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Agenda item 4

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PREVENTION OF AIR POLLUTION FROM SHIPS

A mandatory CO_2 Design Index for new ships

Submitted by Denmark

SUMMARY

Executive summary:	This document contains information regarding the possibilities to develop a mandatory CO_2 design index for new ships. It provides information considered by Det Norske Veritas commissioned by the Danish Government.
Action to be taken:	Paragraph 5
Related documents:	MEPC 57/4/2 and MEPC 57/4/3

Introduction

1 In document MEPC 57/4/3 the Committee is invited to endorse a work process aiming at the development of a mandatory CO_2 design index for new ships. The annex to this document contains a study providing relevant information in that respect considered by *Det Norske Veritas* commissioned by the Danish Government.

2 The study performed by *Det Norske Veritas* is, among other sources, based on a report provided by *Force Technology A/S*. This report is available on the following internet address: http://www.danishshipping.com/pdf/CO2IndexingPrinciplesReport.pdf.

3 According to the information provided a mandatory CO_2 design index for new ships appears to be a feasible policy instrument to reduce greenhouse gas emissions.

4 Furthermore, it is considered that the effectiveness (or impact) of the instrument will be limited initially, mainly if its application is limited to new ships only. On the other hand, the considerations show that there is a potential for a significant environmental impact over a longer period of time.

Action requested of the Committee

5 The Committee is invited to note the information provided in this document and its annex.

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ANNEX

TECHNICAL REPORT

REPORT NO 2007-1891

REVISION NO 03

DET NORSKE VERITAS

Report No: 2007-1891, rev. 03

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TECHNICAL REPORT

Executive SUMMARY

The assessment and analysis work done in this report can be summarised through the following conclusions.

From a purely technical perspective, a CO_2 design index for new buildings appears to be a feasible policy instrument to reduce greenhouse gas emissions. When reviewing the Danish Shipowners' Association (DSA) report, and performing similar analysis on a significantly larger fleet data base (sec. 3.1) it is concluded that the most important of the findings in the report can be corroborated:

- Considering the possible span of size and speed of commercial ships, the CO_2-index can be said to be highly dependent on ship size and to a somewhat lesser degree on speed.
- To represent the function and the operational profile well, a CO_2 index should be dependent on dwt for cargo ships and other representative parameters for offshore, passenger and other ships (e.g. gt, length, numbers of passengers, etc.).
- When the index is plotted as a function of non-dimensional parameters such as Froude number and block coefficient a wide spread is observed. The difference in trends for the various ship types makes it challenging to define simple index limit values, even when the indices are made ship type specific.

Furthermore, four main parameters are combined into an alternative CO_2-index measured in grams per tonne kilometre: specific fuel consumption, installed power, speed and dwt. These parameters represent engine efficiency, energy efficiency and capacity. Improvements of these aspects will result in a better and more consistent index value. Key conclusions are;

- The index should be dependent on size (dwt) and ship type as the design varies between different ship types.
- A benchmark level must be set for each ship type and should be based on dwt, rather than non-dimensional parameters.
- New building should be required to have design parameters that yield an index that is below the benchmark, where the benchmark can be set based on existing design or at an internationally agreed lower level.
- The results of setting a target CO_2 index might be optimised service speed and improved energy utilisation onboard for the specific vessel type and size.
- The benchmark can be set based on existing design, but the final level is a political decision based on which CO_2 emission targets are to be met.

This study has not considered all possible vessel design parameters for their suitability in a possible design index. Further investigation may therefore identify other possible options.

When considering the workability and impact of a CO_2 design index (sec 4.) it was found that considered as a policy instrument it is believed feasible to establish a technical ship CO_2 design index.

It is considered that the operational effectiveness and environmental impact of the instrument will be limited initially, mainly due to its application to new ships only. There is however a

potential for a significant environmental impact over a longer period of time, in particular if mechanisms driving beyond-compliance behaviour are promoted.

Certain issues will need further consideration if the instrument is to be further developed;

- The scope of application must be internationally agreed, and it has to be agreed whether the CO_2 index should be applied to the entire world fleet or only to fleet segments with a statistical data basis sufficient to establish appropriate baseline levels. If the entire fleet is to be covered, provisions must be established for ship types where only limited data exist.
- A mechanism for the definition of a baseline level must be agreed. A suggested first approach is to use a certain percentage below present fleet average.
- A test project or further simulation based on existing vessels under construction is suggested to validate the approach.

The precise design of the policy instrument is an issue that will be open to discussion between policy makers and other stakeholders; however it is quite clear that it will have to represent a trade-off between vessel design technical feasibility/cost and the desired environmental impact.

INTRODUCTION

Background

This report is an evaluation of the feasibility of establishing an appropriate technical ship design index (or indices) for CO_2 emissions.

The objective of establishing a design index is to arrive at benchmark criteria for energy efficient ship designs with a potential for minimum CO_2 emissions. The technical CO_2 index shall describe the ships' design only, hence will not take operational issues into consideration i.e. how the ship is operated under various conditions.

The work is based on information submitted to DNV by the Danish Maritime Authority (DMA), including a proposal for a ship design CO_2 index commissioned by the Danish Shipowners' Association (DSA) and developed by Force Technology.

The basis for the work is the Danish Government intention of preparing a submittal for IMO MEPC57 addressing CO_2 emissions from ships, this report is intended to constitute part of the background material need to prepare such a proposal.

DNV's task is to analyse the above mentioned proposal for workability and impact, and if appropriate, consider alternative/modified design index approaches. In connection with this a brief outline is given of existing CO_2 indices and their associated complexity.

Consideration is also given to the feasibility of applying vessel design indices to existing ships, as well as the feasibility of developing carbon trading schemes using design indices as a basis.

Overview of Danish Shipowner Association / Force Technology Proposal

The following is an excerpt from the Danish Shipowner Association / Force Technology report (hereafter known as the DSA report), providing the gist of the work performed /1/. It is quoted here in full as it summarises the basis for the evaluation work carried out by DNV.

"The objective of this report is to provide a rational basis for the formulation of an alternative technical CO_2 index, which do not depend on operational measures, but on technical data obtainable at the delivery of the vessel. The purpose of this is to stimulate the development of more efficient ships. To do this the report presents some systematic data of CO_2 emission calculations for different ship types and gives some general background information and historical data about propulsion of ships, and fuel consumption of diesel engines.

The paper also highlights the most important parameters, which have an influence on the technical CO_2 index.

The results can be summarized as follows:

1. An alternative technical CO_2 index, which does not depend on operational measures, but on technical data obtainable at the delivery of the vessel, has been formulated.

2. Even without regulation of CO_2 emission from shipping the high fuel costs have provided a strong market driven pressure to develop engines operating almost as fuel efficient as physically possible, taking into account the trade off associated with the regulation of NOx. The overall ship efficiency has also increased during the period from 1924 to 2006. This tendency is not so pronounced in the period from 1950 to the first oil crisis in 1973 because *of relatively higher service speeds motivated by the low fuel prices at that time. The fuel prices provide a strong market drive towards increased efficiency because the fuel cost is a large proportion of the total cost associated with ship operation.*

3. To provide an incentive for all ships to further improve their efficiency an individual CO_2 *index has to be worked out for each ship type (container ships, bulk carries, tankers, Ro-Ro cargo ships and Ro-Ro passenger ships).*

4. The CO_2 *emission is strongly dependant on the ship size and service speed. An attempt has been made to combine these parameters using the ships so-called Froude Number as a single non-dimensional parameter. However in doing so, it has become evident that large cargo ships such as container ships, bulk carriers and tankers will be favoured and loose incentive to improve because they obtain a lower* CO_2 *index more easily than the smaller cargo ships of the same type with low transport capacity. The dependency of the* CO_2 *index on deadweight should therefore be more pronounced. "*

A key element in the DSA/Force study has been the formulation of a CO_2 design index for ships incorporating the Froude number, design speed and payload. An important part of this report is an evaluation of whether the approach can fulfil its intentions, and consideration of whether other approaches may be more suitable.

Other Indexing Options and Initiatives

At present there are various proposals and initiatives for CO_2 indexing schemes proposed or undergoing development. Broadly speaking these can be categorised into design and operational indices, with a common characteristic of the operational indices being that they are strongly affected by business cycle issues. They are thus not fully under the control of the ship owner or operator. A case in point is the IMO voluntary operational index, based on MEPC/Circ.471 /2/. It has a well developed calculation method that has been agreed upon internationally, but is also highly sensitive to parameter variations, leading to a large scatter in index values even when considering single ships, as shown in trials using the index /3/. Other operational indices, such as those developed by industry association Business for Social Responsibility (BSR) and Intertanko, while differing in their approach and limitations also show similar issues /4/.

For the purpose of this report operational CO_2 indices have not been considered further.

Technical design indices have not seen the same degree of development as the IMO operational index, however there has been a certain degree of activity:

The Japanese Ministry of Land Infrastructure & Transport has announced that it will allocate 95 million yen (580 k€) over the next three years to develop fuel-efficiency standards for large ships (reported in Bunkerworld 21 Sept. 07). While there is limited information available this project appears to incorporate both design and operational issues.

There have also been efforts made on developing part indices addressing e.g. hull efficiencies, this also in Japan, reported in 2000 /5/. While the use of part indices may be suitable for optimising energy efficiency for individual ship systems and components, a methodology would have to be established incorporating indices for all relevant systems, as well as a uniform way of combining these into a single vessel index. This approach will necessitate significant development work. It may also be more challenging to establish international acceptance of a large set of individual indices than a single overall vessel design index. This approach has therefore not been given further consideration here.

Life cycle consideration

From an overall point of view it would be reasonable to consider whether ship CO_2 emissions should be examined considering only factors that have an impact on the operations phase, or whether the CO_2 impact of production, scrapping etc. should also be taken into account. One representative Life Cycle Analysis (LCA) study performed indicates that operations account for as much as 96.9% of CO_2 emissions /6/, and while it is indicated that an increasing use of light weight / high technology materials could reduce this percentage towards 90% /7/ it is apparent that energy use in the operations phase is the dominant element as regards greenhouse gas emissions.

It is therefore considered reasonable to focus proposals for mitigating actions on the vessel operations phase.

Evaluations of CO_2 design index options

The purpose of this analysis is to investigate how a CO_2 index can be calculated based on technical design parameters. The first part is a review of the study commissioned by DSA /1/. This study analyses the relationships between several vessel parameters as well as the historical development of these.

The second part puts forward a modified methodology for calculation a design based CO_2 index.

It should be noted that it is not the intention of this section to discuss all the complexities surrounding the development of a CO_2 design index, but to address the main assumptions that need to be made. However, some comments should be given as to the criteria for an index and the associated index limit value (or benchmark value).

The index should reflect the environmental performance of the vessel with regards to Green House Gas (GHG) emissions. In the discussed proposals only CO_2 is considered, as this is the major GHG emitted from a ship. This implies for instance that:

- Ships with same environmental performance should ideally have the same index value
- The function and the operational profile of the ship which have an impact on the design are well reflected in the index. For a number of vessels with significant energy consumption beyond design speed cruising (cruise, offshore supply, offshore support, tugs, etc) this may be a challenge.
- The index band (minimum and maximum values) is ideally as narrow as possible. This would indicate a consistent relation between the design parameter(s) and CO_2-emission.

Danish Shipowners' Association proposal

DSA uses a sample of 212 ships to analyse various methods of calculating a CO_2-index. The intention of this chapter is to use a larger data set to validate and discuss the findings of the DSA study. DSA used only general cargo/container ships in their data set, but this report uses the same plots for dry and wet bulk carriers to see if there are variations between ship types.

DSA argued that there are more technical data available than for example in the Lloyds Fairplay database /8/. For most of the methods however, the data from Fairplay is sufficient and gives a much higher sample of ships data. The findings of the DSA study are tested using this database. The sample size is 12228 ships above 100 gt built in 1960 or later with registered fuel consumption, kW, dwt and speed. The category "Miscellaneous" is excluded as it contains a variety of ships, ranging such as tugs, and fishing vessels. The CO_2-index is based on emissions per transport work (grams per tonne kilometre) and is valid for cargo ships only. Passenger ships and ferries as well as offshore vessels are included but another approach needs to be used on these ships to determine their environmental performance.

Fuel consumption

The first step is to look at specific fuel consumption. After the oil crisis in 1973 the improvement on fuel efficiency of marine diesel engine has been in focus. Lately the introduction of NOx emission limits has influenced upon the fuel efficiency as it is not always possible to achieve NOx-reduction without increasing the fuel consumption /9/. Figure 0-1 shows the development of average fuel consumption per kWh (AFC) for slow and medium speed engines from the period 1960 to present. Note that there are inherent uncertainties in the database. The average fuel consumption per kWh for each ship is calculated using equation 1a:

$$AFC = \frac{FC}{kW \cdot (0.85 + 0.10) \cdot 24} \qquad (1a)$$

Where: kW is installed propulsion power and 0.85 is the average main engine load factor. An additional 0.10 is added to include required auxiliary power. FC is fuel consumption for both propulsion and auxiliary engines. Note that this is not equivalent to specific fuel consumption, as it an average for several engines not necessarily operating at the same rating.

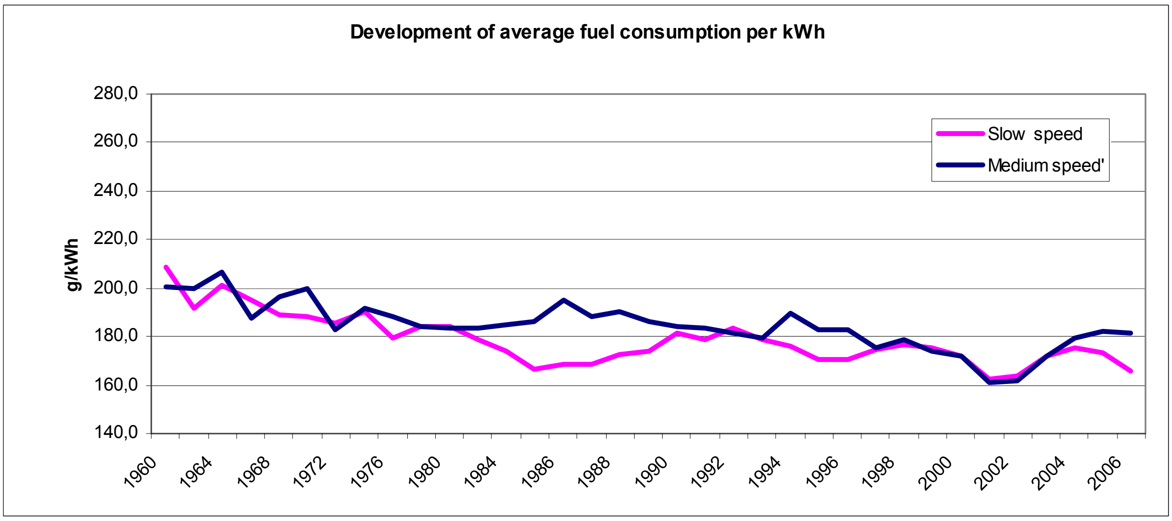

Figure 0-1: Development of average fuel consumption.

Using the average fuel consumption (AFC as g/kWh) and installed engine power the daily fuel consumption (FC as tonne per day) is calculated using the following formula:

$$FC = AFC \cdot kW \cdot (0.85 + 0.10) \cdot 24 \qquad (1b)$$

The comparison of fuel consumption reported by Fairplay and calculated fuel consumption (according to equation 1b) are shown in Figure 0-2. The reported fuel consumption from Fairplay includes auxiliary engines.

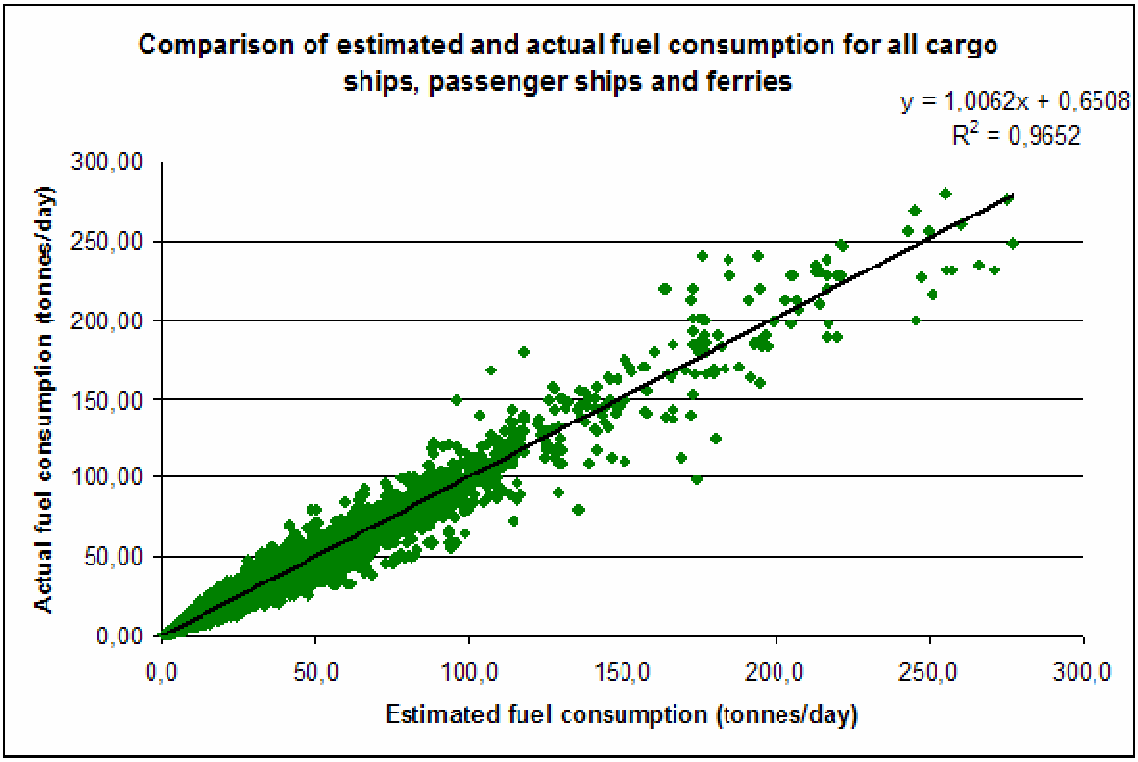

Figure 0-2: Comparison of estimated and actual fuel consumption.

The figure confirms that using 0.85 of MCR for main engines and adding a 0.10 for auxiliary engines give fairly good relation between estimates and actual values (which should be y=x). The uncertainty is on average 12 % difference between estimated and reported fuel consumption.

For the following analyses the actual fuel consumption is used and the CO_2 emissions are calculated based on this.

Historical development of CO_2-index

The CO_2 design index can be calculated as follows:

$$I = \frac{FC \cdot 3.17}{DWT \cdot Speed \cdot 24} \qquad (2)$$

Where: 3.17 is a conversion factor describing tonnes CO_2 emitted per tonne fuel consumed and speed in km per hour. FC is calculated in equation (1b).

The DSA study states that the CO_2 index for general cargo and container ships has decreased in the period from 1973 to 2006. The plot in the study shows a scattered dataset having a span between 6 and 15 g/dwt km. The similar plot using Fairplay data from the period 1960 – 2007 (Figure 0-3) shows the same tendency with approximately the same lower limit but having a slightly higher span (up to 20 g/dwt km). After a significant reduction up to the mid seventies, the lower bound of the index has increased from 4.5 to above 6 g/dwt km the last twenty years.

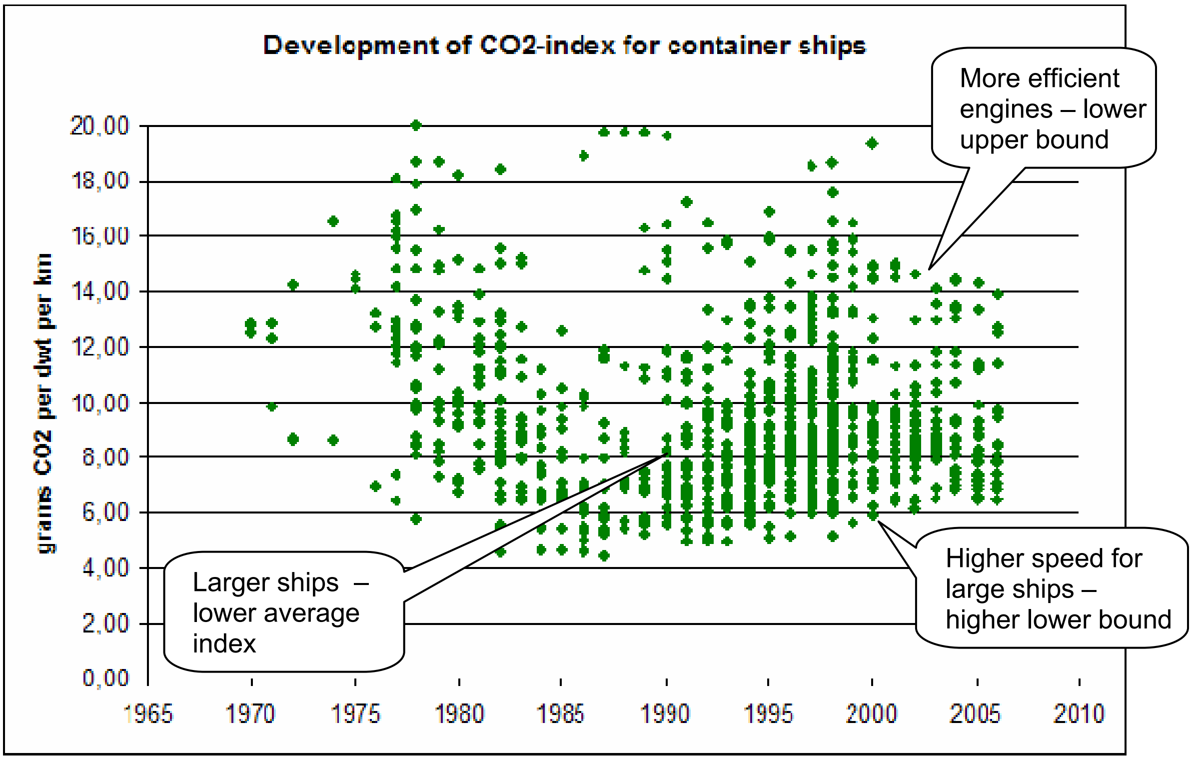

Figure 0-3: Development of CO_2-index by year of build.

From Figure 0-3 it is hard to see a clear tendency in the CO_2 index as function of year of build. There are many factors influencing the index as shown in the commentaries, such as the use of slow speed engines and phasing out steam turbines. The figure shows a great span, indicating that factors such as engine types, size and speed influence the index.

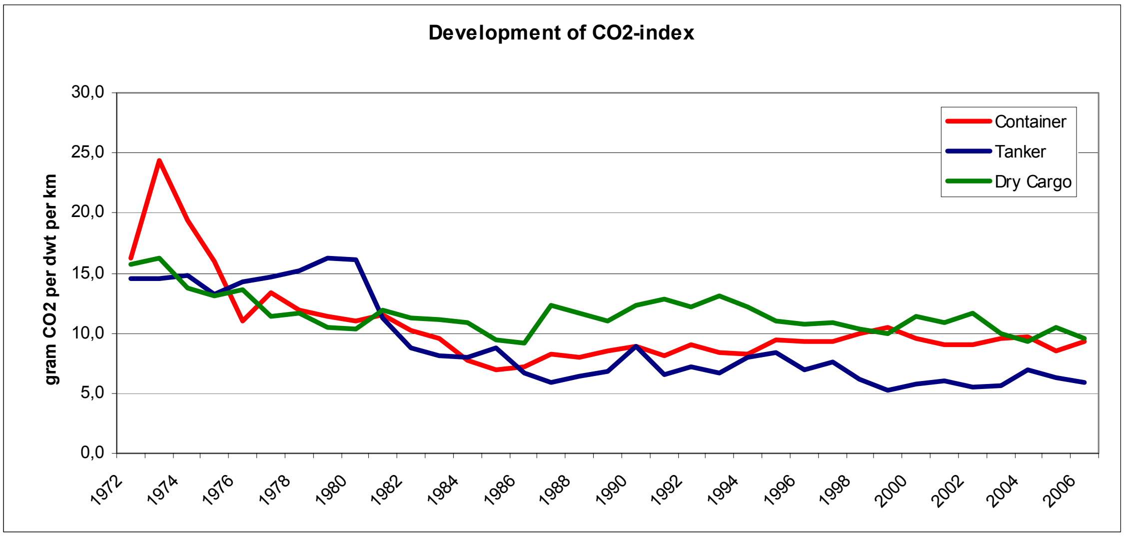

Figure 0-4: Development of CO_2-index for container ships dry cargo and tankers. By year of build.

Figure 0-4 shows the average CO_2 index as function of year for containers, tankers and dry cargo vessels. As can be seen from the figure the CO_2 index for tankers and dry cargo decreases until mid eighties where it stabilises. For container ships the average actually increases slightly until year 2000.

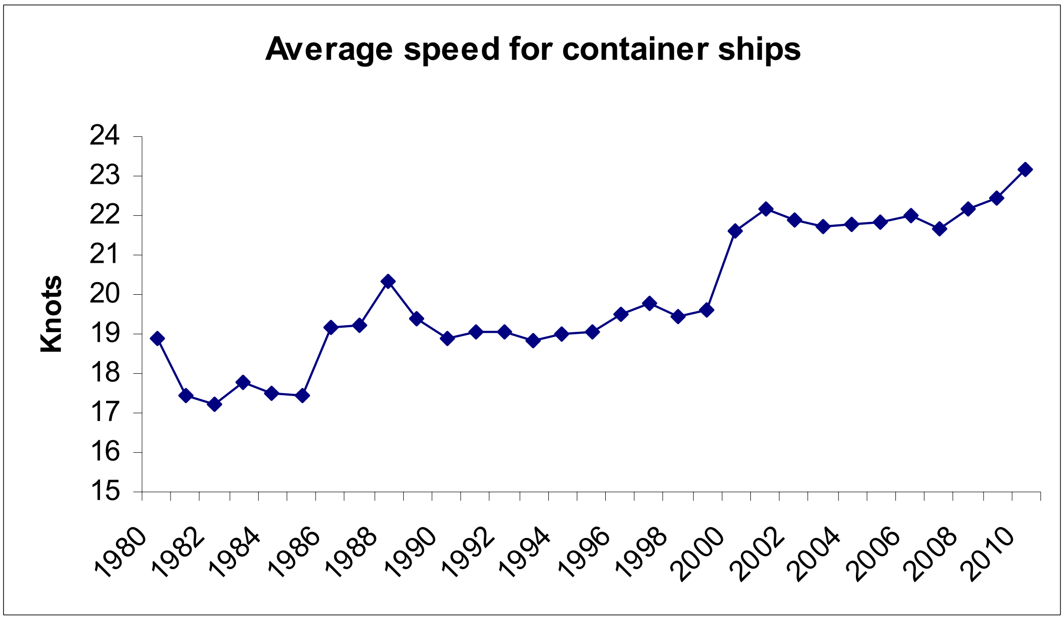

Figure 0-5: Average speed for container ships by year of build 1980-2006, and ships on order 2007-2010.

Figure 0-5 shows the development of speed for container vessels. There was a significant increase around year 2000.

There are three main points to be drawn from the previous three figures:

- More efficient engines decrease the upper bound of the ships. This is where the smallest ships are found and where improvements can reduce the index significantly
- The use of larger ships has decreased the index, both the average and the lower bound.
- For container ships the lower bound increased between 1985 and 2002 due to higher speeds for large vessels. This increased the average CO_2-index.

The index based on historical fleet data is influenced by the three factor described above. The main reason for lower CO_2-indices in the latter years is due to larger ships carrying more cargo than older ships, as well as more efficient engines. This is somewhat countered by increased speed. Even though the speed has a significant impact on the index though higher energy consumption, it is still less than the impact of deadweight.

An analytical approach to explaining this can be done using equation 2. It can be assumed that the fuel consumption increases proportionally to the cube of speed – equation 2a.

$$FC_{New} = FC_{Design} \cdot \left(\frac{Speed_{New}}{Speed_{Design}} \right)^3 \qquad (2a)$$

In other words a 5 % increase in speed demands about 15 % increase in fuel consumption. But due to the speed also influencing the amount of transport work done, the total increase of the CO_2 index becomes approximately quadratic, i.e. $\left(\frac{1.15}{1.05}\right) - 1 \approx 10\%$

The effects can be illustrated further using an example with six cases:

Table 0-1: Six case examples of container ships.

Case	Dwt	Power (kW)	Speed (knots)	CO_2-index (g/tkm)
A	20 000	12 000	19	10.3
B	20 000	14 000	20	11.4
C	25 000	12 000	19	8.2
D	25 000	14 000	20	9.1
E	25 000	12 000	18	8.7
F	25 000	14 000	19	9.8

Parameters not shown in Table 0-1 are considered to be equal for all cases[1]. The cases are chosen based on similar ships in the Fairplay database.

For cases A to D deadweight and power are varied. Increasing the power gives an increase in speed from 19 to 20 knots. In C and D the deadweight is 5000 tonnes higher but this does not affect the speed. The calculation shows that the index for C and D is 2.1 and 2.2 g/tkm below cases A and B respectively.

If considering that larger ships require some more power to maintain the speed, two more cases (E and F) are added. For the sake of comparison the speed in E and F is lowered, maintaining the deadweight and power. The speed reduction gives a slightly increased index by 0.3-0.5 g/tkm. This is caused by E and F having the same fuel consumption per hour as C and D respectively, but using some more time to perform the same amount of transport work.

The index increases with 1.1 g/tkm for case A to case B, and with 0.9 g/tkm for case C to case D. Increased size makes the difference less, but the relative change is the same – 11 %. On the other hand – when comparing A and D then index for the smaller ship (A) is higher than the bigger (D) even if the speed has increased – the difference is 1.2 g/tkm (12 % reduction). The increase in power from 12 000 to 14 000 kW increased the index with about 17 %; the increased speed reduced it by 5 %; while the increased size finally reduced the index by another 20 %. This totals to about 11 % overall reduction.

[1] Average fuel consumption is set to a flat 200 g/kWh for all ships. MCR is set to 95 % of total propulsion power (thus including auxiliary engines). CO_2 emission is set to 3.17 of fuel consumption. Cargo capacity is set equal to deadweight.

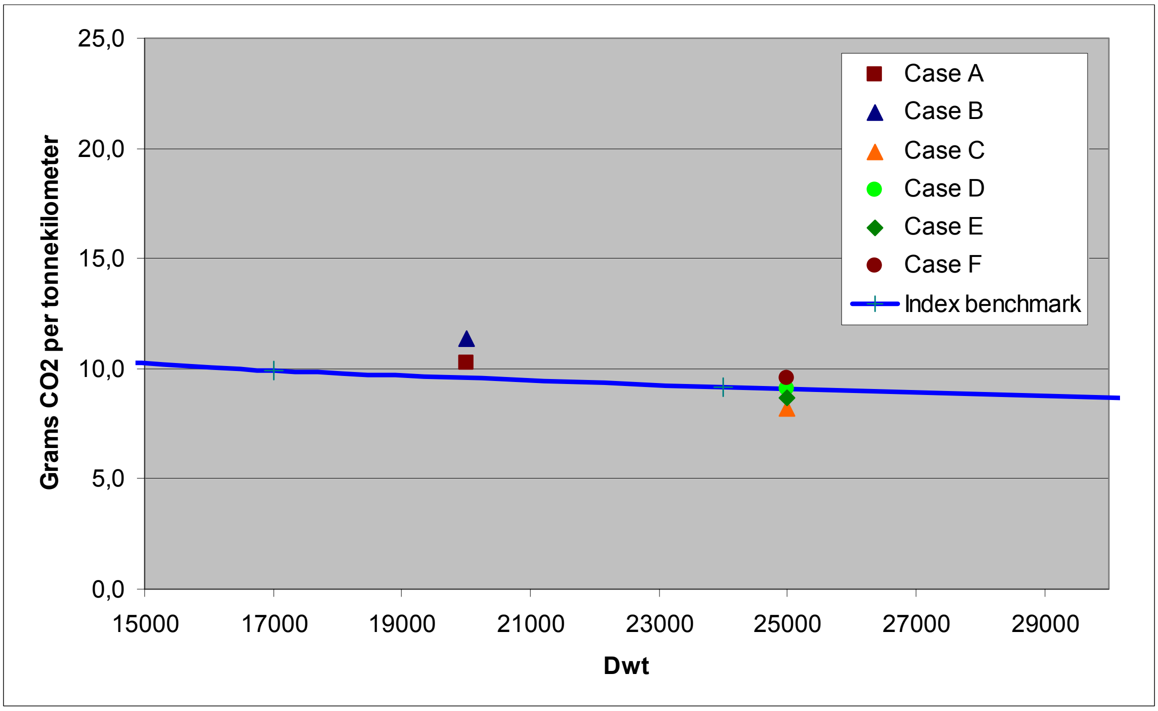

Figure 0-6: Comparing cases with benchmark (see Chapter 0).

When comparing the relative change between dwt and speed, the change in dwt (A and B to C and D) is 25 % and the speed increase (A and C to B and D) is about 5 %, for the same power requirement. In other words, on a relative basis, the index can be said to be more dependent on ship speed than on size. However the possible size span and speed span for an actual ship are quite different; the size of a certain ship type may vary by two orders of magnitude while the speed may vary by say 50 %. Having chosen the appropriate size of the ship the speed choice is very limited. The six cases are shown in Figure 0-6 together with a benchmark that could be used for container ships (the benchmark is developed as in chapter 0). This shows that only cases C and E fall below the index level, being both the largest and slowest ships.

Given the same size of the ship the speed is significant, but with different sizes the speed is less important. Figure 0-7 illustrates this point. The fuel consumption per day is increased but so is the distance sailed. In addition speed is closely correlated with increased ship size, and thus the increase in deadweight more than compensates for the increased fuel consumption. This results in a declining index for larger ships even with higher speed. For this reason it is important to base the index on ships size in order to be able address the effects of design speed.

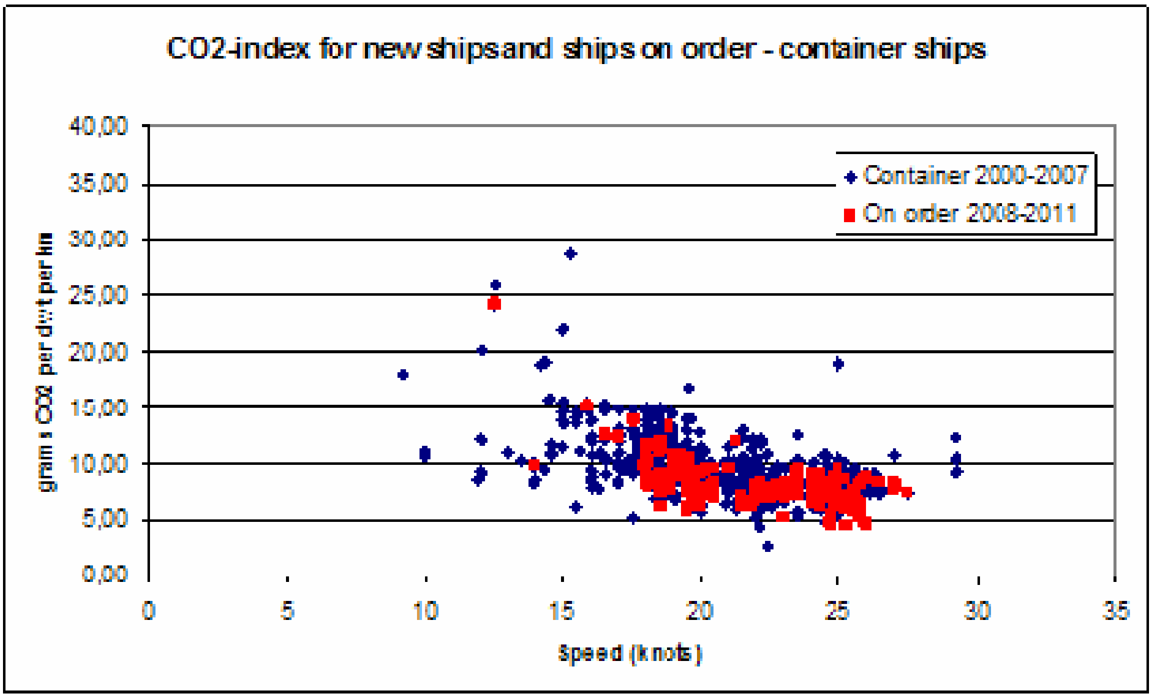

Figure 0-7: Speed vs CO_2-index for container ships.

CO_2-index for present fleet and new builds

The DSA study state that the index is strongly linked to the ship's deadweight and that the index decreases with increasing dwt. Figure 0-8 substantiates the arguments that there is a close relation between the CO_2 index and ship deadweight. The figure separates between container vessels and dry cargo ships.

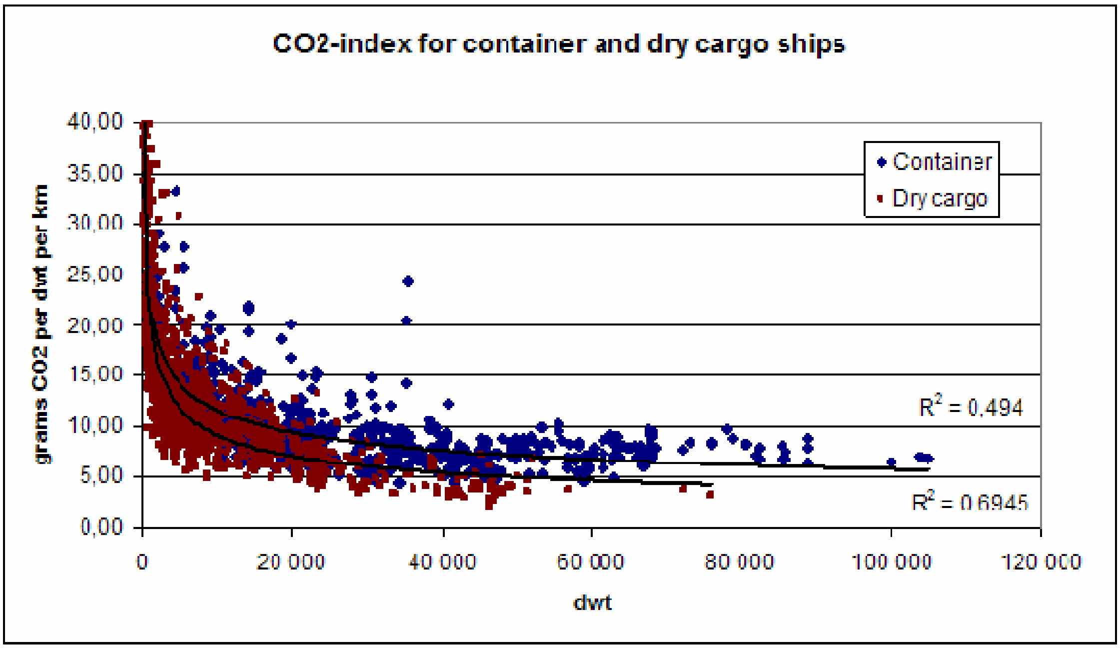

Figure 0-8: CO_2-index and dwt for container and dry cargo ships.

As can be seen from Figure 0-8 there are significant deviations in the CO_2 index for the same ship size. The deviation might reflect good or poor performance in this respect or influence of other factors like different capabilities (equipment, purpose built, etc) which alter the performance.

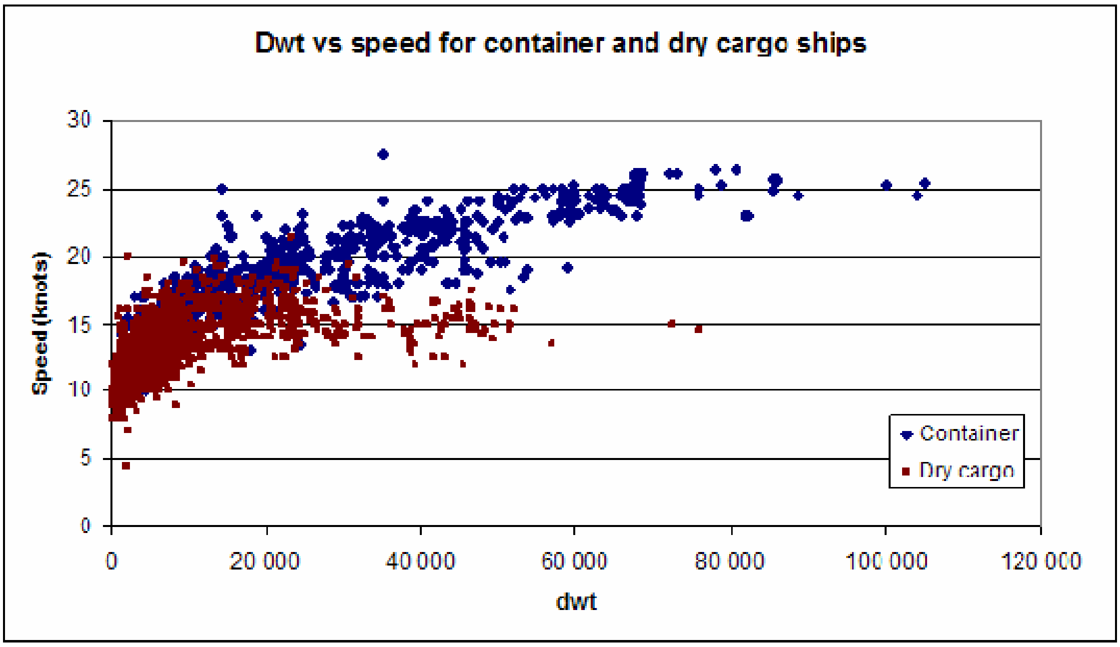

Figure 0-9: Dwt versus speed for container and dry cargo ships.

Figure 0-9 shows the main reason for the deviation. Dry cargo ships above 15000-20000 dwt have a lower cruise speed than container ships of the same size. Using the same index benchmark for these two ship types is not recommended as they have very different designs, resulting in a lower CO_2-index for a dry cargo ship of the same size.

Comparing vessels at the same size having different operating speed will result in different CO_2 indices. The increased speed will raise the ships' CO_2 index, but also increase the overall charter capability. By setting a target value for the CO_2 index for a certain ship type and size, the operating speed will be more predetermined unless the vessels' specific/total energy consumption is improved. The results of setting a target CO_2 index might be optimised service speed and improved energy utilisation onboard for the specific vessel type and size.

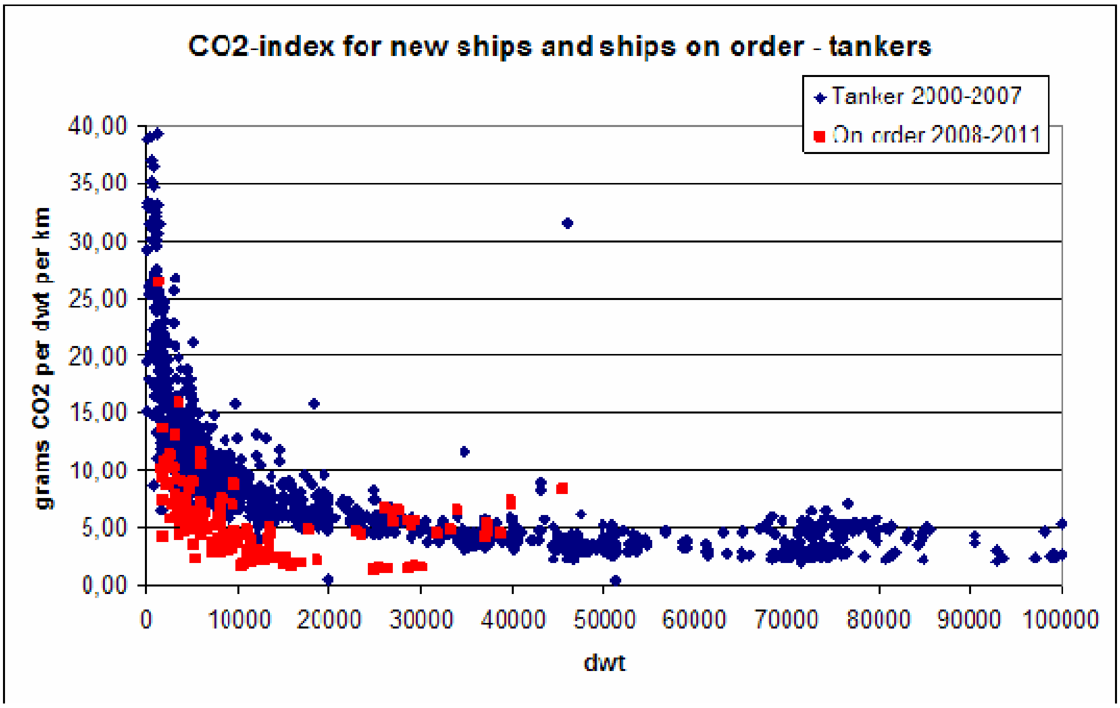

Figure 0-10: CO_2 index for tankers.

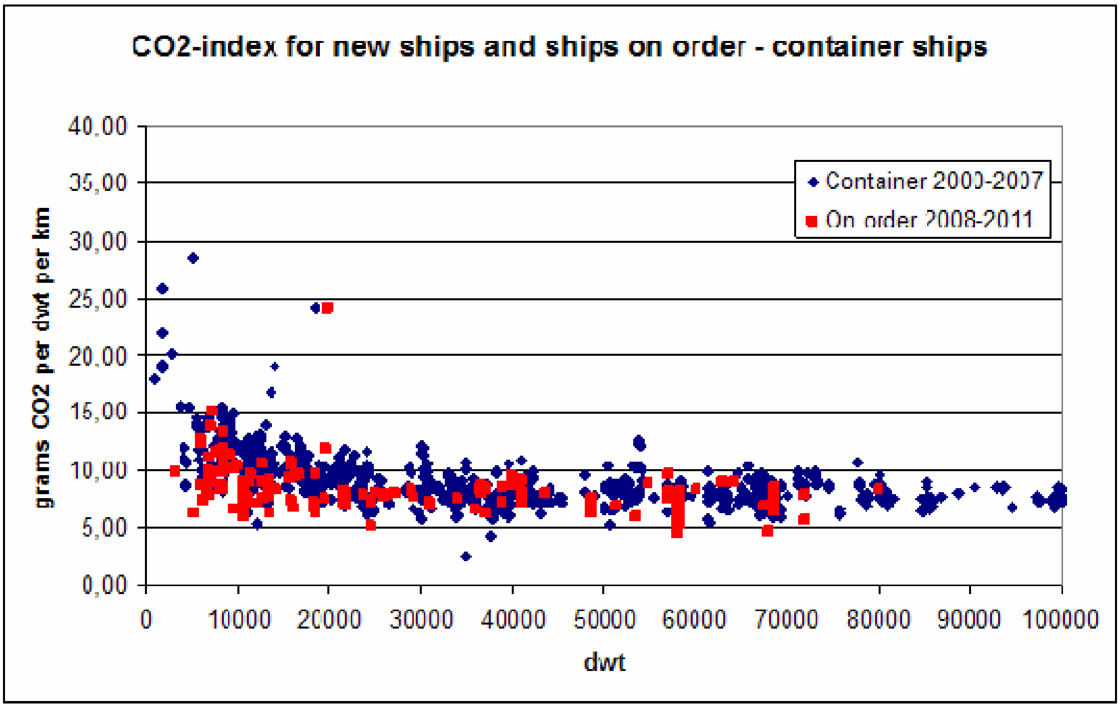

Figure 0-11: CO_2 index for container ships.

Figure 0-10 and Figure 0-11 present the same indices for tankers and dry cargo ships, but include data for new builds, period 2008-2011. The figures indicate that the change in design requirements result in a lower CO_2 index. It should be noted that the future figures are design values which might be changed when actual performance data are reported. A flat average fuel consumption of 170 g/kWh is assumed until 2011 as the fuel consumption is not available for the new ships.

An examination of the data shows an increased speed for tankers on order which gives a lower CO_2-index as the ship moves further per day using the same amount of fuel. The ships do not have increased power installed compared to older ships and therefore the fuel consumption is the same. New ships have a better design (hull shape, propeller, coating, etc) and thus less resistance and more efficient propulsion than older ships.

Froude number

DSA uses three non-dimensional parameters to characterize a ship's resistance in water:

- Froude number
- Block coefficient
- Length-displacement ratio.

The following chapters evaluate the results from the parameter study.

The Froude number is calculated using speed and length as follows:

$$Fn = \frac{Speed}{\sqrt{g \cdot Length}} \qquad (3)$$

Where: *g* is the gravitation constant (*g*=9.81). For all length measurements the length between perpendiculars is used.

The regression line shown in Figure 0-12 is of the same type as in the DSA study but the data set is expanded with Fairplay data. The correlation coefficient is low and the line does not represent a good fit for these data.

Further the DSA study claims a "*slightly decreasing tendency with larger ship length*" of the Froude number. Using a larger data set this conclusion can only be partially confirmed for container ships. The uncertainty and spread of the data is too high, especially for ships below 200 meters, to draw a conclusion. A ship of 150 meters can have the same Froude number as a ship of 200 meters length. The lack of a clear declining trend for container ships is most probably caused by a higher speed level for large ships. For larger container ships (above 250 meters) there is a clearer trend because of a general upper speed limit of about 25-27 knots while the ships are getting longer, giving a slightly lower Froude number.

For tankers and bulk carriers the trend is clearer (Figure 0-13), especially for larger ships. However for ships in the range between 50 and 150 meters there is a high degree of variation in the data. Large tankers and bulk carriers do not increase their speed that much when becoming larger.

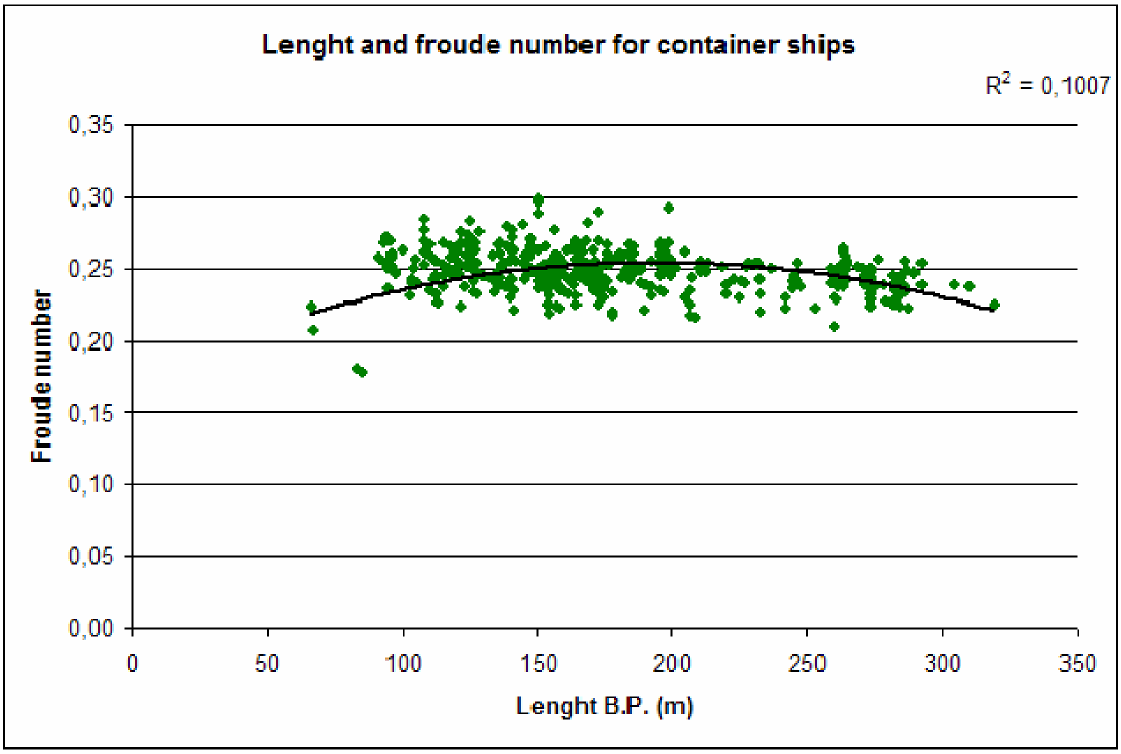

Figure 0-12: Froude number versus length for container ships built in 1992 or later.

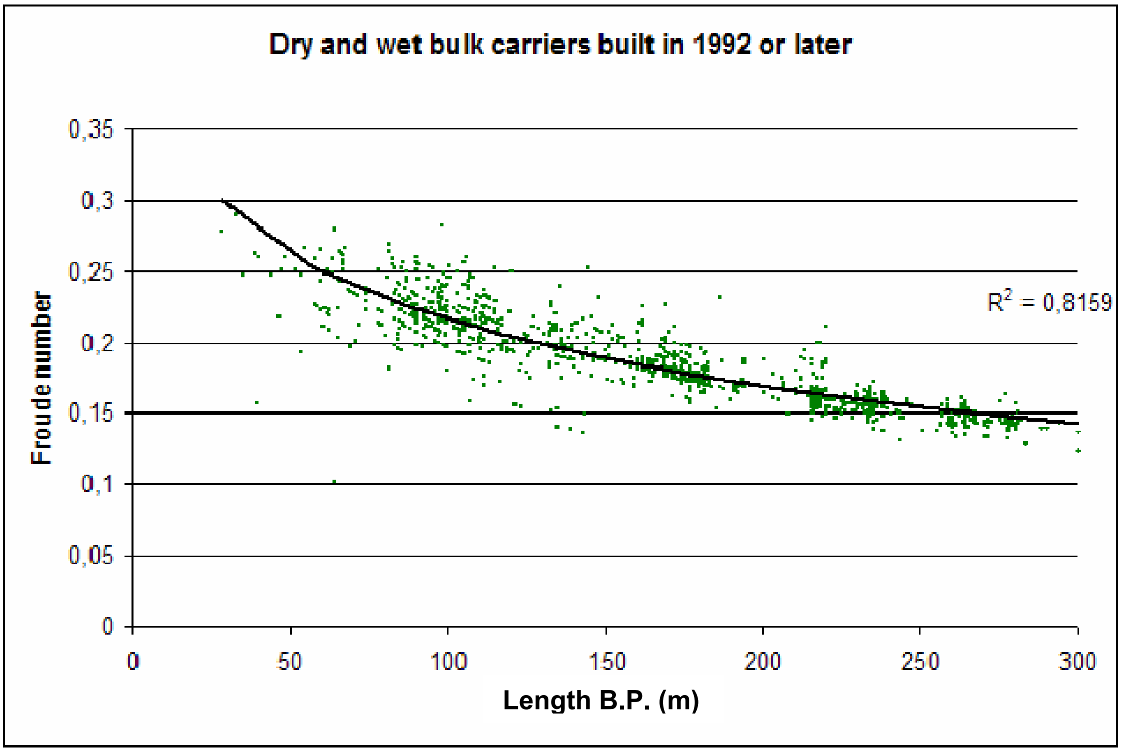

Figure 0-13: Froude number versus length for dry and wet bulk carriers built in 1992 or later.

The next step is to compare the Froude number with the CO_2-index (Figure 0-14). For dry and wet bulk this gives a fairly good correlation, but the spread increases significantly for higher Froude numbers.

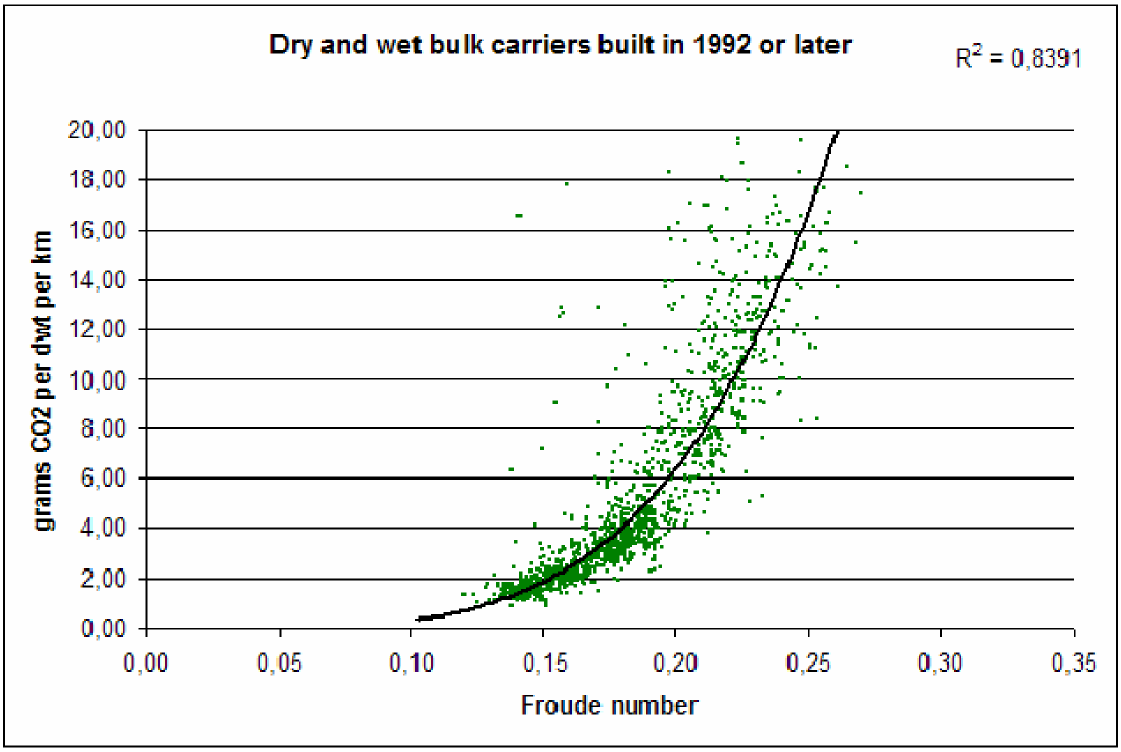

Figure 0-14: Comparison of Froude number and CO_2-index for dry and wet bulk carriers built in 1992 or later.

Block coefficient

The DSA study compares the block coefficient (Cb) to length and Froude number. The Fairplay database does not contain the displacement for the vessels, but for some ships the lightship weight (LSW) is quoted. As the displacement is the sum of dwt and LSW there is only need for a correction function (Displacement = $(a \cdot Dwt^{b}) + Dwt$) for relating displacement to dwt. A regression analysis of the relationships between dwt and LSW shows that they are closely related.

Using this factor the Cb can be calculated using the following equation:

$$Cb = \frac{(a \cdot Dwt^{b}) + Dwt}{LBP \cdot 1.02 \cdot Beam \cdot Draught \cdot \rho} \qquad (4)$$

Where a and b equals 1.38 and 0.89 for container ships and 4.97 and 0.71 for dry and wet bulk carriers /8/. Draught is defined as maximum summer draught. The density of water - ρ - is assumed to be 1.025 tonnes per m^3. 1.02 is used as a correction factor between LBP and LWL /1/.

Figure 0-15 and Figure 0-16 show the plot of Cb and length for the larger data set. This shows that the block coefficient is about the same for all ship sizes. Erroneous data and the use of estimates lead to some outliers, but the trends should not be affected by this. A look at the same plot for tank and bulk carriers shows that for these ship types the block coefficient increases with size. For ships between 50 and 150 meters there are large differences (Figure 0-16).

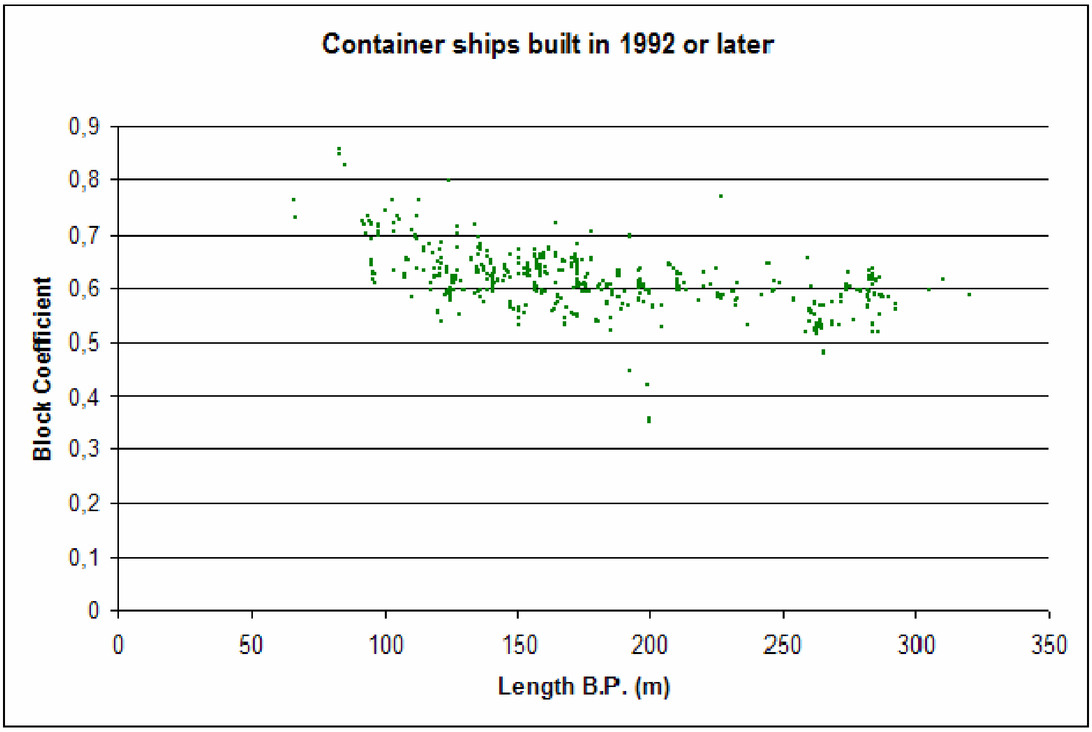

Figure 0-15: Block coefficient versus length for container ships built in 1992 or later.

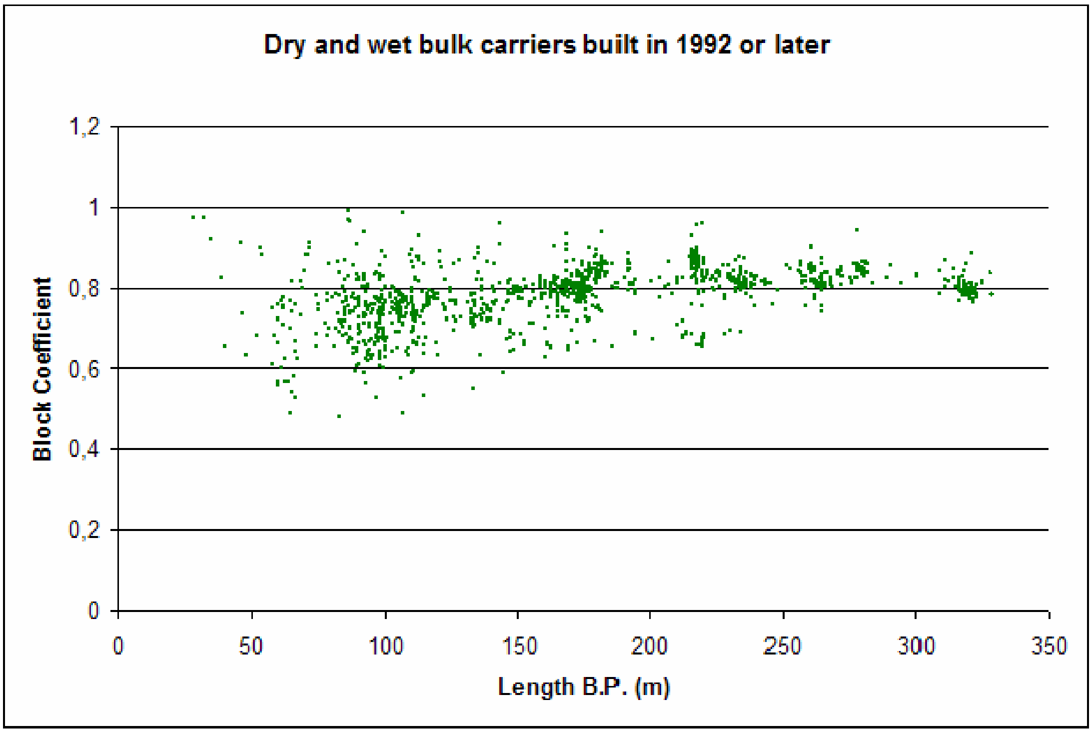

Figure 0-16: Block coefficient versus length for dry and wet bulk carriers built in 1992 or later.

When comparing Cb with Froude number there is a declining trend for the lower and upper bounds. On the other hand there is a large spread between these especially for container ships (Figure 0-17 and Figure 0-18).

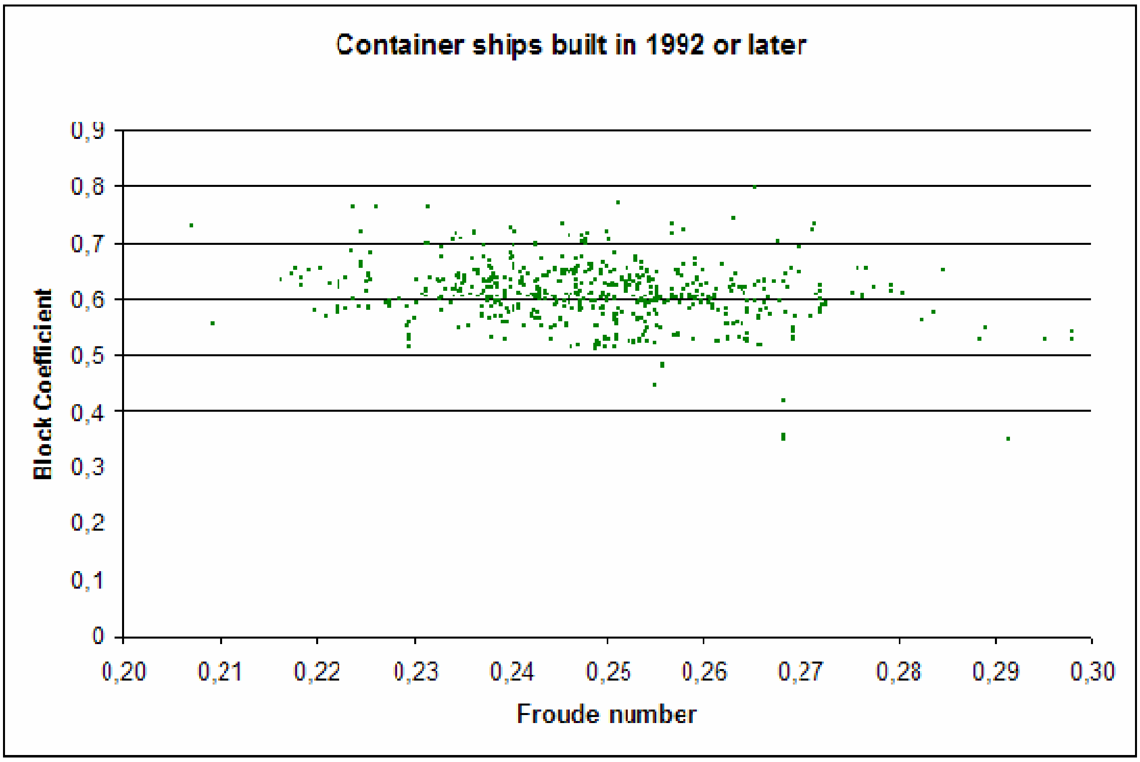

Figure 0-17: Block coefficient versus Froude number for container ships built in 1992 or later.

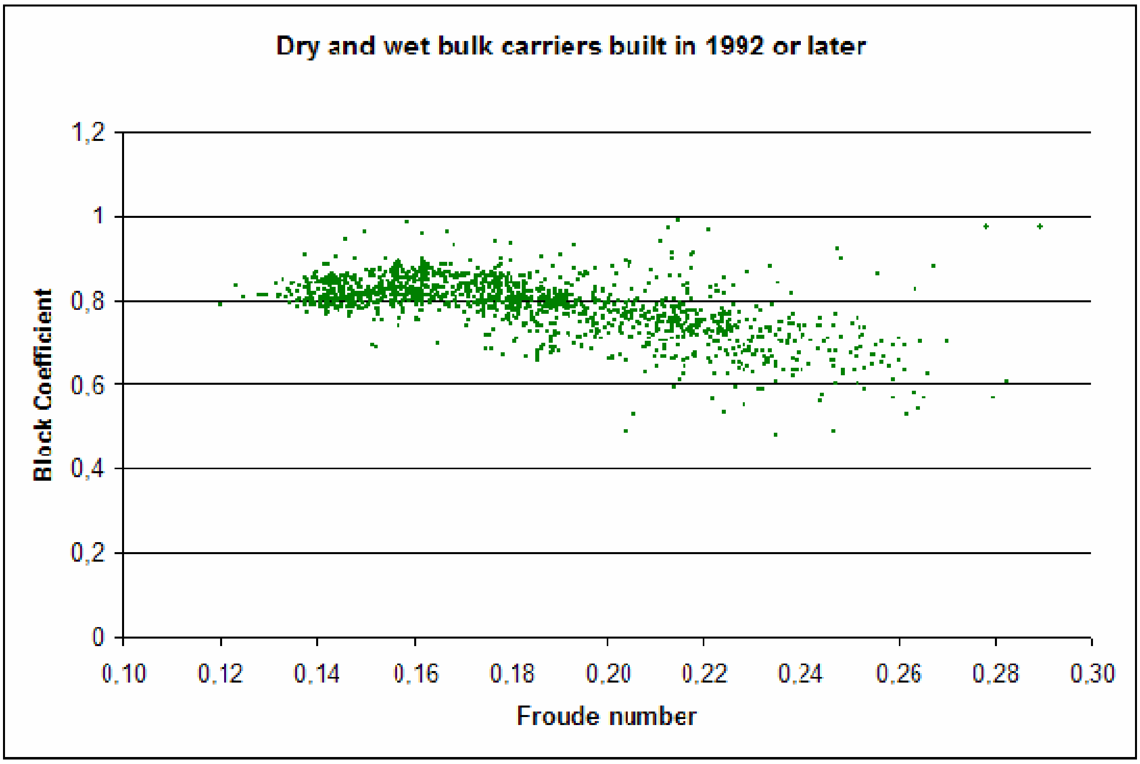

Figure 0-18: Block coefficient versus Froude number for dry and wet bulk carriers built in 1992 or later.

Length-displacement ratio

The last parameter comparison is between dwt and the length-displacement ratio. This ratio is calculated as follows:

$$Ratio = \frac{LBP}{(a \cdot Dwt^{b}) + Dwt} \qquad (5)$$

The parameters a and b are the same as in equation 4. The plots are shown in Figure 0-19 and Figure 0-20. The DSA study indicated an inverse trend where the ratio increases more slowly with increased length. This is valid for container ships as the plot shows (Figure 3-19), while for dry and wet bulk carriers the trend is linear and decreasing (Figure 3-20). For the latter ship types the displacement increases more than the displacement indicating a wider ship with more draft. Container ships are built for speed with a slender hull. It can be argued that for container ships the length-displacement ratio is between 5 and 6 up to about 50 000 dwt where the ratio increases to between 6 and 7.

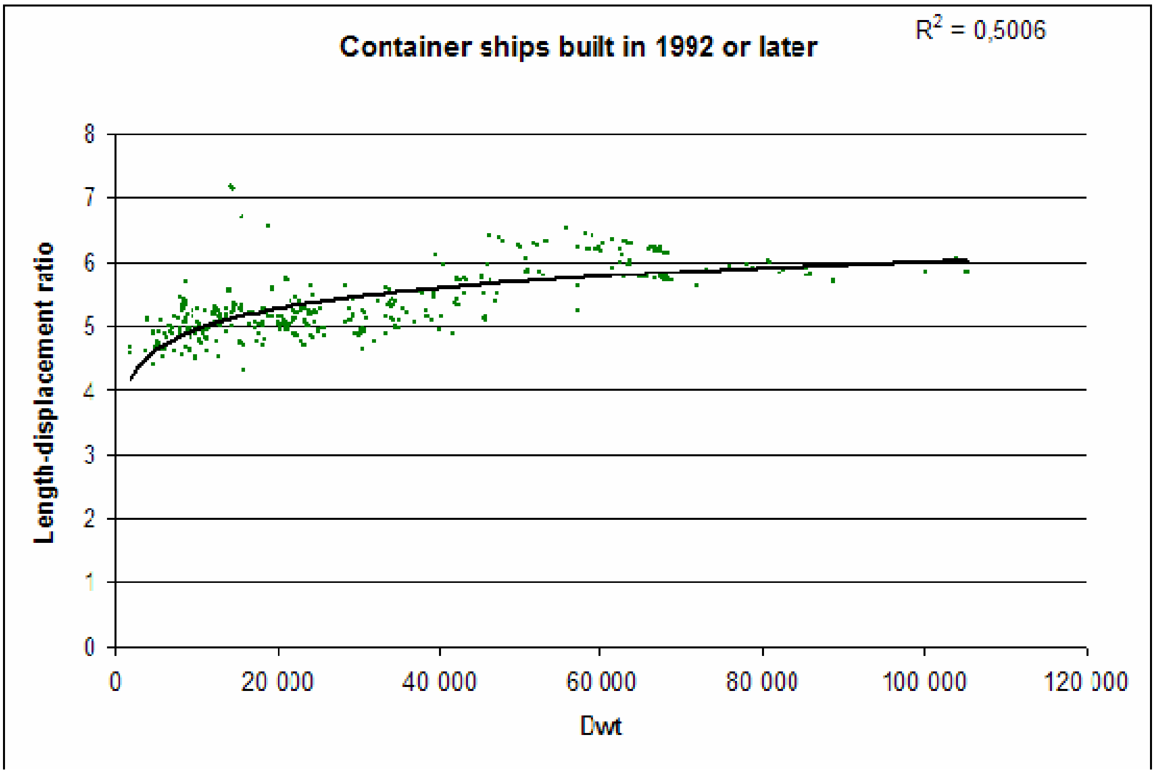

Figure 0-19: Length-displacement ratio versus Dwt for container ships built in 1992 or later.

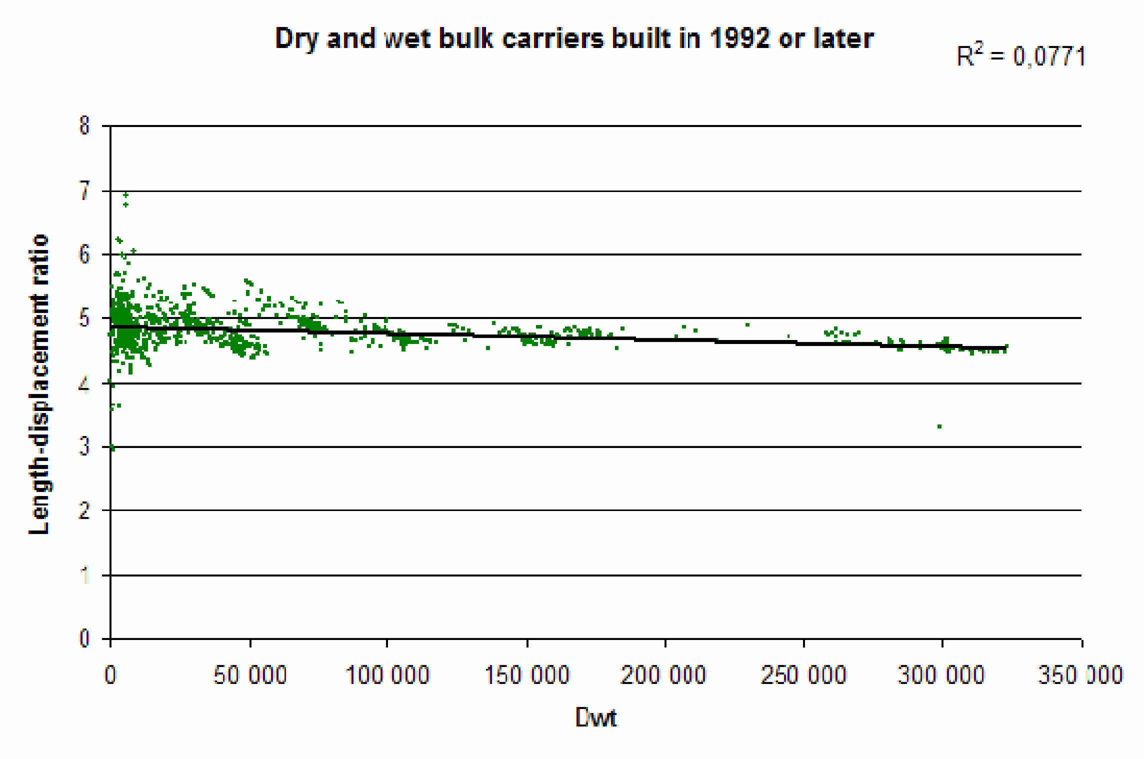

Figure 0-20: Length-displacement ratio versus Dwt for dry and wet bulk carriers built in 1992 or later.

Concluding remarks

The DSA study used a small sample of ships and a computer model for investigating the influence of various parameters on the CO_2-index. Using a larger sample this report confirms the most important findings in this study, but also points out the wide spread in the correlation between the parameters studied, as well as different trends for different ship types.

Based on the analysis this report supports the DSA study on the main conclusions. The following can be concluded:

- The CO_2-index is highly dependent on ship size and to a somewhat lesser degree speed. A CO_2 index should be dependent on dwt for cargo ships and other representative size parameters for offshore, passenger and other ships (e.g. gt, length, numbers of passengers, etc.).
- Using non-dimensional parameters such as Froude number and block coefficient shows a wide spread in the data material. The difference in trends for the various ship types makes them difficult to use in an index, even when the indices are made ship type specific.
- This study has not considered all vessel design parameters, or combinations of them, for their suitability in a possible design index. Further investigation may therefore identify other possible options.

The following chapters will further develop the concept for calculating the index based on a few selected parameters as well as setting a benchmark level for new buildings.

Elements of an alternative CO_2 design index

Based on the findings in the DSA study and other research done on the data material a full methodology for describing alternative CO_2 index is described here. Other internal DNV research has shown that combining other parameters for a design index does not yield any significant benefits and that the aim accordingly should be to make it as simple as possible.

IMO and other industries use emission per transport work (grams per tonne kilometre) as the basis for their indices /2/. This will give a good measure on how well a ship performs relative to other vessels of the same type and size. For ships the propulsion energy needed per tonne declines as the weight capacity increases. Details on advantages and disadvantages of the IMO interim guidelines have been analysed by Marintek and are discussed in detail in /4/.

Advantages:

- Can be compared with other transport modes (like trucks and railways)
- Can be calculated using design variables (g/kWh, kW, length, breadth, draught, speed, volume, etc)

Disadvantages:

- Ship capacity not always measured in tonnes
- Must have different benchmarks per ship type/size

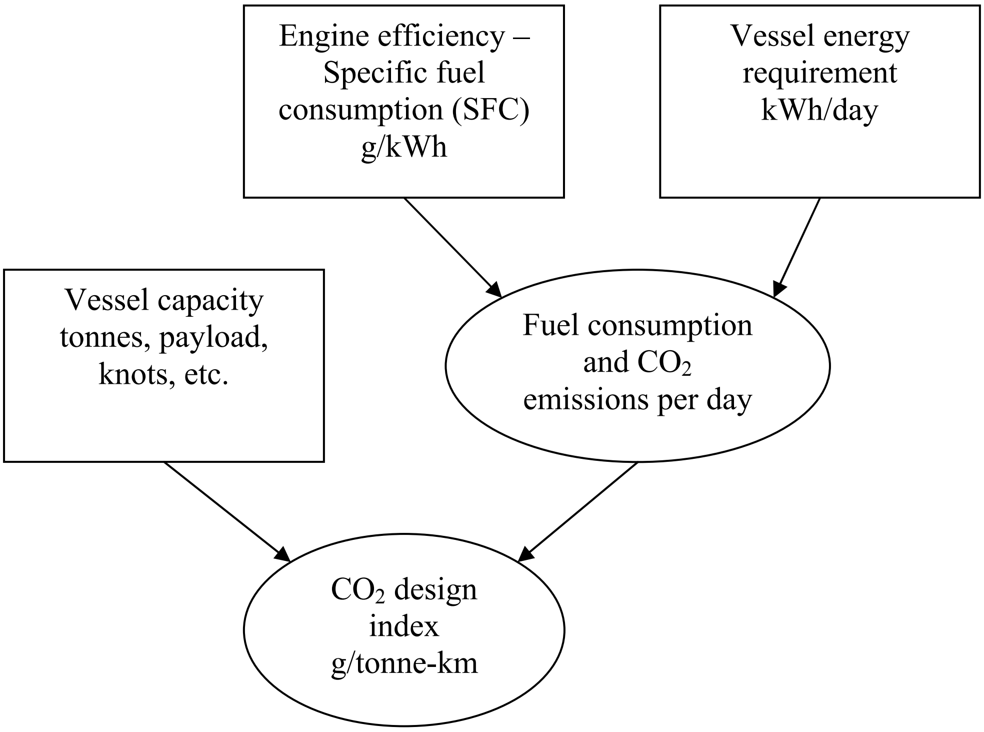

Figure 0-21: Basics for calculating an alternative CO_2 design index.

Figure 0-21 indicates the main parameters that influence the CO_2 index. Equation 5 shows how the index is calculated based on design parameters.

$$I = \frac{AFC \cdot Power \cdot (0.85 + 0.10) \cdot 3.17}{DWT \cdot Speed} \qquad (5)$$

Where: AFC is average fuel consumption (g/kWh) – for this study the average fuel consumption is used instead of specific fuel consumption (se chapter 0). Power is installed kW with 0.85 being the propulsion needed and 0.10 the auxiliary power needed. 3.17 is the conversion factor between fuel and CO_2 emission (based on carbon content). Dwt is the ships capacity and speed is the design speed at 85 % load on the main engines. *I* is a measure of grams CO_2 emitted per tonne kilometre transport work performed at full cargo load, assuming that this is equal to dwt.

The rest of this chapter will go into details on the parameters needed, what measurements can be used to calculate these, and how a benchmark level can be set.

Engine efficiency

First of all the engine has to be considered. The main engine efficiency parameter is specific fuel consumption (SFC) measured in grams per kWh. The CO_2-emission is a fixed factor proportional to the fuel consumption.

SFC is independent of ship size, except for a small increase in efficiency for larger engines due to using low speed engines. When it comes to setting a design index for the vessel this is not sufficient. It does not take into account the size of the engine (i.e. installed power) and gives no incentive for optimizing the engine power to ship size.

The specific fuel consumption will on the other hand be essential for calculating an index together with other parameters, and is important for comparing different engine types and manufacturers.

Vessel energy requirement

The next step will be to look at how much energy the vessel needs for propulsion and to operate equipment such as cranes and reefer holds. This will give a total kWh needed per day on average.

There are large differences between ship types both for propulsion and for auxiliary power. Passenger ships use a large amount of auxiliary power in addition to that needed for propulsion when compared with other ship types, container and ro-ro ships operate at a higher speed than tankers and bulk carriers, etc.

An additional challenge here is that many cargo ships also have their own cargo handling gear such as ramps, cranes, cargo pumps etc. These installations require extra power in port but do not necessarily make the ship less environmentally friendly.

One alternative is to exclude the auxiliary engines and only look at propulsion power. For most ship types this is a significant power consumer and thus it is easier to compare ships within the same category, but with different cargo equipment. However, with diesel-electric power systems becoming more common for some ships types, it will be more difficult to separate propulsion power and auxiliary power.

Using engine efficiency and vessel energy requirement a fuel consumption and CO_2 emission rate per day can be calculated.

Vessel capacity

The last set of parameters needed for an index will be the capacities of the vessel such as speed, deadweight, TEU, lane meters and other measurements.

Deadweight is a measure for how much weight a ship can take including cargo, fuel, and other non-permanent equipment. For some ship types such as dry and wet bulk carriers this corresponds to the ships capacity, while for other types the cargo may be more volume sensitive, meaning that the ship is full before its deadweight limit is reached.

A correction factor may be used when comparing different ship types. For example the payload of a container ship could be set to 60 % of the deadweight, while for bulk carriers and tankers the factor could be up to 95 %. Using a correction factor would only be an inaccurate estimate, and as proposed by DSA, different ships should only be compared with ship of the same category. It can also be argued that for example container ships are designed to carry an average load of 12-14 tonnes per TEU. A design index should not take into account the weight of the containers and using for example 60 % of dwt as potential payload for container ships would give a too low estimate. The issue of carrying empty containers and ballast legs should be an operational issue. Therefore a dwt/payload factor does not need to be reviewed further.

An alternative to dwt would be gross tons or net tons. Gross tons can be used for some ship types such as roro and passenger ships and ferries, but only measures the volume of closed spaces. Net ton measures the volume of cargo spaces and could be an alternative.

Speed is also used as a measure of capacity since it impacts directly on the distance travelled yielding more tonnekilometres per hour.

Larger ships can carry more cargo per kWh resulting in a reduced emission per tonne kilometre. The target for new buildings must be dependent on a capacity of size parameter such as dwt, gross tons, TEU, lane meters, etc. This report agrees with the DSA study in using such parameters, but recommends the use of dwt. Dwt is measured in metric tonnes which is a denomination that is well known and comparable to other transport modes. The analysis shows that ships should only be compared with other ships of its kind. This makes the use of a derived payload measure based on dwt superfluous.

Measurement of index

By using the certified specific fuel consumption, installed power, dwt and operating speed the calculations takes into account changes in engine efficiency and other design parameters. This makes it possible to compare vessels having relatively similar capabilities.

The advantage of the described approach is that it only requires ship design data which is readily available. The uncertainty of measurements during sea trial and reporting error are eliminated and only the design issues are considered. One exception may be that specific fuel consumption should be measured after installation on the ship and not using the engine manufacturers test bench results. However measurements of fuel consumption onboard are difficult and inaccurate. Measurements onboard are therefore not a good alternative for a design index.

In addition only a few variables are chosen. Using an index as incentive can create unexpected results when ship designers start to optimize on reaching the target. The more parameters in use the more such unexpected results can emerge.

Benchmark level for the index

Comparing a short sea tanker with a VLCC would not be fair. Nor would a comparison of a 10000 TEU container ship with a 120000 dwt bulk carrier be relevant even if their deadweight capacity is about the same. The container ship has a different hull shape and higher cruise speed than the bulk carrier.

For some ship types the capacity is not measured in volume or weight. For passenger ships the number of passenger is more relevant. Another alternative would be gross tonnes. Offshore ships are even more difficult to measure as they perform a wide variety of tasks not always involving cargo or passengers.

A benchmark level can be calculated using the present fleet. New ships will be required to be below a certain level defined by a type specific index curve. If desired this level can be reduced over time, reflecting the policy option of a gradual tightening of environmental performance requirements.

Figure 0-22 shows an example on how a benchmark design index level can be set based on average fuel consumption, deadweight and speed using dry and wet bulk carriers. There is a good fit between the regression curve and the plots.

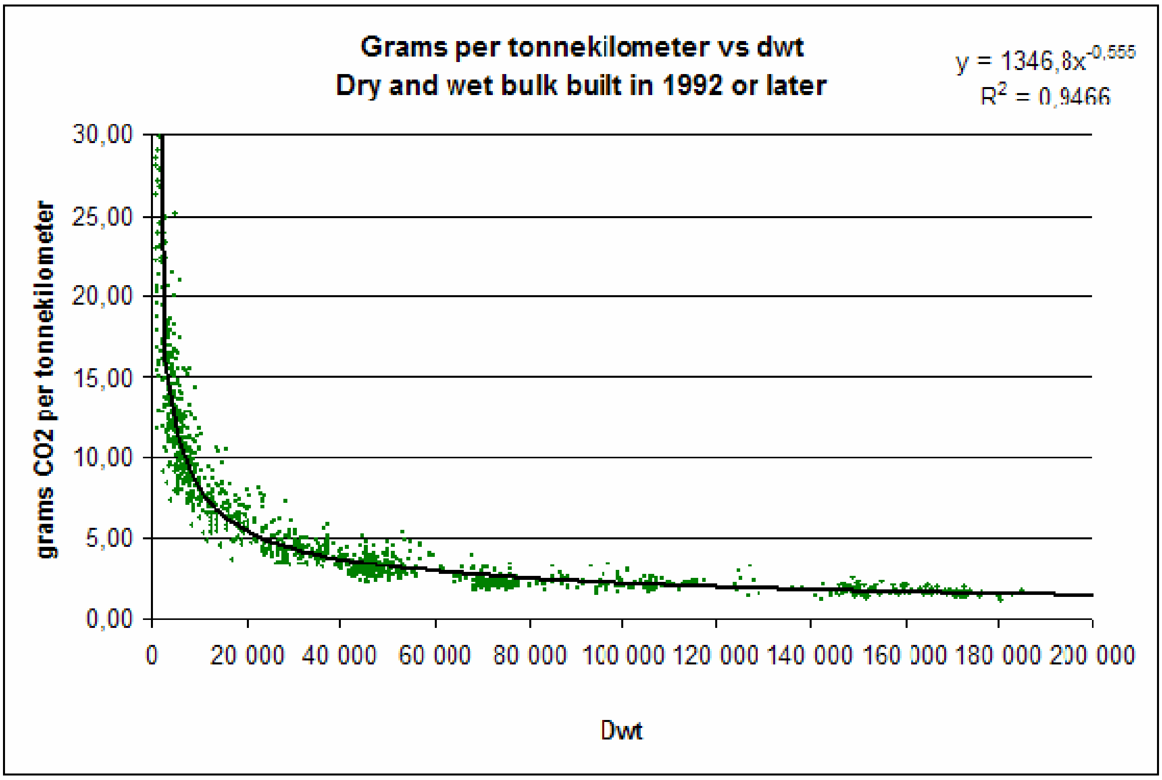

Figure 0-22: Setting a benchmark level.

The benchmark line has a good fit with the present fleet and represents the average CO_2-index for any given deadweight. The band is very narrow especially for larger ships, indicating a consistent relation between the deadweight and CO_2-emission. This makes the line suitable as a base line for a CO_2-design index.

If there is a requirement for new ships to be below the benchmark, this average will be moved downwards creating a more environmentally friendly fleet. The line could be set lower or higher depending on how aggressive the implementation process should be.

It should be noted that this line is valid for dry and wet bulk carriers only. Other ships types such as dry cargo and container ships will need individual lines as they represent different designs and thus different kw/dwt/speed ratios.

Benchmark deviation

Figure 0-23 shows how much the deviation between the curve and the actual values. There seems to be a sharper upper bound than lower bound. Notwithstanding the deviation seems to be a normal distribution and indicates a well fitted regression line for dry and wet bulk carriers. Not having a normal distribution would indicate that the relation between the parameters and emissions could be coincidental.

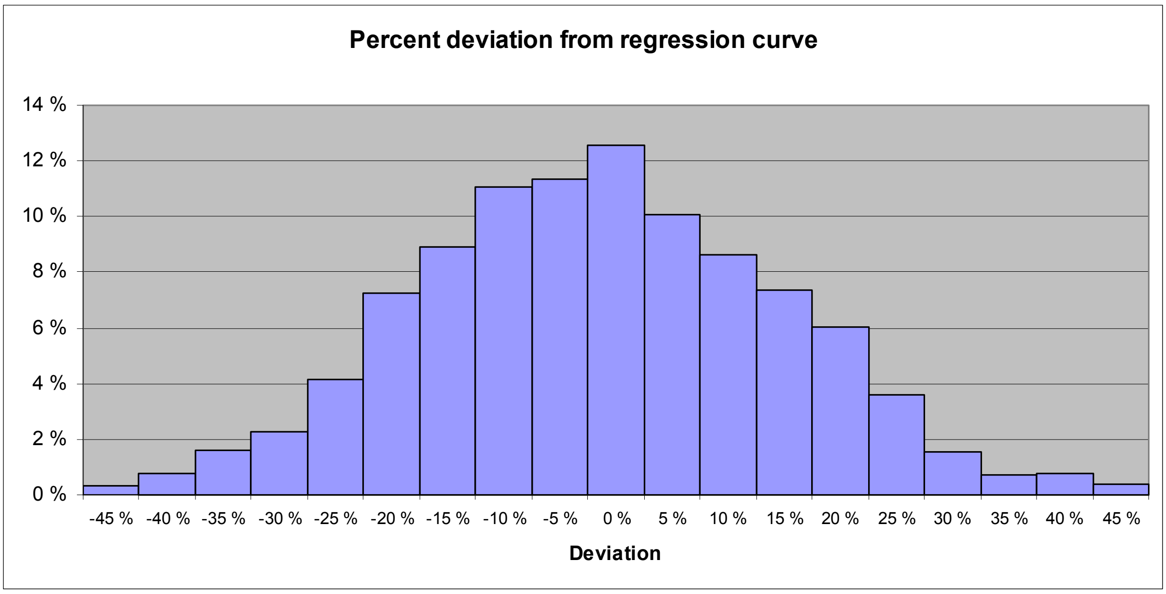

Figure 0-23: Deviation from benchmark line.

Case example

In order to analyse and understand the effects of using the CO_2-index together with a benchmark level as target a case example is presented. Figure 0-22 shows the index as a function of dwt and uses a regression line to set a benchmark level. This line should indicate the average ship for a given dwt. It is assumed that the target is to be better than average in this case. The case ship design parameters are shown in Table 0-2, and the CO_2 index is calculated to be 2.4 g/tkm.

Average fuel consumption	180	g/kWh
Dwt	100000	tonnes
Speed	14	knots
Engine power	11500	kW
Estimated fuel consumption	47	tonnes/day
CO_2-index	2.40	g/tkm

Table 0-2: Case example.

Using the benchmark line, the target for a ship of this size would be a CO_2-index of 2.26 grams per tonne kilometre. In order to meet the target the ship design has to be altered. This can be done in three ways:

- Increase engine efficiency:
  - I: Reduce specific fuel consumption

    Examples: Heat recovery
- Increase energy efficiency:
  - II: Higher speed without increasing the power
  - III: Reducing power without decreasing speed.

    Examples: Hull shape, hull cleaning/coating
- Increase capacity:
  - IV: Higher dwt with the same power and speed.

    Examples: Hull shape, increase length, beam, draught and height

	Base	I	II	III	IV	
Average fuel consumption	180	165	180	180	180	g/kWh
Dwt	100000	100000	100000	100000	115000	tonnes
Speed	14	14	14	15	14	knots
Engine power	11500	11500	10500	11500	11500	kW
Estimated fuel consumption	47	43	43	47	47	tonnes/day
CO_2-index	2.4	2.2	2.2	2.24	2.09	g/tonne-km
Index target	2.26	2.26	2.26	2.26	2.09	g/tonne-km

Table 0-3: Reaching the CO_2 index target.

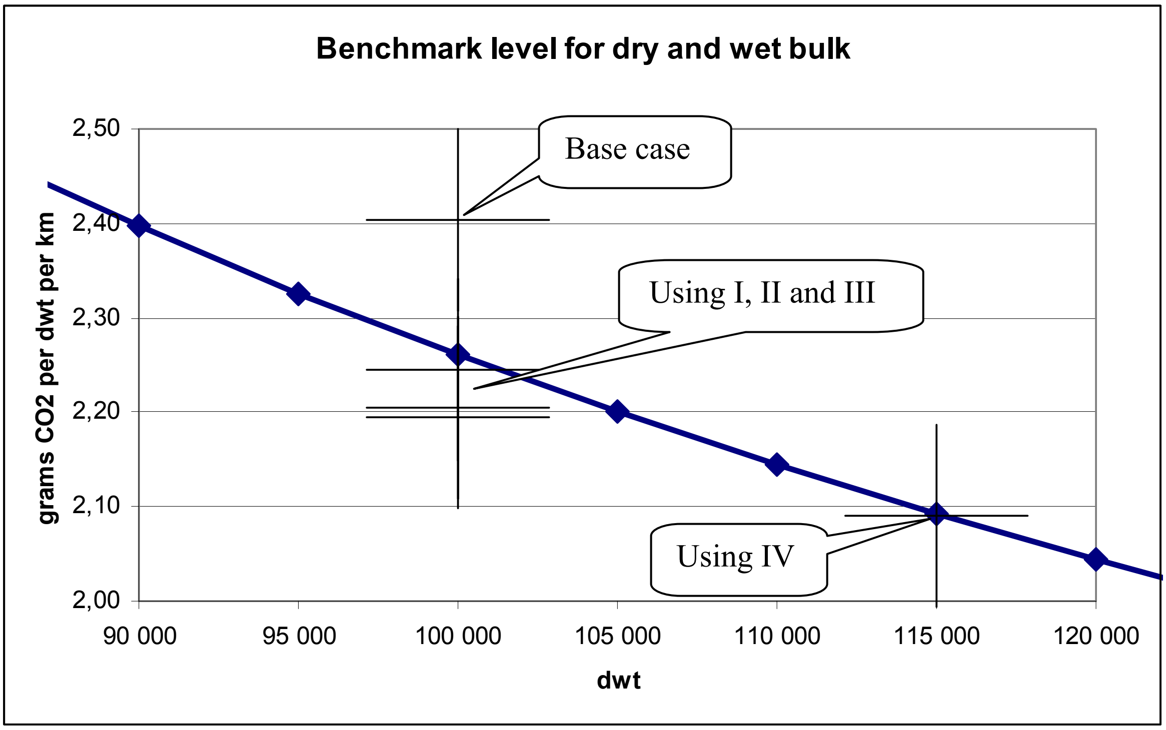

Figure 0-24: Excerpt of benchmark curve with case example.

Figure 0-24 and Table 0-3 show how using the methods described above reduce the CO_2-index to below the target line. Increasing the deadweight (Method IV) has a significant impact on the index, but then the lowered target also has to be taken into account.

Concluding remarks

Four main parameters are combined into an alternative CO_2 design index measured in grams per tonne kilometre: specific fuel consumption, installed power, speed and dwt. These parameters represent engine efficiency, energy efficiency and capacity. Improvements of any of these parameters will result in an improved index value.

An index benchmark value should be dependent on dwt and ship type as the design varies between different ship types. The ship type categories may be set based on what cargo type is transported (i.e. containers, wet bulk, dry bulk, cars etc). A benchmark level can then be set for each ship type based on dwt. New buildings will be required to have design parameters that yield an index that is below the benchmark.

The benchmark can be set based on existing design, but the final level is a political decision based on which targets are to be met.

Discussion

A CO_2 design index can be considered in the same light as a mileage standard for a car. It is not a measure of what a ship actually is emitting; rather, it is an estimate of its energy efficiency for a given set of applied design features under a given set of assumptions. In practical terms this means that even if a ship has a good "mileage standard", its actual emissions will be strongly dependent on how it is operated. However, even if operational measures are needed to make a significant impact on reducing CO_2 emissions, a properly applied design index can at least contribute to lowering the upper bound of the emissions. A design index will also pave the way for lowering emissions significantly by at least creating the possibility of operating in a truly energy efficient manner.

This section will examine a set of issues pertaining to the workability and impact of a CO_2 design index.

Assessment

This sub-section considers four key issues for workability of a CO_2 design index;

- Operational effectiveness
- Legal implications
- Feasibility of Monitoring and enforcement
- Feasibility of implementation / verification issues

These four criteria are identical to those utilised when analysing other policy options in /4/, this is done deliberately to facilitate comparison with conclusions reached there.

Environmental and economic impact issues are examined in more detail in 4.2.2.

Operational effectiveness

Operational effectiveness may be considered as a combination of the amount of emissions covered by the policy option and the degree of incentives for all abatement options that are introduced /4/.

Considering this there are certain limitations for an IMO CO_2 design standard /2/, first and foremost in that it is limited to new ships only. Even if it is applied to all new ships above a defined size worldwide this means that it will have only a gradual impact on the world CO_2 emissions. Given the present rapid growth in world fleet installed power it seems likely that CO_2 design index at best will only offset part of the growth in emissions. It should be noted that this will be dependant on the index target levels defined, as well as on whether these will be subject to regular tightening (as for instance in the US EPA Tier system).

Furthermore, since a design index by definition only applies to new ships, and does not include operational measures, the flexibility regarding choice of abatement measures is limited to that achievable through design measures and the construction process. As long as the design index target is reached there is little or no further regulatory driven incentive for ship operators to apply abatement measures in the operations phase. Of course, high fuel prices will obviously provide a commercial incentive for all operators to reduce their operational expenses by reducing fuel consumption. This has for example contributed to continuous effort by engine manufacturers to meet the market demand for more efficient engines, and is also seen in the strong focus operators have on fuel savings in daily operations. The extent to which efficiency improvement measures actually are applied will of course be subject to economic considerations by the individual operator, taking into account both investment costs and reduced operational costs, while also considering impact on elements as diverse as trading patterns, contractual issues and technical risk. However, these pressures and considerations will apply to all operators and vessels irrespective of whether or not the ships have been designed and constructed under a design index regime.

The short term operational effectiveness of a CO_2 design index is therefore considered to be small. However, it has a potential of achieving significantly increased impact as the index over time is applied to a larger percentage of the world fleet.

Legal Implications

Assuming that a CO_2 design index would be adopted as an IMO regulation and subject to the normal ratification and adoption processes in individual countries there are no foreseeable legal barriers to adopting such an index. The legal considerations can in practical terms be considered identical to those pertaining to other IMO regulations.

Feasibility of monitoring and enforcement

Determination and verification of a new ship's CO_2 design index could be considered the responsibility of the flag state. Since the calculation in principle is a one-off exercise, verified preferably on the basis of as-built data rather than design data only (which conceivably can change during the building process), this can also be done in connection with issuing of certificates by Class Societies, on the behalf of flag states.

There is a limited need for enforcement during a ship's operational lifetime, possibly excepting those cases where the ship is subject to conversion or significant modifications. Details on what kind of certificates a vessel would need to carry in order to demonstrate adherence to the CO_2 design index would have to be defined, but should not represent a significant barrier to adoption.

Feasibility of implementation

Based on the data analysis in section 3 it would appear from a purely technical perspective that a CO_2 design index can be established, provided that it is done in a manner that differentiates between vessel type and size. The requisite ship data can be made available at a fairly early stage of the vessel specification/design process, allowing ship designers to target a specific design index value.

Baselines can be established based on historical data; however it is likely to be a complex issue to agree on precisely what that level should be. A reasonable first approach could be to establish the target baseline at a certain percentage under the average fleet values indicated in section 3. Prior to adoption it would be advisable to simulate the impact of a range of baselines on both existing fleet data, as well as on a range of actual ongoing new-building projects.

Furthermore, a mechanism will need to be established whereby ships with special designs placing them above the baseline won't be unfairly restricted from trading. This is likely to be somewhat complex issue, since the system must cater to special circumstances, while at the same time not be so flexible that it allows designs that simply are poor. Alternatively, a staged approach would be to implement or test an index system only on those fleet segments where sufficient historical data is available to ensure a genuinely appropriate baseline.

Limitations

Another issue is the performance of the ship in adverse weather and wave conditions. A ship design may be better suited for bad weather, but in normal conditions (where the design speed and consumption is measured) it performs just as any other design or may even be worse. It is the ship design that improves the performance under certain operational conditions, but the proposed design index does not take this into consideration, comparing ships only under normal conditions.

To summarise there are issues that need further consideration before a CO_2 design index can be implemented.

Qualitative assessment of likely environmental and commercial impacts

As discussed above there will likely be a limited short term environmental impact of a CO_2 design index as it applies to new ships only. However, the impact will increase proportionally with the introduction of new tonnage to the world fleet. The impact will also be strongly dependent on how aggressive the target baseline is set, which ship types are included and to what extent a gradual tightening of the design index is applied (if at all). A tightening of limits is obviously feasible, but how fast this can be done will depend on how fast designers and shipyards can be expected to develop new technology and system designs.

It should be noted that if the application of a design index leads to a significant cost increase for ships there will be a pressure for life extension on old tonnage with poor environmental performance. This may partially negate some of the positive impact from a design index.

On the other hand, on a longer term it is not inconceivable that design indices or equivalent may be applied retroactively to existing ships. Both regulatory pressures and demand by cargo owners may lead to a situation where compliance with a design standard is a necessary “ticket-to-trade”. In such a case there may be an increasing pressure to either scrap or upgrade older vessels to comply with the index level. A recent example of such a scenario is the introduction of the double hull requirement for tankers where the fleet has been through a forced scrapping period as older single hull ships are prohibited from trading.

Another environmental aspect of a CO_2 design index is its possible use in a graded rating of ships’ environmental performance, as a basis for port / fairway fees and dues. It is quite feasible to extend a baseline-only system to a system where a graded rating also can be issued. This would potentially add a market pressure to build ships with environmental performance beyond minimum compliance.

As should be clear from the above there are several issues that merit further investigation and consideration before a quantitative estimate of emission reduction impact can be made.

With respect to commercial aspects similar considerations apply; an increased price on new vessels is likely to have some impact on freight rates and earnings. However, this effect will be modest compared to the impact of ordinary fluctuations in time charter rates, fuel cost, currency fluctuations etc. Furthermore, it is not likely that a design index will distort the existing competitive conditions in the maritime transportation business, since a key assumption here is that an index will be applied world-wide. One possible exception to this is in regional and short-sea shipping where increased shipping costs may lead to some transportation work being transferred to other modes such as truck or rail. However, this effect is expected to be small, possibly insignificant, for the same reasons as discussed above.

Use of indexing in carbon trading schemes

A special consideration of the possible utility of a design index in a carbon trading scheme has been performed in the following.

In principle it is possible to construct a system whereby a CO_2 design index is coupled to an operational parameter for use in a carbon trading scheme. A simple example would be using the deviation between baseline design index and vessel-specific design index and multiply with a appropriate operational parameter to calculate credits earned (if below baseline) or credits that need to be bought (if actual design index is above baseline). This would presuppose several key issues;

- A CO_2 trading system for ships is established
- A CO_2 design index is not considered as an absolute limit, but something that a ship can be built to exceed provided one is willing to buy quotas, or that the index is applied retroactively to older ships
- A monitoring system for the relevant operational parameters must be in place

The list may be extended, but a key argument against such as system would be that it would have the same complexities as that represented by the IMO CO_2 index /2/ when it comes to monitoring and logging of transportation work. Using solely a design index, would not take into account operational improvements or measures made by the ship operator. This would render such a system of limited value, it is therefore not considered further here.

Conclusions

From a purely technical perspective, a CO_2 design index for new buildings appears to be a feasible policy instrument to reduce greenhouse gas emissions. When reviewing the Danish Shipowners' Association (DSA) report, and performing similar analysis on a significantly larger fleet data base (sec. 3.1) it is concluded that the most important of the findings in the report can be corroborated:

- Considering the possible span of size and speed of commercial ships, the CO_2-index can be said to be highly dependent on ship size and to a somewhat lesser degree on speed.
- To represent the function and the operational profile well, a CO_2 index should be dependent on dwt for cargo ships and other representative parameters for offshore, passenger and other ships (e.g. gt, length, numbers of passengers, etc.).
- When the index is plotted as a function of non-dimensional parameters such as Froude number and block coefficient a wide spread is observed. The difference in trends for the various ship types makes it challenging to define simple index limit values, even when the indices are made ship type specific.

Furthermore, four main parameters are combined into an alternative CO_2-index measured in grams per tonne kilometre: specific fuel consumption, installed power, speed and dwt. These parameters represent engine efficiency, energy efficiency and capacity. Improvements of these aspects will result in a better and more consistent index value. Key conclusions are;

- The index should be dependent on size (dwt) and ship type as the design varies between different ship types.
- A benchmark level must be set for each ship type and should be based on dwt, rather than non-dimensional parameters.
- New building should be required to have design parameters that yield an index that is below the benchmark, where the benchmark can be set based on existing design or at an internationally agreed lower level.
- The results of setting a target CO_2 index might be optimised service speed and improved energy utilisation onboard for the specific vessel type and size.
- The benchmark can be set based on existing design, but the final level is a political decision based on which CO_2 emission targets are to be met.

This study has not considered all possible vessel design parameters for their suitability in a possible design index. Further investigation may therefore identify other possible options.

When considering the workability and impact of a CO_2 design index (sec 4.) it was found that considered as a policy instrument it is believed feasible to establish a technical ship CO_2 design index.

It is considered that the operational effectiveness and environmental impact of the instrument will be limited initially, mainly due to its application to new ships only. There is however a potential for a significant environmental impact over a longer period of time, in particular if mechanisms driving beyond-compliance behaviour are promoted.

Certain issues will need further consideration if the instrument is to be further developed;

- The scope of application must be internationally agreed, and it has to be agreed whether the CO_2 index should be applied to the entire world fleet or only to fleet segments with a statistical data basis sufficient to establish appropriate baseline levels. If the entire fleet is to be covered, provisions must be established for ship types where only limited data exist.
- A mechanism for the definition of a baseline level must be agreed. A suggested first approach is to use a certain percentage below present fleet average.
- A test project or further simulation based on existing vessels under construction is suggested to validate the approach.

The precise design of the policy instrument is an issue that will be open to discussion between policy makers and other stakeholders; however it is quite clear that it will have to represent a trade-off between vessel design technical feasibility/cost and the desired environmental impact.

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