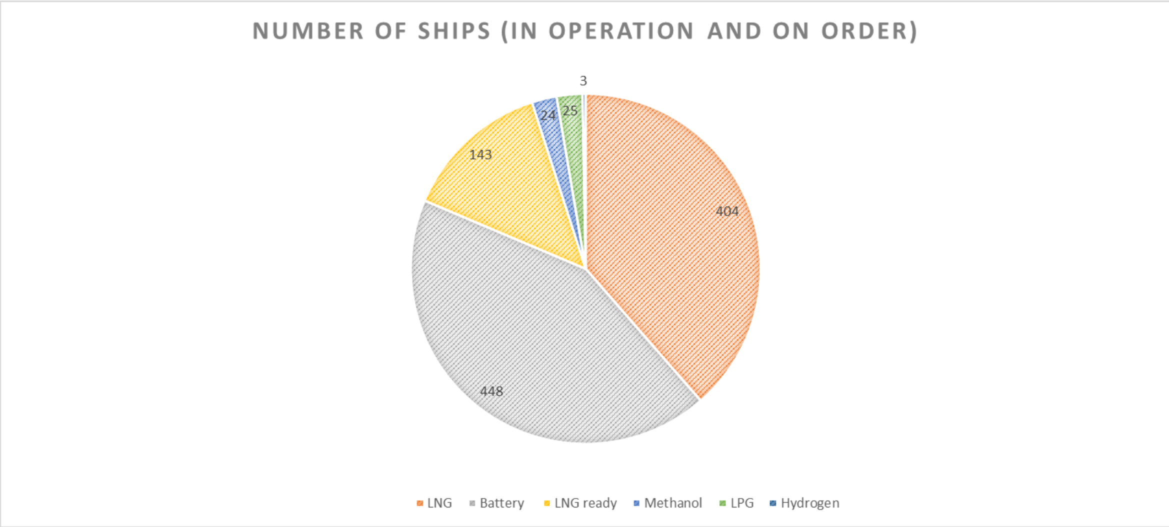

Figure 55 Number of vessels fitted with CO2 emissions reduction technology (Veracity, 2020)

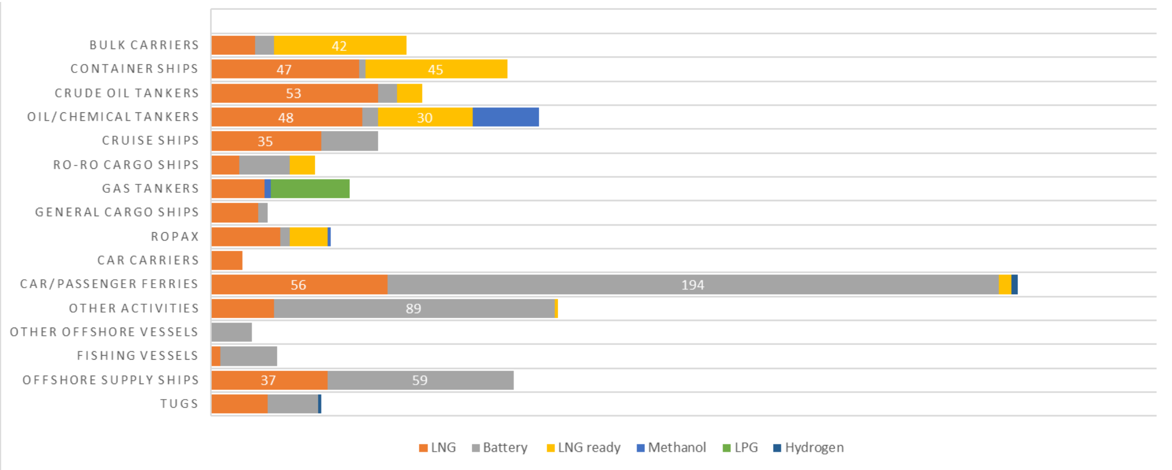

Figure 56 Technology distributed on vessel types (Veracity, 2020)

404 vessels are fitted or planned fitted with LNG propulsion and 243 vessels are equipped with LNG ready technology. It is crude/oil/chemical tankers, container and cruise/passenger vessels that have the highest uptake of LNG technology. Bulk carriers are also getting into LNG but are more LNG ready than exactly using the technology as now.

Battery technology are used mostly on short sea vessels like ferries and offshore vessels.

LPG and methanol are unsurprisingly used on LPG and methanol tankers although these are likely used as a means of 2020 sulphur compliance rather than GHG. and the three hydrogen cases are 1 tug / 2 ferries.

The Veracity platform does not seem to disaggregate ethane as a separate category, but it is worth noting that ethane is used as a fuel on some gas carriers (dedicated to carriage of ethane cargo), again primarily for 2020 sulphur compliance and with a very small improvement in GHG emissions compared to liquid fuels.

4.8.3 Fuels in the EEDI Framework

Fuels are accounted for in the EEDI calculation by the C_f factor which is detailed in the EEDI calculation guidelines. The guidelines currently list 8 fuels:

Table 4-22 Table of C_f factors from EEDI Calculation Guidelines

Type of Fuel	Reference	Lower calorific value (kJ/kg)	Carbon Content	C_f (t-CO2/t-Fuel)
Diesel/Gas Oil	ISO 8217 DMX-DMB	42,700	0.8744	3.206
Light Fuel Oil	ISO 8217 RMA-RMD	41,200	0.8594	3.151
Heavy Fuel Oil	ISO 8217 RME-RMK	40,200	0.8493	3.114
LPG Propane		46,300	0.8182	3.000
LPG Butane		45,700	0.8264	3.030
LNG		48,000	0.7500	2.750
Methanol		19,900	0.3750	1.375
Ethanol		26,800	0.5217	1.913

Marine diesel engines can technically burn any of the first 3 without modification and most ships carry both Diesel/Gas Oil and Heavy Fuel Oil.

The C_f factor that is used in the calculation is linked to the fuel that is used for NOx testing for compliance with the NOx technical code. Currently the C_f factor reflects a tank to wake accounting for carbon which is linked to the relative proportion of carbon in the fuel.

For LNG or LPG dual fuel engines, the C_f factor that is used depends on the relative storage capacity and energy content of the gas and liquid fuels, such that if the gaseous fuel energy content exceeds that of the liquid fuel, the C_f factor for the gaseous fuel may be used, otherwise a weighted hybrid of the two C_f factors is used. This provision was brought in to attempt to prevent abuse where the equipment for gaseous fuel was fitted but not used.

In the future situation where there is a carbon intensity indicator in place, it should be reviewed as to whether such a requirement is still necessary as it constrains the ship design and impinges on the commercial and technical requirements to have some degree of redundancy. The carbon intensity indicator could then be used to monitor fuel usage. Technically even DCS and MRV allow this monitoring today without use of a CII.

It should be noted that there is a disconnect between improving energy efficiency (reducing the amount of energy required per unit of transport work) and reducing carbon intensity. In the EEDI framework – because we measure energy efficiency using carbon as a proxy, we have essentially equated energy efficiency with carbon intensity.

When lower and zero carbon fuels are introduced into the fuel mix, it is possible for attained EEDI to reduce/improve while actual energy efficiency could be worse, and at that point the framework will become less and less effective at being an indicator of energy efficiency and transition to become a hybrid indicator of energy efficiency and carbon intensity. It means that it will eventually not be possible to tell whether an attained EEDI is achieved because of good energy efficiency, or if it uses a lower carbon fuel, without carrying out investigations and calculations.

Most lower carbon fuels require more volume and mass than HFO and MGO, so adoption of these inevitably mean a reduction in deadweight and available volume for cargo all other things being equal.

We already see some of this happening with the shift to LNG – where very similar ships could have significantly different attained EEDI simply because one uses MGO and the other LNG, however in pure energy efficiency terms they are either comparable or the LNG may in fact be slightly worse.

One of the bulk carrier case studies in Report A1 illustrates this clearly, where the design choices made to accommodate LNG means that the power requirements to reach EEDI speed actually exceeds that of a comparable vessel running on MGO. We understand that it also performs worse in waves.

The regulatory status of alternative fuels is given in table 4-23.

Table 4-23 Regulatory status of alternative fuels

Fuel	C_f	EEDI Calculation Guidelines	IGF Code	2 stroke engine	4 stroke engine	Fuel Cell
LNG	2.75*	Yes	Yes	Yes	Yes	Yes
LPG	3.00-3.03	Yes	2023 approval	Yes	No	Unknown
Methanol	1.375	Not for dual fuel	Interim guidelines	Yes	In development**	Yes
Ammonia	0.0***	No	No	In development	In development	In development
Hydrogen	0.0***	No	No	In development	In development**	Yes

*Currently excludes methane slip

**Converted engines are in operation, but not yet available off the shelf

*** Not currently tabulated in the calculation guidelines

4.8.4 Carbon Accounting

As mentioned above, there are two means of accounting for carbon – one is the tank to wake where only the emissions from combustion of fuel is counted (which is currently used in EEDI and the C_f factor), and the other is well to wake where upstream emissions from production and transport are also included.

In general, well to wake emissions are much more variable and therefore require standardised and agreed guidelines to ensure comparability. There are of course the risks and consequences that will need to be dealt with.

It should be noted that EEDI is a design framework – and is not designed to regulate necessarily what happens in operation. With the move to having an operational measure, the need for EEDI to drive the alternative fuel transition of the GHG strategy perhaps reduces.

In the consortium we have discussed perhaps that in this new situation where there is both a design/technical framework (EEDI) and an operational framework (operational CII measure), the EEDI certification should simply reflect the best achievable under ideal conditions and leave the operational part to the short term operational measure rather than attempt to second guess what may happen over a 30 year vessel lifespan in operation.

We now examine both main methods of carbon accounting in more detail.

4.8.4.1 Tank to Wake

This is the current calculation method used to derive the C_f factors in the EEDI calculation. In a situation where the primary fuels are broadly similar in energy and carbon content and are all fossil fuel based and come from a similar extraction and refining process, consideration of only the carbon emissions at combustion is a fair comparison.

The advantages may be summarised as:

- Well understood and easy to implement
- Carbon factors are consistent, based on chemical composition
- Represents actual shipboard emissions

The challenges and weaknesses with this may be grouped into 3 main categories:

1. Where combustion by-products with substantial GHG impacts are not accounted for – e.g. methane slip, black carbon, N_2O then the tank to wake approach underestimates the GHG impact
2. Where the upstream processes differ substantially in GHG impact – e.g. e-fuels are not differentiated from fossil fuels, or brown hydrogen (from coal gasification or LNG) vs green hydrogen from zero/low carbon energy sources
3. Where upstream processes reduce the GHG impact – e.g. biofuels

For category 1 above, combustion by-products are a function of engine technology and engine load as well as fuel. These are broadly consistent over the lifetime of the ship and could potentially be addressed as part of an engine certification process. It is important to note that this is a complex area and testing on a test bed will usually have better results than in operation, thus it is important to ensure that trends observed in testing are also replicated in operation and require careful design of the testing regime.

It is important to also ensure that all GHG impacts are captured in order to facilitate fair comparison between fuels, and to avoid as far as possible a later u-turn after extensive uptake.

The impact of combustion by-products could be represented either as a per ship modification to the C_f or a penalty to SFOC, or as additional factors in the EEDI calculation.

A current topic of discussion is around how methane slip from LNG engines should be taken into account.

If methane slip is accounted for either in C_f or in engine certification, there will be a period of time where the attained EEDI values of ships using LNG as a fuel will appear to regress (until methane slip is reduced by advances in engine technology), and compliance even with Phase 3 (depending on when amendments are adopted) may be jeopardised.

As we indicated, many next generation designs from shipyards (both in the EU and in Asia) feature LNG as a compliance option to SOx, NOx and EEDI phase 3 (and potentially phase 4) regulations. Methane slip generally increases at lower engine loads, but also as load is changed, so static testing under the NOx technical code may not entirely capture methane slip behaviour adequately.

For drop in replacement fuels in categories 2 and 3 above, such as e-fuels or bio fuels, the tank to wake methodology currently does not recognise the GHG benefit of such fuels and there is also the issue that EEDI certification cannot at the moment influence the proportion of such fuels that are used through the lifespan of the ship. On the other hand if a shipowner has access to a long term supply of such fuel (and thus able to meet both 2030 and 2050 targets in this way via OPEX), then it seems EEDI would still require additional spending on technical measures to comply with EEDI regardless of the availability and use of net-zero drop in fuels.

This could either be viewed as an impediment to demand growth and uptake of net-zero fuels in the short to medium term, or a means of ensuring a minimum level of energy efficiency.

However this may favour fuels that are low or zero carbon in tank to wake terms since these fuels will result in a low to zero attained EEDI, although comparisons of total CAPEX and OPEX, and infrastructure availability would still need to be taken into account.

It is easier to explain these concepts with a case study, so let us use again the LNG bulk carrier example and a notional 40% EEDI reduction rate:

Table 4-24 Fuel effect on the EEDI scenarios

	EEDI Attained	Relative to A1	Relative to EEDI Baseline	EEDI Improvement	
A1	3.53		19.22%		MGO
A1.1	3.53	0.00%	19.22%	0.00%	E-MGO or Biofuel
A2.1	2.78	21.25%	36.38%	17.16%	LNG primary fuel
A2.2	3.06	13.31%	29.97%	10.76%	LNG secondary fuel

A2.3	2.50	29.17%	42.79%	23.57%	LNG primary fuel with air lubrication (for illustration)

A1 is the base design using MGO as a fuel, and A1.1 is the same ship using E-fuel or biofuels. If we assume that the E-fuel or biofuel is net zero, A1.1 could in theory comply with the 40% reduction rate, however for EEDI purposes at the moment, it would not be sufficient, and one would need to use LNG as a primary fuel with air lubrication at much greater capex.

Note that in all cases, the ships could theoretically be run on conventional MGO (due to unavailability of supply of biofuel, e-MGO or LNG) without affecting EEDI certification and in this case the LNG ships may potentially have higher CO2 emissions than the conventionally powered ships due to the increased power to achieve the same speed. The risk of this is however very small

It is important to emphasise that we do not think that shipowners or charterers will choose to invest in LNG and simply avoid using it – there are other environmental issues to consider at the same time such as NOx tier 3, lack of visible smoke, reduced black carbon and particulate matter as well as improved SFOC in gas mode that would compel the shipowner to use LNG as far as possible. We also understand that LNG and any alternative fuel (including bio and e-fuels) are provided only under supply agreements which have a duration and minimum quantities, unlike the current method of bunker supply.

In the case above if methane slip was introduced into the calculation, it would have the effect of increasing the attained EEDI of the ships with LNG and potentially decrease the effectiveness of LNG.

The above example also illustrates the very wide range of attained EEDI's possible from the same design but with a just a change in the certified fuel.

4.8.4.2 Well to Wake (WTW)

The well to wake method of CO2 accounting includes the CO2 emitted in production, transportation and bunkering of the fuel. The main advantages of the well to wake method of CO_2 accounting are:

- Allows bio and e-fuels to be appropriately recognised
- Allows carbon intensities in production to be differentiated

Using WTW allows us to have a holistic view of CO_2 footprint of fuels that can be used for decision making regarding the choice of future fuel mix and the work that needs to be done to enable this. It is important to note that well to wake carbon accounting is in effect a combination of well to tank and tank to wake methodologies. However, the current tank to wake methodology does not consider all GHG by-products of combustion, and these must also be addressed, as described above in the Tank to Wake section.

The main challenges are:

1. Large amount of variability in calculation methodology, assumptions and results

2. C_f factors will also exhibit variability due to different processes, inputs and geographical location
3. C_f factors will also change over time as the energy mix decarbonises
4. Risk of CO_2 double counting

Since EEDI is a one-off pre-certification scheme, consistency and certainty of the calculation parameters is required and this is at odds with the underlying variability of WTW carbon accounting.

It is important to note that attempting to use WTW in the carbon factor C_f to calculate EEDI does not have any impact on the operational choices that will be made regarding fuel usage.

Given that most alternative fuels require energy input, and that in most cases that energy has a CO_2 footprint, the more highly refined and manufactured fuels will also have larger CO_2 footprints.

Hence it would not be surprising if the outcome of implementing WTW would be to entrench HFO and MGO and to hinder any transition to alternative fuels until we have sufficient zero carbon energy to make a dent in the fuel mix for the marine sector. This seems to be borne out by analysis from Dr Lindstad, as presented to the FuelEU Maritime discussion in September 2020.

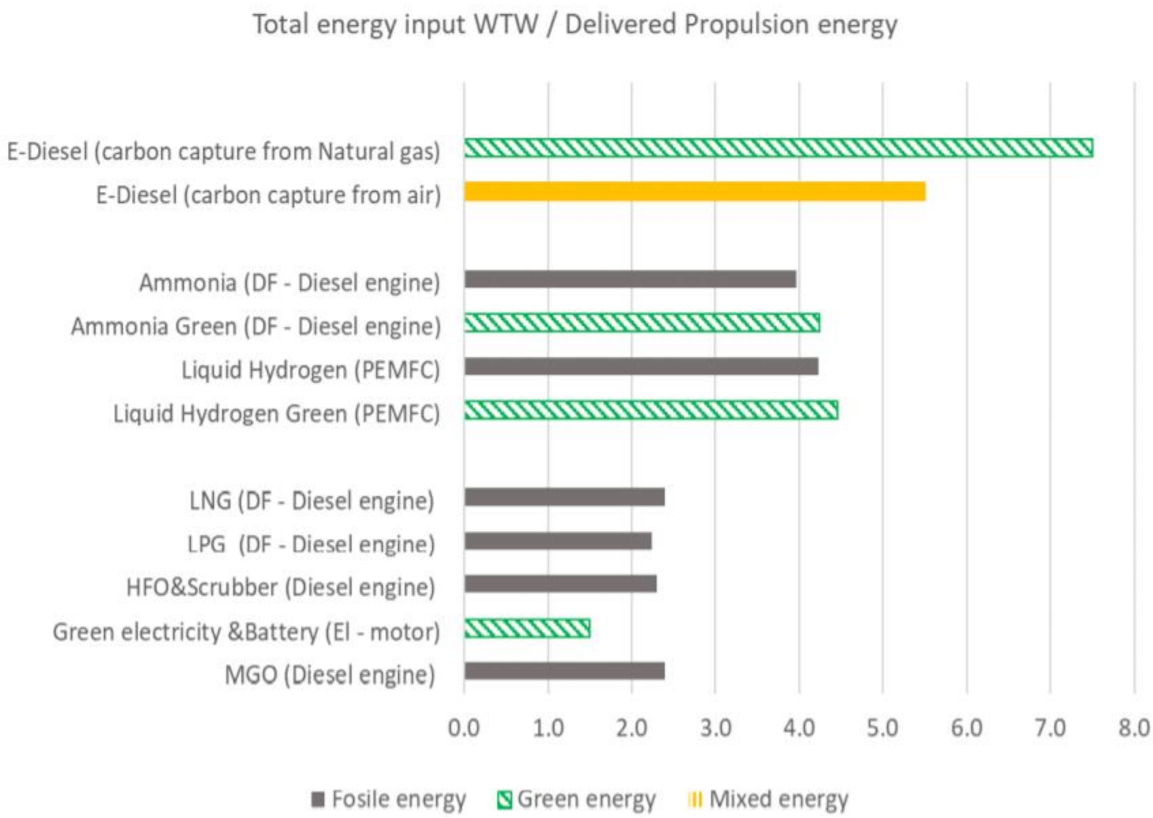

Figure 57 Total energy input Well to Wake per delivered propulsion energy (Lindstadt, 2020)

As such, we cannot see how WTW could be successfully used within the context of the EEDI framework.

It is often suggested that WTW carbon factors could potentially be applied in the context of an operational carbon intensity indicator. Dr. Lindstad's work suggests that in the short to medium term, such an approach would favour HFO, MGO and biofuels and would not allow even small mixes of ammonia or hydrogen from LNG or coal gasification. See the next two charts for the comparison of WTW relative to MGO.

Therefore, use of WTW should be carefully evaluated because there is a significant risk of unintended consequences regarding uptake of alternative fuel.

Our advice would be in the first instance to only use WTW in the context of policy discussions. It should also be made clear that WTW carbon factors will change over time based on policy decisions and market forces and that policy interventions need to be made in the light of this.

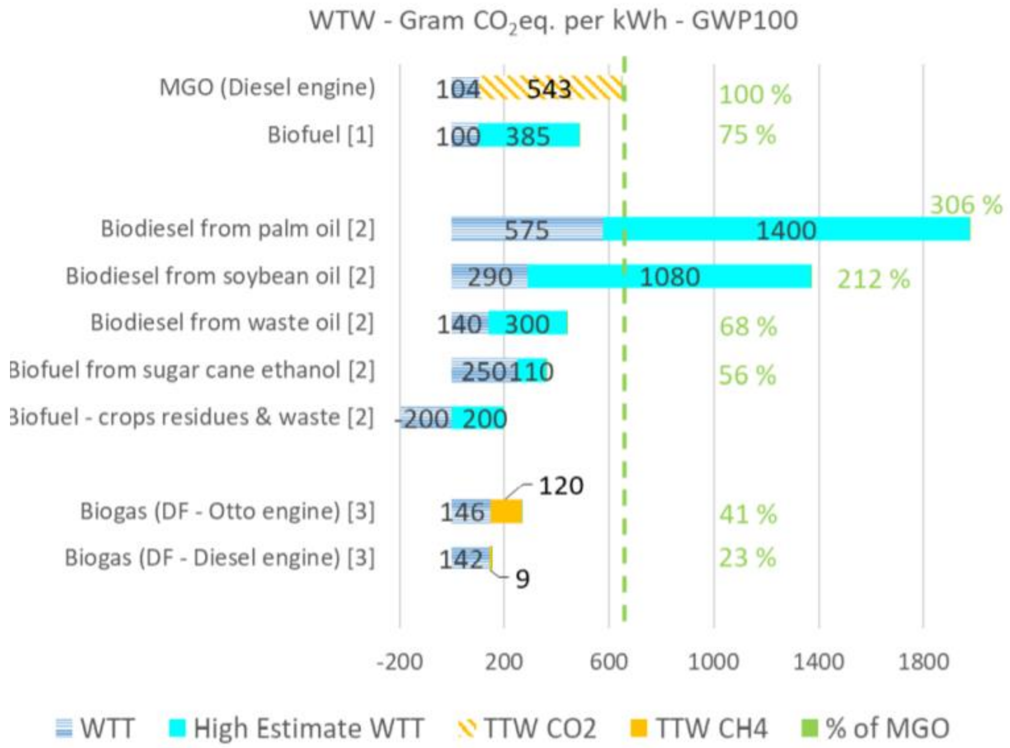

Figure 58 Well to Wake CO2 emissions per kWh for Biofuels (Lindstadt, 2020)

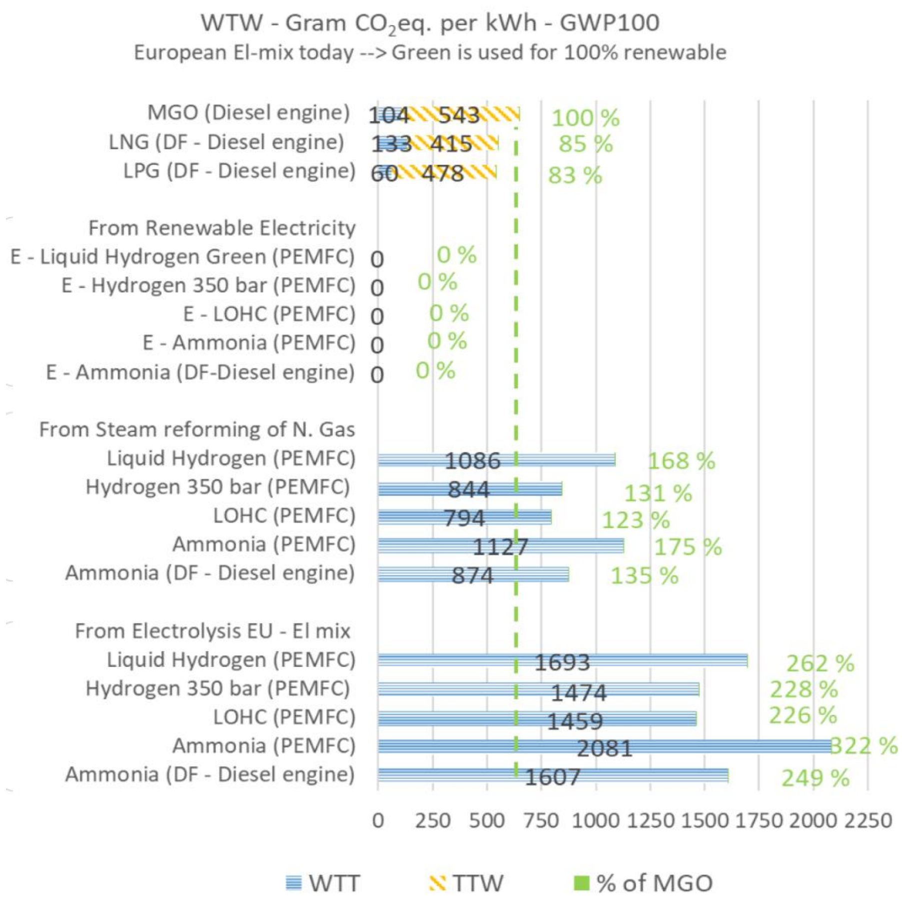

Figure 59 Well to Wake CO2 emissions per kWh for Hydrogen and Ammonia (Lindstadt, 2020)

4.8.5 Future Preference for Alternative Fuels and Power – Task D1 Survey

One of the survey questions asks stakeholders in general what kind of fuel choices and propulsion technologies they would consider for future newbuildings.

The possible choices were as follows, and respondents could pick more than one answer.

- HFO/MGO
- LNG
- Methanol
- Ammonia
- LPG
- Hydrogen for co-combustion
- Electric or hybrid (diesel) electric
- Batteries
- Fuel Cells
- Wind assist or wind propulsion
- Waiting for more clarity before ordering new tonnage

The overview is as follows:

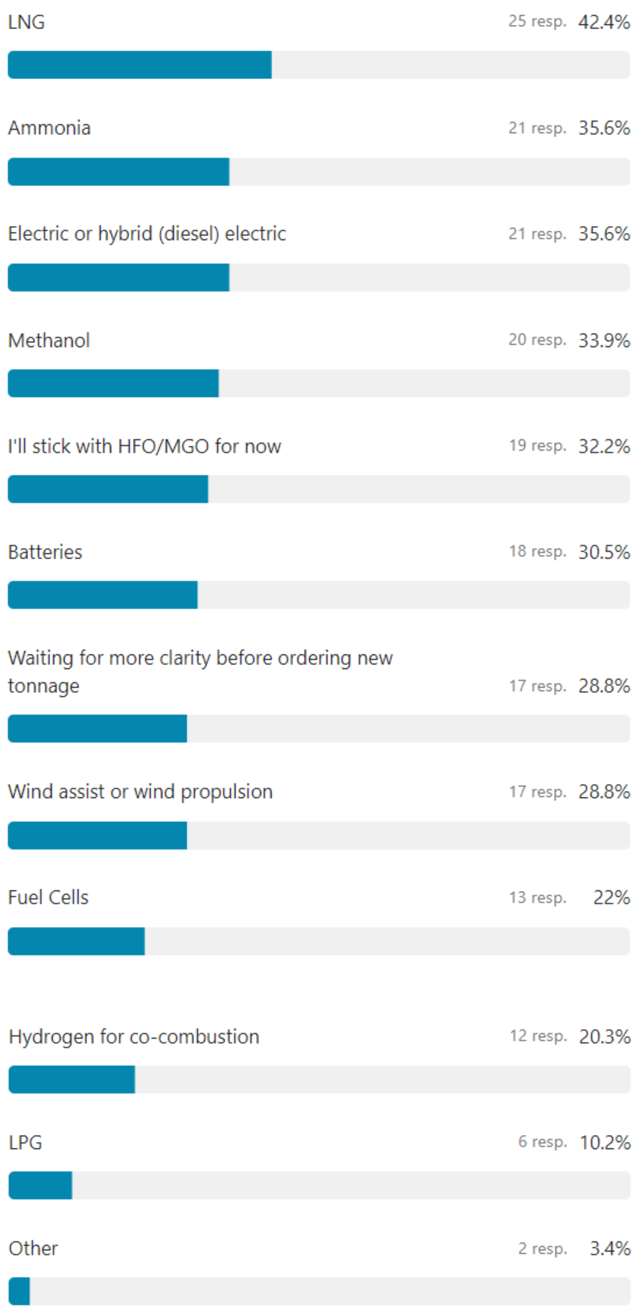

Figure 60 Future fuels and propulsion technologies - Ship Owner Responses

For non-shipyard stakeholders, LNG not surprisingly was the most popular choice due to technology maturity and availability. Thereafter the preference for ammonia, electric/hybrid, methanol and HFO/MGO is somewhat similar. This relatively close ranking may indicate that LNG aside, there are no clear frontrunners, and that the gap between LNG and other fuels is not that large. This likely reflects continuing uncertainty regarding fuel and propulsion choices.

Close to this group are batteries, wind propulsion, and those awaiting more information before making choices.

Bringing up the rear are hydrogen (both fuel cells and combustion) and LPG which is commonly considered a fuel for those carrying it as a cargo.

The shipyard view however looks different.

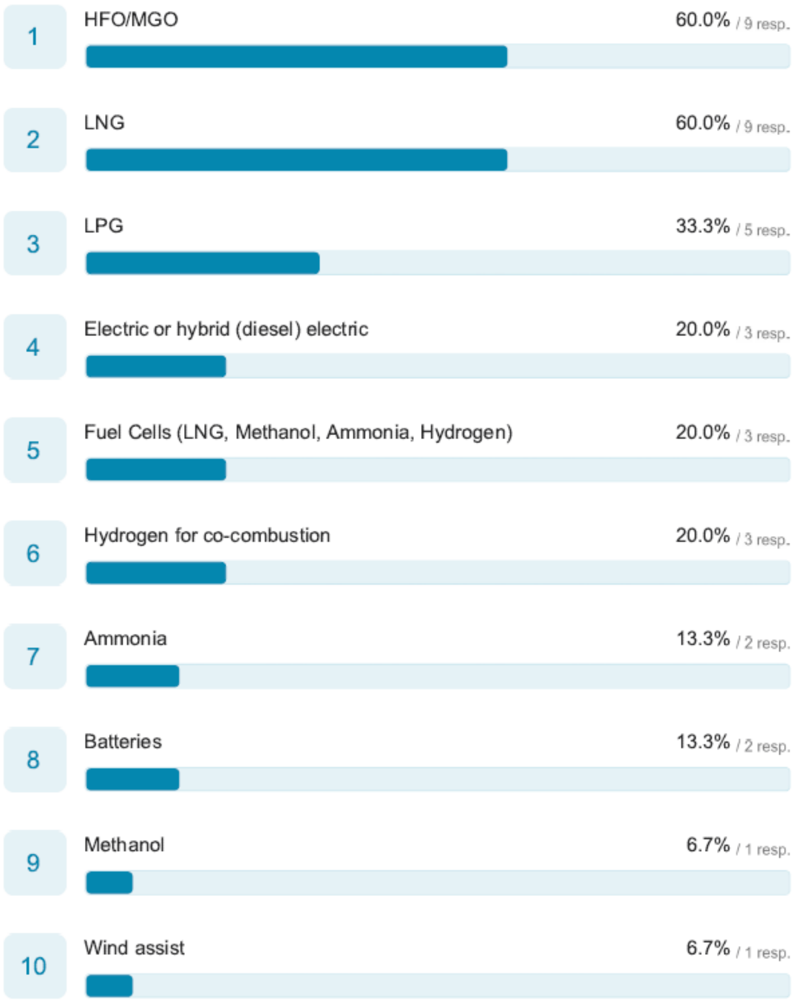

Figure 61 Future fuels and propulsion technologies - Shipyard Responses

While HFO/MGO and LNG are grouped together, there is a much bigger gap to the next most favoured fuel. The shipyards who responded seem to have delivered many gas carriers and this may influence their view on using LPG as a fuel. Thereafter fuel cells, hydrogen and electric/hybrid are grouped together, and ammonia, batteries (as primary propulsion) are ranked ahead of methanol and wind assist.

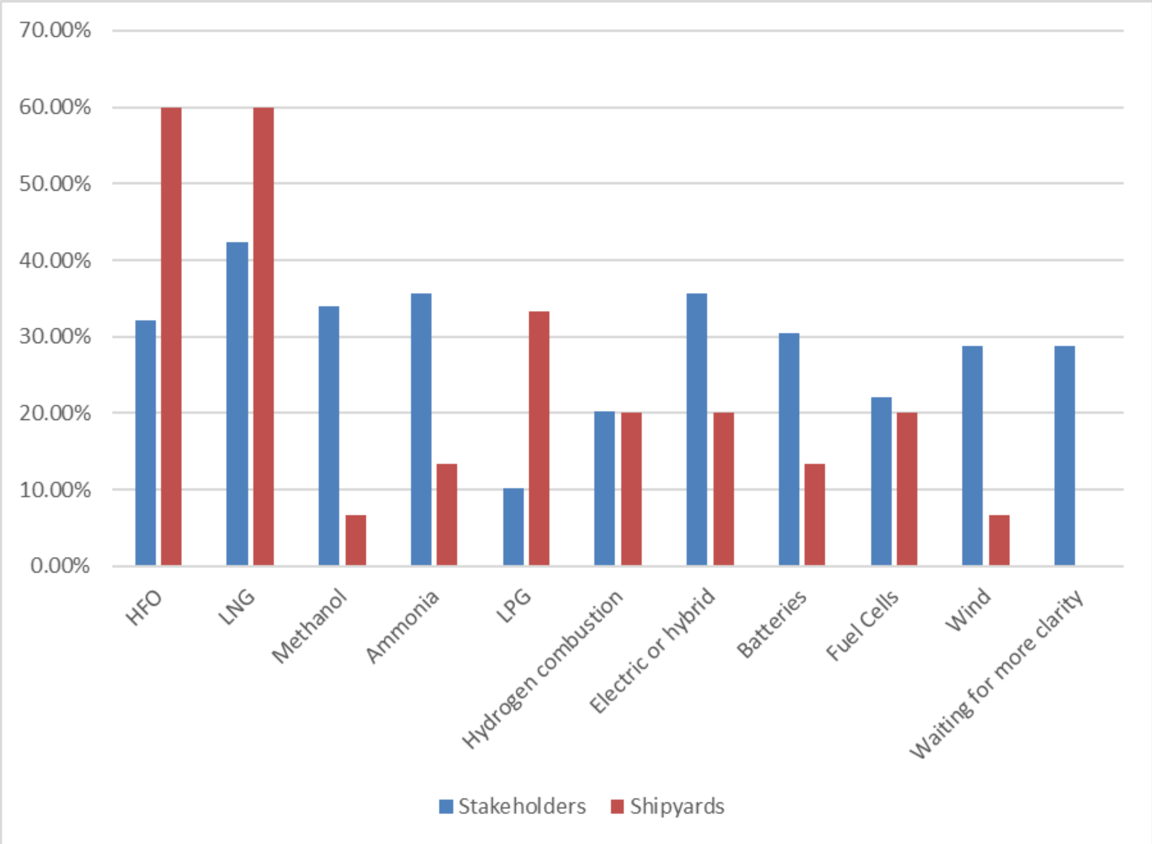

Figure 62 Future fuels and propulsion technologies - Shipyard and Ship Owner responses compared

It is possible that LNG is considered at the same level as HFO due to the fact that many designs being marketed by the shipyards today are LNG dual fuel. For methanol, it may be that up until recently, the only methanol powered ships were chemical tankers that could use cargo as fuel, and it may be if the survey was run again this year, there might be some gains for ammonia and methanol.

Otherwise this highlights a disparity between what shipowners might consider, versus what is being offered by the shipyards.

Averages however don’t necessarily tell the whole story, and we drill down into individual ship types to see if there are different preferences.

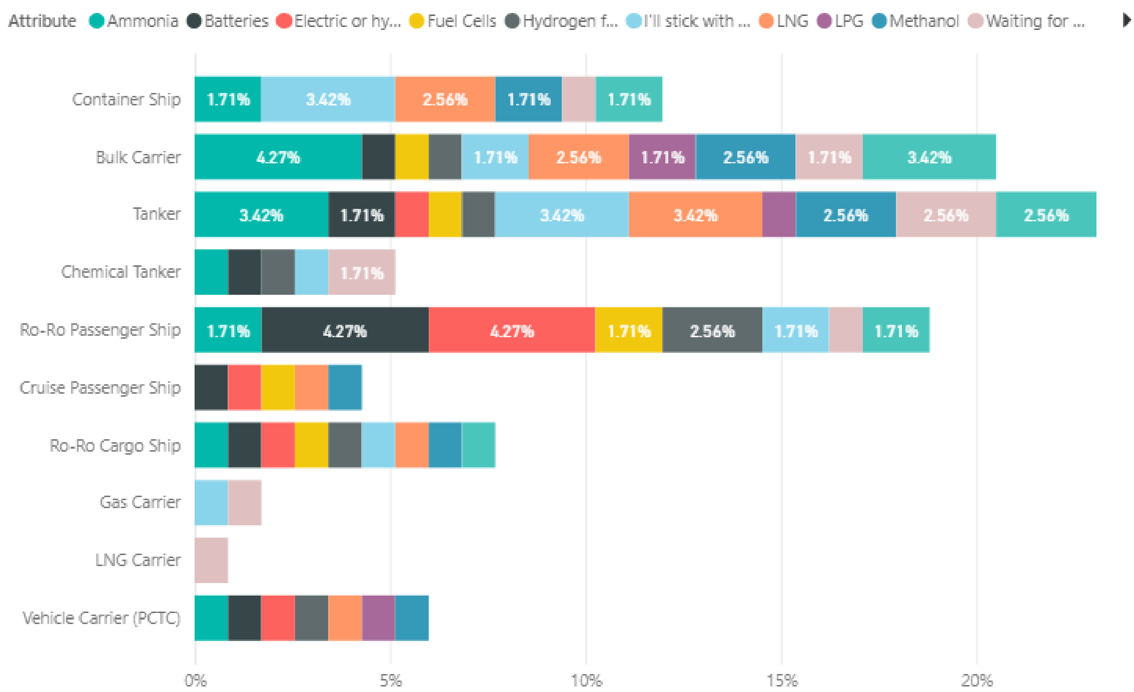

Figure 63 Fuel choices and propulsion technologies

At the time of the survey (late 2020), bulk carrier and tanker owners seemed more positive about ammonia and wind propulsion than containership owners, while batteries, electric/hybrid, fuel cells and hydrogen seem to be of more interest to ro-ro passenger ship owners.

EEDI Phase 3 Possible Solutions

Component	Feature	M/E Power (kW)	Design Speed (kn)	Minimum Propulsion Power	EEDI
Benchmark	Standard design	15,000	14.5	Meet Level 2	-23%
Option A	Main Engine Derating	12,400	13.8	Not met	-32%
Option B	Air bubble+ shaft gen.+WHR+ Sail	15,000	14.5	Meet Level 2	-32%
Option C ★	LNG Fuelled	15,000	14.5	Meet Level 2	-45%

Technically more realistic solution: LNG.

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Figure 64 MARIC view on possible solutions for EEDI Phase 3 for a Newcastlemax Bulk Carrier

The above was taken from a shipyard presentation to European owners as part of a roadshow in 2019 for a Newcastlemax bulk carrier. As can be seen further power reduction was not possible due to the minimum power requirements, so the main engine power level has to be maintained. Option B just about complies with Phase 3, but there is potentially insufficient margin to compliance, creating significant risk to the shipyard.

Note also that a number of solutions need to be implemented simultaneously with attendant cost and complexity. The shipyard concludes that LNG is a technically more realistic solution which would also render the design compliant with an eventual Phase 4.

4.9 Task D1 Survey - Future EEDI Phases

The survey asked what further improvements in technical/design energy efficiency are feasible within a timeframe of 5-7 years from now, excluding wind propulsion and use of alternative fuels.

The reason for excluding these was to understand how much more could be achieved from further incremental optimisation and technologically mature technologies. Wind propulsion and alternative fuels generally have a much larger effect, but adoption is dependent on the regulatory framework for wind, and bunkering infrastructure for alternative fuels.

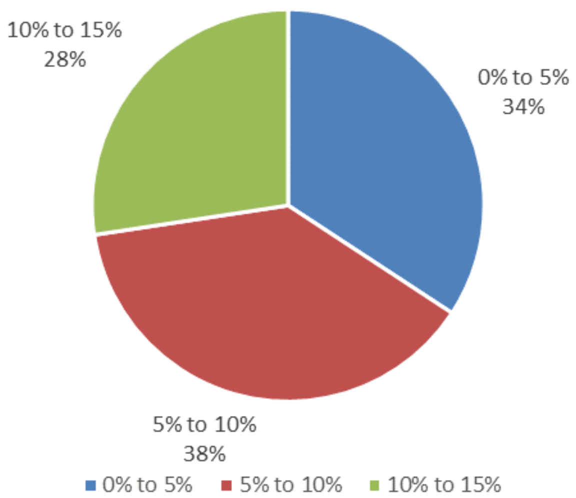

Figure 65 Estimated improvements in design efficiency within 5-7 years – Stakeholders excluding shipyards

The answers were as above. However when reading the responses, it was clear that many stakeholders did not take note that this was asking only about technical/design efficiency and made many comments about operational efficiency and strategies and this affected their choices.

Those who responded with a 0% - 5 % justified the answer with:

- "Design improvement has already done, so there is less room to improve the energy efficiency."
- "I have done various studies on retrofit. I investigated a retrofit of the Boss Cap fin Propeller over a period of 5 Years on a Panamax Bulk carrier and the saving was based on 5 years marginal (not measurable). If these measures would have big savings everyone would have installed them long time ago. In addition due to

additional regulation of exhaust gas treatment system the engine power must increase again. Never the less I hope that battery / Solar & Hydrogen will maybe have some positive influence."

- "Most available methods such as advanced propellers and hull optimisation have already been incorporated"
- "All the low and middle hanging fruits are taken, and further potential might be limited"
- 5-7 years is too short a time, need 15 years from concept to practical application
- "Technology is limited to date, air lubrication is most interesting development"
- "Main engine has been optimised and not sure if much more can be done to reduce consumption. Some gains can be made for power consumers by using more VFDs or batteries"
- "Main engines design and technology are already evolved, hull and propeller designs have reached the maximum possible optimization and we believe that minor space for improvements or new designs has been left"
- "Our new ships have already undergone design reviews and reflect the state of the art."
- "Most of the technical options mentioned have been already used in Phase 1 and Phase 2 tankers. Tankers have practiced for a number of year frequent hull cleaning. Although adding f_w could address operational efficiency in the EEDI formulae, maybe it may create lot of complications (retroactive use?)"
- "Limited further potential for EEDI improvement"
- "Have already implemented lot of energy savings such as waste heat, frequency controlled pumps and fans. Compared to earlier vessels we have already gained 25-30% on the electrical load. Hull form are already hard optimised. Environmental req (e.g. NOx) on engines might increase fuel consumption" – note this comment came from a ship designer of some of the most efficient tankers operating in Europe.
- "for car carriers, most of effort has been taken to comply with Phase 2, and air lubrication is already applied. To improve significantly without batteries or alternative fuels are very difficult."

Those who chose 5% - 10% increase noted the following:

- A number of comments around further efficiency gains are to be found in operation or operational efficiency
- A number of comments around improved coatings and antifouling
- "Profile optimization and propeller optimization have been widely used. According to our research, air lubrication can provide more than 5% energy efficiency improvement."
- "Optimization of hull shape basis operational profile would be a contributor for many owners. Increased efficiencies from ME and AE will give some %. Further heat management, isolation, LED, hybrid solutions (in some segments) and further aero dynamical improvements will help. Also the natural increase in ship size will provide some improvements"
- "Improvements in ship design, power management and engine performance"
- "It is very difficult to improve the ship energy efficiency of the hull form"
- "The question is difficult to judge since that technology mentioned are already existing. I believe that there are many technics already existing, but ROI are to long to justify the investments. That will limit the development"
- "Limited possible changes if we want to keep same operations"
- "It seems to be difficult to decrease so much."

In this category, there were some responses suggesting that increasing ship size, better antifouling and operational efficiency could lead to 5-10% improvement. This of course is not what the question is asking, and it is likely if those respondents were asked to exclude those forms of improvement, they would likely choose the 0% to 5% range.

There were also comments that seemed to allude to a lower savings range and one response referenced LNG.

Those who answered 10%-15% also noted the following:

- "Vessel dimensions must be altered towards longer and more slender design"
- "Simply designing better hulls (slimmer) could achieve that. Bulk carriers and tankers should look less like bathtubs and more like ships. But EEDI will not allow it since the DWT loss will prevent compliance."
- "New technologies in development"
- "Based on experience, optimizing a vessel to an operational profile can give 10-15 % improvement."
- "For tankers the hull optimization is close to limit due to restrictions on min. flat of side. I see rudder technology (gate rudder) and anti-fouling as 2 most apparent improvements for tankers."
- "Most of the new technologies have already been tested. Further improvement is expected but not something extraordinary. The positive effect of different technologies often is not cumulative."
- "Optimism"!
- Based on step wise improvement on our vessel built in 2008, 2013, 2015, 2017 and 2019

Those who answered 10% to 15% seem to expect more significant developments in technology though this is contrasted with the views of those who answered 0% to 5% who believe that the remaining potential is limited.

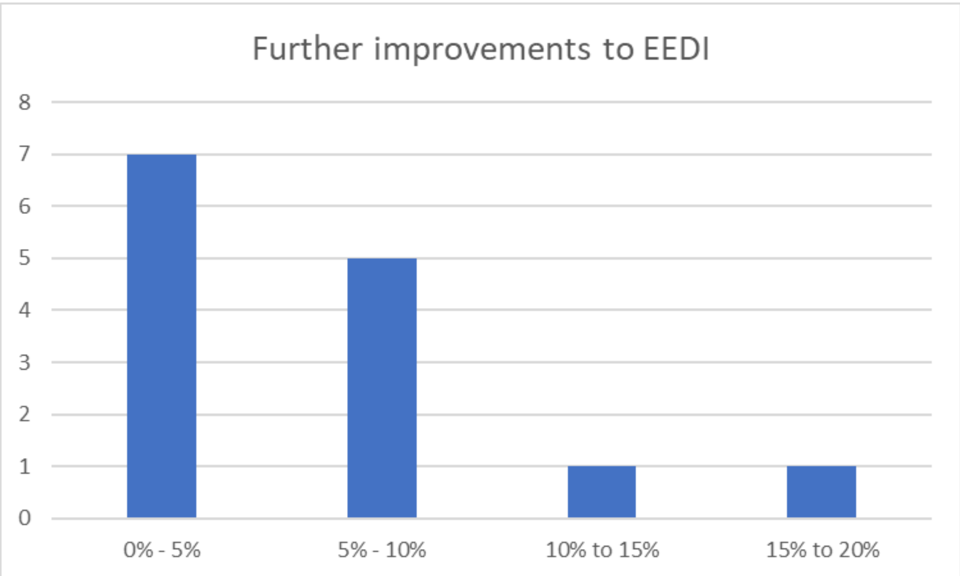

Figure 66 Estimated improvements in design efficiency within 5-7 years –Shipyards only

The shipyards in contrast show a much clearer trend towards the lower improvement potential. When asked what reduction rate should be applied to EEDI Phase 4, the results did not reflect the larger percentages above 10%.

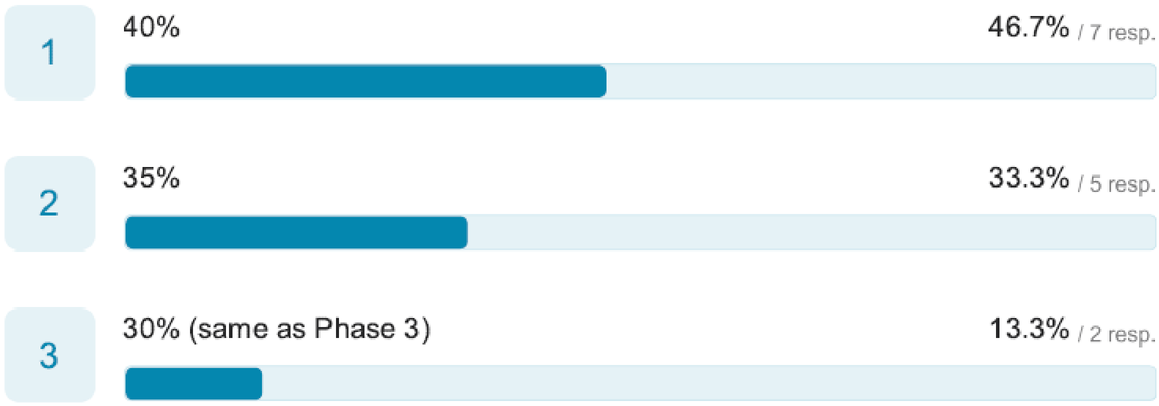

Figure 67 What Reduction Rate should be used for EEDI Phase 4 - Shipyard responses only

The shipyards were also asked about the timing of Phase 4 and their responses were as follows:

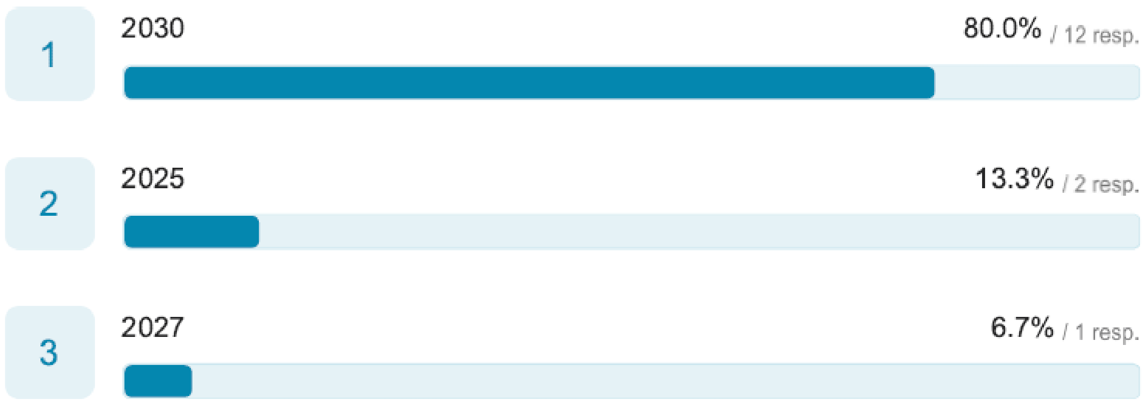

Figure 68 Timing for introduction of EEDI Phase 4 - Shipyard responses only

4.9.1 Views Regarding Minimum Power

In general, most respondents indicated that the installed power levels on bulk carriers and tankers was about right and early concerns about overly long times to pass through the barred speed range appears to have been solved.

The shipyards were asked:

Would you consider the fitting of engine power limitation devices in newbuild ships to allow the calculation point for V_{ref} to be adjusted?

8 shipyards answered that they were unsure, while 6 answered yes and 1 answered no.

For ships that need to comply with the minimum power requirements, how much more can installed power be reduced?

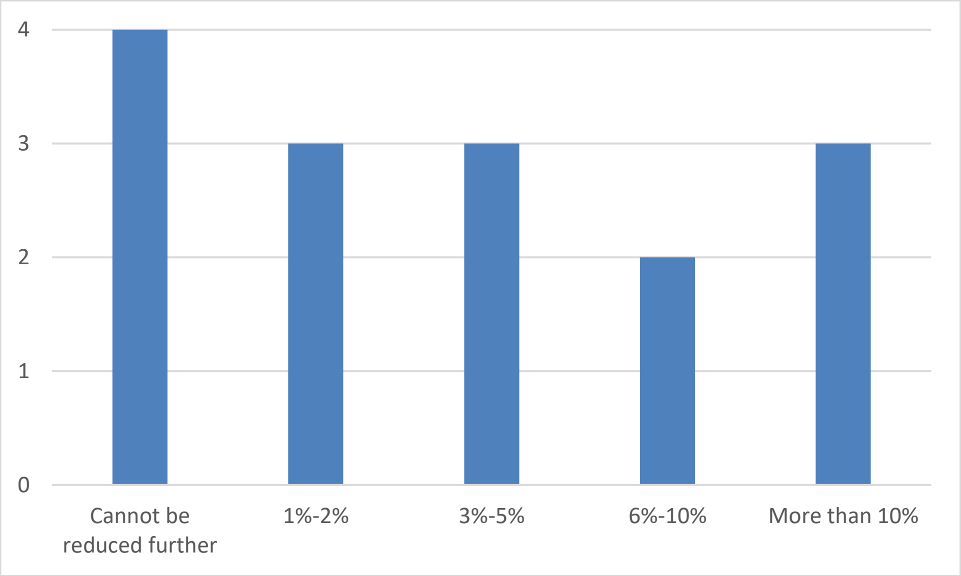

Figure 69 How much more can installed power be reduced while maintaining compliance with Minimum Power requirements

There appears to be significant disparities between the shipyards regarding how much more installed power can be reduced. This may be that different size ranges of tankers and bulk carriers have different margins to the minimum power requirements, and may also reflect a little on the technical capability of the shipyards.

What would be the impact on installed power if we adopted the SHOPERA recommendations for calculation of minimum power?

MEPC 76 agreed to update MEPC.1 Circ 850 with the SHOPERA methodology and scenarios for the Level 2 calculation of minimum power and so the shipyard answers to this are even more relevant.

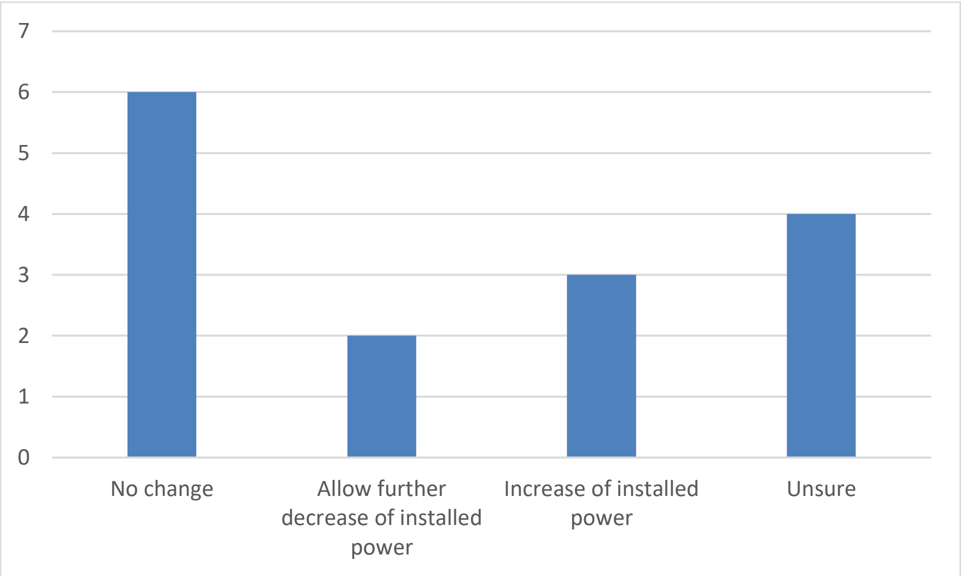

Figure 70 Estimated impact on installed power if SHOPERA recommendations are adopted

Again the answer is not clear cut, but this is reflected also in the disagreement over the impact of the SHOPERA proposals at MEPC 76, particularly over MEPC 76/5/4 which showed the following chart:

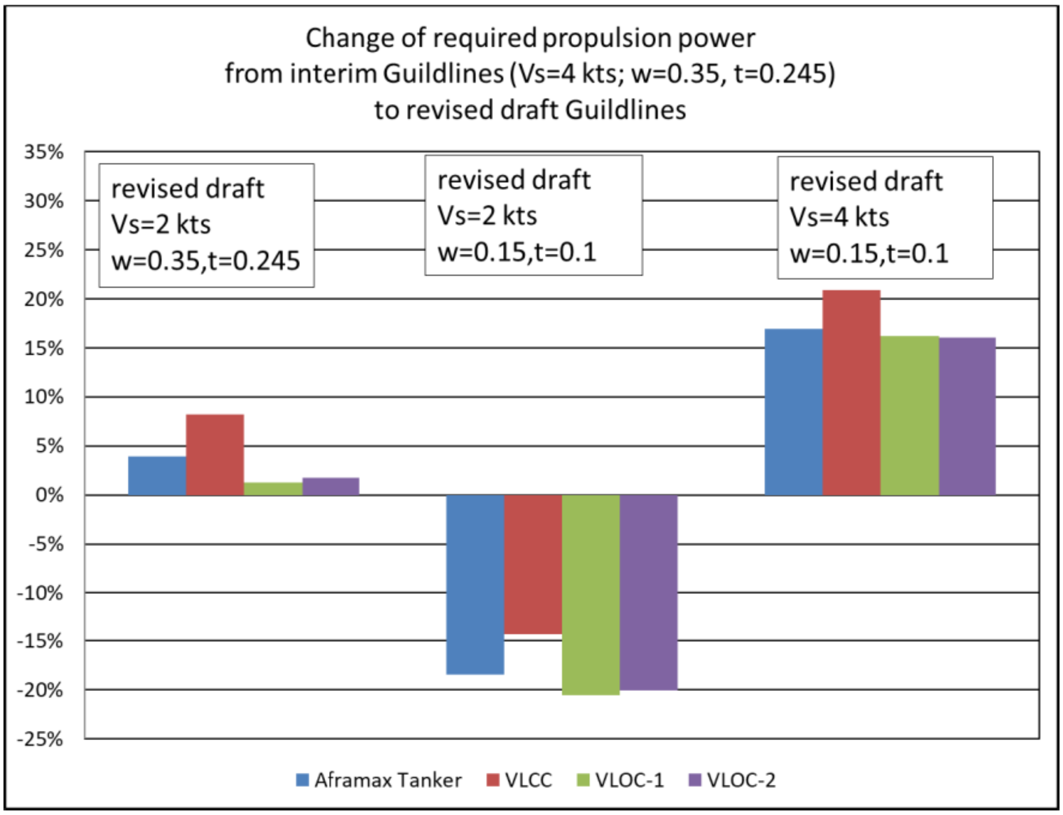

Figure 71 MEPC 76/5/4 Korea Impact of SHOPERA

4.9.2 Suggestions for improvements to the EEDI Framework

The following comments were received:

- Need enforcement of use of implemented emission reduction technology (air-lubrication, WHR, shaft generator, fuel type etc.)
- EEDI should focus more on energy (kW) than CO2.
- Do not think that speed should play such a critical role. Design changes should aim to increase efficiency at the current accepted by the industry operating profile.
- The EEDI is a poor tool for diverse segments and guidance for equivalency should be developed. Today ships are more designed to meet the EEDI even if more energy efficient designs are available, but which would not be in compliance.
- Look at the heat management onboard. Leaner ME and AE will give less exhaust heat. The outcome is that the boiler is running more frequent in order to heat up the non-efficient fuel oil, lubrication and general heat requirement of the vessel. Isolation, electric spot heaters etc could help. Also, the AE system with various sized AE's running depending on required kW together with shaft generators would give some quick wins.
- include Methane slip in SFOC for DF engines.
- The current EEDI formula does not reflect real ship efficiency. The index should be a measure of the efficiency of the design in real operation. Thus it is paramount that f_w is incorporated and furthermore at least the ballast condition should be included. Also, since currently ships operate at both design and reduced (eco) speeds, the index should combine at a minimum 4 conditions, all

being EEDIweather (ie with fw): A. EEDIweather,laden design (full) speed, B. EEDIweather, laden eco speed, C. EEDIweather ballast, full speed, D. EEDIweather, ballast eco speed. Thus The NEW EEDI for bulk carriers could be given by the formula (0.60A+0.60B+0.40C+0.40D)/4 Note: Bulkers on average travel 60% laden and 40% ballast.

Understandably, the new EEDI cannot utilize existing baselines, but some worthwhile work can develop new baselines. The data exists. We cannot keep going with the existing system - it does not lead to design improvements, only paper improvements.

Side benefit 1: The NEW EEDI incorporates the real effects of ESDs.

Side benefit 2: Operational indices (EEOI, AER, CIIs) which in any case are totally unreliable in reflecting the ship's operational efficiency, become obsolete. Instead of using different design (EEDI) and operational indices (EEOI etc.) both disconnected from real efficiency, we should use one index which incorporates the design's efficiency for the purpose it was designed (operation) using typical operational profiles. That's what the automotive industry does (EU5,6 etc.)

- EEDI needs to be tightened, as the current technological advancement means that majority new build vessels are easily able to meet IMO Phase 3 requirements. Further technical and design improvements can be made, but as the EEDI criteria are met easily, advanced technical solutions uptake may not occur.
- Aux Consumption is currently a fraction of ME which doesn't encourage anyone to save on Aux - however the potential is very large by introducing VFD and novel technology to produce electrical power and heat.
- rule to be investigated for small-mid range of vessel

The highlighted comments were further investigated in Task C1.

As usual, the shipyards were asked some additional specific questions:

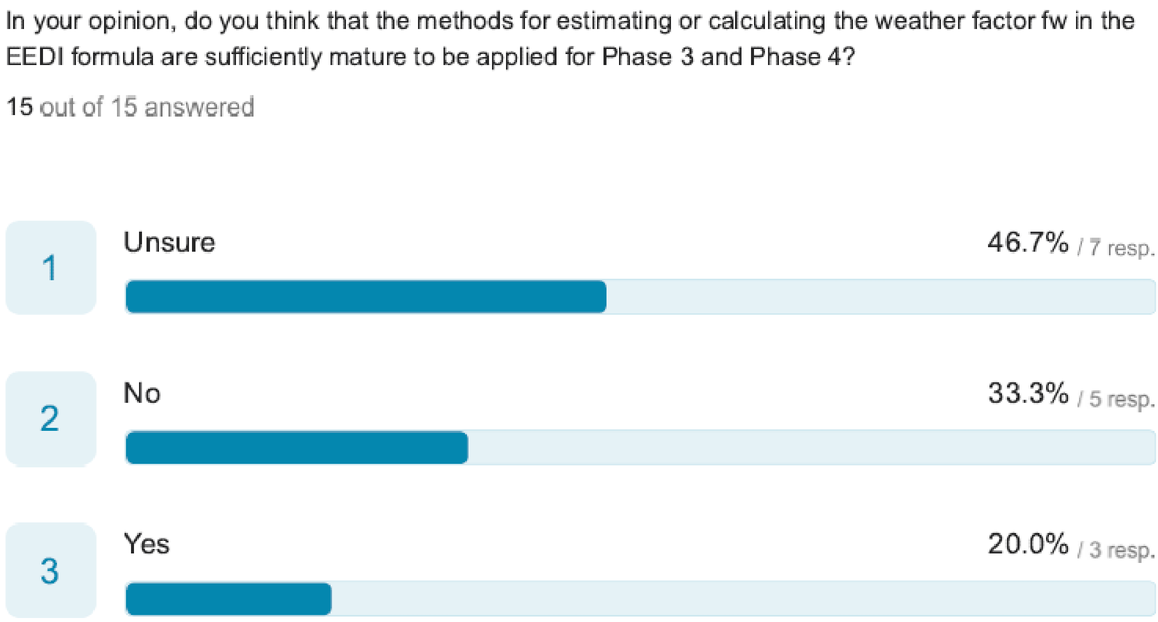

Figure 72 Are the methods for calculating f_w sufficiently mature - Shipyard Responses only

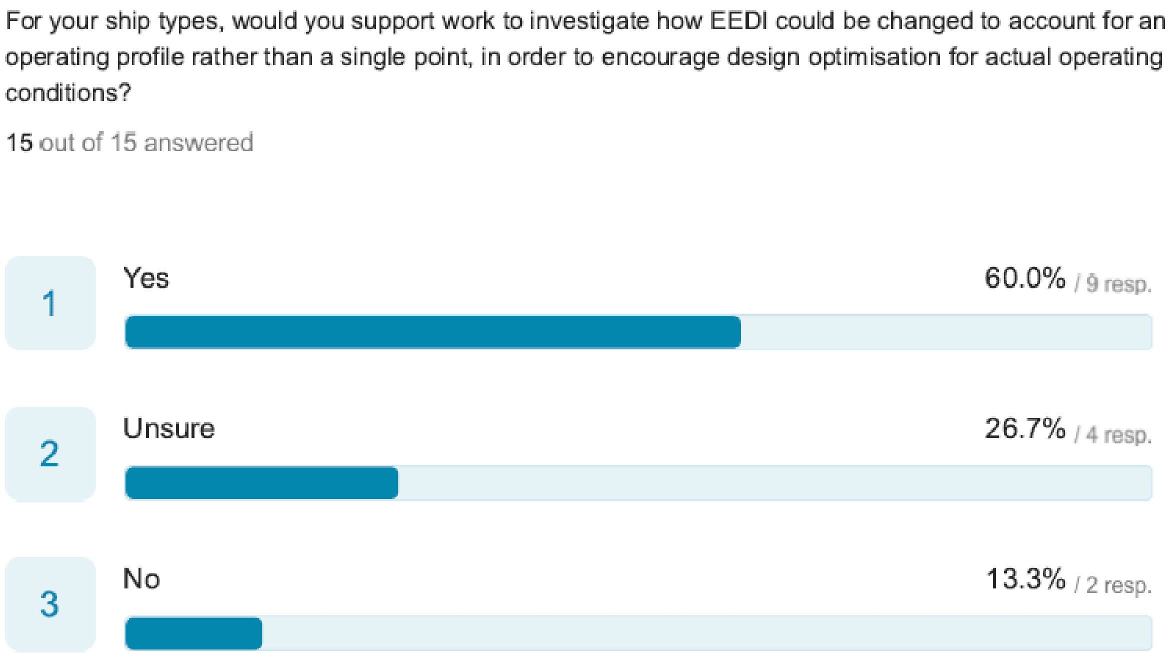

Figure 73 Do you support EEDI being changed to reflect an operating profile - Shipyard Responses only

This was also brought up in the responses and is investigated in Task C.

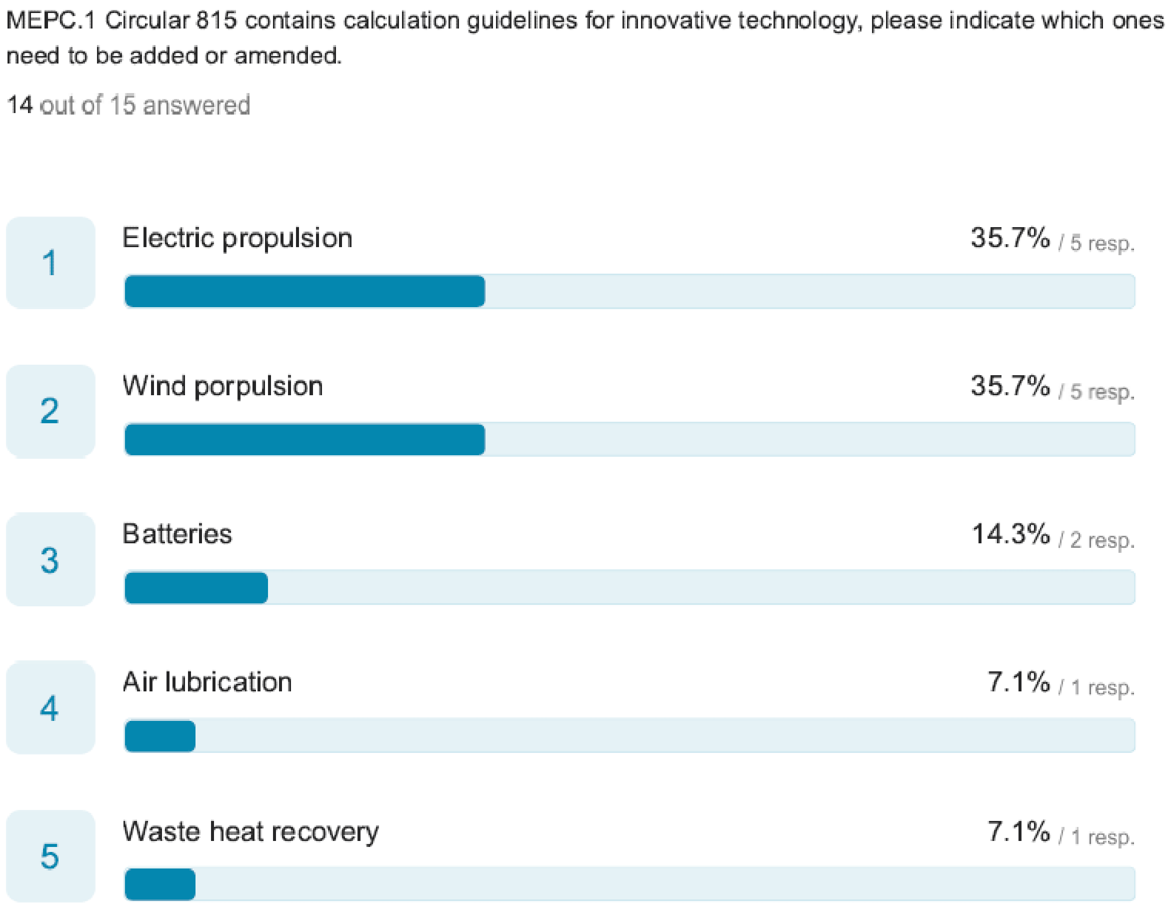

Figure 74 Suggestions for additions and amendments to MEPC.1 Circular 815 - Shipyard Responses only

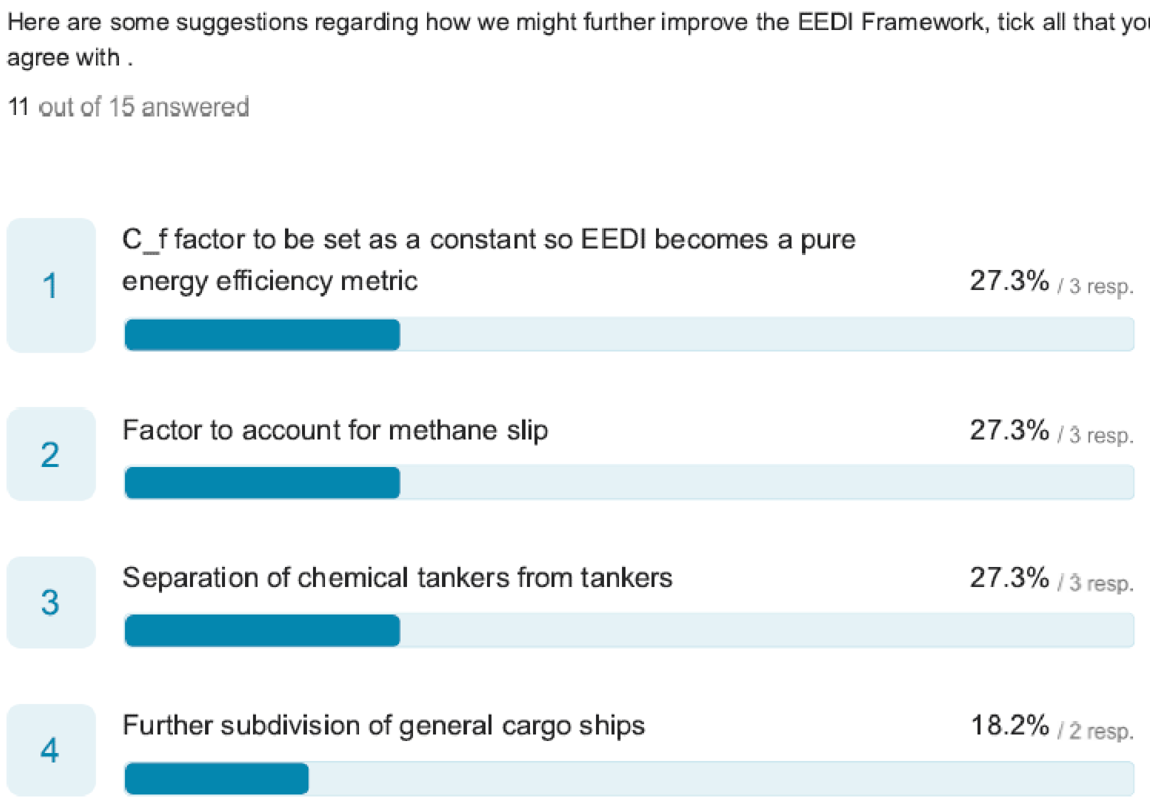

Figure 75 Suggestions for improving the EEDI Framework - Shipyard Responses only

There were also some responses from stakeholders indicating support for moving EEDI towards being independent of carbon factor, as well as other comments supporting implementation of a factor to account for methane slip.

5 TASK C1 FRAMEWORK TUNING - MEPC.1 CIRC.815

This section deals with a number of innovative technologies that are either currently within the EEDI framework in MEPC.1 Circ.815 or innovative technologies that are in use but not yet in the calculation framework.

5.1 Air Lubrication

5.1.1 EEDI Calculation

In the IMO Energy Efficiency Design Index (EEDI) framework, air lubrication is considered as one of the “Innovative Energy Efficiency Technologies” that can improve energy gains through lowering the ship’s skin drag resistance. In 2013, the Marine Environment Protection Committee (MEPC), at its 65th session, agreed to circulate MEPC.1/Circ. 815, the 2013 Guidance on Treatment of Innovative Energy Efficiency Technologies for Calculation and Verification of the Attained EEDI. It should be noted that this is an interim guidance document which will evolve over time by experience gained as a result of use of these technologies.

The attained ship EEDI is a measure of ship energy efficiency as characterized by the amount of CO_2 produced as function of the transport work by a ship. It is calculated using the formula below (MEPC.1/Circ.815)):

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

The MEPC.1/Circ. 815 Guidance categorizes Innovative Energy Efficiency Technologies into 3 categories based their characteristics and effects on the EEDI formula. Air lubrication is classified as Category B-1 for technologies that reduce the propulsion power but do not generate electricity and can be used at any time during vessel’s operation. In effect, the power reduction is through adjustment to the 5th term in the numerator of the EEDI formula.

Therein:

- $\boldsymbol{f_{eff(i)}}$ is the availability factor for innovative energy efficiency technology
- $\boldsymbol{P_{eff(i)}}$ is the output of the innovative mechanical energy efficient technology for propulsion at 75% main engine power.
- CF is the non-dimensional conversion factor between fuel consumption and CO2 emission. The value corresponds to the fuel used when determining the SFC listed in the NOx Technical File of the main engine.
- ***SFC*** is the certified Specific Fuel Consumption, g/kWh, for Main Engine(s) obtained from the NOx Technical File

Since Air Lubrication is a technology that can be used at all times during the operation, $f_{eff(i)}$ should be treated as 1.0. The IMO guidance on treatment of innovative technologies by MEPC.1/Circ.815 recommends $\boldsymbol{P_{eff(i)}}$ to be calculated as follows:

$$P_{eff} = P_{PeffAL} - P_{AEeffAL} \frac{C_{FAE}}{C_{FME}} \frac{SFC_{AE}}{SFC_{ME}} *$$

Each component of the formula above not defined previously is explained in the table below:

Table 5-1 Calculation Variables for Air Lubrication in MEPC.1 Circ.815

Component	Remark
P_{PeffAL} is the reduction of propulsion power due to the air lubrication system in kW. It should be calculated both in the condition corresponding to the *Capacity* as defined in EEDI Calculation Guidelines (hereinafter referred to as "fully loaded condition") and the sea trial condition, taking the following items into account. 1. area of ship surface covered with air; 2. thickness of air layer; 3. reduction rate of frictional resistance due to the coverage of air layer; 4. change of propulsion efficiency due to the interaction with air bubbles (self propulsion factors and propeller open water characteristics); and 5. change of resistance due to additional device, if equipped.	It requires the shipbuilder to have a power/speed curve for the system ON and OFF. Scale effects may be present when model tests are used to derive ship's performance curve. These effects may influence the final numbers when the sea trials are conducted and the power reduction is estimated. It is also remarked that there is not a proposed methodology on how to account for the 5 items listed in the MEPC.1/Circ.815. The industry would benefit of a unified methodology (ITTC, ISO) to perform estimations of the propulsive power reduction.
$P_{AEeffAL}$ is additional auxiliary power in kW necessary for running the air lubrication system in the fully loaded condition. It should be calculated as 75 per cent of the rated output of blowers based on the manufacturer's test report. For a system where the calculated value above is significantly different from the output used at normal operation	It assumes that the blowers/turbine power demand is scaling as the Power/Speed curves. This may not be the case and the guidance leave it open to estimate this value by alternative processes. More details as how to compute this value would be preferred to avoid having unrealistically low values for the auxiliary power required to run the air injection

in the fully loaded condition, the $P_{AEeffAL}$ value may be estimated by an alternative method. In this case, the calculation process should be submitted to a verifier.	system.

5.1.2 *Preliminary and Final EEDI Verification*

Ultimately this technology investment consideration is largely dependent on how air lubrication option benchmark against other alternatives, in terms of full-scale fuel savings under actual operation coupled to the EEDI-reduction potential.

At the vessel's design stage, the EEDI reference speed is estimated based on dedicated model tests for two loading conditions that correspond to the ship's trial draft and the EEDI draft. Tests are carried out at a qualified towing tank facility and cover the scope of resistance and self-propulsion in calm water and no wind. Propeller open water tests to determine the selected propeller efficiency are also required. Although aspects related to the scalability of the airflow beneath the hull are not yet covered for properly in the industry, the EEDI testing scope follows the ITTC recommended practices and ISO 15016:2015 guidelines.

The ISO 15016:2015 can be followed to assess the performance improvement of vessels equipped with air lubrication with one extra set of double runs for each %MCR condition. However, adjustments are yet needed in view to define a unified methodology to correct the sea trials for the added resistance induced by the air lubrication system while it is not operating.

5.1.3 *Challenges in Performance Evaluation*

MEPC1./Circ.815 specifies that for air lubrication systems, the sea trials are to be performed with both the system ON and OFF. The gains are computing by evaluating the reduction in power demanded by the main engines to deliver the same reference speed, Vref. Such a procedure presents the following assumptions:

1. It is possible to derive speed power curves prior to the sea trials based for the air lubrication system ON. This may not be easily achieved in a reliable manner. The existing resistance and propulsion performance prediction method are not applicable in such cases, because the model-ship extrapolation is based on the skin frictional drag coefficient for the 'baseline' surface without skin frictional drag reduction. The challenge relies on scalability inconsistencies as the air flow dynamics beneath the hull need to be properly scaled both to pressure and Reynolds number differences between model and full scales.
2. Furthermore, air lubrication is an inhomogeneous skin friction reduction technique which means that reduction of an examined location, greatly varies whether the injected air layer is present (or not) in the immediate vicinity. Quantification of the drag reduction effect requires dedicated procedures compared to homogenous techniques (e.g. low friction coatings) where the desired drag reduction occurs across the whole hull surface. The ITTC is in the process of setting up model testing and full-scale extrapolation procedures. There are some facilities around the globe that are capable to performed

depressurized tests, in which the pressure scaling of the system could be respected. However, the challenge will remain to scale the Reynolds number as towing model tests are performed on a Froude number equivalency.

3. The air lubrication systems when they are turned off will only induce residual added resistance. This may not be the case for all the air lubrication systems. At present there is no clear guidance in the regulations as how to correct the sea trials performed when the system is turned off for the potential added resistance of the air release units and/or cavities. MEPC1./Circ. 815 mentions that the change of resistance due to the additional device is to be taken into account, but it does not further guidance on how to perform the corrections. As the net gains reported in the literature are in some cases small (1 to 2%), accounting correctly for the added resistance of the air lubrication apparatus when these are not operating is paramount. In view of failure of the system, the added resistance should not compromise the safety and performance of the ship.

In some cases, gains are reported against voyage data. When doing so, some aspects can potentially lead to high uncertainties. Besides point 2 cited above, when evaluating sea trial data, uncertainty may arise when the environmental aspects are not correctly accounted and controlled between the ship's operation with the air lubrication ON and OFF (data recording requirements may need amendment). Proper handling, filtering and post-processing of the data is advised when relying on voyage data to estimate gains by air lubrication systems.

Moreover, based on the available documentation of the systems analyzed in this study, it is not possible to clearly identify the use of the same consistent methodology for evaluation of sea trials voyage data. Hence, it is not possible to directly compare the performance of the different systems presented in this document.

5.1.4 Interaction with Minimum Power Requirements

Although the system is intended to be used most of the time, a situation may arise when the system is not operating. As such, the minimum power requirements are to include for any potential added resistance of the air cavities or air lubricators when in adverse conditions. As of now, MEPC.1/Circ.850 interim guidelines account for different contributions to the total resistance such as calm water, aerodynamic, waves and appendages. The air lubrication system, inherent part of the hull, should then be included in these terms.

Although for some systems (where the units are less intrusively added to the hull), the Minimum Power Requirements may appear more straightforward to be calculated, it remains to be further studied the interference of these systems on the general performance of the vessel under extreme conditions.

5.1.5 Proposed Way Forward

Gradually the industry appears to be embracing the air lubrication concept, mostly the bubble and air layer drag reduction systems, as for this documentation is available demonstrating their efficiency both at sea trials and in-voyage conditions. Nonetheless, gains publicly available vary from 2 to 10% depending on the system and on the ship.

As proposed way forward may be based on the following aspects:

- A more detailed procedure needs to be developed or adapted to include for a performance correction procedure due to the added resistance of the system when the same is turned off. These may be directly included into the ISO

15016 / ITTC guidelines as an extra correction step. A clear and uniform methodology needs to be included. This will lead to fairer and more transparent estimation of the net gains of the air lubrication system.

- The methodology may rely on the use of CFD modelling or model tests of the vessel with and without the cavities or air release units.
- Dedicated model tests may be used during the preliminary and final EEDI verification. At this stage, there is not a clear methodology/procedure in the industry on how to correctly account for the scalability issues of the system: the air flow beneath the hull which does not scale with the Froude number as the classical towing tank procedures rely upon. Further development of the ISO 15016 and related ITTC guidelines need to be adapted for Air Lubrication applications.
- Based on the literature found, it appears that as the vessel speed increases, the amount of air that needs to be pumped beneath the hull increases. On the other hand, the power required to inject higher volumes of air increases quadratically. This may lead to a speed above which the gross power gains are smaller than the power needs for the air lubrication system to operate. Finding the optimum balance in terms of size of the auxiliary systems to run the air lubrication system (which consume energy and space) and potential gains seems important to allow the gains to be sustained over a large window of speed and loading conditions. From a design and completeness of purpose perspective, it is advised the system to be tested to the widest range of operating condition as possible.

It should be noted that savings calculated and demonstrated within the EEDI framework may be applied for EEXI, with the caveat that tank tests will not be available. Also, the savings calculated under EEDI may differ significantly under the CII framework which is much more dependent on the whole operating profile.

However a major problem exists with the uptake of air lubrication systems for newbuilds. Shipyards are generally unwilling to guarantee the performance of a third party system, especially when it concerns ship performance, which has both contractual penalties and regulatory compliance implications. So uptake of this will generally be limited either to shipyard developed systems – Mitsibishi and Samsung being examples of this, or where the shipowner is willing to provide the system as an Owner's supply item, however this inevitably means that the attained EEDI calculation will not include the contribution of the air lubrication system, and this will not be reported to the IMO EEDI database.

5.2 Wind Assisted Propulsion

An introduction to the different wind assisted propulsion technologies was presented in the report to Task B, so we will not repeat or update that here. At the same time, some further developments have taken place since this section was written in 2020, notably the finalisation of the MARIN/ABS WiSP JIP project, leading to a likely WiSP 2 JIP, as well as a number of submissions to MEPC 76 with concrete suggestions on amendments to MEPC.1 Circ.815 on estimation methods of wind assisted propulsion. There is work to coordinate these submissions into MEPC 77 however the outcome of this is not yet known. As such, this section will simply reflect the situation as of late 2020 since concrete steps are already being taken.

5.2.1 *Ship Design Evaluation*

When assessing the feasibility of a new design that incorporates a wind-assisted propulsion technology, a number of parameters need to be carefully evaluated in terms of safety, performance, suitability to vessel's trading operations and cost:

- Intact and damage stability
- Structural integrity and steel weight calculations
- Bridge visibility
- Cargo operations at intended ports, air draft restrictions
- Seakeeping performance
- Operational envelope of the chosen installation (wind direction and relative speed)
- Effect of increased windage area due to installation and interaction with existing superstructure on baseline ship
- Risk assessment in terms of safety and environmental performance
- Impact of heeling and leeway to resistance
- Impact of the WASP on the manoeuvrability performance of the vessel needs to be assessed.

It is important that each project is considered as a 'concept design' i.e., by applying a holistic approach in order to optimize the matching of the wind propulsor to the hydrodynamic performance of the vessel, the selected engine and propeller.

5.2.2 *Challenges in Performance Evaluation*

The main issue to be addressed is the quality, transparency and verification of predicting savings in fuel and emissions. Such savings are usually predicted on the basis of calculations, but the assumptions and conditions adopted for these calculations vary wildly amongst publications. As a consequence, reported savings are not necessarily comparable, and it is not always certain whether predictions meet a specified quality standard. Thus, guidance and knowledge are required about the methods and assumptions to be used.

ABS and MARIN have launched a Joint Industry Project (JIP) to compare prediction methods, establish the effect on the results obtained and to determine the preferred methods. Similarly, a research project funded by Interreg North Sea Europe Programme, WASP, led by SSPA focus on improving the technical, commercial, and regulatory knowledge of Wind Assisted Propulsion.

In terms of EEDI calculation, the generated thrust by the wind propulsion system and the necessary energy required (e.g., for Flettner rotor spinning), need to be defined per wind speed and angle. A weighted average is taken of wind angles and speed based on wind distribution worldwide. The result is converted to reduction in CO2 emissions by effectively reducing the required engine.

While the principle is clear, several issues need to be clarified:

- Methods used to determine the wind propulsion force and required energy; whether data from literature are adequate or whether dedicated predictions have to be made using, e.g., scale model tests or CFD; and the level of detail required, e.g., geometry, grids, scale factor.
- Whether the global wind profile is representative of ships using wind-assisted propulsion, and the effect of actual operating routes.

- Constraints that should be taken into account, e.g., maximum allowable heel angle or the ability to keep course in large seas that go together with high wind velocity.
- The framework does not consider additional losses associated with wind-assisted ship propulsion. Research conducted by MARIN has identified components, such as reduced efficiency of the propulsion installation in part-load, reduced propeller efficiency, and increased hull and rudder resistance due to leeway.

Addressing these issues will contribute to improving the methods to quantify CO2 reduction in the EEDI framework in a probabilistic sense. In addition, a transparent and validated method is required to assess performance, which is a key driver in owners/operators investment decision-making.

5.2.3 EEDI Calculation

In the EEDI calculation formula, wind propulsion systems are represented in the numerator by the formula's 5th term component:

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

Therein:

$\boldsymbol{f_{eff(i)}}$ is the availability factor for innovative energy efficiency technology

$\boldsymbol{P_{eff(i)}}$ is the output of the innovative mechanical energy efficient technology for propulsion at 75% main engine power.

$\boldsymbol{C_F}$ is the non-dimensional conversion factor between fuel consumption and CO_2 emission. The value corresponds to the fuel used when determining the SFC listed in the NOx Technical File of the main engine.

SFC is the certified Specific Fuel Consumption, g/kWh, for Main Engine(s) obtained from the NOx Technical File

Since wind-assisted propulsion can only be deployed when certain environmental conditions are met, the availability factor $\boldsymbol{f_{eff}}$ would not be equal to 1 which limits the contribution of the system to the vessel's overall efficiency.

The IMO guidance on treatment of innovative technologies by MEPC.1/Circ.815 recommends that the calculation of the available power output to be carried out by the below formula:

$$\left(f_{eff} \cdot P_{eff}\right) = \left(\frac{0.5144 \cdot V_{ref}}{\eta_T} \sum_{i=1}^{m} \sum_{j=1}^{n} F(V_{ref})_{i,j} \cdot W_{i,j}\right) - \left(\sum_{i=1}^{m} \sum_{j=1}^{n} P(V_{ref})_{i,j} \cdot W_{i,j}\right)$$

Each component of the above formula is explained in Table 1 below accompanied by a set of remarks on the maturity of the approach adopted by the IMO MEPC:

Table 5-2 Calculation Variables for Wind Propulsion in MEPC.1 Circ.815

Component	Remarks
V_{ref} is the ship reference speed measured in nautical miles per hour (knots), as defined in the EEDI calculation guidelines.	The vessel fitted with a wind propulsion system would be optimized across the intended operational profile (2 or more draft/speed combinations) to allow for maximum available efficiency gains.
η_T is the total efficiency of the main drive(s) at 75 per cent of the rated installed power (MCR) of the main engine(s). η_T shall be set to [0.7], if no other value is specified and verified by the verifier	The wind assisted propulsion system contributes to the vessel's thrust by converting wind energy. The vessel's total efficiency, η_T is not independent from the technology applied and may be affected (either positively or negatively) by the prevailing environment.
$F(V_{ref})_{i,j}$ is the force matrix of the respective wind propulsion system for a given ship speed V_{ref}.	The force matrix has been calculated by the system manufacturer for the vessel's intended operational profile, not necessarily having the EEDI reference speed in mind. Furthermore, there are no guidelines to verify the methodology applied by the manufacturer to derive the matrix including applied scope and assumptions made.
$W_{i,j}$ is the global wind probability matrix	The global wind probability matrix is not representative of the vessel's intended routes and may provide a more conservative approach to the gains obtained.
$P(V_{ref})_{i,j}$ is a matrix with the same dimensions as $F(V_{ref})_{i,j}$ and $W_{i,j}$ and represents the power demand in kW for the operation of the wind propulsion system	Similar concerns apply here as in the force matrix $F(V_{ref})_{i,j}$ component.

Table 1: Calculation Inputs of Available Power Output by a Wind Propulsion System

Based on the above, it appears that the recommended guidelines at present stage do not provide a realistic evaluation of the system's benefits to the vessel's efficiency but rather a simplified on-paper estimate.

A representative example is described in document MEPC 74/INF.39 submitted by China. As shown in the Table below, the vessel's Attained EEDI may improve dramatically (14.4% in EEDI terms) when comparing the efficiency obtained by use of the global wind probability matrix (21.1%) and that by the matrix of the vessel's intended trading routes (35.5%).

Table 5-3 Comparison of Wind Propulsion Impact on EEDI - MEPC 74/INF.39

	Attained EEDI	% below Baseline
Baseline Ship	2.061	19.5%
Ship with Rigid Sails	2.027 (global wind matrix)	21.1%
Ship with Rigid Sails	1.888 (wind matrix for vessel's intended route)	35.5%

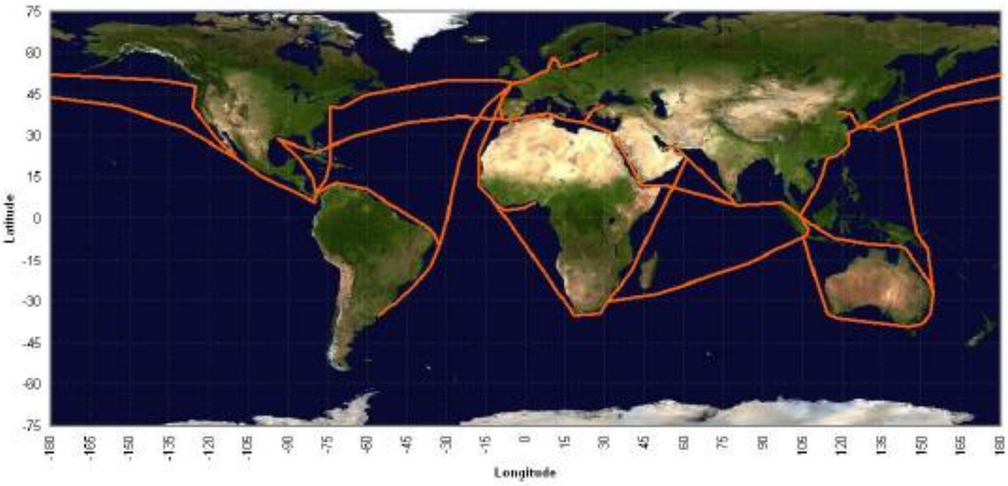

Figure 76 Global Shipping Routes (Source: MEPC 74/INF.39)

The paper notes that in practice, owners and shipbuilders will observe in advance whether there are available wind resources in the intended operating routes of the ship, and then decide whether to install a wind propulsion system. Therefore, it is recommended to allow that a typical ship with wind propulsion system can adopt an alternative wind probability matrix for its EEDI calculation derived from the average weighted routes in which this typical ship can operate in. In this way, the calculated contribution of its wind propulsion system to the ship's EEDI will be more objective.

5.2.4 Preliminary and Final EEDI Verification – Existing Scope

Ultimately this technology investment consideration is largely dependent on how wind assisted propulsion options benchmark against other alternatives, in terms of full scale fuel savings under actual operation coupled to the EEDI-reduction potential.

At the vessel's design stage, the EEDI reference speed is estimated based on dedicated model tests for two loading conditions that correspond to the ship's trial draft and the EEDI draft. Tests are carried out at a qualified towing tank facility and cover the scope of resistance and self-propulsion in calm water and no wind. Propeller open water tests to determine the selected propeller efficiency are also required. The EEDI testing scope follows the ITTC recommended practices and ISO 15016:2015 guidelines.

The wind force matrix for EEDI would be based on the delta Δ of wind propulsion coefficients ΔC_{Fx} derived by wind tunnel test results where the vessel model is tested with and without the innovative technology under assessment. Details of the methodology are given in document MEPC 74/5/30.

Formal guidelines on the method to verify the fuel efficiency contribution of wind-assisted ship propulsion systems have not been issued by the IMO.

The ITTC committee recognizing the promising fuel savings, has determined that new self-propulsion test procedures will be required for hybrid sailing vessels (combination of sails and diesel engine propulsion) to assess the hydrodynamic flow to the propeller and overall effect to the vessel's propulsive efficiency including extrapolation methods.

Full scale trial procedures applied at the vessel's delivery stage are currently governed by the ISO 15016:2015 Guidelines following the IMO directive. The ISO guidelines scope covers test runs performed in a calm water environment to confirm the vessel's speed in EEDI conditions based on the predictions at the design stage. The prescribed trial environment and process are not conducive in evaluating the wind technology. Even if the system is not operating, its presence may result in deviations from the earlier speed/power prognosis due the added windage drag among other factors.

MARIN in collaboration with ABS have undertaken a Joint Industry Project to assess the performance evaluation and regulatory compliance of ships equipped with wind-assisted propulsion. The objectives are to:

- Establish recommended procedures to determine the performance of wind-assisted ship propulsion. This will allow for fair comparison of the different designs in the current market and enable a higher overall quality of performance predictions.
- Demonstrate that the recommended procedures through case studies
- Document challenges in existing regulation and propose new regulations catered to WASP.

Specific to tankers and bulkers, assessing the performance of wind propulsion technologies in a way that allows for fair comparison will help ship designers and owners better understand how these measures will affect compliance with EEDI Phase 3.

5.2.5 Minimum Propulsion Power

While the interim guidelines for assessment of minimum propulsion power by MEPC.1/Circ.850 evaluate the ability of the vessel to maintain maneuverability under adverse conditions, the main engine selection process does not account for the thrust contribution of a wind-assist technology including if and how this should be deployed under the assumed environment.

In this respect, even though such technology investment aims to contribute to a lower main engine MCR which in turn will lower the vessel's EEDI, the current regulatory scope is missing the necessary prescriptive requirements.

It is understood that the MPP guidelines examine head wind conditions. For such conditions and most of the Wind Assistance technologies, no benefits of the installation would be expected. Nonetheless, it may be noted that for some technologies, such as Flettner Rotors, it has been found that keeping a minimum rotation rate even in head wind may reduce the drag of the WASP system. Therefore, it is important to assess during the design stages of a WASP if it is beneficial to assume its operation for the calculation of the Minimum Power Requirements. The vessel's speed of advance is dependent on the vessel's windage area, rudder area and main dimensions and a hydrodynamic analysis is performed to determine if the main engine torque limitations can provide the required thrust to the propeller. It is recommended to examine how the below components that are part of the MPP Level 2 Assessment can be properly modified to accommodate the optimization of a vessel design that incorporates wind propulsion technologies:

- Definition of vessel's advance speed taking into account the wind assisted propulsion installation. Noting that depending on the particulars of the technology, the inclusion of the WASP may reduce or increase the total wind drag or not in head wind conditions.
- Contribution of the wind propulsion system to the propeller thrust in order to maintain the speed of advance
- Expand the examined wind field range (relative direction and speeds) to assess if and when the system contributes to the ship's response under adverse conditions. Corresponding evaluation of sea state needs to be considered.

Additionally, the current MPP Level 2 assessment and proposals of improvement under consideration (MEPC 71 / INF. 28 by Denmark, Germany, Japan, Spain and IACS) considers a detailed approach to compute the required power in adverse conditions making use of propeller curves, hull hydrodynamic characteristics, etc.

On the other hand, the methodology to derive the power gains by WASP systems as per MEPC 1 / Circ. 815 is open and in principle allows for any methodology to be applied (under the condition it is accepted by a Recognized Organization). An uniformization of the calculation methodologies for both the EEDI and MPP would be beneficial for the industry as it would bring both consistency and easiness for the design process of any energy saving technology to be used on a vessel.

5.2.6 EEDI – Proposed Way Forward

From industry experience so far, a reluctance to adopt wind assisted propulsion technologies is more than evident. Apart from the cost related aspects (which are outside of the present work scope), the procedural ambiguities related to the verification of the technology's contribution to the vessel's EEDI, play a significant role. A vessel's EEDI calculation is in essence based on one operating point, in terms of loading condition and power. From this set regulatory perspective, calculating average energy savings by a system using a multitude of operational points and wind conditions as provided in MEPC.1/Circ.815 may be contradicting. The procedure described in the IMO circular may be more suitable when assessing vessel in-service performance.

ABS is currently involved in a major JIP focusing on wind propulsion system which focus on improving the methods for transparent performance prediction and review the regulatory perspective including status of rules and regulations, identify gaps and make recommendations, and provide examples on establishing compliance.

ABS opened a consultation with the JIP participants on the potential way forward to allow for a better inclusion of Wind Assisted Propulsion in the EEDI calculation.

Initially, ABS put forward a proposal simplifying one aspect of the EEDI calculation for WAPs. Currently, as detailed in section 2, the gains due to wind are "weighted" making use of a wind probability matrix. Currently this matrix accounts for the main global maritime routes wind probability (MEPC 62-INF.34 [7]). As shown by this JIP project and other submissions to the IMO (MEPC 74/INF.39), the global wind matrix can provide a lower fuel saving estimation as it includes for routes that have low wind probability.

Wind Assisted Propulsion is an Energy Efficiency Technology just like a hydrodynamic improvement such as Mewis Duct, Bulbous Bow Retrofit and others. Contrary to WAP, the fuel savings by these hydrodynamic improvements are assessed only with regards to one operational point: Reference Speed (Vref), 75% MCR and EEDI Draft.

The initial proposal by ABS was to focus EEDI formula on only one operational point to be applied for the wind-assisted propulsion system (WASP) evaluation at EEDI draft and 75% MCR power. This would rely on defining one specific wind speed and wind direction in updated Guidelines, applicable to all ships and WASP systems. As an initial proposal, ABS suggested the use of beam wind condition and a wind speed of 18 knots. This operational point could be adapted according to the WAP in question, as to provide the most realist gains.

The intention of using a single point is to simplify the fuel saving estimation making it comparable to the procedure for the other technologies and allow for a more straightforward procedure for sea trials.

As noted, the currently sea trials are performed following the ISO 15016:2015. ABS proposed an adaptation of this methodology as follows:

1. The vessel would be trialed **without** the wind assisted propulsion system active to determine the Power Speed curve (full blue line in **Figure 79 Power Speed Curves derived based on proposed sea trials**) at sea trial draft (according to 15016:2015): WASP is to be considered as not-installed, hence corrections for windage are needed.
2. Dedicated trials are carried out **with** the wind assisted propulsion system active. Provided that the system performs as expected, the process should result in a new Power Speed curve (full red line in **Figure 79 Power Speed Curves derived based on proposed sea trials**).
3. Correct the sea trial measurements for the EEDI draft based on pre-calculations / model tests, resulting this way into the dashed blue and red lines.
4. Finally, correct the Power-Speed for the system ON curve from step 3 to the EEDI wind speed of (18) kn, achieving the final Power Speed curve (dotted green line in **Figure 79 Power Speed Curves derived based on proposed sea trials**) which gives $VREF_{EEDI}$ at P_{WASP_EEDI}

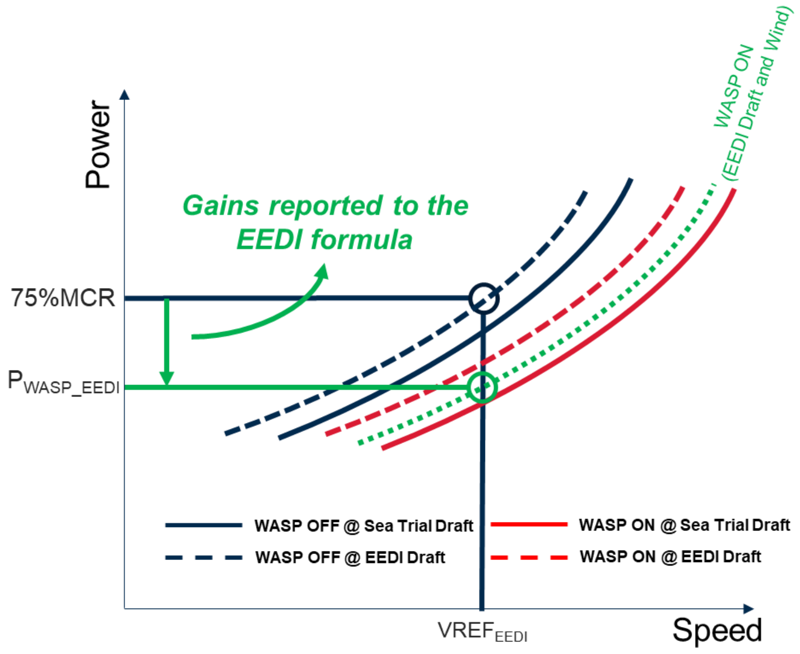

Figure 77 Power Speed Curves derived based on proposed sea trials

The above methodology entails a few considerations:

- EEDI compliant sea trials to be carried out for ship with WASP system OFF, in accordance with ISO 15016:2015 and relevant ITTC procedures
- For a fair comparison, added windage effects from sail, rigging, rotor, etc. should be deducted from the total wind resistance, to derive the Power-Seed curves for ship without WASP
- Procedures need to be developed using relevant elements from ISO 15016:2015 (double runs, accounting for current, etc.) for ship with WASP system ON performance in wind
- Same loading condition to be used as in EEDI sea trials, typically ballast condition
- Procedure for extrapolation of results from WASP (system ON) at sea trial draft to EEDI draft needs to be developed: possibly use as basis model tests and/or other pre-calculation procedure, assume WASP performance at EEDI draft to be same as in the ballast draft
- The prevalent wind conditions need to be determined: average absolute wind direction, time histories of relative wind speed and relative direction
- Sea trial runs with WASP system ON to be done in beam wind conditions (absolute wind direction perpendicular to ship track)
- Trial run length to be of sufficient length to account for natural variability in encountered wind speeds
- Possibly a minimum average wind speed could be specified below which WASP trials cannot be conducted, e.g. (7) knots

Speed trials should be conducted with WASP system ON at EEDI sea trial draft:

- WASP system settings to be determined by maker/vendor

- Main engine at (two / three) power settings around 75% MCR; measure WASP energy consumption
- Determine resulting speeds with system ON, corrected for waves and current; possibly in beam wind and beam waves, RAW effects will be limited
- Determine P-S curve with WASP ON at sea trial draft for the prevailing sea trial wind conditions
- Using tuned physical model, estimate the P-S curve with active WASP at the EEDI draft and wind speed of (18) knots
- Determine power difference between power required without WASP and power required with WASP at Vref: value to be used in the EEDI Formula.

Based on the above, a consultation was performed to all the JIP participants with two questions.

1. Do you agree that the EEDI WASP prediction (currently in MEPC.1/Circ.815) should be simplified, specifically to use just one wind speed and angle to predict performance?
2. Do you agree with the proposed methods for trials, which are used to define the verified performance?

In summary the answers showed that:

EEDI Formula: the partners of the JIP strongly support that the EEDI formula is kept as is and that a wind probability matrix is used. Nonetheless, some participants have proposed the following improvements:

1. There should be an opening in the regulations to allow for the EEDI to be calculated using route-specific wind statistics
   - ABS Comment: this would make the EEDI route specific. Therefore, new mechanisms would need to be developed and enforced to propeller verify that the vessels are operating within the approve routes. As an alternative, as it was noted in a meeting with the JIP participants on 18 December 2020, the Global Wind Matrix could be revisited so to include routes optimized for wind propulsion (weather routing based on historical/hindcast data).
2. There could be a revision of the world wind probability matrix so to update it to more realistic wind-fitted routes (one could think that wind assisted vessels could take a slightly different route to optimize exposure to beneficial winds).
   - ABS Comment: this is feasible and the second phase of the WiSP JIP could tackle this point
3. The regulation could be improved so to better define how to derive the forces and which factors to account for such as: Atmospheric Boundary Layer, use of CFD, etc.
   - ABS Comment: this is feasible and the second phase of the WiSP JIP could tackle this point

ABS initial proposal was to calculate the EEDI index for 1 wind speed and angle. Based on the feedback, ABS analyzed the sensitivity of the EEDI index to the number of angles and to the wind speed. Based on analysis carried out on two vessels fitted with Wind Assisted Propulsion the graphs in Figure 5 and Figure 6 were derived, referred here as vessel 1 and vessel 2. These figures show the baseline EEDI without Wind Assisted Propulsion, the reference calculation with the Wind Probability Matrix from INF.34 paper and 9 other cases with different combinations of wind speeds and angles as below:

- Three wind speeds are analyzed
- For each wind speed the calculation is done by including of 1, 3 and 4 angles with all having the same weight:

  1 Angle: 90 degrees in absolute direction

  3 Angles: 45, 90 and 135 degrees in absolute direction (180 being stern wind)

  4 Angles: 45, 90, 135 and 180 degree in absolute direction (180 being stern wind)

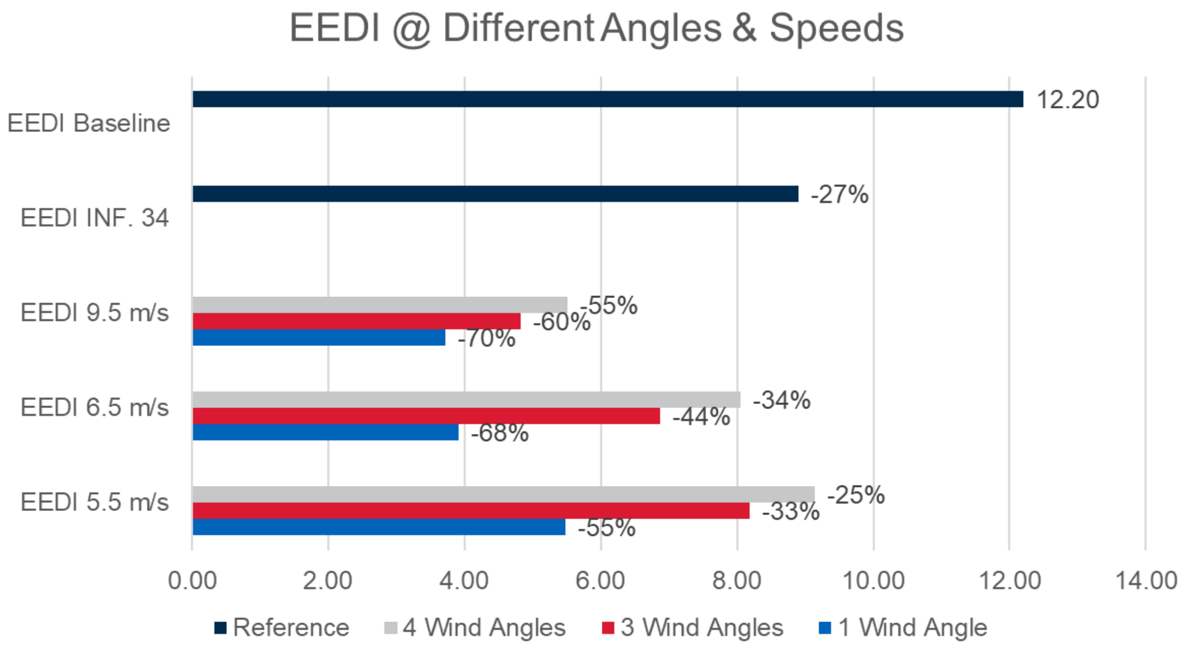

Figure 78 Effect of Wind Speed and Wind Angles on the EEDI rating for Vessel 1

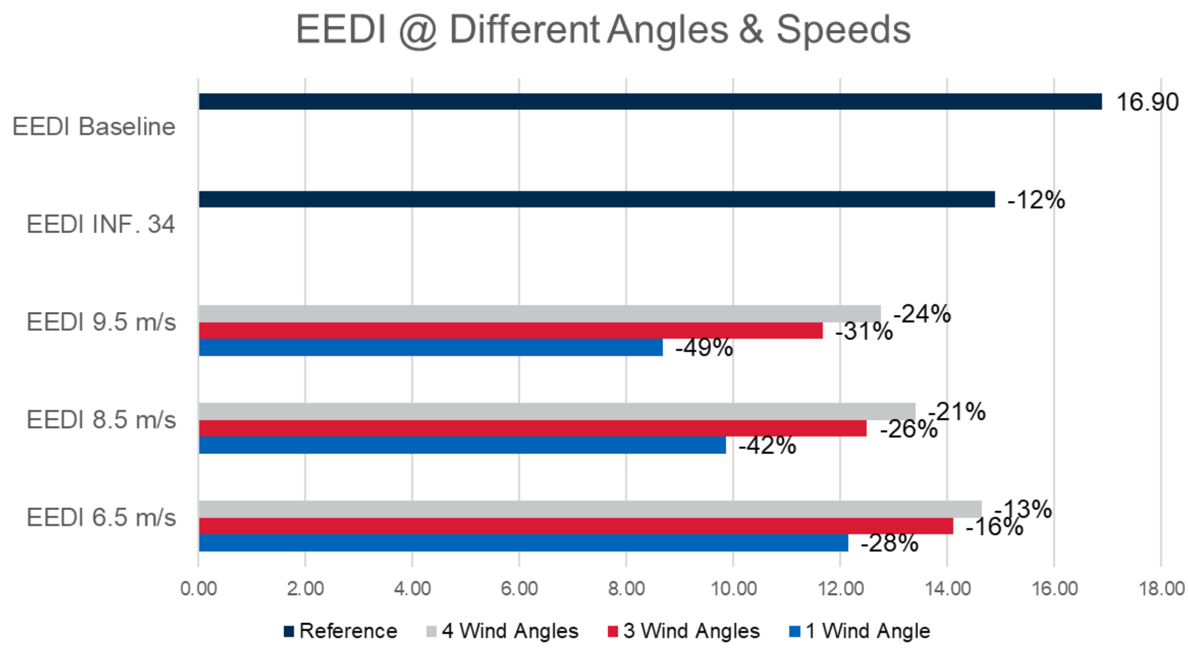

Figure 79 Effect of Wind Speed and Wind Angles on the EEDI rating for Vessel 2

It can be seen that the results are very sensitive to the number of wind directions and wind speed used for the calculation. It can be shown that a combination of angles and wind speed can be found for both cases that allows to achieve an EEDI rating comparable to the reference case where the global wind probability matrix is used.

It is important to note that the Vessel 1 and Vessel 2 have different WASP system : the first is equipped with a sails system and the later by Flettner rotors. These results allow stating that further investigation into how to include different angles and wind speed into the EEDI calculation may show an alternative to using the current global wind matrix probability. These numbers also show that **it is possible to find a simplified methodology accounting for fewer wind speeds and angles.**

Sea Trials Methodology: the partners of the JIP generally supported the proposal to develop dedicated sea trial procedure by using as basis the current ISO 15016:2015 guidelines. The following comments were traced by some of the participants:

- It may be challenging to find good conditions (with proper wind speed and not significant waves) to perform sea trials. Option could be to rely on land based tests or on in-service trials or well defined technical studies (making use of CFD, wind tunnel tests or others).
- It is important to well calibrate the sensors to correctly measure the wind conditions during the tests
- It is important to consider for different wind angles so to get a good overview of the potential gains. This can be done by targeting absolute wind directions or by varying the %MCR and consequently the vessel's speed and the apparent wind angle.

With the upcoming EEXI regulation (calculation aligned with EEDI but applicable to existing ships of 400 GT and above) which will be enforced from 2023 onwards, it is expected that many vessels will need to undergo a modification to remain compliant. Wind Assisted Propulsion is a technology that can be used to reduce the EEXI index. Hence, it is strongly suggested that a joint effort to be undertaken between Wind Assisted Propulsion System designers, flag states, regulatory actors, shipowners to update the

MEPC/1/Circ.815 can not only profit EEDI by also EEXI regulation. The findings from WiSP JIP coordinates by MARIN and ABS and WASP research project coordinated by SSPA would be relevant for this update.

August 2020 Update – The findings of the WiSP project were fed into the informal group tasked by the Chair of MEPC 76 to consolidate all wind submissions for resubmission to MEPC 77. Many of the technical considerations from the WiSP project were accepted and have been incorporated into the proposed revisions to MEPC.1 Circ.815. There was also a general acceptance that these recommendations are interim, pending work to be done by WiSP2, a continuation of WiSP.

Additionally, the current requirements (MSC. 137 (76)) for sea trial manoeuvrability tests require calm environment (limited wind and waves). A WASP system when integrated to a vessel makes an integral part of the propulsive system. Therefore, it would be fair to assume that its influence on the manoeuvrability performance of the vessel is not to be neglected. Consequently, it is important to investigate how to include the WASP into the manoeuvrability assessment and if the sea trials procedures should be consequently appended.

Lastly, as mentioned earlier, Minimum Power Requirement are part of the EEDI verification, especially if EEDI is obtained by power reduction. Currently a proposal was put forward (MEPC 74 / INF. 28) which accounts for improvements in the MPP evaluation. An uniformization of the calculation methodologies for both the EEDI and MPP would be beneficial for the industry as it would bring both consistency and easiness for the design process of any energy saving technology to be used on a vessel.

5.3 Waste Heat Recovery

Waste heat recovery systems take heat or exhaust gas to produce electricity. The typical waste heat recovery systems such as exhaust gas boilers which produce useful heat are not included if they do not ultimately produce electricity.

Waste heat recovery is considered in category C-1 in Circular 815 with the formula:

$$P_{AEeff} = P'_{AEeff} - P_{AEeff_{loss}}$$

Where:

P'_{AEeff} is the power produced by the waste heat recovery system

$P_{AEeff_{loss}}$ is the necessary power to drive the waste heat recovery system

P_{AEeff} is not however limited to the value of P_{AE} but as described in paragraph 2.1.1 of Appendix 1 of Annex 2 of MEPC.1/Circ. 815 *"The power generated by the system under this condition and fed into the main switch board is to be taken into account, regardless of its application on board the vessel."*

In other words, while P_{AE} for most cargo vessels is a small and fixed proportion of the installed power of the main engine, to account for the necessary power to drive propulsion machinery systems and accommodation electrical loads, P_{AEeff} can substantially exceed P_{AE}. From MAN's technical paper on waste heat recovery systems, "it is possible to generate up to 11% of the main engine power" while P_{AE} is at most 5% of MCR for ships with less than 10,000 kW installed, and less for ship's equipped with larger engines.

The technical paper also notes that SFOC for waste heat recovery tuned engines becomes worse, around 1-2%, and this does not appear to be accounted for in the EEDI calculation.

While waste heat recovery generates electricity and improves the overall thermal efficiency of the engine, it is closely related to the power output of the engine and reduces as engine load reduces. In comparison, shaft generators may provide a much more constant source of power. Hence for ships which do not operate close to design speeds, the contribution of waste heat recovery is likely overstated, and assuming f_{eff} as 1 is likely to be an overestimate.

5.3.1 Case Study – 10,000 TEU Containership

In the EEDI database, waste heat recovery is most commonly installed on container ships (4 out of the 9 installations listed in the IMO EEDI Database as of 3 Feb 2021), where the power generated is used to supply reefer loads. Let's use an illustrative case study.

~10,000 TEU containership

Deadweight	123,450 tonnes
MCR	40,300 kW
P_{ME}	30,225 kW
P_{AE}	1257.5 kW
Actual hotel load (incl. reefers)	2,500 kW
P_{AEeff} (Waste heat recovery)	2,500 kW
$SFOC_{ME}$	164.9 g/kWh
$SFOC_{AE}$	210 g/kWh
V_{ref}	21.3 knots
EEDI	9.14 g/kWh

If we were to apply a shaft generator, the P_{AE} value of 1257.5 kW would switch over to $SFOC_{ME}$ and result in an EEDI of 9.04 g/kWh (**1.1% improvement**).

If instead we would apply waste heat recovery (under the current rules), we could deduct all 2,500 kW of P_{AEeff} and result in an EEDI of 8.23 g/kWh (**10% improvement**).

Note however in the EEDI calculation, deduction of 2,500 kW means that effectively P_{AE} is zero, but even some of P_{ME} is deducted.

Even with this generous treatment, this does not seem to have promoted uptake of waste heat recovery systems, perhaps indicating some issues in application. In our discussions with shipowners who have fitted both waste heat recovery and shaft generators, a preference was expressed for shaft generators because they provided more consistent output which could be relied upon, while waste heat recovery systems would push the ships to maintain higher speeds in order to obtain the benefit.

If we limited the waste heat recovery deduction to P_{AE}, just as we do for shaft generators, the EEDI would be 8.68 (**5% improvement**). Note that improvement percentages are relative to the original ship, and not to the EEDI baseline. The improvement relative to the EEDI baseline will be around 45% less.

5.3.2 Inconsistencies

The inconsistencies of the current regime are that:

- Total output of the waste heat recovery may exceed actual demand (although the likelihood of this being the case is low, due to the cost and space requirements of WHRS)
- Waste heat recovery figure P_{AEeff} depends on the ship operating at close to design speeds, and in many cases likely overstated
- There is a discrepancy in treatment between shaft generators and waste heat recovery where the former is limited to P_{AE} while the latter is not
- Diversion of waste heat to produce electricity means that heating needs (e.g. for heating of HFO, hot water or cargo heating) must be provided by an oil fired boiler, which is also not considered within the EEDI calculation

This gives ships fitted with waste heat recovery an unfair advantage over ships not fitted with waste heat recovery because the improvement is being over-estimated. This is also not in line with the EEDI concept which expressly excludes maintenance of cargo, thrusters etc and makes it difficult to carry out comparisons with ships that do not have waste heat recovery installed.

It is important to note that waste heat recovery systems do provide a significant benefit to fuel consumption in practice, the issue here is in the current calculation methodology it has an unfair advantage that has arisen because of the way the requirements have been drafted.

5.3.3 Proposed way Forward

The proposed way forward for this would be:

- to limit the maximum deduction of waste heat recovery to the value of P_{AE} as it is done for shaft generators. Waste heat recovery still has an advantage in that shaft generators exchange the SFOC of the auxiliary engines with the better SFOC of the main engine, whereas waste heat recovery simply removes any emissions associated with P_{AE}
- Require f_{eff} to be calculated based on the intended operating profile of the vessel. This could be seen as optional because the imposition of the CII framework will require consideration of the operational profile at design stage and restrict installation of WHRS to those where it may be fully beneficial.

6 TASK C1 FRAMEWORK TUNING - TECHNOLOGIES NOT COVERED BY MEPC.1 CIRC.815

6.1 Non-Conventional Propulsion

MEPC 74 INF 20 and MEPC 74/5/13 explore the possibility of extending the coverage of the EEDI formula to ships with non-conventional propulsion apart from LNG carriers and cruise passenger ships. While non-conventional propulsion is referenced, it is clear that the target of the documents is really diesel electric propulsion. However, there are issues with the definitions themselves. The relevant definitions here are (taken from MARPOL Annex VI):

Conventional propulsion in relation to chapter 4 of this Annex means a method of propulsion where a main reciprocating internal combustion engine(s) is the prime mover and coupled to a propulsion shaft either directly or through a gear box.

Non-conventional propulsion is in relation to chapter 4 of this Annex means a method of propulsion, other than conventional propulsion, including diesel-electric propulsion, turbine propulsion, and hybrid propulsion systems.

Diesel electric and steam turbine propulsion for LNG carriers is covered under 2.2.5.1 $P_{ME(i)}$ of the EEDI Calculation Guidelines assuming 83% of the rated output power of the motor

Diesel electric propulsion for cruise passenger ships is covered under 2.2.5.3 $P_{PTI(i)}$. but assuming that P_{ME} is zero and P_{PTI} is 75% of the rated power consumption of the shaft motor multiplied by the efficiency of the shaft motor.

This lack of consistency in calculation methodology for diesel electric systems indicates the difficulty in defining a suitable methodology to extend EEDI to all diesel electric propulsion in any ship type. One issue to note is that the cruise passenger ship population is homogenous in terms of propulsion system, while the LNG carrier fleet consists of both conventional and non-conventional propulsion (steam turbine and diesel electric).

6.1.1 Diesel Electric Propulsion

Although not further defined, diesel-electric propulsion involves a number of generator sets in a system providing power to both propulsion and auxiliary/hotel demand enabling the system to optimise engine load amongst the generators and therefore SFOC.

With the exception of LNG carriers and cruise passenger ships, implementation of non-conventional propulsion on ships excludes them from the EEDI framework. One of the main reasons is that the losses in the propulsion chain are much greater in a ship with non-conventional propulsion, and this is also addressed in the two MEPC 74 submissions.

For a **conventional direct drive configuration**, the engine is connected directly to the shaft and propeller, so the only losses are in the shaft, of the order of **1-2%.**

Adding a gearbox introduces some additional losses, another **1-2%.**

In a **diesel electric system**, the generator results in losses going from mechanical to electrical power, around **3-5%**. Turning the electricity back into mechanical power involves conversion and further losses, another **4-8%**. This assumes the use of a shaft line with shaft motors. With podded propulsion, MEPC 74/5/13 submitted by Norway estimated an additional **6%** loss in propulsion efficiency. EE-WG 1/2/9 suggests that the efficiency of a diesel electric system at full load is between 0.88 to 0.92, ie around **10%** losses.

With these losses, any ship which is fitted with a diesel electric system would perform poorly in any comparison with a similar ship fitted with a directly driven shaft/propeller configuration when calculated with the assumptions used in EEDI, namely at a fixed MCR point and speed.

EE-WG 1/2/9 as far back as 2010 showed the below chart based on a comparison of tankers which shows the difference when calculating with EEDI.

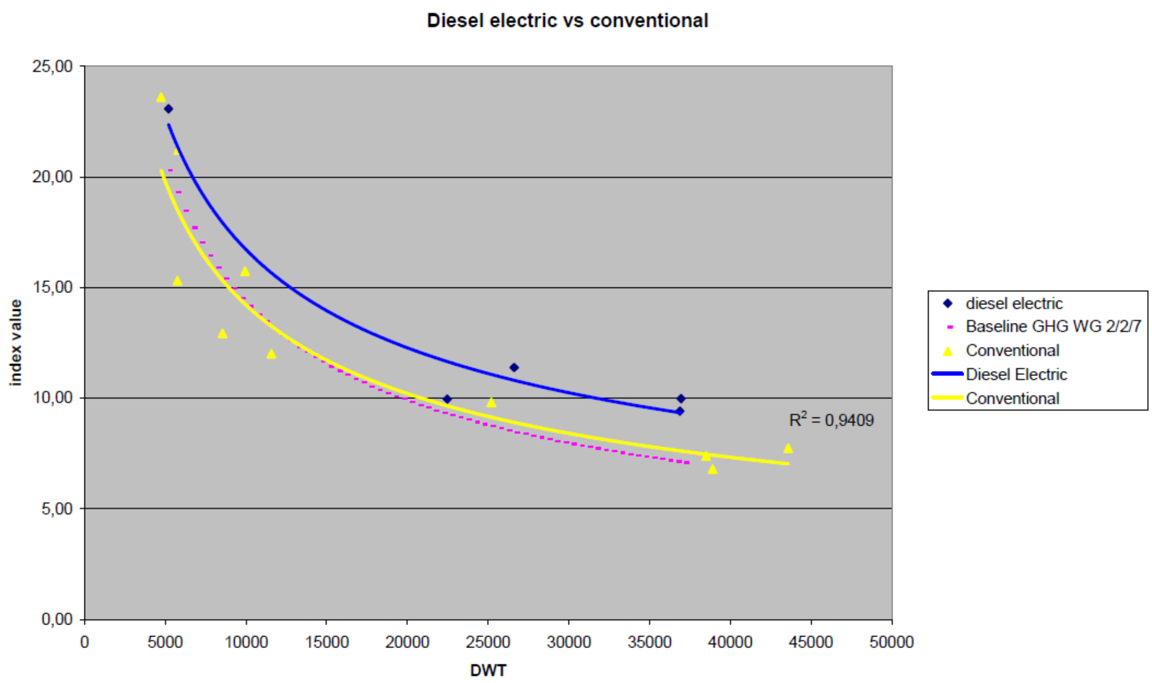

Figure 80 Comparison of Diesel Electric and conventionally propelled tankers (EE-WG 1/2/9)

This begs the question as to why install a diesel electric or hybrid propulsion system. The reason is that few ships consistently operate at the EEDI point, and some spend a significant amount of time operating far away from the EEDI point. As such propulsive efficiency reduces for fixed pitch propellers and engine SFOC gets worse at lower loads, at which the diesel electric systems with controllable pitch propellers are overall able to maintain better efficiencies.

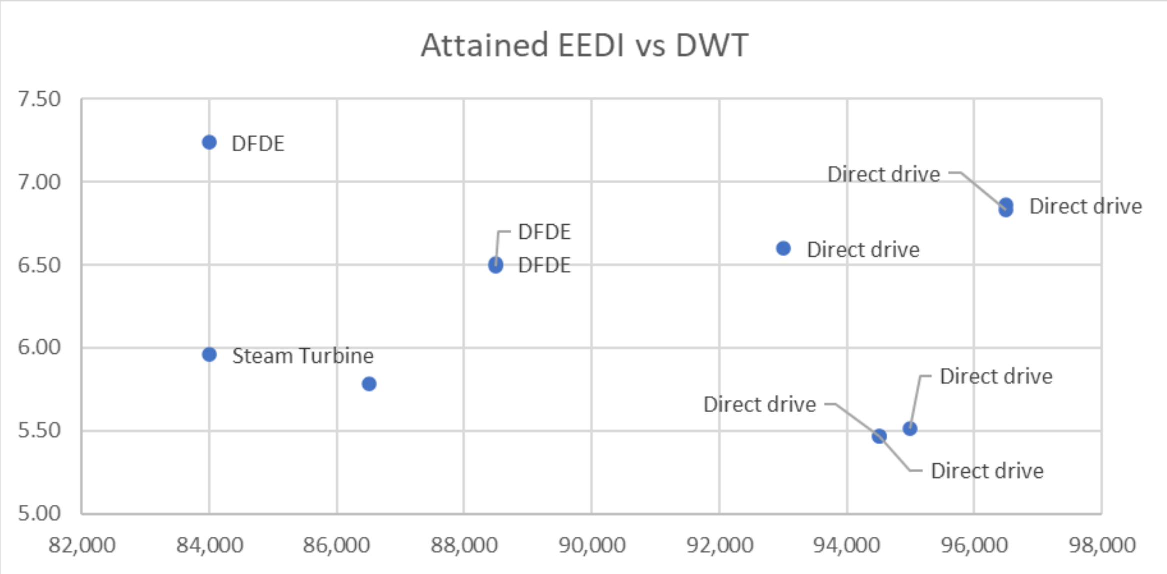

Figure 81 LNG Tankers from the IMO EEDI Database

In Task A1, we provided the above chart comparing LNG carriers with different propulsion options and it may be seen that the direct drive dual fuel ships seem to be capable of much better EEDI than the DFDE ships, though it is not entirely clear which Cf factor has been used for the calculation.

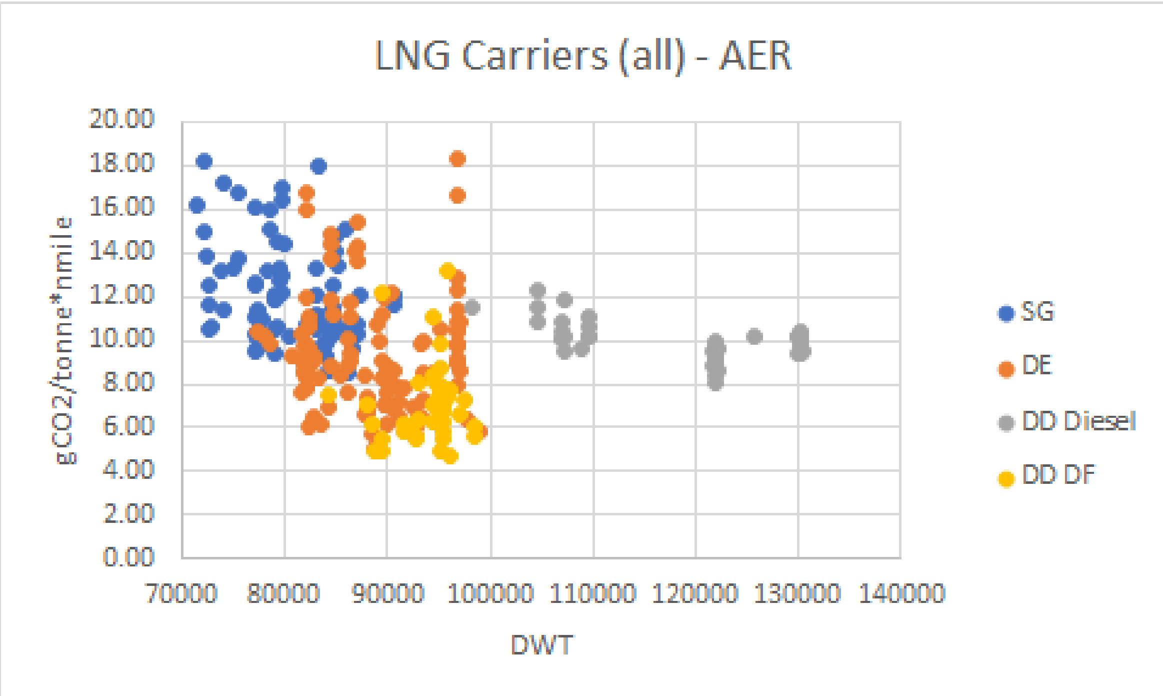

Figure 82 LNG Tankers by Propulsion Type - Courtesy EMSA

The above chart looks at the AER of LNG carriers with a variety of different propulsions systems – steam turbine (SG), diesel electric duel or tri fuel (DE), direct drive diesel (DD Diesel) and direct drive dual fuel (DD DF). With an EEDI calculation, on top of dealing with the losses explained above, the direct drive dual fuel engines are two stroke engines with around 145 g/kWh SFOC in gas mode or 165 g/kWh in liquid fuel mode, versus diesel electric systems which typically use 4 stroke engines at 155 g/kWh in gas mode (estimated from the heat rate) or 176 g/kWh in liquid fuel mode. So the diesel electric equipped ships should appear to be largely disadvantaged compared to the direct drive dual fuel ships.

However it may be clearly seen that while there is significant variation in performance, the best diesel electric ships are competitive with direct drive dual fuel ships. An additional factor that is not considered within the EEDI calculation is that where there are significant auxiliary loads (for gas reliquefaction for example), the diesel electric configuration allows better optimisation of engine load and SFOC compared with the direct drive ships.

The suggestion to derive a correction factor to "level up" the efficiency of diesel electric propulsion seems superficially attractive, but the problem is that such a correction factor is likely to be an estimated static value which may either over or under correct. As technology improves, some of the losses may reduce over time, while the actual saving of a diesel electric system depends on the operating profile and the operation of the ship and is hence quite variable.

We should be cautious about introducing some sort of regulatory incentive which may lead to unintended consequences, such as the fitting of diesel electric systems where the operating profile does not lead to significant CO_2 savings or efficiencies. The EEDI framework is currently too inflexible and limited to make an adequate assessment of the benefits of a diesel electric system. It should also be noted that diesel electric systems are treated differently within the calculation guidelines depending on whether it is an LNG carrier or a cruise passenger ship, and this alone should cause us to reconsider a blanket correction factor applies to diesel electric propulsion for all ship types.

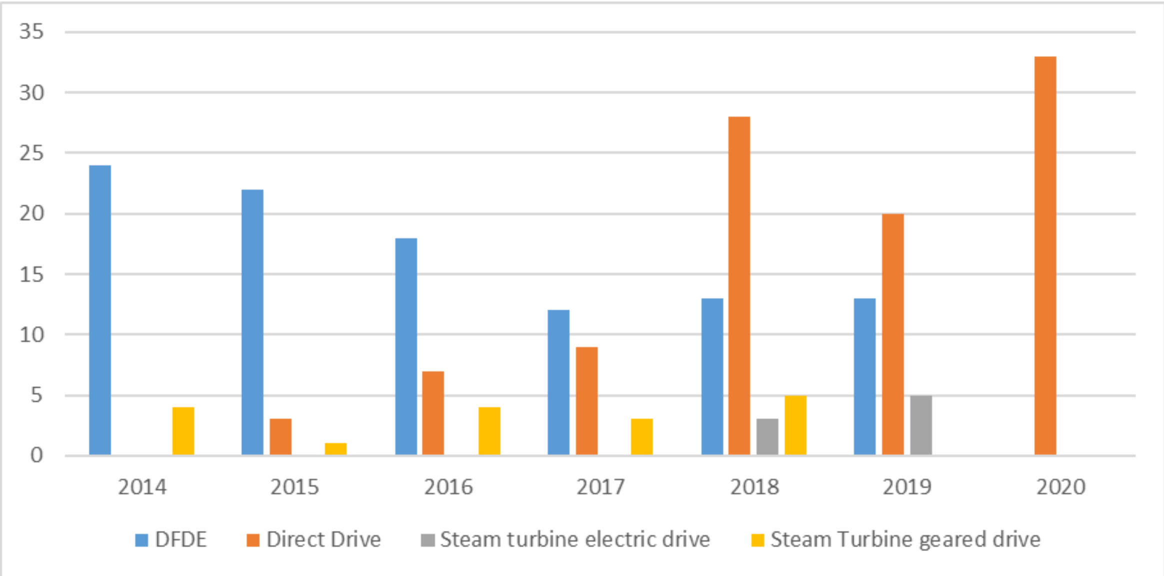

Figure 83 Order book of LNG Carriers (IHS)

Note that the implementation of EEDI for diesel electric propulsion within LNG carriers does not include a correction factor to level up the difference as the segment also includes ships with steam turbine and conventional propulsion. Normally this would lead to objections about the unfairness of the implementation, but in this case it seems that the industry has almost transitioned away from diesel electric propulsion entirely as all LNG carriers delivered in 2020 were direct drive dual fuel. Therefore there are some questions as to whether the calculation methodology for diesel electric propulsion for LNG carriers was entirely appropriate.

The second substantial proposal contained within the MEPC 74 documents suggests that a weighted operating profile could be used to demonstrate the benefits of the diesel electric system. There are significant challenges with this proposal which is acknowledged by the submitters of MEPC 74/5/13 and MEPC 74 INF.20.

While we have done significant work to analyse weighted operational profiles, which is further detailed in a later part of this report, specific to diesel electric there are the following challenges:

- Diesel electric propulsion generally shows its superiority in different operating modes, however those operating modes vary significantly between different ship types with different purposes, so the concept of defining a standard weighted average of operating profiles may lead to further unfair treatment, however it will be difficult to verify and implement without some kind of operating profile standardisation
- These operating modes are generally slower, and even without the enhanced efficiency of a diesel electric system, would in any case demonstrate improved attained EEDI
- Optimisation of large non-propulsion electrical auxiliary loads play a part in attractiveness of diesel electric systems, but this is also generally not part of the EEDI framework
- As mentioned in the MEPC 74 submissions, comparing this against other ships with non-conventional propulsion and the baseline becomes an exercise in trying to fit a square peg into a round hole and rapidly becomes highly complex along with greatly increasing the risk of unintended consequences

Given that MEPC 74 INF.20 suggests that only 0.395% of shipping emissions are due to diesel electric propulsion, the significant challenges and unintended consequences that are likely from the development of both a correction factor and weighted operating profile approach seem to outweigh any potential benefit of extended the scope of EEDI to cover all ships with diesel electric propulsion. The highly variable nature of the savings which may be expected is highlighted by the different treatment of diesel electric propulsion for LNG carriers and cruise passenger ships, and there is a risk of technology development outpacing rigid and prescriptive regulatory frameworks.

Therefore we do not recommend any further work on expanding EEDI to cover diesel electric propulsion for all ships, based on the above explanations, given that the topic has been discussed without clear progress since 2009, and particularly in light of the fact that the CII measure will be implemented to provide a much fairer and simpler comparison. We also would suggest to remove diesel electric propulsion from the EEDI work plan.

Shipowners, shipyards and ship designers today are well aware of the necessary tradeoffs and potential savings, and being free to make those decisions (taking into account the higher capital cost of diesel electric propulsion) without the encumbrance of an approximate regulatory construct will provide the least obstruction to continued innovation.

6.1.2 Turbine Propulsion

Turbine propulsion is likely to encompass:

- Steam turbine propulsion because the characteristics are different compared to conventional marine diesel engines (see separate treatment for LNG carriers)
- Gas turbine propulsion because the characteristics are different compared to conventional marine diesel engines

The conclusion here is that apart from steam turbine propulsion being implemented on LNG carriers, use of steam turbine propulsion on any other ship types would lead to exclusion from the EEDI framework.

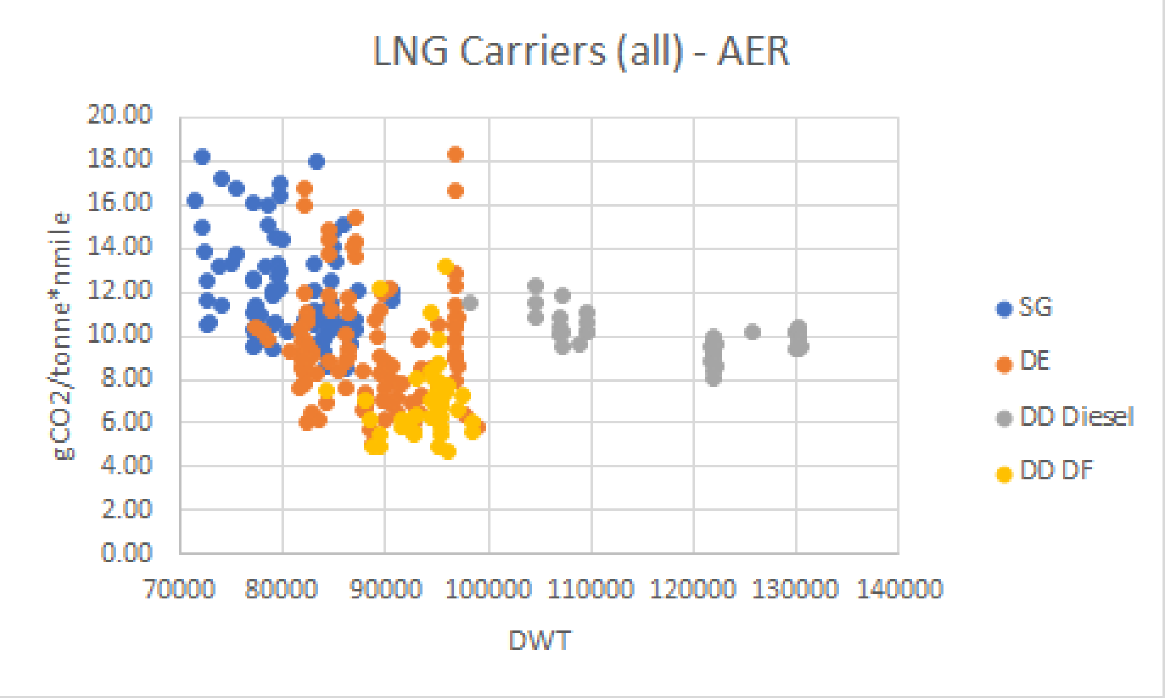

Figure 84 LNG Tankers by Propulsion Type - Courtesy EMSA

Notice that here the steam turbine ships to actually appear to less efficient than the diesel electric or direct drive dual fuel options. However in the case of LNG, steam turbines have significantly lower levels of methane slip and if methane slip is included, then the overall efficiency of LNG driven steam turbines might be somewhat different.

As such we would suggest to maintain the exclusion of turbine powered ships (apart from LNG carriers), from application of EEDI.

6.1.3 Hybrid Propulsion

The MARPOL Annex VI definition is not clear about what is a hybrid propulsion system.

GHG-WG 2/2/12 (2009) has a table which attempts to explain the different types of propulsion systems:

Table 6-1 Types of Propulsion Systems - GHG-WG 2/2/12

Propulsion system applicable to general merchant ship	Prime movers for propulsion	Prime movers for electric power generation
	Machinery available for propulsion	Machinery available for electric power generation
Conventional propulsion system	Main engine	Aux. engine
	M/E	A/E, S/G, WHRS
Diesel-electric propulsion system	Aux. engine	Aux. engine
	A/E, shaft motor	A/E, WHRS
Hybrid propulsion system	Main engine or aux. engine	Aux. engine
	M/E or A/E, shaft motor, PTI	A/E, S/G, WHRS
Steam turbine propulsion system	Steam turbine	Steam turbine, aux. engine
	S/T, main boiler	T/G, A/E

EE-WG 1/3 suggests that hybrid propulsion could include ships provided with main engines (ie conventional propulsion) and PTI motors with gear boxes, and ships with gas turbines operating as auxiliary power generators.

RINA (the Italian Class Society) suggests in their Class Rules:

> *Hybrid propulsion system: a propulsion system having two or more different sources of power such as mechanically transmitted power from internal combustion engines, electrical power or hydraulic power so arranged that the ship may be propelled by using the different power sources both separately and in combination*

The definition hinted at in MEPC 74 INF.20 suggests hybrid means **battery hybrid**, but when these discussions were held back in 2009/2010, battery hybrid does not appear to have been considered.

As far as can be ascertained, MEPC 59/4/2 first mooted the use of the term hybrid propulsion systems as a means of referring to ships with propulsion systems that are a mix or are somewhat more complex than the typical direct driven shaft and propeller. Since that time the EEDI calculation guidelines have advanced significantly to include LNG carriers with both steam turbine and diesel electric propulsion, cruise passenger ships with diesel electric propulsion, and ro-ro passenger ships with conventional propulsion (which were originally considered a problematic and complex segment when the EEDI framework was being developed).

As an example, a hybrid propulsion system could be a directly driven shaft/propeller augmented by a PTI/shaft motor solution – however this appears to be covered in 2.2.5.3 of the EEDI calculation guidelines where V_{ref} is derived at P_{ME} + $P_{PTI,Shaft}$ or 75% of the limited power if the propulsion system is limited by verified technical means.

For systems where the PTI is there to boost the power output, the calculation procedure is fair. However where the PTI is there to optimise low power/slow speed operation (which would result in fuel saving), the calculation methodology is unable to demonstrate an efficiency benefit, similar to the issue faced with diesel electric propulsion vs conventional propulsion when the benefits are realised in operating conditions that are not at 75% MCR.

Work done in the WiSP Joint Industry Project indicates that ships with significant amounts of wind assist, or even primary wind propulsion exhibit very different propulsion characteristics and may significantly change the design and implementation of the conventional propulsion system such that it may perform poorly in the EEDI condition. MEPC 74 INF.20 also seems to consider that ships fitted with sails and kites could be considered as non-conventional propulsion. Additionally the prediction method found in MEPC.1/Circ.815 seems to be less suitable and more uncertain for larger contributions from wind.

6.1.4 Proposed Way Forward

MEPC 74 INF.20 suggests that 0.395% of shipping emissions is attributable to ships with diesel electric propulsion (excluding cruise and LNG, from Figure 3). The suggestion in MEPC 74/5/13 is to develop a correction factor or allow for the calculation of a weighted EEDI for multiple load points. It should be noted that the concept of a correction factor (with a value of 1.1) was proposed as far back as 2010 in EE-WG 1/2/9 but never further developed. We think that neither of these suggestions are advisable as explained above.

However the CII framework will now be implemented which will be able to demonstrate the utility of diesel electric/non-conventional propulsion as can be seen in the LNG carrier example above.

As such we would propose to leave the framework for EEDI as is without trying to draw more ships with diesel-electric propulsion into the scope of EEDI. These ships would in any case be subject to CII. This deals with the charge that EEDI might stifle innovation. In any case innovation will progress faster than we are able to update the regulations so it is better not to attempt to impose some form of EEDI on such ships which will introduce a rigid and prescriptive method of assessing energy efficiency. Note that fuel cells may only be integrated within an electric system with electric motors or pods and so this approach would also cover fuel cells.

For implementation of fuel cells within ship types that are already using non-conventional propulsion, this is likely covered by the concept that SFC_{AE} is the power weighted average.

However we would also recommend clearly indicating what non-conventional propulsion covers, particularly under the heading of hybrid propulsion which requires some clarification. After some discussion with a number of IACS members, it is clear there is no common understanding amongst IACS members on this point.

For hybrid propulsion systems where the fuel or efficiency savings may not be demonstrated within the EEDI framework but require consideration of the operating profile, we would recommend retaining the exemption.

Additionally we would recommend that wind assist that leads to attained EEDI savings of 15% or more are also excluded from complying with a required EEDI due to the modifications that will be required to maximise the contribution of the wind assist and the uncertainty of the calculations at this level of wind contribution. **This position has also been suggested to the informal group looking at amending MEPC.1/Circ.815 that will report to MEPC 77.**

6.2 Batteries

Batteries are somewhat related to the above discussion on diesel electric or hybrid propulsion, except they may also be implemented within the auxiliary electrical system instead or in addition to propulsion.

Batteries may be used in a variety of ways:

- Peak shaving where the battery acts as a buffer to handle peak loads and allows the generators to run at optimum SFOC
- As the main power source for all of or a portion of a voyage e.g. during manoeuvring, initial voyage segment or in port as a replacement for shore power
- Spinning reserve reducing the need for additional gensets to be on standby at low load and poor SFOC

Additionally the batteries may be charged from shore, or onboard as part of the peak shaving and this potentially changes the effect.

6.2.1 Case Study – Scandlines Ferry Prinsesse Benedikte

A case study of the Scandlines ferry Prinsesse Benedikte follows – which reduced CO_2 emissions by about 15%.

The 4 stroke engines/gensets onboard have the following SFOC curve where optimum SFOC point is somewhere around 80-85% and gets worse at higher or lower loads.

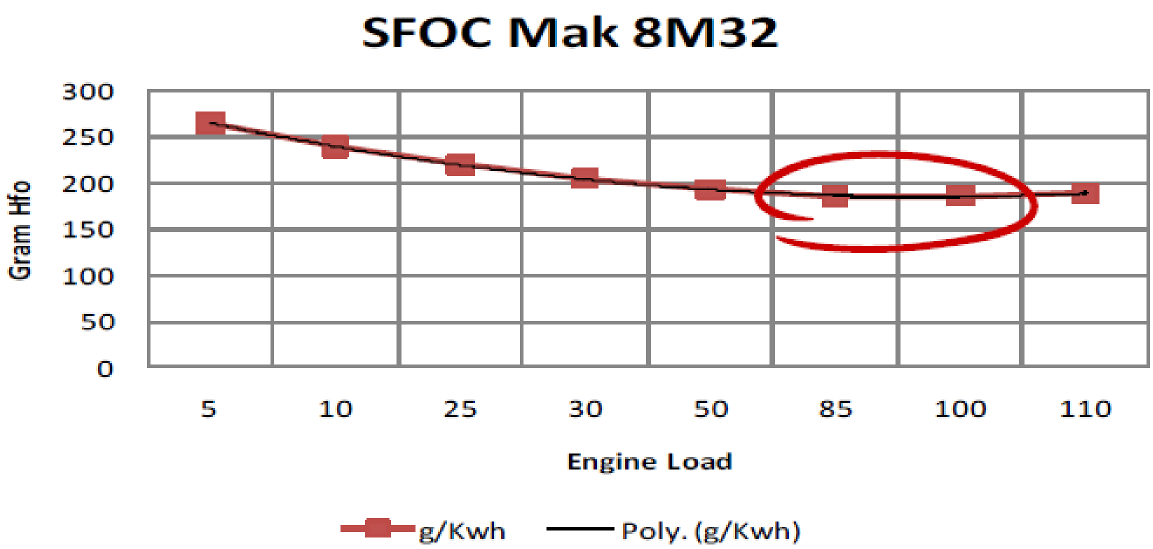

Figure 85 SFOC for MaK 8M32

However the vessel runs with around 1-3 diesel gensets at 40-55% load at sea on average and 8-10% load in ports (for redundancy and safety reasons). The vessels are diesel electric, however if they were diesel mechanical, these figures might potentially be worse.

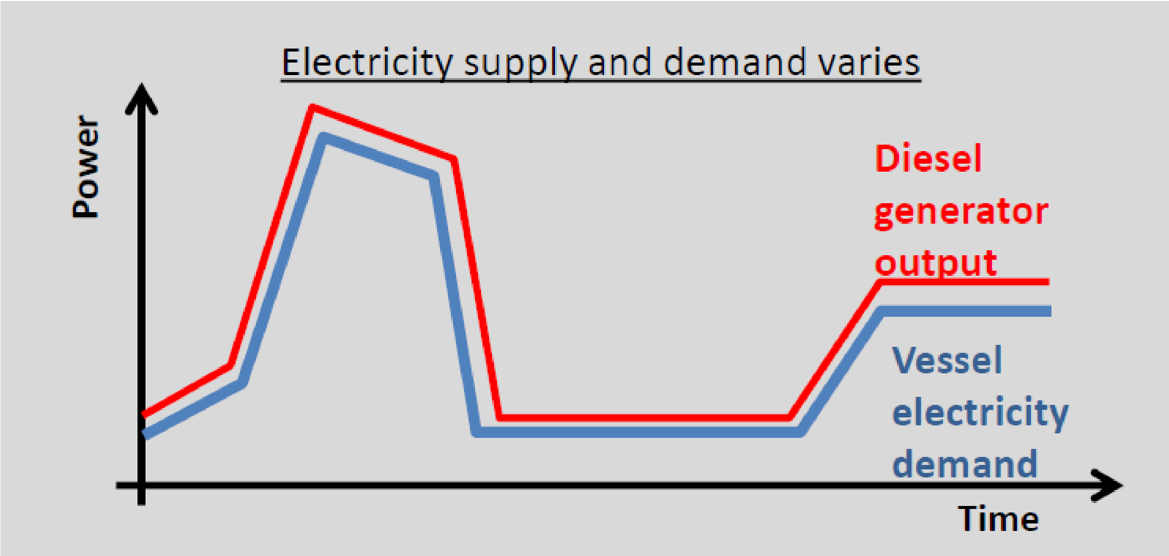

Figure 86 Schematic of Power demand and supply - courtesy Scandlines

With the battery system installed, generally only 1 generator is needed at sea and in port, running at 85-90%, keeping the engine load at the optimum SFOC point.

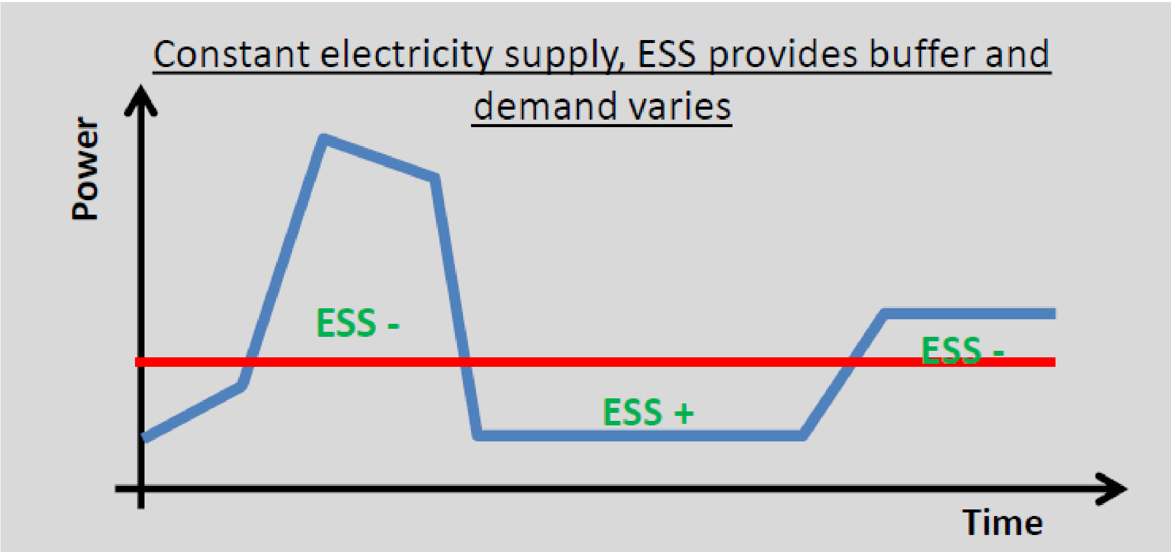

Figure 87 Energy demand and supply with batteries - Courtesy Scandlines

A schematic of the specific load profile is shown below.

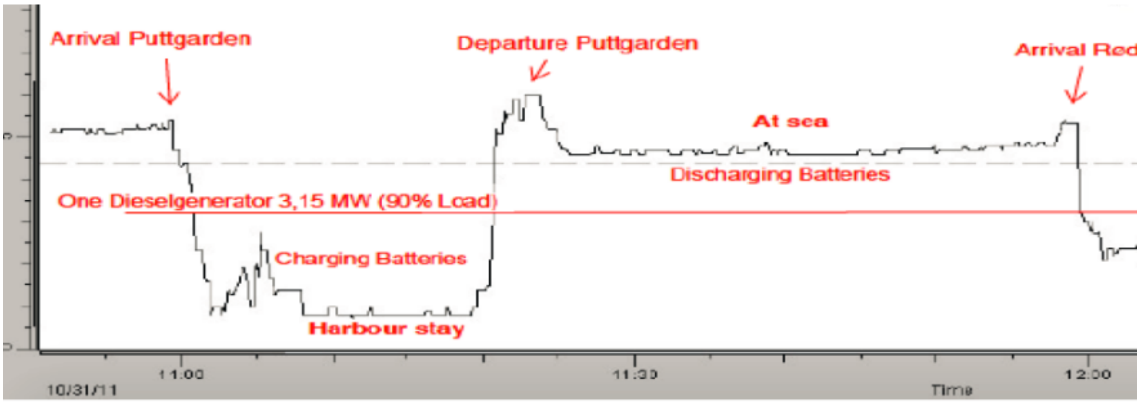

Figure 88 Actual Electrical Demand Prinsesse Benedikte - Courtesy Scandlines

Note the battery system has 2.7 MWh capacity which could fully propel the vessel for 30 minutes.

Trying to estimate suitable savings within the EEDI framework is challenging:

- In the Scandlines example above, even as a diesel electric system, the gensets were not able to be run at the optimum SFOC point due to the nature of the operating profile and the need to keep gensets online for redundancy and safety. However the EEDI calculation already assumes that the engines are run at optimum SFOC (SFOC is at 75% MCR) and the amount of fuel saving from peak shaving is very much dependent on the operating profile, which is not currently considered by the EEDI calculation.
- This means implementing a battery system even within diesel electric propulsion cannot be directly accounted for by adjusting the SFOC since it is already assumed to be optimal
- If the batteries are charged from land, then from a tank to wake perspective (which is what the EEDI framework is currently based on), the ship has bunkered zero carbon fuel for use, but the difficulty is deciding how much P_{ME} should be reduced or what proportion of C_f should be adjusted.
- If the batteries are used for manoeuvring or in port or some other auxiliary power requirement, these are not included in the EEDI calculations, but nevertheless result in fuel saving

In our research we have found that battery systems are ignored in the calculation of EEDI, even though as demonstrated by the case study, the fuel savings may be substantial. Even in the case of a battery system incorporated in a recently delivered ship with conventional propulsion, where the batteries may be charged by shaft generators on the main engine driven shafts, but used for auxiliary power, manoeuvring or in port, efficiency gains can be made, but the battery system was not even mentioned in the EEDI technical file.

6.2.2 Proposed way forward

The challenge is capturing the appropriate savings which vary depending on how the battery is used and charged. A number of options are possible:

1. Back calculate savings via operating profile and apply to the EEDI – meaning in the example above, (ignoring that it is an existing diesel electric ropax and not subject to EEDI), to apply a 15% reduction to the calculated attained EEDI
2. Use the f_{dfgas} concept by comparing the energy content of the batteries with the fuel capacity, though this may give somewhat variable results depending on how much fuel capacity is provided. An alternative would be to compare the

energy content of the batteries with the energy content of the fuel consumed over a period, e.g. 8 hours or 24 hours – this is further detailed below

3. Use the 4th or 5th term of the EEDI formula – innovative energy efficient technologies, however much more data needs to be collected from ships fitted with batteries in order to derive a robust calculation methodology
4. Exempt ships with installed battery capacity above a certain threshold for a number of years until a further review may be conducted, relying on the CII to assess the impact and avoid ineffective installations

The f_{dfgas} concept adjusts the C_f value depending on the proportion of energy content of the alternative fuel relative to the conventional liquid fuel. The fuel storage capacity of most ships is of several days or weeks duration and so any battery capacity will be dwarfed and be relatively insignificant, so it would be necessary to adjust the reference to fuel consumption over a defined period.

From MRV Data, the Prinsesse Benedikte consumes around 20 tonnes of fuel per 24 hours, at 197 g/kWh. This translates to around 102 MWh output vs the 2.7 MWh capacity of the battery system. A way of deriving the benefit to C_f could be as follows:

((102 x 3.206) + (2.7 x 0))/(102 + 2.7) = 3.12 which approximates to a 2.6% improvement to the C_f and EEDI value. In this case this is far below the actual result.

If the period were reduced to 4 hours:

((17 x 3.206) + (2.7 x 0))/(17 + 2.7) = 2.767 which approximates to a 13.7% improvement in the C_f and EEDI value (but not to the EEDI Baseline).

However further work needs to be done on other applications of this to derive a robust estimation method. As such, the preference would be either to option 1, which is to estimate the savings through the operating profile and then to adjust the attained EEDI, or option 4 which is to exempt ships with installed battery capacity above a certain threshold (which could be as a proportion of MCR or auxiliary demand), or simply to exempt ships with installed battery capacity, and again to allow the CII and the cost of the battery systems to guide the installation of such systems to obtain the most benefit.

We end this section with two warnings.

The savings due to implementation of battery technology are extremely variable and there will also be operating profiles where the savings made will be marginal. The EEDI framework should not be used to artificially promote the uptake of batteries. What would be of significant benefit is to support battery projects (whether newbuild or retrofitting) together with provision of public access to the resulting data, particularly for ships with conventional propulsion.

Current lithium ion battery chemistry has significant environmental effects due to the mining of the minerals required and we need to balance the potential GHG savings with overall sustainability.

7 TASK C1 FRAMEWORK TUNING - ALTERNATIVE FUELS

The role of fuels in the EEDI framework revolves around the carbon factor C_f. While the concept of this carbon factor is often termed tank to wake, in reality it is simply a chemical ratio, and the issue of incomplete combustion (which includes methane slip, and potentially N_2O slip) is not considered.

Fuels could be classified in the following groups:

1. Fossil fuels which contain carbon – MGO, MDO, LFO, HFO, LNG, LPG
2. Fossil fuel derivatives which contain carbon – Ethane, Ethanol, Methanol
3. Drop in fuels which contain carbon – Biofuels, synthetic or e-fuels
4. Fuels which do not contain carbon – Ammonia, hydrogen, nuclear

All the fuels above are not tied to a particular form of propulsion, except for nuclear which will use steam turbine or potentially electric propulsion.

Fuels in groups 1 and 2 are well served by the C_f factor, with the exception that methane slip will need to be considered – however this is a complex area which we will examine further.

Drop in fuels in group 3 are emit the same amount of carbon as fuels in groups 1 and 2 when used and are chemically identical. These fuels may be (but not always) low carbon or net zero fuels because of processes in the well to tank portion of the fuel lifecycle. Currently the EEDI framework is unable to distinguish between these fuels and their fossil fuel equivalents.

Fuels in group 4 do not contain any carbon and do not emit carbon when used. Combustion of ammonia may lead to N_2O (nitrous oxide which is different from NOx) slip which is a potent greenhouse gas with a GWP worse than methane. Fuels in this group would be assigned a C_F factor of zero under the current system leading to attained EEDI values of zero – effectively exempting such ships from the EEDI framework.

Estimating the impact of alternative fuels on EEDI is not always as trivial as exchanging the carbon factor of one fuel for another. The specific fuel oil consumption of engines vary depending on the fuel used due in part to the different calorific value, while most alternative fuels have containment and fuel handling requirements that result in an increase in lightweight and a corresponding decrease in deadweight for the same size of vessel. However for ships which use cargo as an alternative fuel, this penalty may not exist.

Until recent changes to the IMO EEDI Database submissions, the type of fuel and f_{DFgas} was not submitted to the database and this significantly hampers analysis of the existing data of 6000+ EEDI ships.

7.1 Effect of ECA Regulations

For specific vessel designs having difficulty meeting the later EEDI Phases, the SFOC value (Tier II or Tier III) to be used in the EEDI calculation plays an important role in terms of compliance. Shipyards and owners often assess the % time of the vessel's intended voyages inside ECAs to justify use of a lower SFOC value that satisfies both the NOx requirements and EEDI regulations. For example, a typical VLCC operating profile often comprises of annual voyages mostly (90% of the time) outside of ECA.

Generally Tier III operating modes have worse SFOC compared to the Tier II modes. There are a number of different Tier III options which result in different SFOC in both Tier II and III modes, and are based on an expectation of the likely percentage of time spent in an ECA, compatibility with scrubbers and fuel sulphur content. Below is an example of a MAN G60ME-C9.5:

Table 7-1 Comparison of Tier II and III SFOC - MAN G60ME-C9.5

Tier III Compliance Technology	Tier II SFOC (g/kWh)	Tier III SFOC (g/kWh)	Percentage increase SFOC
EcoEGR	158.0	165.0	4.4%
EGRBP	162.5	167.0	2.8%
High Pressure SCR	162.5	163.5	0.6%
Low Pressure SCR	162.5	163.5	0.6%

The current EEDI calculation guidelines MEPC.308(73) require that the Specific Fuel Consumption (SFOC) for each of Main Engine(s) and Auxiliary Engine(s) applied on EEDI formula are:

a. $SFOC_{MEi}$ at 75% of MCR for Main Engine(s). Main Engine(s) certified to NOx Technical Code 2008 test cycles E2 or E3.

b. $SFOC_{AEi}$ at 50% of MCR for Auxiliary Engine(s) – if multiple non-identical Auxiliary Engines are installed, the SFOCAE is the power-weighted average for the SFC_{AEi} of the respective engines (i). Auxiliary Engine(s) certified to NOx Technical Code 2008 test cycles D2 or C1.

It is however not stated clearly which of the NOx Tier II or Tier III certified $SFOC_{ME}$/$SFOC_{AE}$ values shall be applied in the EEDI formula. It is noted within the Guidelines, in footnote 6 relating to $f_{eff(i)}$, the availability factor for innovative energy efficiency technology, that EEDI calculation should be based on the normal seagoing condition outside Emission Control Area designated under regulation 13.6 of MARPOL ANNEX VI.

Shipyards often obtain confirmation from Owners that the vessel's predominant mode of operation would be outside of ECA in order to base the attained EEDI calculation on NOx Tier II SFOC values. The vessel's flag administration would normally need to be informed.

Use of dual attained EEDI values on the IEE certificate (corresponding to engine NOx Tier II and NOx Tier III certification) has not been agreed upon by the IMO yet.

A related issue is that for dual fuel engines, NOx testing is sometimes only conducted for one of the fuels, and therefore even if the vessel is intended to be operated on the alternative fuel, for the purposes of the EEDI calculation, only carbon factor for MGO is used.

7.1.1 Proposed Way Forward

For now, we recommend maintaining the status quo, considering also that these differences are captured within the CII framework and the extent of ECAs is fairly limited.

7.2 Methane Slip

The methane slip of propulsion engines vary from negligible in steam turbines, to 0.2-0.3 g/kWh for the MAN ME-GI engines operating on the diesel process, increasing to 1.0-1.5 g/kWh for the latest Otto Cycle engines from WinGD X-DF 2.0, and 2.8 g/kWh for the latest 4 stroke dual fuel Otto Cycle engines. Note that these numbers already reflect an improvement from the 5.5-6.0 g/kWh slip figures that used to be quoted for 4 stroke Otto Cycle engines.

The Thinkstep study used slightly lower figures to the figures above derived from engine manufacturer's data and presentations, however this is not significant.

However there are some further considerations:

- While in Tier II mode the ME-GI engines are better than the X-DF engines on methane slip, in Tier III mode, the X-DF engines may be better in overall GHG emission due to the higher SFOC of the ME-GI engines in Tier III mode
- There is some evidence that the Otto-cycle engines have no visible soot in gas mode compared to the ME-GI engines – meaning that potentially black carbon needs to be considered in tandem
- Low load behaviour may also need to be compared between the engines, where methane slip typically increases with lower loads, and this is not accounted for in the EEDI framework, neither for the main nor auxiliary engines which are more likely to be run at low load
- Accelerating and decelerating also increases methane slip

It has been suggested by a number of submission to MEPC to consider using a CO_2 equivalent basis (based on measurement of methane slip parent engine certification on the test bed), however it has not been clear what has been intended.

7.2.1 Proposed Way Forward

For calculation of the main engine term, we have:

$$P_{ME} \text{ x } CF_{ME} \text{ x } SFC_{ME}$$

For a ME-GI engine with 10,680 kW and P_{me} of 8,010 kW, the calculation today for an without considering methane slip (assuming LNG as primary fuel) would be 8,000 x 2.75 x 145 = 3,193,988 g CO_2.

Conceptually adding in methane slip it would become:

$$P_{ME} \text{ x } (C_{FME} \text{ x } SFC_{ME} + C_{FMEslip} \text{ x } SFC_{MEslip})$$

8,010 x (2.75 x 145 + 84 x 0.2) = 3,328,556 g CO_2, an increase of **4.2%** assuming a **GWP_{20} of 84** and a slip of 0.2 g/kWh.

If we considered the X-DF with a methane slip of 1.5 g/kWh, the calculation becomes:

8,000 x (2.75 x 145 + 84 x 1.5) = 4,203,248 g CO_2 an increase of **31.6%**

LNG typically improves the numerator in the EEDI equation by around **23%** through improvements to SFOC and the carbon factor. On this basis, methane slip negates any benefit from LNG from around **1.1 g/kWh** or around 0.8% of SFOC.

For ships where LNG is not the primary fuel:

$P_{ME(i)} \cdot (f_{DFgas(i)} \cdot (C_{FME\ pilot\ fuel(i)} \cdot SFC_{ME\ pilot\ fuel(i)} + C_{FME\ gas(i)} \cdot SFC_{ME\ gas(i)} + C_{FME\ slip(i)} \cdot SFC_{ME\ slip(i)}) + f_{DFliquid(i)} \cdot C_{FME\ liquid(i)} \cdot SFC_{ME\ liquid(i)})$

Within the EEDI framework, we will need to specify the value of $C_{FMEslip}$ which for now we are assuming as 84 using GWP_{20}.

Outside the bounds of the EEDI framework, consideration should be given to the development of a measurement protocol and associated amendments to MARPOL Annex VI to standardise the measurements and weighting of methane slip.

We think it is better to be explicit about including a methane slip in this way and to leave room for addition of other GHG later, than to suggest that it is CO_2 equivalent but have to leave out N_2O and black carbon.

Before implementation of the methane slip factors, consideration also needs to be given to the difference between ships where the majority use liquid fuels, and ships where the majority already use LNG:

- For ship types that have only a small proportion of LNG fuelled ships, there are no real issues with implementing the methane slip factor as the majority are still being compared with liquid fuelled ships where the carbon factor is unchanged
- For ship types which have a large proportion of LNG ships (e.g. LNG carriers, and potentially cruise ships in the future), the comparison of new ships implementing the methane slip factor to a reference line and population of ships that do not account for methane slip may cause problems, potentially even in reaching of Phase 3 targets

However implementation of a methane slip factor is probably more critical than agreeing Phase 4 EEDI because the EEXI and CII framework currently does not account for methane slip either.

Note a factor accounting for black carbon would need to be applied to HFO and MGO as well, however again ensuring comparability with the EEDI baselines will need to be considered.

7.3 Carbon Factor C_F

As mentioned in the introduction to this chapter, the carbon factor works reasonably well for fossil fuels which contain carbon. Where this system begins to breakdown is where there are drop in fuels which are chemically identical to their fossil counterparts where some modification of carbon intensity is occurring upstream in the well to tank portion not currently covered by the chemical derivation of C_F.

This includes biofuels where carbon is first removed from the atmosphere, or e-fuels where production of the fuel may be low or zero carbon, but carbon needs to be added to the fuel e.g. methane or methanol.

There are two basic points of view on this:

1. A ship running on significant amounts of biofuel should be able to pass EEDI via a credit to the carbon factor
2. We need to implement full well to wake carbon factors in EEDI and even CO_2e to account for other GHGs

The answer to both is that EEDI defines the technology that goes into a ship and not the fuel. In the case of drop in biofuels, EEDI cannot determine or control the percentage of biofuel a ship may use through its life and there are practically no technological modifications required to the ship which might justify an improved EEDI. Any impact of such fuels is better accounted for in the CII framework.

For well to wake carbon factors, and CO_2e the concept is about trying to incentivize the "greenest" technology. The advantages and disadvantages of well to wake and tank to wake approaches for carbon accounting are discussed in some detail in Task B. In addition to the issue explained above in that EEDI cannot determine the type of fuel to be used throughout the lifetime of the ship, most fuels tend to have a number of production pathways which will result in different carbon factors.

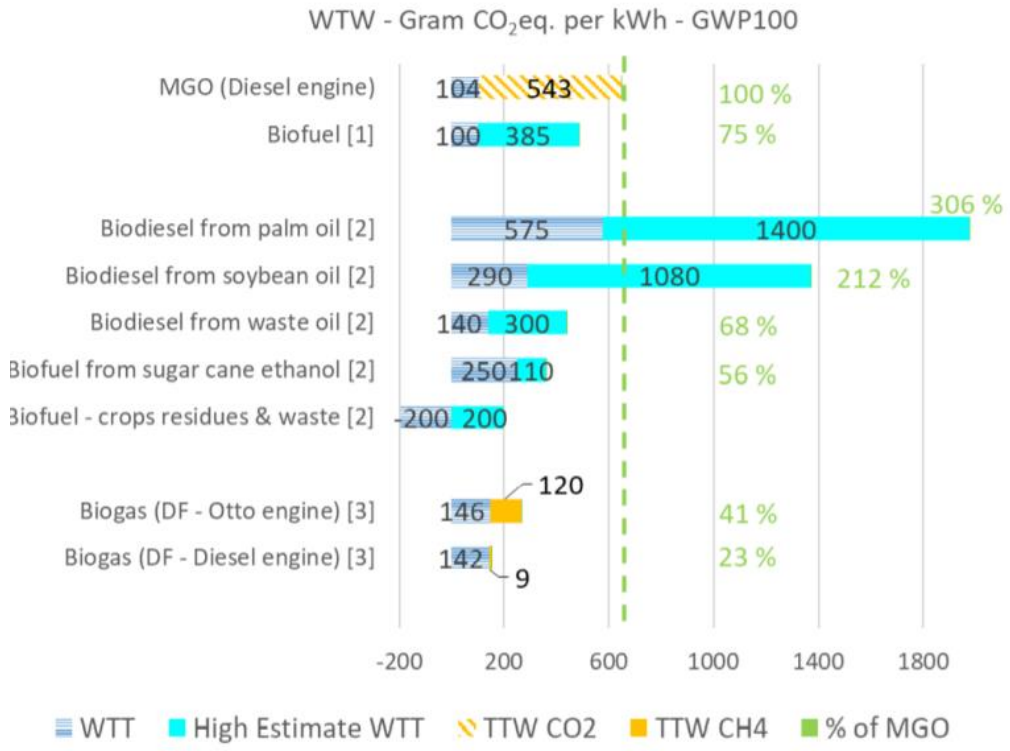

Figure 89 Comparison of WTW for Biofuels - Lindstad/SINTEF

As can be seen above different production pathways alone may lead to quite different estimates, however there are also significant variations in assumptions which can lead to quite large differences. This presents a problem in defining well to wake carbon factors – should it be an average or maximum for each type of fuel. Or if there are multiple values for each fuel type, which should be used in EEDI? Once selected this would need to be linked to ongoing certification, however it is difficult to guarantee to only use fuel from a particular production pathway.

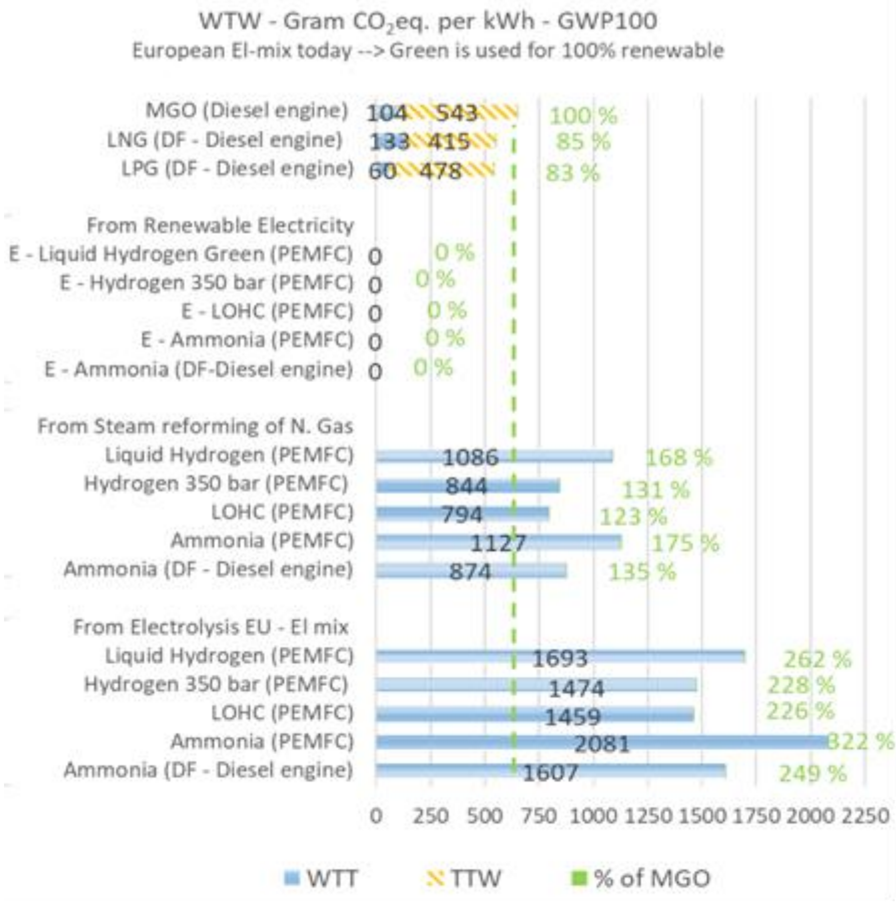

Figure 90 Comparison of WTW values of e-fuels - Lindstad/SINTEF

The above chart shows the large variability in different fuels, and demonstrates how use of well to wake in the EEDI framework risks entrenching fossil fuels and constraining innovation due to the much higher well to wake values of the alternative fuels as seen above.

7.3.1 Proposed Way Forward

Therefore we recommend that only tank to wake carbon factors are used for EEDI, however slip factors such as for methane should be included as described above.

However it is recommended that work on lifecycle analysis of fuels is prioritised in order to help provide policy direction and recommendations in the coming years. Such work may focus fuel production along certain pathways and reduce the uncertainty in the assumptions, and the use of well to wake in the EEDI framework may then be re-evaluated.

Fuels with no carbon molecules such as ammonia or hydrogen would therefore have a carbon factor of 0 under a tank to wake system and this should be included in the table of C_F factors in the EEDI calculation guidelines. For single fuelled vessels we think this is reasonable due to the significant innovation that will be needed, and the additional weight of the fuel containment systems that will be significant and change the design of such ships compared to the conventionally fuelled peers. However such ships would still go through the EEDI certification process, though some thought would be required to ensure that relevant information is collected for policy decision making.

For dual fuelled vessels, those with an ammonia-ready or hydrogen-ready notation that will initially be using conventional fossil fuels should continue to comply with EEDI, potentially using the dual fuel calculation methodology as adapted depending on the design compromises that have been made.

The above applies to ships with conventional propulsion, however where fuel cells are used, by default these will be classed as non-conventional propulsion and excluded from EEDI.

7.4 Dual fuel calculation method

Currently the dual fuel calculation method is as follows:

$$f_{DFgas} = \frac{\sum_{i=1}^{ntotal} P_{total(i)}}{\sum_{i=1}^{ngasfuel} P_{gasfuel(i)}} \times \frac{V_{gas} \times \rho_{gas} \times LCV_{gas} \times K_{gas}}{\left(\sum_{i=1}^{nLiquid} V_{liquid(i)} \times \rho_{liquid(i)} \times LCV_{liquid(i)} \times K_{liquid(i)}\right) + V_{gas} \times \rho_{gas} \times LCV_{gas} \times K_{gas}}$$

$$f_{DFliquid} = 1 - f_{DFgas}$$

f_{DFgas} is the fuel availability ratio of gas fuel corrected for the power ratio of gas engines to total engines, f_{DFgas} should not be greater than 1;

V_{gas} is the total net gas fuel capacity on board in m^3. If other arrangements, like exchangeable (specialized) LNG tank-containers and/or arrangements allowing frequent gas refuelling are used, the capacity of the whole LNG fuelling system should be used for V_{gas} . The boil-off rate (BOR) of gas cargo tanks can be calculated and included to V_{gas} if it is connected to the fuel gas supply system (FGSS);

V_{liquid} is the total net liquid fuel capacity on board in m^3 of liquid fuel tanks permanently connected to the ship's fuel system. If one fuel tank is disconnected by permanent sealing valves, V_{liquid} of the fuel tank can be ignored;

ρ_{gas} is the density of gas fuel in kg/m^3

ρ_{liquid} is the density of each liquid fuel in kg/m^3

LCV_{gas} is the lower calorific value of gas fuel in kJ/kg;

LCV_{liquid} is the lower calorific value of liquid fuel in kJ/kg;

K_{gas} is the filling rate for gas fuel tanks;

K_{liquid} is the filling rate for liquid fuel tanks;

P_{total} *is* the total engine power, P_{ME} *and* P_{AE} in kW;
$P_{gasfuel}$ *is* the dual fuel engine installed power, P_{ME} *and* P_{AE} in kW;

If f_{DFgas} is 0.5 and above, LNG is considered as the primary fuel and the C_F value of LNG, 2.75 may be used for the EEDI calculation. If it is below, then the C_F value is adjusted as follows:

$P_{ME(i)} \cdot (f_{DFgas(i)} \cdot (C_{FME\ pilot\ fuel(i)} \cdot SFC_{ME\ pilot\ fuel(i)} + C_{FME\ gas(i)} \cdot SFC_{ME\ gas(i)}) + f_{DFliquid(i)} \cdot C_{FME\ liquid(i)} \cdot SFC_{ME\ liquid(i)})$

The concept is to try to avoid a token installation of LNG and primarily use diesel while claiming the full benefit. It should be noted that when examining the MRV and DCS database, ships which are able to use LNG tend to always use it, since it is also relevant for SOx and NOx compliance and LNG bunker supply contracts tend to have minimum quantities. However the concept does deal with so called LNG ready notations which may not be fully fitted out with LNG storage and handling equipment.

7.4.1 Proposed Way Forward

In assessing the fitness of purpose of this clause there are two main issues:

1. The calculation methodology assumes that one fuel is a gas and the other fuel is a liquid. While this is the case for most alternative fuels, not all alternative fuels are gases e.g. methanol/ethanol
2. For fuels of similar calorific value, setting f_{DFgas} = 0.5 as a threshold for primary fuel is reasonable, e.g. MGO at 42,700 kJ/kg and LNG at 48,000 kJ/kg. However methanol has a calorific value of 19,900 kJ/kg and this may impose an overly strict constraint

A proposed way forward would be to amend the EEDI calculation guidelines to clarify that gas may also include alternative liquid fuels, but for these alternative fuels the f_{DFgas} threshold may be lowered at the discretion of the Administration.

8 TASK C1 FRAMEWORK TUNING - OPERATING PROFILE

8.1 Introduction

The benefit to society is one of the parameters that is included in the EEDI formula i.e. to be able to transport as much cargo as possible with the lowest CO2 emissions. So, the vessels EEDI is calculated to the laden conditions and thereby reflects a CO_2 emission considering the vessel transporting the full cargo load.

In reality vessels are not operating always at the EEDI conditions. Tankers and bulkers have intermediate ballast voyages and container vessels are often sailing at varying draughts on the different voyages.

If vessels are optimized for the EEDI condition and there are little effort in the improving the design for other loading conditions and speeds, then a vessel that complies with the EEDI conditions might be a bad performer when it is out of the EEDI condition.

Looking at the operational profile section in the Task A report, we see that e.g. bulk carriers on sea voyages sail at sea 65% of the time and is in laden condition 60% of this time and in ballast condition for 40% of this time. The vessel will typically emit less CO_2 in the ballast condition but the benefit to society is very little, since it is sailing without any cargo.

It could then be considered to include also the “off-EEDI” condition in the evaluation of the EEDI so vessels that has an overall good design would be rewarded on the attained EEDI.

Going back to the bulk carriers above, the EEDI for the ballast condition should then be calculated and an “average” EEDI based on the laden and ballast values would then be the output.

Including the “ballast condition EEDI” and calculating the EEDI with the “normal EEDI formula” with a reduction in deadweight to match the ballast condition, the penalty to the EEDI is very significant. To deal with this, it would be reasonable to consider always using the maximum deadweight and to only the change in V_{ref} at the EEDI power in ballast and laden respectively.

8.2 Basic Considerations

Comparison of two Kamsarmax bulker vessels, one from 2008 and one vessel from 2019. The vessels are of the same design and from the same shipyard. Differences on design, EETs and engine/propeller as shown in the following table:

Table 8-1 Design Comparison of 2008 and 2019 Kamsarmax Bulk Carriers

	Vessel 1	Vessel 2
Year built	2008	2019
EEDI	pre EEDI	EEDI phase 1 (EEDI = 3.69)
Design changes		
ME MCR		-1%

ME RPM (at MCR)		-21%
Propeller diam.		+13%
Cb		-1%
Additional design changes		Reduced bulbous bow Pre swirl fins Rudder bulb High efficiency propeller

The differences in fuel oil consumption for the two vessels are given as in the following table:

Table 8-2 Comparison of Fuel Consumption of 2008 and 2019 Kamsarmax Bulk Carriers

Speed	Average difference in FOC [t/24hrs]	
	Ballast	Laden condition
12 knots	10%	10%
14 knots	11%	17%

The reduction of emissions is somewhat higher in the laden condition at the design speed than it is ballast. Considering that the vessel design is optimized for the EEDI condition and not for the ballast condition, the reduction in emissions in ballast from the old vessel to the newer, seems to be related to the engine/propeller modifications and not to design improvements out of the EEDI condition.

To include the ballast condition in the evaluation of the EEDI and to being able to formulate something towards the existing EEDI, the following approach could be taken:

Two similar size MR tankers (DWT Scantling) built before EEDI regulations

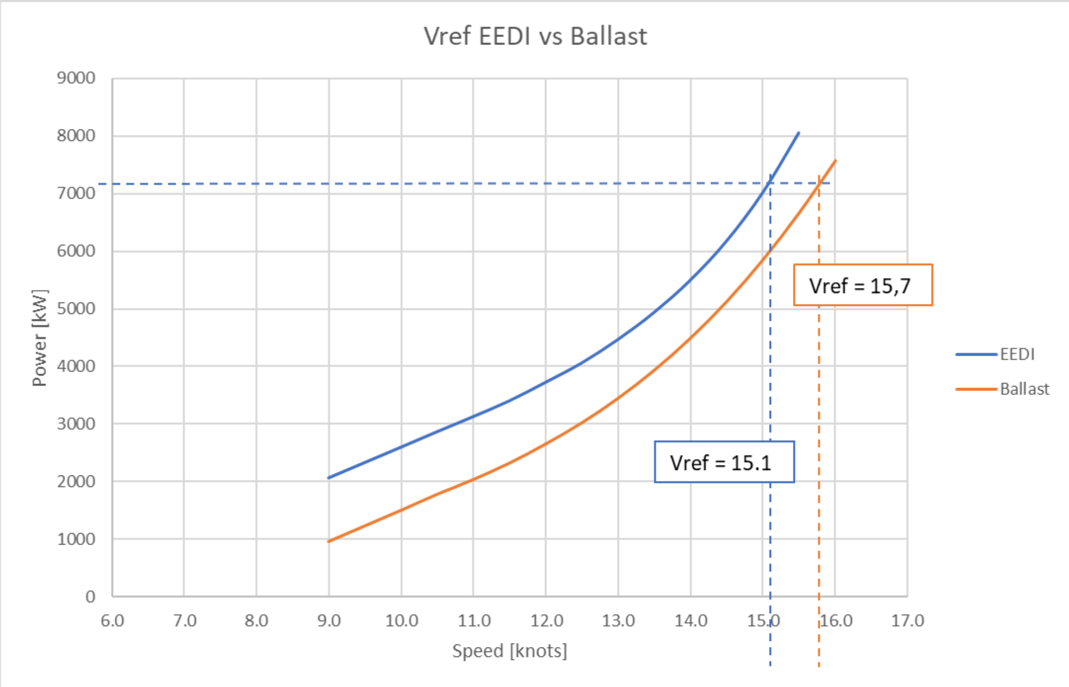

Figure 91 Speed Power Curve MR Tanker Built 2008 – VPS Data

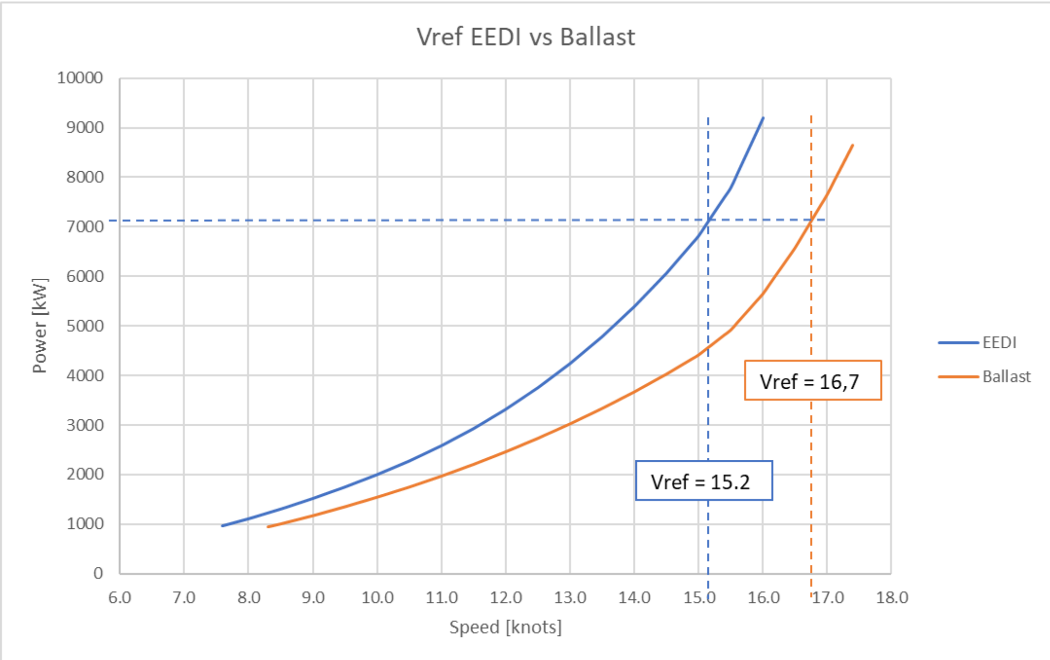

Figure 92 Speed Power Curve MR Tanker Built 2010 – VPS Data

The speed/power curve at the EEDI condition defines the V_{ref} at 75% MCR. By including the ballast curve and using the 75% MCR as argument the V_{ref} ballast could then be found. The V_{ref} ballast would then indicate the difference in design in ballast between the 2 vessels and a scheme to adjusting the attained EEDI could then be made e.g. by using a relation between V_{ref} EEDI and V_{ref} ballast.

In order to demonstrate how this might work in practice, let’s consider two bulk carriers both with EEDI of 3.69 but with the speed power curves as shown above. In this example vessel 1 would then have a modified EEDI of:

$$15.1/15.7 * (3.69) = 3.55$$

and the vessel 2 would have a modified EEDI of:

$$15.2/16.7 * (3.69) = 3.36$$

Thereby vessel 2 would then be rewarded by a smaller EEDI due to the better ballast design.

Another way to reward the vessels could be to maintain the V_{ref} and then find the reduced power in ballast condition and use this on the EEDI calculations. What however still needs to be solved is how the modified EEDI is used, since it provides a large reduction in EEDI which is not immediately comparable to the EEDI baseline.

It is also important to look at cases for existing vessels, to verify if there is any effect on the vessels in service today.

8.3 Case Study - Tankers

Tankers comparisons from different yards, building year 2008.

Table 8-3 Comparison of 2 Tankers built 2008

Vessel	DWT, sc [ton]	Draught, sc [m]	MCR [kW]	EEDI speed [knots]	Ballast speed [knots]
#1	45994	12.2	9480	14.1	15.6
#2	50000	13	7800	14.1	15.3

The above two vessels are typical for the vessels that were put in the market in the period before the financial crisis. Large variations in installed power were seen and odd sizes propellers led to various performance behaviour for the different vessels. With the inclusion of the EEDI regulations, vessels have been “streamlined” with respect to installed power, rate of RPM and propeller dimensions (for fixed propellers at least) and the differences in the performance in “off EEDI” conditions seems to be levelled out.

Tankers comparison from different yards, building year 2019. Speeds found at 75% MCR

Table 8-4 Comparison of 4 tankers built 2019

Vessel	DWT, sc [ton]	Draught, sc [m]	MCR [kW]	EEDI speed [knots]	Ballast speed [knots]
#1	50,880	13.3	7700	14.1	15.6
#2	50,000	13	7800	14.1	15.3

#3	49,936	13.3	7180	14.4	15.4
#4	49,999	13.3	7588	14.4	15.4

Looking at vessels built in the EEDI period, 4 vessels are compared in the table above. The installed power and the V_{ref} are in the same range. For vessels #1 & #2 there is 100 kW difference in power and V_{ref} at the EEDI condition is the same. In the ballast condition there is a slight difference (0.3 knots) in the ballast performance. For vessels #3 and #4 both EEDI and ballast speeds are the same at the EEDI power.

By applying the "reduction rule" mentioned in the previous section, there will hardly be any difference (1 on the second digit) in the attained EEDI for all the 4 vessels built in 2019. Based on this small sample of tankers there does not appear to be any advantage to take the ballast condition into account.

However what is not clear is whether implementation of this would encourage further optimisation to be carried out at ballast condition.

8.4 Case Study - Bulk carriers

A similar view can be taken when looking at bulk carriers.

Bulker vessels comparison from different yards, building year 2018-2020. Speeds found at 75% MCR

Table 8-5 Comparison of 4 Bulk Carriers built 2018-2020

Vessel	DWT, sc [ton]	Draught, sc [m]	MCR [kW]	EEDI speed [knots]	Ballast speed [knots]
#1	81607	14.47	9660	14.42	15.3
#2	81550	14.45	9932	13.8	14.9
#3	81783	14.43	9660	14.8	15.3
#4	81606	14.5	9660	14.8	15.3

Of the 4 vessels in the table above, vessel #2 seems to be the vessel with the less favourable design when looking at installed power, V_{ref} and comparable ballast speed. The three other vessels are more or less similar on all parameters. Vessel #1 are built in 2018 where #3 &#4 are built in 2019/2020 which might indicate why there is difference in V_{ref}.

For bulk carriers and tankers sailing in either ballast or laden condition and built in the EEDI period, it does not seem to be relevant to include the EEDI design evaluation towards also including the ballast condition, since there does not seem to be a major difference in the ballast design performance between the vessels.

8.5 Case Study - Container ships

Many vessels are highly optimized to perform the maximum to a certain operating point. In cases where some of the operational parameters are off the design point, the performance of the vessel might be worse than anticipated. An example is shown in the figure below:

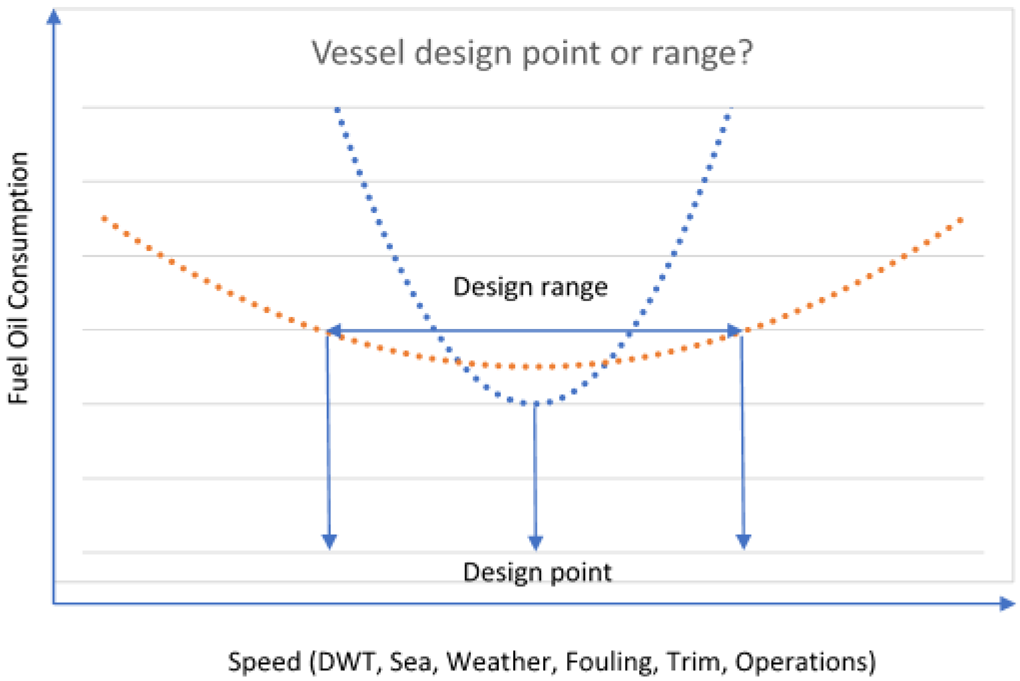

Figure 93 Comparison of fuel consumption at design point and over a range

In those cases, the actual CO2 emissions could be less in an operating range than for the one-point optimization and if the vessel operate in the range as exemplified above.

Table 8-6 Comparison of 2 Container Ships

Vessel	DWT, sc [ton]	Draught, sc [m]	MCR [kW]	EEDI speed (75%scantling) [knots]	Ballast speed [knots]
#1	104449	14.0	38505	22.2	22.8
#2	123587	14.0	40264	22.3	22.6

The 2 vessels are designed to almost the same V_{ref}, vessel #2 is 0.1 knot higher and there is little difference in the ballast performance. Vessel #1 has a better overall performance since it maintains an average speed profile at higher draught (at the same engine load = 75%), see figure next page.

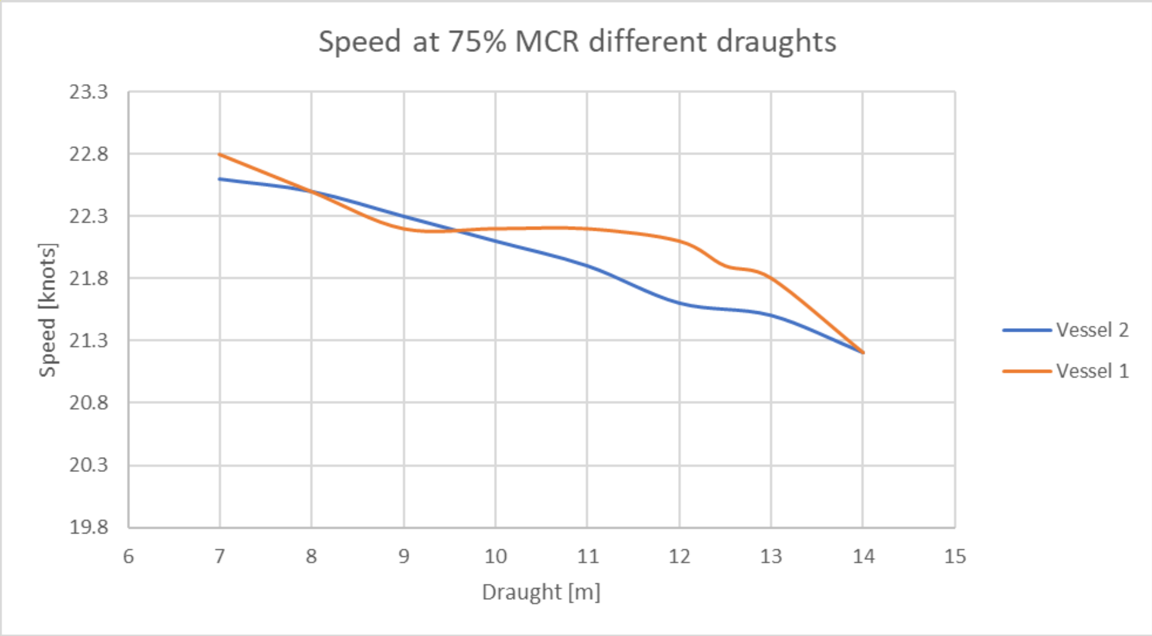

Figure 94 Comparison of Speed at 75% MCR at different draughts - VPS Data

This shows significant difference in speed at different draughts but also points where the speeds are similar. For the above examples the 70% draught condition will likely show a divergence, but this does not necessarily tell the whole story. The difficulty however is trying to assess what the operating draught range ought to be, how many different draughts should be considered and how to weight these different operating points, given that shipowners may choose different optimisation criteria for different routes and ship sizes.

Additionally it should be noted that the picture that may emerge at other power levels may also be different.

The typical operational profile for the two vessels above is as in the figures on the next page.

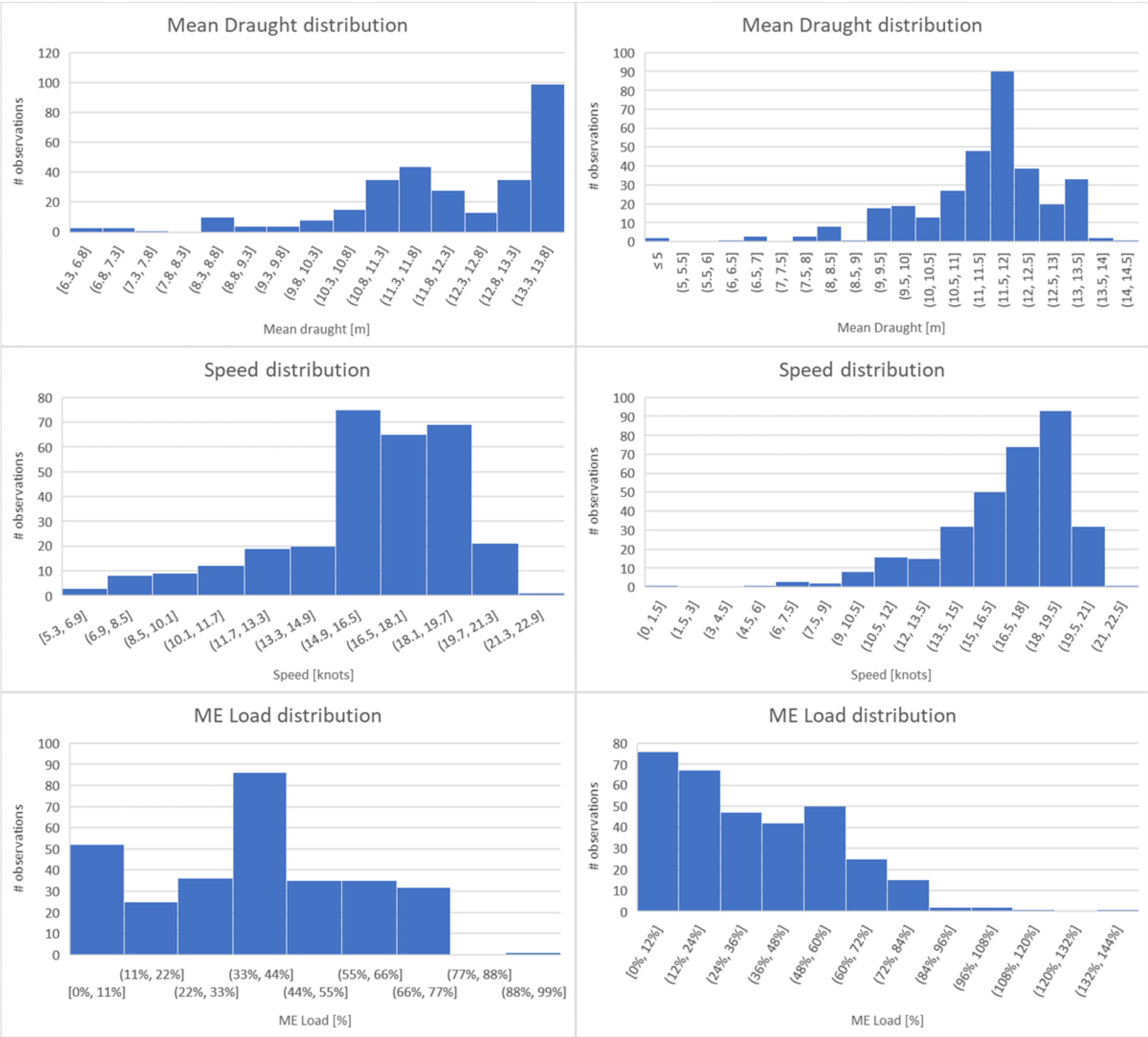

Figure 95 Comparison of container ship operating profiles

As can be seen the vessels are operated very differently and picking other operational points to be evaluated within EEDI could also incentivise optimisation at the wrong point. On the other hand, it is clear that the ships are hardly ever operating at the EEDI conditions which should lead to considering if the EEDI is a relevant index for the vessels in this case. It captures the design efficiency but not at the actual operating profile.

8.6 Eco Speed

One option not really evaluated above concerns potentially evaluating EEDI at different speeds, but at the same draught. The challenge then becomes how to define the alternative speed(s), but also that engine SFOC is variable and an improved EEDI could be gamed by choice of the slower speeds. On the other hand, the alternative speed could be mandated. This could be based on market averages for eco speed, noting that these may change over time.

An example is below:

82,000 dwt bulk carrier 9,900 kW installed power, P_{me} 7431 kW V_{ref} 14.83 knots, SFOC 162.7 g/kWh. Attained EEDI 3.465.

Eco speed 12 knots – equivalent P_{me} 3,800 kW, SFOC 176 g/kWh. Attained EEDI 2.522.

Any combination of the two attained EEDI would of course be better than the attained EEDI calculated at 14.83 knots and therefore no longer be compatible with the EEDI baselines and require new baselines to be drawn up.

8.7 Proposed Way Forward

In conclusion, for bulk carriers and tankers, while it is possible to take ballast situations into account, this does not appear to lead to any meaningful differentiation of performance. For containerships, while there appears to be a clear differentiation of performance, selection of the appropriate operational points will be challenging and have possible unintended consequences.

If the CII had not been implemented, perhaps there would be merit to investigate this further together with some shipyards and shipowners, however with CII in place, it is uncertain as to whether implementing an operating profile in EEDI would be able to drive any further savings.

For the use of Eco speed, we will take this theme up again in the conclusions.

9 TASK C1 FRAMEWORK TUNING - MINIMUM PROPULSION POWER

9.1 Introduction

The IMO regulation introducing minimum propulsion power requirements under MARPOL Annex VI, has been discussed in summary under Task A. We will provide a short overview of the existing interim guidelines again here to better set the stage for a direct comparison with the latest proposed methodology to finalize the document and the engine power limitation alternative proposal. As already emphasized, this is an action of particular importance by the IMO MEPC now that EEDI requirements for new ships follow the Phase 2 limits, heading into 30% reduction from the baseline by 2025.

The EEDI is a goal-based technical standard to reduce the carbon dioxide (CO_2) emissions from shipping industry. To improve a ship's EEDI, innovative technologies like hull form optimization, air lubrication, energy saving devices or use of alternative fuels can be considered. In addition, the most effective way to reduce the EEDI rating is to reduce the ship's service speed. Reducing ship speed in terms of design efficiency will however result in reducing installed main engine MCR. Therefore, to ensure safe manoeuvring in adverse condition, the Minimum Propulsion Power (MPP) requirement was introduced to the EEDI regulations.
As a result of the conflicting nature of the EEDI and MPP requirements the engine selection for large tankers, bulk carriers and combination carriers have become a design challenge. The extensive case studies undertaken by the EU research project SHOPERA and similar studies in Japan for bulk carriers and tankers indicate that it could be difficult to simultaneously satisfy both MPP and EEDI Phase 3 and in many cases Phase 2 requirements.

9.2 IMO Interim Guidelines on Minimum Propulsion Power by MEPC.1/Circ.855

The purpose of the IMO's Minimum Propulsion Power (MPP) requirements is to assist verification that ships fulfilling EEDI requirements also have sufficient power installed to remain manoeuvrable under adverse conditions as specified in the IMO guideline. The MPP requirements apply to tankers, bulk carriers and combination carriers with at least 20000 DWT, and are outlined in MEPC.1/Circ.850/Rev.2.

The MEPC guideline offers two assessment levels. In the level 1 assessment the vessel's installed power is simply compared with type-specific minimum power lines determined through a regression based on deadweight. The vessel's installed power is considered to be acceptable if it is not below the minimum required.

If the vessel does not fulfil the level 1 assessment criteria, it must successfully undergo a Level 2 assessment.

The level 2 assessment involves a more detailed investigation of the vessel's performance which also takes into account the main engine characteristics.

The Level 2 assessment is comprised of the following steps:

- Based on the windage area and rudder area a required advance speed of the vessel is determined, which lies between 4 and 9 knots
- for that advance speed a total resistance under defined adverse conditions of wind and wave is estimated

- using the estimated resistance, the propulsive coefficients and the propeller open water characteristic, a corresponding operating point for the propeller is found in terms of delivered power and rpm.
- A shaft efficiency is applied to obtain the required engine brake power PB
- At the propeller rpm of the operating point under adverse conditions, the resulting required power PB is checked against the engine load diagram to verify that the engine is capable of developing the necessary torque under those conditions.

If the required power under adverse conditions lies below the main engine's available power at corresponding rpm, the ship should be considered to have sufficient power to maintain the manoeuvrability in adverse conditions.

Weather and sea state conditions that define adverse weather are determined by the IMO interim guidelines based on vessel main parameters.

The Level 2 assessment requires the determination of wave added resistance through model tests in regular waves. Empirical formulae are also referenced, although not directly specified. The ability to accurately estimate the added wave resistance becomes a critical component for the ship to be verified compliant with MARPOL Annex VI, Chapter 4 and issued an IEE certificate.

According to the MEPC guideline, the propulsive coefficients thrust deduction (t), wake fraction (w) and relative rotative efficiency (η_R) as well as the form factor (k) can be estimated or taken from model tests. Conservative estimates for these values are provided in the guideline. The model test conditions are not specified in the guideline, although they can have a significant effect in particular on the thrust deduction fraction.

9.3 Draft Revised Guidelines for Determining Minimum Propulsion Power to Maintain Manoeuvrability of ships in adverse conditions by MEPC 71/INF.28

In an effort to address the various ambiguities described for the interim guidelines, a collaborative effort was made by certain IMO member states. With support by IACS, and taking into account the outcomes of the work by the research project Energy Efficient Safe Ship Operation (SHOPERA) and Japan's research project, the draft revised guidelines were submitted to the IMO MEPC through document MEPC 71/INF.28. Supplementary technical data and supporting information on the weather scenarios examined and ship response are given in document MEPC 71/INF.29. A comparison with the interim guidelines in Figure 1 shows the draft revised proposal to apply a higher threshold in terms of safety as it has raised severity levels of the prevailing environment.

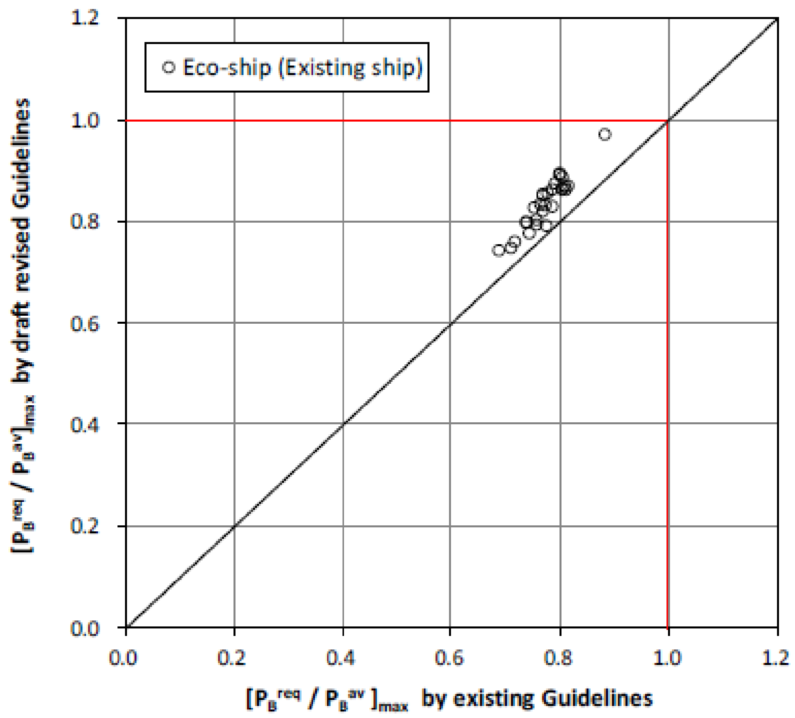

Figure 96 Maximum ratio of required brake power to available brake power according to existing Guidelines (x axis) and draft revised Guidelines (y axis). PBreq/PBav < 1. 0 indicates that ship can fulfil requirements of existing or draft revis

The key similarities and differences between the interim guidelines and the draft revised guidelines are summarized in Table 9-1.

Table 9-1 Key Differences Between Interim Guidelines by MEPC.1/Circ.850 and Draft Revised Guidelines by MEPC 71/INF.28

	Interim Guidelines MEPC.1/Circ.850/Rev.2	Draft Revised Guidelines MEPC 71/INF.28
Definition of adverse weather	Based on ship main dimensions (Lpp).	Based on ship main dimensions (Lpp).

conditions (wind and sea state)	Wind and waves resistance is calculated for head direction (0 deg) only. Peak wave periods range from 7-15 sec	Maximum added resistance in seaway is accounted for wind and wave directions from head to 30 degrees off-bow. Peak wave periods range between 3.6√hs to the greater one of 5.0√hs or 12.0 seconds, with the step of peak wave period not exceeding 0.5 seconds Wind directions range from head ε=0 to 30 degrees off-bow ε=30.
Ship speed (Vs)	Based on windage area and rudder area	Set at 2 knots
Self propulsion factors (t, w)	conservative estimates are provided if there are no values from tank tests.	t, w default values are not given. The document does reference MEPC.232(65) but does not provide guidance on use of paragraph 3.13 and Table 2
Form factor (k)	Empirical estimate is provided if there is no value from tank tests.	No guidance is provided on how to obtain k
Wind added resistance definition	Numerical calculation formula to be used in accordance with ITTC Recommended Procedures Wind resistance coefficient (head wind) can be obtained: • Wind tunnel tests	Numerical calculation formula to be used in accordance with ITTC Recommended Procedures Maximum resistance over wind directions from head ε=0 to 30

	• Approved numerical calculations • Taken at value equal to 1.	degrees off-bow ε=30 Wind resistance coefficients can be obtained: • Wind tunnel tests • Approved numerical calculations • Taken at value equal to 1.1 • Taken at value 1.4 for ships with specific deck crane configurations
Wave added resistance definition	If seakeeping model tests are not available, the quadratic transfer function of the added resistance may be obtained from an equivalent method verified by the Administration.	The maximum over wave directions from head ε=0 to 30 degrees off-bow ε=30 Added resistance in short-crested irregular waves may be regarded as be the maximum over wave directions from head ε=0 to 30 degrees off-bow ε=30 If seakeeping model tests are not available, the quadratic transfer function of the added resistance may be obtained from an equivalent method verified by the Administration. A semi-empirical methodology is provided in the Appendix.
Rudder resistance due to manoeuvring	N/A	Taken at 3% of propeller thrust, T.

In the following section we will provide use case comparisons using the Interim Guidelines by MEPC.1/Circ.850/Rev.2 and draft revised guidelines by MEPC.71/INF.28.

For the wave added resistance component we have examined the different alternatives offered by the IMO guidelines and evaluated the methodologies by use of data by seakeeping tank tests.

9.3.1 *Aframax Tanker*

For an example Aframax tanker design, the MPP Level 2 Assessment was carried out following the existing interim and proposed draft guidelines. The results are shown in Table 2 below.

For present vessel design, wave added resistance (RAW) results by seakeeping tank experiments in regular waves were available (see Figure 3). It should be noted that the MPP Level 2 Assessment criteria were successfully met by both the existing and proposed draft guideline requirements when the tank test data were taken into account in the MPP calculation.

Table 9-2 Example AFRAMAX Tanker – MPP Assessment Level 2 Results

	Interim Guidelines MEPC.1/Circ.850 **(RAW based on wave QTF derived from ISO 15016:2015 D3)**	**MEPC 71/INF.28** **(RAW based on short-crested irregular wave QTF by empirical formula)**	**MEPC 71/INF.28** **(RAW based on long-crested irregular wave QTF by empirical formula)**	**MEPC 71/INF.28** **(RAW based on wave QTF derived from ISO 15016:2015 D3)**
Deadweight (MT)	115000	115000	115000	115000
ME MCR (kW)	13000	13000	13000	13000
Propeller diameter (m)	7.8	7.8	7.8	7.8
Speed of Advance (kn)	4.61	2	2	2
Significant wave height (m)	5.26	5.76	5.76	5.76
Mean wind speed (m/s)	18.50	22.0	22.0	22
Calm Water Resistance (kN)	98	72	72	72
Aerodynamic Resistance (kN) *	172	229	229	229
Wave Added Resistance (kN)	635 (evaluation at 0 deg heading)	719.50 (maximum value determined at 0 deg heading)	788.60 (maximum value determined at 30 deg heading)	608.5 (evaluation at 0 deg heading)

Self Propulsion Factors (t, w)	Nominal IMO (t: 0.245, w: 0.350)	Nominal IMO (t: 0.245, w: 0.350)	Nominal IMO (t: 0.245, w: 0.350)	Nominal IMO (t: 0.245, w: 0.350)
Required Power (kW)	6708	8072	8867	6845
Required Torque (kNm)	1024	1169	1246	1045
Compliance Margin (%)	96%	104% (required power exceeds the engine torque limitation)	107% (required power exceeds the engine torque limitation)	98.6%

(*) Aerodynamic resistance has been assessed for head winds only.

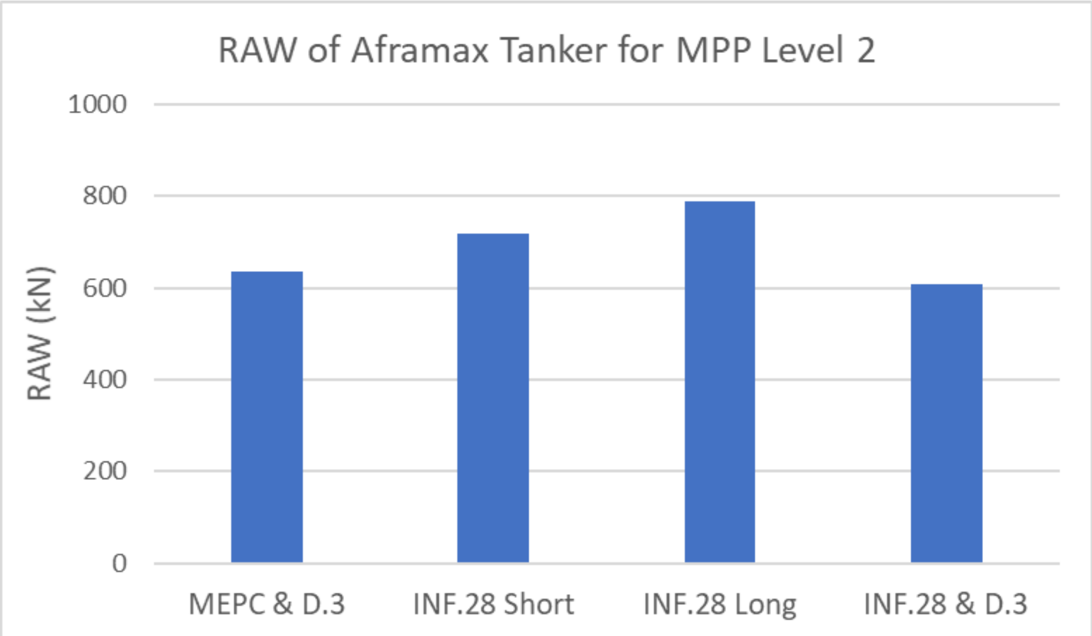

Figure 97 Comparison of Wave Added Resistance (RAW) results based on examined methodologies.

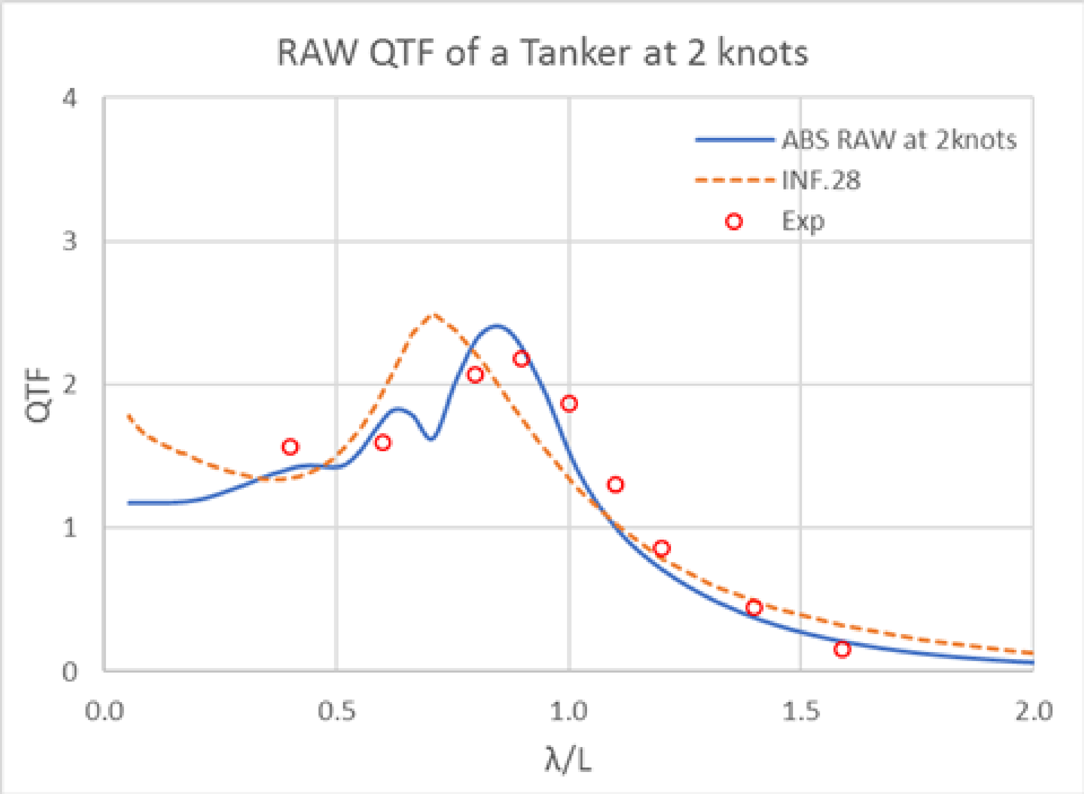

Figure 98 Quadratic Transfer Functions (QTF) results comparison based on examined methodologies (ABS RAW software utilizes the ISO 15016:2015 D3 Method)

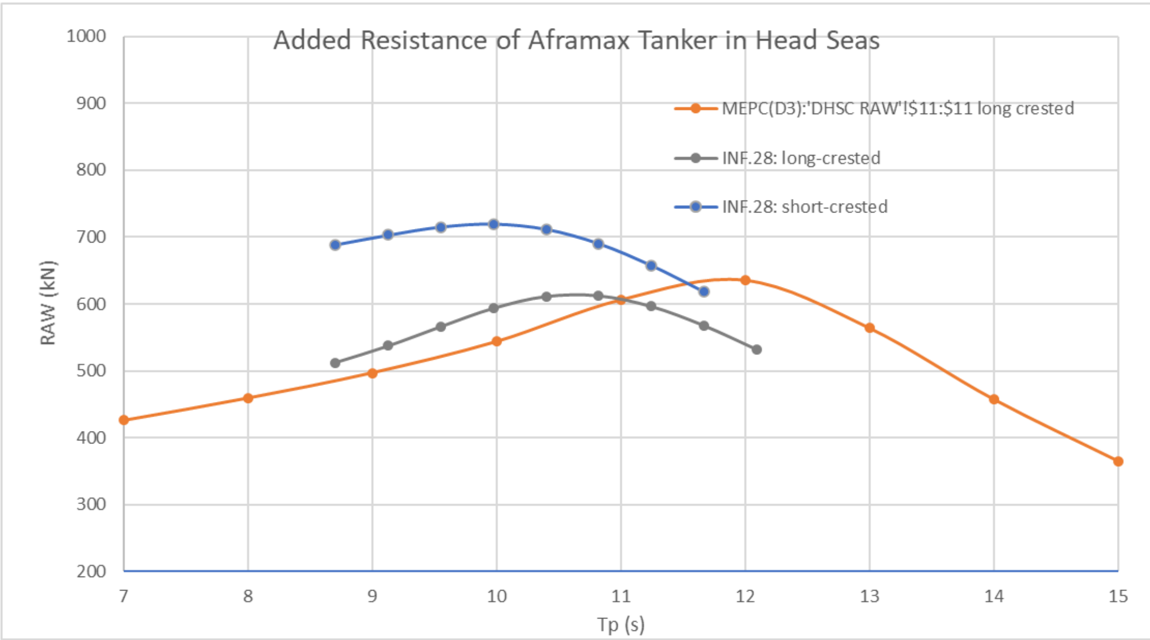

Figure 99 Added Resistance comparison in Head Seas (0 deg) based on examined methodologies

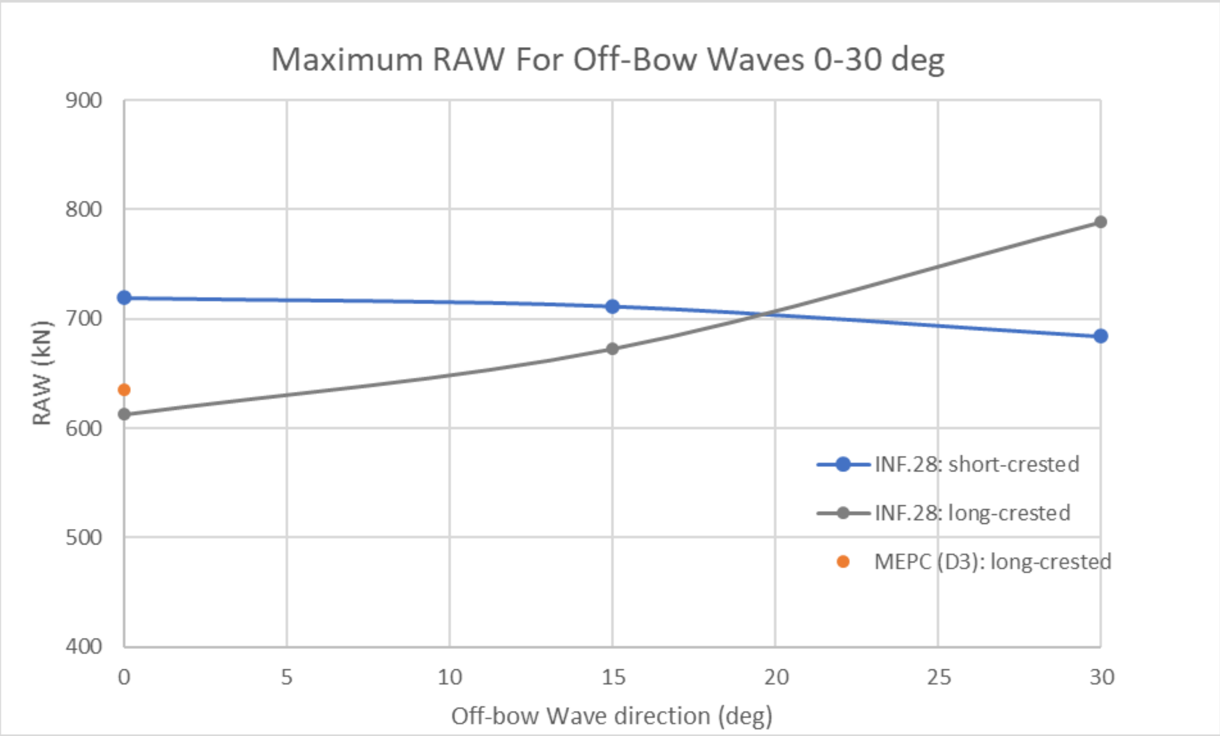

Figure 100 Maximum Wave Added Resistance from quartering waves (0-30 deg) based on examined methodologies

9.3.2 Conclusions

Based on the case studies examined we see that the draft proposed guidelines by MEPC 71/INF.28 provide a more conservative approach to the minimum propulsion power evaluation framework.

Weather and sea state condition criteria have been strengthened requiring maximum values from results corresponding to examination of a broader (and more realistic) range of direction angles. The required speed of advance has been adjusted accordingly to a standard value of 2 kn for all ships based on examination of selected stringent scenarios for adverse conditions that expand the scope and strengthen the manoeuvrability criteria of the interim guidelines by MEPC.1/Circ.850:

Table 9-3 Scenarios for Ship's Handling in Adverse Conditions - MEPC.1 Circ.850

Table 1 Scenarios for ship's handling in adverse conditions

	Scenario 1	**Scenario 2**	**Scenario 3**
Area	Coastal areas	Coastal areas	Coastal areas
Weather conditions	BF6 for L_{pp}<200 m BF7 for L_{pp}>250 m	BF7 for L_{pp}<200 m BF8 for L_{pp}>250 m	BF8 for L_{pp}<200 m BF9 for L_{pp}>250 m
Encountered wave and wind angle	All headings including head, beam and following seas	All headings including head, beam and following seas	Head seas to 30 degrees off-bow for a situation of weather-vaning
Propulsion ability	Speed through water at least 8 knots	Speed through water at least 6 knots	Speed through water at least 2 knots
Steering ability	Ability to perform any manoeuvre in seaway from any heading	Ability to perform any manoeuvre in seaway from any heading	Ability to keep heading into head seas to 30 degrees off-bow

The SHOPERA project concludes that Scenario 3 would be the most demanding, in terms of required main engine power. Technical background and details on the comparison and conclusions can be sourced in document MEPC 71/INF.29. The revised draft guidelines by MEPC 71/INF.28 are based on Scenario 3.

The derivation of wake fraction and thrust deduction coefficients has not been addressed further from what is already the requirement of the interim guidelines. The proposed draft amendments were examined here by use of the conservative default values proposed by the IMO. It is noted that different approaches have been implemented by Shipyards in the past where self-propulsion coefficients are taken from tank experiments, including calm water self propulsion tests with or without load variation for resistance increase. It is advisable that the IMO supports a dedicated study to review and potentially update the existing requirements as we head into EEDI Phase 3.

9.3.3 MEPC 76 Outcome

The Correspondence Group on Air Pollution and Energy Efficiency recommended adoption of the methodology in MEPC 71/INF.28 with a 2 knot advance speed and the suggested definition of adverse weather conditions, even though there was concerns raised that there was the possibility that in some cases the new methodology might lead to further power increases.

As shown above, the requirements will in some cases lead to an increased requirement for torque. While an increase in engine power is one option, as indicated in the Task A1 report, reducing the propeller pitch is perhaps more likely. What this does is likely to increase the pressure on shipyards to continue to drive down attained EEDI values while trying to meet the MPP requirements. It will be some time before we have a concrete view of the implications in terms of attained EEDI, but at this stage it will have potentially minor or no impact, especially at the more advanced shipyards, but may show some impact in the second tier shipyards. At this stage, the application of shaft power limitation for newbuilds is unclear and a work plan to progress this work was set out in the CG report MEPC 76/5/1.

9.4 MPP Requirements for ships below 20k DWT

The applicability of the guidelines from a capacity perspective is currently limited to ships of 20,000 DWT and above. The main reason behind this restriction is that a systematic evaluation of the required standard environmental conditions for ships with deadweight less than 20,000 DWT has not yet been completed. A solid proposal is envisaged for the future, and ongoing studies in the IMO are currently addressing this issue.

One relevant study was funded by the Netherlands Administration to obtain better insights into minimum propulsion power requirements of ships of less than 20,000 DWT and published in document MEPC 70/INF.28.

The study focused on evaluating manoeuvrability criteria in terms of maintaining a sustained speed in head waves, heading recovery and track keeping regardless of the relative direction of wind and waves for approximately 50 ships of the Dutch fleet of relevant cargo carrying capacity mainly with a ‘standard propulsion system’ of CPP propeller and 4-stroke diesel engine. The criteria were selected based on the best knowledge of the researchers of the study on representative examples to examine bollard pull as a more appropriate requirement for the vessel to meet acceptable manoeuvrability margins.

The study concluded that available thrust at low speeds, in terms of the effective bollard pull, is the governing parameter that determines the sustained speed and the ability to recover head seas.

On the other hand, the effective bollard pull that is required for a timely recovery of the relative safety of head seas:

- Is quite sensitive to the adopted weather conditions. The step from the condition with 1-Month and 10-Year return period roughly doubles the requirements
- Shows a clear contribution from the longitudinal wind drag. The effect of the longitudinal position of the superstructure is small.
- Is roughly proportional to ship length
- Is relatively in-sensitive to the "manoeuvring" characteristics
- Is clearly highest for the ship with the lowest slenderness parameter. The difference in required thrust between the normal and extremely full block ship is roughly a factor of 2.
- Is relatively insensitive for the loading condition

Outcome of the study was the example criteria scheme shown below to better evaluate bollard pull as the most appropriate measure to address manoeuvrability requirements. Discussions on the topic are ongoing.

Table 9-4 Example Criteria for Bollard Pull for ships of less than 20,000 DWT - MEPC 70/INF.28

	Restricted waters	Coastal	Ocean
Head seas	Min. x knots in y years wind-wave cllimate	Min. x knots in y years wind-wave cllimate	-
Track keeping	All relative headings in xx years wind-wave climate	All relative headings in xx years wind-wave climate	-
Return to head seas	A minimum success rate of x/x, in yy years wind wave climate	A minimum success rate of x/x, in yy years wind wave climate	A minimum success rate of x/x, in yy years wind wave climate

9.5 Engine Power Limitation Proposal

The IMO MEPC has been reviewing proposals submitted by different member states on the implementation of engine power limitation (EPL) or shaft power limitation (SHAPOLI). Both concepts are centered on controlling the power transmitted from the engine to the propeller through a proposed power limiting system arrangement (including sensors, control unit, data recording and processing units, engine internal system, etc.). The arrangement is proposed to be non-permanent but tamper proof. This means that override action should only be taken by the ship's master to allow availability of the power reserve if the vessel encounters adverse weather.

The aim of these proposals is to resolve the difficulty that very large vessels (bulkers and tankers) face on meeting both the EEDI requirement of the later Phases and the MPP Level 2 Assessment.

A number of concerns have been raised on the implementation of EPL/SHAPOLI mainly on the lowest allowable limiting level, demonstration of compliance and, how this measure would affect the requirements of the NOx Technical Code and EIAPP certification.

EPL should typically not result in a substantial modification, i.e. no changes need to be made to the NOx Technical File. However, the relationship between EEDI calculation and NOx Technical Code (NTC) including issues about engine operational profile, rated power and SFC should be clarified in the context of shaft power/engine power limitation in order to obtain a consensus.

In terms of safety and vessel strength requirements that may be affected by implementation of the SPL/SHAPOLI measure, it is understood that these should be assessed based on the installed engine MCR and revolutions NMCR (un-limited). Table 2 below lists the various requirements to be examined e.g., those for NOx certification, engines, power transmission systems, shafting, propellers, torsional vibration, other devices in the engine room, steering gear, sea trials, hull construction, tankers, pure car carriers, and also CSR for Bulk Carrier & Oil Tankers.

Table 9-5 Safety and Strength Requirements to be Examined under EPL/SHAPOLI Measures

Category	Requirement	Element	IMO / IACS / Class Rules
NOx	NOx Limits	NMCR	MARPOL VI/13
	NOx Measurement	Number of revolutions, Output	MARPOL VI/13 NOx Technical Code
Engines	Speed Governor	NMCR	IACS UR M3
Power	Strength of Gears	MCR, NMCR	Class Rule

Transmission Systems	Diameter of Gear Shafts		
	Diameter of Flexible Shafts		
Shafting	Diameter of Intermediate Shafts	MCR, NMCR	IACS UR M68
	Diameter of Thrust Shafts		
	Diameter of Propeller Shafts		
	Diameter of Stern Tube Shafts		
	Diameter of Coupling Bolts		Class Rule
Propellers	Thickness of Blade	MCR, NMCR	Class Rule
	Fillet Radius between Root of Blade and Boss of the Propeller		
	Diameter of Blade Fixing Bolts of CPP		
	Pull-up Length	Ship speed at MCR	IACS UR K3
Torsional Vibration	Torsion Vibration Stresses on Intermediate Shafts, Thrust Shaft, Propeller Shafts and Stern Tube Shafts	NMCR	IACS UR M68
Other Device in E/R	Capacity of fuel service tank	MCR	Class Rule
	Capacity of Fuel Oil Supply Pumps		
	Capacity of Lubricating Oil Pumps		
	Capacity of cooling pumps		
	Capacity of Sludge Tanks		
Steering Gear	Performance of Maine Steering Gear	Ship speed at MCR	SOLAS II-1/29
	Performance of Auxiliary Steering Gear		
Sea Trials	Speed Test	MCR, NMCR	Class Rule
	Astern Test		
	Steering Test	Ship speed at NMCR	SOLAS II-1/29
	Turning Test	MCR, NMCR	Class Rule
	Performance Test of machinery installations		IACS UR M51
	On Board Noise Measurements	MCR	SOLAS II-1/3-12 The Code on Noise Levels on Board Ships
Hull Construction	Strengthening of Bottom Forward	Ship speed at MCR	Class Rule
	Transverse Frames below Freeboard Deck abaft of After Peak Bulkhead		
	Shell Plating of Bottom Forward		
	Strength of hatch covers, coamings and portable beam		
	Stress in the End of Stiffeners supporting the Longitudinals penetrating Floors in Tanks		
Tanker	Compressive Stress of Supporting Structures of Independent Tanks	Ship speed at MCR	Class Rule
PCC	Transverse Frames and Side Longitudinals of Bow Flare	Ship speed at MCR	Class Rule
	Side Stringers and Web Frames of Bow Flare		
CSR for Bulk Carrier & Oil Tankers	Bow Impact Pressure	Ship speed at MCR	IACS CSR-B&T
	Side Shell Plating of Fore Part		
	Side Shell Stiffeners of Fore Part		
	Primary Supporting Members of Fore Part		

9.6 Proposed Way Forward

In light of the changes agreed at MEPC 76 and further work due on shaft/engine power limitations for new ships, we do not propose any concrete way forward at the moment, except to take note of the strength and safety requirements provide above in the table.

10 TASK C1 FRAMEWORK TUNING - WEATHER FACTOR

EEDI is a theoretical index, being a snapshot of ship's performance at a rarely used draft (maximum) and in ideal sea conditions (no wind and no waves). As a result, ships with similar EEDI's may have very different performance in real sea conditions. The industry has fresh memories of very full bow ship designs (to increase displacement / deadweight), which at sea trials performed well but which, in real sea conditions of Beaufort 3 or 4, exhibited reduced speed capability and increased fuel consumption compared to similar designs or EEDIs with a more slender bow.

A truer picture of a ship's actual performance could be reflected in the EEDI if the weather coefficient ($\boldsymbol{f_w}$) were actually used (currently the $\boldsymbol{f_w}$ in the EEDI formula is taken as 1.0), where $\boldsymbol{f_w}$ = Vw /$\boldsymbol{V_{ref}}$. The weather coefficient $\boldsymbol{f_w}$ is a measure of the drop in ship speed at 75% MCR in weather conditions of Beaufort 6, see Figure 1.

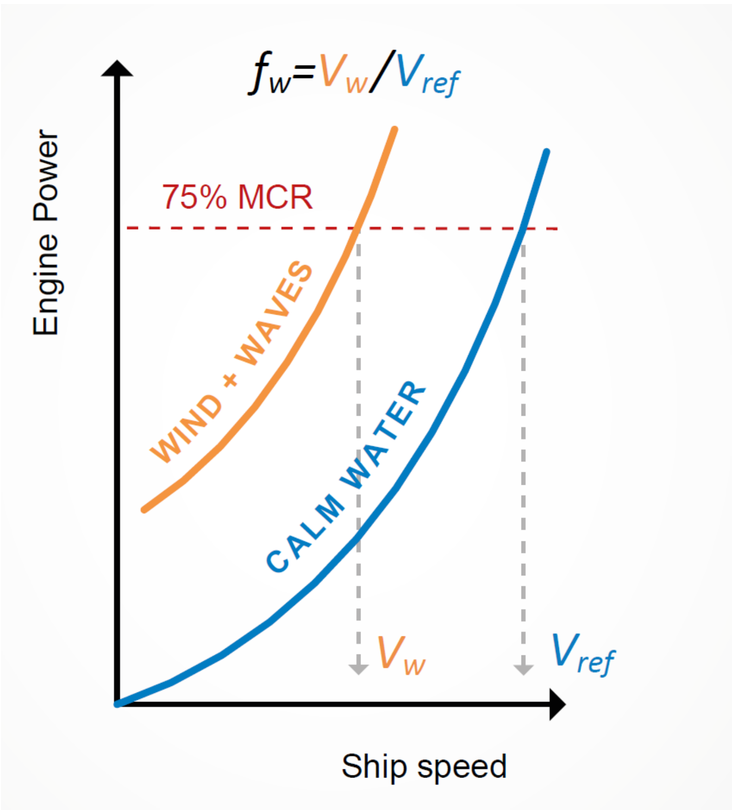

Figure 101 Overview of the weather factor fw, IMO (2012)

A typical range for $\boldsymbol{f_w}$ for slow speed ships (bulk carriers and tankers) is 0.80 – 0.95, which in itself is an indication of the extreme variation in design efficiency that is not captured in the EEDI (a ship losing less speed - i.e. with $\boldsymbol{f_w}$ = 0.95 - is the more efficient.) Each ship design has its own $\boldsymbol{f_w}$ which can be determined experimentally by model tests. The IMO provides guidelines for the calculation of $\boldsymbol{f_w}$ as well as typical values in MEPC.1/Circ.796. Experimental values included in said IMO circular show that, for same deadweight ships, the $\boldsymbol{f_w}$ can vary widely, see Figure 2.
For example, for 300,000 dwt tankers, $\boldsymbol{f_w}$ ranges from 0.83 to 0.94. Obviously the 0.94 design is far more efficient than the 0.83, dropping only 6% in speed from Beaufort 0 to Beaufort 6, versus 17% for the less efficient design. Since this speed drop is at the fixed power of 75% MCR, it is a direct measure of the efficiency of the ship's hull lines (especially bow shape).

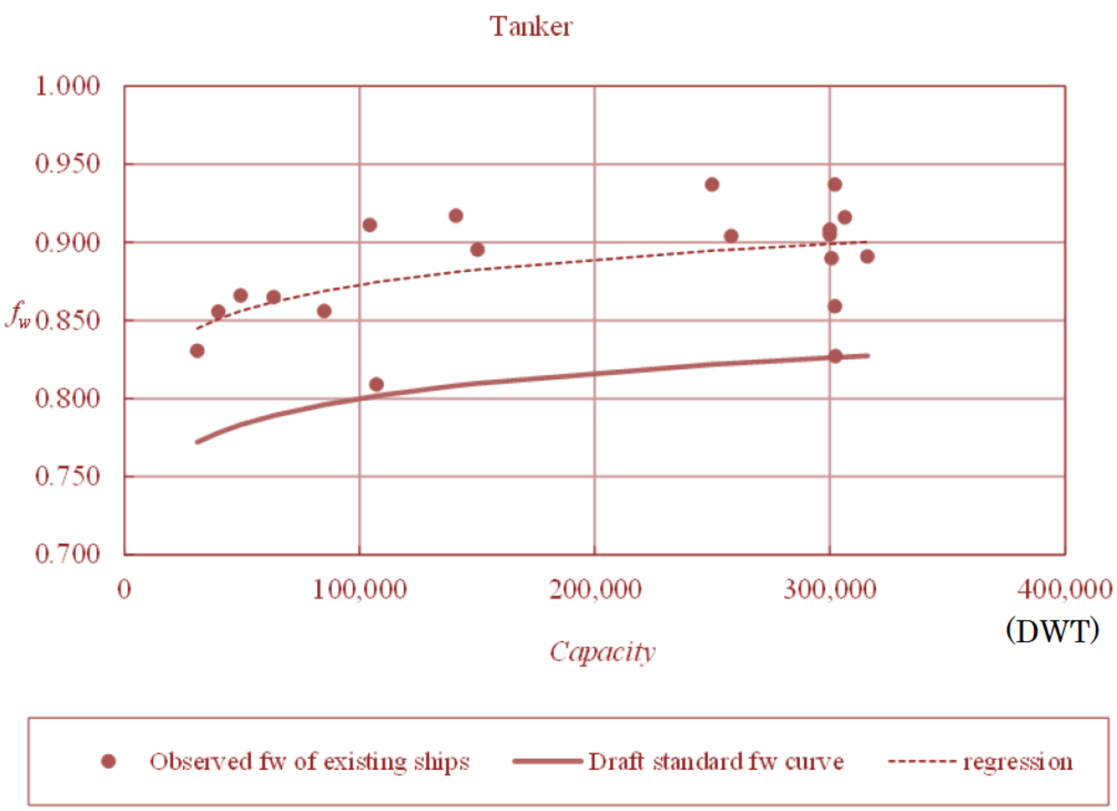

Figure 102 Standard fw curve for Tanker, IMO MEPC.1 Circ.796 (2012)

The IMO Standard f_w value is calculated by the formula fw = a x ln(Capacity) + b

Where the standard f_w value parameters are shown in Table 1 below.

Table 10-1 IMO standard f_w parameters

Ship Type	a	b
Bulk Carrier	0.0429	0.294
Tanker	0.0238	0.526
Containership	0.0208	0.633

Including actual f_w in the EEDI formula, resulting in "Attained EEDI weather", would provide a more realistic picture of the ship's efficiency in real operating conditions. At present, both ships in our example may have identical EEDI's, but their actual performance will be very different. Furthermore, the "less efficient" ship, due to smaller engine, may even have a better "Attained EEDI" than the more efficient ship but, in reality, may emit much more CO_2 when operating at the same speed.

It has been observed in the past that, due to the large speed drop, such poor designs tend to increase their operating horsepower output to partially recover the loss and thus achieve a more "competitive" speed, thus operating at 90% MCR or more, which increases the engine's specific fuel oil consumption exponentially.

Obviously then, $\boldsymbol{f_w}$ and "Attained EEDI weather" are crucial pieces of information of a ship's real efficiency.

An example from SSPA database where a number of seakeeping model tests have been used to determine f_w values for tankers ranging from 2,500 to 150,000 deadweight tons, see Figure 103. The f_w values are plotted along with the IMO standard curve. As can be seen, agreement between full-scale data and SSPA's model test results is good. The generic IMO standard curve on the other hand is extremely conservative because fw is underpredicted, i.e. speed loss is significantly overpredicted.

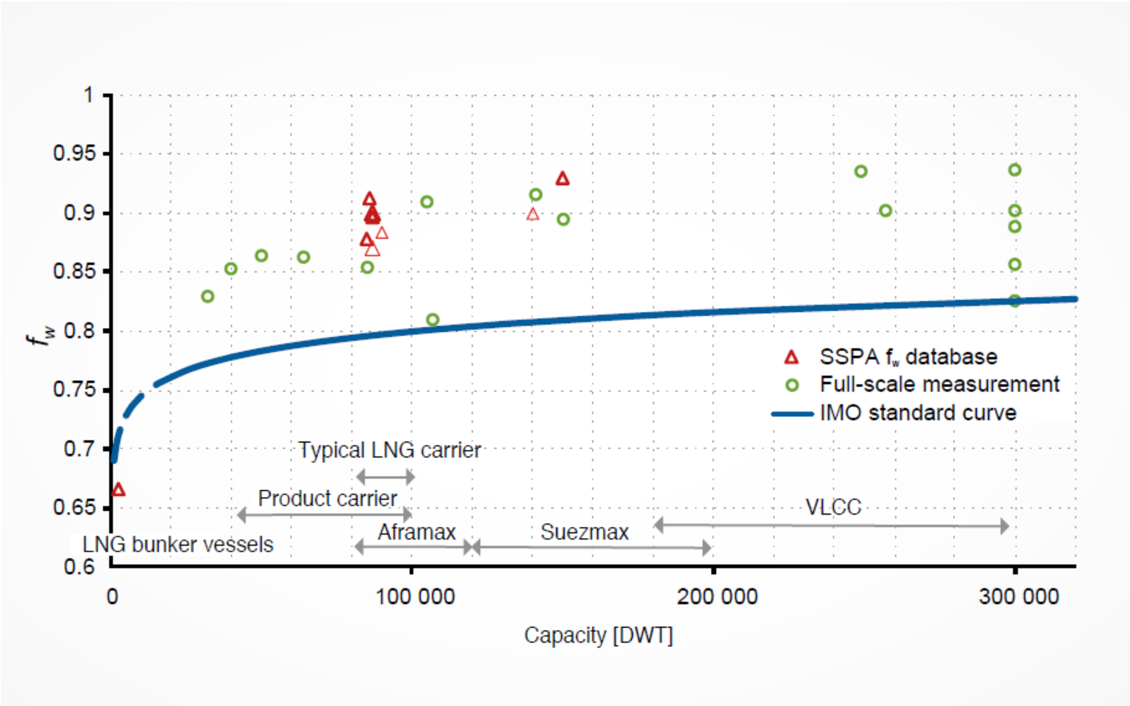

Figure 103 SSPA seakeeping model tests results on f_w vs the IMO standard curve, SSPA (2017)

Related distortion: Ships with larger engines, having lower actual (in real operating conditions) fuel consumption at same speed and deadweight, will have higher (worse) EEDI than otherwise identical standard ships.

Some owners install larger engines on a shipyard's standard design (e.g. one extra cylinder) in order to be able to operate at the optimum specific fuel oil consumption (SFOC) point of 70-75% MCR in real weather conditions of Beaufort 4 - 5, instead of 75% MCR at the calm conditions of EEDI. Thus they are able to achieve V_{ref} (or the design speed[1]) in real weather conditions, whereas a typical EEDI ship would need to operate at much higher MCR than 75% to achieve the same speed. The larger engine ship has a higher (worse) EEDI, typically by about 15%, yet for the same speed and draught it might

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[1] Practically V_{ref} is approximately equal to a typical ship-building contract's "design speed". V_{ref} is speed at maximum deadweight (70% DWT for container vessels), at 75% MCR but with no sea margin. Design speed is speed at the reduced design draft, typically at 85% MCR but with 15% sea margin.

save typically 7 - 7.5 % in fuel consumption. This is a direct contradiction of the EEDI premise and could easily be alleviated by using ‘EEDI weather’.

10.1 EEDI - Threshold for Performance in Waves

Dedicated studies have been carried out to investigate how hull forms, optimized with respect to performance in realistic sea-conditions, can gain recognition under the EEDI regulatory framework.

The approach described in Lindstad et al [3] shows that by including a threshold for performance in waves (real sea) to the sea trial analysis results for calm water, the overall achieved emissions reductions can be better recognized through the EEDI scheme. The study suggests to build on the existing sea trial planning and conduct scheme by ISO 15016:2015 and apply an adjustment of the vessel’s calm water performance for real sea conditions (e.g. 35% allowance for head seas of significant wave height 3m). Figure 104 shows an example of how this proposal would work with vessels having to satisfy the requirement for both calm seas and agreed sea state. The same vessel design is compared in it’s traditional (higher CB) and optimized more slender (lower CB, elongated hull)

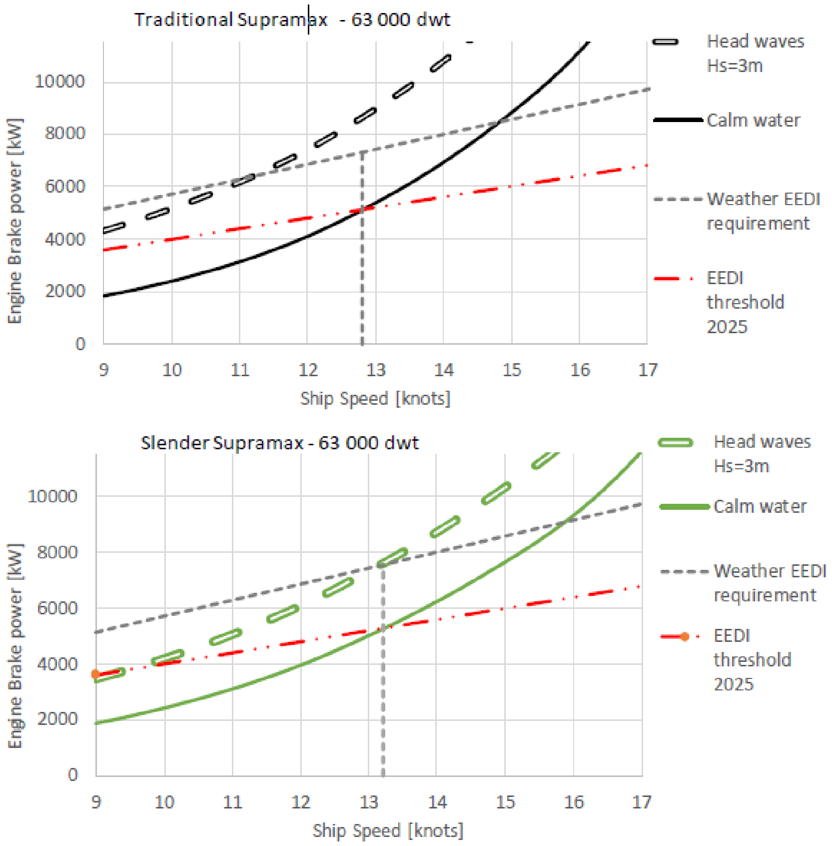

Figure 104 Sea trials including calm sea and agreed sea states for a bulk carrier with optimized hull form, Lindstad et al (2019)

versions.

10.2 Procedures for calculating the weather factor

The procedure of calculating the weather factor can be defined by a process instead of defining a specific methodology since many variations of the methods are available. ITTC has published a recommended procedures and guidelines for calculating the weather factor f_w for decrease of ship speed in wind and waves.

The guidelines contain a review of different components in the calculation sequence:

- Representative sea states and ship size
- Ship condition
- Added resistance in wind
- Added resistance in waves

For the added resistance in waves the different methods and codes are described including the verification and validation procedures for each.

Further the methods to determine the resistance components are listed with respect to fidelity and to practicality.

The guidelines recommended practical method is given in table 2 below.

Table 10-2 Recommended practical method for f_w prediction, ITTC (2018)

<table>
<tr><th>Component</th><th>Recommended Method</th><th>Alternative Method</th></tr>
<tr><td>Calm-water resistance</td><td>Towing Tank Test
(7.5-02–03–01.4 & 7.5-02-02-01)
Calm water tank tests already mandatory for EEDI-compliance / pre-verification</td><td>CFD
(7.5–03–02–03)</td></tr>
<tr><td>Added resistance due to wind</td><td>Blendermann (1993),
Fujiwara (2005)
(7.5-04-01-01.1)</td><td>Wind Tunnel Test</td></tr>
<tr><td rowspan="4">Added resistance due to waves
(choose any method to the right)</td><td colspan="2">Slender-body theory + Maruo’s Formula + NMRI’s formula for short waves
(7.5-04-01-01.1)</td></tr>
<tr><td>3D panel method</td><td>+ NMRI’s formula for short wave diffraction component
(7.5-02-07-02.1 & 7.5-02-07-02.2)</td></tr>
<tr><td colspan="2">CFD</td></tr>
<tr><td colspan="2">Seakeeping experiment
(7.5-02-07-02.1 & 7.5-02-07-02.2)</td></tr>
<tr><td>Power Increase due to wind and waves</td><td>Follow procedure 7.5-02-07-02.2, depending on method chosen:
Open-water propeller tests
(7.5-02-03-02.1)
Propulsion tests
(7.5-02–03–01.1)</td><td>CFD</td></tr>
<tr><td>f_w evaluation</td><td>Speed-power curve</td><td>By iteration</td></tr>
</table>

10.3 Case Studies

A number of vessels are used in a case study to analyze the weather factor for different vessel types. The vessels types are tankers, bulkers and container vessels and they are evaluated at the following conditions.

- 75% MCR
- Scantling draught (container vessels 70% of scantling draught)
- Calm seas Beaufort number 0
- Wind and Sea state corresponding to Beaufort number 6 (Head Seas)

To get to the results for the weather factor, a simulation with a propulsion model of the vessel and the resistance components including a Blendermann correction on wind and a STA1 correction on waves is done and the results are shown in the Figures 5 to 7 below. The f_w values are plotted with the (blue) IMO reference line for the different vessel types.

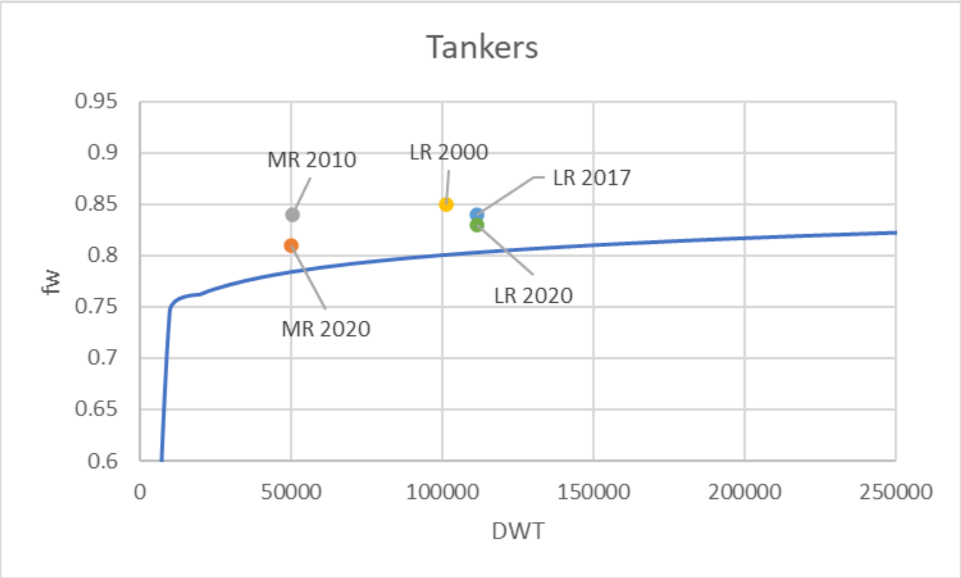

Figure 105 f_w calculated for a range of tankers vs the IMO reference line

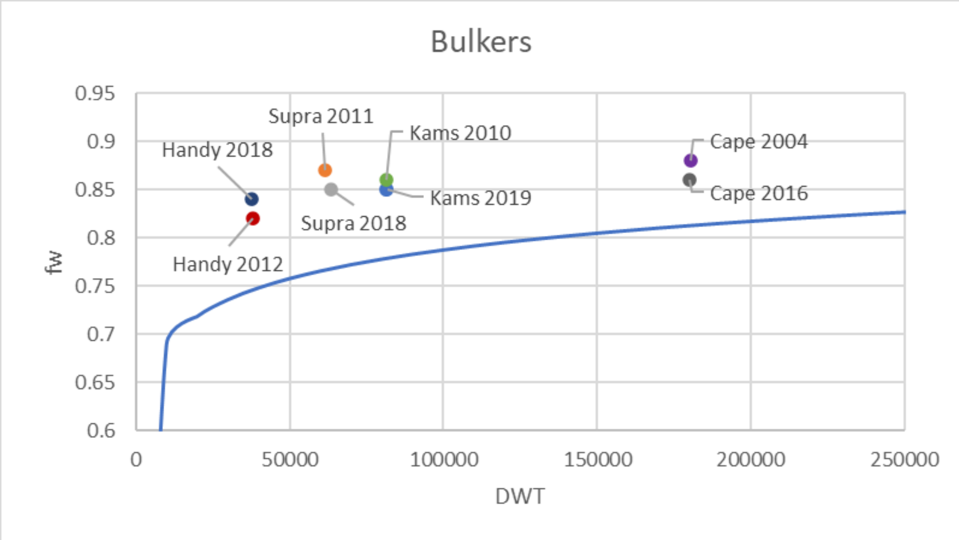

Figure 106 f_w calculated for a range of bulkers vs the IMO reference line

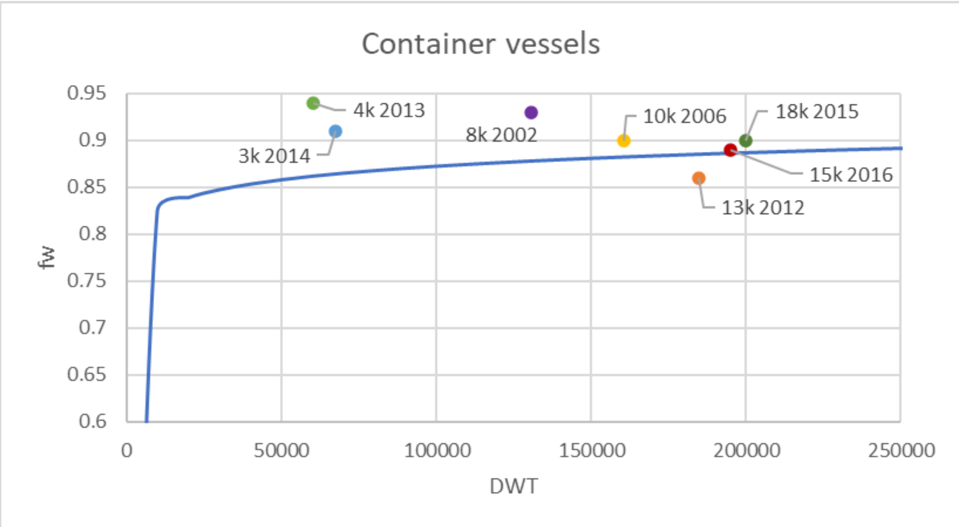

Figure 107 f_w calculated for a range of container vessels vs the IMO reference line

The results from the analyses show for tankers and bulkers that the f_w in general is lower (worse), the newer the vessels are. It corresponds the general lowering of power/lower RPMs and the design of these vessels going towards being bulkier over time.

For the container vessels, the older designs and the smaller vessels have good f_w performance where the larger vessels are around the IMO reference line. One vessel is below, probably because an older design with a derated engine.

It matches the observations done in the Task B report with regards to engine / propeller changes and design changes for bulkers/tankers and capacity changes for the container vessels.

A more comprehensive study is suggested for investigation into weather factor determination with respect to methods for resistance calculation, inclusion of different vessels types and verification with full scale data.

Actual monitored data shows that the IMO curve is overly conservative, and is unable to distinguish between ships with different performance in weather.

It should also be noted that the f_w coefficient is in the denominator and will result in a larger EEDI. Should this be implemented, there will need to be both an attained EEDI calculated without f_w and an attained $EEDI_{weather}$ with f_w. There are potentially three options:

1. Only the attained EEDI calculated without f_w may be compared against the EEDI baselines, but the $EEDI_{weather}$ may be used as an additional criterion.
2. Alternatively a minimum f_w could be set, but not used in the calculation of attained EEDI.
3. We revise the baselines with a f_w value included noting that the greater the speed loss, the smaller f_w will be and the larger the attained EEDI weather will be

Option 2 could potentially be used to ensure a minimum standard of f_w, however this may also constrain further improvements in attained EEDI. The challenge however is still reliably predicting f_w at design stage – some shipyards seem more confident on this than others as evidenced by their answers to the survey conducted in Task D1.

However in the context of the implementation of CII, the poorer performance of fuller form vessels may become apparent and lead to changes for newer designs.

What this however also demonstrates is that optimization for EEDI appears to have been happening and this has been detrimental to heavy weather performance, and further increases in reduction rates for future phases may become counterproductive and lead to further over optimization at the EEDI point.

11 Task C1 Framework Tuning - Other EEDI Aspects

11.1 Reliance on Engine Power

Main engine power is dominant in two ways – it is the majority of the power and therefore CO_2 output when the vessel is underway, but also when reducing speed, power reduces much more (the cubic relationship) and this is the mechanism for improving attained EEDI. EEDI doesn't take into account stationary and manoeuvring parts of the operating profile where auxiliary power may play a larger role, however taken over the entire operational profile, the majority of CO_2 emissions are still propulsion related, even for cruise ships that have very high hotel loads. In this sense it is reasonable that EEDI is dominated by engine power.

Take two identical ships, where one is fitted with an extra cylinder and therefore has higher power output used for the EEDI calculation and slightly higher speed. In the EEDI calculation the vessel with the extra cylinder will result in a worse EEDI and technically this comparison is valid.

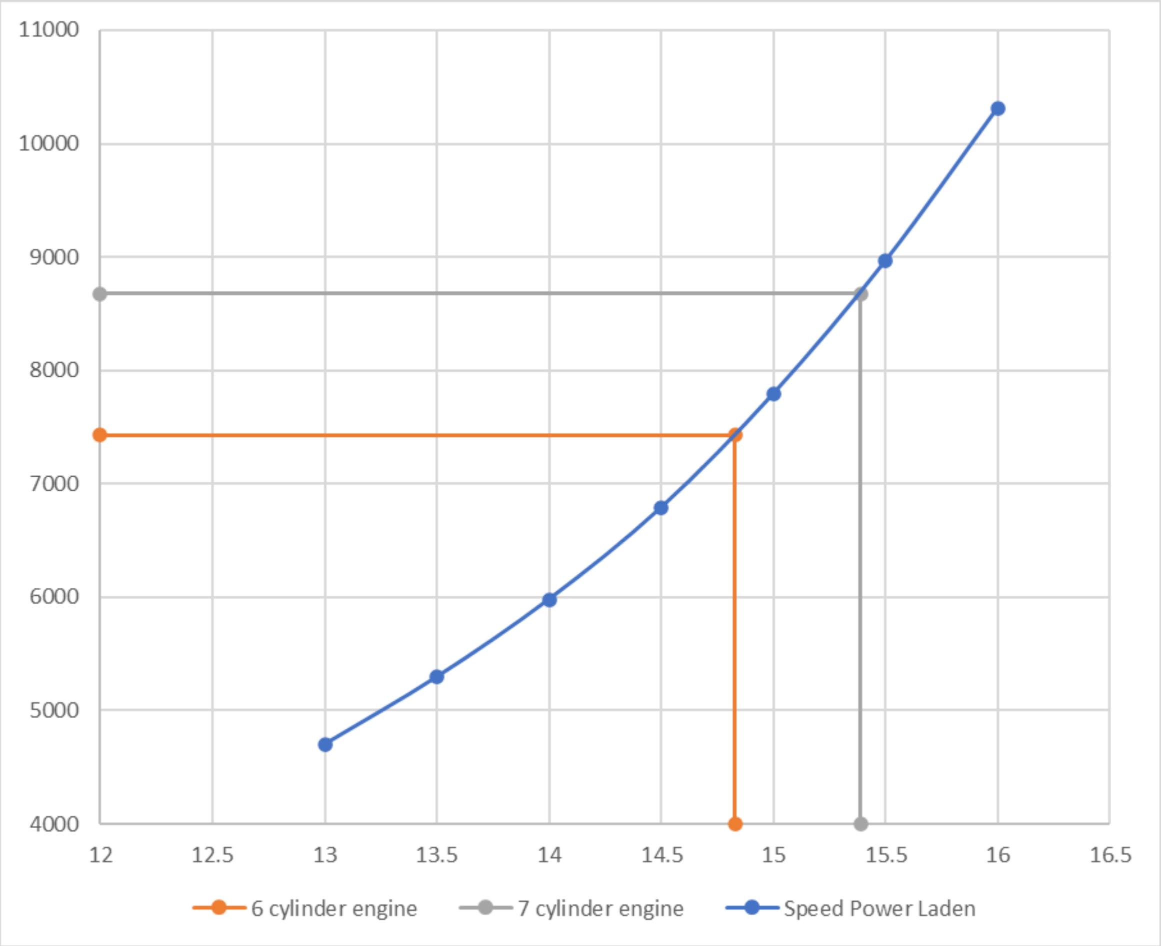

Figure 108 Speed Power Comparison between 6 and 7 cylinder engine

In the above example, Vessel A with the 6 cylinder engine has P_{me} of 7431 kW and a V_{ref} of 14.83 knots while the sister vessel (Vessel B) with the 7 cylinder engine has a P_{me} of 8675 kW and a V_{ref} of 15.39 knots.

The attained EEDI of Vessel A is 3.535 (18.86% better than the baseline) while the attained EEDI of Vessel B is 3.956 (9.21% better than the baseline). Vessel B is of course capable of a higher speed than vessel A, but the question is whether the almost 10% discrepancy in EEDI is a true reflection of the relative efficiencies of the two vessels.

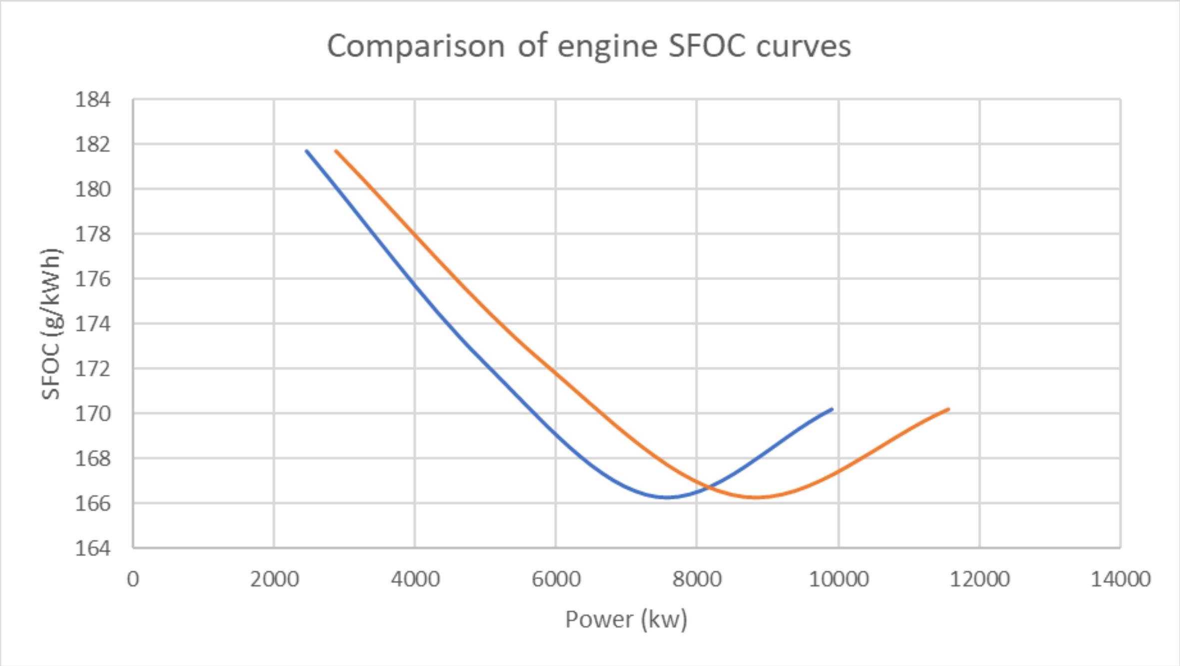

Figure 109 Comparison of 6 and 7 cylinder engine SFOC curves

If both ships were operated at the same power, this would likely result in a very similar speed, that is the ships are fundamentally of similar efficiency (identical hull form) and what the EEDI framework does is to assume that a ship with more installed power will be operated at a higher speed, which is not necessarily true.

However the other missing aspect is that EEDI is evaluated at calm water speed, and so in heavy weather, the required power to move at a certain speed increases. As can be seen in the chart above, at higher engine power, vessel B has a better specific fuel oil consumption, meaning that if the operating profile of the vessel means that it frequently operates in this range, Vessel B is more fuel efficient than Vessel A. Conversely if in a situation with widespread slow steaming, then Vessel A is more fuel efficient than Vessel B. Now the profile of SFOC curves can be modified to be flatter due to various low load tuning modes, but in the above example, the difference in SFOC is just 1.8% at its worst.

And so EEDI exaggerates efficiency differences in certain situations, and as long as the operational profile is not considered, EEDI is only an approximate basis for comparison.

In the drive for improved EEDI there will be pressure to reduce power and speed further. In the above example, the ship is designed for speeds faster than what it normally operates at, and therefore the lower powered ship is on balance likely to be more efficient. However once the reduced power begins to converge with actual operating speeds, then on balance the higher powered vessel will be more efficient.

We do not see any solution to this, except that the CII framework takes all this into account and it is likely that going forward shipyards will need to design for CII compliance over a number of years.

11.2 Auxiliary Power

P_{AE} is the required auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodation, e.g. main engine pumps, navigational systems and equipment and living on board, but excluding the power not for propulsion machinery/systems, e.g. thrusters, cargo pumps, cargo gear, ballast pumps, maintaining cargo, e.g. reefers and cargo hold fans.

There are 3 ways of calculating auxiliary power (P_{AE})under the EEDI framework:

1. For installed power of 10,000 kW or less, P_{AE} is calculated as a fixed 5% of MCR
2. For installed power above 10,000 kW, P_{AE} is calculated as 2.5% of MCR plus 250 kW
3. For passenger ships where the P_{AE} is significantly different to the method calculated by the ratio method, an electric power table (a modified load balance) should be used

In the first case, P_{AE} will account for around 6.25% of EEDI and for the second case, the behaviour follows the progression below:

MCR	% EEDI
5000	6.25%
10000	6.25%
15000	5.26%
20000	4.76%
25000	4.46%
30000	4.26%
35000	4.11%
40000	4.00%
45000	3.91%
50000	3.85%

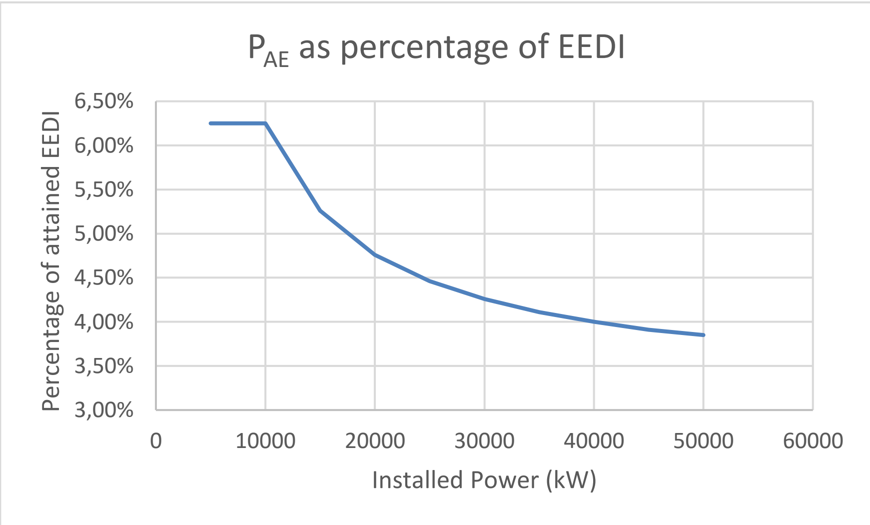

Figure 110 P_{AE} term as a percentage of EEDI - Engine ratio method

Therefore making large savings in auxiliary power will only translate to small improvements to the attained EEDI for non passenger ships, even if the actual savings are more significant (e.g. auxiliary savings apply to all operational phases including in port, at anchor and during manoeuvring).

However many ships have significant auxiliary loads that are either intermittent in nature (ballast system, cargo handling systems e.g. cranes, discharge pumps, thrusters), or somewhat constant (e.g. reefer consumption) that are not captured within the EEDI calculation and hence there is little to no regulatory incentive to make improvements in this area.

Additionally this ratio only holds true if ships are always sailing, which is not the case. In the case of the chemical tanker Hafnia Lise used as an example in the Green Ship of the Future Retrofit project, it spent 172 days a year in port (47%) and an additional 15 days idle (4%), where the auxiliary fuel consumption would become a much larger percentage of the total than indicated in the curve above.

GHG-WG 2/2/17 compared the engine ratio methodology with two other estimation methods of P_{AE} – Alternative Method 1 which sums up 50% of the power of all auxiliary engines onboard and Alternative Method 2 which used an electrical power table.

Type of vessel	Number of Available data	Percentage of the estimated P_{AE} against the P_{AE} using the formula of the Interim Guidelines (i.e. based on MCR_{ME} only) Figures in parentheses are average for each category.		Remarks
		Alternative Method 1 – Bottom-Up	Alternative Method 2 – using electric power table	
dry cargo carriers	42	122.95% ~ 467.8% (212.4%)	47.5% ~ 181.1% (89.7%)	24 vessels less than 10,000 kW MCR_{ME}
Tankers	40	118.4% ~ 412.2% (225.0%)	65.1% ~ 127.3% (94.0%)	22 vessels less than 10,000 kW MCR_{ME}
gas carriers	17	173.3% ~ 528.4% (254.4%)	82.1% ~ 296.6% (130.3%)	15 vessels less than 10,000 kW MCR_{ME}. Not including turbine engine ships.
container ships	15	224.4% ~ 423.0% (299.3%)	68.4% ~ 150.9% (102.2%)	4 vessels less than 10,000 kW MCR_{ME}
general cargo ships	14	162.2% ~ 199.2% (212.1%)	64.7% ~ 178.2% (109.8%)	13 vessels less than 10,000 kW MCR_{ME}
ro-ro ships	1	235.7%	147.7%	
PCC/PCTC	13	94.6% ~ 379% (255.1%)	88.2% ~ 170.5% (111.5%)	2 vessels less than 10,000 kW MCR_{ME}
ro-ro passenger ships	1	285.0%	259.0%	
passenger ships	3	236.5% ~ 2282.4% (929.1%)	178.8% ~ 197.3% (186.8%)	
others ships	4	195.8% ~ 664.6% (467.4%)	64.9% ~ 152.3% (104.2%)	Reefer, etc.
Total of major ship types[5]	128	(233.6%)	(100.7%)	

Figure 111 Table 3 of GHG-WG 2/2/17 (Japan)

Technically alternative method 2 is the more accurate approach, but the average values were not very different from the MCR ratio method and this was used to justify this methodology.

Implementation of auxiliary power energy saving is not accounted for because P_{AE} is calculated as a fixed ratio. Some have tried to utilise an electric power table to prove the savings however for some ships (as shown in the table above), especially smaller ships, the calculated P_{AE} is already at the lower end of a realistic electrical load, or even beyond, so matching this value with all the energy efficient devices in place is challenging, never mind demonstrating any improvements. The table above shows significant scatter such that many ships would have much higher P_{AE} in practice than estimated by the ratio method.

Should there be any energy saving of cargo maintenance loads e.g. reefers, or thrusters, cargo pumps with variable frequency drives etc, this is not reflected in the EEDI as it is out of scope of the electric power table.

A related issue is that provision of shore power connections and any associated use are not considered.

For passenger ships using the electrical power table, it has been found that due to the similarity between a load balance (which is used for sizing generators, and which therefore contains margins to exaggerate loads) and an electrical power table (which is designed on the other hand to minimise the electrical load), there is a sizable difference between the calculated value and the load actually measured in service, with the calculated value being in some cases being significantly higher.

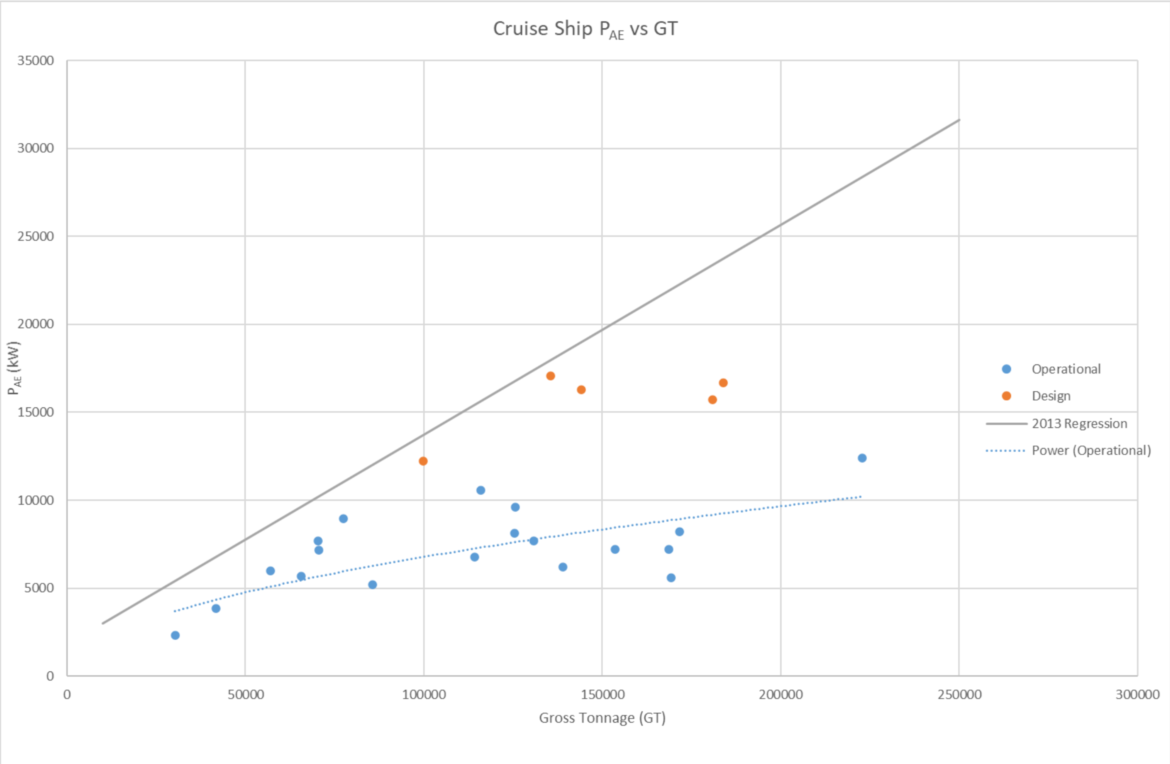

Figure 112 Cruise Ship P_{AE} Design, Measured and Estimated Regression

In the above chart, the design points are the results of the electrical power table, while the blue points are measured onboard, averaged over a year.

There are a number of reasons for this discrepancy:

- While the electrical power table (EPT) is based on modified load balance, a load balance has margins to exaggerate the load for generator sizing, while the EPT tries to minimise the load. However stakeholders including the shipyard and the classification societies struggle to adapt to the different context, and so there are often disagreements about how much the load should be reduced
- Absorption chillers which are used for HVAC systems utilise waste heat as a source of power and result in significant energy savings, however their contribution is defined via their nominal cooling capacity in kW and does not reflect the actual electrical energy usage
- Variable frequency drives allow electric motor driven machinery to be run at modest reductions in speed but large reductions in power. However the requirement in the EPT is for the maximum rated power to be used and so there would be no difference between a variable frequency driven pump and an conventionally driven one

11.2.1 Proposed Way Forward

For ships that utilise the engine ratio method of deriving P_{AE}, we should be careful not to exceed the boundaries of the EEDI framework and go into cargo related consumption If in any case these are improved via use of a battery system, we recommend that the overall improvements are reflected in the calculation of the attained EEDI.

However we would suggest that where auxiliary energy saving measures are implemented within the scope of the EEDI, such as LED lighting, or variable frequency pumps, the calculated saving may be directly **deducted** from the derived P_{AE} value.

An example would be:

> For a ship with 8,000 kW installed power, P_{ME} of 6,000 kW and calculated P_{AE} of 400 kW, auxiliary power energy saving measures consisting of LED lighting and variable frequency drives amounting to 120 kW is implemented, and so P_{AE} is adjusted to 280 kW for the calculation of attained EEDI, leading to a 1.9% improvement of the EEDI relative to the version without energy saving devices. However note this may be 20%-60% less in EEDI reduction rate terms as those are relative to the EEDI baseline.

Another option would be to allow deduction of these savings under P_{AEeff}.

In general, for variable frequency drives, we should allow for a minimum of [20%] saving from the rated power which may then be applied either in electrical power tables or for estimating the savings for deducting from the engine ratio derived P_{AE}. Greater savings than this may be accepted if proven by calculation.

A minimum saving for absorption chillers needs to be derived, however this could be based on in service data for previous installations.

For the calculation of the EPT, an additional service factor will need to be implemented to account for the fact that certain equipment like variable frequency drives, smart systems do not operate at rated power, and that absorption chillers use much less power than their rated power suggests. We would suggest adding a service factor of capacity kc which will then be part of the service total factor of use ku = kl*kd*kt*kc.

An example from item 32 of the example EPT in the EEDI Calculation Guidelines (FWD engine room supply fan) would be:

Rated electric power =	94.4 kW
Service factor of load kl =	0.95
Service factor of duty kd =	1
Service factor of time kt =	1
Service factor of capacity kc =	0.75 **(this is the new factor)**
Pload original =	89.7 kW
Pload new =	94.4*0.95*1*1*0.75 = 67.3 kW

11.3 Boilers

There are three main types of boilers used onboard ships – oil-fired boilers, exhaust gas boilers (economizers) that use waste heat and composite boilers which are a mix of oil-fired and exhaust gas boilers. The fuel consumption of oil-fired boilers is not included in the scope of the EEDI calculation, however the use of exhaust gas boilers to provide heating is also not considered. The diagram below from the EEDI calculation guidelines indicates what is excluded.

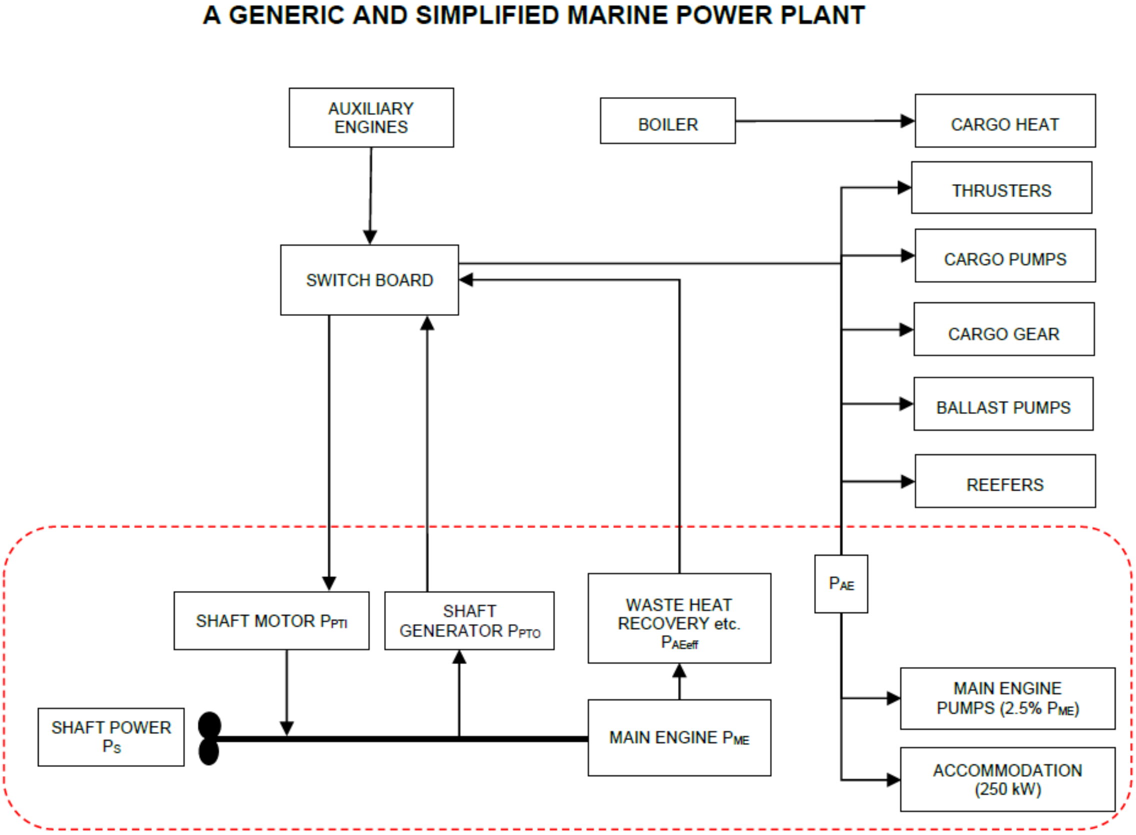

Figure 113 Simplified Illustration of a Marine Power Plant from EEDI Calculation Guidelines

Operationally, most boilers are used to heat HFO used as fuel onboard ships, or to heat cargo and calorifiers that provide hot water. Note that for EEDI purposes, the SFOC and C_f is based on MGO because most NOx testing is conducted with MGO, and hence there is in theory no need to heat fuel.

Exhaust gas boilers have been standard equipment onboard ships since well before implementation of EEDI. Depending on the sizing of the exhaust gas boilers and the heat demand, operational profiles and slow steaming may result in reduced heat in the exhaust gas and require use of the oil fired boiler. This is also an aspect that is not considered in the contribution of the waste heat recovery system.

11.4 Correction Factors

An extensive treatment of correction factors was carried out in Task A1. Of these, there are two correction factors that may require adjustment:

- F_c cubic capacity correction factor for chemical tankers
- F_{jroro} for ro-ro cargo and ro-ro passenger ships

One of the significant differences between these two correction factors is that F_c is not included in the derivation of the reference line for tankers, while F_{jroro} is used in the derivation of the reference line for ro-ro passenger and ro-ro cargo ships, and any changes to the F_{jroro} correction factor will require new reference lines to be calculated.

11.4.1 F_c cubic capacity correction factor for chemical tankers

The F_c correction factor was originally developed because dedicated chemical tankers built to the IBC Code tended to have a different design from product tankers of the same deadweight in terms of beam, draught and also number of tanks, essentially reduced deadweight for the same size of ship. However due to market drivers, over time the design of chemical tankers has changed, and many product tankers have also been built to the IBC Code on the off chance that they need to carry Type II or III cargoes, but where their design is not fundamentally different from other product tankers. This has meant that the correction factor over corrects in some cases, and this manifests itself in over achievement up to around 50,000 dwt which may be seen in the chart below:

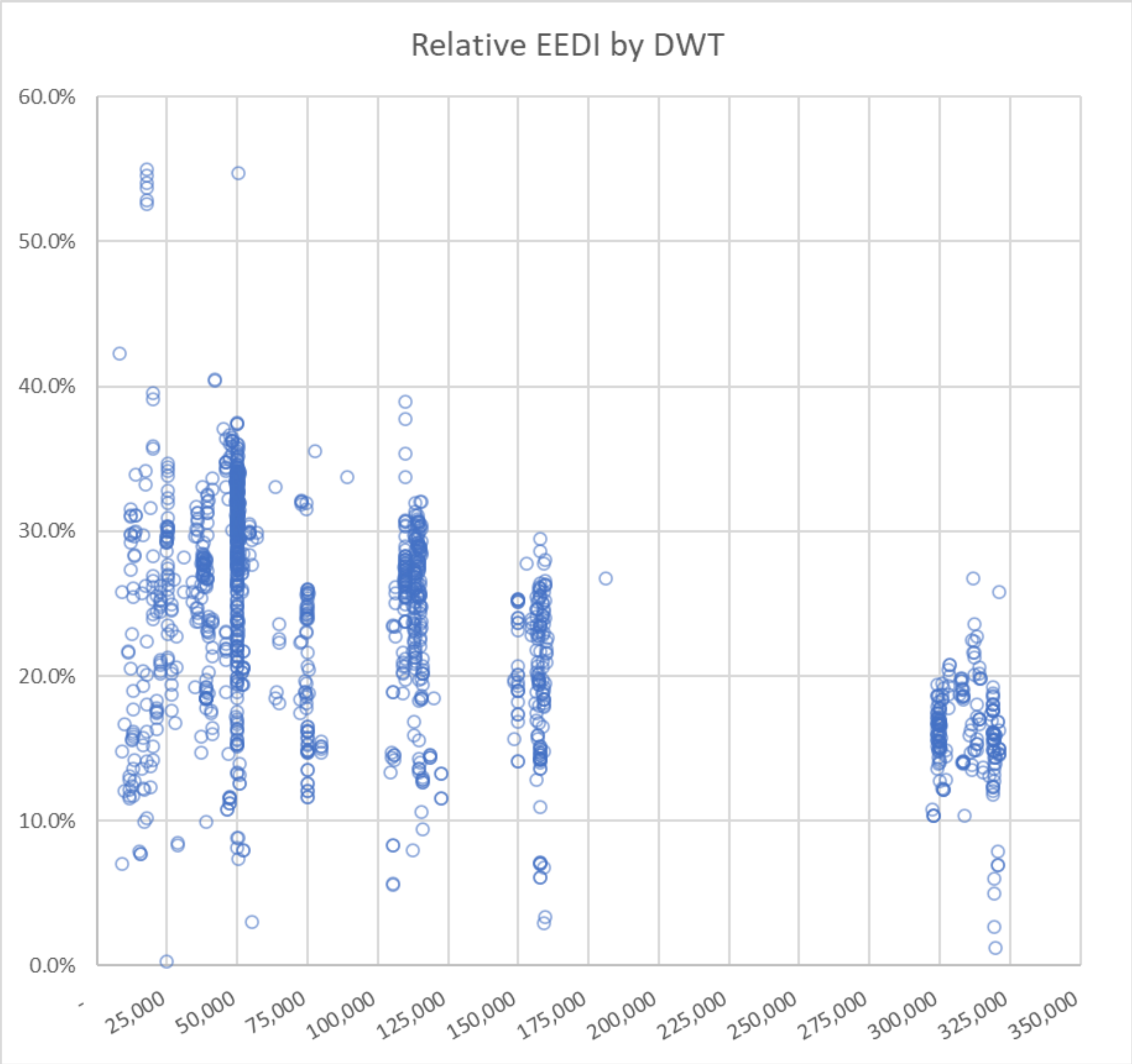

Figure 114 Tanker Relative EEDI from IMO EEDI Database

There is a need to collect and plot the attained EEDI of chemical tankers without the correction factor, and to check if the corrections are actually justified based on the design of the ships. If we try to set further reduction rates (which will need to be size dependent) based on the information currently submitted to the IMO EEDI database, then it will no longer be possible to build product tankers that do not conform with the IBC Code as the reduction rate will be beyond reach for these vessels.

Another possibility is to separate chemical tankers from tankers as is done for EU MRV and the IMO GHG studies, although some work will need to be done as to whether compliance with the IBC Code alone is a sufficient criterion.

It is also possible that the outcome of this work will show that a chemical tanker correction factor is in most cases no longer needed except for ships with very high number of segregated tanks and then the threshold for use of the correction factor needs to be adjusted.

11.4.2 F_{Jroro} for Ro-Ro Cargo and Ro-Ro Passenger Ships

Many will be aware of the significant problems that have been caused by this correction factor to the sector, and there is a real risk that continued maintenance of this correction factor into Phase 4 may totally inhibit new construction in these sectors.

The correction factor exhibits a very strong normalising effect, for example minimising the main engine term in the EEDI down to just 25% of its original value, and also showing that faster ships may have a better EEDI than slower ships. The main issue however is that the correction factor is necessary to include the sector within the EEDI framework because the segment is in reality made up of a very diverse group of ships with very different operating profiles.

During work carried out for defining the CII baselines for these ships types, it became apparent that deadweight is a very poor proxy for capacity for these ships, and that GT, while not perfect, is better for both ro-ro cargo and ro-ro passenger ships.

As such work on a new scheme to include these ships would likely involve complete revision of baselines to use GT, and also to consider a number of speed dependent baselines, recognising that different routes will require different speeds. For context, the ro-ro passenger ships within the EEDI database have a V_{ref} range between 18-28 knots and the ro-ro cargo ships have a V_{ref} range between 8-22 knots, while bulk carriers have a range between 12.5 and 16 knots.

11.5 Recommendations for EEDI database

The purpose of the IMO EEDI database is to permit analysis of key trends, however in its current format the analysis is limited because insufficient data is submitted to allow fair analysis. The latest amendments regarding data to be submitted is an improvement, but still insufficient. We would suggest the following additions:

- Mandatory reporting of all correction factors, otherwise it is not possible to understand if a good attained EEDI is due to exceptional design, errors, correction factors or a combination
- Mandatory report of all carbon factors. With the last amendments only f_{dfgas} was added and this is insufficient
- Value of PTO or PTI used
- For passenger ships, value of P_{AE}
- Values of P_{AEeff} and P_{eff} so the actual contribution of different technologies may be assessed
- Value of SFOC and indication of whether this is in Tier II or Tier III mode and the type of fuel associated with the SFOC figure

We also recommend that these requirements are made retrospective (excluding the non-mandatory ships) rather than prospective and there should be an assessment of the accuracy of the submissions due to the high error rate of P_{ME} described in the Task A1 report.

There are also cases where innovative technology is fitted but not used in the calculation of the attained EEDI. It should become mandatory to include this in the EEDI technical file and to calculate the value of P_{eff} and P_{AEeff}, but it should remain optional for the purposes of calculating the attained EEDI. That way, we would have a more complete picture.

This report also proposes further changes, such as the inclusion of a methane slip factor and a factor for batteries, which if adopted should also be submitted.

In order to be a useful tool for setting future phases of EEDI, a robust QA/QC system needs to be developed to correct all the data currently in the database as well as to ensure data quality going forward. For the case of P_{ME} and installed power as well as the container ship issue, this should be solved by requiring P_{ME} and installed power to both be recorded, and for both 100% and 70% deadweight to be recorded in the database

We are not entirely convinced by the need to anonymise ships or by the rounding up that is carried out because this actually decreases the resolution of analysis carried out with the database.

12 TASK C1 FRAMEWORK TUNING - SHIP TYPES

12.1 HSC

High speed craft are ships built to the High Speed Craft Code and must meet a speed threshold in order to be certified accordingly. Some high speed craft are passenger ships while others are in effect ro-ro passenger ship, carrying both vehicles and passengers.

The IHS classification system does not distinguish between high speed ro-ro passenger ships and ro-ro passenger ships, while the MARPOL Annex VI definition of ro-ro passenger ships “means a passenger ship with roll-on-roll-off cargo spaces” could be construed to include high speed ro-ro passenger ships.

In practice EEDI is not applied to high speed ro-ro passenger ships although we have heard several reports of this query coming up in relation to newbuilding projects. We have a copy of the database of ships used to derive the ro-ro passenger ship EEDI reference line in MEPC 65/4/4 and can confirm that this does not contain any HSC.

Additionally the correction factor fj_{roro} and fc_{ropax} were both developed without any consideration of HSC ships and calculation of EEDI or EEXI with these correction factors will lead to unpredictable results.

An additional development in this field should also be taken into account. In recent years, there has been a trend of multi-hull craft that look superficially similar to HSC, but designed for much lower speeds (10-20 knots) and which are employed on primarily domestic routes, but through special dispensation are built in part to HSC requirements. Such vessels are likely to eventually make it to international traffic, but will again be distinct from both HSC and conventional ro-ro passenger ships or ro-ro cargo ships.

12.1.1 Proposed Way Forward

There are potentially a number of ways forward:

- One is to amend the definition of ro-ro passenger and ro-ro cargo ships MARPOL Annex VI to clarify that these categories do not include ships built to the requirements of the HSC Code
- Another is to clarify that both attained and required EEDI does not apply to multi-hull craft
- Bearing in mind the INTERFERRY document in MEPC 76/7/14 regarding establishment of a separate CII for HSC, a new definition of HSC could be created in MARPOL Annex VI, but only to apply for CII since data and appropriate reference lines to derive an EEDI baseline and any associated correction factors will take a long time to finalise and in any case CII will likely be dominant

Note that the above 3 points are not mutually exclusive.

12.2 Vehicle Carriers

The official term in MARPOL Annex VI for vehicle carriers is ro-ro cargo ship (vehicle carrier). In the correspondence group on carbon intensity guidelines there was some confusion between vehicle carriers and ro-ro cargo ships because of the similarity in terminology which also extended to the discussions at ISWG-GHG 8. For avoidance of doubt and further confusion, we would suggest they are simply called vehicle carriers.

The discussions on EEXI ended up with the application of a correction factor for vehicle carriers according to MEPC 76/7/35 on the basis that newer ships have substantially increased their volumetric capacity with minimal changes to deadweight. This is in part due to the expansion of the Panama Canal which removed the previous 32.2m beam restriction, and which has enabled both improved stability from wider beam, but also additional decks. This is also the reason why for CII, cgDIST based on GT was agreed for vehicle carriers.

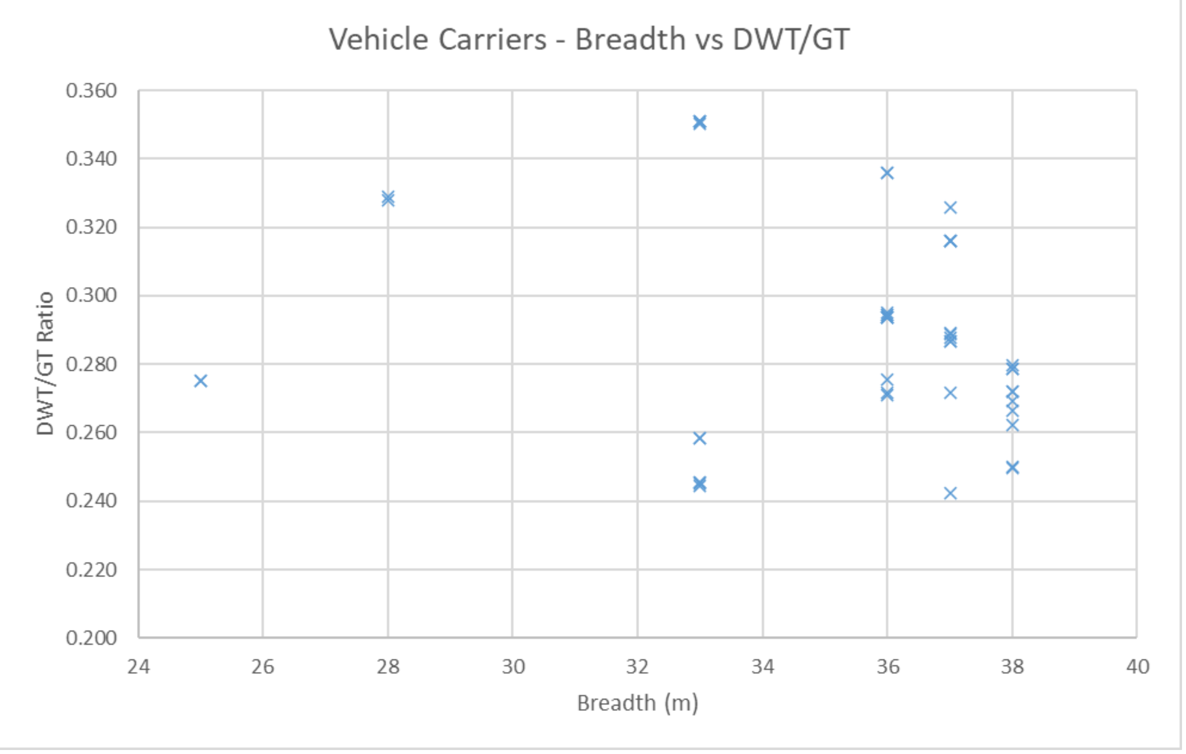

Figure 115 Vehicle Carriers - Comparison of Breadth vs DWT/GT

The above is taken from the IMO EEDI database but with GT added, as may be seen the majority of EEDI ships have a DWT/GT ratio less than 0.3, particularly those with a wider beam.

It is likely that GT would be a better measure of capacity for vehicle carriers, however due to the need to maintain comparability with the baseline which is deadweight based, it seems that a correction factor is required.

We expect that the CII requirement would ultimately govern the efficiency of vehicle carriers and this is only a means of adjusting the capacity.

12.2.1 Proposed Way Forward

It is suggested that ro-ro cargo ships (vehicle carriers) are simply renamed vehicle carriers to avoid further confusion with ro-ro cargo ships.

The correction factor implemented in EEXI should also be applied to EEDI.

12.3 Passenger Ships

MARPOL Annex VI provides the standard definition of passenger ship – ie a ship which carries more than 12 passengers. It seems that this was done in order to support the definition of the cruise passenger ship and ro-ro passenger ship type.

However while there is no required EEDI for passenger ships that are not cruise passenger ships with non-conventional propulsion or ro-ro passenger ships in Regulation 24 (in the revised MARPOL Annex VI post MEPC 76) and no associated reference line or reduction rates, passenger ships are referred to in Regulation 22, ie an attained EEDI should be calculated.

And yet the calculated values are not submitted to the IMO EEDI database because passenger ships are not subject to required EEDI in Regulation 24.

This oversight extends to the IMO DCS where there is a category called passenger ships but no reference lines have been calculated.

This means that there are passenger ships and cruise passenger ships with conventional propulsion, above 400 GT which are compelled to calculate an attained EEDI, undergo EEDI trials, with no perceivable regulatory or CO2 benefit.

We would suggest that references to passenger ships are simply removed from regulation 22 with a commensurate reduction in administrative burden. Note it has already been removed from regulation 23 Attained EEXI.

12.4 Ships which may fall into one or more categories

The EEDI concept works best for ship types where the designs are somewhat homogenous, such as bulk carriers and tankers, where the EEDI baselines exhibited statistical R^2 values greater than 0.9. For ship types that exhibit greater scatter in the data making up the EEDI baseline, this is invariably caused by there being a much greater diversity of designs, technical characteristics and speeds.

Good examples of this are:

- the general cargo ship segment, which encompasses a wide variety of diverse ship types designed for different speeds and purposes, including general purpose ship types that are purposely designed to be flexible
- The ro-ro passenger ship segment for which the deadweight does not correlate properly with the actual size of the ship, and where port/infrastructure constraints, varying ratios of passenger and cargo capacity and speed profile lead to wide variations of ship design even at the same deadweight

The solution used so far has been correction factors, which are not without their own problems.

In the amended MARPOL Annex VI, Regulation 22 (Attained EEDI) says:

Regulation 22
Attained Energy Efficiency Design Index (attained EEDI)

1 The attained EEDI shall be calculated for:

.1 each new ship;

.2 each new ship which has undergone a major conversion; and

.3 each new or existing ship which has undergone a major conversion, that is so extensive that the ship is regarded by the Administration as a newly-constructed ship;

which falls into one or more of the categories in regulations 2.2.5, 2.2.7, 2.2.9, 2.2.11, 2.2.14 to 2.2.16, 2.2.20, 2.2.22, and 2.2.26 to 2.2.29 of this Annex. The attained EEDI shall be specific to each ship and shall indicate the estimated performance of the ship in terms of energy efficiency, and be accompanied by the EEDI technical file that contains the information necessary for the calculation of the attained EEDI and that shows the process of calculation. The attained EEDI shall be verified, based on the EEDI technical file, either by the Administration or by any organization duly authorized by it.[35]

In particular "The attained EEDI shall be calculated for [ships] **which falls into one or more of the categories**".

Regulation 24.4 on Required EEDI says "If the design of a ship allows it to **fall into more than one of the above ship type definitions specified in table 2, the required EEDI for the ship shall be the most stringent (the lowest) required EEDI**.

Together, these two regulations create significant confusion over the application of EEDI. Let's use a case study of a roro container ship, known in the industry as a Con-ro.

12.4.1 Case Study – Conro

Conros are typically a hybrid of a container ship and a ro-ro cargo ship or a vehicle carrier. They take a number of different forms as can be seen in the pictures below:

Figure 116 ConRo Grande Luanda

Figure 117 ConRo Atlantic Star

Figure 118 ConRo Plyca

Figure 119 ConRo Bahri Abha

Figure 120 ConRo OPDR Canarias

Figure 121 ConRo Transfighter

One of the reasons for the existence of such ships is that they utilise the economies of scale by combining two types of cargo into a larger ship which would otherwise need to be carried by two smaller ships, where cargo volumes are limited.

When attempting to follow the requirements, calculation of attained EEDI becomes complex:

- If containership, the capacity is calculated at 70% deadweight, and technically
- If it is a vehicle carrier, the GT/DWT ratio may modify the required EEDI
- If it is calculated as a roro vessel, the correction factor fj_{roro} applies which may reduce the main engine term in the EEDI calculation to as little as 35% of the original, however note that the correction factor was developed without any reference to Conros

Also to be noted is that the relationship between dimensions, displacement and deadweight for the different ship types are different – containerships have a relatively large deadweight because the containers may be stacked, however roros need to have the decks in place, increasing lightweight and reducing deadweight. Having a hybrid of containership and roro means that its deadweight may categorise it with ships of different dimensions and displacement.

For required EEDI, the regulation imposes the most stringent EEDI. A cursory examination would suggest that this is either an accidental penalty or a deterrent to shipowners and shipyards and it is obvious that the attained EEDI of a hybrid ship would be compromised.

In practice many Conros are exempted from compliance with EEDI by their flags(and potentially EEXI) since the regulations are virtually impossible to implement, and the total fleet is relatively small. The situation with EEXI is more uncertain.

A related problem is that in the IHS database system, many Conros are categorised as pure ro-ro cargo ships, this may be seen in the IMO Data Collection system where INTERFERRY are seeking to separate the Conros for CII purposes.

12.4.2 Proposed Way Forward

We would propose to remove the "or more" wording in Regulation 22, and removing Regulation 24.4 which says that the most stringent EEDI should apply. We think it is unlikely that shipowners would invent new ship types that are hybrids in order to get out of EEDI compliance, and class societies will still be able to apply judgement if something is genuinely a hybrid or an attempt to circumvent the rules.

A potentially wider problem is the categorisation of ship types based on the IHS system is likely to be inadequate, since this is based on function rather than design features.

13 TASK C1 FRAMEWORK TUNING - PROMOTING LOW CARBON SOLUTIONS

One of the objectives of Task C1 was that the EEDI should aim at speeding up the deployment of low carbon solutions, as well as innovative non-conventional power solutions such as batteries, fuel cells and hybrid solutions.

It needs to be borne in mind that EEDI is not the only barrier to widespread adoption, and other barriers include safety regulation, TRL level, fuel availability and market barriers (including cost).

There are also technical barriers, such as the somewhat lower volumetric energy density of some alternative fuels which require increased amount of storage volumes, or may impact range.

There is also the danger of promoting solutions that look good in the context of EEDI, but in reality have a lower fuel saving potential, due to the limitations of assessment at the EEDI condition. In the end, promoting low carbon solutions involves a wide variety of policy instruments and also requires decisions on which ones are to be pushed.

On the other hand the solutions that will make the most difference will be somewhat apparent in the CII measure, therefore we would suggest that the aim should be that EEDI should not present any obstacle to the uptake of energy efficiency or low carbon solutions. We will examine the options in turn:

1. Alternative fuels – This is primarily regulated with the carbon factor. For LNG, apart from the addition of the methane slip factor as described above, there will still be a significant improvement from switching to LNG. For fuels with no carbon content, we suggest that a carbon factor of zero is used, so while they will still undergo EEDI certification, such ships will always meet the required EEDI. We should of course consider additionally calculating the EEDI of such ships with a carbon factor for MGO, so we have some understanding of the actual energy efficiency of these ships, however overall the framework does not present any obstacles to alternative fuels
2. Fuel Cells – for most ship types, implementation of fuel cells will require moving to electric propulsion, or a hybrid of conventional and non-conventional propulsion which then effectively exempts them from application of EEDI. In the case of cruise passenger ships and LNG carriers which use non-conventional propulsion, we would suggest that this should be left to the Administration because while fuel cells may use ammonia and hydrogen, they are also able to use methanol and LNG, and it in part depends on what proportion of the installed power is provided by the fuel cells. Subject to some text being added to the calculation guidelines to that effect, we do not see that EEDI provides any impediment to use of fuel cells
3. Batteries – batteries are currently not accounted for at all in the EEDI framework and therefore presents an obstacle to adoption of batteries. Our proposal as described above is to either exempt ships with battery installations, or to apply the estimated savings from batteries to the attained EEDI.
4. Non-conventional propulsion – as mentioned above, we are against developing a correction factor to level up non-conventional propulsion (primarily electric propulsion) to conventional direct driven propulsion systems. We prefer that such ships are kept out of the EEDI framework to allow shipowner and shipyards to make their choices on technical grounds based on an understanding of the operating profile of the vessel, and that this will be demonstrated in CII performance. As such keeping the status quo does not place any obstacles to adoption.

5. Wind propulsion – There is a small group reporting to MEPC 77 aiming to revise the calculation method used to estimate the contribution of wind assisted propulsion in MEPC Circular 815 to promote the installation of wind assist. We have separately proposed here and to the group that for wind assist that saves more than 15% of EEDI, such ships should be further exempted from EEDI compliance and considered non-conventional propulsion, and this should extend to LNG carriers and cruise passenger ships. Together, this makes wind assist both more attractive, and allows ships with significant amounts of wind assist to optimise the design of the vessel without being constrained by EEDI.
6. Air Lubrication – we have proposed some changes to the calculation methodology to better derive the net effect of air lubrication.
7. Waste heat recovery – We think the current scheme for waste heat recovery is overly generous, but even with this, uptake has been fairly limited for reasons that we have also explained. For now we propose an adjustment to limit the contribution from waste heat recovery which is more in line with the expected savings.

What should also be borne in mind is that shipyards take on the risk of guaranteeing the performance of a ship in the contract, and the addition of third party equipment potentially jeopardises certainty.

We are now seeing ships being equipped with energy saving devices, but these are not mentioned in the EEDI technical file, nor used for the calculation of the attained EEDI. It is clear that this is not something that may be solved within the EEDI framework, apart from trying to ensure that an attained EEDI with the energy saving device should additionally be calculated and submitted in the brief description section of the revised EEDI reporting template.

14 Phase 4 EEDI – Putting it Together

In the preceding chapters we have suggested changes to the EEDI framework to improve how it works, some of these changes would lead to increases or reductions in attained EEDI as follows:

Table 14-1 Summary of Proposed Changes to Calculation of Attained EEDI

	Increase or Reduce EEDI	Summary
Air lubrication	Increase	Tweaks to MEPC.1 Circ.815
Wind	**Reduce**	Tweaks to MEPC.1 Circ.815
Waste heat recovery	Increase	Limiting effect of waste heat recovery
Non-conventional propulsion	NA	Continue to exclude non-conventional propulsion
Batteries	**Reduce/NA**	Either exclude ships with batteries, or back calculate effect over the operating profile and apply to EEDI
Methane Slip	Increase	Suggestion for methane slip factor based on GWP_{20}
Operating Profile	NA	No change suggested
Minimum propulsion power	Increase	Amendments at MEPC 76 may increase attained EEDI values for some ships
Auxiliary Power	**Reduce**	Introduction of additional factor for EPT and allowing deductions from the ratio method without use of EPT

These changes are fairly minor, however broadly they change the impact of the different solutions.

What this chapter now looks at is the bigger picture, in the context of trying to understand what kind of reduction rate should be applied to EEDI Phase 4, and the associated time frame.

First it will be useful to look at the impact of EEDI on operational efficiency. The IMO Data collection system indicates the EEDI score of the ships that are in the database, and this allows us to plot AER values of EEDI ships and non-EEDI ships. The results are as follows.

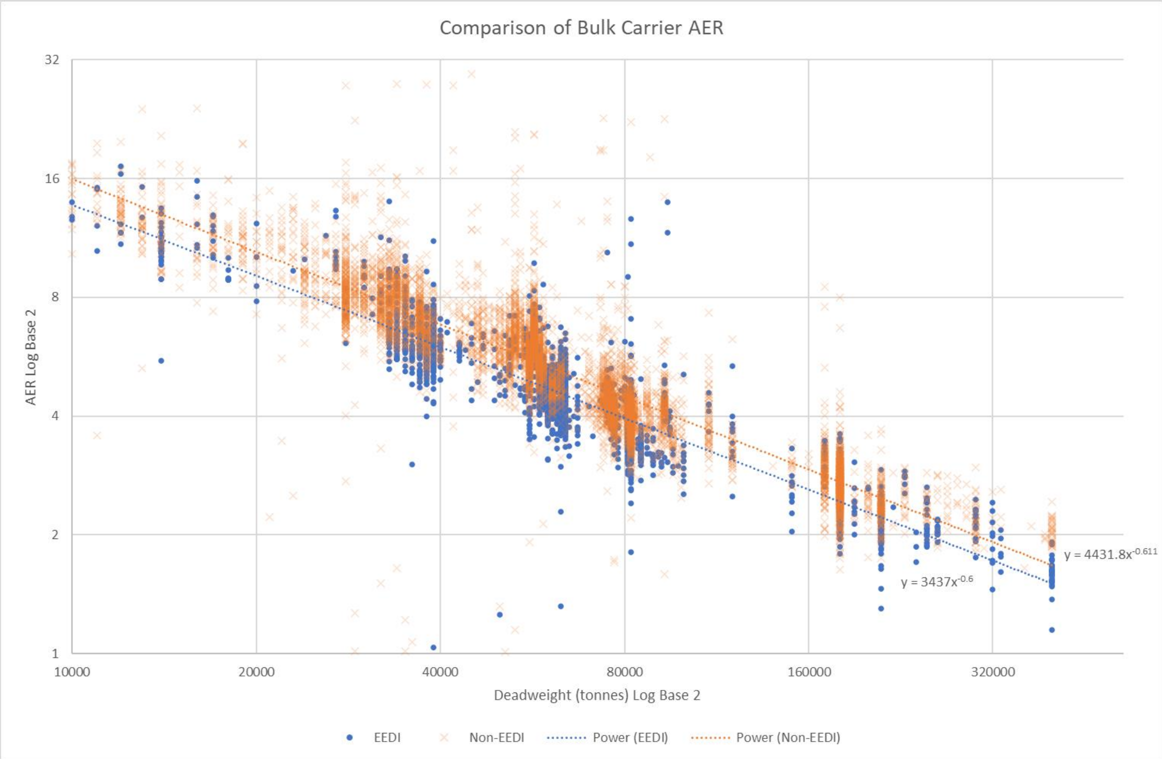

Figure 122 Comparison of EEDI and Non-EEDI Bulk Carrier AER – IMO DCS

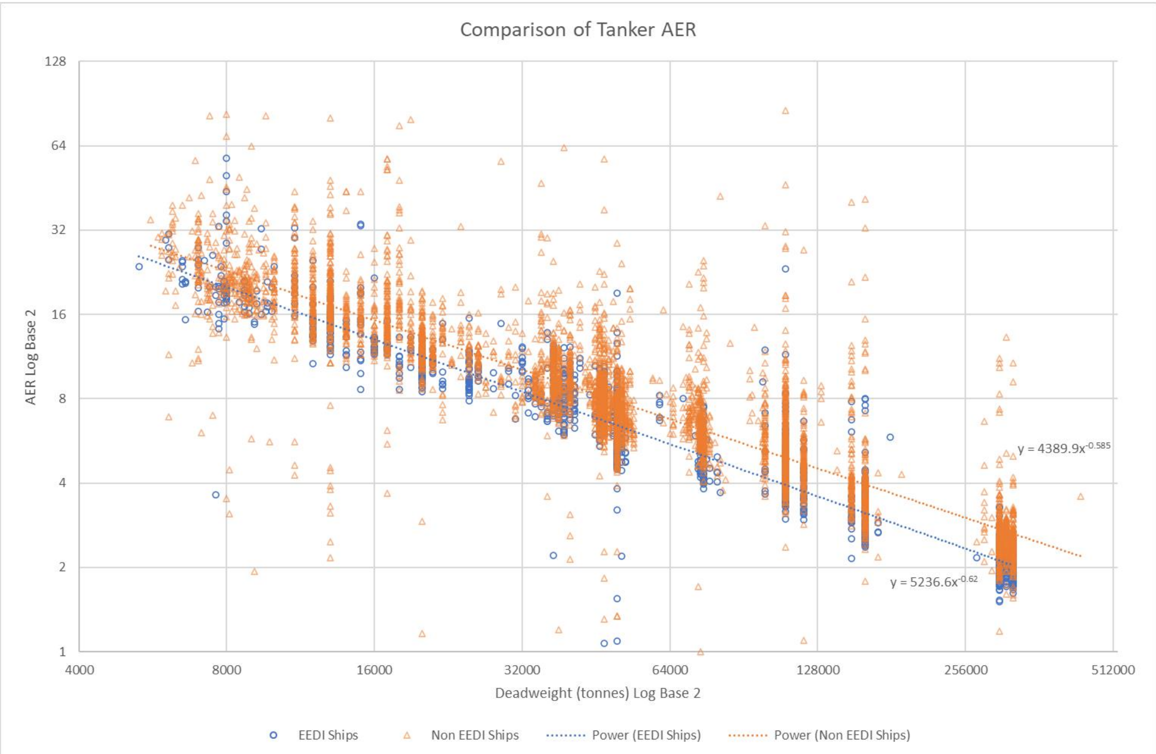

Figure 123 Comparison of EEDI and Non-EEDI Tanker AER – IMO DCS

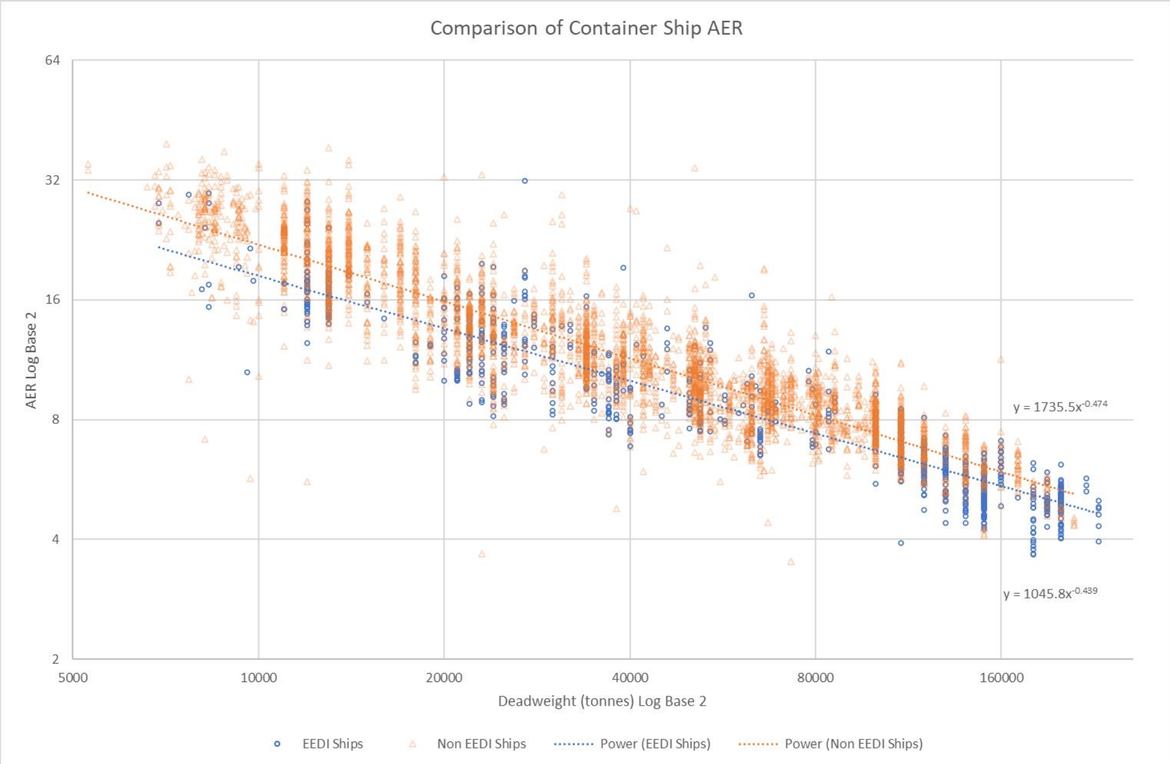

Figure 124 Comparison of EEDI and Non-EEDI Container Ship AER – IMO DCS

Table 14-2 Comparison of AER for EEDI and pre EEDI ship - IMO DCS data

	Deadweight	Non-EEDI Avg. AER	EEDI Avg AER	Percentage Difference
Bulk Carriers	35000	7.42	6.45	12.99%
Bulk Carriers	81000	4.44	3.90	12.18%
Bulk Carriers	210000	2.48	2.20	11.26%
Tanker	50000	7.83	6.39	18.33%
Tanker	109000	4.96	3.94	20.52%
Tanker	300000	2.74	2.10	23.29%
Container	12000	20.23	16.93	16.29%
Container	40000	11.43	9.98	12.68%
Container	200000	5.33	4.92	7.62%

The difference in AER between EEDI ships and non-EEDI ships is presented in the table above and also summarised in the chart below.

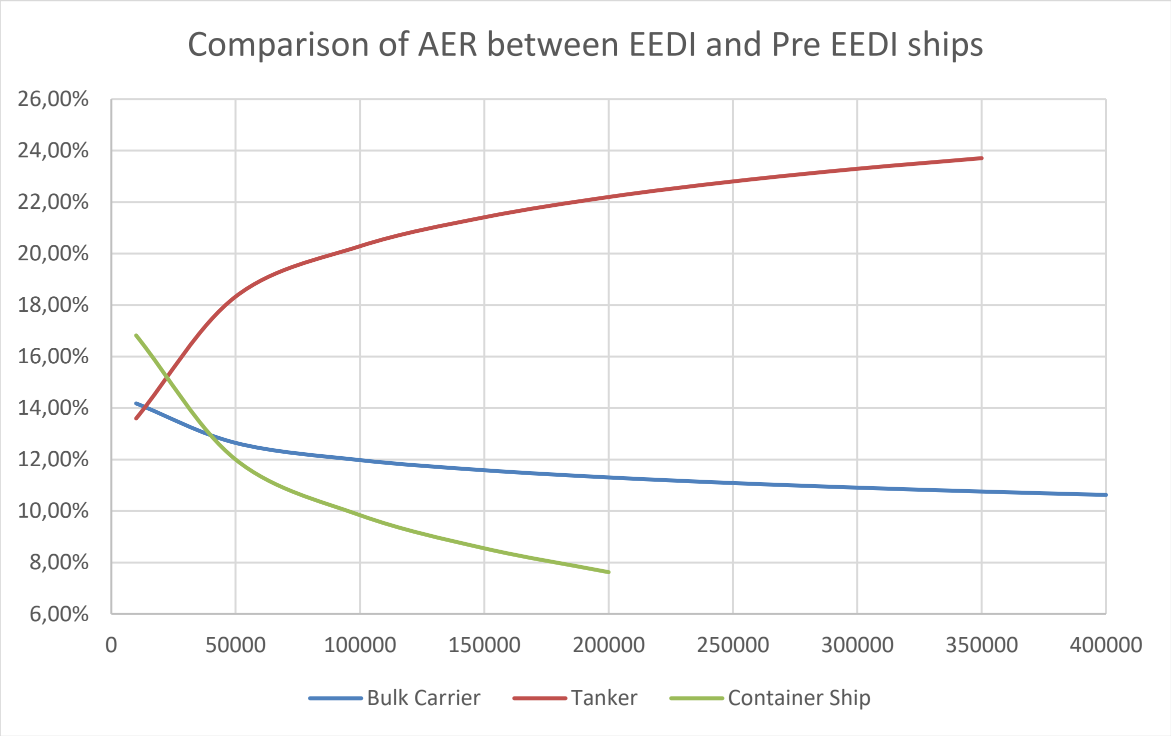

Figure 125 Comparison of AER between EEDI and Pre EEDI Ships – IMO DCS

This needs to be compared to the following EEDI charts:

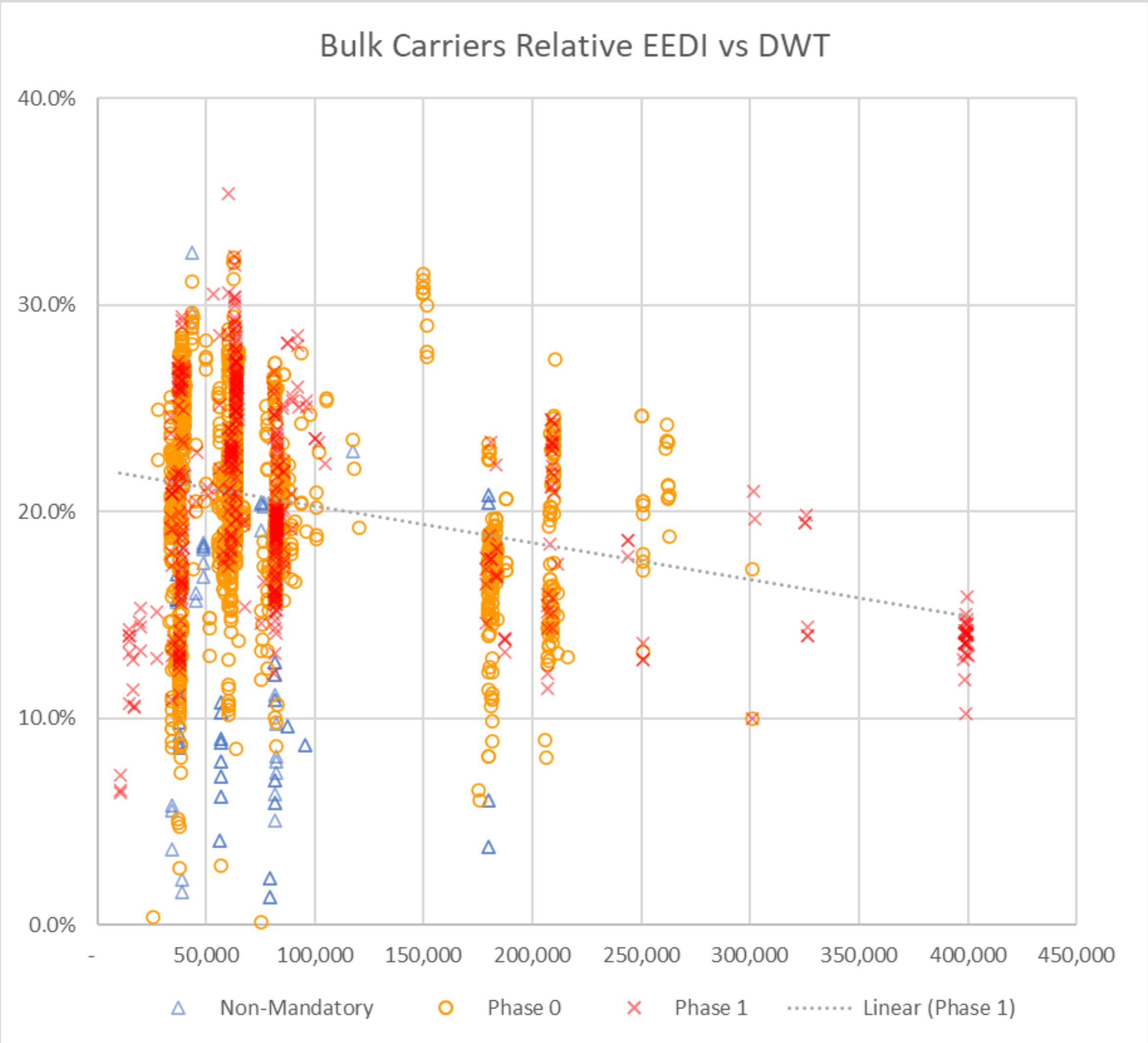

Figure 126 Bulk Carrier Relative EEDI - IMO EEDI Database

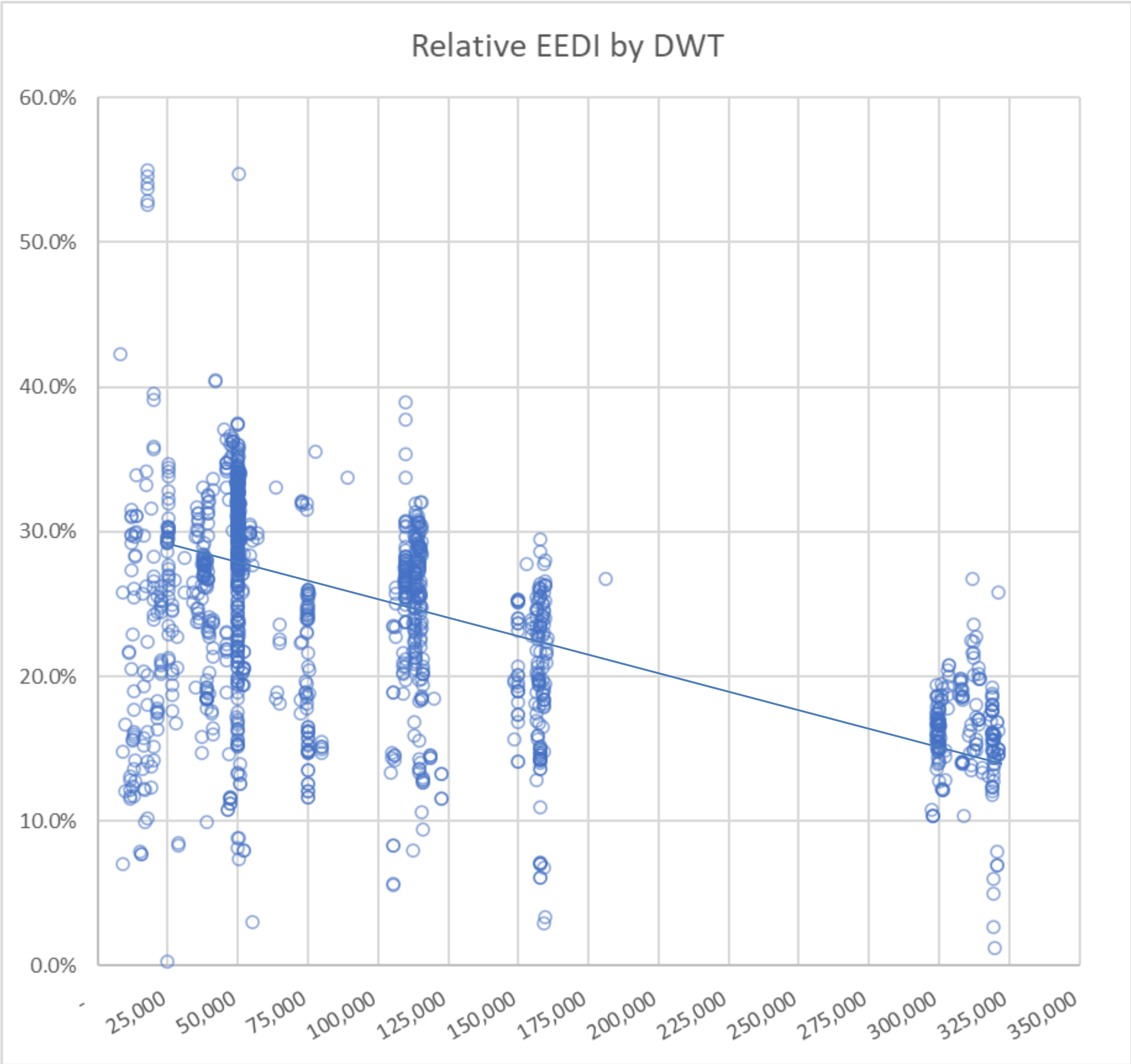

Figure 127 Tanker Relative EEDI - IMO EEDI Database

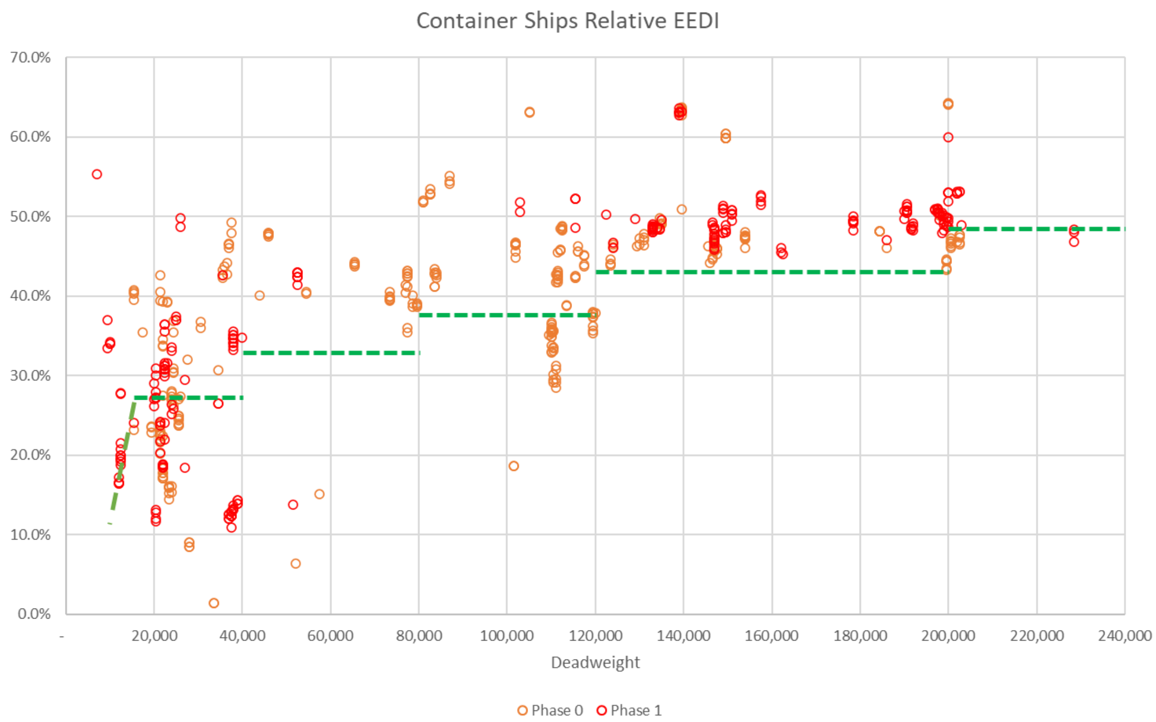

Figure 128 Container Ship Relative EEDI - IMO EEDI Database

Some observations:

- For bulk carriers and tankers, the relative EEDI decreases with increasing deadweight,
- In AER terms, the gap between EEDI bulk carriers and non-EEDI bulk carriers also decreases with increasing deadweight as expected, but for tankers, the gap in performance increases with increasing deadweight
- For container ships, relative EEDI increases with increasing deadweight, but in AER terms the gap between EEDI containerships and non-EEDI containerships decreases with increasing deadweight
- Bulk carrier relative EEDI seems to be in the range of 22% to 14% on average, but the gap in AER is around 14% to 11%
- Tanker relative EEDI is in the range 30% to 15% but the variation in AER is from about 14% to 24%
- Container ship relative EEDI is in the range of 28% to 50%, but the variation in AER is from 17% down to 7.5%

In aggregate the operating profiles of the fleet of EEDI and non-EEDI ships should be the same, so the differences in AER should be primarily down to the way design choices manifest in operating profiles.

Possible explanations for the discrepancies are:

- Containerships have engaged in a lot of retrofitting of existing ships, especially the larger ones to close the gap with newer ships, compared with the EEDI reduction rates of the order of 30% to 50% achieved, and this reduces the gap between EEDI and non-EEDI ships
- The regression for containerships looks biased – the line should probably be lower for the large ships, and is being influenced by other deadweight ranges
- The operating profile of larger tankers seem to benefit more from EEDI design choices

In general, EEDI ships exhibit better operational carbon intensity than non-EEDI ships, however, there does not appear to be a simple correlation between relative attained EEDI and AER and thus the impact of further EEDI phases is somewhat unpredictable and is likely heavily influenced by the type of solution chosen for compliance.

14.1 EEDI Baselines

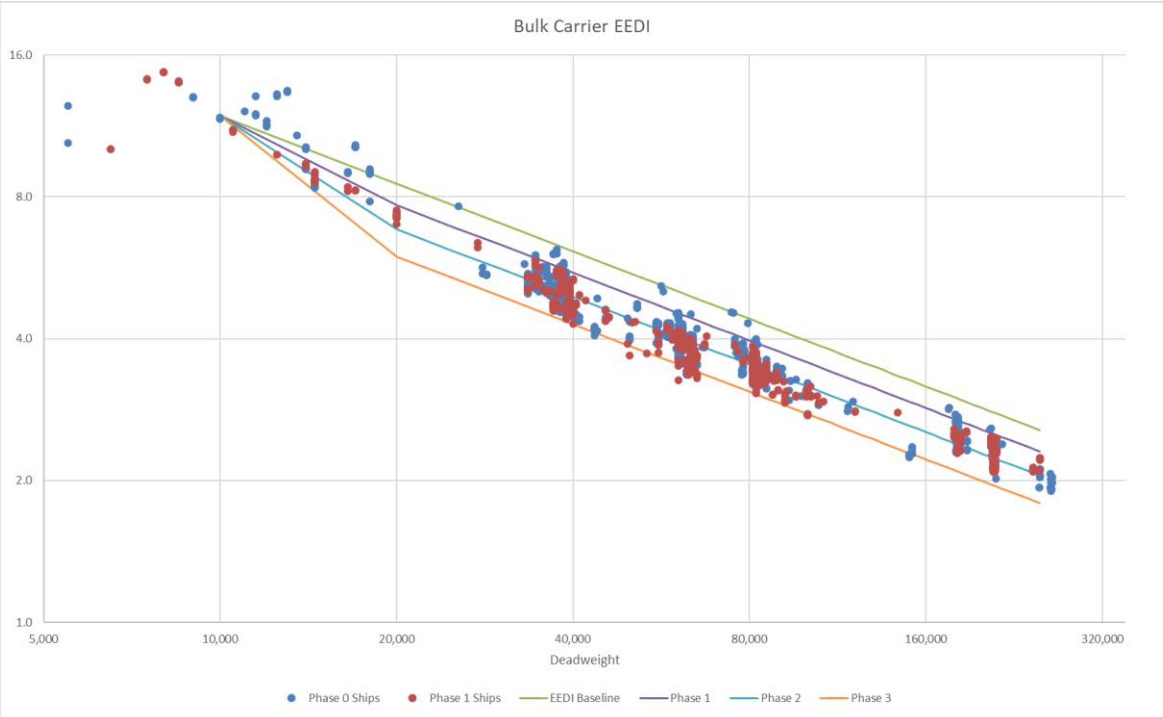

Figure 129 Bulk Carrier EEDI Log format - IMO EEDI Database

When comparing the EEDI Baseline and phases with the actual EEDI bulk carriers, it becomes apparent that the improvement rate of the EEDI is not the same across different size ranges. In the above chart, the ships up to 20,000 deadweight seem to mostly meet Phase 1, with only a few ships meeting Phase 2, while the larger ships seem to mostly meet Phase 2, with a few ships already meeting Phase 3. While the transition area between 10,000 dwt and 20,000 dwt seems to work well, adding a Phase 4 will lead to a very steep threshold which means that small changes in deadweight will lead to large differences in EEDI compliance.

However, it is clear that these smaller ships have improved, as evidenced by the fact that the Phase 1 ships are noticeably better than the Phase 0 ships, and so this indicates that the shape of the EEDI reference line was most likely heavily biased towards where the majority of the ships are – 35k-120k dwt.

There may be a need to redraw the baselines to be size dependent, however this require need some additional data from Phase 2 and Phase 3 in order to be a good basis for Phase 4.

Note that we are using a log form of the typical EEDI chart because this shows the situation more clearly for the small ships which would otherwise be located at a part of the curve which has a very steep gradient.

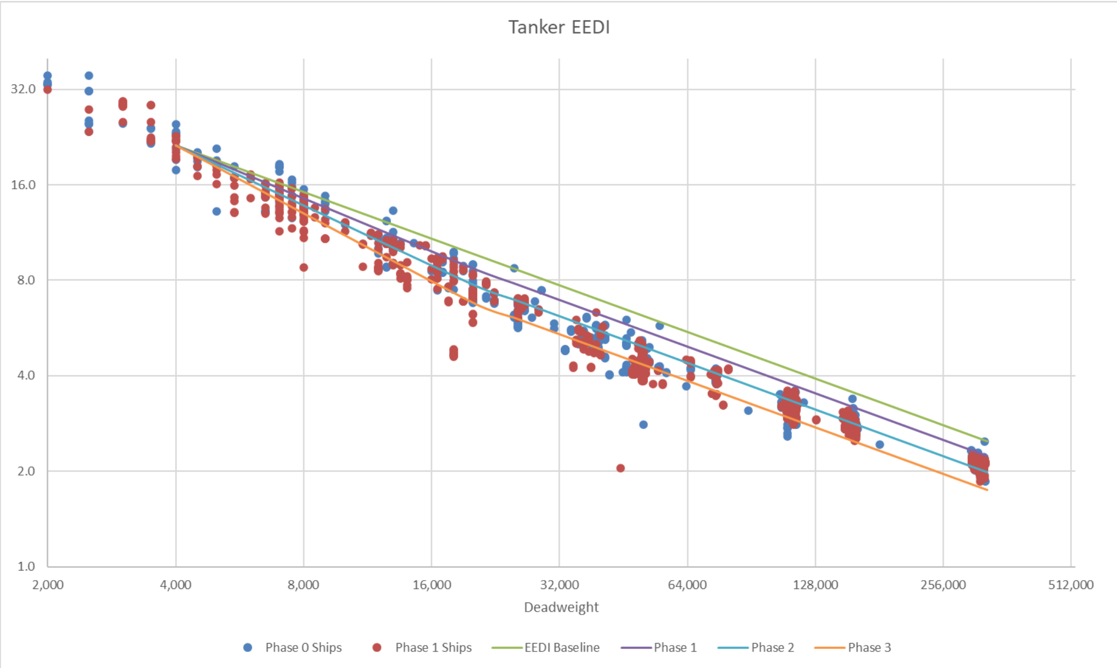

Figure 130 Tanker EEDI Log Format - IMO EEDI Database

The situation with tankers is similar, although it seems that the chemical tanker correction factor is causing some over-achievement from 4,000 dwt to 50,000 dwt and may then necessitate some adjustment to the baselines or separation of chemical tankers from tankers.

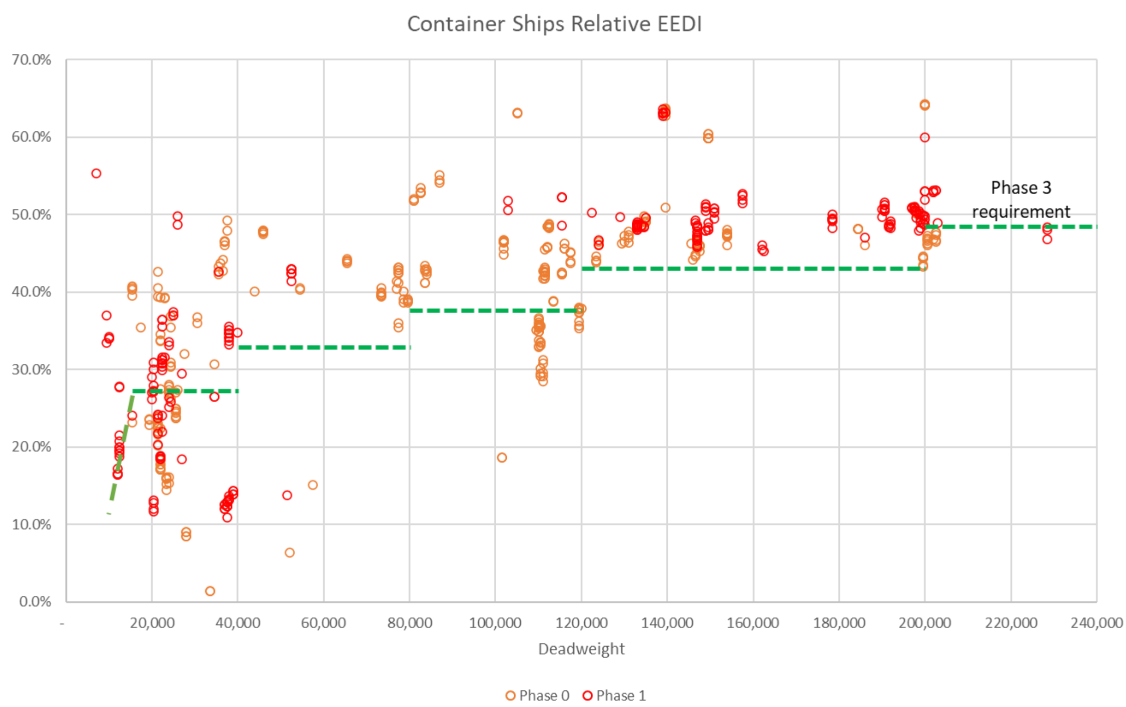

Figure 131 Container Ship Relative EEDI - IMO EEDI Database

The situation with containerships is more complex due to the stepped reduction rates, but again there seems to be a marked difference in EEDI achievement which is deadweight dependent, indicating issues with the original shape of reference lines, something which was also raised in the Task A1 report.

This points towards the need to derive new baselines, which will also allow for other changes to the EEDI framework.

14.2 Reduction Rates

At the moment we consider that the Phase 1 ships (some of which comply with Phase 2) represent the state of the art in terms of energy efficiency and hydrodynamic optimisation for now.

Many Phase 3 compliant vessels being marketed today (even Phase 4 compliance is advertised) by shipyards are LNG powered. The reason for this is that there are very few technologies that provide certainty of improvement of the order of 5-10%, and which are wholly within the control of the shipyard, who take on the risk of guaranteeing the performance of the ship. And most shipyards will try to have designs which they can build as a series over a number of years that will remain in compliance.

Work done in Task A1 generally showed that efficiency improvements do not follow a gradual trend but seem to be characterised by a step change that was a response to the financial crisis followed by a period of plateau or small improvements indicating incremental optimisation. This typically means that the rate of improvement is potentially tailing off, absent major innovation.

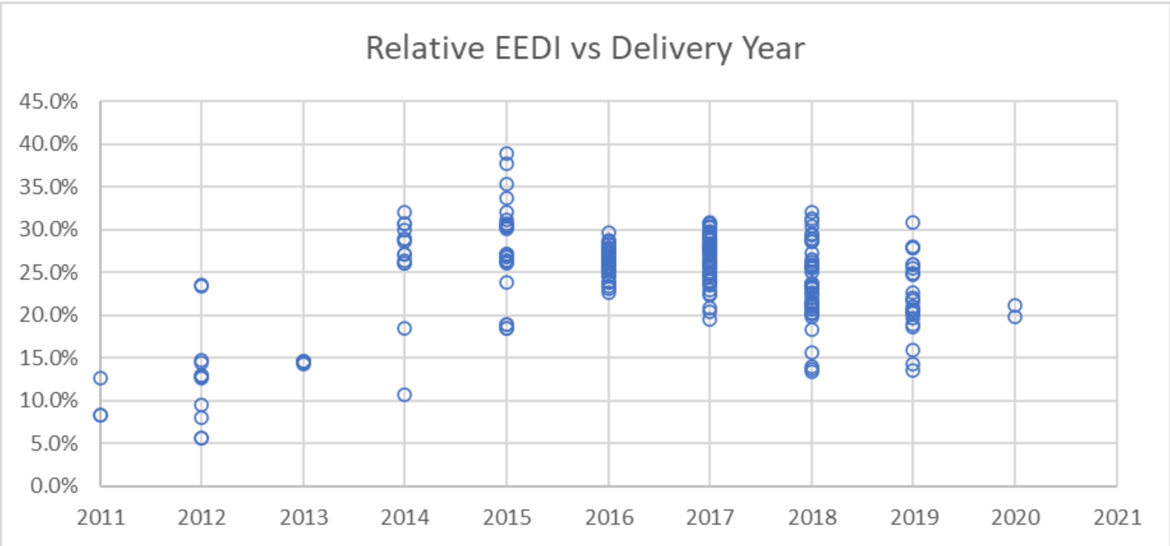

Figure 132 Aframax Relative EEDI by delivery year - IMO EEDI Database

The above is the chart of relative EEDI of Aframaxes from the task A1 report. Those of 2014 and 2015 benefitted from a more favourable sea trial analysis procedure before it was updated, but thereafter the relative EEDI performance is flat. On average the segment is at about 25% better than the baseline.

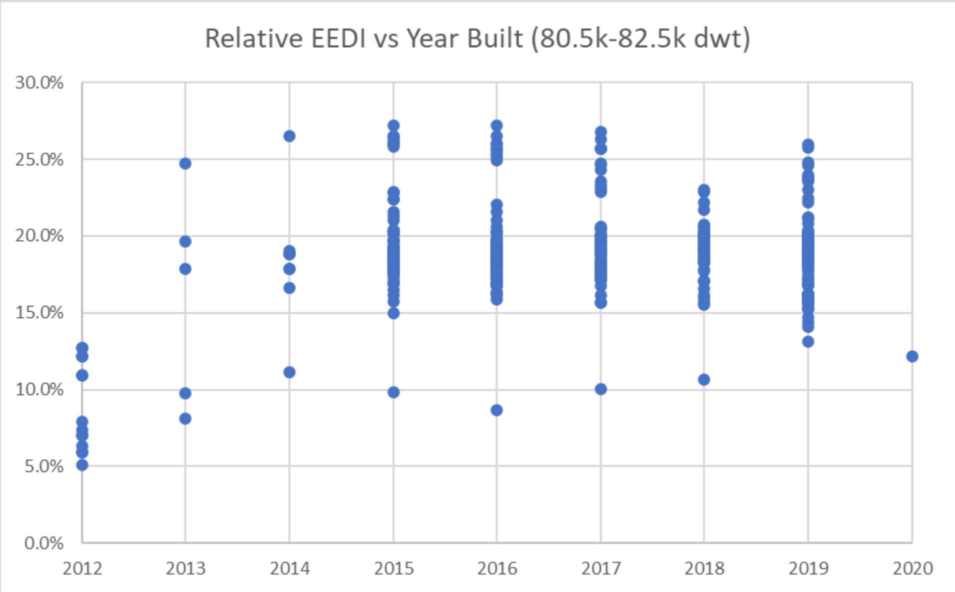

Figure 133 Kamsarmax Relative EEDI by delivery year - IMO EEDI Database

A similar picture emerges with Kamsarmax bulk carriers, a highly competitive tonnage size. Average achievement is a bit lower than for the Aframax tankers, a bit more than 20%.

Alternative fuels aside, only air lubrication, wind assist and, in some applications, batteries have the potential to provide more than 5% improvement in fuel consumption. This circa 5% might be sufficient to bring the Aframax tankers into compliance with Phase 3, but not for Phase 4, while it may not be sufficient to bring the Kamsarmax bulk carriers in compliance with Phase 3. However, note that shipyards are not currently including some technologies in the calculation of the attained EEDI, and the current calculation methodology for wind assist seems to give rather low savings (e.g. MEPC 74 Inf.39 indicating a 1.6% improvement for a pair of hard sails on a VLCC when trials indicated around 5% of the main engine power).

There is also an additional complication. If we consider addition of an energy efficiency technology which typically would save 5% of P_{ME} for 2 different sizes of bulk carrier:

14,500 dwt with P_{ME} of 2,900 kW Attained EEDI 8.66 EEDI Baseline 9.957 V_{ref} 14 knots

> In this case a 5% reduction in P_{ME} results in 4.7% reduction in EEDI relative to the donor vessel with an attained EEDI of 8.254. The donor vessel is 13.03% better than the baseline while the vessel fitted with the EET is 17.10% better than the baseline ie **4.08%** better in EEDI terms.

64,000 dwt with P_{ME} of 5,600 kW Attained EEDI 3.59 EEDI Baseline 4.904 V_{ref} 14 knots

> In this case a 5% reduction in P_{ME} again results in 4.7% reduction in EEDI relative to the donor vessel with an attained EEDI of 3.42. The donor vessel is 26.79% better than the baseline while the vessel fitted with the EET is 30.23% better than the baseline ie 3.43% better in EEDI terms. Here the progression from a 5% saving in P_{ME} to **3.43%** improvement in EEDI terms is worse than the 14,500dwt vessel because the attained EEDI is a greater percentage improvement over the baseline.

And so, the better a ship performs relative to the EEDI baseline, the less impact technologies will make, and since the performance of wind assist, batteries and even air lubrication may be somewhat variable, so for contractual certainty shipyards prefer to implement alternative fuel options – LNG with approx. 15% better C_f, but the calorific value is also better leading to around 10% better SFOC.

Note that even if LNG may improve the EEDI of an individual ship by around 23%, when compared to the baseline, this would be reduced to around 18% and 16% respectively in the examples from above. To this we need to include the contribution from methane slip which would further reduce the effect of LNG going forward.

Putting these together:

- Ships are highly optimised for energy efficiency; further incremental improvement is likely to be limited
- There are only a few solutions that are not yet widely implemented which may result in improvements of 5% or more, these are wind assist, air lubrication, batteries and alternative fuels. Of these, alternative fuels provide the most certainty in the calculation of the EEDI and minimum risk in shipbuilding contracts, and hence they are prioritised
- The EEDI formulation which calculates percentages against a baseline reduces the effect of energy saving solutions as ships improve, while implementation of a methane slip factor will reduce the effectiveness of LNG as a solution, especially for 2 and 4 stroke engines on the Otto cycle where methane slip negates or exceeds the advantage that LNG has

The question becomes whether implementation of Phase 4 will cause a major shift to LNG (using 2 stroke engines on the diesel cycle, or Otto cycle engines if methane slip can be dramatically reduced) because all other alternative fuel types are lagging behind in availability and infrastructure. In the event that LNG is not a desirable alternative, the implementation of EEDI Phase 4 may need to be paused. It should also be noted that if the methane slip factor is introduced in time for some Phase 3 vessels but not all, there will be significant discrepancies in attained EEDI.

We think it is premature to suggest a reduction rate for Phase 4 due to the interaction with the CII framework, LCA analysis and potential market-based measures, and are not confident that adding another 10% reduction rate for Phase 4 is the right approach because the roadmap for achieving this is unclear. Some policymakers would suggest that having high ambition would stimulate the necessary innovation and is a necessity given the urgency of the climate situation, however the major constraint in this case is infrastructure roll out of alternative fuels, both the production as well as the bunkering infrastructure across the world.

Also, questions remain as to whether EEDI, with its very limited overview of efficiency in technical design terms only, is the right policy framework to be extended.

It should be noted that the roll out of LNG bunkering infrastructure over the last 20 or so years has resulted in LNG being available only in some major ports. The relevant statistic is that there are around 20 LNG bunker vessels around the world, some serving a number of ports, due to the lack of concentrated demand. In contrast, the Port of Rotterdam alone has around 150 dedicated liquid fuel bunker vessels and the world fleet of bunkering vessels likely numbers over a thousand.

It should also be noted that LNG carriers primarily use boil off gas from their cargo and it may make little sense to transition to any other fuel given the need to manage boil off, and so the potential for further improvements to the LNG carrier fleet via an alternative fuel may be more limited than for other ship types which run primarily on MGO or HFO. Similarly, for gas carriers, there seems to be a transition to run on LPG or ethane which has a carbon factor that is only around 6% better than MGO, compared to 15% for LNG.

14.3 Timescale of Phase 4

From the discussions that have ensued in the EEDI Phase 4 correspondence group, the typical choices for the start of Phase 4 have been either 2027 or 2030. This is achieved by adding the established 5-year block (a concept created by the EEDI framework) to the current start dates for phase 3 which are either 2022 or 2025.

In general, those ship types which have had their Phase 3 start date accelerated to 2022 (General Cargo ships, Cruise passenger ships, LNG carriers, Gas carriers above 15,000 dwt) are typically due to the fact that the original reference lines were incorrectly drawn, or that market conditions had altered design speeds from the average between 1998-2008 that was used as the basis for the EEDI. Otherwise, the rate of improvement is no different from the other ship types with Phase 3 from 2025 onwards in terms of incremental optimisation of energy efficiency.

Hence for Phase 4 we would propose to realign the dates for all ship types in conjunction with the revision of the baselines. Our recommendation is that 2027 is too early to start Phase 4 and a later date should be considered.

Due to the need for boiloff gas management, it is assumed that LNG carriers are not able to transition to any other alternative fuels. In terms of uptake of energy saving devices, some are more suited to some ship types, sizes or operating profiles than others, however without any significant uptake of batteries, air lubrication or wind propulsion so far it is difficult to estimate the impact of these technologies.

There is an obvious link with availability of alternative fuels and associated infrastructure that should be assessed, but the missing step is knowing which alternative fuels are likely to be developed and incentivised.

In this report we have not touched on further speed and power reductions as an avenue to comply with future phases of EEDI. The challenge is that the market broadly requires ships to be capable of certain speeds with margins in place. If new ships are built with lower speed capability, they will have difficulties trading, and there will also potentially be a rush to order ships before entry into force of the new phase. Getting the timing right is an important part of the transition. Previous speed reductions have been imposed by the market as a response to poor trading conditions and the EEDI framework alone is unable to do that.

However, the CII framework is likely to force existing ships to slow down over time such that existing ships will no longer have any inherent advantage over new ships. With this, the design of new ships will most likely adapt, and we expect that shipyards will begin to build ships with an eye towards CII compliance for a minimum number of years.

Accepting slower newbuild vessels over time means even more ships need to be built to maintain and increase transport capacity, but the timing of this is linked to alternative fuel engine availability and infrastructure, and may end up with older vessels trading for longer, or a rush to build and order new ships before the start of the new phase.

14.4 Relevance of EEDI

EEDI was the first mandatory design technical standard to help drive energy efficiency in new ship design. With the implementation of the EEXI, the EEDI concept has been extended to existing ships, increasing its impact. However with the implementation of the CII framework which encompasses both operational and design technical approaches in a more holistic way, the necessity and relevance of EEDI needs to be evaluated, especially as more stringent reduction rates take effect.

A consideration is that we are in a transition period, moving from design energy efficiency to a mix of operational energy efficiency, and then on to a transition to zero carbon alternative fuel and propulsion, and so it is prudent to evaluate whether earlier regulatory instruments are superseded by a newer framework that is just as effective or more. If so, then there should be a process to remove the earlier regulatory instruments. For now, until we have experience with the implementation and results of the CII framework, EEDI remains important, however this may change post 2026 with the setting of the reduction rates for 2027-2030.

One solution being mooted is for EEDI to become energy based, that is to disallow the use of any C_f apart from that of MGO, the concept being that this will ensure a minimum level of energy efficiency, leaving the CII framework to deliver the fuel transition. It is envisaged that LNG carriers will be allowed to use LNG as the sector almost entirely used LNG.

The challenge with this option is that ships that use alternative fuels generally have less deadweight for the same size of vessel due to the containment and fuel handling systems compared to a conventional vessel with only liquid fuel tanks. In an EEDI calculation, this will reduce the size of the denominator while the numerator remains the same and will therefore compare unfavourably with conventionally fuelled ships.

Additionally, there will be an issue regarding the relevant SFOC to be used. This could be an option for primarily dual fuel vessels where the engine is capable of using MGO. However, using this solution will require a wholesale re-evaluation of the reduction rates and for some vessels even Phase 3 reduction rates may no longer be achievable without the option of an alternative fuel.

Some of the basic limitations of the EEDI remain, such as evaluating the efficiency at a single point which may not be how the ship will operate.

To go even further, one could envisage a formula such as:

$(P_{ME}+P_{AE})/(V_{ref}*DWT)$ which could still include some capacity correction factors.

Overall, an energy based EEDI may have challenges incorporating wind assist or batteries (since the overall energy to move the ship is the same). In the formula above, improvements to engine SFOC would not be recognised. So, although an energy based EEDI is an interesting option, more analysis is required, together with a view on which types of efficiency should be recognised.

There is another option to be considered on its own or in tandem with an energy based EEDI is to go for a speed based EEDI where the speed is fixed for each type of vessel, chosen to be closer to the intended operating speed for a ship type or segment. In this way, then all ships are assessed at the same speed, and differences in the required power and SFOC may be compared on the same basis.

It is however clear that any such change to the EEDI will require new baselines and a significant rewrite of the calculation guidelines.

The last suggestion for EEDI in a post CII landscape would be that it should be used as part of the corrective action plan for D and E rated vessels, particularly those which are in operating profiles that will always lead to poor CII, and that a check should be made that attained EEDI (or EEXI) meets a certain requirement, though it should not be used to match the required CII reduction rate.

14.5 Proposed Way Forward

Overall, we would suggest that the following tweaks to the EEDI framework are carried out as soon as reasonably possible:

1. Methane slip factor
2. Wind propulsion adjustments (in part being addressed by small wind group reporting to MEPC 77), but MARPOL amendment to categorise significant wind propulsion (ie over 15% of EEDI) as non-conventional propulsion is also needed
3. Adjustments to auxiliary power (default deductions for variable frequency pumps, etc, and service factor of capacity for the electric power table)
4. Inclusion or exemption of vessels fitted with batteries

Adjustments to the ship type categories may also be considered at the same time – HSC, Vehicle carriers and ships which may fall into one or more categories.

We then propose that we ensure that the EEDI database is fit for purpose for collecting relevant and verified data for the different forms that Phase 4 EEDI may take, but wait for the full effect of CII, and results from LCA before carrying out the necessary analysis. This may need to be done post 2026, indicating that the earliest implementation of EEDI Phase 4 could be 2028 or 2029.

With the appropriate data, we may engage in wholesale revision of the EEDI concept, however this will most likely involve definition of new baselines that account for the state of the market.

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