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Is reducing speed the right mitigating action to limit harmful emissions of seagoing RoRo cargo carriers?

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Abstract

The Energy Emission Design Index (EEDI) is an index indicating the CO_2 emission per transportation effort, for example the emitted tons CO_2 per ton mile, to be calculated for each new design. The required index for new designs will be gradually lowered in the coming years resulting in either improved energy efficiencies or speed reductions.

RoRo carriers are key stones in shore based logistical systems and as a result diverse in design speeds and main dimension ratio's. This diversity could be threatened by the relative simplicity of the EEDI regulations. This article aims to estimate the influence of the EEDI approach on 30 existing RoRo cargo carriers. The attained EEDI's per design are determined. Also the costs per transport effort are calculated based on the private costs and based on the social costs, both at the economically optimum speeds based on a uniformly applied sailing profile. The social costs are based on all emissions because the number of Environmental Special Area's is limited and the impact of speed reductions will not be limited to climate change. The expected speed reductions for these designs based on the EEDI, but also the required speed reductions when taking into account the total social costs are used to estimate the effectivity from the EEDI regulations. Amongst others it was concluded that the existing diversity in service speeds and main dimension ratio's will be jeopardized by the EEDI regulations.

Keywords: EEDI, External costs, Economic performance, Vessel, Ship, RoRo, Design, Maritime technology, Maritime economic, Emissions, Sustainability, Level playing field

Introduction

Emissions from ships are mostly emitted in a global context far from land. This combined with the fact that a new regulation requires the approval from many countries results often in a relatively slow process when developing and introducing emission reducing measures for the maritime world. Nevertheless, emission reduction has got its attention from the IMO, at first the sulphur and NOx emission reductions are regulated in the SECA areas. Finally there are now the new regulations for the CO2 emissions, regulated by means of the Energy Efficiency Design Index (EEDI). The fact that this has happened reflects the worldwide acceptance of the necessity of emission reducing measures.

The essential goal of the EEDI regulations for new-buildings is decreasing the CO2 emissions per unit of transport capacity. The latter can be in principal a ton-mile or a cubic-meter-mile. This depends on the specific gravity of the cargo.

The principal formula used to express the index (Germanische Loyd, 2013) :

$$EEDI\ Attained = \frac{\{\sum f_j \left(P_{ME\,(i)}\ \times C_{FME\,(i)} \times SFC_{ME\,(i)}\right) + P_{AE}\ x\ C_{FAE} x SFC_{AE}\}}{f_i x\ f_l x\ f_w x\ f_c x\ Capacity\ x\ V_{ref}}$$

With P_{ME} = 75 % of the MCR of the main engine, the power required to create V_{ref} at trial condition.

The factor f_j being a ship-type or specific design dependent correction factor.

The summation means that each Main Engine has to be taken into account separately. The parameters used in the equation are P_{ME}, 75 % of the installed power, C_{FME} the CO_2 emissions in ton per ton fuel and per type of fuel, the SFC (specific fuel consumption in gram per kWh) of that specific engine. This, plus the emissions from the auxiliary engines determined by a statistical defined power consumption based on the installed main power. The rules describe corrections for the usage of PTO's (Power Take Offs) on the main engines, these corrections are not reflected in the formula above.

For Ro-Ro vessels the factor f_j is defined as follows:

$$fj = f_{jRoRo} = \frac{1}{Fn^{\alpha}\ \times\ (Lpp\ /\ B)^{\beta}\ \times\ (Bm/Ts)^{\gamma}\ \times\ \left(Lpp/\sqrt{\nabla}\right)^{\delta}}$$

This function with the above shown parameters compensates for off standard main dimension ratio's and design speed variations. These are often the case with Ro-Ro vessels due to the specific services and conditions in which these vessels operate. These kind of corrections are not applied for Bulk carriers.

The capacity correction factors in the EEDI formula:

f_i Correction for structural deadweight reducing design features. (safety, corrosion, ice-class and fatigue) The Ro-Ro EEDI has no Ice class correction.

f_l Correction factor for general cargo ships

f_w Correction factors for decreased speed at sea conditions at Beaufort 6 in order to calculate the EEDI weather. It has to be set on 1 for the normally attained EEDI calculation.

f_c Deadweight correction factor for gas and chemical tankers.

The attained EEDI has to be less than the reference line expressed by the following formula:

$$\text{EEDI reference} = a \cdot b^{-c}$$

With a and c constants defined per ship-type and b the design deadweight of the vessel. It is the intention to lower these reference lines each year, in 2015 with a total of 30 %. It has to be noted that this approach is focused on the design speed. The design speed in this paper is the speed with a clean hull, without added resistance due to waves and at approximately 75 % of the maximum continuous rating of the engine. The 25 % reduction is composed by two chosen factors, one to reduce the maintenance bill, often 10 % and a sea margin most often 15 %. These figures suggest that you can just add them, however, the calculation is more complex. Intermediate speeds and their corresponding fuel consumption is an area which can often be substantially improved with sometimes large effects on the voyage costs.

Research questions

It seems a goal based regulation, not specifying the means. However, a lack of real means will result in speed reductions and actually changing the regulation into a prescriptive one. Also the relative simplicity of the correction factors for off standard main dimensions and speed in comparison to power prediction methods like Holtrop & Mennen (Holtrop & Mennen, 1984), still used today in the conceptual design phase, could result in undesirable speed reductions in some off standard designs typical for RoRo carriers. Then, the consequence will be more ships and/or less products shipped. These questions will be addressed.

Speed reductions based on the minimum social costs per ton-mile, could differ substantially from the speed reductions required to get some designs in line with the EEDI regulations. With other words does this measure reflects the impact of the social costs ?

Are the proposed reductions in required power achievable ? If not, speed reduction is the only answer. Is speed reduction defendable? For example the required power for bulk-carriers has dropped with 40 % in 30 years. From this 40 %, 20 % is achieved by an improvement of the engine performance and the other 20 % by hydrodynamic improvements. (Frouws, 2012) The EEDI regulations require a drop of required power of 25 % in 10 years.

This paper tries to evaluate these aspects looking from the perspectives of the society as well as from the ship-owner.

Methodology

This study is focusing on Ro-Ro cargo carriers. A ship-type with an interesting variation in main dimension ratios and design speeds. To be able to deal with all the research questions the following information and calculated performance indicators thought to be necessary:

- A description and interpretation from the emissions and there impacts on the environment, in terms of marginal external costs in combination with emission aspects like fund and stock pollutants. But also the possibilities for their abatement.
- Determination from the attained EEDI for a set of 30 diverse existing RoRo cargo carriers from which the information is well known and thoroughly gathered and composed. These attained EEDI's will be set out against the in the future planned reference lines. Secondly the determination of the required speed in order to achieve the attained EEDI planned in 2025. In this way one is testing existing designs in their ability to fulfil the future regulations for new designs.
- Calculation of the costs per ton mile and lane-meter mile at the economic speed per vessel. The economic speed is the speed with the lowest costs per ton mile and/or lane-meter mile. The port time is set on 40 % of the total time. The calculations are executed with the NPV method and include all costs, except loading discharging costs. The voyage, running and capital costs are modelled as a function of relevant

> parameters from the vessel (Aalbers, 2000). The designs are actually regarded as new buildings. At first the current new-building value is determined afterwards a net present value calculation of all the costs is made per vessel assuming a lifetime of 30 years with 60 % own capital. These calculations were repeated, but then based on the social costs which means an increase in the voyage costs, the latter depends strongly on the speed.

Including the marginal external costs of all emissions is the only way to compare the consequences of emissions from several sources in a consistent way. However, the law deals with these emissions in separate regulations which has the disadvantage that the overall more holistic picture could be lost. By setting the CO_2 emission regulation in the total perspective of all emissions makes it easier to judge the quality from the EEDI approach.

There are other aspects which has to be taken into account for example the ease of dealing with a specific emission in combination with the long term effects. This aspect is approached in a more qualitative way.

The economic calculation model used, determines the costs of transport expressed in euro per ton mile using 80 % of the deadweight on average and being in port for 40 % of the time. Also the costs per lane-meter mile are determined based on an average filling rate of 60 % of the available lane-meters and again a port time of 40 % of the year. All the costs who are normally covered by a voyage charter. The existing vessels in the database are regarded as new-buildings in the calculations, despite their age. By this approach and by excluding price effects, a fair design comparison becomes possible. In reality varying second hand prices and sailing profiles can change the real transport costs per ton-mile dramatically.

The used emission rates and marginal external costs applied in these calculations are shown in Table 1.

The external cost rates are averaged values for European sea areas and based on Clean Air for Europe (CAFE) Program 2005. The chosen external costs for CO2 is the lowest estimate, known upper values are at least 80 euro which shows the difficulty in estimating the effects of climate change.

Table 1 Marginal external costs and emission rates as a function of the tons of fuel

Emission rates per kg or ton fuel and external costs per ton emitted.

4 stroke diesels and	CO2	SO2	PM	HC	CO	NO_x Tier 1	NO_x Tier 2	CH4
LNG emission rates	ton per ton	kg per ton	kg per ton	kg per ton	kg per ton	kg per ton	kg per ton	kg per ton
HFO (2,5 % S)	3.114	52.5	12.5	3.33	3.33	80	60	0.099
LFO (0,05 % S)	3.151	1.05		3.33	3.33	80	60	0.099
DO (MDO) (0,05 % S)	3.206	1.05	2.3	3.33	3.33	80	60	0.099
GO (0,05 % S)	2.750	1.05		3.33	3.33	80	60	0.099
LNG pure	3.000			3.23	8.39	8.4		50
LNG/DO (4 till 6 % DO)	2.780		0.6	3.13	8.13	60		50
External costs/ton	€ 15	€ 6 000	€ 12 000	€ 2 000	€ 22	€ 4 900	€ 4 900	€ 2 000

In order to make a fair economic comparison between the designs it is important to determine those speeds where the costs per ton mile or lane-meter mile are the lowest. Which is defined here as the economic speed. Otherwise the effects of large design speed variations in the database would prevail.

There is a balance between the capex and opex. Where the opex will increase exponentially per ton-mile with increasing speed, the capex per ton-mile will decrease. The economic optimum speed is determined enabling us to compare the designs in their economic optimum operational performance.

Results

Emissions

The considerations and calculations below are based on HFO as main engine fuel and MGO for the auxiliaries. These fuels when burned in an engine tend to emit CO_2, SO_2, PM, HC, CO and NO_x. The Sulphur content of HFO is assumed to be 2,5 %. The PM emission is strongly coupled to the Sulphur content. Table 2 shows the share of certain emission combinations in the external costs as a percentage of the fuel costs (average). the fuel costs are based on figures from April 2015. The NO_X emission rates on Tier 2 maximum allowable emission. (see Table 1)

The external costs of the SO_x and NO_x emissions are larger than the external costs of CO_2 emissions. Partly due to the low estimation applied. The SO_x and NO_x emissions are dealt with in the regulations in Sulphur Emission Control Areas (SECA) and/or Emission Control Areas (ECA), the CO_2 emissions are worldwide approached. The reason is that the acid rain problem (SO_x and NO_x) is more locally oriented than the GHG emissions like CO_x and methane. It has to be kept in mind that the used external cost figures are based on the estimations of the consequences of emissions at sea in the coastal areas from Europe. The majority of the costs included are on shore, where the fund pollutants tend to change in stock pollutants.

Many people have forgotten that the acid rain problem in the 70's was largely solved by a cap and trade approach resulting in for example replacing the sulphur containing coal as a fuel and/or the application of sulphur scrubbers in the shore based power plants in combination with SCR systems to abate the NO_x emissions. With other words reversible till a certain height.

The CO_2 emissions, the cause of climate change, cannot be reduced easily. Burning hydrocarbons means CO_2 emissions. This tends to become a major problem. Emitting CO_2 in huge amounts since 1800 has increased the content of CO_2 in the atmosphere. The combination of an increasing world population, a decreasing usable agricultural area and water shortages due to the GHG effects is not a fine perspective and tends to increase the marginal costs substantially in the future.

Table 2 Average external costs as a function of the average fuel costs

External costs all emissions as a perc. of the fuel costs	Excluding SOx and PM	Excluding SOx, NOx and PM	CO_2
224 %	99 %	15 %	13 %
Price HFO	€ 335.00		
Price MGO	€ 565.00		

The EEDI will lower the acceleration of the emissions but not decrease the flowrate. The study from the IMO (Bazari & Longva, 2011), page 24, shows clearly that the emission rate is not expected to decrease because of the estimated required hydrocarbon fuel to serve the world population.

The "attained EEDI" for the dataset of existing vessels

The dataset used is based on multiple sources, for example (RINA 1990 to RINA 2011), several publications about these vessels, internet sources and is believed to be as precise as possible for publicly available information sources. The combinations of design speed and required power are based on the given information of the corresponding percentage of the MCR of the main engine, often 90 % and the, in the design applied sea margin of mostly 15 %.

In other words, the design speed in the database is reached with approximately 75 % of the MCR. The attained EEDI calculation requires 75 % sharp. Figure 1 shows the calculated attained EEDI's for the dataset based on the design speeds.

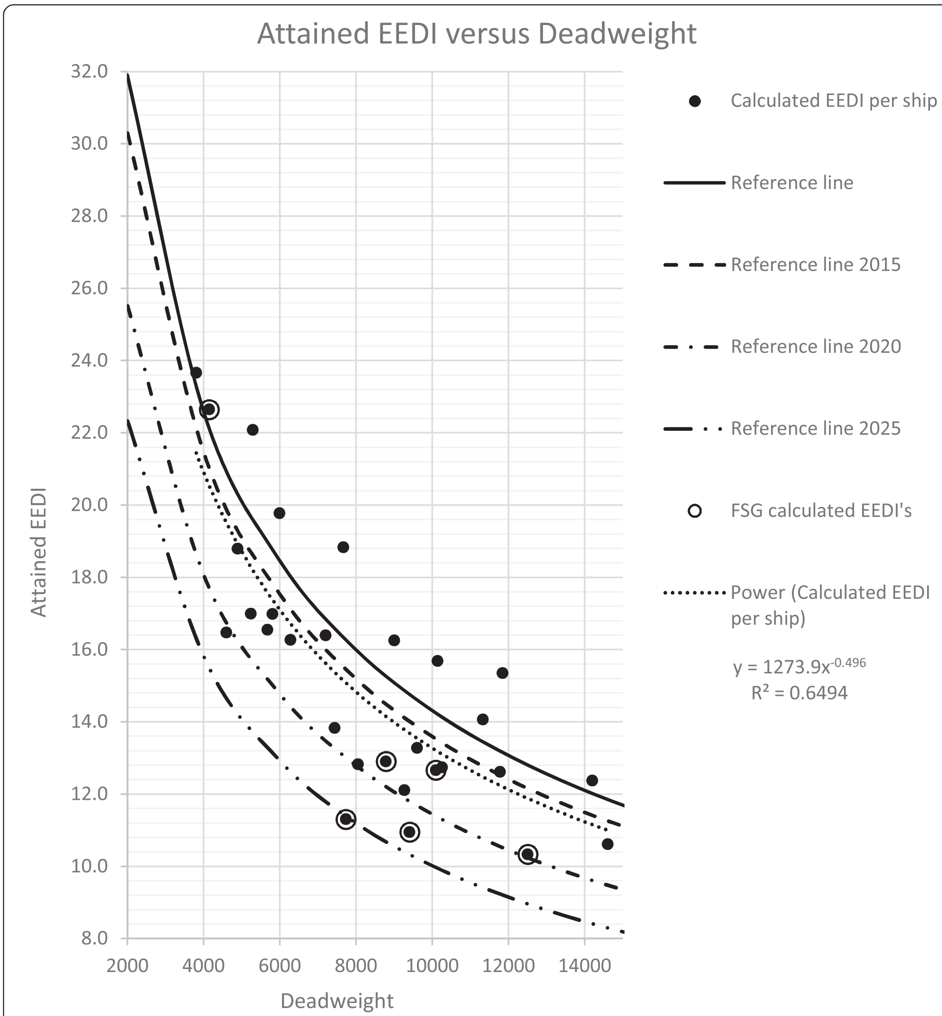

Fig. 1 Calculated attained EEDI's

In the figure are 6 vessels designed and build by the Flensburger Schiffbau-Gesellschaft. Several publications about their design process are used to get the database correct. The publication about the 142 meter vessel with 4140 ton deadweight is one of them. (Tobias Haack, 2009) This vessel is off standard in terms of the number of decks(4) in relation to its length, more decks require a certain breadth. It had to be short and wide because of the size of the berth in the port. On the other hand the research during the design phase involved substantial CFD calculations in order to improve the fuel consumption. The attained EEDI for this off standard design is not good. An identical design in 2025 should have an EEDI just below 16 instead of the attained EEDI of close to 23. This should mean a power reduction of 30 % or a speed reduction of 3,6 knots in order to comply. Its design speed was 21,6 knots to keep up with the required schedule. A power reduction of 30 % is not realistic taking into account the effort already taken to reduce its fuel consumption. It seems that off standard length breadth and deadweight volume ratios are not taken into account correctly by the attained EEDI calculations. It should be realised that one of the major reasons of this low EEDI is the fact that the EEDI is based on the deadweight while this vessel, in this trade, is more oriented on selling lane-meters which increases the "garage" volume while increasing its lightweight and decreasing its deadweight.

The reference line 2015 is achieved easily by the majority of the designs, indicating that the remarks made in the assessment of the EEDI (Bazari & Longva, 2011) are correct. They state that 30 % reduction will be achievable, at first because the starting reference line is above the average and secondly that there are enough possibilities to improve the designs. Looking to the performance of the FSG vessels it seems that it is more the application of the available knowledge that can do the job than a "to be expected innovation". However, the rate of improvement required by the reference line of 2025 is without radical innovation not foreseeable in the future after 2025.

The EEDI, if well applied will mainly force the ship-owners to design the vessels according the state of the art. If that recipe does not work anymore, there is only one alternative, speed reduction.

The question can also be considered from a different point of view. Which design speed should be necessary to reach the 2025 EEDI level? The results of these calculations are summarised in Fig. 2.

The balls reflect the original design speed. The triangles the required speed in order to comply with the 2025 reference line from the EEDI.

There is one current vessel that does not require a speed reduction, that design is from FSG.

The average required speed reduction is 2,74 knots with an original average speed of 20.49 knots, this results in a new average speed of 17,75 knots. May be positive from the environmental point of view but on the other hand, it will influence the schedules. As soon as the latter aspect influences the competitiveness with, for example, trucks it could be questionable in terms of overall environmental effect. The variance in design speed is mainly due to schedule requirements, for example daylight operations or just night operations for sleeping truck drivers. For this vessel type it could be sometimes wiser to exclude design speed considerations in the attained EEDI.

This graph shows also the large spread in the design speeds indicating the very different design goals as a result of the different businesses served.

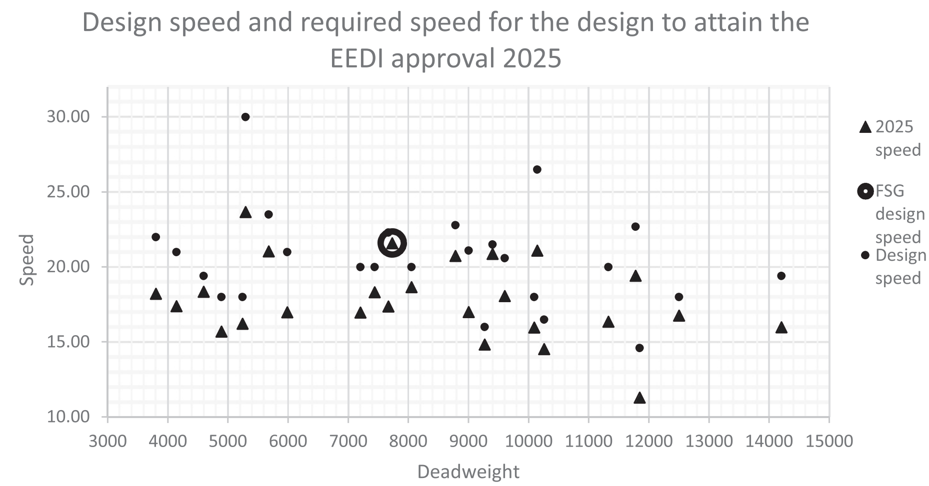

Fig. 2 Required design speed to get EEDI approval in 2025 (existing vessels)

Economic considerations

The economic calculations of the marginal private and social costs are summarised in Fig. 3. The cost items involved are based on the costs covered by voyage charters. It has to be realised that these calculations are executed at the economic speed which are different in the case of private costs or social costs. So, the transport carrying capacity per year is different.

Figure 3 indicates clearly the substantial impact of the marginal external costs on top of the marginal private costs. Secondly it has to be realised that these costs are achieved at the economic speeds.

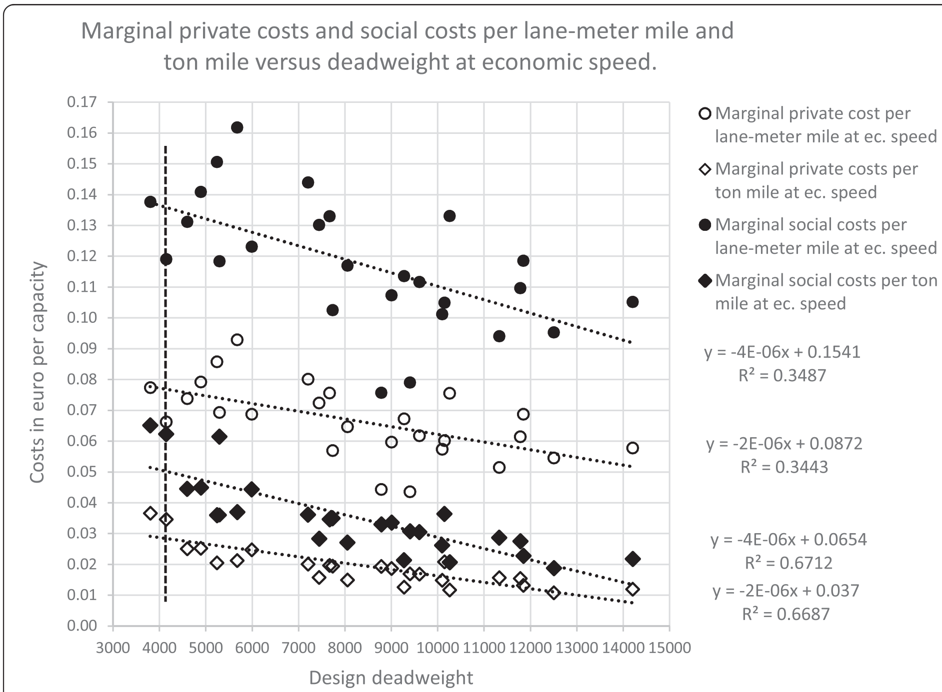

Fig. 3 Marginal private and social costs per ton mile and lane-meter mile at economic speeds

For a ship type the EEDI will be based on one type of "capacity", normally tons deadweight or volume, the latter is proportional to lane-meters in the case of RoRo carriers. Taking again the 142 m design as discussed at Fig. 1 (Tobias Haack, 2009) (see vertical dotted line) some remarkable effects can be seen. Both, marginal private and social costs per ton mile are relative high, the marginal costs per lane-meter mile are however extremely low and even in comparison to larger vessels. In combination with Fig. 2 you can conclude that such a design in 2025 will be forced to increase its private costs by decreasing its design speed from 21 knots to 17 knots based on the EEDI. The economic speed from this vessel based on marginal private costs is 19.5 knots and based on social costs a merely 13.3 knots. (see Fig. 4) This line service is a connection between Ireland and England, the schedule is dictated by logistical reasons.

The corresponding economic speeds at private and social costs are shown in Fig. 4. The economic speeds are determined by means of an iteration in order to find the speed with the lowest overall costs per ton mile. The calculated economic speed based on the marginal social costs is on average 72 % from the economic speed based on the marginal private costs. This means that from the societal point of view a speed reduction from around 25 % is defendable. The average economic speed of the vessels in the database based on private costs is 19,08 knots, based on social costs 13,6 knots, a difference of 5.48 knots. The difference with the speed reduction as a result of the EEDI, 2.74 knots, is large. Due to the exponential increase of fuel consumption with speed, the difference will be substantial in terms of fuel consumption. Speeds based on the social costs will require roughly 30 % more vessels to get the same transport capacity.

Conclusions

The perspective from the societal point of view differs strongly from the private cost point of view from the ship-owner. The EEDI approach helps, but as long as the external costs are not really included in the cost equations the right decisions in terms of design and operational speed or required investments to avoid emissions will not be taken.

The external costs are mainly based on the acidifying emissions, not on GHG related emissions. The low chosen external costs of the CO_2 emissions are 13 % of the fuel costs and as a result has a limited effect on the economic speed based on the social

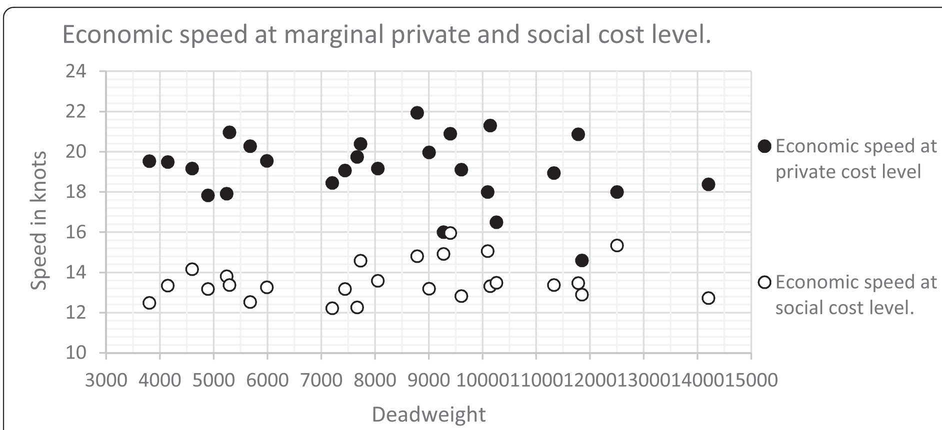

Fig. 4 Economic speed at marginal private costs and social costs

costs. However, it is extremely difficult to reverse the usage of hydrocarbons as a fuel in shipping, due to the required energy density. So, a substantial increase in marginal external cost of CO_2 emissions can be expected. This makes a straight forward comparison only based on current marginal external costs between GHG related emissions (Stock pollutants) and acidifying emissions (Fund pollutants) not credible while looking to all these aspects.

When on board measures are taken abating acidifying emissions and health threatening emissions the required speed reductions to reduce the social costs can be limited. Further research is required on this aspect. However at this moment there are no requirements outside the SECA area's.

A new calculation method taking into account the threat of the different emissions in the future based on forecasts could help to value and judge the situation. Especially because the NPV method applied did not take into account the expected raise in the marginal costs nor the expected impact of these emissions after the ship will be scrapped.

This study seems to give good reasons to charge the external costs to the shipowners. That could help to solve the problem of the acidifying emissions. However, it does not much in the field of decreasing the CO_2 emissions and as a result the CO_2 content of the atmosphere. A situation, hardly to reverse, but also difficult in its abatements possibilities. One could reduce the emission per ton deadweight, but the tons are still increasing.

The EEDI reference lines as proposed in 2025 are most likely achievable. On the other hand the suggested improvement with 30 % is misleading. The major gain will be forcing designers to apply the state of the art in their designs and/or in combination with speed reductions. Speed reduction can be wrong when the competiveness with other more emitting transport modalities suffers.

The EEDI system seems to punish "off standard" designs in terms of main dimension ratio's and or high design speed. That can be counterproductive from the environmental point of view in specific logistical situations, especially when competing with other modalities, but also if one off standard ship can replace two standard ships. This could be solved by allowing alternatives like the method of the 'Environmental Impact Statement' in those cases where the overall environmental performance will improve.

Separately dealing in the regulations with different kinds of emissions decreases the potential growth of the application of LNG as a fuel. This fuel is favourable for sulphur, NO_x, PM and CO_2 emissions. Its use is financially mainly credited in SECA areas. In other areas it will only enable higher speeds because of the lower attained EEDI, actually areas where higher speeds are less important because the schedule problems are less.

The focus of the EEDI regulations on the design speed of the vessel underestimates the possible reductions of the fuel consumption at lower speeds. For example The current practice of running the controllable pitch propeller on a constant rpm because of the PTO lowers the propeller efficiency substantially at lower speeds.

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The author is a Naval Architect and is currently active as Assistant Professor in Ship design and Shipping Management. After his graduation he has hold positions in the port/shipping business in the gas and chemical trade, manager from a 300 km liquid gas transport pipeline system, assistant superintendent in the polyethylene granulate production and manager from a design department, active in the design of municipal wastewater plants and pumping stations.

Authors' contribution

The author declares that he has collected all the data and made all the calculation models behind the results presented in the paper and that he has written this paper without the help of co-authors besides a language check and the work from the reviewers.

Competing interest

I declare that there are no financial neither non-financial competing interests as indicated today February 2, 2016 in your description of competing interests on the site from the Journal Shipping and Trade in relation to this paper.

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