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Executive summary

The overall objective of B1 is to improve the energy efficiency of ship operations and also identify areas for system efficiency upgrades. This deliverable D-B1.4.2 is the final deliverable of Flagship B1.

This document is the final and concluding deliverable from the work package B1 in Flagship. It contains four main chapters which are:

- The Introduction
- IMO 2009 GHG study and its 2050 scenarios, versus the 450 ppm target.
- The Developed methodology for energy efficiency improvement
- Utilising the methodology to improve the energy efficiency

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TERMS AND DEFINITIONS

CEN	European Committee for Standardisation
CO_2	Carbon Dioxide
DWT	Deadweight tonnage
ESP	Energy saving potential
E_{TECH}	Technical efficiency indicator
E_{TOT}	Total efficiency indicator
E_{UTIL}	Utilisation efficiency indicator
EU	European Union
Ft	feet (imperial unit of measurement)
G	Gram
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
IEA	International Energy Agency
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organisation
k€	Thousands of Euro
kWh	kilowatt hour
LNG	Liquid Natural Gas
M	Metre
MCR	Engine Maximum Continuous Rating
MDO	Marine Diesel Oil
ME	Main Engine
MEPC	Marine Environment Protection Committee
Mm	Millimetre
Nm	Nautical mile
OECD	Organisation for Economic Co-operation and Development
RO-PAX	Roll on/Roll off Passenger (ferry)
Ro-Ro	Roll on Roll of ship
SFC	Specific fuel consumption
SFOC	Specific fuel oil consumption
TEU	Twenty-foot equivalent unit
WG	Working Group
XML	Extended Mark-up Language

Table of contents

1. Introduction

This document is the final and concluding deliverable from the work package B1 in Flagship. It contains four main chapters which are:

- The Introduction
- IMO 2009 GHG study and its 2050 scenarios, versus the 450 ppm target.
- The Developed methodology for energy efficiency improvement
- Utilising the methodology to improve the energy efficiency

1.1 Background - relation to Flagship and introduction to problem

The overall objective of B1 is to develop a methodology for assessment of energy efficiency, making it possible to forecast the impact of operational decisions, develop options for energy efficient design of machinery, energy consumers and control of both, and quantify requirements for new buildings. Even if shipping is the transport mode with the highest energy efficiency, there is a need to make it more energy efficient due to:

- Foreseen energy shortages in the future and higher cost of energy
- The current climate debate and the foreseen need to reduce emissions
- The fact that there is an identified potential for improving the energy efficiency even with today's technology

From the late 1980'es and up until 2007 the world trade growth was higher than in any other period during the last 200 years, and the trade and transport volumes nearly doubled. At the same the world energy consumption increased from 8 732 Mtoe - million ton oil equivalent units in 1990 to 12 013 Mtoe in 2007[i]. This, however, has created increased challenges in relation to available energy sources and increased emissions of greenhouse gases from the use of fossil fuel. In the report Greenhouse Gas Emissions from Ships (Buhaug et al 2009)[ii], prepared for IMO by an international consortium lead by MARINTEK, the total consumption by seagoing vessels is calculated to be 333 million ton (excluding navy & other military activities). This means that sea going vessels consume approximately 15 % of the total 2 134 Mtoe used by the transport sector. The comparable figure for aviation is 233 Mtoe and 10 % of the total.

On the international scene it is important to note that the current international discussion within the United Nations Framework Convention of Climate Change (UNFCCC) also covers international shipping. The Kyoto Protocol article 2.2 invites Annex I countries to the protocol to pursue the limitation or reduction of greenhouse gas emissions (GHG) from shipping while working through IMO. IMO Resolution A.963(23) urges member states to develop a methodology to describe the GHG efficiency of ships, and in doing so give priority to CO_2 as the main GHG from ships. One of the objectives in the European Union strategy to reduce air emission from ships is to reduce ships unitary emissions of CO_2[1]. This is equivalent to increasing the fuel efficiency of the ship which will also result in reduction of fuel related emissions (CO_2, SO_x, NO_x, HC, particulates, and heavy metals).

The objective of the subproject B1 may be described by three part objectives:

- Support the European Community policies on reduced environmental impact from shipping by improving the energy efficiency of ship operations by providing tools for improvement to the ship operators (“motivate and assist”).
- Develop a monitoring system of ship and fleet efficiency enabling the ship owner to perform continuous assessment of own performance (“to see and understand”).
- Develop supporting material enabling the ship owners to improve energy efficiency (“enable improvement”).

1.2 Previous work in B1

This deliverable D-B1.4.2 is the final deliverable of Flagship B1. In deliverable D-B1.1 “Influence of external factors on the energy efficiency of shipping” [1] the requirements of fleet optimisation is evaluated. Deliverable D-B1.2 “Analysis of Power Requirements” [2] depicts the requirements of ship optimisation, and the need for a measurement campaign aboard a large seagoing vessel is presented. Concepts for ship energy efficiency monitoring are developed and possible operational and technical means are discussed. In the latest deliverable D-B1.3 “Methodology for Energy Efficiency Monitoring, Trials and Development” [3], different approaches for efficiency monitoring are presented, which are planned to be tested by the partners.

In the forefront of the IMO MEPC 59 meeting, a paper was prepared for the Flagship management as discussed at Flagship meeting in Athens, May 2009. This public paper summarized the Flagship B1 results for use in the development and implementation of the Ship Energy Efficiency Management Plan -SEEMP. The paper depicted the extensive approach of Flagship B1 for optimization of fleet, ship, and ship machinery and equipment. The paper was distributed to Flagship Management and partners on July3rd 2009 for further dissemination as a basis for discussions and demonstration of Flagship results as implementation option for the SEEMP.

The D1-4.1 deliverable follows the previous ones closely by presentation of concept and results of the measurement campaign. As the final deliverable of the onboard energy efficiency side of B1, a short overview of the Flagship B1 achievements regarding onboard energy efficiency is added as an extension of the original scope of the deliverable.

1.3 Task B1.5 Energy efficiency improvements

In the final task of B1 we have used the main results from the previous tasks and develop a model for energy efficiency improvements both on vessels and at a fleet level.

The CO_2 emission efficiency of transport can be expressed as mass CO_2 / tonne*kilometre where CO_2 expresses the total emission from the activity and tonne*kilometre expresses the total transport work. For a given period, the CO_2 emission efficiency is then defined as:

$$CO_2 efficiency = \frac{CO_2}{ton * kilometre}$$

Where

CO_2 = Total CO_2 emission emitted from the vehicle within the period
Tonne*kilometre = Total actual tonne-kilometres transported within the same period

Using this definition, it is implied that all CO_2 emissions from a vehicle occurring within the reporting period are counted, whether or not the train, ship, lorry or other is loaded with goods. It is also implied that the CO_2 efficiency will be dependent on the load factor, i.e. the amount of cargo that is actually carried when loaded.

MEPC - the marine environmental protection committee of IMO are currently debating a number of measures for how to measure and reduce the GHG emissions from shipping. These measures have been discussed in detail in previous deliverables of B1. The main ones discussed are:

- A mandatory design index called EEDI which gives specifies the maximum allowed emissions for all new vessels to be built
- An operational indicator called EEOI to measure the real operational performance of all cargo transporting vessels
- A ship energy efficiency management plan called SEEMP which shall be used as a common working tool to make ships more energy efficient.
- A fuel levy or an emission trading scheme which both will make using fuel more expensive since this cost will come on top of today's bunker price.

All of these ones have been seen and more or les debated separately both by IMO and by the shipping community in general. However based on the knowledge gained in B1 the recommendation is to stop seeing measures individually and instead combine them. The approach and methodology for doing this is presented in chapter 3.

2. IMO 2009 GHG study and it's 2050 scenarios, versus the 450 ppm target.

In the report Greenhouse Gas Emissions from Ships (Buhaug et al 2009)[iii], prepared for IMO by an international consortium lead by MARINTEK, the total consumption of bunker oil (HFO, MDO, LNG) by seagoing vessels in 2007 was calculated to be 333 million ton which gave a total CO_2 emissions of 1 Billion ton (excluding navy & other military activities). For 2020 and 2050 emission scenarios was calculated based on the growth figures from main IPCC scenarios as shown in table 1 below. The GDP line contains the annual GDP growth for each scenario. The next line contains the assumed annual growth in sea transport for each of the scenarios. The two last lines contain a high growth scenario were sea transport increases more than the growth in GDP and a low where it increases much less.

Table 1: Cargo and ship matrix

		A1B	A1F	A1T	A2	B1	B2
GDP (1)		3.9 %	4.0%	3.6 %	2.4 %	3.3 %	2.7 %
Total Transport Demand	Base	3.3 %	3.3 %	3.3 %	2.6 %	2.5 %	2.1 %
	High	5.3 %	5.3 %	5.4 %	4.2 %	4.1 %	3.5 %
	Low	1.5 %	1.5 %	1.5 %	1.2 %	1.1 %	0.9 %

This gives 2050 scenarios where the emissions in 2050 varies between 2 and 3 billion tons of CO_2, which is an increase of 100 to 200 % compared to today as shown in figure 1 The upper max line with 7 billion ton of CO_2 in 2050 is what we get if the growth in maritime transport and emissions increase with the same annual percentage up to 2050 as it did from 1990 to 2007. The min line is base on the low growth figures from the table above in combination with a very optimistic forecast for the development of new technology.

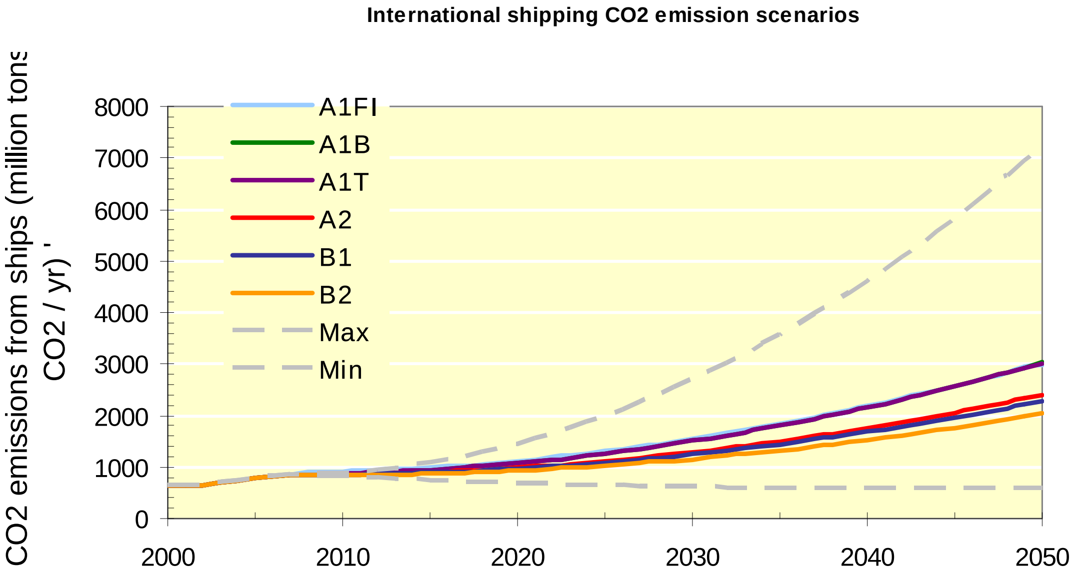

Figure 1: International Shipping CO_2 emission scenarios up until 2050

While the previous figure showed the allocated figures for the whole world fleet, table 2 shows the increase for each vessel type, if we use the average base figure for the six scenarios which is 2,85 %. For the container vessels, the assumption for annual growth is 4,8 % while it's 2,3 % for all other segments up until 2020 and then 1,65 % up to 2050. The main argument for assuming a higher growth regarding container transport is that the container transport has grown with more than 10 % year on year since 1970 while the other shipping segment has grown with less than half of this.

This gives the following key figures for the development from 2007 to 2050:

- Billion ton miles increases from 42 to 129 which is more than a 200 % increase
- The fuel consumption increases from 331 to 1151 million ton, if we have the same fuel efficiency as today. This is an increase of more than 250 %, which is higher than the growth in billion ton miles due to the increased marked share of the container vessels which are less energy efficient than the average of the world fleet.
- The growth in fuel consumption up until 2050 is reduced to approximately 100 % when the effect of new technology and economy of scale through bigger average vessels are taken into consideration (39 % aggregated fuel improvement)
- The container vessels will in 2050 use 55 % of all fuel and do 40 % of billion ton miles. This makes the Container vessel the primary target for though requirement if IMO and the world society agrees on cutting emissions from shipping

Table 2: Billion ton nm, Fuel consumption and gram CO2 per vessel segment

Vessel type	2007 Billion ton miles	2007 Fuel in million ton	Gram CO_2 per ton nm	2050 Billion ton miles	2050 Fuel in million ton	Fuel with aggregate 39 % improve-	Gram CO_2 per ton nm in 2050 if 39% improvements are achieved
General Cargo	2.382	31,7	42	5.145	68	42	26
Dry Bulk	16.137	57,9	11	34.856	125	76	7
Reefer	258	6,9	84	557	15	9	51
Container	7.501	82,3	35	55.807	612	374	21
Crude oil tankers	10.061	30,8	10	21.732	67	41	6
Oil product tankers	1.257	9,9	25	2.715	21	13	15
Chemical tankers	1.919	15,4	25	4.145	33	20	15
RoRo	485	11,6	75	1.048	25	15	46
RoPax	160	21,4	421	346	46	28	257
LNG	852	9,1	34	1.840	20	12	21
LPG	401	4,4	35	866	10	6	21
Ferry	10	1,8	567	22	4	2	346
Cruise	18	8,7	1.523	39	19	11	929
Yacht	0,4	1,3	10.238	1	3	2	6245
Offshore	135	12,1	282	292	26	16	172
Service	86	18,0	659	186	39	24	402
Fishing	43	7,7	564	93	17	10	344
Sea River	16	0,5	98	35	1	1	60
Total	41.721	331,5	25	129.724	1151	702	17,0

The IMO ordered the IMO 2009 GHG study as part of their work regarding climate change and as a preparation to COP 15 in December 2009 in Copenhagen. The core of the climate change debate is to limit the temperature increase to 2 degrees by keeping the CO_2 amount in the atmosphere bellow 450 ppm. If we shall achieve this, all emissions must be reduced as shown in the next figure and it will implify that shipping emissions already in 2050 must be less than half of what they are today. With today's emission of 1 billion ton, this gives a 2050 emission of less than 0,5 billion ton CO_2 corresponding to les than 165 million ton of fuel which is less than 25 % of the 2050 levels in the IMO GHG study.

In absolute terms it means that the gram CO_2 per ton nm which is 25 today, and which will be improved to 17 in 2050 as assumed by the IMO 2009 GHG study, has to be reduced down to 4 gram CO_2 per ton nm. In percentage terms the reduction from 25 to 4 is an 85 % reduction.

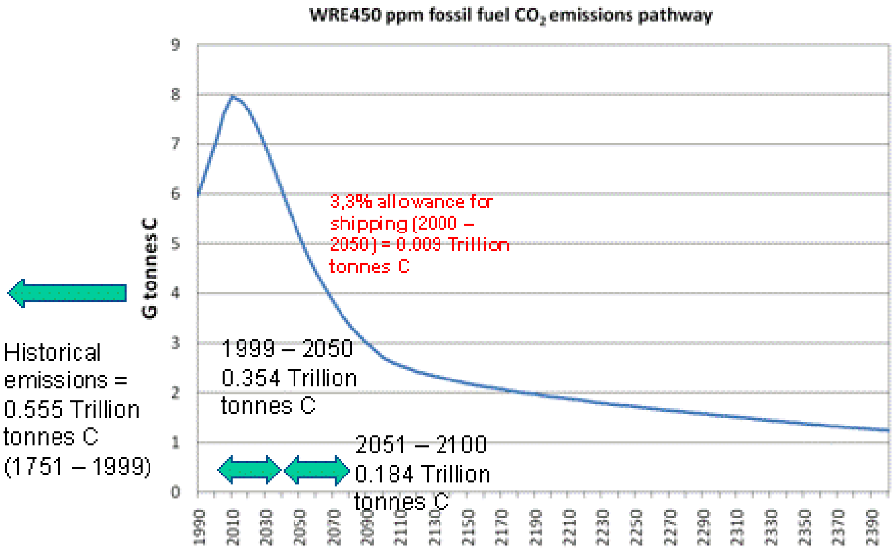

Figure 2:

3. The Developed methodology for energy efficiency improvement

The proposed methodology is to combine the EEDI, EEOI and the SEEMP. The EEDI formula has been presented in previous B1 deliverables, but for readability of this report we repeat it in chapter 3.1. For readers which are familiar with the formula we recommend you to go directly to chapter 3.2.

3.1 The Proposed IMO Energy Efficiency Design Index is as follows:

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} C_{FME_i} SFC_{ME_i} P_{ME_i}\right) + P_{AE} C_{FAE} SFC_{AE} + \left(\sum_{i=1}^{nPTI} P_{PTI_i} - \sum_{i=1}^{nWHR} P_{WHR_i}\right) C_{FAE} SFC_{AE} - \left(\sum_{i=1}^{neff} f_{eff} P_{eff} C_{Feff} SFC_{ME_i}\right)}{f_i \,\text{Capacity}\; V_{\text{ref}}\, f_W}$$

If the shaft generator is provided, the Normal Maximum Sea Load can be calculated using SFC_{ME} instead of SFC_{AE}
Where:

1. C_F is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content. The subscripts $_{MEi}$ and $_{AEi}$ refer to the main and auxiliary engine respectively.
2. V_{ref} is the ship speed, measured in nautical miles per hour (knot), on deep water in the maximum design load condition (Capacity) as defined in paragraph 3 at the output of the engine(s) as defined in paragraph 5 and assuming the weather is calm with no wind and no waves. The maximum design load condition shall be defined by the deepest draught with its associated trim, at which the ship is allowed to operate. This condition is obtained from the stability booklet approved by the Administration.
3. *Capacity* is defined as follows:
   a) For dry cargo carriers, tankers, gas tankers, container ships, ro-ro cargo and passenger ships and general cargo ships, deadweight should be used as *Capacity*.
   b) For passenger ships, gross tonnage in accordance with the International Convention on Tonnage measurement of ships 1969, Annex 1, regulation 3 should be used as *Capacity*.
4. *Deadweight* means the difference in ton between the displacement of a ship in water of relative density of 1.025 at the deepest operational draught and the lightweight of the ship.
5. *P* is the power of the main and auxiliary engines, measured in kW. The subscripts $_{ME}$ and $_{AE}$ refer to main and auxiliary engine, respectively. The summation on *i* is for all engines with the number of main engines (*NME*) and the number of auxiliary engines (*NAE*).
   5.1 $P_{ME(i)}$ is 75% of the rated installed power (MCR) for each main engine (i).
   5.2 $P_{PTI(i)}$ is 75% of the rated power consumption of shaft motors.

5.3 P_{WHR} is the rated electrical power generation of waste heat recovery system at $P_{ME(i)}$.
5.4 P_{eff} is the main engine power reduction due to innovative energy efficient technology.
5.5 P_{AE} is the required auxiliary engine power to supply normal maximum sea load including necessary power for machinery, systems, equipment and living on board in the condition where the ship engaged in voyage at the speed (V_{ref}) under the design loading condition of *Capacity*.

5.5.1 For ships with a main engine power of 10000 kW or above P_{AEi}, is defined as:

$$P_{AE(MCRME>10000KW)} = (0.025 \times \sum_{i=1}^{nME} MCR_{MEi}) + 250$$

5.5.2 For ships with a main engine power below 10000 kW P_{AEi}, is defined as:

$$P_{AE(MCRME<10000KW)} = 0.05 \times \sum_{i=1}^{nME} MCR_{MEi}$$

6. V_{ref}, *Capacity*, and P should be consistent with each other.
7. *SFC* is the designed specific fuel consumption, measured in g/kWh, of the engines at the power output of P determined by paragraph 5. The subscripts $_{MEi}$ and $_{AEi}$ refer to the main and auxiliary engine, including any boilers, respectively. The auxiliary engine Specific Fuel Consumption (SFC_{AE}) is that recorded on the EIAPP Certificate[2] at the engines 50% of P_{AEi} MCR power or torque rating.
8. f_j are corrections to account for ship specific-design elements:

   The f_j coefficient for ice-classed ships is determined by the standard The f_j "table/curve" which is to be contained in the Guidelines.
9. f_w is a non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed (e.g., Beaufort Scale 6), and should be determined as follows:
   a) It can be determined by conducting the ship-specific simulation of its performance at representative sea conditions. The simulation methodology should be prescribed in the Guidelines developed by the Organization and the method and outcome for an individual ship shall be verified by the Administration or an organization recognized by the Administration.

   b) In case that the simulation is not conducted, f_w value should be taken from the "standard f_w" table/curve. A "Standard f_w" table/curve, which is to be contained in the Guidelines, is given by ship type (the same ship as the "baseline" below), and expressed in a function of the parameter of *Capacity* (e.g., DWT). The "Standard f_w" table/curve is to be determined by conservative approach, i.e. based on the data of actual speed reduction of as many existing ships as possible under the representative sea conditions.

   c) f_w should be taken as 1.0 until the Guidelines for the ship-specific simulation (paragraph .1) or f_w table/curve (paragraph .2) becomes available.

10. f_{eff} is the availability factor of any innovative energy efficient technology.

11. f_i is the capacity factor for any technical/regulatory limitation on capacity, and can be assumed one (1.0) if no necessity of the factor is granted.
12. Reduction factors:
    a) f_{eff} is the availability factor of any innovative energy efficient technology;
    b) P_{eff} is the main engine power reduction due to innovative energy efficient technology;
    c) SFC_{eff} is the specific fuel consumption of the main engine at P_{eff}; and
    d) Cf_{eff} is the CO_2 conversion factor of the fuel used in the main engine.

3.2 Methodology for energy efficiency improvement

The developed methodology combines the EEDI, the EEOI and the SEEMP. In basic the concept is to calculate the EEDI for all vessels, not only the newbuilds, and use that as baseline for the EEOI assessment. The role of the SEEMP in this is to be the improvement tool to close GAP's.

The proposed EEDI scheme which currently are being tested out at a voluntarily basis is the result of a process which has been ongoing in IMO for a long time now. The scheme to be tested is characterized by:

- Vessels are grouped into vessel types, and for each of the types, baseline values and thresholds are calculated as a function of vessel size
- Speed is not included in the formula, but since the regression curves are calculated based upon the existing vessel speed for each of the types, the suggested scheme will enable vessels types which sails fast today to do the same in the future
- The suggested scheme has so many correction factors which makes it quite complicated both to understand the rules and to practice them.
- A system treating vessels differently based upon cargo handling technology criteria and not by real performance can easily be seen as a way to created unfair competition in the market.

The general formula for calculating the baseline value is

$$\text{Baseline value} = a * \text{Capacity}-c \quad (\text{capacity} = \text{dwt})$$

where the a and c values for each vessel type is defined by column two and three in table 3 Column three to ten shows baseline value for each vessel type as a function of vessel size and column eleven shows percentage improvement when a vessel increase from 5 to 60 000 dwt.

Table 3: Ship type and calculation of threshold as a function of dwt

Ship type and calculation of threshold as a function of dwt	a	c	1000	5000	15000	30000	60000	120000	240000	Percentage decrease from 5' to 60 000 dwt
Dry bulk carriers	1354	0.5117	39.5	17.3	9.9	6.9	4.9	3.4	2.4	-72 %
Tankers	1951	0.5337	48.9	20.7	11.5	8.0	5.5	3.8	2.6	-73 %
Gas carriers	1253	0.4597	52.3	25.0	15.1	11.0	8.0	5.8	4.2	-68 %
Container ships	139	0.2166	31.2	22.0	17.4	14.9	12.9	11.1	9.5	-42 %
General cargo ships	290	0.3300	29.7	17.5	12.2	9.7	7.7	6.1	4.9	-56 %
Ro-Ro cargo ships	19788	0.7137	143.0	45.3	20.7	12.6	7.7	4.7	2.9	-83 %

When these curves are plotted as graphs where the y-axis is gram CO_2 per ton nm and the x –axis is vessel size the result becomes as shown in figure 3. The shape of the curve looks logical for the dry bulk carriers, the tankers, the gas carriers and the general cargo ships while both the RoRo and the container curves can be questioned marked. This due to the fact that the RoRo curve is much steeper than the other indicating a much bigger fuel efficiency improvement as a function of scale than for any other vessel type, while the container one is so flat that there hardly are any energy efficiency improvement as a function of scale.

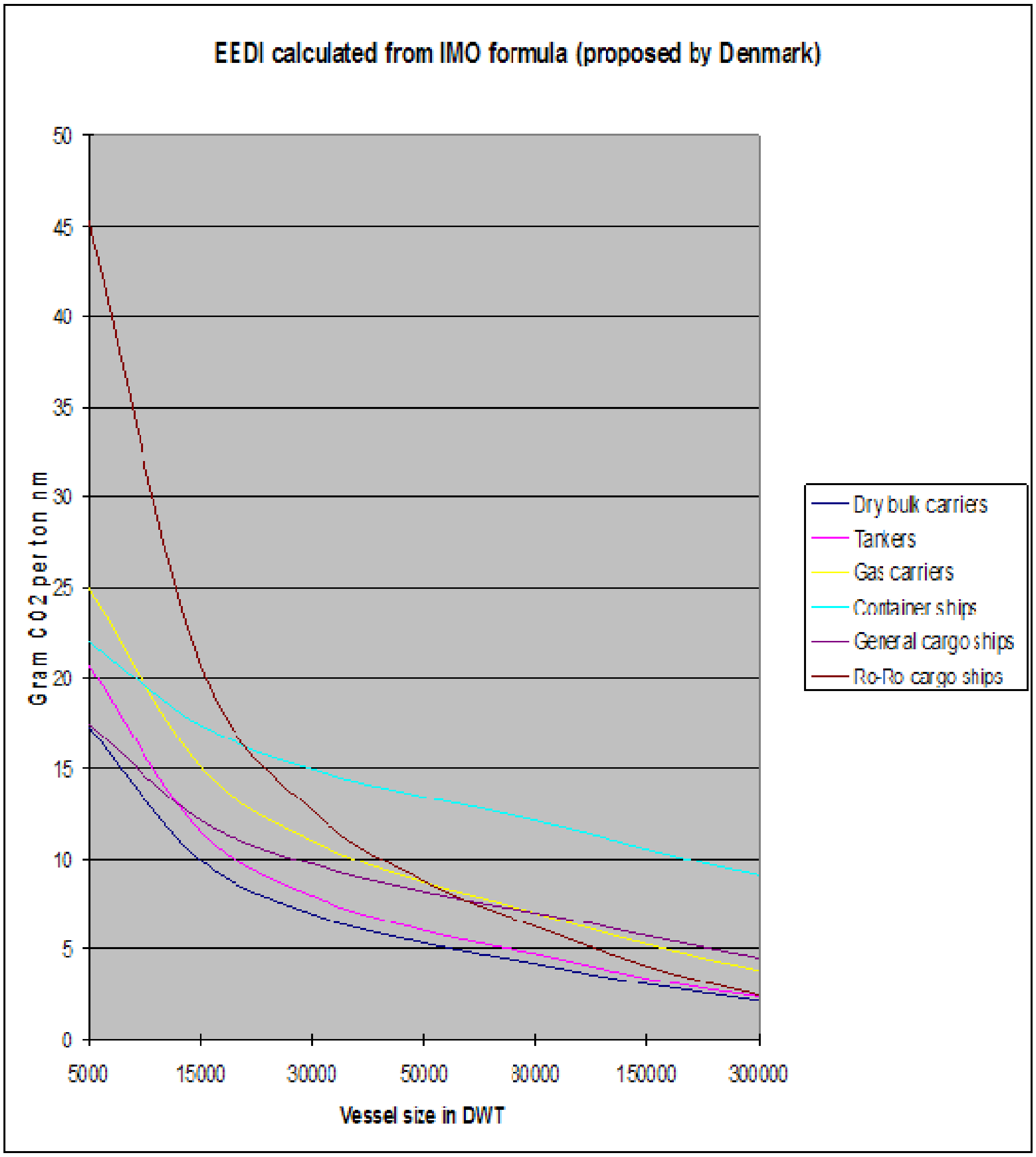

Figure 3: Baseline for Gram CO_2 as a function of vessel type and size

Our conclusion is that these curves show the shortcoming of the proposed EEDI scheme and therefore we will instead propose a formula for calculating the baselines and the thresholds which are vessel type and cargo handling independent. The proposal is described in detail in the next chapter.

3.3 Proposal for an amended EEDI purely based on dwt and speed

The main advantage with the proposed amendment of the EEDI is:

- Vessel types and groups become no issue any more since all vessel types which transport cargo (freight) is treated in the same way
- The formula creates no unfair competition since all vessels are treated independently of cargo handling technology. This means that a RoRo and container vessel with the same dwt and speed will have exactly the same formula to satisfy.
- There is only one baseline to calculate
- Since speed is included in the formula improving energy efficiency becomes a main issue for all vessels to be built independent of if they will be fast, average or slow. This is quite different from the suggested IMO scheme which in practice only set requirements for the faster vessels
- The approach of the formula might also be used for simplifications of all other allowances for auxiliary engines, ice class and so on

The setup for the suggested formula is

Gram CO_2 per ton nm = A * capacity $^{-D}$ * Speed Factor
A = constant = 3000
Capacity = dwt of the vessel
D = constant = 0,59
Speed = service speed of the vessel with MCR = 75 % of max MCR
Average fleet speed for the whole database of all vessels included has been calculated to be 13,2 knots. Number of vessels included are 58769.

$$Speed\ \ Factor = \frac{(\text{Speed} + (\text{Speed - Average fleet speed })^{1,15})}{\text{Average fleet speed}}$$

When vessel speed is equal to or less than 13,2 knots the Speed Factor is simplified to be

$$Speed\ \ Factor = \frac{(\text{Speed })}{\text{Average fleet speed}}$$

The next two tables shows the results when the formula is tested out. Table 4 shows only vessels above 44 000 dwt while table 5 shows the whole fleet. The testing is based upon the Lloyds Fairplay database (fleet values as they were ultimo 2007). The first columns shows the vessel type and size, the second number of vessels in each group, the 3rd one average dwt, the 4th average speed, the 5th engine size, the 6th the calculated EEDI performance, the 7th is the EEDI threshold as suggested by the IMO formula (originally proposed by the Danish). Finally the 8th column gives the values calculated by the suggested formula presented above.

Table 4: EEDI calculation for the world's cargo fleet above 44000 dwt

	No of ships	Dwt	Speed	Engine size [kW]	Gram fuel per kWh	EEDI calculated based upon dwt and 75 % MCR	EEDI threshold as suggested by Danish IMO formula	EEDI calculated with a vessel type independent formula
Crude oil tanker 200++	506	295.237	15	24.829	190	2,4	2,3	2,4
Capesize dry bulk 120'++	782	172.251	14	15.427	190	2,8	2,8	2,9
Crude oil tanker 120-200'	356	151.734	15	17.162	190	3,4	3,4	3,4
Product tanker 75'++	47	112.054	15	14.582	200	4,0	3,9	4,2
Cont 8500 TEU++	206	105.995	25	67.369	190	11,4	11,4	10,4
Crude oil 75-120'	660	103.403	15	12.728	200	3,9	4,1	4,1
Dry Bulk 85'-120'	119	93.752	14	11.969	190	4,0	3,9	4,1
Container 6500 TEU	175	80.084	25	60.277	190	13,4	12,1	12,5
LNG 60'++	229	76.346	20	27.087	210	9,0	7,1	8,4
Panamax dry bulk 60'-85'	1447	72.219	14	9.801	190	4,2	4,4	4,8
Crude oil tanker 50'-75'	198	66.261	15	10.571	200	5,2	5,2	5,2
Container 4000 TEU	1068	55.297	23	37.208	190	12,9	13,1	13,6
LPG 45'++	118	53.262	17	13.401	210	7,5	8,4	7,6
Product tanker 25' - 75'	630	51.120	15	9.532	200	6,0	6,0	6,2
Chemical tanker 40'- ++	533	47.614	15	9.361	210	6,6	6,2	6,5
Handymax dry bulk 35'-60'	1937	46.069	14	8.214	190	5,5	5,6	6,3
RoRo 35'-++	20	44.603	18	20.226	190	11,1	9,5	10,3

The conclusion which can be made is that the suggested vessel type independent formula gives good results when tested against the real vessel values. In the table at the next page also the smaller vessels has been included.

Table 5: EEDI calculations for the world's cargo fleet

	No of ships	Dwt	Speed	Engine size [kW]	Gram fuel per kWh	EEDI calculated based upon dwt and 75 % MCR	EEDI threshold as suggested by Danish IMO formula	EEDI calculated with vessel type independent formula
Crude oil tanker 200++	506	295.237	15	24.829	190	2,4	2,3	2,4
Capesize dry bulk 120'++	782	172.251	14	15.427	190	2,8	2,8	2,9
Crude oil tanker 120-200'	356	151.734	15	17.162	190	3,4	3,4	3,4
Product tanker 75'++	47	112.054	15	14.582	200	4,0	3,9	4,2
Cont 8500 TEU++	206	105.995	25	67.369	190	11,4	11,4	10,4
Crude oil 75-120'	660	103.403	15	12.728	200	3,9	4,1	4,1
Dry Bulk 85'-120'	119	93.752	14	11.969	190	4,0	3,9	4,1
Container 6500 TEU	175	80.084	25	60.277	190	13,4	12,1	12,5
LNG 60'++	229	76.346	20	27.087	210	9,0	7,1	8,4
Panamax dry bulk 60'-85'	1447	72.219	14	9.801	190	4,2	4,4	4,8
Crude oil tanker 50'-75'	198	66.261	15	10.571	200	5,2	5,2	5,2
Container 4000 TEU	1068	55.297	23	37.208	190	12,9	13,1	13,6
LPG 45'++	118	53.262	17	13.401	210	7,5	8,4	7,6
Product tanker 25' - 75'	630	51.120	15	9.532	200	6,0	6,0	6,2
Chemical tanker 40'- ++	533	47.614	15	9.361	210	6,6	6,2	6,5
Handymax dry bulk 35'-60'	1937	46.069	14	8.214	190	5,5	5,6	6,3
RoRo 35'-++	20	44.603	18	20.226	190	11,1	9,5	10,3
LNG 30'-60'	18	44.574	18	15.969	275	13,0	9,1	9,8
Crude oil tanker 15'-50'	212	38.631	14	7.707	210	6,8	7,0	7,0
Chemical 25'-40'	469	34.686	15	8.930	210	8,6	7,4	8,0
LPG 25'-45'	68	33.570	17	11.298	200	9,6	10,4	9,9
Container 2300 TEU	789	33.243	21	20.000	190	12,9	14,6	15,2
RoRo 25'-35'	49	28.403	19	16.492	190	13,4	13,1	14,7
Handysize 15'-35'	1920	26.071	14	6.656	190	8,0	7,4	8,7
General Cargo 15'++	1215	25.341	15	8.080	190	9,3	10,2	10,3
LNG 15'-30'	8	24.386	18	12.536	275	19,1	12,1	13,4
Container 1400 TEU	832	20.512	19	12.662	190	14,6	16,2	17,2
LPG 15'-25'	60	19.264	16	8.657	210	13,8	13,4	13,1
Chemical 15'-25'	370	18.987	14	6.409	210	11,6	10,2	10,8
RoRo 15'-25'	360	18.565	19	13.854	190	17,3	17,8	18,9
Product tanker 15' - 25'	107	18.418	14	5.616	200	10,2	10,3	10,4
Reefer 15'++	22	16.075	21	14.972	200	20,8	11,9	24,0
General Cargo 10' -15'	710	12.434	15	5.666	190	13,6	12,9	14,9
Products 10' - 15'	98	12.318	13	3.847	200	11,5	12,8	11,2
Reefer 10'-15'	203	11.691	20	11.037	210	22,9	13,2	27,2
Container 700 TEU	1161	10.022	17	6.794	210	19,8	18,9	21,4
RoRo 5'-15'	678	9.844	18	9.735	210	27,7	28,0	23,4
Coastal Dry Bulk 5-15'	464	9.318	13	3.565	210	14,4	12,6	13,7
Chemical tanker 5'-15'	1028	9.161	13	3.695	210	14,9	15,0	14,2
LNG 0'-15'	10	8.609	16	5.798	275	27,9	19,4	20,1
LPG 5'-15'	205	7.985	15	4.857	210	20,0	20,1	19,5
Reefer 5'-10'	372	7.155	18	6.387	230	27,3	15,5	28,3
General Cargo 5' -10'	2654	6.957	13	3.280	210	17,4	15,7	16,7
Product tanker 5' - 10'	471	6.540	12	2.742	210	16,7	17,9	15,9
Crude oil tanker 0-15'	121	3.638	12	1.926	210	21,7	24,5	21,8
Container 200 TEU	167	3.080	13	2.319	230	30,7	24,5	26,6
General Cargo 1'-5'	7806	2.545	12	1.328	230	24,3	21,8	25,9
LPG 0'-5'	652	2.116	13	1.825	230	37,4	37,1	31,1
Chemical tanker 0-5'	1468	1.984	12	1.278	230	29,7	33,9	30,3
Reefer 0- 5'	629	1.952	13	1.901	230	39,9	23,8	34,6
Products 0 - 5'	3553	1.712	11	1.118	230	32,2	36,7	30,9
Small Dry Bulk 0-5'	854	1.585	11	1.071	230	33,5	31,2	32,2
RoRo 0'-5'	1303	1.292	12	2.502	230	84,3	119,1	41,4

Figure 5 shows the baseline requirement in gram CO_2 per ton nm given as a function of vessel size. The y-axis shows the gram CO_2 per ton nm and the x-axis shows vessel size. The curves plotted are for the speed's 14, 20 and 25 knots and in addition a curve showing the emissions we will get if a hull designed for 14 knot is powered to make 25 knots. As we can see the proposed formula gives a requirement so that a 25 knot hull has to have 50 % less resistance and fuel consumption than a 14 knot hull shape.

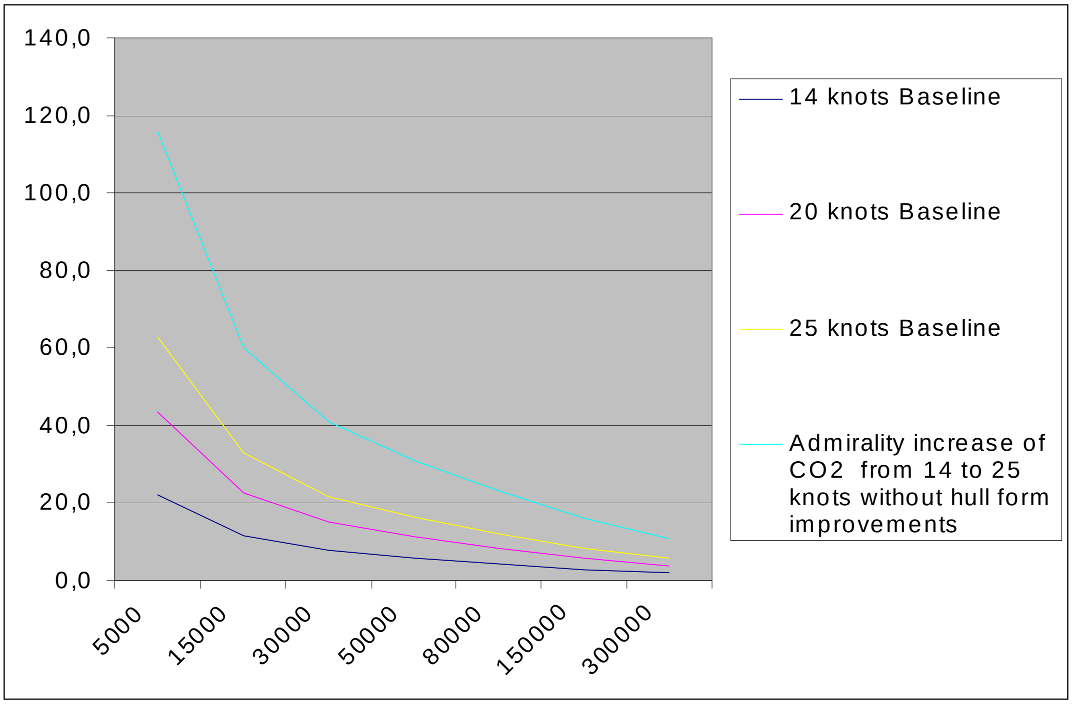

Figure 5: Baseline CO2 per ton nm given as a function of vessel size

Our conclusion is that we recommend the suggested amendment of EEDI by treating all cargo vessels types equally and only focus on gram CO2 as a function of the vessel size and its speed. The main argument in favour of the proposal is that it:

- Create no unfair competition between vessel types since it treat's all vessel types equally.
- It's simple and easy since it's only one formula
- It requires that all new vessels to be build has to be more energy efficient since it set a speed related requirement while the proposed IMO formula in most cases only will give an effect for vessel with an average speed above the average for the vessel group.

3.4 The EEOI and carbon footprint certificates to cargo owners

The conceptual idea behind the introduction of the Energy Efficiency Operational Indicator – EEOI was to introduce a common tool to evaluate the performance of ships, or fleets, with regards to CO_2 emissions. It directly relates the ratio of mass of CO_2 discharged by the ship to the transport work the ship does, by comparing data from the fuel use and the units of cargo carried by a ship. It was hoped that its development would help in providing a CO_2 emissions baseline for the industry, which could be used in conjunction with controls, regulations and other methods to reduce CO_2 emissions from shipping. After much discussion at IMO, the MEPC, at its fifty-third session (July 2005), approved the Interim Guidelines for Voluntary Ship CO_2 Emission Indexing for Use in Trials. Since then these discussions has continued in IMO and the only progress made, is that MEPC 59 agreed to issue slightly amended guidelines for further voluntarily testing.

It's hardly any surprise that voluntarily testing was the only thing which was agreeable in 2005, but it's certainly a disappointment that no real achievements were made at MEPC 59. In 2005 the world and the transport sector were still in a growth period which started in the late 1980'es and cumulated in 2007. During this period the world trade growth was higher than in any other period during the last 200 years, and the volumes transported by sea going vessels was nearly been doubled. The main focus of business was on minimising both cost and resource consumption through establishing lean production processes, while low energy prices generated few incentives to optimise logistics and transport operation in terms of energy efficiency. When the European leaders meet in March 2007 things had changed a lot compared to this, due to higher energy cost and increased environmental concern caused by global warming. What they agreed on the meeting, gives strong implications for transport and logistics, since they agreed that both energy consumptions and emissions must be significantly reduced up until 2020. They also redefined the responsibility for a manufacturer to include all energy usage and emissions along the whole supply chain, compared to the old view that each actor is responsible for its own actions. This new approach is illustrated in figure 6.

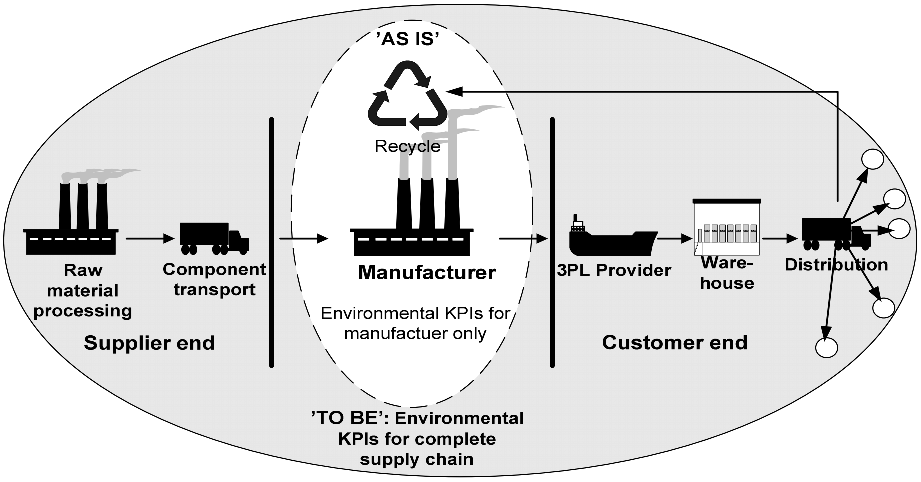

Figure 6: Environmental KPI's for the complete supply chain

At the same time leading manufactures like Procter & Gamble and the biggest supermarket chains of the world which are Wall-Mart, Carrefour and Tosco all have stated clear targets for the need to reduce energy consumption and emissions. A key target for all of them is that the carbon footprint (CO_2) which reflects all energy used to produce the product from the stage of sourcing the raw materials to distribution of the finished goods shall be printed on the product as information to the customers. This will then enable both environmentally concerned customers to choose those products which gives lowest impact and the major super market chains to set clear targets for reductions to be achieved by their producers.

3.5 Approach for efficiency indicator development

To develop efficiency indicators it is necessary to develop three main elements

- **Data collection -** automated system for necessary parameters (including routines for calibration, and maintenance of sensors and adjustments of settings to correct fuel grades etc if necessary
- **Data analysis** – methodology and tools for extracting and analysing the data. Key challenges –definition of parameters, filtering, data validation, selection of comparable sets
- **Data presentation** giving an output that is easily accessible and understandable.

Several types of registrations and presentations are needed to provide documentation of good operational performance and to demonstrate benefits of technical modifications and improvements. E.g.:

- Selection of ship speed
- Utilisation of cargo capacity
- Utilisation of energy along sea-legs
- Energy efficient navigation relative currents and weather
- Maintenance and tuning of hull, propeller and machinery to the best efficiency
- Modifications of hull, propeller and machinery to the best efficiency
- Accumulation of CO2 emissions relative transport work

Working with improvements of the ships efficiency it is important to have several perspectives at the same time, i.e. both a holistic view of the ships efficiency and the “divide and rule” approach to find the areas with best improvement potential. These improvement areas should be managed in the SEEMP.

But first we will suggest a practical approach for accumulation of CO2 emissions relative transport work. This is not a settled “standard”, but a way to further explore and investigate how ship management of today can start approaching use of efficiency indicators and SEEMP. To do this it is practical for a ship manager to select a couple of ships as pilots in exploration and enhancement of the use of the EEDI, EEOI and SEEMP.

First it is important to calculate the baseline indicator, the EEDI for the ship. The case/ example ship we have selected is a ship with a deadweight of 40 000 tons with a main engine with maximum continuous rating (MCR) of 10 000 kW. The SFOC for the main engine is 170 g/kWh and the SFOC for the auxiliary engines is 180 g/kWh. The conversion factor between CO2 and fuel is selected to be 3.14 even if it can range in the area 3.1 – 3.2, 3.14 (pi) is easy to remember.

The expression in chapter 3.1 with input as stated below give an EEDI, energy efficiency design index:

$$\text{EEDI} = 6.7\ [\text{g CO2} / (\text{tdw x n.m})]$$

As ships are not filled up with cargo all the time it is reasonable to have EEOI results higher than the EEDI for the ship. We will in the following show an example where EEOI are calculated based on sets of selected registrations. But first we will emphasize some common "shortcomings" in registrations and presentation of emission data from ships today.

- Heat value is not included in efficiency assessments, it should be
- Source of conversion factors are not given/validated

New records of registrations should be stored for each switch in cargo or switch in use of fuel. Such record and accumulation of same are given below. The 3 month accumulation is calculated to have a period sensitive to changes in cargo amounts, speed etc. but that is not so short that ballast legs included dominate the results. The 1 year accumulation is calculated as this figure is useful towards annual reports, budgets and prognosis for years to come.

Table 6: Registrations….

	REGISTRATIONS - ENVIRONMENT - Port to Port			**3 MONTHS**	**1 YEAR**	**VOYAGE 1**	**VOYAGE 2**
Notes		**VOYAGE DATA**	**Unit**	**Data**	**Data**	**Data**	**Data**
		Ship	[Text]	**Ship A**	**Ship A**	Ship A	Ship A
		IMO number	[7-digits]	**1234567**	**1234567**	1234567	1234567
		From Date	yyyy-mm-dd	**2009-12-24**	**2009-12-24**	2009-12-24	2010-01-06
		To Date	yyyy-mm-dd	**2010-01-21**	**2010-01-21**	2009-12-31	2010-01-21
		Fm Port (Name)	[Text]	**N/A**	**N/A**	Yanbu	Rotterdam
		- Latitude	[Pos N/S]	**N/A**	**N/A**	27º 04' 35.09" N	51º 55' 20.91" N
		- Longitude	[Pos E/W]	**N/A**	**N/A**	49º 41' 44.40" E	4º 28' 13.02" E
		To Port (Name)	[Text]	**N/A**	**N/A**	Rotterdam	Houston
		- Latitude	[Pos N/S]	**N/A**	**N/A**	51º 55' 20.91" N	29º 41' 16.08" N
		- Longitude	[Pos E/W]	**N/A**	**N/A**	4º 28' 13.02" E	94º 59' 03.79" V
		Cargo moved	tons	**N/A**	**N/A**	40 000	30 000
		Ballast moved	tons	**N/A**	**N/A**	0	0
1		Distance	n.m.	**8 896**	**8 896**	3 844	5 052
	MDO cons.	ME	tons	**3**	**3**	1	2
	"	AE	tons	**2**	**2**	1	1
	"	Boiler	tons	**3**	**3**	1	2
	"	IGG	tons	**2**	**2**	1	1
	MGO cons.	ME	tons	**1**	**1**	1	0
	"	AE	tons	**1**	**1**	1	0
	"	Boiler	tons	**1**	**0**	1	0
	"	IGG	tons	**1**	**1**	1	0
2	Heat value - mean	HFO	kJ/kg	**40 620**	**40 620**	40 232	41 125
2	"	MDO	kJ/kg	**42 155**	**42 155**	42 155	42 155
2	"	MGO	kJ/kg	**42 800**	**42 800**	42 800	42 800
	LSHFO cons. - mean	ME	tons	**250**	**250**	150	100
	"	AE	tons	**22**	**22**	10	12
	"	Boiler	tons	**23**	**23**	8	15
	"	IGG	tons	**9**	**9**	4	5
	HSHFO cons. - mean	ME	tons	**1 075**	**1 075**	450	625
	"	AE	tons	**60**	**60**	20	40
	"	Boiler	tons	**85**	**85**	30	55
	"	IGG	tons	**40**	**40**	15	25
3	Sulhur percentage	LSHFO	%	**2**	**2**	1.15	1.3
3	"	HSHFO	%	**2.76**	**2.76**	2.20	3.50
3	"	MDO	%	**0.15**	**0.09**	0.15	0.15
3	"	MGO	%	**0.00**	**0.00**	0.00	0.00
	OTHER	Bilge - Disch. to sea	m^3	**0**	**0**	0	0
		Grey W.	m^3	**130**	**130**	50	80
		Black W.	m^3	**100**	**100**	40	60
		Garbage	m^3	**0**	**0**	0	0
		Food	kg	**256**	**256**	100	156
		VOC - Disch. to air	tons	**0**	**0**	0	0
		Plastic - Burned	m^3	**0**	**0**	0	0
		Paper - Burned	m^3	**0**	**0**	0	0
		Plastic - Del. to shore	m^3	**2**	**2**	0	2
		Food - Del. to shore	kg	**0**	**0**	0	0
		Other - Del. to shore	kg	**0**	**0**	0	0
		HFC - Fire & Cool used	kg	**150**	**150**	150	0
		Chemicals alltogether	litres	**600**	**600**	470	130

An extract of results on table format are given below.

Table 7: EEDI calculations for the world's cargo fleet

ENVIRONMENTAL REPORT		3 MONTHS	1 YEAR	VOYAGE X	VOYAGE X-1
VOYAGE DATA	Unit	**Data**	**Data**	Data	Data
Ship	[Text]	**Ship A**	**Ship A**	Ship A	Ship A
IMO number	[7-digits]	**1234567**	**1234567**	1234567	1234567
From Date	yyyy-mm-dd	**2009-10-24**	**2008-12-24**	2010-01-06	2009-12-24
To Date	yyyy-mm-dd	**2010-01-21**	**2010-01-21**	2010-01-21	2009-12-31
Transport work	tons x n.m.	**915 960 000**	**3 358 520 000**	151 560 000	153 760 000
Fuel cons. HFO	tons	**11 340**	**41 580**	745	515
Fuel cons. MDO	tons	**90**	**330**	6	4
Fuel cons. MGO	tons	**36**	**132**	0	4
fuel energy / tr. work	J/(tons x n.m.)	**170.2**	**156.0**	203.8	137.0
fuel mass / tr. work	g/(tons x n.m.)	**4.173**	**3.925**	4.955	3.401
CO2	g/(tons x n.m.)	**13.269**	**12.481**	7.559	4.859
CO	g/(tons x n.m.)	**0.017**	**0.016**	0.020	0.014
NOx	g/(tons x n.m.)	**0.209**	**0.192**	0.247	0.172
SO2	g/(tons x n.m.)	**0.245**	**0.225**	0.344	0.147
P.M.	g/(tons x n.m.)	**0.017**	**0.016**	0.020	0.014
THC	g/(tons x n.m.)	**N/A**	**N/A**	N/A	N/A
Bilge - Disch. to sea	m3	**0**	**0**	0	0
Grey W.	m3	**360**	**477**	80	50
Black W.	m3	**300**	**367**	60	40
Garbage	m3	**0**	**0**	0	0
Food	kg	**796**	**939**	156	100
VOC - Disch. to air	tons	**0**	**0**	0	0
Plastic - Burned	m3	**0**	**0**	0	0
Paper - Burned	m3	**0**	**0**	0	0
Plastic - Del. to shore	m3	**2**	**7**	2	0
Food - Del. to shore	kg	**0**	**0**	0	0
Other - Del. to shore	kg	**0**	**0**	0	0
HFC - Fire & Cool used	kg	**225**	**550**	0	150
Chemicals alltogether	litres	**935**	**2 200**	130	470

Results of special interest can also be presented on charts like the CO2 emissions below where the mean EEOI is 14.85 g/(tdw x n.m.)for the ship where the EEDI = 6.7 g/(tdw x n.m.).

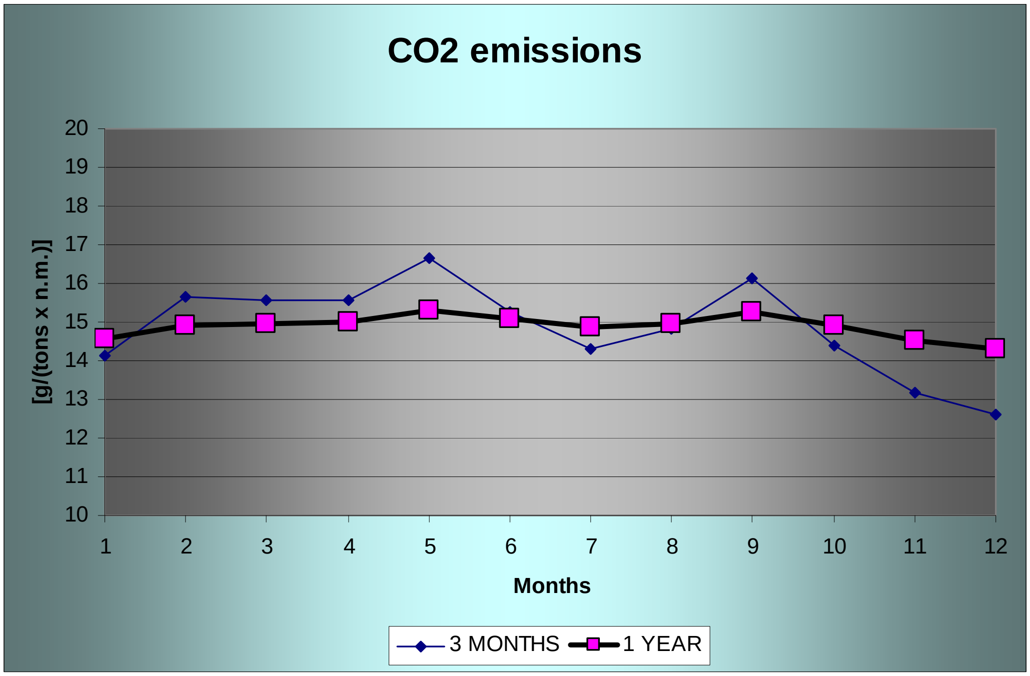

Figure 7: XYZ

3.6 SEEMP, Ship Energy Efficiency Management Plan

The Ship Energy Efficiency Management plan provides a possible mechanism for monitoring ship and fleet efficiency performance over time and some options to be considered when seeking to optimize the performance of the ship. The efficiency options given within the plan are divided into operational efficiencies and technical upgrades. A wide range of efficiency options are provided but the list is not exhaustive list and items can be added to as new efficiency options are realized.

4. Utilising the methodology to improve the energy efficiency

Figure 8 illustrates how EEOI targets can be defined as the result of different EEDIs for a ship of approximately 46,000 tdw. The different EEDIs are calculated on basis of:

- EEDI from sea trial data or a prolongation of these in sea trial documentation
- EEDI baseline defined by the MARINTEK formula
- EEDI 10% better than the baseline – i.e. for a green ship or shipping company

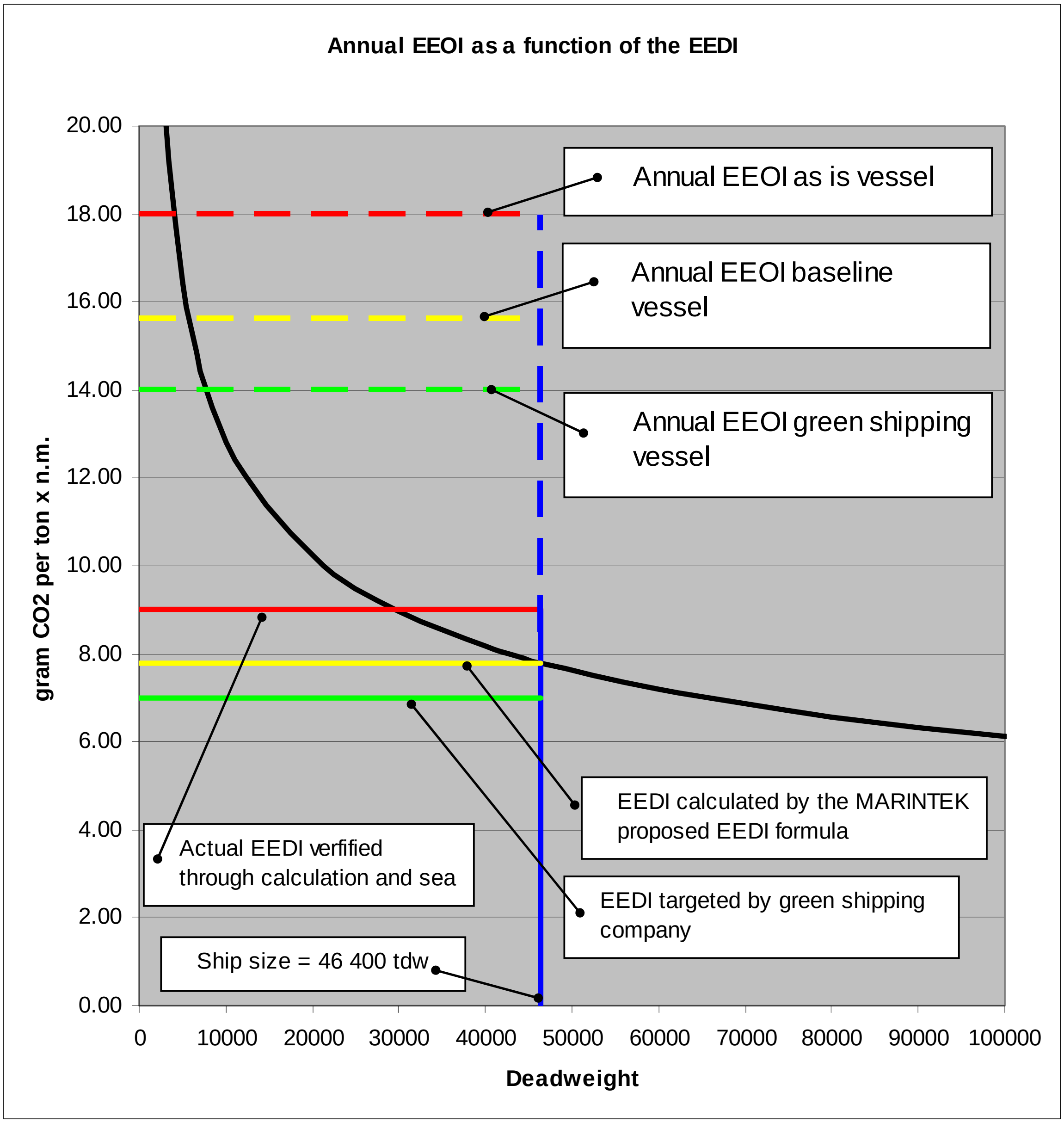

Figure 8: Annual EEOI as a function of EEDI

The EEOI targets defined in Figure 8 are 2 times the EEDI values. This means that the EEOI targets are obtainable for ships that utilise their cargo capacity approximately half of its sailing time when operating at a fixed speed, like some oil tankers do. However, there are some issues influencing this estimate:

- Ships usually burns less fuel on ballast legs than on cargo legs
- Ships operating at a fixed speed burns more fuel when they get older
- Ships use energy while they are not moving and for cargo operations
- Ships can easily improve their EEOI by reducing their speed

Altogether these pros and cons are effects that are important to be aware of, but they need no special treatment in EEOI calculations if community wish a fair and straight forward way to benchmark and follow-up ships performances. I.e. energy use and transport work could be followed, benchmarked and utilised for significant improvement using the EEDI, EEOI and SEEMP. But to obtain this for the world oceangoing fleet of ships for different segments they have to undergo the same calculations/ classifications with respect to EEDI and EEOI. If we fail to treat ships of different segments equally calculation wise we can be pretty sure that we do not get a baseline norm. However, if a serious baseline norm are achieved we have to accept that some cargo trades occupies cargo areas more than others, and other operate with higher speed than others – this should be reflected in the EEDI and EEOI results, and NOT equalised (hided) by some special treatment for some ships or ship types.

5. References

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