Report for Project 6543

"Study on tests and trials of the Energy Efficiency Design Index as developed by the IMO"

Applicability and Refinement of the EEDI for RoRo, RoPax Vessels and Specialized Ships

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This study is the result of DELTAMARIN's work for EMSA.
It does not reflect the views or official positions of EMSA or the European Commission.

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List of definitions, abbreviations and symbols

-“RoRo cargo ship (vehicle carrier)” means a ship with multi deck ro-ro cargo ship designed for the carriage of empty cars and trucks.

-“RoRo cargo ship (volume carrier)” means a ship with a deadweight per lane-meter less than 4tons/m, designed for the carriage of cargo transportation units.

-“RoRo cargo ship (weight carrier)” means a ship with a deadweight per lane-meter of 4tons/m or above, designed for the carriage of cargo transportation units.

-“RoRo passenger ship” means a passenger ship with ro-ro spaces or special category spaces.

-“RoPax vessel” means a RoRo passenger ship.

-“RoRo cargo vessel” means all RoRo cargo ships excluding vehicle carriers.

AHTS	Anchor Handling / Tug / Supply, offshore vessel category
EEDI	Energy Efficiency Design Index
GHG	Green House Gas
HSC	High Speed Craft
IHSF	IHS Fairplay, the source database for ship information agreed to be used in EEDI definitions (register 10.01 (Shippax 3.3.57))
IMO	International Maritime Organization
PCTC	Pure Car / Truck Carrier
SFOC	Specific Fuel Oil Consumption (of an engine, g/kWh)

DWT	Deadweight
GT	Gross tonnage
L_{BP}	Length between perpendiculars
LM	Lane meters
P_{AE}	Auxiliary engine power
PAX	Passenger number
P_{ME}	Main engine power
v	Speed of the vessel

1. Introduction

1.1. Background

A CO2 design index has been in development within the IMO. The index is currently commonly known as the Energy Efficiency Design Index (EEDI). Once approved, it will in theory reduce CO2-emissions from new ships in the future. If the EEDI will be approved in the next MEPC meeting (62), it will first apply to conventional vessels. After the initial phase of two years, the index will be expanded to also include RoRo and RoPax vessels.

The main goal of the EEDI is to reduce global CO2 emissions, however, without distorting competition or restricting trade or growth among other things. By expanding the EEDI to include short-sea shipping vessels, especially European RoRo and RoPax vessels, there is a great risk of affecting the main design parameters of these vessel types in such a way that future designs will be extremely difficult, if not impossible to complete. These difficulties are caused by special vessel characteristics such as high service speeds as well as installed reserve power that are required by short-sea shipping vessels.

This study will further investigate whether any modifications or adjustments could be defined for the EEDI methodology, so that RoRo and RoPax vessels could be included within the EEDI scope.

1.2. Basis of the work

Deltamarin has been tasked by the European Maritime Safety Agency (EMSA) to conduct a study and organize a workshop on the developments and impacts of the Energy Efficiency Design Index (EEDI) for RoRo and RoPax vessels. The purpose of the study is to evaluate the current state of EEDI for these ship types and from a technical and design point of view make recommendations on possible improvements to the EEDI methodology and the measuring of energy efficiency.

The contract awarded by EMSA covers the following tasks:

Task 1: Refinement of the EEDI formula for RoRo and RoPax ships

- Identify possible correction factors to be included in the EEDI formula
- Assess the current baseline approach and the various IMO submissions made at MEPC
- Refine or adjust the EEDI baselines
- If required, assess and develop methodology for an alternative approach and evaluate its emission reduction potential
- Test and analyze the suitability of the proposed approach forward

Task 2: Develop methodology to address the energy efficiency of purpose build vessels

- Identify possible ship categories not currently in the scope of EEDI
- Identify correction factors and baselines on the basis of representative ship samples to include particular ship categories in the current EEDI approach
- Develop an alternative method to improve energy efficiency at the design phase for purpose built vessels

In addition to the two tasks, a workshop was to be held for parties representing the entire European maritime segment. This workshop on the EEDI for RoRo and RoPax vessels was held on April 19-20, 2011. The main focus of the workshop was to present Deltamarin's findings and proposals to the participants and to have open discussions around them.

1.3. Source data

Data to be used for the ships in this study is mainly based on the IHS Fairplay database and various IMO submissions. In addition to the IHSF ship database, source data will also include comparisons with Deltamarin's own AVEC ship database as well as detailed data on a few individual ships that have been designed in-house. Due to confidentiality issues, in-house data has not been shown in this report.

2. RoRo and RoPax ship types and the speed-power relationship

2.1. RoRo ship types

RoRo vehicle carriers

The RoRo vehicle carriers are simple ships designed mainly for transportation of cars and trucks. These ships include pure car carriers (PCC's) and their close relatives, the pure car / truck carriers (PCTC's). Vehicle carriers usually have box-shaped superstructure fully enclosing and covering the cargo area. In addition, the vessels typically have a stern and a side ramp for loading and unloading of thousands of vehicles during port calls.

The purpose of the RoRo vehicle carriers is mainly transporting cars and trucks from factories to suppliers near consumers. Typical routes include Japan - USA (three week travel time) or Europe - USA (two week travel time), thus the vehicle carriers are typical ocean going vessels operating long times at the design speed. A typical RoRo vehicle carrier is presented in Figure 1 and typical itineraries in Table 1. Durations and routes are based on Höegh Autoliner timetables. A route between Baltimore (USA) and Le Havre (France) is a typical North America – Europe connection and the leg across the Pacific is e.g. from Tokyo to New York via Panama Channel.

Figure 1 - Höegh Autoliners PCTC

Table 1 – Example itinerary for a RoRo Vehicle Carrier

Route	*Time*	*Average speed*	*Distance*
N. America – Europe	11 days	13 knots	3500 nm
Japan - N. America	25 days	16 knots	9500 nm

RoRo weight carriers

RoRo weight carriers are designed for carriage of cargo transportation units, with deadweight per lane meter equal to or higher than 4 tons. The design criteria for these ships are very diverse, varying from typical European-built RoRo weight carriers that are designed for transportation of paper products or rolling heavy cargo to special, combined container - RoRo cargo vessels.

Typically the RoRo weight carriers are dimensioned by available cargo volumes, examples being the paper product carriers serving one or two factories and transporting the products to markets. When these ships operate as part of a logistics chain, schedules are usually very tight. For some of the ships the design speed of the vessel is determined by the sailing schedule on a certain route, a typical example being a 7 day roundtrip between Finland and UK.

However, in order to be competitive some of the RoRo weight carriers are highly flexible and are therefore designed to be able to carry highly varying cargo from passenger cars to very heavy special vehicles. As the ships design criteria, schedules and operation areas vary very much, there is a large scatter of design speeds and installed engine powers within the same size groups. Since many weight carriers are typically North-European ships, the vessels also have an ice-class that further affect the power requirements and deadweight of the ship.

A typical RoRo weight carrier is presented in Figure 2.

Figure 2 - M/S Norstream

Route information for M/S Norstream is presented in Table 2. The ship is in regular traffic between Middleborough (UK) and Zeebrugge (Belgium) with overnight schedules. The vessel loads in the evening, then travels through the night and unloads in the morning. This “overnight-operation” is typical to all RoRo traffic, as it makes the “next-day delivery” possible inside European markets.

Table 2 – Example itinerary for a RoRo Weight Carrier

Departure (Middlesbrough)	9 p.m.
Departure (Zeebrugge)	8.30 p.m.
Time	15 ½ hours
Average speed	17 knots
Distance between ports	270 nm

RoRo volume carriers

RoRo volume carriers are mainly built for transportation of trucks and trailers. The deadweight per lane meter is less than 4t/m. The design speed of the vessels is mainly determined from sailing schedule for which the ship is designed to, typical examples in Europe being short UK to the Continent lines that are designed to be integral parts of the highway network. The typical cargo on these ships includes e.g. trucks, containers on trailers, light vehicles etc. The cargo is typically more valuable than on RoRo weight carriers and thus the customers are willing to pay more for faster transportation. Schedules are tight due to the fast transport times and minimized harbor times. Ice-class is also common on these ships as many of them operate in e.g. the Baltic Sea.

One example of a RoRo volume carrier, the M/S Finnpulp, is presented in Figure 3. A typical itinerary for this RoRo volume carrier is for example the route between Kotka, Finland and Bilbao, Spain. Route information is presented in

Table 3.

Figure 3 - M/S Finnpulp

Table 3 – Example itinerary for a RoRo Volume Carrier

Departure (Kotka)	Tue 10 p.m.
Arrive (Bilbao)	Mon 2 p.m.
Time	136 hours
Average speed	16 knots
Distance between ports	2200 nm

RoPax vessels

RoPax ships include all vessels with a car deck that are carrying over 12 passengers. The ships are specially designed for certain routes and schedules, thus having highly varying main dimensions and engine configurations. These vessels are designed to complete the transport task in the given schedule in all weather conditions around the year as well as catch possible delays. Some of the RoPax vessels are so called "night ferries" (i.e. "cruise ferries") - travelling overnight, and some "day ferries", doing only day trips and staying at port overnight. Due to the high diversity of the ships it is very difficult to compare them directly against each other as no common design criteria exists.

The night ferries have typically a large hotel for passengers, providing at least cabins, restaurants and other facilities for the people onboard whereas day ferries might well only offer a single cafeteria for the passengers during short voyages.

Typical cargo includes (but is not limited to) passengers, cars, trucks and other vehicles. The cargo carrying flexibility implies multiple requirements to the cargo area, as typically the ship has to be able to carry both large amount of light cargo, such as light passenger vehicles, but also have the possibility to transport heavy vehicles. As such, the RoPax vessels are a complicated combination of RoRo volume, RoRo weight and passenger ships. In addition, many of these ships operate during the winter time in the Northern part of the globe, so an ice-class is common on these ships. A typical RoPax "cruise ferry" is presented in Figure 4.

Figure 4 – M/S Color Fantasy

One example of a night ferry is e.g. M/S Color Fantasy operating between Oslo, Norway and Kiel, Germany. The vessel is designed specifically for that exact route, taking into account the speed limits on the Oslo fjord and sometimes very rough weather conditions on the Northern Sea / Skagerrak. Data on the itinerary is presented in Table 4.

Table 4 – Example itinerary for a RoPax vessel

Departure (Oslo / Kiel)	14.00
Arrival (Oslo / Kiel)	10.00
Average speed	18 knots
Distance	360 nm

2.2. The effect of speed on the required propulsion power

For fast ships operating according to tight, inflexible schedules, large amounts of reserve propulsion power is needed for redundancy and keeping up the precise schedules that have to be maintained in all conditions. These relatively large power reserves are maintained for example in order to catch schedules in case of delays.

The physical relationship between required propulsion power and speed can be estimated roughly with the following equation;

$$Power = a * v^3$$

In the formula, "a" is a ship specific constant and "v" the speed of the vessel. The dependency is demonstrated in Figure 5, where it can be noted that for example dropping the speed from 22kn (P_{REQ} = 18MW) to 18kn (P_{REQ} = 8,5MW) inflicts a 18,2% drop in the speed but a 52,8% drop in required propulsion power. The dramatic dependency is demonstrated by reducing the speed by only 0,5kn (2,3%), when the power requirement is dropped by 1750kW (or 9,7%).

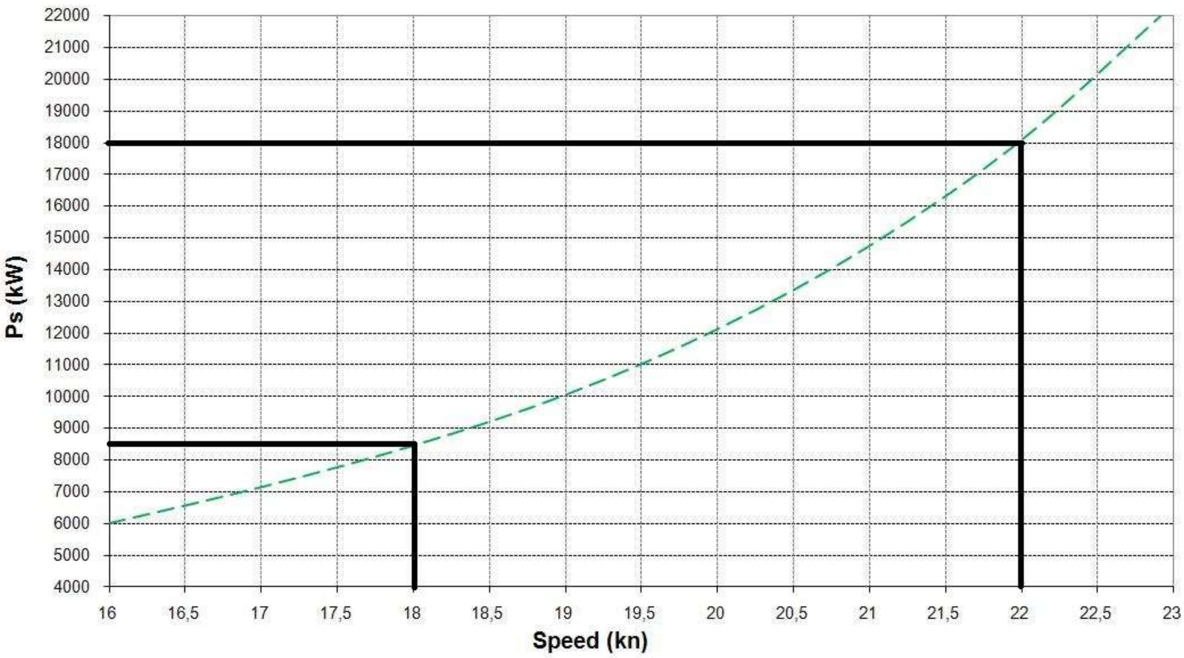

Figure 5 - Typical speed-power curve

In Table 5 and Table 6 the effect of the speed-power relationship is demonstrated through two ships of roughly the same size. Stena Freighter is a typical RoRo volume carrier operating with relatively constant itinerary between Sweden and Germany, carrying "light cargo" such as trucks and trailers. Schieborg, on the other hand, is a RoRo weight carrier, carrying trucks and other vehicles, as well as containers and other heavy cargo on varying itineraries on the Mediterranean.

Table 5 - Comparison between a weight and volume carrier

Ship's name	**Stena Freighter**	**Schieborg**	
Type of the ship	Volume carrier	Weight carrier	
Length	182,8	183,1	m
Deadweight	10 048	12 457	tons
Lane meters	2 705	2 475	m
P_{ME}	23 040	10 920	kW
v_{DES}	22	18	kn
Transport work done in 5 hours	1 105 280	1 121 130	t * nm
CO_2 in 5 hours	68 159	32 305	kg

As can be seen from the table, the RoRo weight carrier does slightly greater transport work (measured in dwt * nm) in five hours even though the speed of the vessel is significantly (~18%) slower. In addition, the amount of consumed fuel (and thus the amount of emitted CO_2) is roughly 50% lower in the RoRo weight carrier due to the significantly lower main engine power, which is due to the speed-power relation presented earlier in this chapter.

Another example of the drastic effect of speed on the propulsion power requirement and thus on the amount of consumed fuel is presented on Table 6, where a typical RoRo volume carrier is examined. The vessel is on a route between an island and continent in around-the-clock-traffic. The distance between the ports is roughly 130nm and the typical operation profile of the vessel is such that the travel time is 6 hours and the turnaround time in the port is 2 hours.

Table 6 - Transport work comparison and logistics

22kn speed (3 trips / day); 6h (sea) + 2h (port) / trip			
Transport work done in 24 hours	3 979 008	t * nm	
CO2 in 24 hours	245 373	kg	
13,2kn speed (2 trips / day); 10h (sea) + 2h (port) / trip			***Difference to base case***
Transport work done in 24 hours	2 652 672	t * nm	-33,3%
CO2 in 24 hours	59 166	kg	-75,9%
13,2kn speed (2 trips / day); 2 ships, 10h (sea) + 2h (port) / trip			
Transport work done in 24 hours	5 305 344	t * nm	+33,3%
CO2 in 24 hours	118 332	kg	-51,8%

In case the speed would be reduced to 13,2kn so that the ship would do 2 trips a day (10hours transport time, 2 hour turnaround), the impact would be that the transport work performed would be 33% less but the amount of consumed fuel and thus the amount of emissions would drop by roughly 75%.

If, in addition, instead of one fast vessel the owner would replace the old fast vessel with two new vessels that operate at the 13,2kn design speed, the impact would be that the total transport work performed would be 33% greater and still the amount of consumed fuel and thus CO_2 emissions would be roughly half of that of the one fast vessel.

However, in reality the impact would most probably not be as drastic as the calculations do not take into account emissions during other operating modes, such as maneuvering and port time. In addition, the expenses and environmental burden caused by additional vessels should be taken into account when evaluating the total environmental impact. Thus, the example is solely intended for pointing out the dramatic effect of speed on the fuel consumption of a marine vessel.

3. EEDI applicability for RoRo and RoPax vessels

3.1. A brief history of the EEDI

The Energy Efficiency Design Index EEDI and the baseline approach originate to MEPC 57 (4/2008), where it was agreed that Denmark and Japan would prepare a draft text for assigning an energy efficiency design index for ships and submit it to the intersessional meeting of the Working Group on Green House Gases (6/2008). Denmark's submission (GHG-WG 1/2/1) and Japan's submission (GHG-WG 1/2/2) contained the base idea of the forthcoming index and baselines, where RoRo vessels were included as ro-ro cargo ships and RoPax ships were assigned into the passenger ship group. The draft guidelines, after improvements were presented in MEPC 58 (10/2008) as Denmark's submission (MEPC 58/4/8). The main conclusion of the submission regarding RoRo and RoPax vessels was:

> *"Deadweight and volume is an appropriate measure for most ship types. However, for ro-ro cargo ships and passenger ships, lane meters and number of passengers respectively were tested, but these capacity measures were found to be not consistent enough to give baseline with sufficient correlation. Gross tonnage seems to be more appropriate, even if it does not directly correspond to the capacity of the ship. For passenger and ro-ro cargo ships, samples with speed below 15 knots were excluded. These vessels had a different baseline curve because of their low speed. Further, ships with aluminium hulls were excluded as they perform significantly different from steel ships. A separate baseline was not calculated for these ship groups."*
> *MEPC 58 / 4 / 8, July 31, 2008*

In MEPC 59 (7/2009) further discussions on EEDI and its applicability were held. Many problems regarding RoRo and RoPax vessels, as well as passenger ships in general, were highlighted. The problems highlighted were for example the short-sea shipping challenges regarding EEDI, the large amount of different propulsion technologies, high auxiliary power loads on passenger ships, how to take different waste heat recovery systems into account etc... Defining capacity was also argued, noting that e.g. in addition to GT the RoPax vessels carry lane meters. However, no real solution for unanimous definition of capacity was presented and in the end it was agreed to have GT as the capacity measure for RoPax and passenger ships.

> *"the uncertainties in use of GT for passenger vessels may be compensated by using a correction factor taking into account the number of passengers, lane-meters and other peculiarities for passenger and ro-pax vessels; and*
>
> *ro-pax vessels often have complex design and act as bridges in the transport chains competing also with land-based transport modes."*
> *MEPC 59 / 4 / 2, April 8, 2009*

The working group on Green House Gases agreed (MEPC 59 / WP8, July 2009) that due to the significant variations in the baselines for ro-ro cargo ships, the actual vessel group should be split into three separate groups; ro-ro volume carriers, ro-ro weight carriers and ro-ro vehicle carriers. The vehicle carriers would be pure car / truck carriers and the weight / volume carriers would be separated by dividing deadweight by total lane meters (if the calculated value would be <4t/lm, the ship is classified as ro-ro volume carrier and if the value would be ≥4t/lm, the ship would be classified as a ro-ro weight carrier). However, the exact value and dividing principle were left open for further discussions and studies.

In submission MEPC 60/4/6 Denmark tried to give an answer to the ro-ro dividing principle discussions and the overall ro-ro vessel categorization. Regarding vehicle carriers it was concluded that the data correlation is good enough and the current baseline approach is feasible for the ships in the group. However, similarly good correlation was not found within the ro-ro volume or weight carriers, even though some analogy was found within the ro-ro volume carrier group having deadweight / lane meter value of over 4,5t/lm.

> *"The remaining volume- and weight carriers are not clearly divided into two distinct groups. However, it appears as if the ships with a deadweight per lane meter below approximately 4.5 t/m seem to have a service speed above approximately 17.5 knots. This confirms the theory that true volume carriers in general are designed and built to be light and fast, while weight carriers have a much wider range of service speeds."* *MEPC 60 / 4 / 6, December 18, 2009*

Nevertheless, the document states that the correlation in ro-ro vehicle and volume carrier groups would be good enough to justify the EEDI baseline approach. However, it was concluded that for the ro-ro weight carriers the current baseline approach is not feasible. Final conclusions are stated in the following quote;

> *"Action requested of the Committee*
>
> *22 The Committee is invited to:*
>
> *.1 endorse that ro-ro cargo ships should be divided in three sub-groups: vehicle carriers, volume carriers and weight carriers;*
>
> *.2 agree that a baseline with a satisfactory correlation can be established for vehicle carriers;*
>
> *.3 endorse that volume- and weight carriers should be separated by a deadweight per lane meter of 4 t/m;*
>
> *.4 decide that volume carriers should be characterized by a deadweight per lane meter of 2 t/m or above but below 4 t/m, and that weight carriers should be characterized by a deadweight per lane meter of 4 t/m or above but below 8 t/m;*
>
> *.5 agree that a baseline with a satisfactory correlation can be established for volume carriers; and*

.6 consider how to proceed concerning weight carriers."

MEPC 60 / 4 / 6, December 18, 2009

The proposals presented in MEPC60/WP.9 (3/2010) were agreed in MEPC 60 (4/2010). The main contents of the proposals were that due to the problems in the EEDI baseline approach for ro-ro and passenger vessels, the requirement "attained EEDI ≤ required EEDI" shall not apply to passenger ships, ro-ro ships and ro-ro passenger ships until a suitable EEDI baseline is determined for such ship types. Furthermore, the same was concluded in the report of the working group on Energy Efficiency Measures for ships (MEPC 61/WP10, 9/2010) and furthermore agreed in MEPC 61 (10/2010), that:

> *"9.3 develop a work plan with timetable for development of EEDI frameworks for ships not covered by the draft regulations and guidelines on the method of calculation of the attained energy design index for ships and for technologies in document MEPC 61/5/20" MEPC 61 / 24, October 6, 2010*

The schedule and preliminary ideas will most likely be presented in MEPC 62, which will be held in July, 2011. As such there is no exact schedule for the event available at the time this report is written.

3.2. Current status of the EEDI

There have been challenges with the EEDI baseline approach for certain ship categories, most notably regarding ro-ro cargo vessels, ro-ro passenger ships, passenger ships and small ships in general. The problems are mainly due to the fact that the aforementioned ship types are typically designed to specific routes (usually with main dimension limitations) and / or to specific transport tasks with tight timetables (RoRo vessels), or not to an actual route at all (cruise vessels). Altogether, there is a very high scatter in the ship design speed and actual operation speeds, leading to a wide variation in propulsion power requirements and machinery configurations of the vessels and thus to a high scatter in the calculated EEDI values.

The current status of EEDI for RoRo and RoPax vessels is "under development" and all RoRo and passenger ships are excluded from the "attained EEDI ≤ required EEDI" requirement until a suitable method for including them in the EEDI baseline approach has been found, as noted in the following quote.

> *"The group also recalled the agreement reached at the first intersessional meeting that passenger ships, ro-ro passenger ships and all ro-ro cargo ships (vehicle carrier, weight carrier and volume carrier) should be excluded from the application of regulation 4 (required EEDI) in the first stage, and that a suitable application method should be developed at a later stage." MEPC 61 / WP.10, September 30, 2010*

In addition, according to MEPC 61/5/3 - "Reduction of GHG emissions from ships, report on the outcome of the intersessional meeting of the working group on energy efficiency measures for ships" (July 7, 2010), the timeframe for implementing EEDI for RoRo cargo vessels and RoPax vessels is at earliest after "Phase 0" (from January 1, 2015) of the reduction scheme.

It can be concluded that the EEDI approach for RoRo cargo vessels and RoPax vessels is open for further studies and discussions, of which many are currently underway.

3.3. Source data inconsistencies and validity

Doubts and discussions have been held regarding the source data inconsistency in the officially agreed source database for the EEDI baseline calculations, the IHS Fairplay database. As it is not mandatory for the ship owners to supply ship data to the IHSF database, the accuracy of the data is questionable and thus the baselines and the EEDI requirements might be drawn according to false information.

The data inconsistency issue was discussed in document "Guidelines for calculation of baselines for use with the Energy Efficiency Design Index", submitted by Denmark and Japan (MEPC 60/4/7). The submission compared IHSF database data to a sample of verified ship data consisting of 170 container ships and 11 RoRo cargo ships. The results are as following;

> *"11 The analysis showed the following:*
>
> *.1 The mean EEDI was 2.6% lower for container ships and 5.4% higher for ro-ro cargo ships when using the LRFP database compared to using original data.*
>
> *.2 The service speed in the LRFP database was on average 1.3% higher than the speed at 65% deadweight and 75% main engine power for container ships.*
>
> *.3 The service speed in the LRFP database was on average 0.5% higher than the speed at 100% deadweight and 75 % engine power for ro-ro cargo ships.*
>
> *.4 The main engine power in the LRFP database was on average 1.6% lower for container ships and 0.2% lower for ro-ro cargo ships.*
>
> *.5 For one container ship and* ***two ro-ro cargo ships, the deadweight in the LRFP database deviated more than 10% from the correct deadweight****. This error in the deadweight did not affect the average EEDI due to the large population of container ships. However, due to the small population of ro-ro cargo ships the average EEDI was heavily affected by the error in deadweight. Without this error the 5.4% mentioned above would have been only 1.5%. However, it should be kept in mind that the small population was a result of the fact that there were only original data available for 11 ro-ro cargo ships."* *MEPC 60 / 4 / 7, December 18, 2009*

The mentioned LRFP database is the same as IHSF database. The bolded quote states the most important output of the document, namely that the deadweight difference was over 10% with 18% of RoRo cargo ships. This is most probably due to the fact that on part of the ships deadweight is given out as scantling deadweight, as opposed to the design deadweight which would be the correct value to be used in the calculations. However, the example shows that there are serious inconsistencies in the IHSF data and further consideration should be paid on the source data validity.

Similar inconsistencies are most probably present in the fields for speed and main engine power, as these can be given out as trial speed (at 100% of maximum power) or as design speed (usually at 85% of maximum power). As there is no standardized way to measure lane meters, similar inconsistencies are most probably also present in the reported lane meter data. The distribution of RoRo cargo vessels into volume and weight carriers could therefore be untruthful.

A sample of source data was validated as a test with data from the Deltamarin AVEC-database for RoPax vessels, where exact information on the vessels has been collected. The results are shown in Table 7 (negative values mean that the value in the IHSF database is smaller than the verified data). The data validation was made for a sample of 36 RoPax vessels, built between 2000 and 2010.

Table 7 - Deltamarin AVEC-database data vs. IHSF data comparison

	Difference
Lpp (m)	0,7 %
P_{ME} (kW)	2,1 %
GT	-3,6 %
DWT	-2,5 %
PAX	4,3 %
v (kn)	-0,6 %
Lanes (m)	-0,4 %
Cabins	5,8 %
Sample size	36 ships

The largest variations were in passenger and cabin numbers, but also main engine power variations were quite large. This is probably due to the fact that shaft generators have for some reason been included in the IHSF total engine power value. In three cases (~8%) the difference in e.g. deadweight was more than 20%, and in 7 cases (~20%) the difference was over 10%. These differences are most probably due to the different measurements, some are reported in scantling draught and some in design draught. In the EEDI the design draught deadweight should be used. Also the differences in gross tonnage were large, three vessels having differences of over 20% in the data. These are significant differences and considering the fact that the variations are in values that are directly used for the EEDI calculations, it can be concluded that the accuracy of the current database is questionable.

Considering the definition of baselines, the inconsistency of power, capacity and speed in the database potentially leads to too low “Average Index Values” and thus can make the requirement too tight for certain ship types.

When work on possible correction factors or alternative methods will be developed in greater detail, it is recommended that the following data should be gathered:

- Main dimensions of ship (DWT, GT at scantling and design, length, width, draft)
- Installed engine power, including make and model
- Installed auxiliary power, sea load
- Specific fuel oil consumption (SFOC) at 75% and 100%
- Speed power curve or vessels speeds at 75% and 100% MCR (design DWT)
- Lane meters, cargo space area/volume, cargo deadweight
- Number of passengers, including cabins

The question whether the gathered data should be verified information based on the existing IHSF database or if an entirely new coordinated vessel database should be developed, remains open. If a new database would be developed, it should also be decided to which party this responsibility would fall on and what level of transparency the data should have. At the very least, the required data should be clearly defined and presented in a uniform template, which could for example be developed and enforced by the IMO. In addition for this template to be recognized worldwide, the data should be crosschecked with other industry sources such as flag state administration, classification societies and shipyard data.

3.4. The EEDI formula

The EEDI formula as defined in MEPC.1/Circ.681 is applied in this study with the general calculation guidelines. The formula is as follows:

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

Where:

C_F = non-dimensional conversion factor between consumed fuel and emitted CO_2. Subscripts $_{ME(i)}$ and $_{AE(i)}$ refer to main- and auxiliary engines.

V_{ref} = ship speed, measured in knots, in maximum design load condition (capacity), assuming deep water and calm sea and no wind.

Capacity = for conventional vessel types deadweight and gross tonnage for passenger ships and RoRo passenger ships.

$P_{ME(i)}$ = power of main engines measured in kW at 75% MCR having deducted shaft generators.

$P_{AE(i)}$ = auxiliary engine power in kW, the electrical load required to supply normal maximum sea load.

$P_{PTO(i)}$ = shaft generator power in kW at 75% output of each installed shaft generators.

$P_{PTI(i)}$ = shaft motor power in kW at 75% output of installed shaft motors.

$P_{eff(i)}$ = 75% of the main engine power reduction (kW) due to innovative mechanical energy efficient technology.

$P_{AEeff(i)}$ = auxiliary power reduction (kW) due to innovative electrical energy efficient technology measured at $P_{ME(i)}$.

SFC = specific fuel oil consumption of engines, measured in g/kWh, of the engines. Subscripts $_{ME(i)}$ and $_{AE(i)}$ refer to main- and auxiliary engines.

f_j = non-dimensional correction factor to account for ship specific design elements.

f_w = non-dimensional coefficient indicating the decrease of speed in representative sea conditions.

$f_{eff(i)}$ = availability factor of each innovative energy efficiency technology.

f_i = capacity factor for any technical or regulatory limitation on capacity.

When looking at the different variables in the formula and the things that affect them in the RoRo cargo vessel group, it can be noted that e.g. speed is decided by the operation area (schedules) and thus it is not necessarily a variable that can be changed by the designer. Capacity is decided by the transportation task and possible main dimension limitations, whereas SFOC is in most cases fairly constant. Again, these things can not be adjusted by the designer. The required power is closely related to the speed of the vessel and the possible ice-class. Here the designer has some room for making improvements as the hull form and other aspects affecting the energy efficiency of the vessel can be modified to reduce overall power requirements.

3.5. Evaluation of the current baseline approach

At the moment there are no official guidelines for EEDI baseline definition for RoRo or RoPax vessels. However, for purposes of this study the common baseline approach as defined in “Guidelines for calculation of reference lines for use with the energy efficiency design index” (Annex 4, MEPC 61/5/3) are used. For calculating the EEDI values, the formula as presented in “Interim guidelines on the method of calculation of the energy efficiency design index for new ships” (MEPC.1/Circ.681) is utilized as noted in the previous chapter. The baseline calculation guidelines are included as Appendix 1 and the EEDI calculation guidelines as Appendix 2.

The basic approach of the baseline definition method is to use the following formula to the source data in order to draw a regression line for the group in question. However, there are multiple uncertainties when defining the baselines, one of which is the source data inconsistency as noted in Chapter 3.3. Another uncertainty is that the baseline calculation method does not take into account e.g. the different ice-classes of the vessels, possible shaft generators or other machinery differing from the conventional approach.

$$Estimated\ Index\ Value = 3{,}1144 * \frac{190 * \sum_{i=1}^{n_{ME}} P_{MEi} + 215 * P_{AE}}{Capacity * v_{ref}}$$

The baselines are defined as regression curves according to the calculated index values, excluding incomplete datasets and points that are deviating more than two standard deviations from the first regression curve.

The source database used for this study is Lloyds Register Fairplay (IHSF) register 10.01 (Shippax 3.3.57). The split into different ship groups is done according to “Guidelines for calculation of reference lines for use with the energy efficiency design index” (Annex 4, MEPC 61/5/3) as attached to this report (Appendix 1). The delivery dates of the ships used in the study are 1.1.2000 - 31.12.2010.

Based on the guidelines and source data, three assumptions are made:

- P_{ME} is taken as 75% of reported main engine power in the IHSF, and thus it is assumed that the power in IHSF database is the maximum engine power.
- P_{AE} is calculated according to the general cargo ship guidelines for RoRo cargo vessels. However, there are no guidelines for defining P_{AE} for RoPax vessels at the moment and thus the relation between P_{ME} and P_{AE} is defined according an estimate by real ship data from Deltamarin’s own sources as presented in Table 8. As seen, the average electric sea load on RoPax vessels is 8,2% of P_{ME} and thus in this study it is assumed that the relation, P_{AE} = 0,082 * P_{ME} is valid for all RoPax vessels.

Table 8 - RoPax Sea Load

GT	P_{ME} [kW]	Sea Load [kW]	Sea Load % of P_{ME}
4 630	4 680	304	6,5 %
5 209	8 000	676	8,4 %
8 760	8 640	1 131	13,1 %
12 670	13 440	1 248	9,3 %
13 906	8 640	738	8,5 %
13 906	8 640	738	8,5 %
22 382	18 900	750	4,0 %
54 919	54 440	4 122	7,6 %
		AVG:	**8,2 %**

- The speed v_{REF} is to be taken at design deadweight and 75% of P_{ME}. However, the IHSF database does not define on which conditions the speed stated in the database is measured. Therefore, taking into account the physical dependency P_{ME} = $a*v^3$, which can be expressed as $v = \sqrt[3]{\frac{0{,}75P_{ME}}{a}}$. “a” is disregarded and thus the applied factor for multiplying the reported speed in IHSF is $\sqrt[3]{0{,}75} = 0{,}91$

3.5.1. RoRo vehicle carriers

The design criteria for RoRo vehicle carriers are rather uniform when ships of similar capacity are compared. The capacity itself is commonly measured in lane meters or number of cars, not as deadweight, as the number of cars expresses the actual capacity of the ships more realistically. The design speed of vehicle carriers is typically between 17 and 20 knots, and commonly propulsion machinery is based on single slow speed two stroke engines.

RoRo vehicle carriers are typically designed for worldwide transoceanic operation. Usually there are certain limitations for main dimensions, such as maximum L_{OA} when piloting to Japanese ports and the Panama channel limitations. These main dimension limitations cause the ships to carry excessive ballast as the only available dimension for enlarging the capacity is upwards and additional weight is required near the bottom to keep the ship stable. The excessive ballast is included in the deadweight and thus as capacity in the calculations. Therefore a more fair way for defining the capacity for these ships could possibly be lane meters.

Figure 6 shows RoRo vehicle carriers plotted according to the EEDI guidelines. Only 8 ships were removed due to the standard deviation exceeding 2 as shown in Table 9.

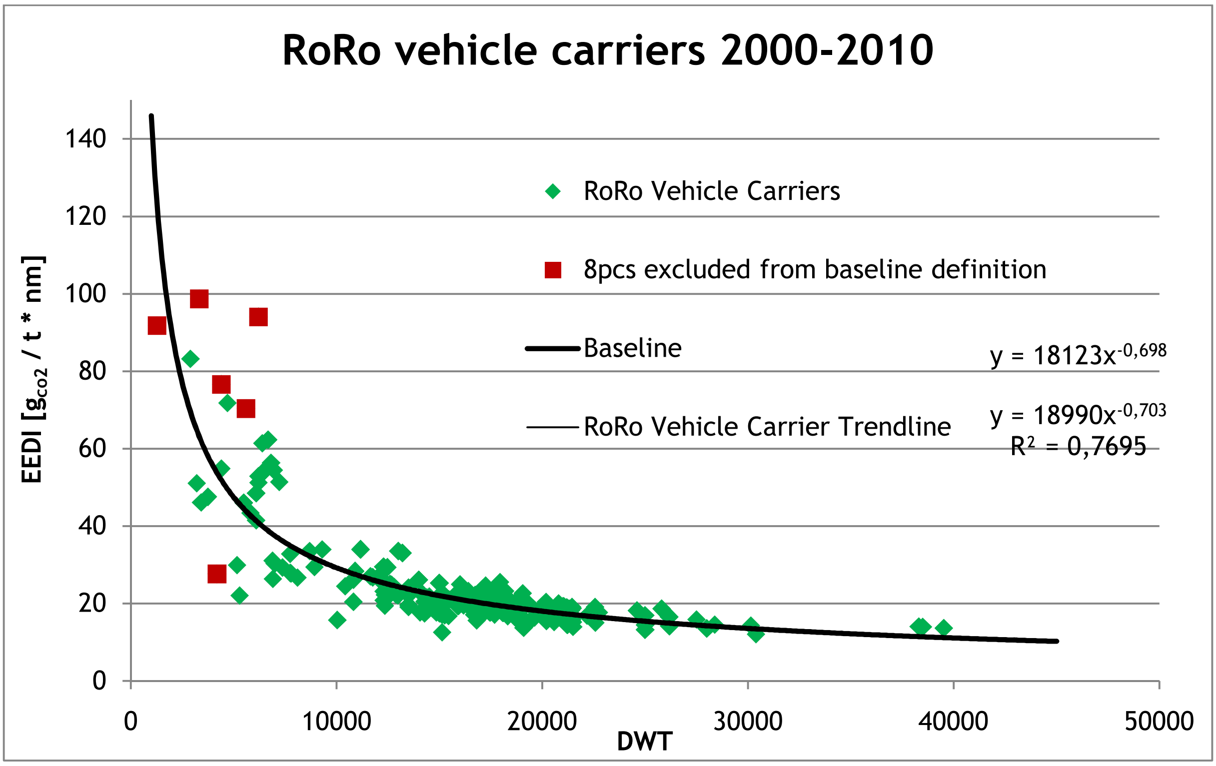

Figure 6 - RoRo Vehicle Carriers

Table 9 - RoRo Vehicle Carrier sample data

Sample size	pcs	438
Excluded from baseline calculation	pcs	8

As can be seen from the graph, the correlation is relatively good for ships over 10 000 DWT and as the RoRo vehicle carriers are quite similar ships, EEDI could be considered as a feasible approach for measuring the energy efficiency of RoRo vehicle carriers with deadweight of 10 000 DWT or higher.

3.5.2. RoRo weight carriers

The RoRo weight carriers are ships typically carrying various forest industry products or other heavy RoRo cargo. As the ships are in scheduled traffic between two specified ports, usually serving a small number of factories, the design criteria for the ships varies significantly and the main dimensions are often strictly set.

The RoRo weight carriers plotted according to the EEDI guidelines are shown in Figure 7. As can be seen, the scatter is relatively large and data correlation poor. Only three vessels were excluded from the baseline calculation due to the standard deviation exceeding 2. The sample data information is shown in Table 10.

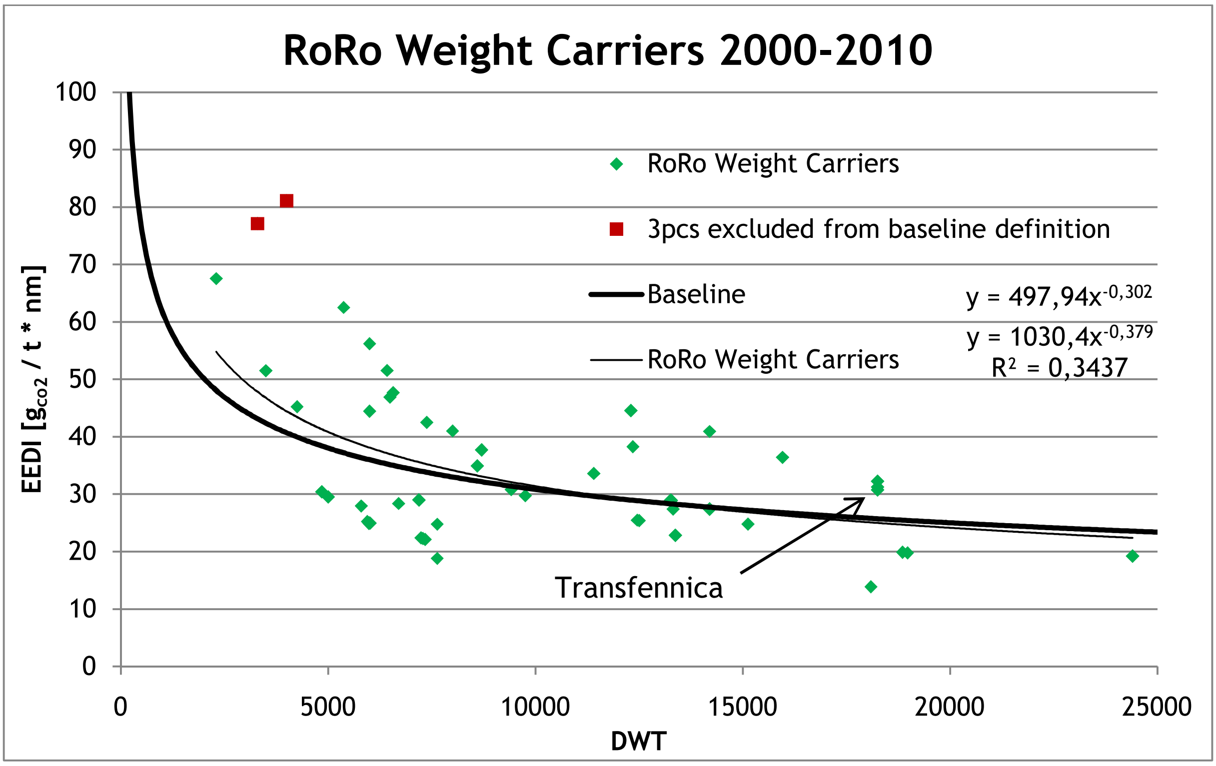

Figure 7 - RoRo Weight Carriers

Table 10 - RoRo Weight carrier sample data

Sample size	pcs	82
Excluded from baseline calculation	pcs	3

Currently there are no ice-class correction factors defined for RoRo ships and thus the ice-strengthened ships are put at a disadvantage in the present method of calculation, as their EEDI value is higher due to higher main engine power requirements. For example, the European built 18 250 DWT vessels with high index value are the Transfennica vessels built in Poland. These vessels are built to ice class 1A super and the installed power is due to ice breaking and not for achieving the service speed.

Generally speaking there does not seem to be any unifying feature for RoRo weight carriers, except that deadweight per lane meter equals or exceeds 4 tons. Design speed, powering, selected main dimensions etc. seem to vary considerably case-by-case, resulting in large scatter and low correlation of the EEDI values.

3.5.3. RoRo volume carriers

RoRo volume carriers have higher speeds than RoRo weight carriers as the cargo is more valuable, and the cost of speed is lower for lighter cargo. RoRo volume carriers are also often designed for effective harbour operation as the turnaround time in ports is minimized due to often short distances travelled and thus relatively long times spent in harbours. Due to the high flexibility of the vessels and diverse operation profiles, they are not necessarily as optimally efficient on long legs with constant speeds as the oceangoing vessels. Similarly to RoRo weight carriers, also many of the volume carriers have an ice-class. As there are no guidelines for ice-class corrections, multiple ships are put into a disadvantaged position due to their greater lightship weight and higher main engine power requirements than similar ships without ice-class.

The scatter of the EEDI values is relatively large as seen from Figure 8 and the baseline is relatively steep already under 10 000 DWT. The sample size is relatively small as shown in Table 11 and no ships were excluded from the baseline definition.

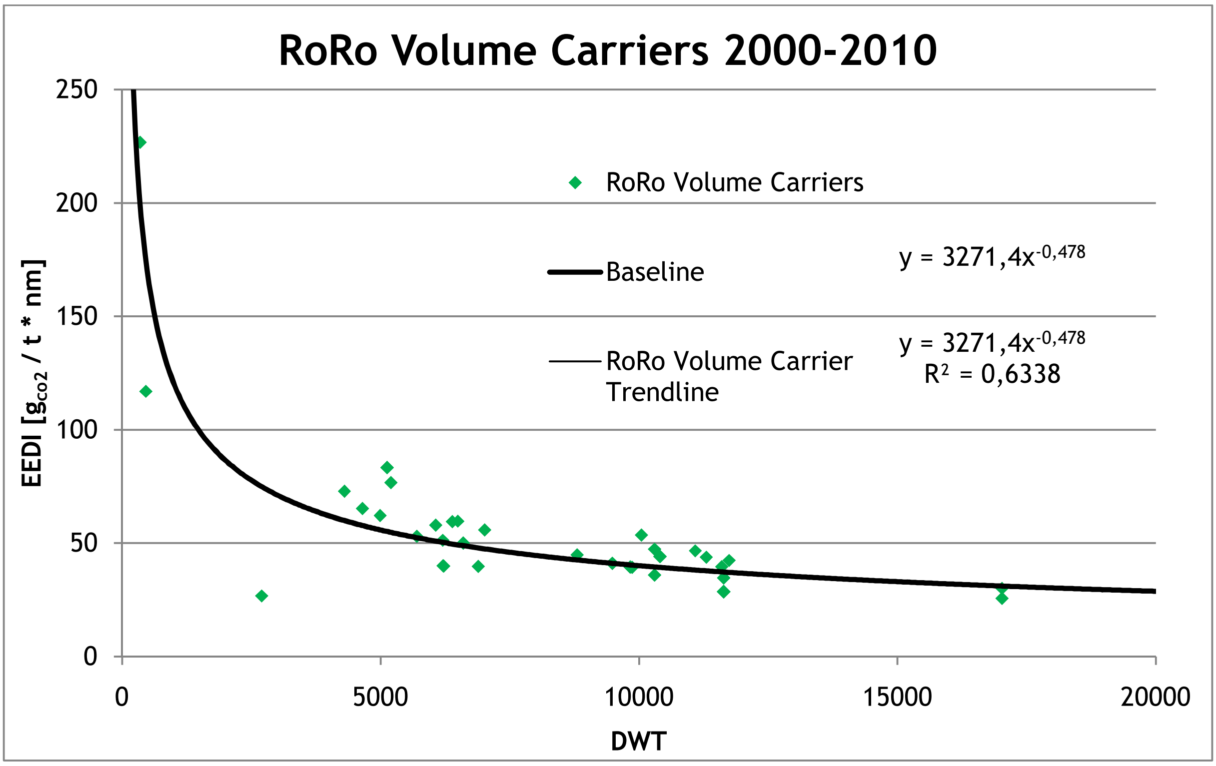

Figure 8 - RoRo Volume Carriers

Table 11 - RoRo Volume carrier sample data

Sample size	pcs	59
Excluded from baseline calculation	pcs	0

3.5.4. RoPax vessels

A RoPax vessel is a combination of a passenger vessel and a RoRo ship. However, the design criteria for this ship group are even wider than for pure RoRo ships or passenger ships. This is due to the significant flexibility of such ships and the highly varying transportation tasks.

The sample size of RoPax vessels is relatively large as shown in Table 12. However, due to the baseline definition limitations as stated in MEPC 60/4/7 (all ships whose design speed is under 15kn are excluded) and relatively large scatter (ships with standard deviation exceeding 2 are excluded), roughly 1/3 of all RoPax vessels are excluded from the baseline calculations. As shown in Figure 9, most of the RoPax vessels excluded from baseline definition are small ships, which are typically transporting a small number of cars and passengers between island and continent, or ships in continuous ferry-operation over a strait like in the Danish straits. Typically these small vessels are either very fast high speed crafts or slow ferryboats.

However, excluding such a large number of ships causes unsteadiness in the baseline definition and a question rises if the baseline describes the ship group reliably when roughly 1/3 of the source data is excluded from the definition.

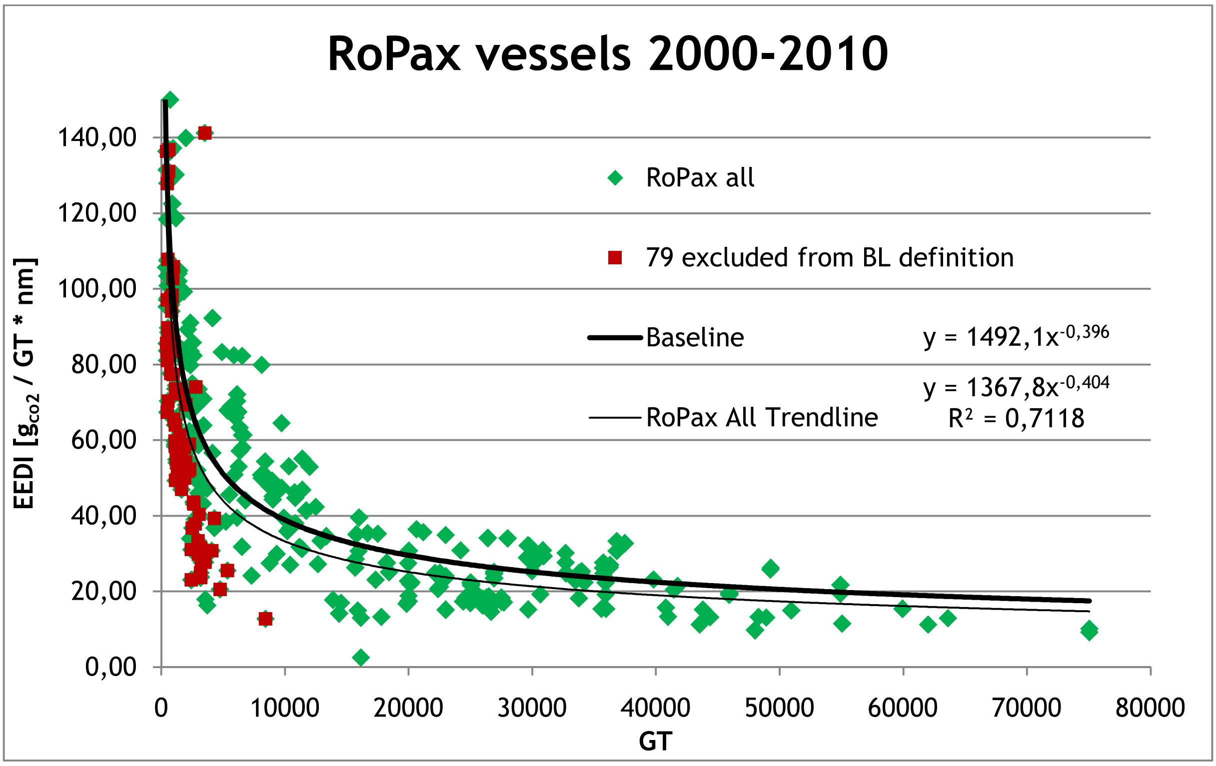

Figure 9 - RoPax vessels

Table 12 - RoPax sample data

Sample size	pcs	385
Excluded from baseline calculation	pcs	79

Another problem with RoPax vessels is the big scatter in powering and speed. As the vessels are designed for specific routes and transportation tasks, also the speed and power are dimensioned for reasonable schedules on that specific route taking into account possible speed limitations and weather conditions. Additionally, ship dimensions such as draught and length may often be limited due to special requirements in the operating area. RoPax ships typically have considerable margins in engine power for a variety of reasons – discussed later in this study.

3.6. Evaluation of the latest IMO submissions affecting RoRo/RoPax vessels

3.6.1. GHG-WG 2 / 2 / 13

-GHG-WG 2 / 2 / 13 - "Consideration of the Energy Efficiency Design Index for new ships - Further development of index methodology as presented at MEPC 58" (6 February 2009) **-Submitted by Interferry**	
Executive summary:	This document provides information on ongoing work for developing an alternative methodology for calculating the attained Energy Efficiency Design Index for ships
Comments:	The submission discusses the present EEDI baseline approach for RoRo ships. It concludes that for ships engaged in short sea shipping, the proposed methodology does not grant the intended fair basis for comparison. Instead of "regular EEDI", the submission proposes that the EEDI should be divided into two parts; -Efficient Propulsion Design Index EPDI, that expresses required propulsion power per capacity as a function of service speed (Fn_L). -Efficient Auxiliary and Utility Systems Design Index, for which the submission does not give calculation guidelines or further ideas. Most probably it would follow the "Electric Power Tables" (EPT) guidelines, under development by CESA. This proposal is discussed in more detail in subchapter 0.

Efficiency Propulsion Design Index (EPDI) + Auxiliary and Utility Systems Design Index

The Interferry submission proposes to define the energy efficiency of RoRo cargo vessels and RoPax vessels according to separate index for propulsion power (EPDI) and for auxiliary power (Auxiliary and Utility Systems Design Index). The calculation method for EPDI, shown in following formula, is pretty similar to the present EEDI formula. The numerator describes the amount of produced CO_2 for propulsion power, whereas the denominator includes the capacity of the vessel.

$$EPDI = \frac{\left(\sum_{i=1}^{nME} C_{FMEi} * SFC_{MEi} * P_{B,MEi}\right) - \left(\sum f_{eff} * P_{eff} * C_{eff} * SFC_{MEi}\right)}{Capacity}$$

The EPDI of sample ships would then be plotted against Froude's number ($Fn_L = \frac{v(\frac{m}{s})}{\sqrt{g * L_{BP}}}$).

The EPDI is calculated taking into account 75% of the main engine power ($P_{B,ME}$), specific fuel consumption is taken as 190g/kWh and the carbon factor (C_F) is taken as 3,1. Capacity is defined as gross tonnage (GT) for RoPax vessels and deadweight (DWT) for RoRo cargo vessels.

The auxiliary power would be calculated according to specific “Auxiliary and Utility Systems Design Index”, for which the submission does not give any calculation guidelines. However, a specific “Electric Power Tables” that could possibly be used is under development by CESA.

The EPDI is calculated separately for RoPax vessels (capacity defined as gross tonnage) and RoRo cargo vessels (capacity defined as deadweight). The results for RoPax vessels are shown in Figure 10 and for RoRo cargo vessels in Figure 11.

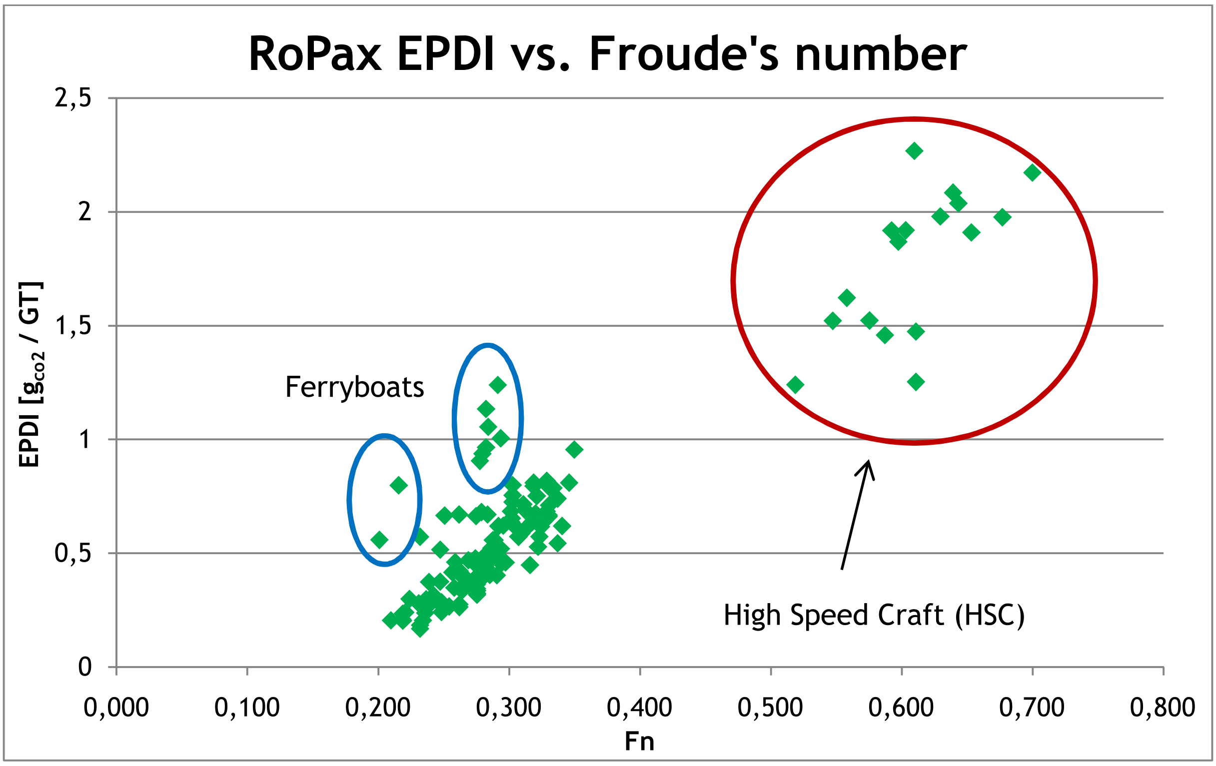

Figure 10 - EPDI for RoPax vessels

The EPDI index seems to be able to define the required propulsion power against the speed of the vessel pretty well. There are three clear separate groups, one for high speed craft (HSC) between Froude number 0,5 - 0,7, one for ferryboats (slow and small ferries, circled by blue in the chart) and third and largest group for “conventional RoPax vessels”. However, as it is not able to take the auxiliary power into account, the method is not feasible for regulating the energy efficiency.

One of the main problems in the EPT is the definition of requirements by the existing fleet, as the values attained from defining the electric power needs for the existing ships would be used to regulate the allowed auxiliary powers for the new ships. This problem is highlighted on ships with diesel-electric propulsion as they do not have separate auxiliary engines for generators and electricity production.

For RoRo volume and weight carriers the EPDI is calculated and shown in Figure 11. As can be seen, the two groups are mixed and as such do not give clear difference between the volume or weight carriers, even though the tendency on volume carriers are the higher EPDI values and for weight carriers the lower EPDI values. The speed variations (or Fn variations) are pretty large, from 0,175 to 0,3.

The two deviating volume carriers with high EPDI values are small and slow vessels operating in the Caribbean.

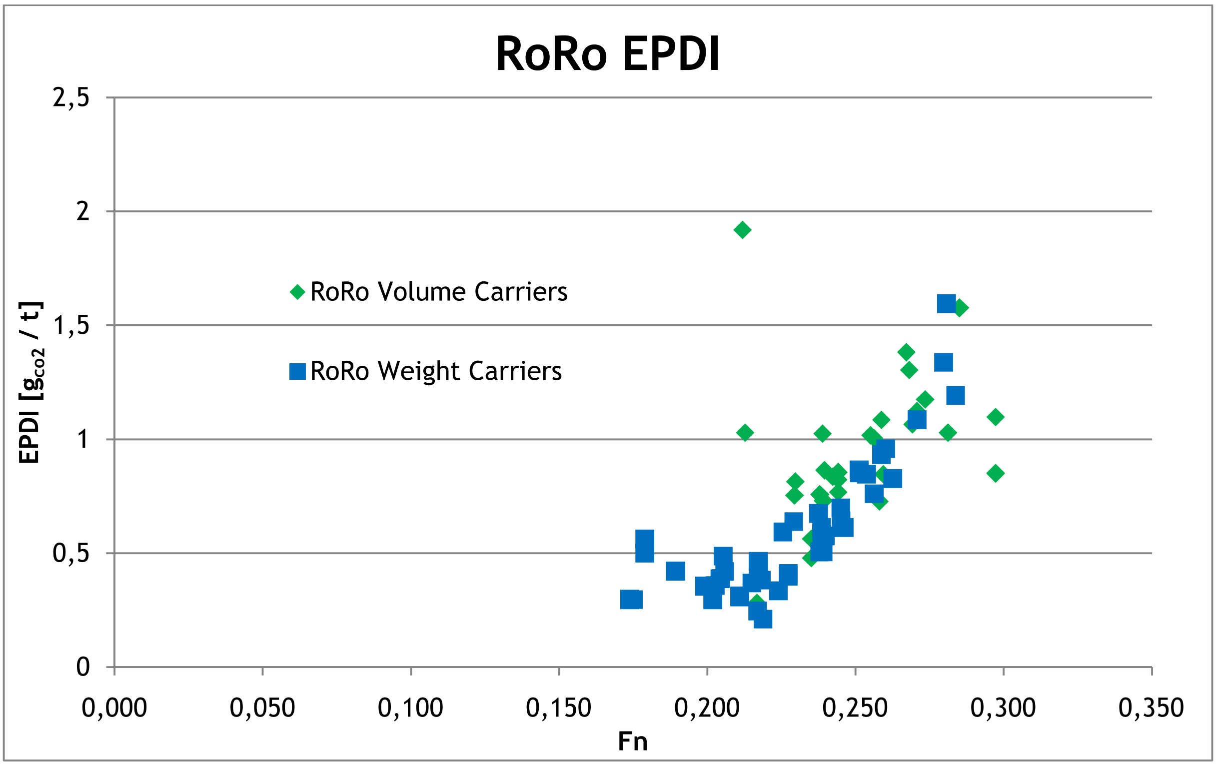

Figure 11 - EPDI for RoRo vessels

As seen from the figures, EPDI describes the propulsion efficiency of the vessels relatively well and clear groups are seen especially on the RoPax chart. However, as the electric loads are not taken into account, the “luxury level”, or the total electric load allocated to each passenger in the vessel is disregarded and thus the total values will have a higher scatter. This is due to the fact that the “cruise ferries” have significantly larger electricity needs for the passengers as the day ferries in short routes and scarce services onboard.

Altogether it can be concluded that the Froude number compared to EPDI value is relatively promising way for defining even a part of the energy efficiency of a vessel and as such it should be taken into account in the coming tests within this study. Froude’s number is tested for RoRo cargo vessels in Chapter 4.1.3.1 and for RoPax vessels in Chapter 4.2.3.

3.6.2. GHG-WG 2 / 2 / 22

<table>
<tr><td colspan="2">-GHG-WG 2 / 2 / 22 - "Consideration of the Energy Efficiency Design Index for new ships - CO_2 reduction requires efficient instruments based on sound technical solutions" (6 February 2009)

-Submitted by the Community of European Shipyards' Associations (CESA)</td></tr>
<tr><td>Executive summary:</td><td>This document provides conclusions from the trial application of the draft Energy Efficiency Design Indexing (EEDI) to complex, highly optimized ships. The results show that fundamental elements of the EEDI concept have not been developed to a level of technical maturity that would allow mandatory application. CESA describes problems that still have to be resolved and proposes improvements of the baseline. CESA strongly recommends fully developing and verifying all aspects of CO_2 indexing before approval and reiterates that complementing market-based instruments are indispensable.</td></tr>
<tr><td>Comments:</td><td>The submission summarizes findings of four studies conducted in German technical universities on the EEDI applicability for RoRo vessels. The main findings are that the data scatter is large and in its present stage the EEDI is not feasible for regulating vessels involved in short sea shipping.

The submission includes four annexes, which are described in more detail;

1) Consequences of EEDI regime on the design of RoRo cargo vessel. Various aspects are presented, but the conclusion is that EEDI, at its present stage, implies a speed / power limit on ships. No solutions for including the problematic vessel groups into the EEDI approach are suggested.

2) Investigation of several efficient RoRo ships. Conclusion was that the only way they would pass EEDI limits is by reducing speed and thus the amount of installed power.

3) Alternative baseline concept for EEDI for RoRo vessels is presented, the main point being that when defining the baselines, additional factor "speed divided by deadweight" should be included in the formula. It was also pointed out in the annex that at its present stage EEDI is very weakly dependent on deadweight and depends mostly on the power / speed ratio. The proposed baseline approach is discussed in more detail with other baseline proposals in Chapter 4.1.3.2.

4) The proposal gives brief ideas on EEDI modifications concerning diesel electric propulsion.</td></tr>
</table>

3.6.3. MEPC 60 / 4 / 6

-MEPC 60 / 4 / 6 - "Prevention of air pollution from ships - Consideration of ro-ro cargo ship subgroups in the EEDI for new ships" (18 December 2009) **-Submitted by Denmark**	
Executive summary:	This document substantiates the split of the original group of ro-ro cargo ships into vehicle carriers, volume carriers and weight carriers. It is proposed that volume carriers should be characterized by a deadweight per lane meter of 2 t/m or above but below 4 t/m, and that weight carriers should be characterized by a deadweight per lane meter of 4 t/m or above but below 8 t/m. Satisfactory baselines are calculated for vehicle carriers and volume carriers, and the Committee is invited to consider how to proceed concerning weight carriers.
Comments:	The document studies dividing the original ro-ro cargo ship group into RoRo vehicle, volume and weight carriers, and if the current EEDI baseline approach is feasible for such ship groups. RoRo vehicle carriers fit well into the EEDI baseline approach as they are ships with relatively uniform design criteria and similar (roughly 17-20kn) design speeds. Correlation is good and standard deviation reasonable. However, dividing rest of the RoRo cargo ships into volume and weight carriers by deadweight / lane meter does not give acceptable correlation as the standard deviation is very poor due to large scatter of design speeds and overall design criteria.

3.6.4. MEPC 60 / 4 / 7

-MEPC 60 / 4 / 7 - "Prevention of air pollution from ships - Guideline for calculation of baselines for use with the Energy Efficiency Desing Index" (18 December 2009) -Submitted by Denmark and Japan	
Executive summary:	The submitters propose guidelines for calculating baselines for use with the energy efficiency design index (EEDI) framework and for documenting the selection of the input data needed in a transparent and robust way. Further, it is proposed to include refrigerated cargo carriers as a special category of ship types in the interim guidelines on the method of calculation of the energy efficiency design index for new ships (MEPC.1/Circ.681).
Database robustness:	*11 The analysis showed the following:* *.1 The mean EEDI was 2.6% lower for container ships and 5.4% higher for ro-ro cargo ships when using the LRFP database compared to using original data.* *.2 The service speed in the LRFP database was on average 1.3% higher than the speed at 65% deadweight and 75% main engine power for container ships.* *.3 The service speed in the LRFP database was on average 0.5% higher than the speed at 100% deadweight and 75 % engine power for ro-ro cargo ships.* *.4 The main engine power in the LRFP database was on average 1.6% lower for container ships and 0.2% lower for ro-ro cargo ships.* *.5 For one container ship and two ro-ro cargo ships, the deadweight in the LRFP database deviated more than 10% from the correct deadweight. This error in the deadweight did not affect the average EEDI due to the large population of container ships. However, due to the small population of ro-ro cargo ships the average EEDI was heavily affected by the error in deadweight. Without this error the 5.4% mentioned above would have been only 1.5%. However, it should be kept in mind that the small population was a result of the fact that there were only original data available for 11 ro-ro cargo ships.*
Comments:	The document's contents regarding RoRo and RoPax vessels is the study on the accuracy of source data in the IHSF database. Analysis was carried out for 170 container ships and 11 ro-ro cargo ships, which were not more than 10 years old. EEDI was calculated to the ships according both to IHSF data and actual data received from ship owners or yards. The results are listed in the previous table "database robustness" and as can be seen, serious inconsistencies are present, especially regarding the deadweight of the ro-ro ships. These inconsistencies are discussed in more detail in Chapter 3.3 of this study.

3.6.5. MEPC 60 / 4 / 47

-MEPC 60 / 4 / 47 - "Prevention of air pollution from ships - Comments on the interim guidelines on the method of calculation of the Energy Efficiency Design Index for new ships based on a study on tests and trials of the EEDI formula" (28 January 2010) **-Submitted by Austria, Bulgaria, the Czech Republic, Estonia, France, Germany, Hungary, Ireland, Latvia, Lithuania, Luxembourg, the Netherlands, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, the United Kingdom and the European Commission**	
Executive summary:	The European Commission, in cooperation with the European Maritime Safety Agency (EMSA), conducted a study on tests and trials of the Energy Efficiency Design Index as developed by IMO. The study provides test results and an overview of technological options to do reduce the attained EEDI.
Main outcomes:	*5 The calculation method for the EEDI is mature and simple, and the index can be calculated for ships representing the majority of world DWT capacity. However, the calculated index value does not express the actual transport efficiency of a ship since it is only calculated for a single design point and not for the complete operation and loading profile. For the same reason the index values of different types of ships are not directly comparable with each other.* *6 It is essential to identify clearly the ship types where the EEDI actually is a comparable measure of efficiency and to recognize the consequences of establishing limitations for the index value.* *7 It is demonstrated through examples that the EEDI would in many cases lead to power limitations for new ships. This, in turn, would standardize design speeds at a certain level depending on ship type and size.* *8 Regarding the applicability of the EEDI, it is concluded that the current approach could be feasible, with certain reservations, for ocean-going cargo ships, e.g., over 15,000 – 20,000 DWT depending on ship type, which have uniform design criteria, i.e. tankers, bulk carriers, containerships, LNG-carriers, LPG carriers, ro-ro vehicle carriers and the largest general cargo ships. These ships account for the majority of CO2 emissions from shipping.* *9 Nevertheless, the current EEDI approach is so far less suitable for certain ship types, small sizes vessels and for ships designed for a certain route or special purpose as well as for ice class ships, ro-ro and ro-pax, e.g., short sea shipping.*
Comments:	The document's contents regarding RoRo's and RoPax's are related to short sea shipping challenges with EEDI; EEDI does not reflect the actual transport efficiency of ships involved in short sea shipping as the value is calculated only at one "design" point. Also the problems of capacity definition were brought up.

3.6.6. MEPC 60 / 4 / 48

-MEPC 60 / 4 / 48 - "Prevention of air pollution from ships - Comments related to trial calculations of the EEDI for subgroups of ro-ro cargo ships" (29 January 2010) **-Submitted by INTERFERRY and CESA**	
Executive summary:	This document comments on the outcome of performed tests and trials in accordance with the grouping of ro-ro ships in vehicle carriers, volume carriers and weight carriers. The performed grouping reveals that only vehicle carriers represent a consistent group of comparable ships as standard ship types (e.g. bulk carriers and tankers). It is therefore concluded that further refinement and improvement for a reasonable design assessment of ro-ro cargo ships should be required.
Comments:	The submission points out that the diversity within the RoRo volume and weight carrier groups is very high due to highly variable design criteria. Additionally, the submission implies that the definition of volume / weight carriers by deadweight per lane meter is not suitable as the value or proposal does not reflect any reasonable design criterions. The second main point in the submission shows that there is a serious problem regarding EEDI baselines and the present RoRo volume / weight carrier grouping. For example a ship with deadweight of 10 000 DWT has baseline requirement of 27,1 g_{CO2}/t*nm if it is classified as RoRo weight carrier, whereas the limit for similar RoRo volume carrier would be 40,8 g_{CO2}/t*nm. In reality the two ships can well be very similar, the only real difference being the deadweight / lane meter value where the difference may well be as low as e.g. 0,2 t / lm. This, however, should not justify the difference between the two required EEDI values. This matter is discussed in more detail in Chapter 4.1.2 of this study.

3.6.7. MEPC 60 / WP.9

-MEPC 60 / WP.9 - "Prevention of air pollution from ships - Energy Efficiency Measures for Ships - Report of the Working Group on Energy Efficiency Measures for Ships" (25 March 2010)	
Comments:	This report presents the outcome of the working group on energy efficiency measures for ships. The group agreed that for RoRo volume and weight carriers, further investigation would be needed in order to find a way to draw feasible baselines for them with less scatter and higher correlation than with the present approach. Thus, until methods of calculation of the EEDI are determined, the requirement "attained EEDI ≤ required EEDI" shall not apply to passenger ships, ro-ro cargo ships (vehicle, volume and weight carriers) and ro-ro passenger ships.

3.6.8. EE-WG 1 / 2 / 8

-EE-WG 1 / 2 / 8 - "Further improvement of the draft text for mandatory requirements of EEDI and SEEMP - Comments on the draft EEDI regulations 1 and 4" (21 May 2010) **-Submitted by the Community of European Shipyards' Associations (CESA)**	
Executive summary:	This document comments on the draft EEDI regulations 1 and 4 set out in document MEPC 60/WP.9. With regard to ro-ro cargo ships other than vehicle carriers, it is proposed to reconsider the definition and to introduce a lower threshold value of 15,000 DWT for the mandatory application of a required EEDI. An alternative baseline reduction scheme is outlined, which will allow for technically feasible reduction of GHG emission, which reduces prediction uncertainties and tedious reviews of new technologies
Comments:	The submission proposes that the investigation into the definition of RoRo cargo ships (other than vehicle carriers) is reopened in order to find appropriate and technically sound EEDI baselines for such vessels. Also, the submission proposes to use 15 000 DWT as threshold value for the mandatory required EEDI application for RoRo ships.

3.6.9. EE-WG 1 / 2 / 10

-EE-WG 1 / 2 / 10 - "Further improvement of the draft text for mandatory requirements of EEDI and SEEMP - Considerations on the establishment of EEDI-baselines" (21 May 2010) **-Submitted by Germany and Sweden**	
Executive summary:	This document is submitted to support discussions on the establishment of EEDI baselines, in particular with regard to ro-ro cargo ships.
Comments:	The objective of the submission is to illustrate the problem of a rather poor correlation between the power law regression curve and the capacity, DWT, for ships of small capacity in general and RoRo ships in particular. The idea is illustrated through presenting how the EEDI basic idea, "calculated EEDI = (impact on the environment) / (benefit to the society)", correlates with various transportation tasks of RoRo vessels and concluded that the current approach is not feasible to short sea shipping. Furthermore, the poor correlation and high standard deviation of RoRo ships are shown in addition to ideas presenting various EEDI baseline modifications by correction factors representing e.g. block coefficient, L/B or B/T - ratio. The correction factors are discussed in more detail in Chapter 4 of this study.

3.6.10. MEPC 61 / 5 / 3

<table>
<tr><td colspan="2">-MEPC 61 / 5 / 3 - "Reduction of GHG emissions from ships - Report of the outcome of the Intersessional Meeting of the Working Group on Energy Efficiency Measures for Ships" (7 July 2010)

-Note by the Secretariat</td></tr>
<tr><td>Comments:</td><td>The Note reports the outcome of the Intersessional Meeting of the working group on Energy Efficiency Measures for Ships. The decisions affecting RoRo and RoPax vessels are that all ro-ro cargo ships (vehicle carriers, weight carriers and volume carriers) are excluded from the first phase of EEDI but noted that the implementation of the EEDI for these ship types should be treated in the same manner as for other ship types.

Another decision also affecting RoRo ships is that if a cut-off limit for EEDI is to be established, it is to be based on the capacity of the vessel, and there should be a single baseline for each ship type.</td></tr>
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3.6.11. MEPC 61 / 5 / 15

<table>
<tr><td colspan="2">-MEPC 61 / 5 / 15 - "Reduction of GHG emissions from ships - Information to facilitate discussion on GHG emissions from ships" (23 July 2010)

-Note by the Secretariat</td></tr>
<tr><td>Executive summary:</td><td>This document provides information on the contribution of CO_2 emissions from each ship type and size, and the Energy Efficiency Design Index (EEDI) coverage based on the cut-off lower limit agreed at EE-WG 1</td></tr>
<tr><td>Comments:</td><td>The Note gives estimation on the amounts of CO_2 the various ship types are emitting and the coverage of the designed EEDI. The amount of total CO_2 emissions from ship types not covered by present EEDI are 25,9% of total CO_2 emissions of shipping. The 25,9% is distributed as follows;

-Passenger ships: 1,9%

-RoRo Vehicle carriers: 2,5%

-RoRo Weight and Volume Carriers: 1,6%

-RoPax vessels: 7,3%

-Others: 12,6%</td></tr>
</table>

3.7. Conclusions on the current EEDI approach for RoRo and RoPax vessels

3.7.1. General

In its present form, the EEDI is not feasible for regulating the energy efficiency of RoRo cargo vessels (weight and volume carriers) or RoPax vessels. The unsuitability of EEDI is due to the fact that the scatter of data is too large for defining feasible baselines. The design criteria for these ship types vary too much. However, for RoRo vehicle carriers the current EEDI approach seems feasible, although either a lower cut-off limit or some correction factor will need to be defined for the smaller vessels.

In case the current EEDI approach is also applied to RoRo and RoPax vessels, multiple things should be reconsidered - mainly the suitability of the baseline approach and how to verify and justify the dimensions such as the capacity or the lane meters of the vessels.

Altogether, the EEDI might not be the most suitable way to define or regulate CO_2 emissions of scheduled traffic or short sea shipping in general. This view is supported by the multiple IMO submissions presented in previous subchapters, submissions conducted by multiple research organizations and other acknowledged associations.

It can be concluded that the current EEDI philosophy as such is not applicable for transportation systems defined by schedules. With these kinds of ships, application of the EEDI could easily lead to sub-optimization and probably to the use of oversized vessels as a strict EEDI approach would concentrate the cargo to big hubs, thus increasing the size of vessels used.

3.7.2. The EEDI for RoRo Weight / Volume Carriers

Currently the RoRo weight and volume carriers are distributed by a dividing factor deadweight / lane meter value of 4t/lm. However, the dividing factor is not justified by any technical argument or common design criteria. As the distribution principle is technically weak and the data correlation is very poor, it can be concluded that the EEDI baseline approach does not give justification for utilizing the EEDI for RoRo volume or weight carriers with the present calculation guidelines.

To be able to include the RoRo volume / weight carriers into the EEDI, it should be considered if the baselines could be defined by taking the special properties of the vessels into account, for example by defining the capacity of the vessels in lane meters or by speed-dependent factors. Altogether, transporting deadweight is not the real transportation task of the RoRo vessels, but carrying lane meters is. Thus, lane length or cargo area/volume is a more logical measure of capacity than deadweight for RoRo vessels. These aspects are discussed in more detail in Chapter 4.1.3 of this study.

In addition, as the scatter of design speeds is very large due to different transportation task and overall design criteria and limitations, it should be studied if speed could be included into baseline definition or the attained EEDI calculation formulas in order to enhance the feasibility of the EEDI approach for such ships. As such, one way forward could be comparing RoRos to other means of transport, such as trucks and rails, though such an approach is hardly feasible or relevant in a regulative sense.

A strict EEDI approach for RoRo volume carriers is a bit questionable since it would reduce the operation speeds on certain routes and thus make short sea shipping schedule-wise less attractive when compared to road or rail transportation. From the overall emission point of view the whole transportation chain has to be considered for trucks and trailers including different distances and specific emissions on sea and road routes. Short-sea shipping is compared against other means of transport in Chapter 5.2 of this study.

3.7.3. The EEDI for RoPax vessels

The main challenge of the current EEDI baseline approach regarding RoPax vessels, in addition to the challenges mentioned previously with RoRo volume / weight carriers, is that of defining the capacity of the vessel. In addition to lane meters (trucks, other heavy vehicles and passenger vehicles), the vessels also carry passengers. Some of the RoPax vessels have cabins and large “hotels” for the passengers (night ferries), and some have only small public spaces (day ferries).

One option for implementing RoPax vessels into the EEDI baseline approach could be by defining a special “capacity factor”, which would reflect the passenger capacity with gross tonnage, and lane meter capacity with deadweight. However, such an approach is very challenging as the trailers and other heavy vehicles can be, to some extent, measured by deadweight but the passenger vehicle capacity is mainly volume related. Additionally, using gross tonnage for capacity definition does not necessarily characterize the real “cargo capacity” as the gross tonnage does not make any difference between cargo and machinery spaces. All in all, developing a suitable “capacity factor” could be the best way to include RoPax vessels into the current EEDI baseline approach. These issues are discussed in more detail in Chapter 4.2.3.3 of this study.

Overall, the current EEDI approach would limit the design speed of new vessels. That could make newbuildings on some route, where high speed vessels are most practical, less feasible. The end result would then be to either use older vessels or shift to road or air transportation. In other words, a very rigid EEDI approach could in the end lead to transition of the cargo away from RoPax vessels, since in many cases RoPax ships are actually competing against all of the other methods of transportation. The cargo could be shifted to container vessels or general cargo vessels and the passengers to airplanes and roads. This is of course possible, but not certainly desirable from the industry’s point of view.

4. Possible EEDI adjustments for RoRo cargo and RoPax vessels

In this chapter the possible adjustments to the EEDI methodology for RoRo cargo vessels and RoPax vessels are studied in order to find a method to fairly include them as part of the EEDI baseline approach. As mentioned previously, RoRo vehicle carriers will not be included in closer examination as this ship group appears to work adequately with the current EEDI methodology. For RoRo cargo carriers, the current cargo vessel grouping is studied and source / sample data validity is discussed further. Various alternative methods to include the RoRo cargo vessels and RoPax vessels into the EEDI baseline approach with alternative baselines are studied.

4.1. RoRo cargo vessels

4.1.1. Analysis of the sample set based on the IHSF source data

The source data from the IHSF database (Lloyds Register (IHSF) - Fairplay register 10.01 (Shippax 3.3.57)) has to be filtered in order to exclude the data points which do not have full information on the ship. The results of data filtering are shown in Table 13, thus only the vessels with full data as shown in the table are included in further tests.

Out of the original 653 RoRo ships, 579 (89%) are included in the conventional EEDI calculations. After filtering, 74 (11% of original 653) RoRo weight carriers and 51 (8% of original) RoRo volume carriers were remaining for further studies. Thus, the sample size used in the calculations and tests on RoRo cargo vessels within this study in the following chapters is 125 vessels.

The distribution of the calculated EEDI values according to conventional guidelines is shown in Figure 12 for the 141 RoRo cargo vessels. When comparing the figure to Figure 13 where the filtered data (125 RoRo cargo vessels) is shown, it can be seen that even though the number of data points has been reduced by 16 pieces the scatter, correlation and standard deviation tendencies have remained. Furthermore, the baseline is roughly at the same level, so it can be concluded that using this set of 125 RoRo cargo vessels, or “filtered data” in the forthcoming calculations and tests will give valid results. In case a suitable method for including the RoRo cargo vessels into the EEDI baseline approach is found, it will be verified with proven, accurate data.

Similarly to the other ship groups such as “General cargo ships” or “Gas tankers”, the smallest vessels (in this case the vessels with DWT < 1000) are excluded as it is not seen feasible to include them into the EEDI approach due to their highly variable transportation tasks and because the number is so small that there are no substantial emission reductions available by regulating this group. Additionally, the design criteria for such ships do not correlate with the design criteria of the larger vessels. The final cut-off limit will be defined within the IMO at a later stage.

Table 13 - RoRo vessel source data info

	All		*RoRo Weight carriers*		*RoRo Volume carriers*		*RoRo Vehicle carriers*	
	PCS	**% remaining**	**PCS**	**% remaining**	**PCS**	**% remaining**	**PCS**	**% remaining**
IHSF data	653	100,00 %		100,00%		100,00%		100,00%
Other than conventional propulsion system removed	647	99,08 %	-	-	-	-	-	-
Empty datasets (power, deadweight or speed) removed	598	91,58 %	-	-	-	-	438	-
Missing lane meters removed (weight + volume)	579	88,67 %	-	-	-	-	-	-
For conventional EEDI	**579**	88,67 %	**81**	100,00%	**60**	100,00%	**438**	-
Missing L_{BP} removed	-	-	74	91,36 %	53	88,33 %	-	-
Small ships (DWT < 1000) removed	-	-	-	-	51	85,00 %	-	-
After filtering	**563**	**86,22 %**	**74**	**91,36 %**	**51**	**85,00 %**	-	-

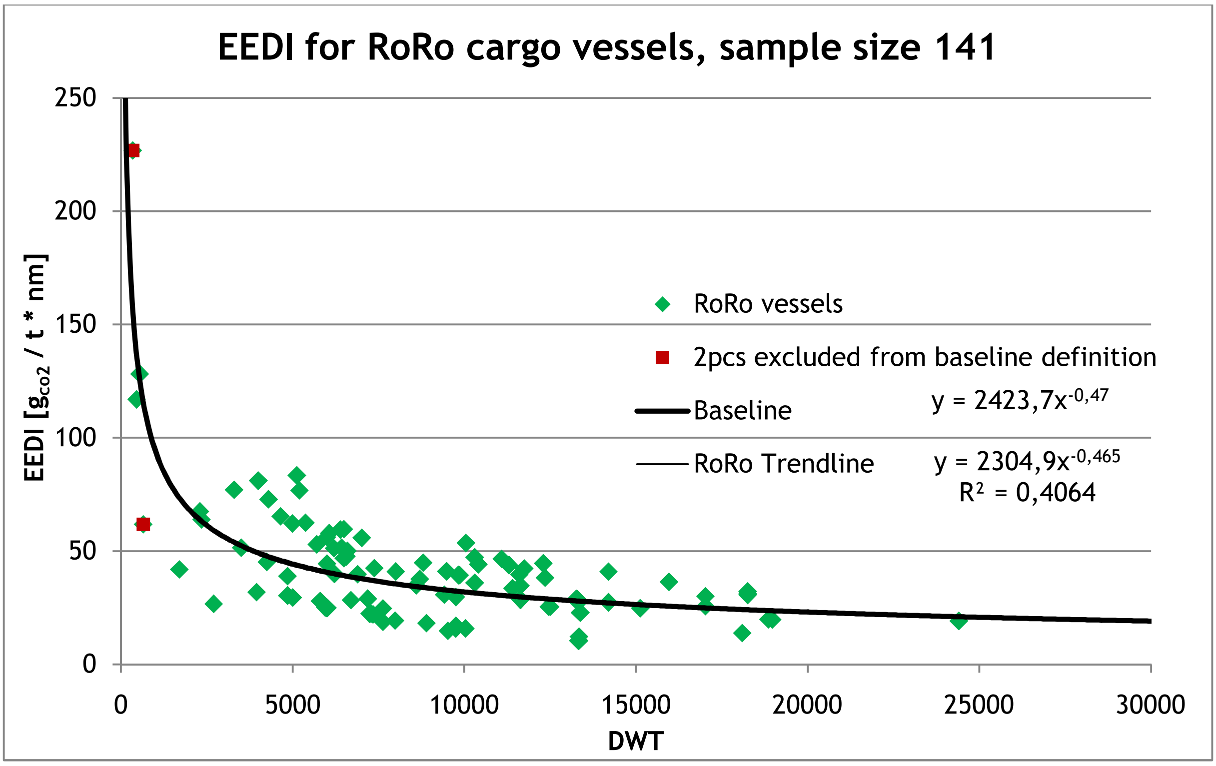


Figure 12 - EEDI for RoRo cargo vessels

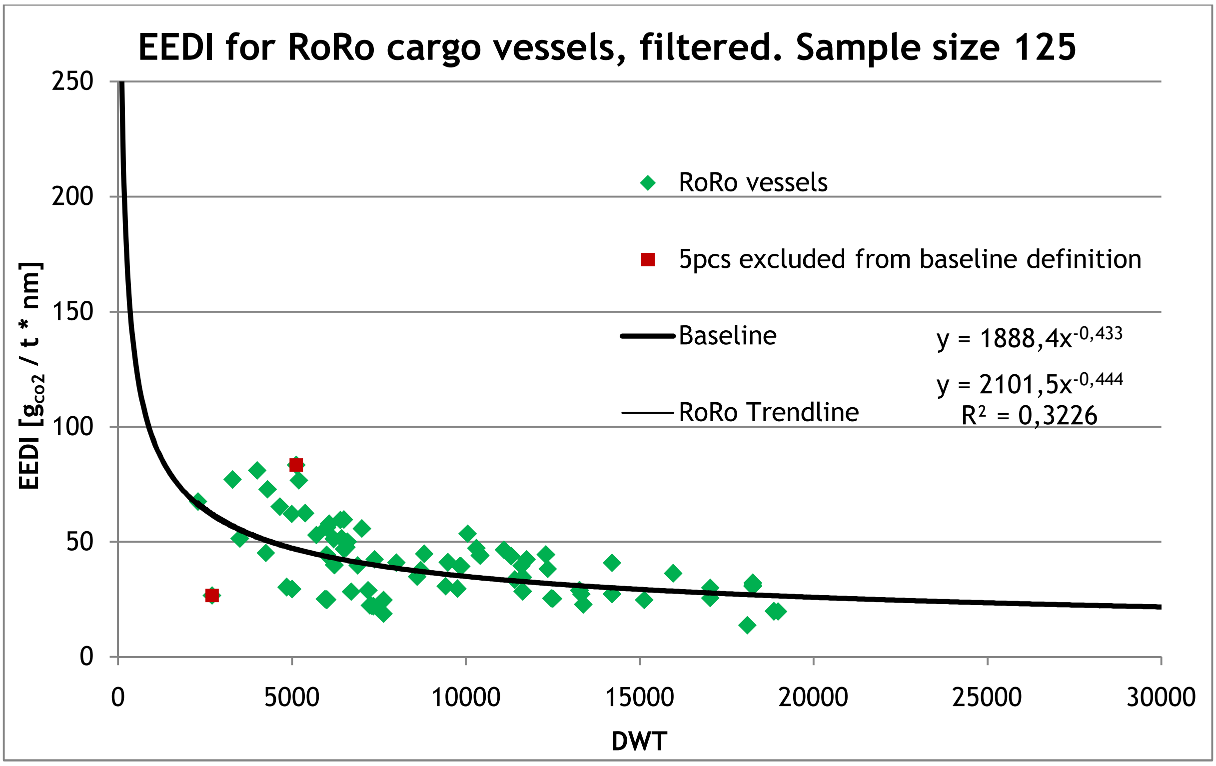


Figure 13 - EEDI for RoRo cargo vessels (excluding vehicle carriers), filtered

The sample size of 125 vessels also includes four sister ships, as can be seen from the figure above. These vessels over 5000 DWT have been excluded from the baseline definition.

4.1.2. Evaluation of the present RoRo cargo vessel distribution

According to the latest EEDI calculation guidelines, “Guidelines for calculation of reference lines for use with the energy efficiency design index” (Annex 4, MEPC 61/5/3), RoRo cargo ships are distributed into three separate groups, namely RoRo volume carriers, RoRo weight carriers and RoRo vehicle carriers. The categorization principle is that the weight and volume carriers are distributed by deadweight / lane meter equaling or exceeding 4t/lm (weight carriers) or passing under 4t/lm (volume carriers). The vehicle carriers are a separate group intended purely for carrying of empty cars and trucks.

As noted in chapter 3.7, the current approach is considered feasible for RoRo vehicle carriers but not feasible for RoRo volume or weight carriers. This is due to two main reasons. First of all, the scatter of transport tasks and design criteria is too large to reliably measure the vessels with the current approach. Secondly, the dividing criterion between “RoRo weight carrier” and “RoRo volume carrier” is technically irrelevant. As seen in Figure 14, even though there is clear tendency for the weight carriers for lower speeds and for volume carriers towards higher speeds, no clear distribution is visible between the two groups. Additionally, there is huge a scatter in the calculated EEDI values within similar speeds, e.g. at 20kn there is a 60 unit difference (~400%) and at 22kn there’s EEDI value variation from 25 to almost 85, in other words, a 340% difference.

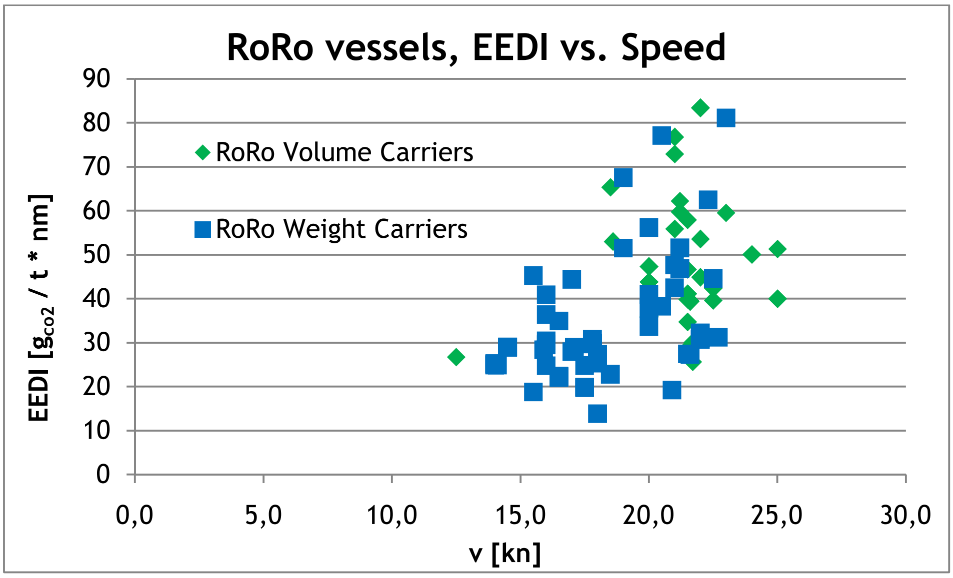


Figure 14 - RoRo vessel, excluding vehicle carriers, speed distribution vs. EEDI value

The present RoRo weight / volume carrier distribution principle has been left open for further discussions and considered as unfeasible in multiple IMO MEPC submissions. It can be noted that if plotted in the same graph there is no clear reason visible for dividing the RoRo weight and volume carriers into separate groups as demonstrated in Figure 15.

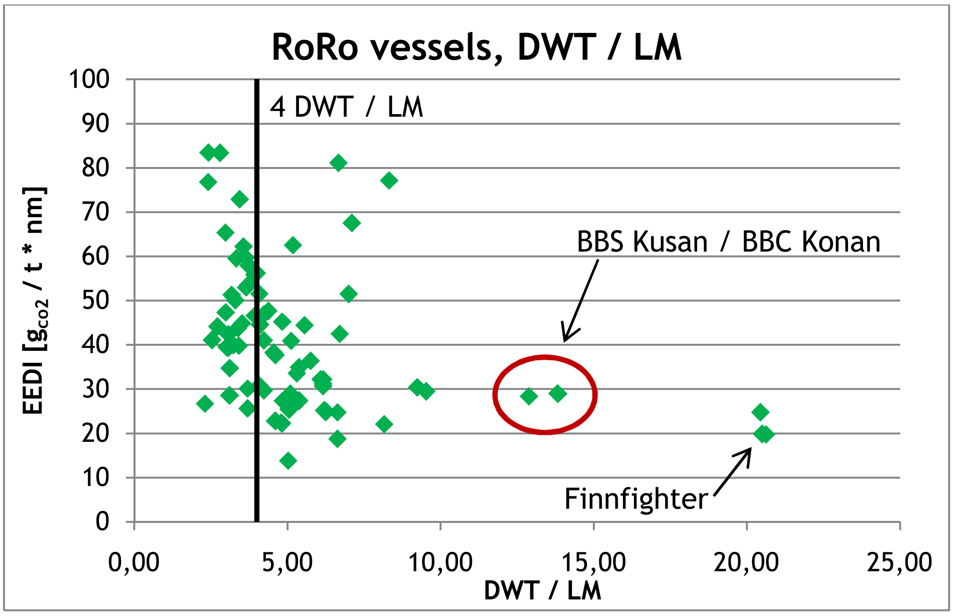


Figure 15 - RoRo DWT / LM distribution vs. EEDI value

It can be noted that there is no "border" between DWT/LM greater or equal to 4dwt/lm (RoRo weight carriers) or under 4dwt/lm (RoRo volume carriers) and thus it is concluded that the present RoRo weight/volume carrier distribution should be reconsidered. In the following EEDI tests and evaluations in this study the RoRo cargo vessels are treated as a single group.

The ships with dwt / lm over 10t/lm usually have containers or bulk as the main cargo, with only a small amount of lane meters, e.g. one RoRo deck for cargo flexibility and for serving the special needs of the specific transport task. As such the vessels are "basic bulk carriers or containers" with added flexibility.

The vessels with ~14-15 DWT / LM value are "BBC Kusan / BBC Konan", designed for heavy cargoes and for also carrying other cargo than pure RoRo cargo. The ones with over 20dwt / lm are very specialized ships, such as the Finnfighter, a pallet vessel / bulk carrier with only a small RoRo capacity.

Another problem with the RoRo weight / volume carrier distribution is the deadweight per lane meter limit of 4t / lm. As shown previously in Figure 15, there is no clear border between the groups and thus there is a loophole possibility. Modifying the DWT / LM - ratio is simple, as there is no standardized method for defining lane meters and the deadweight of the vessel can easily be affected by e.g. designing large fuel tanks which are left empty in everyday operations. The reason for such modifications is, as shown in Figure 16, that the difference between RoRo weight and RoRo volume carrier baselines is significant. As seen, there is large difference between the allowed EEDI values, from 15% to 50% depending on the DWT of the vessel.

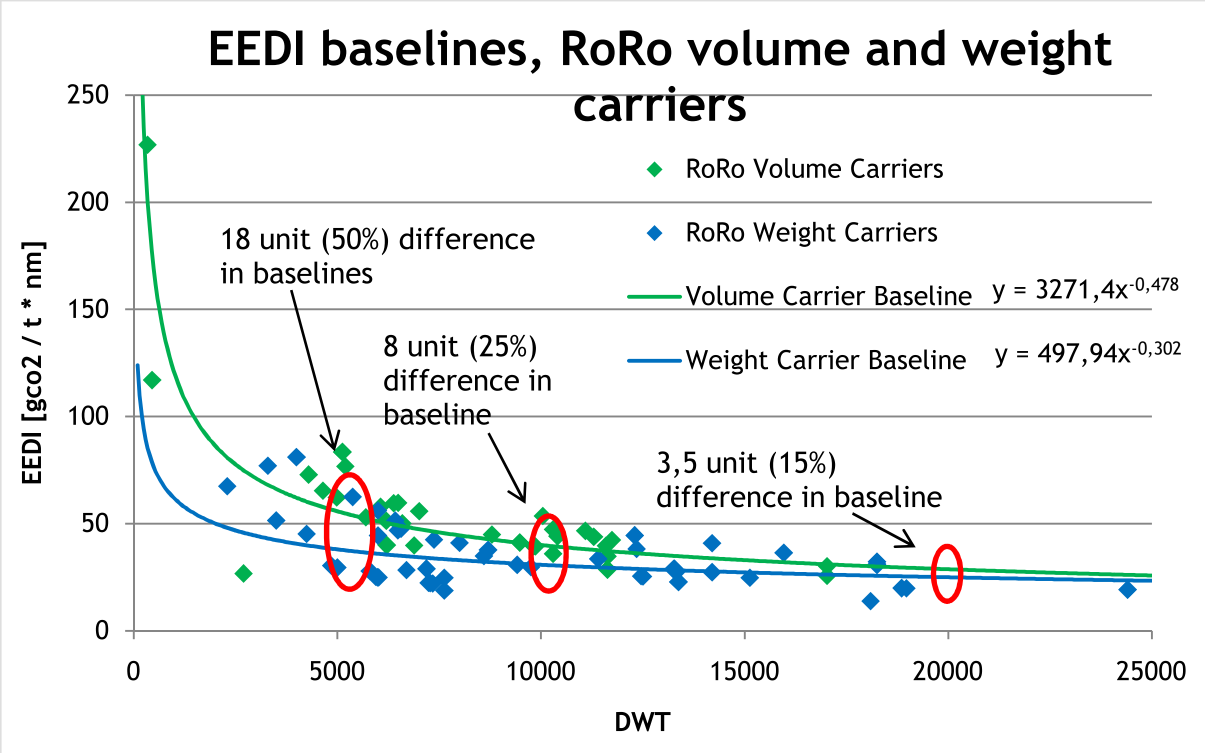


Figure 16 - RoRo Volume and Weight carrier EEDI overlap

Altogether it can be concluded that the distribution of RoRo cargo vessels into three groups does not seem feasible as it is not based on clear differences in the design of the vessels. Instead, the RoRo cargo vessels should be divided into two groups, namely to the vehicle carriers as defined in the present criteria and to RoRo cargo vessels, which would consist of both RoRo weight and volume carriers.

4.1.3. Possible EEDI modifications for RoRo cargo vessels

Possible modifications to the EEDI baseline approach were studied and tested in order to try to find a method to also include the RoRo cargo vessels in the scope of the EEDI. In the following chapters the designation "RoRo cargo vessels" will exclude RoRo vehicle carriers due to reasons discussed in the previous chapter. Also, vessels whose deadweight is under 1000 DWT have been excluded.

4.1.3.1. Correction factors for the EEDI formula and baselines

In order to include the RoRo cargo vessels in the EEDI baseline approach, multiple tests were done. One of these tests consisted of determining whether a specific ship type correction factor could be identified in order to include RoRo cargo vessels in the conventional EEDI baseline approach. Additionally, different capacity factors such as lane meters or the gross tonnage were tested in place of the currently used deadweight to see if they would give better correlation than the present deadweight approach. The EEDI value was also plotted against Froude's number and the completed transport work (speed * deadweight and speed * lane meters) for the same reasons.

The EEDI formula is presented in its complete form in Chapter 3.4. When calculating the EEDI values for existing vessels, the formula can be simplified to:

$$EEDI = \frac{Power * SFOC * C_f}{Capacity * Speed}$$

Now, when evaluating the possible new EEDI approach of the baseline definition for existing ships, it can be noted that there are not many ways to affect the EEDI baseline or calculated EEDI. Basically the only option is to use various capacities to try to find a common nominator for the ships, or alternatively scale the EEDI values according to a specific property of the vessels, such as the capacity or speed.

In Figure 17, the present RoRo vessels (built 2000-2010) are plotted according to the EEDI values calculated according to the MEPC.1/Circ.681 guidelines as presented in Appendix 2.

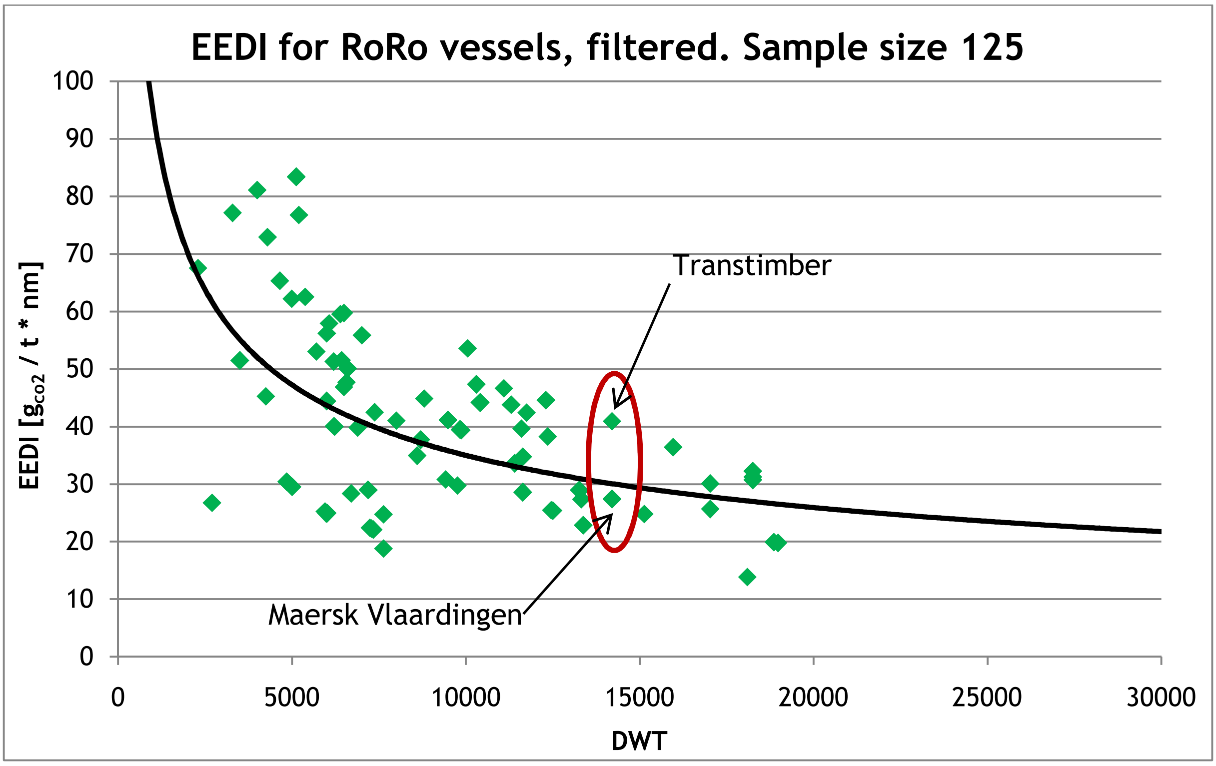


Figure 17 - RoRo conventional EEDI

In the figure above, two similar ships of the same size have been selected for closer examination. The other, Transtimber, is operating in the Baltic and North Seas and has an ice-class 1 A Super and thus high power. The other, Maersk Vlaardingen, operates in the Mediterranean and is not required to have an ice-class. Transtimber has a lower design speed, but higher main engine power and therefore ends up above the EEDI baseline, whereas Maersk Vlaardingen fulfils the EEDI requirement. This example points out that the specific properties of the vessels should be taken into account.

The various EEDI formula correction factors tested are listed in

Table 14.

Table 14 - Summary of tested correction factors for RoRo vessels, chart data

EEDI for RoRo vessels, excluding vehicle carriers		
Table / Appendix	***Capacity in EEDI formula***	***EEDI baseline / X-axis***
Figure 17	DWT	DWT
Figure 18	LM	Capacity = LM
Figure 19	GT	Capacity = GT
Figure 20	DWT	Fr
Figure 21	DWT	Transport work (LM x v)
Figure 22	DWT	Transport work (DWT x v)
Figure 23	Speed factor	DWT

Replacing capacity with lane meters (Figure 18)

Using lane meters as the capacity in the EEDI formula and the baseline definition, the correlation and standard deviation of the group are enhanced. However, a sufficient level of correlation was not reached and thus the method can be considered unfeasible. Especially the vessels with less than 1500 lane meters have a very wide scatter in the calculated EEDI values, most probably due to the different transportation task criteria (small RoRo full on lane meters vs. large RoRo with only a small amount of lane meters).

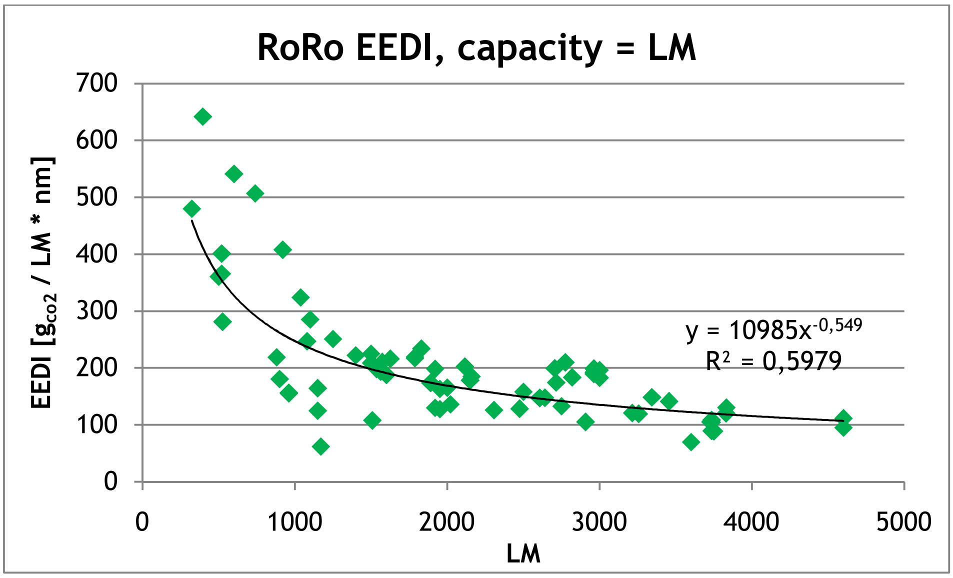


Figure 18 - RoRo EEDI, Capacity = LM

Replacing capacity with gross tonnage (GT), Figure 19

Similarly to lane meters, when replacing the capacity both in the EEDI formula as well as in the baseline with gross tonnage, the standard deviation and correlation are improved but are still not good enough for regulative actions and as such the method is not considered feasible. Especially smaller ships (< 10 000 GT) have a high scatter in the calculated EEDI values, similarly to small ships in the previous tests.

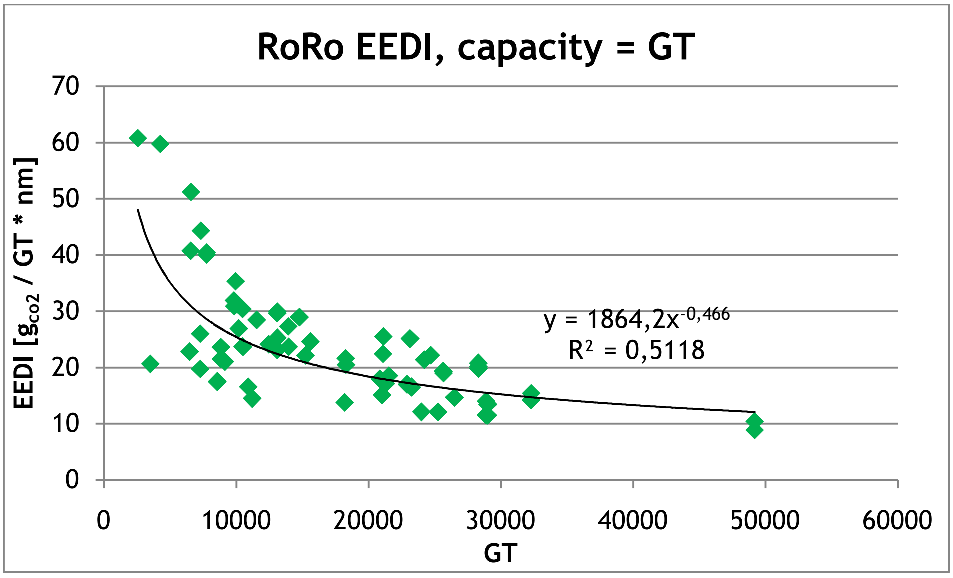


Figure 19 - RoRo EEDI, capacity = GT

Using Froude's number as X-axis, Figure 20

Plotting the EEDI values against Froude's number, i.e. the speed-length ratio of the vessel, does not give good results. It can be clearly seen that the Froude numbers between the sample data settles roughly between 0,175 and 0,3. Due to the high scatter and low correlation, it can be concluded that this is not the correct method to evaluate the energy efficiency of these vessels.

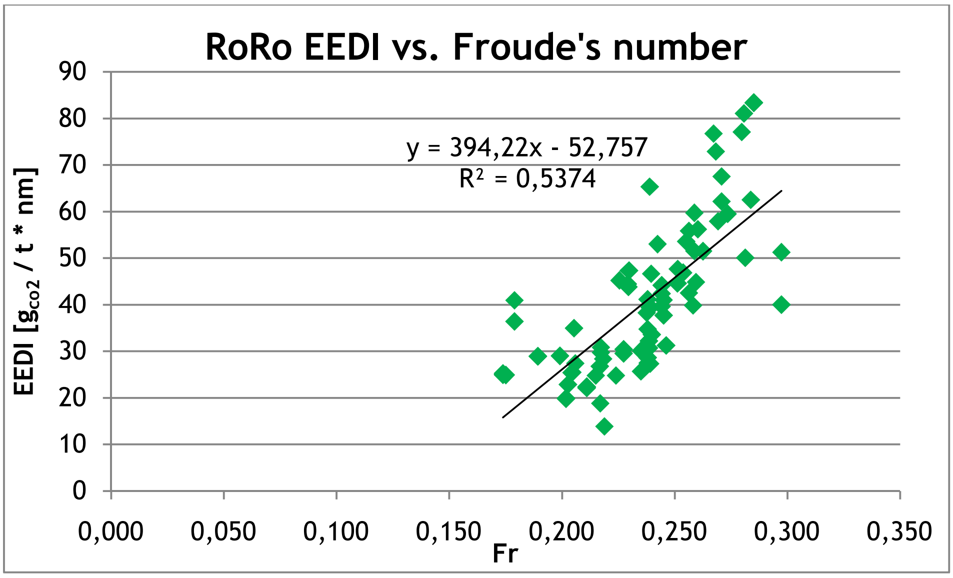


Figure 20 - RoRo EEDI vs. Froude's number

Measuring energy efficiency by completed transport work (LM * v), Figure 21

If plotting the completed transport work in "lane meters * speed" against EEDI values, it can be seen that the scatter of data is very high and no correlation exists. This is due to the highly varying transport tasks and design criteria of the vessels.

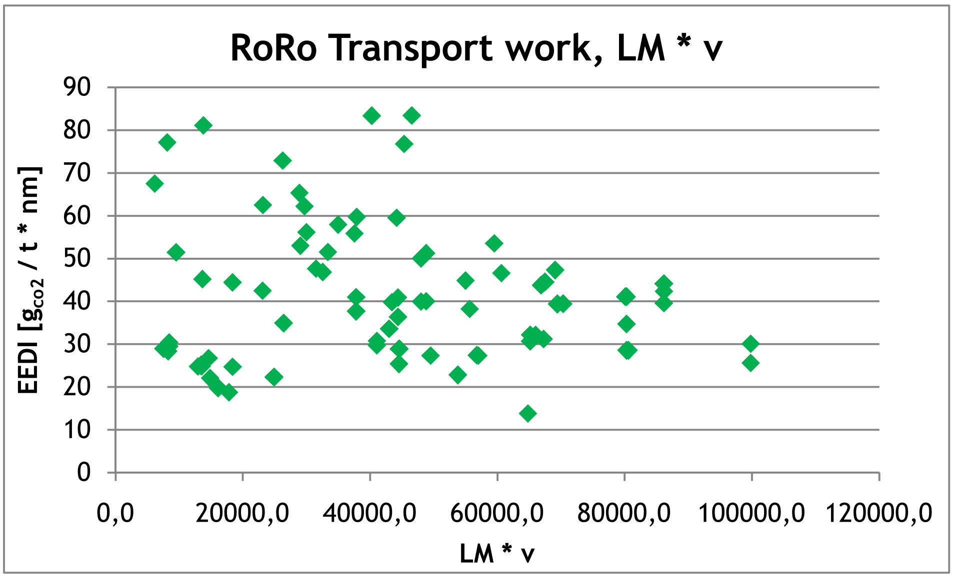


Figure 21 - RoRo Transport work

Measuring energy efficiency by completed transport work (DWT * v), Figure 22

Plotting calculated EEDI value against completed transport work in (deadweight * speed), it can be noticed that even though the scatter is slightly better than in the previous case, the scatter is still too high for a regulative basis. The scatter is due to different transport tasks and design criteria of the vessels.

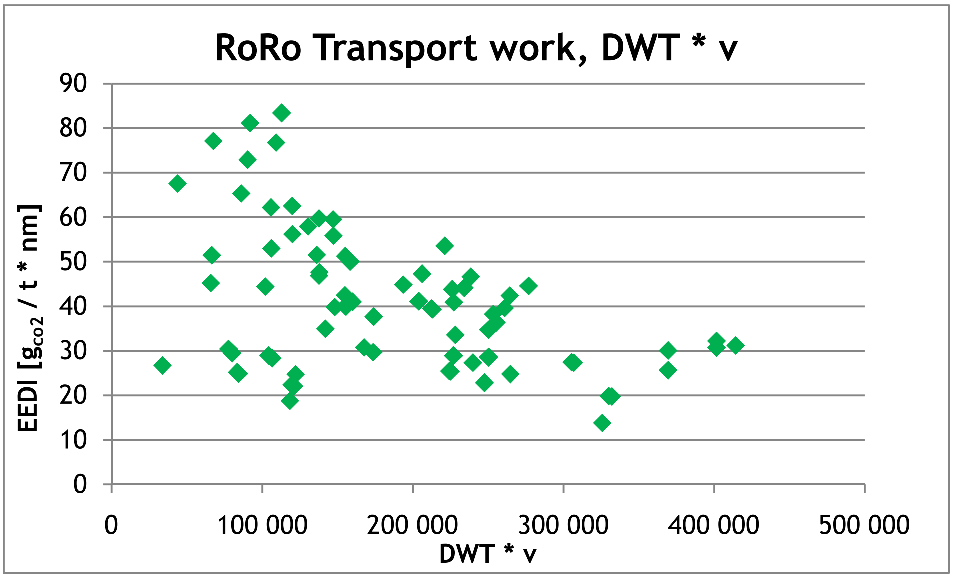


Figure 22 - RoRo Transport work, DWT * v

Using a speed factor to take into account the higher power requirements of the faster vessels, Figure 23

The idea is to multiply the attained EEDI value of the ships with higher design speed than the average speed of the group with "Speed of the vessel / Average speed of the group". If the speed of the vessel is higher than the average speed the attained EEDI value is decreased and if the speed of the vessel is under the average the attained EEDI is retained. Thus, e.g. a ship with higher speed is allowed to have the higher power than the average of that group and the slower vessels retain the attained EEDI values.

However, the result of such approach is that the differences between the vessels are not much evened out but instead remain pretty similar to the conventional EEDI approach and thus a speed factor is not seen as a feasible option.

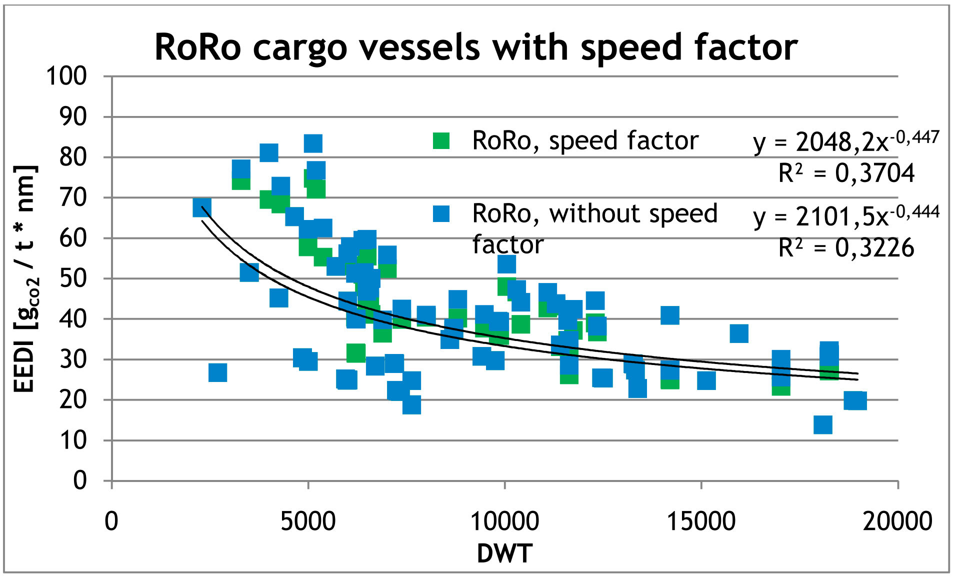


Figure 23 - RoRo EEDI with speed factor

The main problem with the conventional EEDI approach seems to be that instead of the capacity measurement, the real problem is that the relation between power and speed has been calculated linearly. However, in reality the dependency between the two is related to the third power as noted in Chapter 2.2. Another problem is the large scatter of the transportation tasks, which lead to varying design criteria and no real correlation between the vessels. This is because some of the vessels have slow speed 2-stroke engines and a low design speed and carry mostly bulk cargo in addition to some rolling cargo. Whereas other ships have medium speed 4-stroke engines and a high design speed and carry expensive light cargo. Thus, there is no unifying dimension available with which the vessels could be ranked.

Altogether it can be concluded that since the design criteria (= capacity and speed) vary so much, it seems that there is no common factor for RoRo ships to be included in the conventional EEDI baselines approach. Instead, the required EEDI for the vessels could be dependent on the design speed as discussed in more detail in Chapter 4.3.

4.1.3.2. Alternative baseline approach for RoRo cargo vessels

Alternative methods for defining the baselines were tested in order to evaluate if the RoRo cargo vessels would have a better fit with another baseline approach. The conventional baseline definition formula is shown in the formula below:

$$Baseline = a * Capacity^{-c}$$

In the formula "a" and "c" are constants that are defined by a regression line. The capacity is defined as DWT for RoRo cargo vessels.

As can be seen, the baseline is proportional to the capacity of the vessel. As tested in the previous subchapter, such approach where the required EEDI is compared to this kind of conventional baseline does not give good enough correlation with the tested capacities.

In order to find better correlation for the RoRo cargo vessels, alternative methods for defining the baselines were tested. First of all, the capacity in the formula was replaced by (v/capacity), as proposed already in GHG-WG 2/2/22 by CESA. The idea is shown in the following equation;

$$Baseline = a * \left(\frac{v_{ref}}{capacity}\right)^{-c}$$

The reasoning behind is that the fast vessels having less cargo are treated dissimilar to large vessels with large amounts of cargo. The result is shown in Figure 24, and as can be seen the scatter of data is high and correlation bad. This is due to the fact that the chart mixes slow vessels with a medium amount of cargo to fast vessels with large amounts of cargo. The two different subtypes of RoRo cargo vessels have varying design criteria and often very dissimilar design and power levels, leading to a high scatter of data points.

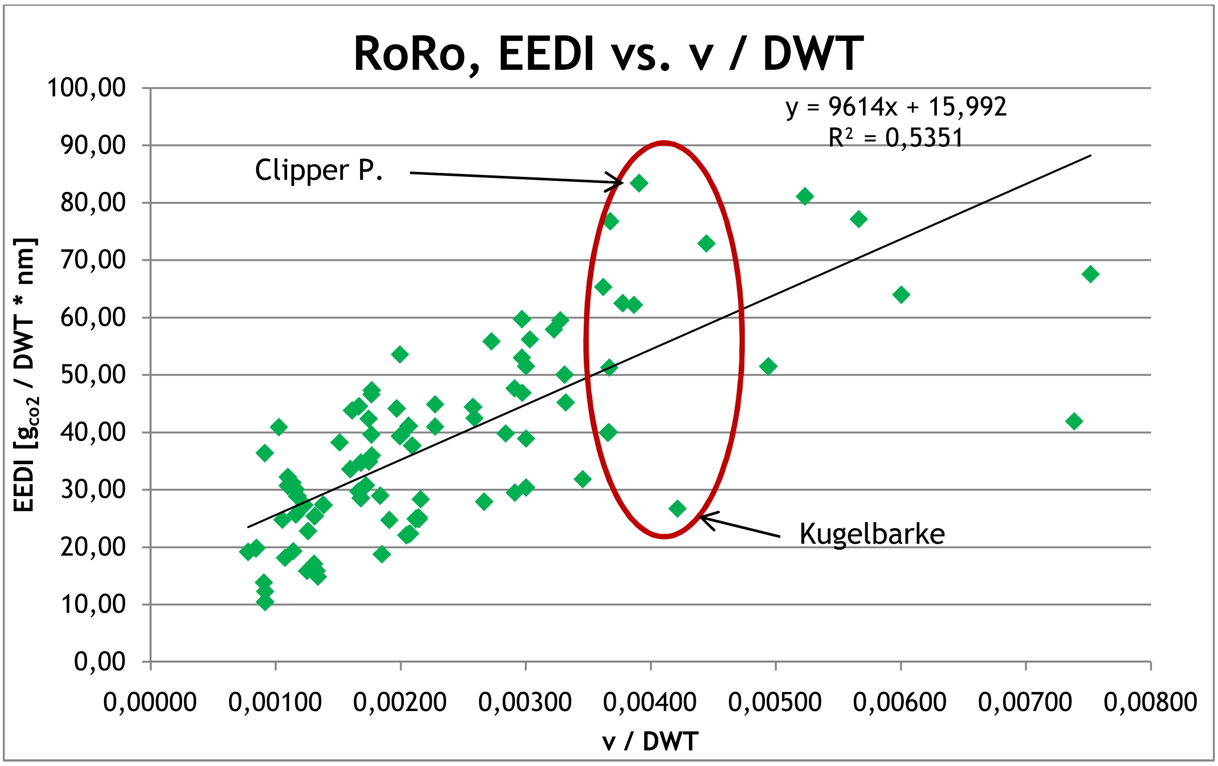


Figure 24 - RoRo EEDI, v / Capacity

For example, Kugelbarke which is the lower ship in the graph is designed to carry Airbus parts and offshore wind turbines on short voyages. The vessel is slow and small, thus receiving a low EEDI value.

On the other hand, the four sister ships (Clipper Pace / Panorama / Pennant / Point) operating between Ireland and UK get very high EEDI values because they are fast RoRo vessels with a low deadweight. The vessels are relatively small and have a high design speed of 22kn, thus the propulsion power requirement is high.

The EEDI formula and modified baseline requirement can be expressed in simplified form as:

$$EEDI = \frac{Power}{Capacity * Speed} = Baseline = \left(\frac{Speed}{Capacity}\right)^{-c}$$

One can notice that the importance of capacity diminishes whereas more emphasis is put on speed. This is physically a better way to evaluate a RoRo vessel, especially because the power is related to the speed in the third power, the physical dependency is enhanced. Because of that, the next step is to increase the speed to the third power for the baseline and define the previous "capacity" in the baseline formula as $\frac{v^3}{DWT}$. The results are shown in Figure 25.

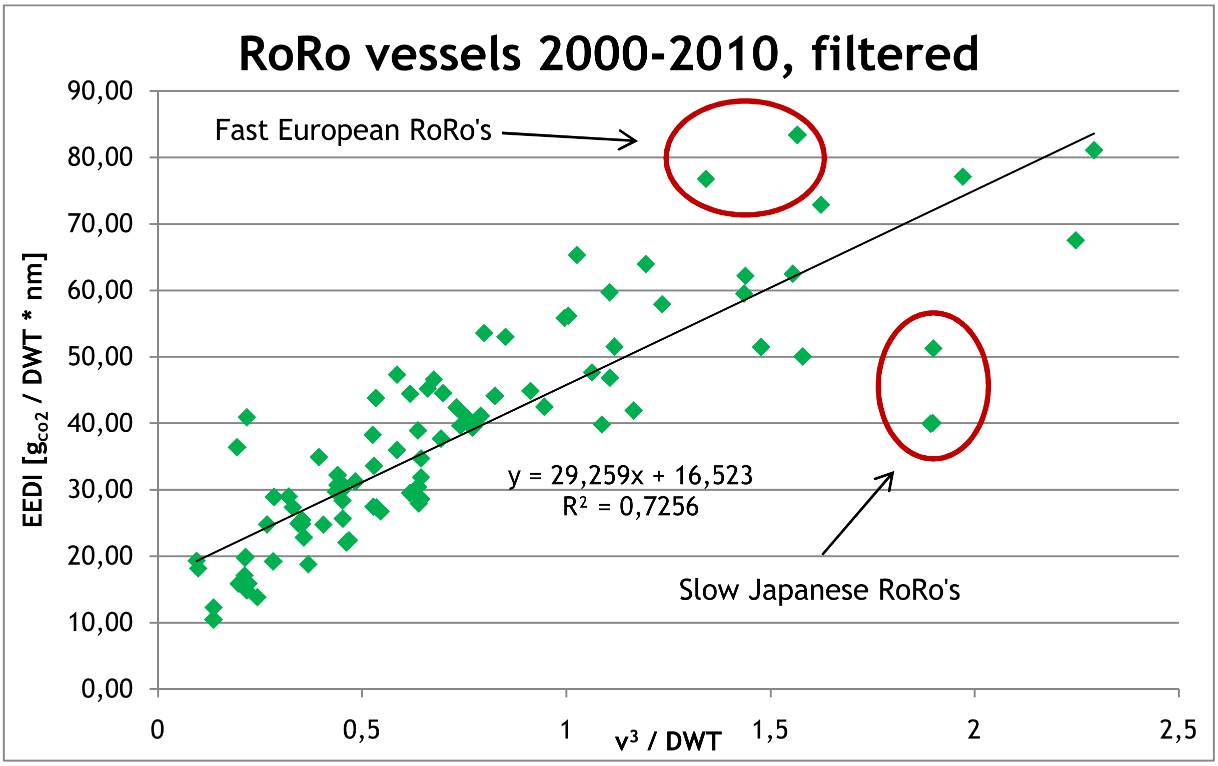


Figure 25 - EEDI vs. v^3 / DWT

Defining the conventional capacity in the baseline formula as v^3 / DWT seems to give relatively promising results. The data correlation is relatively good, though absolute variations are large. The circled ships present the two extremes of the RoRo cargo vessel group. The selected Japanese ships are relatively slow, have one slow-speed main engine with one shaft line and propeller, whereas the European counterparts are quick with a limited draught, which drives the design away from the possible optimal solution. This leads to higher power requirements and a higher EEDI value. The European ships are often ice-strengthened, which reduces the deadweight and increases the power requirements. However, these two ship pairs could not replace each other as the transportation tasks and operating areas are too different.

Although the v^3/DWT approach seems to give fairly good results, speed-wise this is not the case. To give a more detailed outlook on the results, small ships below 5000 DWT were excluded and the remaining ships were grouped into speed groups within 2kn intervals. From the figure below, it can be noticed that the scatter of the data remains large within the selected speed intervals. Since the variations in the v^3/DWT approach are large for ships with similar speeds, the approach cannot be considered feasible.

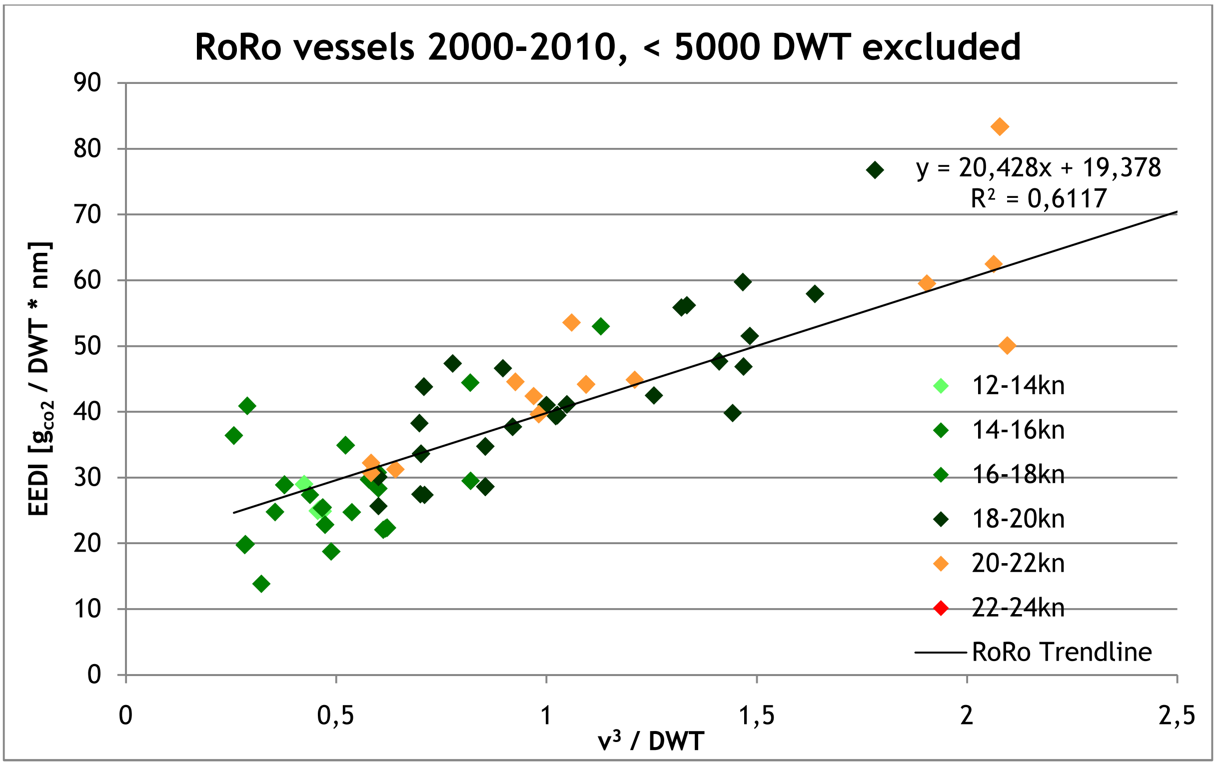


Figure 26 - RoRo EEDI vs V^3/DWT speed groups

The size of the speed groups are presented in Table 15.

Table 15 - RoRo cargo vessels, speed groups for v^3/DWT

	PCS	%
12-14kn	6	5,4 %
14-16kn	25	22,3 %
16-18kn	11	9,8 %
18-20kn	41	36,6 %
20-22kn	26	23,2 %
22-24kn	3	2,7 %
Total:	112	100,0 %

A more feasible option could be to define a progressive EEDI that would utilize the present EEDI approach but combine it with speed-dependent baselines. This way, vessels with similar design speeds could be compared with each other. These speed dependent baselines are discussed in more detail in Chapter 4.3.

4.2. RoPax vessels

4.2.1. Analysis of the sample set based on the IHSF source data

The IHSF data for RoPax vessels was filtered in order to retain datasets containing all the required information for further studies. The results of the data filtering are shown in Table 16.

Table 16 - RoPax source data info

		RoPax	
	PCS	**PCS removed**	**% remaining**
IHSF data	499	-	100,00 %
Other than conventional propulsion system removed	446	53	89,38 %
Empty datasets (power, gross tonnage or speed) removed	385	114	77,15 %
v < 15kn and R^2 > 2 removed	306	193	61,32 %
For conventional EEDI	**306**	**193**	**61,32 %**
Missing lane meters or passenger number removed	164	335	32,87 %
Missing L_{BP} or DWT removed	157	342	31,46 %
Final dataset	**157**	**342**	**31,46 %**

The original data set from the IHSF database contains 499 RoPax vessels. Out of them, 306pcs (or 61,32%) have been used for defining the conventional EEDI. However, for the purposes of this study the source data was filtered even further, so that vessels with all the required data were left. The final data set used in this study consists of 157pcs (or 31,46%) of the original data.

Comparing the filtered data (Figure 28) to the original datasets (Figure 27) used for the conventional EEDI definition, it can be noticed that the baselines and data scatter have remained relatively similar. Therefore the filtered data used in the following studies can be presumed to represent the whole RoPax group fairly well.

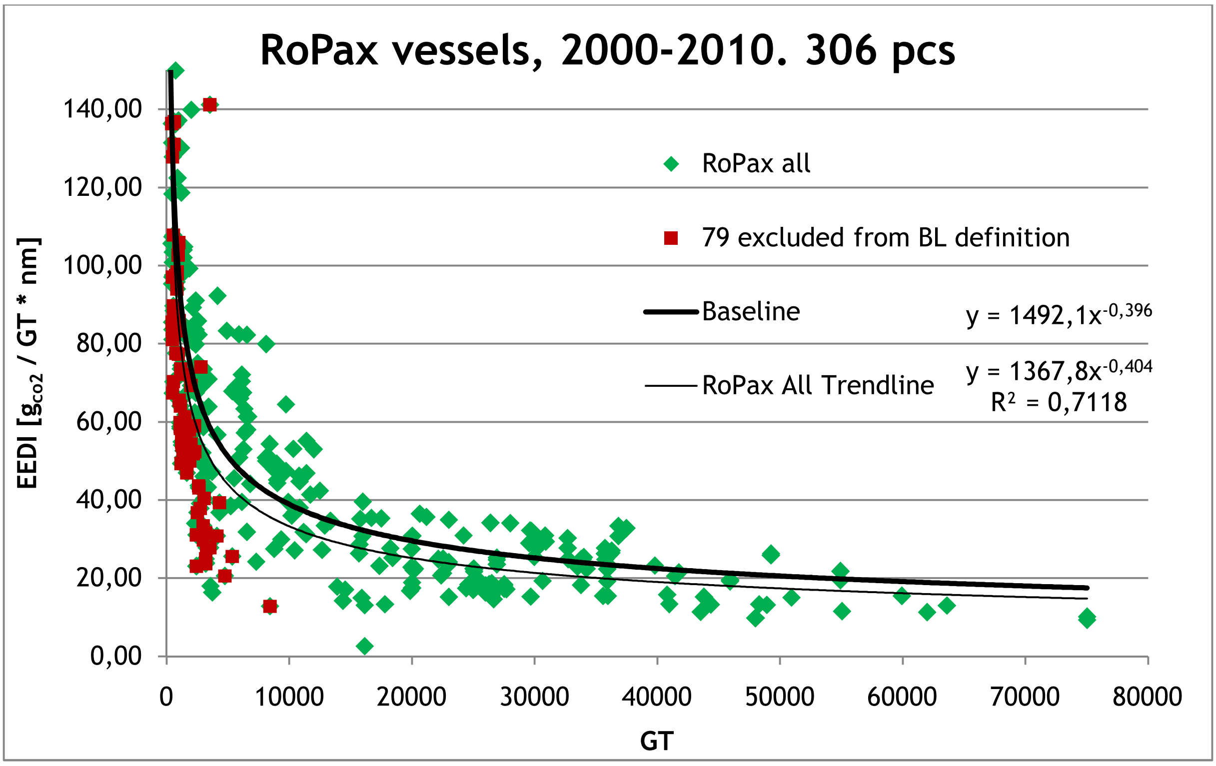


Figure 27 - EEDI for RoPax, all

Even though the tendency and scatter of the data between the two sets is retained quite well, a question arises whether the remaining 157 samples represent the whole group sufficiently. Nevertheless, this inconsistency is noted in the following studies and it is acknowledged that by drawing the baseline proposals with roughly 30% of the original sample data, a large margin for error exists and the final proposal should be verified at a later stage with as large and comprehensive data group as possible.

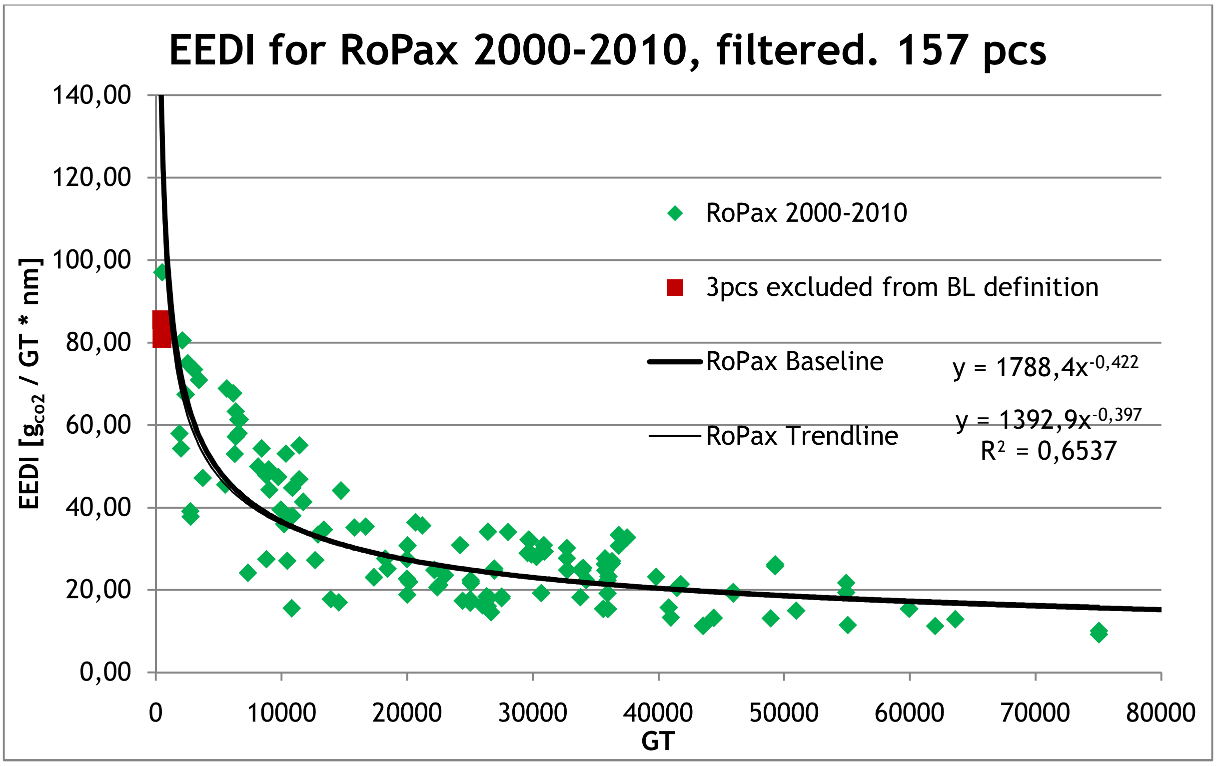


Figure 28 - EEDI for RoPax vessels, filtered

4.2.2. Evaluation of RoPax vessels as one group

The RoPax vessel group contains multiple vessels with varying design criteria. As the basic definition "Ro-Ro passenger ship means a passenger ship with ro-ro spaces or special category spaces" - suggests, there is a plethora of different types of ships within the group. The RoPax vessels are defined as a single group in the EEDI, even though the high scatter in the conventional EEDI baseline approach shows that there might be various subgroups inside the main RoPax group that could be separated or completely excluded from the EEDI approach.

The speed variation within the RoPax vessel group is very high due to specific schedules that depend heavily on the operation area and transportation task. In Figure 29 the conventionally calculated EEDI values are plotted against speed. The speed varies from roughly 10kn (ferryboats) to 42,5kn (high speed craft). The remaining "group" then forms the "conventional RoPax" - vessels, which by themselves have a highly variable transportation task and design criteria due to different operation areas and main dimension limitations and thus also a relatively high scatter.

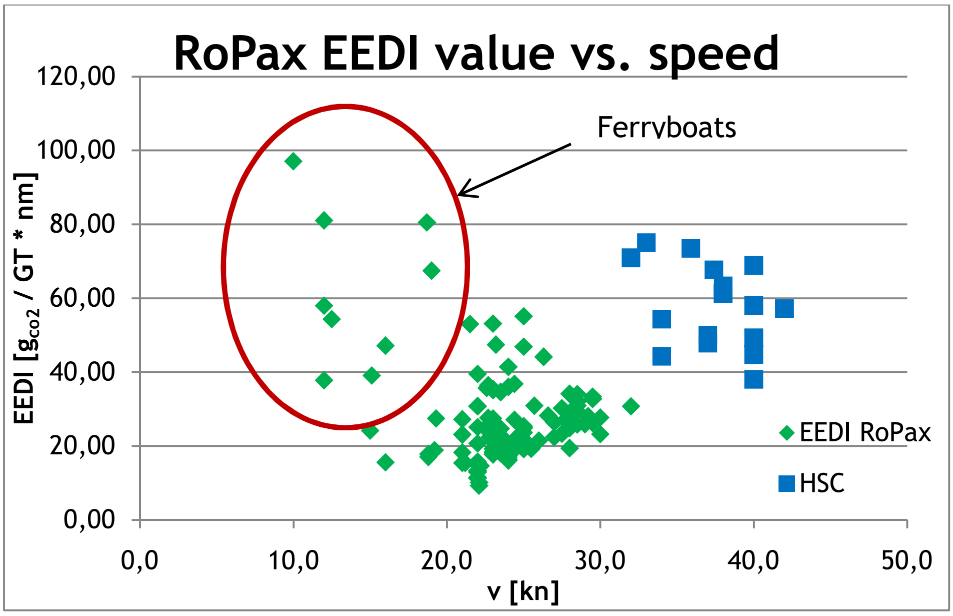


Figure 29 - EEDI vs. speed

When comparing the EEDI values against Froude number (Figure 30), three clear groups are even more visible. The fast multi-hull vessels have a Froude number between 0,5 - 0,7 and thus form a clear separate group, whereas the ferryboats have high EEDI values with lower Froude numbers (0,2 - 0,3) due to small capacities and sizes. The largest group is formed by the conventional RoPax vessels and exists roughly between the EEDI values of 20 and 40.

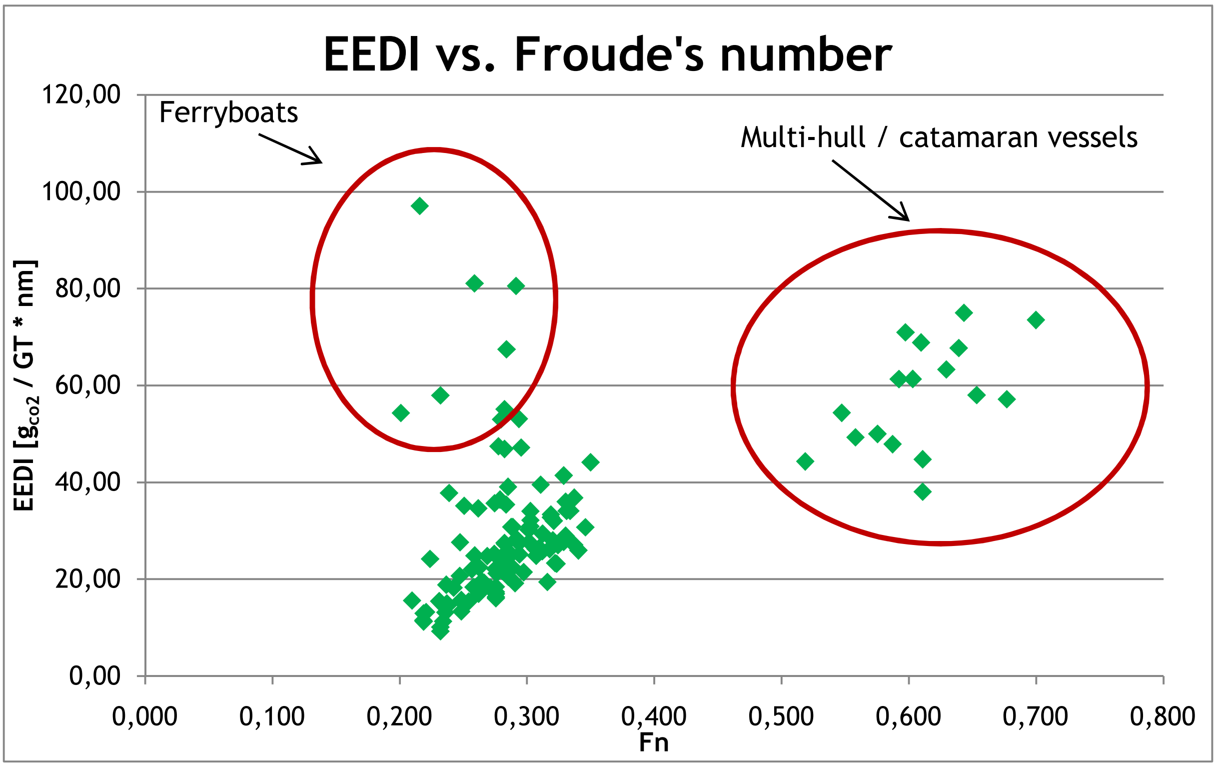


Figure 30 - RoPax vessels, EEDI vs. Froude's number

The group between 0,5 - 0,7 Fn is formed by multi-hull catamarans, operating short distances with high speeds and carrying mainly passengers (valuable cargo). Usual operating areas include Mediterranean, Tasmania or Japan. These ships are quite competitive when compared to the alternative services of airplanes and high-speed trains.

On the other hand, the slower ships with higher EEDI values consist of ferryboats usually in local traffic. The ferryboats are small due to the low volumes of freight and do not carry many passengers. Often they also have ice-classes, and thus common operation areas for them are for example northern Europe and the British Islands.

When evaluating these various RoPax subgroups further in order to find common nominators for the various groups, one could plot the EEDI values against the completed transport work or a passengers / lane meters - relation. The transportation work is calculated by multiplying the sum of lane meters and passengers with speed. The result is shown in Figure 31. Another option, plotting the calculated EEDI value against the passengers / lane meters ratio is shown in Figure 32. As can be seen from the figures, there is no clear distinction between different groups, which is due to the fact that there is no common transportation task function for which the vessels have been optimized or designed for. Instead, basically every ship represents a different transportation task or function. Thus, the transportation work as a capacity is not considered a feasible approach.

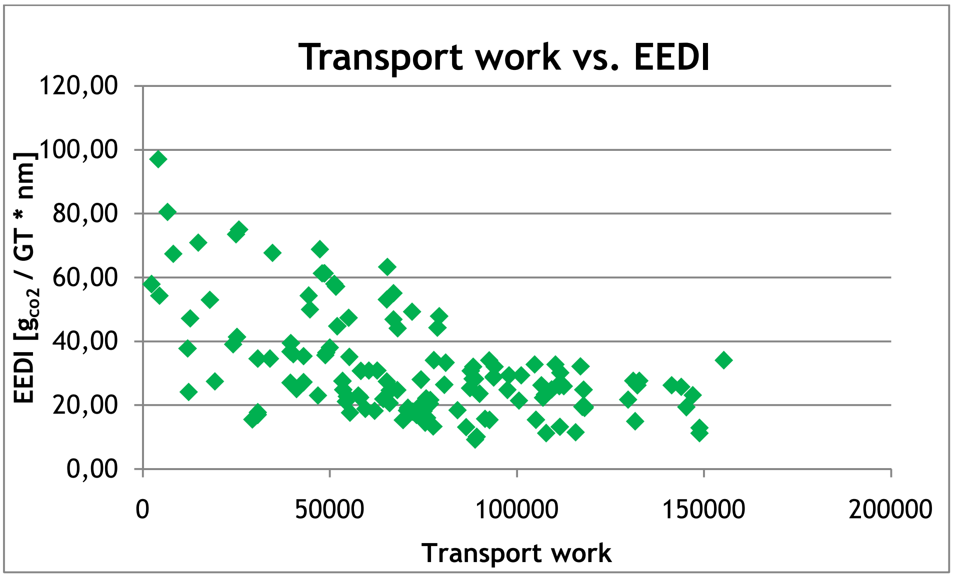


Figure 31 - RoPax transport work

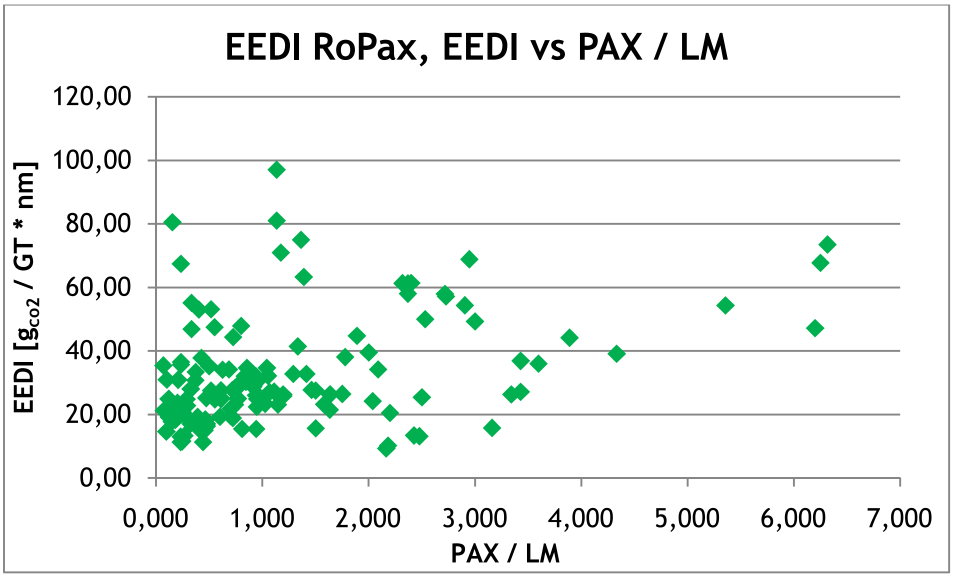


Figure 32 - RoPax EEDI vs PAX/LM relation

Dividing the RoPax vessels by a passengers / cabin relation gives better results scatter-wise. The EEDI values are plotted against a passengers / cabins ratio (for ships which have cabins) in Figure 33. The figure shows the relation for vessels with cabins (102 out of 157 samples have cabins). As can be seen, a great number of the plotted ships have cabins for most of the passengers, whereas part of the ships have only a very limited amount of cabins that are intended for elderly people and for families with small children.

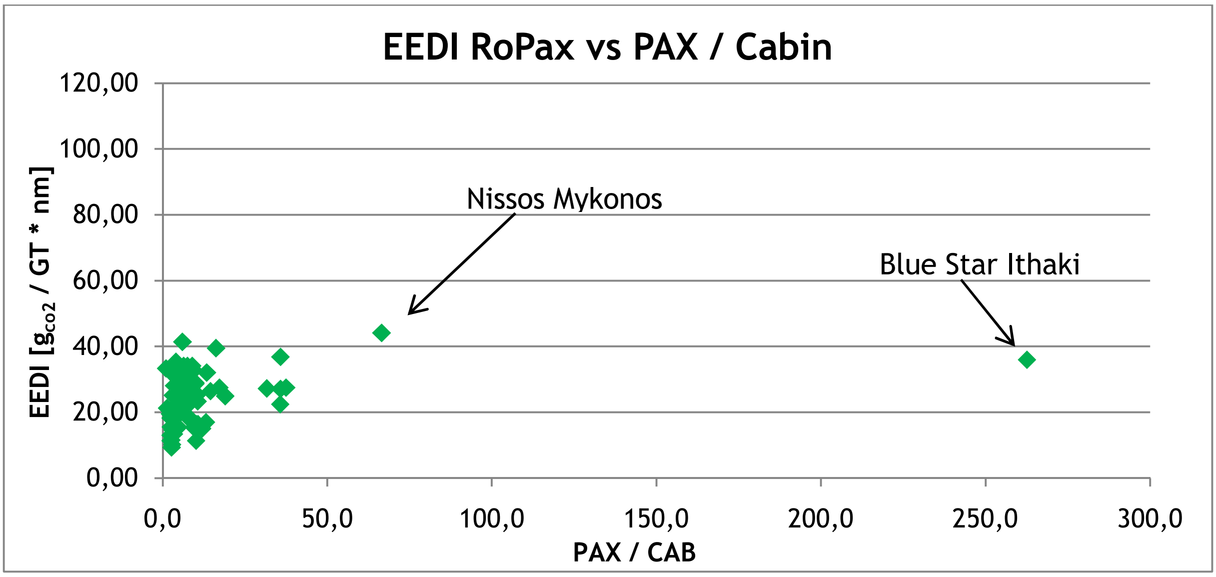


Figure 33 - EEDI vs. PAX / Cabin

The two deviating ships, Blue Star Ithaki (263 PAX / cabin) makes a 15h round trip per day, including port time and visit multiple harbors on the way. Nissos Mykonos (66,5 PAX / cabin) is in 24h/day operation on short legs in the Greek archipelago and has only a few cabins. Both of the examples are ferries with relatively short routes and thus there is no need for cabins for all of the passengers. However, fly seats are provided for all passengers in addition to a small number of cabins for handicapped people in order to provide better service for people travelling longer distances during the night time.

When investigating the passenger / cabin - relation further, a relatively clear group of night and day ferries is formed, even though the number of passengers per cabin varies considerably. The variation is partly due to the inconsistent source data, but also due to the fact that, again, the ships have very different transportation tasks. Some of the vessels have only a few cabins and most of the passengers stay at lounges and fly seats, whereas other ships have a cabin place for each passenger.

The passengers / cabin - relation is shown in Figure 34, where it is assumed that ships having less than 10 passengers per cabin are "night ferries", travelling overnight and have both cabins and fly seats for the passengers. RoPax vessels with more than 10 passengers / cabin are considered "day ferries", rarely sailing through the night. However, these "day ferries" may also operate throughout the night but only on short routes, where cabins are not necessary.

As can be seen from the figure, the EEDI value distribution within the "night ferry" - group is quite even, the EEDI values being roughly between 20 and 40. Especially when approaching 2 passengers / cabin - value, the more "traditional" cruise ferries, the EEDI values are getting closer to 10.

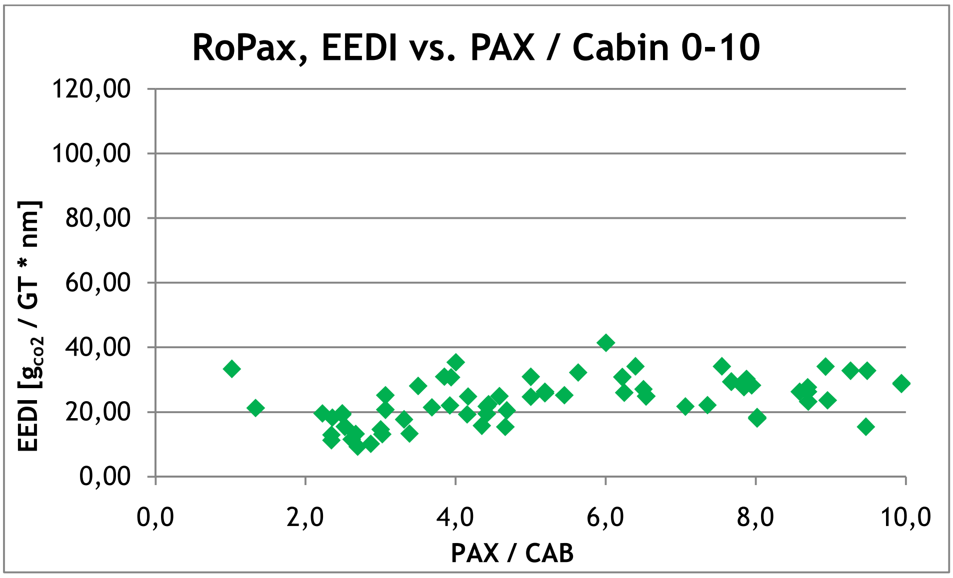


Figure 34 - EEDI vs. Pax / Cabin for night ferries

After dividing the RoPax vessels into two groups, namely night and day ferries, the EEDI values are plotted according to "the conventional formula" in Figure 35. For the "day ferries" the EEDI values are widely spread. This is due to the fact that the group contains small specialized vessels such as high speed craft (HSC) and ferryboats and on the other hand large ferries transporting passengers and rolling cargo during day time. The EEDI values of the "night ferry" group are more evenly distributed between 10 and 40, as the design criteria are more similar and the sizes of the vessels are larger, thus evening out the differences in powering of the vessels.

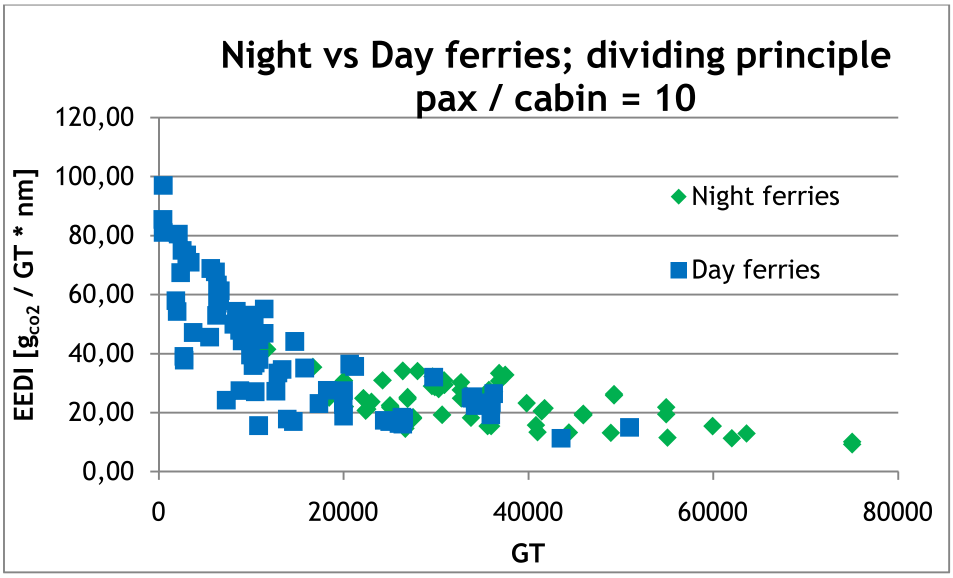


Figure 35 - EEDI distribution, night vs. day ferries

The number of night and day ferries in the sample dataset is pretty even, as shown in Table 17.

Table 17 - The number of night and day ferries

Night ferries	79pcs
Day ferries	78pcs

Overall it can be concluded that no uniform design criteria for the entire RoPax group exists. There seems to be subgroups, such as high speed craft, ferryboats and night and day ferries. However, dividing the RoPax group into these subgroups is not seen feasible. A simpler way would be to exclude the smallest, specialized RoPax vessels, from the EEDI scope by setting the lower "cut-off limit" to e.g. 10 000 GT similarly to other vessel groups in the current EEDI approach.

4.2.3. Possible EEDI modifications for RoPax vessels

As the current EEDI baseline approach is not considered feasible for RoPax vessels, various correction factors for the EEDI formula and baseline were tested in order to evaluate if a suitable correction factor could be identified in order to also incorporate RoPax vessels into the EEDI baseline approach.

The EEDI formula can be simplified to:

$$EEDI = \frac{Power * SFOC * C_f}{Capacity * Speed}$$

Where the numerator stands for the produced CO_2 emissions, the denominator represents the completed transportation work. When taking a closer look at the formula from a RoPax vessel's point of view, it can be concluded that most of the variables have been set by the transportation task of the vessel and cannot be affected during the ship design phase.

For example the speed of the vessel is decided by the operating area through schedules and the capacity by the amount of available cargo, which may often be very limited (e.g. from a small island to the continent). The required power is closely related to the speed of the vessel and possibly an ice-class, whereas the SFOC is relatively constant and cannot be affected significantly.

When evaluating the possible EEDI approach it can be noted that there are not many ways to affect the EEDI value or baseline and thus the calculated EEDI. Basically the only option is to use various capacities to try to find a common nominator for the RoPax vessels, or alternatively scale the EEDI values according to specific properties of the vessels, such as the Froude's number or by trying to define the RoRo and PAX efficiencies separately.

4.2.3.1. Correction factors for the EEDI formula and baselines

In order to find out if there exists a feasible way to include RoPax vessels into the conventional EEDI baseline approach, different correction factors were tested both for the EEDI formula as well as the baselines. The various correction factors tested are shown in Table 18. The RoPax vessels included in the tests are the filtered 157 ships as specified earlier.

Multiple tests were done by replacing the current capacity of the gross tonnage of a vessel, by e.g. lane meters, deadweight or the maximum passenger capacity to see whether any of these would give a better correlation. Additionally, plotting the EEDI value against Froude's number (capacity in EEDI defined either in passengers or GT) was also tested.

Table 18 - RoPax EEDI modification chart data

EEDI for RoPax vessels		
Table / Appendix	***Capacity in EEDI formula***	***Capacity in EEDI baseline***
Figure 28	GT	GT
Figure 36	DWT	DWT
Figure 37	LM	LM
Figure 38	PAX	PAX
Figure 39	GT	Fr
Figure 40	PAX	Fr

Replacing the capacity with deadweight (DWT), Figure 36

When replacing the capacity both in the EEDI formula and in the baseline definition by the ship's deadweight, the scatter of the data increases and the correlation and standard deviation decreases. Therefore this is not a feasible option for defining the EEDI for RoPax vessels.

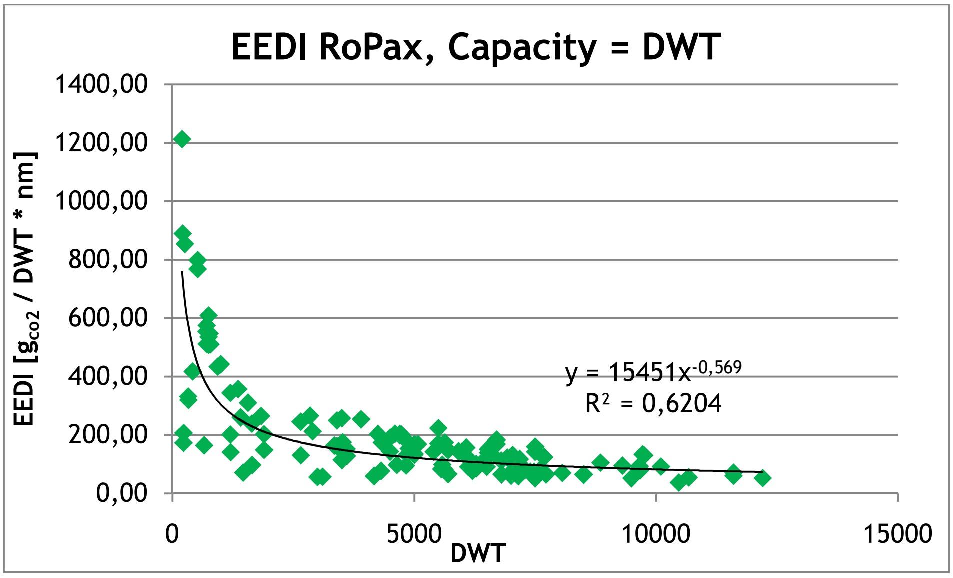


Figure 36 - EEDI RoPax, Capacity = DWT

Replacing the capacity with lane meters (LM), Figure 37

When replacing the capacity by lane meters both in the EEDI formula and the baseline definition, the scatter of the data is even higher. This is due to the fact that the variations in lane meter capacity on the ships are extremely high due to the different transportation tasks and thus varying design criteria. In addition, part of the scatter is due to the fact that there is no standardized way to define lane meters. As there are many different types of RoPax vessels, from "cruise ferries" traveling between two major cities overnight to "island ferries" in scheduled short local traffic, the ratio between passengers and lane meters is high as shown before in Figure 32. Thus, defining the capacity as lane meters is not seen as a feasible option.

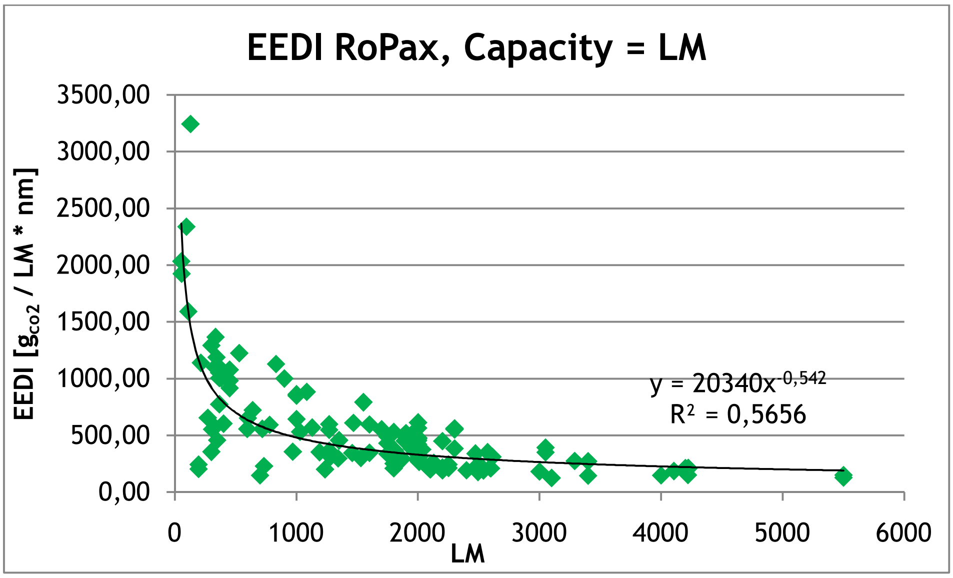


Figure 37 - EEDI RoPax, Capacity = LM

Replacing the capacity with the maximum amount of passengers (PAX), Figure 38

If the capacity in the EEDI and baseline definition is replaced by the amount of passengers, the scatter of the data increases even further when compared to the conventional EEDI baseline approach. It can be clearly seen that no clear correlation between the EEDI value and the passenger number exists and thus defining the capacity in passengers for RoPax vessels is not seen as a feasible option.

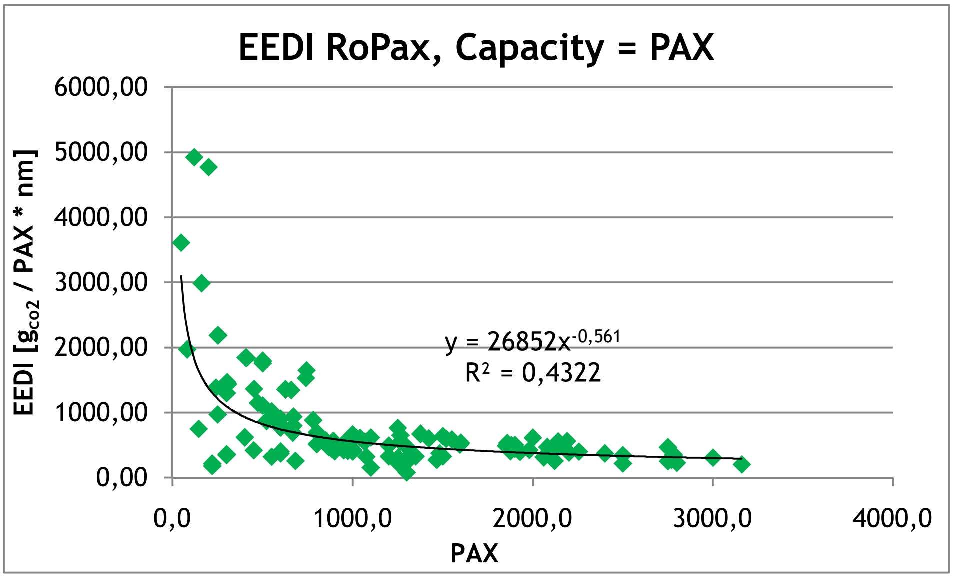


Figure 38 - EEDI RoPax, Capacity = PAX

Plotting the EEDI (capacity in GT) against Froude's number, Figure 39

When plotting the RoPax EEDI values (calculated with GT as capacity) against Froude's number, it can be seen that two clear groups are formed as seen in the chart below. Fast ferries have a high Froude's numbers (0,55 - 0,75) whereas conventional vessels have a Froude's number between 0,2 and 0,4. However, there is an extremely high scatter within similar Froude number values in the calculated EEDI. For example, at Froude's number of 0,3 the EEDI value scatter is from 20 to 80. Thus, this approach is not considered feasible.

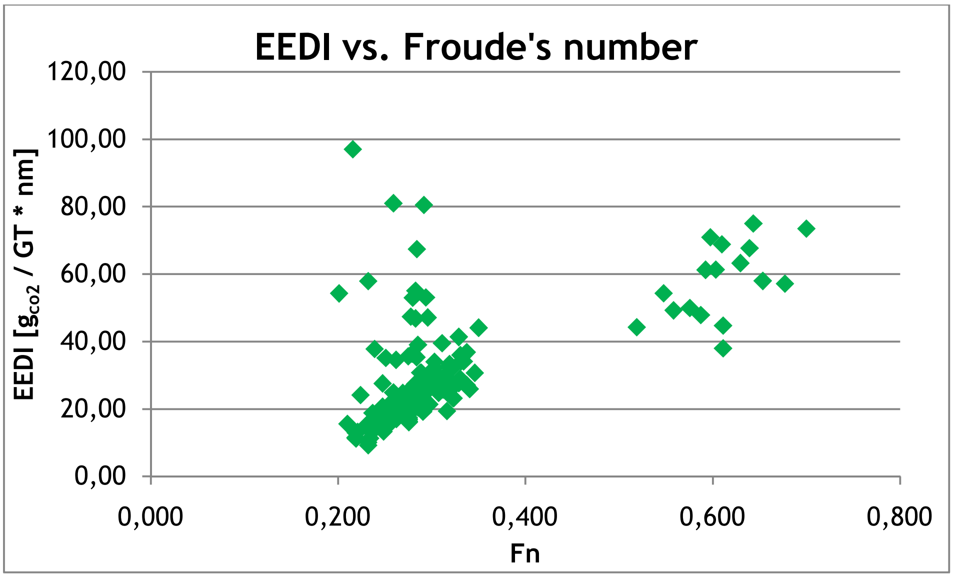


Figure 39 - EEDI vs. Froude's number

Plotting the EEDI (capacity in PAX) against Froude's number, Figure 40

When plotting the calculated EEDI values (capacity defined in passengers) against Froude's number, it can be seen that the groups noted in the earlier chart are emphasized and the scatter is even higher.

One group consists of fast multi-hull vessels (Fr 0,5 - 0,7), whereas the other of conventional ferries (Fn 0,2 - 0,4). As can be seen, the scatter within similar Froude numbers is very high (e.g. at Fn 0,3 from ~400 to ~5000). This is due to the highly varying passenger numbers and speeds. All in all, not even this approach can be considered feasible for including RoPax vessels into the EEDI.

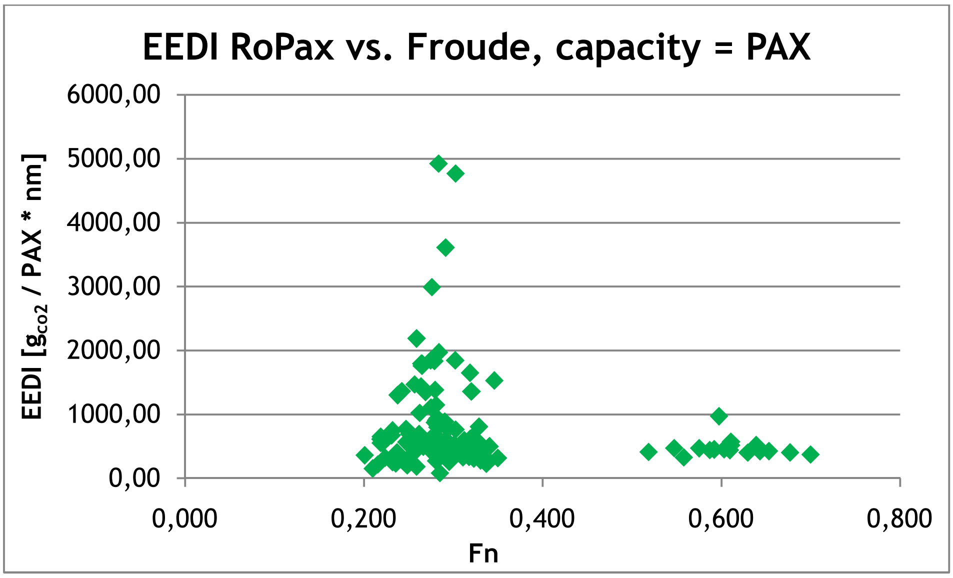


Figure 40 - EEDI RoPax vs Froude, Capacity = PAX

4.2.3.2. Alternative baseline approach for RoPax vessels

As with RoRo cargo vessels (in Chapter 4.1.3.2), a similar approach for an alternative method for defining the EEDI baseline for RoPax vessels was also tested. The results are shown in Figure 41.

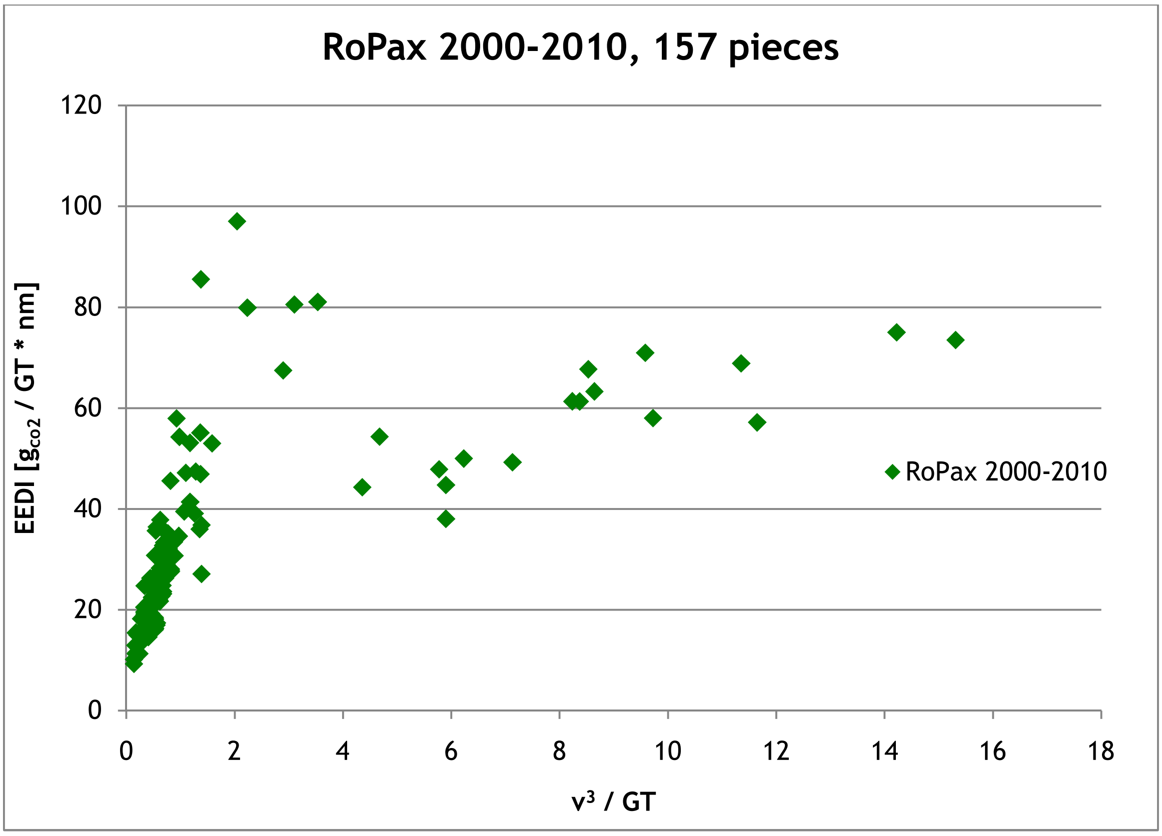


Figure 41 - RoPax EEDI vs v^3/GT

The scatter of the data in the v^3/GT - approach is large for RoPax vessels. For example, the vessels attaining v^3/GT value over 5 are all fast multi-hull vessels. In order to evaluate the approach further, the smaller vessels (GT < 15 000) causing the largest variations are excluded and the vessels are plotted in 2kn groups as shown in Figure 42. As can be seen from the figure, the variations remain large within the similar speed groups as the differences in vessel transportation tasks and designs are significant.

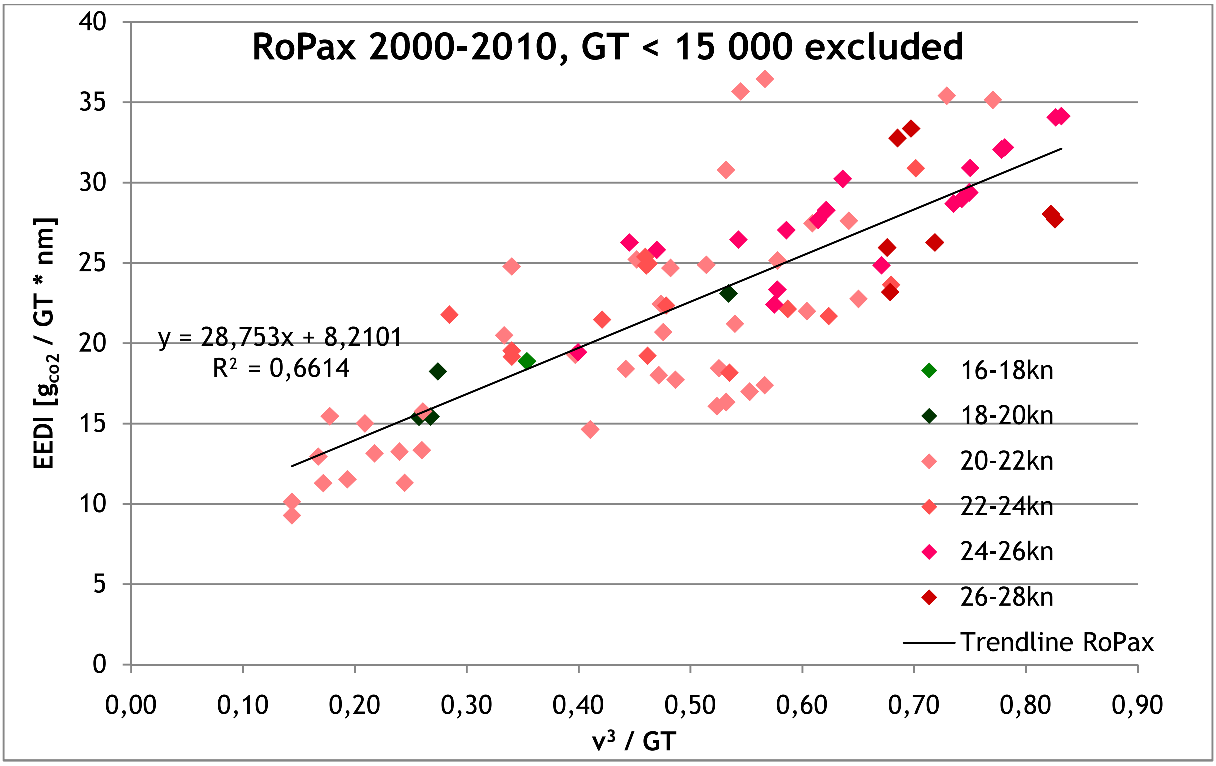


Figure 42 - RoPax EEDI vs v^3/GT speed groups

The speed groups and relative sizes used in the previous chart are shown in Table 19.

Table 19 - RoPax vessel speed groups for v^3/GT approach

	PCS	%
16-18kn	1	0,9 %
18-20kn	5	4,7 %
20-22kn	47	44,3 %
22-24kn	17	16,0 %
24-26kn	24	22,6 %
26-28kn	12	11,3 %
Total:	106	100,0 %

It can be concluded that the v^3 / GT - relation seems to give better results and data correlation than the conventional EEDI approach. However, as the variations in the v^3/GT approach are very large even within the selected speed intervals, the "v^3/GT as baseline for EEDI" method cannot be considered feasible.

Therefore a more feasible option would be to define a method that would take into account both cargo types carried by RoPax vessels (passengers and rolling cargo) as is studied in chapter 4.2.3.3. Another option would be to define a progressive EEDI that would utilize the present EEDI approach and combine it with speed-dependent baselines thus comparing vessels with similar design speeds with each other. These speed-dependant baselines for RoPax vessels will be discussed in greater detail in chapter 4.3.

4.2.3.3. Separate baselines for both cargo types of RoPax vessels

Defining the so called "capacity factor" for RoPax vessels has been discussed on many occasions, as it has become important to be able to measure and allocate emissions from the RoPax transportation to the type of cargo (passenger, truck, bus, container). A factor that would justifiably allocate the total GHG emissions from RoPax vessels between passengers, passenger vehicles and trucks / other rolling cargo should be defined.

The basic idea behind the capacity factor is that the area (or volume) that is assigned to each cargo type is used to define the relative emissions. In this study, a sample of 20 RoPax vessels built in 2000-2010 and for which full information was available was used. The conventionally calculated EEDI values for the vessels are shown in Figure 43.

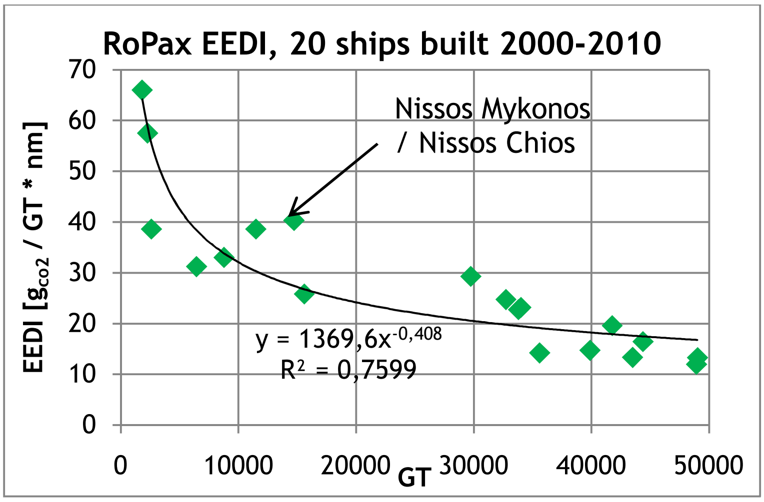


Figure 43 - RoPax EEDI for 20 sample ships

In order to define which part of the total emissions, or the EEDI value, is allocated for carrying passengers and which part is for RoRo cargo, a distribution method was developed. The idea is that the weight allocated for the transportation task was used, and the dividing principle for the emissions would then be the relative value of these weights. For transporting RoRo cargo, truck lane meters were used as the capacity, using two tons per lane meter as the average value for cargo weight. For transporting passengers, the ship's public areas were used together with the standard weight factors from Deltamarin's extensive database for evaluating the weight of the passenger areas. Passenger vehicles were included in the passenger area.

The values were then calculated for the 20 ships in Deltamarin's database. Two examples of RoPax vessels with the calculated EEDI values are shown in

Table 20. As can be seen from the table, these two ships represent the two different cases of RoPax vessels - one carries mainly RoRo cargo with some passengers, whereas the other carries more passengers than RoRo cargo.

Table 20 - Example of RoPax vessels

Example 1				Example 2		
			Capacities			
	50000		GT		45000	
	3000		Passengers max		1000	
	1000		Trailer lane meters		3500	
m^2	***kg/m^2***	***t***	***Passenger area weight***	***m^2***	***kg/m^2***	***t***
9000	110	990	Public & stairs	3000	110	330
11000	125	1375	Passenger cabins	5000	125	625
250	150	38	Utility rooms	500	150	75
2500	125	313	Crew facilities	275	125	344
750	150	113	Catering	500	150	75
1000	150	150	Hotel service	200	150	30
		2978	Total			**1479**
	kg/m	***t***	***RoRo area weight***		***kg/m***	***t***
1000	2000	2000	Trailer lanes	3500	2000	7000
	60 %		***Share of passengers***		**17 %**	
	40 %		***Share of roro cargo***		**83 %**	
	g_{co2} / GT * nm				***g_{co2} / GT * nm***	
	12,03		***EEDI***		16,48	
	7,22		EEDI x PAX %		2,80	
	4,81		EEDI x RORO %		13,68	

The calculated EEDI values are then divided between RoRo and PAX - transportation tasks according to the calculated relative values. The calculated values are plotted and shown in Figure 44.

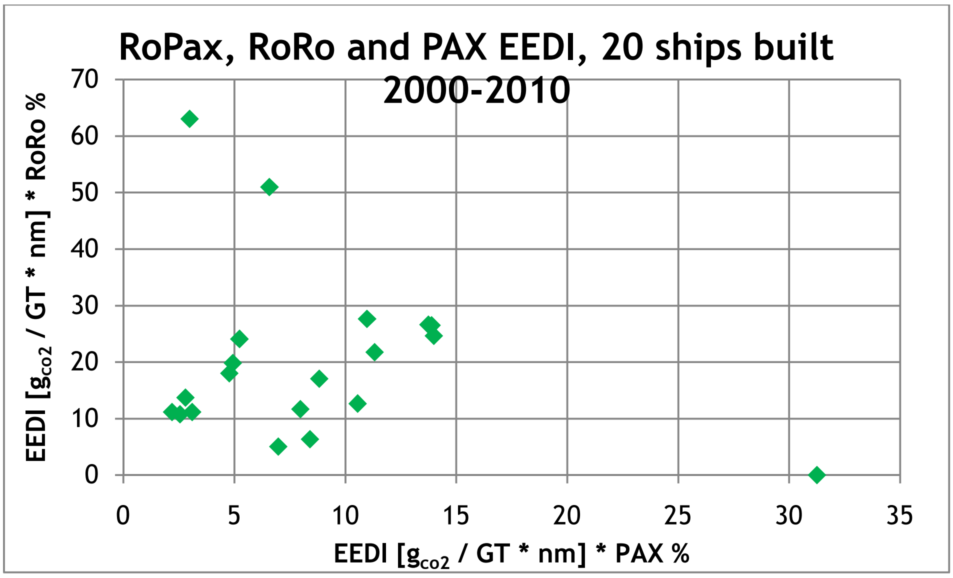


Figure 44 - RoPax PAX vs. RoRo efficiency

As can be seen, the variations in the RoPax PAX / RoRo EEDI efficiency chart are very high, which highlights the fact that even though the total emissions can be distributed to both transport tasks with exact data and good reliably, the large variations between different ships still exist. These variations, which are due to the differences in transportation tasks and design criteria, still remain. Therefore it is not seen that this could be the correct way to include RoPax vessels into the EEDI approach.

One additional problem regarding this "capacity factor" approach is collecting the sufficient information for the baseline definition, as defining these baselines reliably requires a substantial amount of accurate information of the existing vessels.

Instead of a capacity factor, a better way to regulate the allowed power and energy efficiency could be comparing the emissions with the speed of the vessel in speed-dependent groups as discussed in more detail in Chapter 4.3.

4.2.3.4. Conclusions on the correction factors, auxiliary engine power and lower cut-off limit

The main problem with RoPax vessels is that the transportation tasks for which the vessels have been designed for are very different. The cargo ratio between passengers and lane meters varies greatly. In addition, some of the vessels have very high design speeds (multi-hull vessels) and others a very slow design speed (ferryboats). These differences lead to a high scatter in the installed engine power of the vessels and thus to a high scatter of the EEDI values.

Alternatively, the capacity problem with RoPax vessels could be solved by evaluating how valuable the cargo is. In other words, it can be assumed that as the passenger cargo is light and valuable, higher speeds are allowed even if it will be reflected in the price of the ticket. On the other hand, vessels with a large trailer capacity, thus being heavier and requiring more propulsion power, are forced to keep prices lower in order to successfully compete against alternative transportation methods. Thus the "allowed power" for these heavier ships will be lower.

The result from trying to redefine the capacity for RoPax vessels was that the overall EEDI scatter was not reduced when compared to the currently used capacity of gross tonnage (GT). It can be concluded that using GT is still the best option for defining the capacity of RoPax vessel in the EEDI.

Auxiliary engine power in the RoPax vessel group

As seen earlier, the relatively uniform design criteria and overall larger size of the "night ferries" leads to roughly similar EEDI values. The larger capacity in gross tonnage is naturally due to the fact that cabins take up space, thus requiring a larger superstructure. However, one important aspect not taken into account by the EEDI formula is the fact that the relative amount of auxiliary engine power might differ considerably between RoPax vessels of similar sizes. This is due to the "luxury level" of some vessels, meaning that one ship of 20 000 GT might be carrying 2 000 passengers and 300 cars with relatively simple services, but another ship of similar size might well be carrying only half of the "cargo" thus providing more services and amenities to the passengers and requiring larger amounts of electricity per GT. These two "subtypes" of RoPax vessels will score differently in the EEDI.

Cut-off limit for the RoPax vessel group

The RoPax vessels built in 2000-2010 are shown in Figure 45 when calculated according to the conventional EEDI baseline approach. As can be seen the scatter of EEDI values increases greatly for ships below 15 000 GT. Due to the highly variable RoPax vessel subgroups found in Chapter 4.2.2 and thus the sudden increase of scatter in the EEDI values, the ships below 15 000 GT are considered to consists of specialized ships that should not to be included in the EEDI approach and therefore it is proposed to exclude these vessels from the EEDI approach.

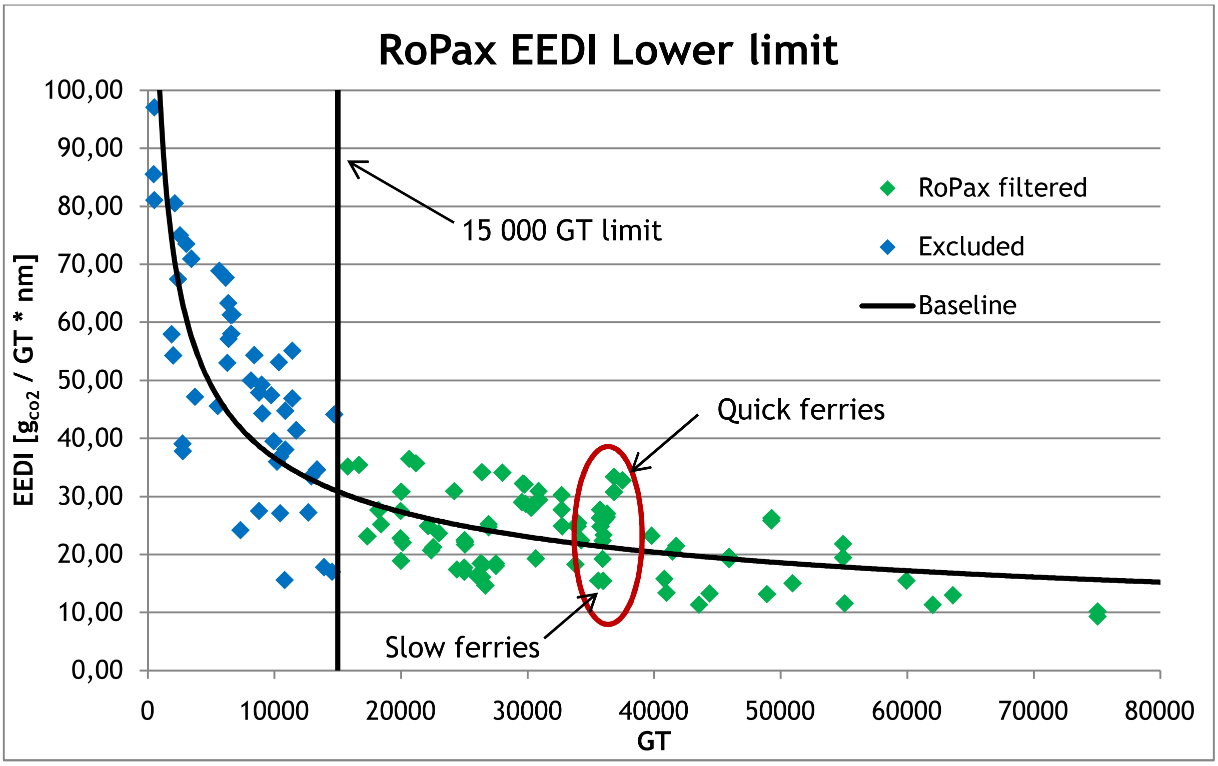


Figure 45 - EEDI for RoPax 2000-2010

Even though the smallest ships are excluded from the data, a relatively high scatter still remains. One example are ships with roughly 37 500 GT. The vessels in question are “quick ferries” Festos Palace and Europa Palace operating in Greece and in the Mediterranean. Their design speed is over 30kn and they were designed to reduce the existing travel time from 10 hours down to 6 hours. This led to high power requirements and thus a high EEDI value. On the other hand, an example of a “slow ferry” in the chart above is e.g. Mont St. Michel, a “traditional cruise ferry” that crosses the English Channel in 5,5 hours as opposed to the 4 hour crossing times of faster catamarans. In these cases as well as many others, the scatter and high EEDI values are due to design differences and not to accidentally inefficient design.

The effect on the lower limit to the sample size is shown in Table 21 where it can be seen that roughly 1/3 of the filtered source data is excluded from further studies.

Table 21 - 15 000 GT limit effect on the RoPax vessel sample size

RoPax 2000-2010, filtered	157pcs
GT < 15 000	50pcs
Remaining	107pcs

4.3. Speed dependent baselines

As the RoRo and RoPax vessels have widely varying design speeds and transportation tasks, the conventional EEDI baseline approach is not seen feasible for them as discussed in the previous chapters. Therefore the concept of speed dependant baselines was studied further. This is based on the idea that the baselines, or in other words the required EEDI values, would depend on the design speed of the vessel.

Tests were made to evaluate if such an approach would be feasible for RoRo cargo vessels and RoPax vessels. For testing purposes, the vessels were divided by their design speeds into two knot intervals to identify whether a clear correlation exists between each speed group.

4.3.1. Speed dependent baselines for RoRo cargo vessels

RoRo cargo vessels (excluding vehicle carriers) have very dissimilar sailing profiles and transport tasks, thus finding a common design criteria for the vessels is quite difficult as discussed in the previous chapters. Therefore, the approach involving speed-dependent baselines was tested for them.

The RoRo cargo vessels were plotted at two-knot intervals and shown in Figure 46. As can be seen, small ships with less than 5000 DWT have the highest speed variations, and for this reason have been excluded as their calculated EEDI variations are too large to be regulated effectively.

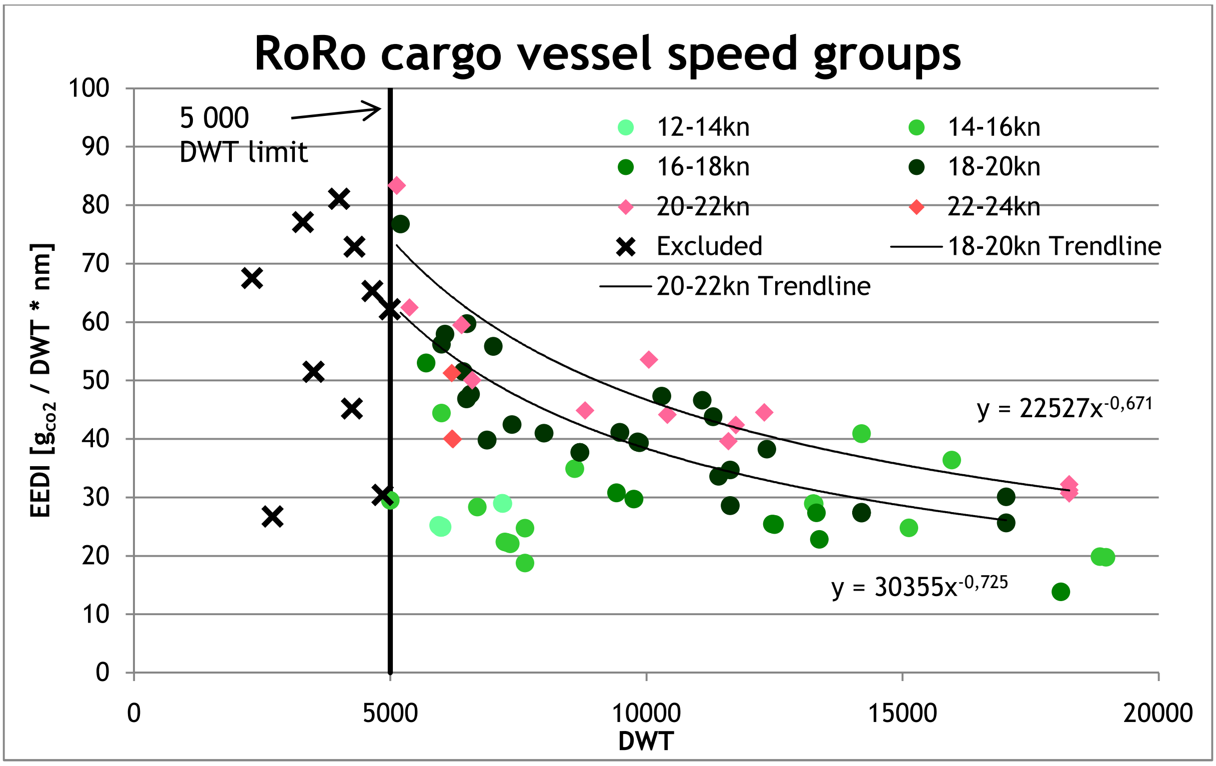


Figure 46 - EEDI speed groups for RoRo cargo vessels excluding vehicle carriers

The sizes of the speed groups are shown in Table 22. As can be seen, there are three major groups: one at 14-16kn, one at 18-20kn and one at 20-22kn. Since the two largest groups are between the range 18-22kn, these have been selected as the basis for the main baselines in this approach.

Table 22 - RoRo cargo vessel speed groups

Speed	*PCS*	*%*
Excluded	13	-
12-14kn	6	5,4 %
14-16kn	25	22,3 %
16-18kn	11	9,8 %
18-20kn	41	36,6 %
20-22kn	26	23,2 %
22-24kn	3	2,7 %
Total	112	100,0 %

The regression lines are drawn according to the conventional EEDI calculation guidelines for the two largest speed groups. The difference between the two regression lines stays relatively similar, the function being "$y = 431{,}84x^{-0{,}429}$". The largest single speed group, 20-22kn, is defined as a "baseline" and the other baselines for the different speed groups at two-knot intervals are scaled according to the regression line difference "$y = 431{,}84x^{-0{,}429}$". The results are shown in Figure 47 together with the 112 RoRo vessels built 2000-2010. As can be seen from the results, correlation of the data is good and thus the method is considered feasible for regulating the EEDI for RoRo cargo vessels, excluding vehicle carriers.

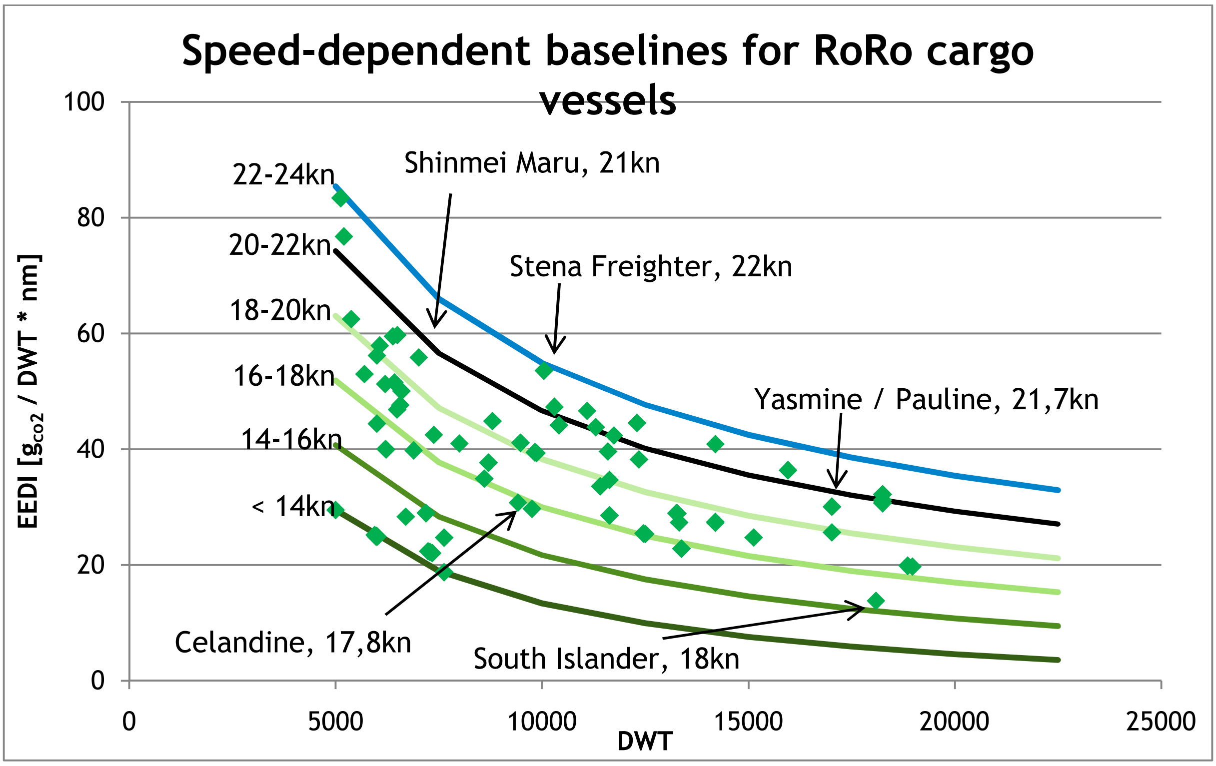


Figure 47 - Speed dependent baselines for RoRo vessels

4.3.2. Speed dependent baselines for RoPax vessels

For calculating the speed dependant baselines, the RoPax vessels were plotted at two-knot intervals according to their design speeds and the calculated EEDI values against their gross tonnage. As noted in previous chapters, the smaller ships have usually either a very low or a very high design speed, which has been emphasized in Figure 48.

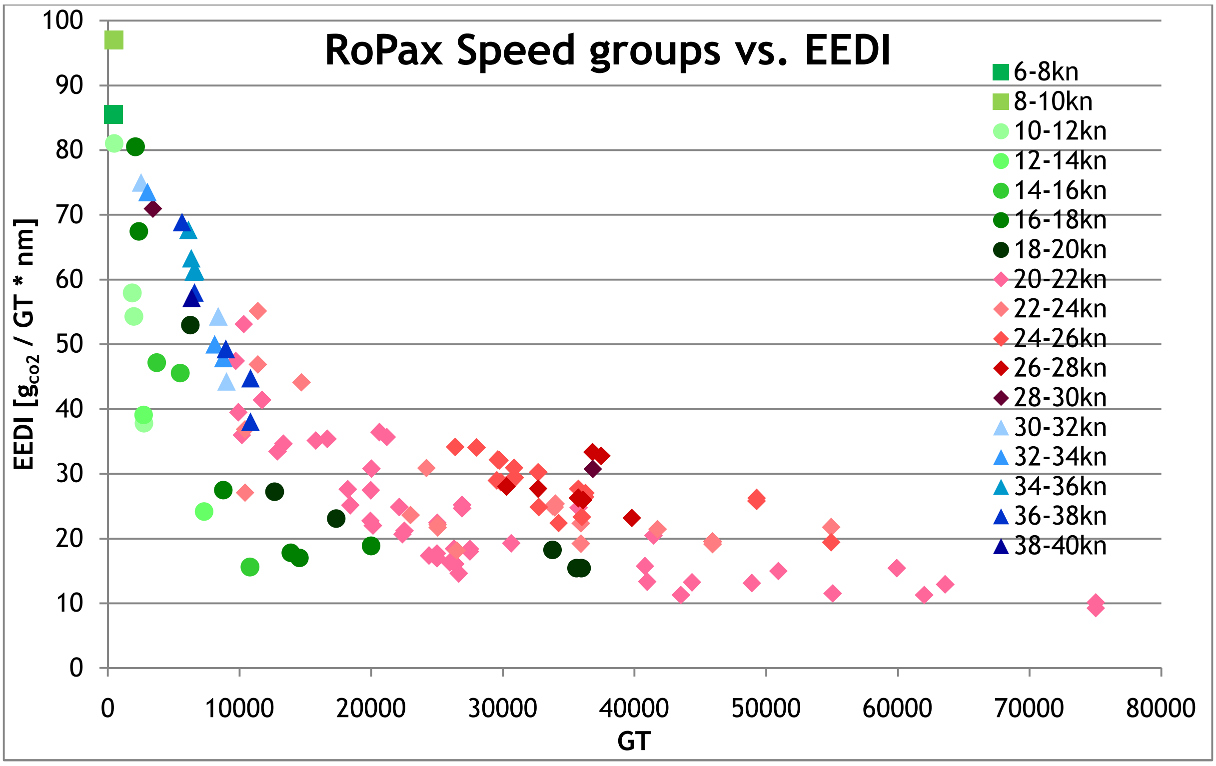


Figure 48 - EEDI speed groups for RoPax vessels

The number of vessels in each group is presented in Table 23. Speeds between 20 and 26kn are the most common ones, containing in total 65% of the total number of vessels.

Table 23 - RoPax Speed Group sizes

Speed	*PCS*	*%*	*Speed*	*PCS*	*%*
6-8kn	1	0,6 %	24-26kn	24	15,3 %
8-10kn	1	0,6 %	26-28kn	12	7,6 %
10-12kn	4	2,5 %	28-30kn	2	1,3 %
12-14kn	2	1,3 %	30-32kn	3	1,9 %
14-16kn	3	1,9 %	32-34kn	3	1,9 %
16-18kn	6	3,8 %	34-36kn	5	3,2 %
18-20kn	7	4,5 %	36-38kn	5	3,2 %
20-22kn	56	35,7 %	38-40kn	1	0,6 %
22-24kn	22	14,0 %	**Total**	157	100,0 %

Because of the high variations in the EEDI values of small vessels, the vessels whose gross tonnage is under 15 000 were excluded. After that, regression lines were drawn for the two largest speed groups. The results are shown in Figure 49. The two prevailing groups are the 20-22kn with 47 vessels and 24-26kn group with 24 vessels. According to the plotted regression lines, the difference between the two lines was calculated to follow the equation: $y = 478{,}09x^{-0{,}369}$.

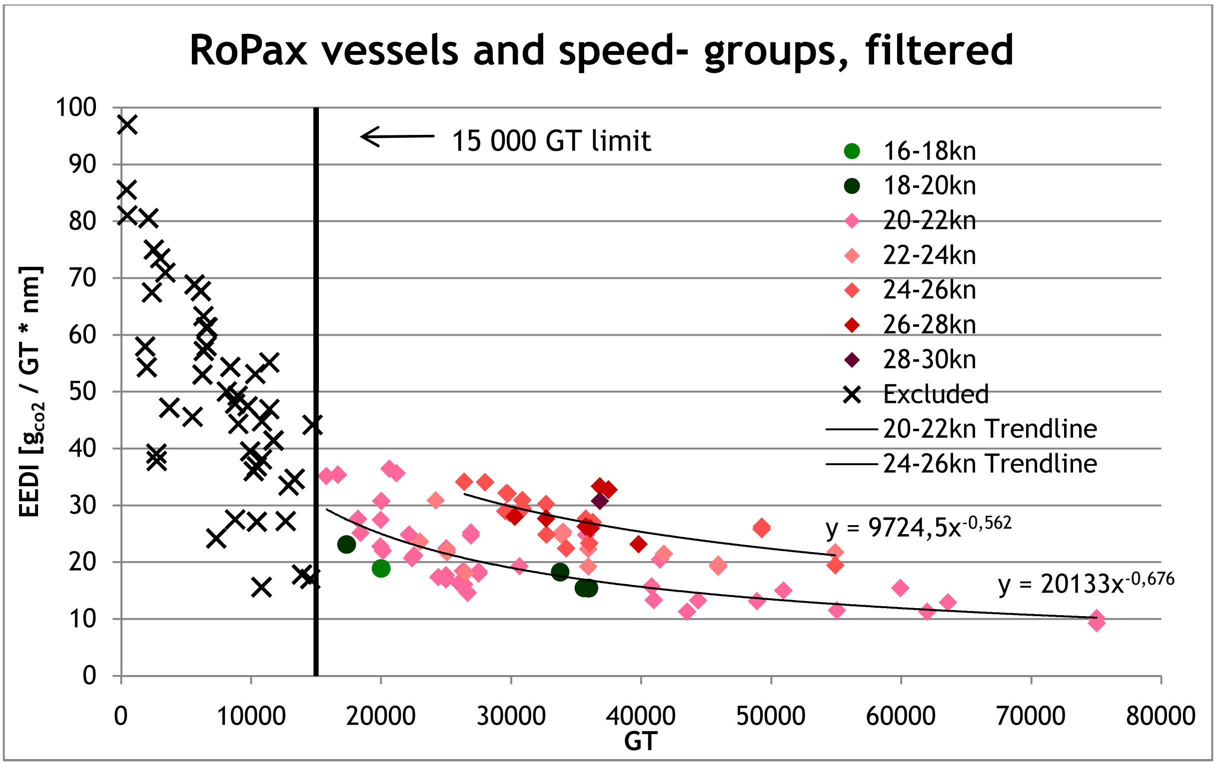


Figure 49 - EEDI Speed baselines for RoPax vessels

The smallest vessels, which are also the slowest and fastest vessels, were excluded from the speed-dependant baseline approach. The sizes of the remaining speed groups are shown in Table 24.

Table 24 - Sizes of speed groups, under 15 000 GT excluded

Speed	*PCS*	*%*
Excluded	50	-
16-18kn	1	0,9 %
18-20kn	5	4,7 %
20-22kn	47	43,9 %
22-24kn	17	15,9 %
24-26kn	24	22,4 %
26-28kn	12	11,2 %
28-30kn	1	0,9 %
Total	107	100,0 %

As the 20-22kn vessel group forms the largest single group (47 vessels, 44%), it is decided to be the main RoPax vessel baseline. The baselines for slower or faster RoPax vessels are then drawn according to the baseline in 2kn intervals. The baselines are defined according to the scaled difference between the two regression lines ($y = 478{,}09x^{-0{,}369}$).

The speed-dependent baselines at two knot intervals are shown in Figure 50 together with the 107 filtered RoPax vessels built in 2000-2010. As is readily seen, the correlation with the data points is good and the solution altogether seems to be feasible.

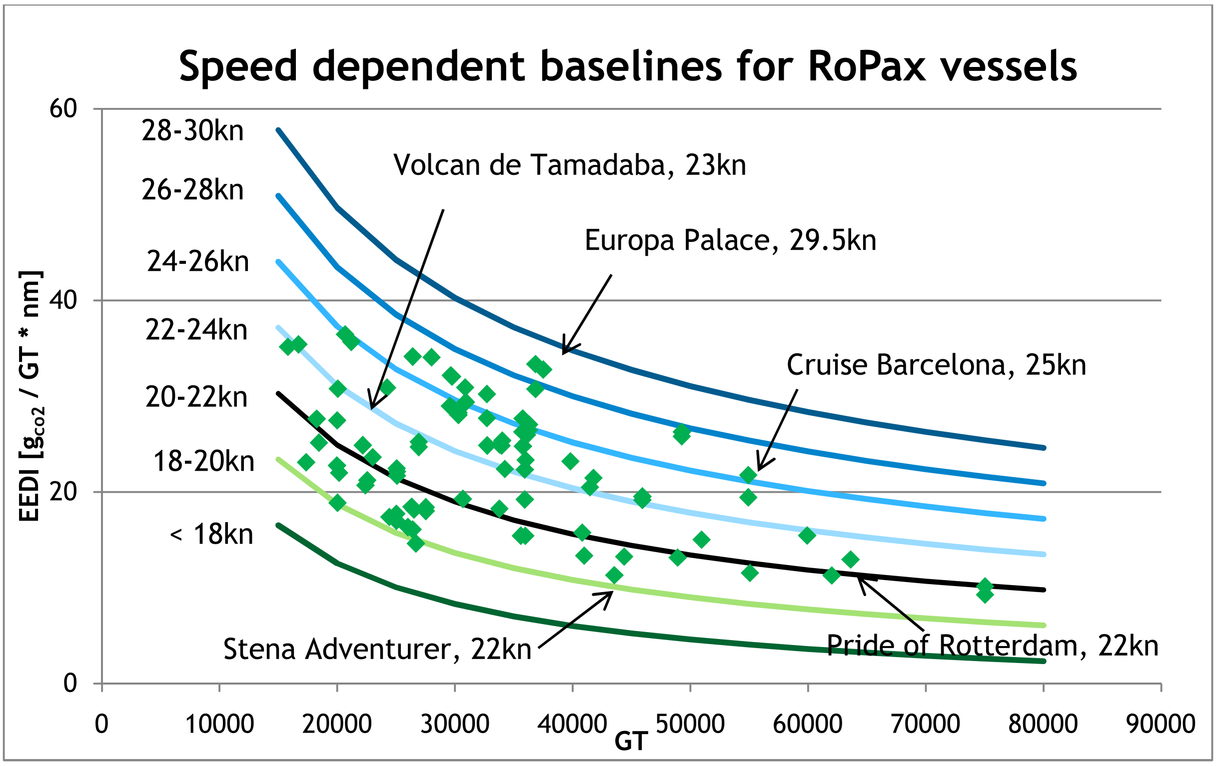


Figure 50 - Speed dependent baselines for RoPax vessels

4.3.3. Allowed methodology to attain the required EEDI value

If in the case of the conventional EEDI baseline approach a vessel gets a higher EEDI value than allowed, there is always the possibility to lower the attained EEDI value by reducing the design speed and de-rating the main engine(s). This possibility ensures that in practice every ship can fulfill the EEDI requirement. Reasons for not complying with the EEDI requirements could be for example last-moment changes to the hull form or machinery. On the other hand, if the vessel has already been designed too close to the EEDI limit it could fall short of fulfilling the requirements during the sea trials due to uncertainties or other mistakes done during the design or construction of the vessel.

With a strict speed-dependent baseline approach for the EEDI, a similar possibility to fulfill the EEDI requirement by simply reducing speed and de-rating engine(s) does not exist as the required EEDI is directly connected to the speed of the vessel. As a solution, a specific cut-off limit for the speeds should be defined. This cut-off limit would then form the minimum EEDI value for all vessels with a design speed below, for example, 17kn. The cut-off limit should ensure that all of the ship groups are treated fairly while maintaining some level of strict requirements for all vessels.

In order to evaluate the cut-off limit, one example of a RoPax vessel was studied. As a starting point, the example vessel did not fulfill the EEDI requirement in the first place due to a high design speed of 27,5kn. This design speed was lowered in 0,1kn intervals and the corresponding propulsion power requirement taken from the vessel specific speed-power curve, which was based on model tests. The EEDI requirement was scaled in corresponding intervals according to the principles discussed in the previous chapter. The results are plotted in Figure 51.

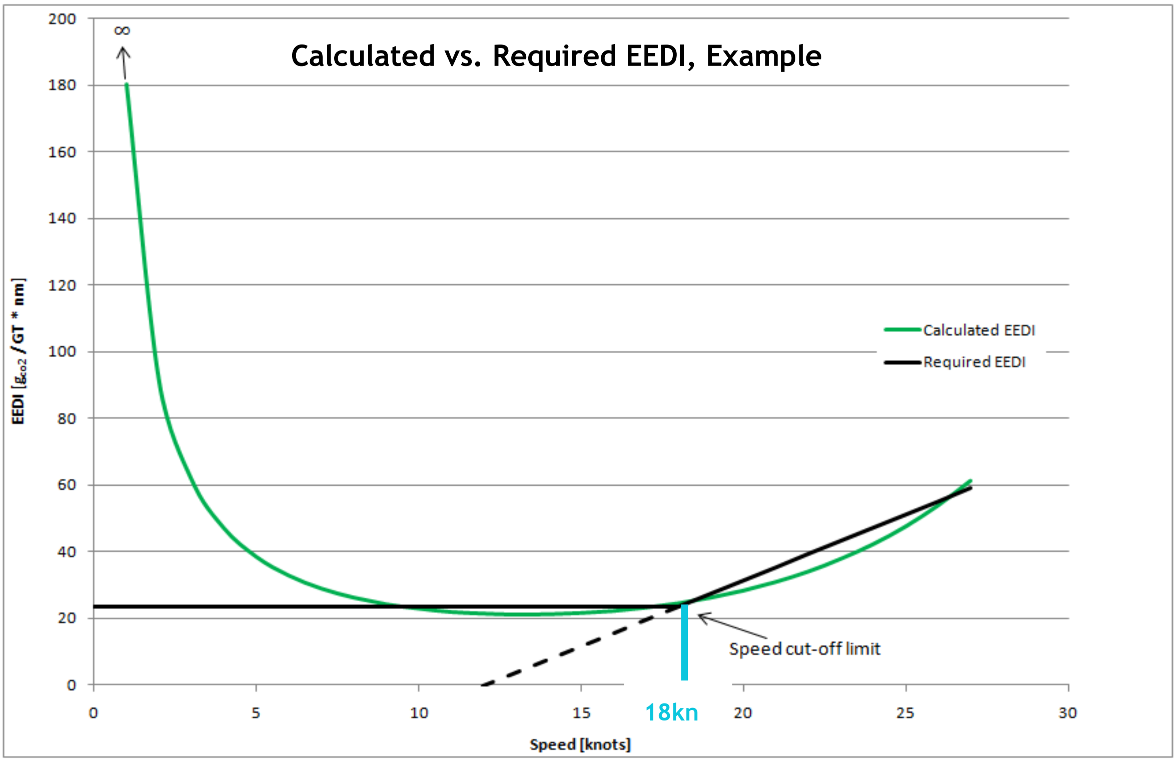


Figure 51 - Example of speed reduction vs. EEDI requirement on RoPax vessel

As can be seen from the figure, the required EEDI value follows a linear curve, whereas the attained EEDI value follows a polynomial-curve. The difference in the curves is due to the EEDI taking the speed-power ratio linearly into account ("Required EEDI" - curve), whereas the actual speed-power dependency and behavior is portrayed by the "Calculated EEDI" - curve.

The attained EEDI value falls until it reaches a certain threshold value at speed of around 15kn, after which it rises again. This behavior is due to the fact that the benefit to the society (defined as $speed * capacity$) is gradually approaching zero when the speed is reduced, whereas the impact to the environment (defined as $power * fuel\ consumption$) remains relatively constant at lower speeds as the auxiliary engine power becomes dominant and propulsion power diminishes. In the end the calculated EEDI value rises until infinity, as shown in the figure.

The case vessel would fulfill the EEDI requirement at design speeds between 18kn and 26kn. The calculated EEDI value does not decrease after a certain threshold value is reached at the speed of roughly 15kn, though the EEDI requirement decreases linearly all the way to zero. For this vessel a suitable "Required EEDI cut-off limit" would be at 18kn, as there is no way to reduce the "calculated EEDI" - value by reducing the speed and propulsion power below the threshold value of ~18kn as otherwise the auxiliary engine power would become dominant while the "benefit to society" would decrease rapidly, leading to higher EEDI values.

Considering the vessels with low design speeds and high EEDI values (caused by e.g. main dimension limitations), decreasing the attained EEDI value by lowering the design speed and thus propulsion power of the vessel might not be enough to reach the required EEDI value, unless a cut-off limit is not introduced. This is caused by the low propulsion power requirement at low speeds, as the auxiliary engine power is relatively much larger than on vessels with high speeds and thus large amount of propulsion power.

As shown in the figure a lower speed cut-off limit of 18kn could be used for the required EEDI, meaning that if the vessel's design speed is under 18kn it will always be measured against the 18kn baseline and the vessels with a higher design speed would be required to fulfill the requirement defined by the design speed, until a higher cut-off limit of e.g. 30kn is reached. This method would enable the vessels having a high design speed the possibility to decrease their design speed (de-rating engine(s)) thus reducing the attained EEDI value until the EEDI requirement is fulfilled, similarly to the current EEDI approach.

It is important to note that the values and curves used in the previous example are only valid to this specific case vessel. Defining an exact cut-off limit for the entire vessel group requires further research, although the basic ideology can be implemented throughout the vessel group. A similar approach can also be used for the RoRo cargo vessel group.

Altogether it can be concluded that if speed-dependent baselines were to be implemented for RoRo Cargo vessels and RoPax vessels, a lower cut-off limit should be defined separately for the two groups in order to develop a justified method for regulating the energy efficiency of these vessels.

4.4. Correction factor for reserve power

Vessels involved in short-sea shipping have in many cases installed reserve power in order to ensure safe, economic and efficient operation in changing environmental and service conditions. Main reasons for installing reserve power to the vessels are to maintain schedules in all weather conditions year-round and to enable maintenance on the engines during the voyages, as the harbor times are not long enough for routine maintenance.

Due to safety / redundancy reasons RoRo cargo vessels and RoPax vessels are typically built with two propellers with one or two engines per shaft line. The variety of engine configurations for RoPax vessels used in this study is shown in Table 25.

Table 25 - Number engines on RoPax vessels used in the study

Number of main engines	PCS	%
2	60	38,2 %
4	93	59,2 %
6	1	0,6 %
unknown	3	1,9 %
Total:	**157**	**100,0 %**

In the present EEDI formula the propulsion power used in the calculations is taken as 75% of P_{ME}. However the remaining 25% power reserve is only suitable for deep-sea shipping. For short-sea shipping and especially for RoPax vessels, the typical power reserve is 25% for one engine, as it is a typical design principle to dimension the main machinery to maintain the design speed in calm weather with only three engines out of four. This allows for maintenance to be carried out on any of the engines during the voyage. The fourth engine is only used in rough weather conditions and for catching schedules, if required.

The RoRo cargo vessels used in short-sea shipping are typically equipped with either two or four engines, whereas the RoRo cargo vessels used in deep-sea shipping usually have only one main engine as shown in Table 26.

Table 26 - Number of engines on RoRo Cargo vessels used in the study

Number of main engines	PCS	%
1	53	42,4 %
2	68	54,4 %
4	4	3,2 %
Total:	**125**	**100,0 %**

Considering a RoPax vessel is designed to do its design speed with 75% (or less) of its engines in calm weather with a 85% load on the engines, it will lead to a total engine usage of $\frac{3}{4} * 85\% = 63{,}75\%$. Thus, the power reserve / sea margin factor for RoPax vessels should instead be 100% - 63,75% = 36,25% instead of 100% - 75% = 25%.

The EEDI formula at its current stage is as follows (MEPC.1/Circ.681):

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

The correction factor used to take into account ship-specific properties is f_j. The correction factor could be used to allow RoPax vessels have reserve power, thus reducing their EEDI values and enabling the installation of a certain level of the crucial reserve power. Thus, defining the f_j correction factor as 0,85 could be used for RoPax vessels in order to allow the installation of some amount of reserve power. For RoRo Cargo vessels, the same amount of reserve power could be allowed in a similar method. In this way, short-sea shipping and the ship groups belonging to it would be treated fairly. However, a more in-depth study should be made on what the actual level of allowed reserve power could be.

5. Alternative methods to measure the energy efficiency of RoRo and RoPax vessels

This chapter highlights and points out the positive and negative sides of alternative methods for evaluating the energy efficiency of RoRo cargo vessels and RoPax vessels. These methods could be used as part of the basic EEDI methodology for some special cases where attaining an EEDI value below the required baseline is extremely difficult. For example, in such a case, the energy efficiency of a new vessel could be demonstrated by comparing its EEDI value with other existing vessels on the same route or its CO2 emissions with other modes of transportation.

Two fundamentally different alternative methods to measure the energy efficiency were studied. One is based on the idea of a standard operation profile, where the vessel's energy efficiency is measured at the sea trial in three (or more) predefined operating points and then compared with the global fleet averages for that vessel type. This method would be similar to the current emission tests for new cars and trucks. The other is a method where the ship is compared against other means of transportation tasks on the same route. For example, this could mean an existing ship on the same route or other modes of transportation such as trains, trucks or airplanes.

5.1. Standard operation profile

The speed dependent operation profile ideology originates from the emission tests conducted on new passenger cars and trucks. In the emission test the cars and trucks are given a standard driving profile which they drive on a chassis dynamometer while the emissions are measured continuously. Then, either the cumulative emissions or emissions at specific load points are selected and later regulated.

The driving profiles used for road vehicles are weighed averages of typical driving cycles. For example the one used for urban buses is the so called “Braunschweig City Driving Cycle”, 11km long cycle with frequent stops. The Braunschweig cycle is presented in Figure 52.

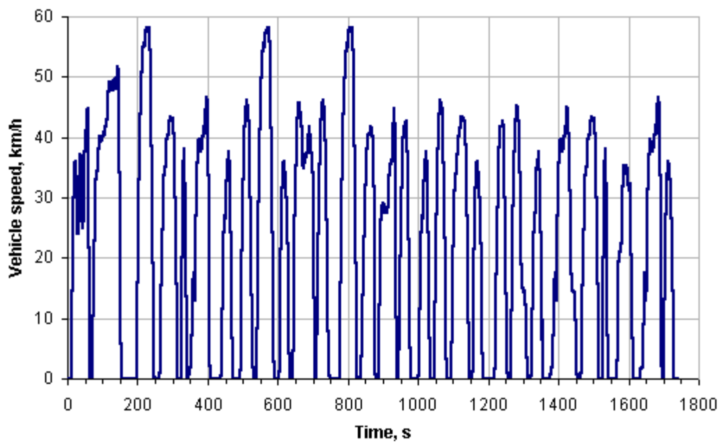


Figure 52 - Braunschweig test cycle

Similarly to road vehicles, a standardized cycle for RoRo cargo vessels and RoPax vessels could be developed. As the design speeds and transport tasks are dissimilar, a single and universal driving cycle that would be applicable to all different RoPax or RoRo cargo vessels cannot be developed. Instead, the profile should be modularized in such a way that it takes the distribution of different design speeds into account.

There are basically two different approaches to defining the standardized operation profile - method. The first one would be such that the ship has to fulfil the emission requirements on three (or more) different speeds. The selected speeds could for example be at 100%, 75% and 50% of the design speed. This approach is illustrated in Figure 53. Fulfilling the requirements at different speeds would mean utilizing speed-dependent baselines, thus raising the question that is the "standardized operation profile" just a more complex version of the speed dependent baseline approach.

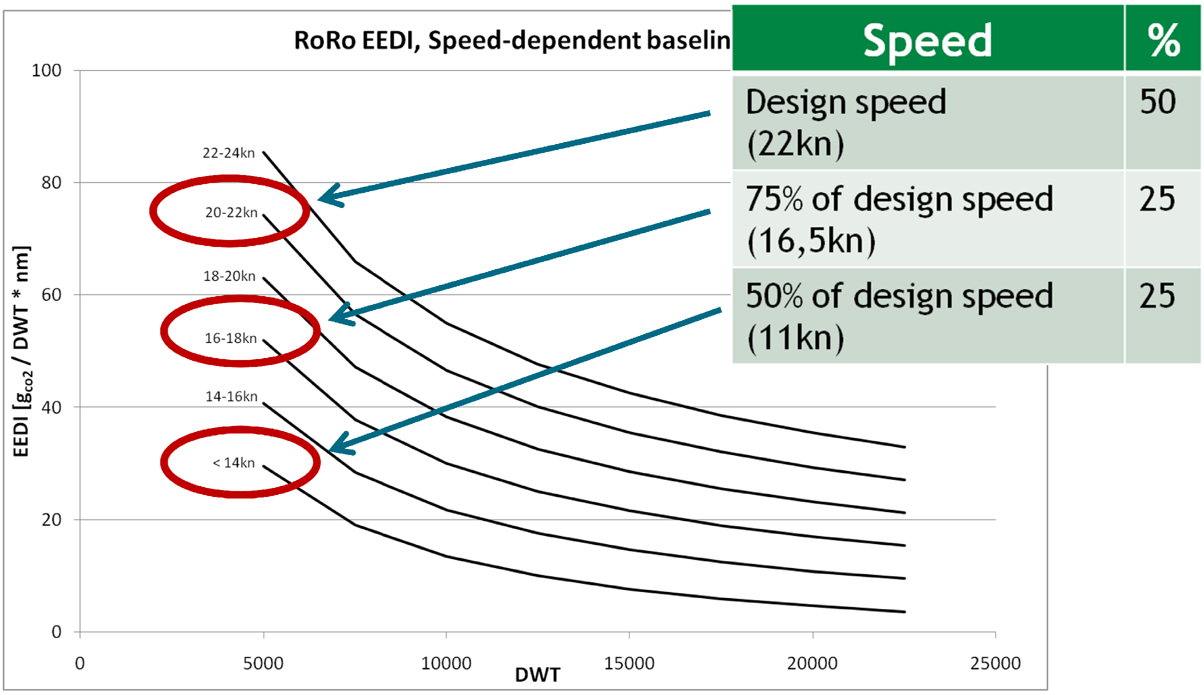


Figure 53 - RoRo, Standard Operation Profile limits

Another approach to the standardized operation profile would be to weigh the emissions at different speeds and then sum up the total emissions. This way the amount of total emissions would be limited to a certain maximum, depending on the speed of the vessel. The basic idea is demonstrated in Figure 54. It is important to notice that the speed of the vessel is taken into account only at 10kn and onwards in 1kn steps. In the example, each speed has been weighed equally.

However, this approach proves problematic as well, in that it does not recognize vessels of a different size from one another. The approach only compares the absolute emissions relative to the engine power. Therefore the ideology should be developed further by also taking into account the size of the vessel as well as other properties.

Speed	Weighting %
11	10
12	10
13	10
14	10
15	10
16	10
17	10
18	10
19	10
20	10
Total	**100**

Speed	Weighting %
11	14,3
12	14,3
13	14,3
14	14,3
15	14,3
16	14,3
17	14,3
18	
19	
20	
Total	**100**

Speed	Weighting %
11	20
12	20
13	20
14	20
15	20
16	
17	
18	
19	
20	
Total	**100**

Figure 54 - Speed group weighting

Perhaps the greatest problem with these two approaches is defining the baselines to which the measured emissions would be compared. There is no existing database for such measurements for a large number of vessels, and collecting the sufficient amount of data from all existing vessels is very challenging if not impossible. On the other hand, the present EEDI data of the vessels could be utilized to define a starting point for the first five years. The data collected during these five years could then be used to define more exact baselines that could be tightened, for example, every 5-years.

As such these two alternatives would further expand the speed-dependent baseline approach (Chapter 4.3), as the approaches attempt to model the typical RoRo cargo vessels and RoPax vessels in operation, and not determining the energy efficiency of a vessel only by looking at a single operating point.

These models require a lot of development in order to make them usable. As such, a possible loophole with these approaches might be the so called “cycle beating”, which means that the engines (and thus emissions) are optimized only at the specific measurement points. This could mean that in reality the actual emissions might differ considerably from the measured ones.

5.2. Comparison with existing and alternative modes of transportation

The simple approach to ensuring that new vessels in the future are more energy efficient than existing ships, would be to compare new built vessels with existing ones. For the comparison to be straightforward, the new vessel should transport a similar amount and type of cargo and operate on the same route as the existing vessel. However, even though this would be a simple and accurate way of validating the improvement in energy efficiency, there are two fundamental problems. First, in many cases the operating routes are not simple legs between two ports or the new vessel will not be even operating on the same route, making such an approach inapplicable. Second, this sort of comparison would require using sensitive data in the form of carried cargo quantity and detailed fuel consumption (in many cases from competitors), which are rarely available publicly.

An alternative method to regulate the energy efficiency of a new ship would be to compare it with other means of transportation, such as trains, trucks and airplanes. This would depend heavily on the route the ship is designed for, as alternative transportation options might not exist at all.

The ideology was further studied with the help of three case examples. The three routes and vessels on them are such that Deltamarin has full information on them, so exact data on fuel consumption could be utilized. For the alternative transportation methods, namely trucks, airplanes and trains, the data and average emission factors were taken from a Finnish research called VTT LIPASTO.

In the case examples, the ships are RoPax vessels, but in principle the same conclusions and relative emission quantities are also valid for RoRo cargo vessels.

5.2.1. Case examples of transportation tasks in different locations

5.2.1.1. Turku – Stockholm

The first example is a route between Turku, Finland and Stockholm, Sweden. Alternative transportation methods competing with ferry connection are road and air transport. The possibilities are that passengers which would normally travel by ferry will instead use airplanes, trucks/buses or passenger cars. The route options are presented in Figure 55 with details.

	Transportation	Distance (km)	Duration (h)
(green)	Ferry	280	12
(blue)	Road	1800	23
(red)	Plane	260	0,5

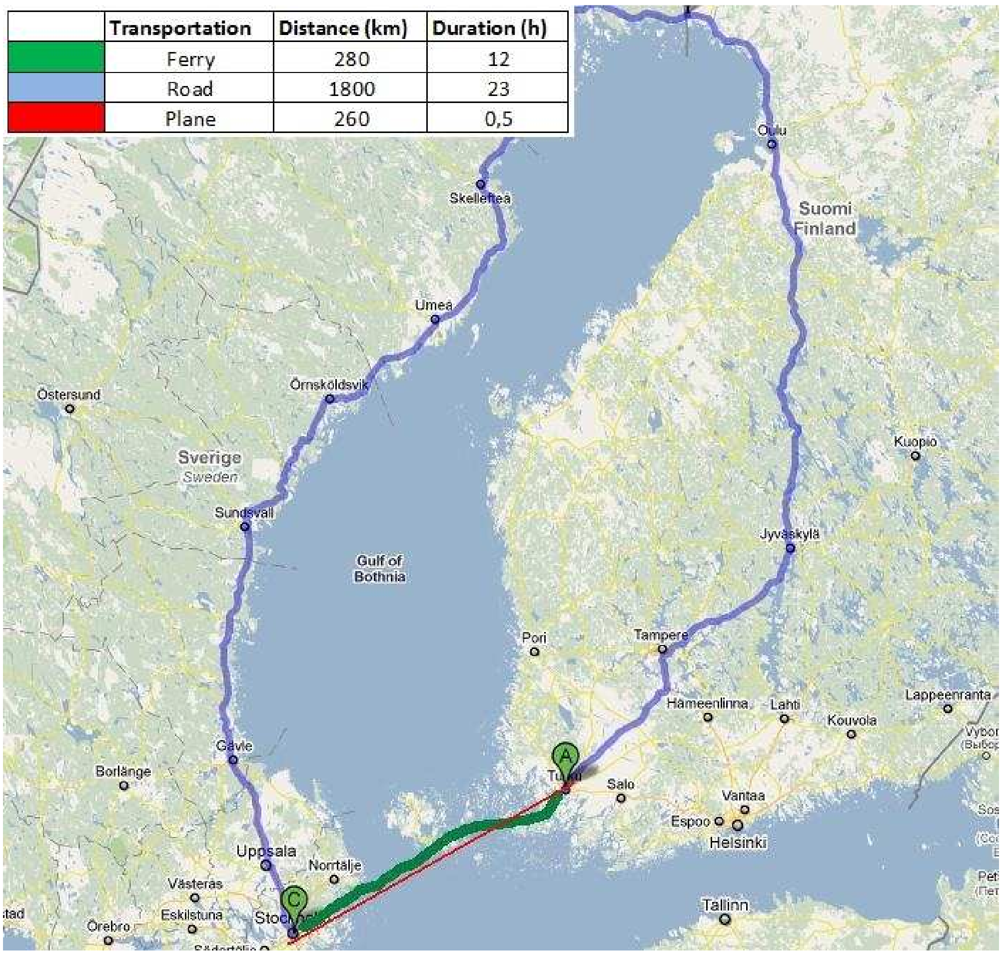


Figure 55 - Route options between Turku and Stockholm

The efficiency of transportation is measured purely in total CO_2 emissions, presented in Table **27**. The ferry data is from the Deltamarin database, and the average emissions for road and air transport are from the VTT LIPASTO - database. The CO_2 emissions / fuel consumption of the ferry are allocated to the different cargoes according to the amount of space each "transportation task" requires. This method is the same as discussed earlier in Chapter 4.2.3.3. The amount of passengers is divided into passenger cars by an average of 1,9 persons per vehicle (Finnish average in 2009) and the remainder are to fly by plane.

The total amount of emissions from ferry operations amounts to 98 tons of CO_2, whereas emissions from the alternative transportation modes amount to 278 tons of CO_2.

Table 27 - Turku-Stockholm one-way trip CO2 emissions by different means of transportation

Turku-Stockholm, one-way				
Sea	Semi-trailers	Cars	Passengers	Total CO_2 emission by sea per one-way trip (ton)
Ferry	59	98	2200	**98**
Road	Pc.	Distance by road (km)	CO_2 emission (g/vehicle km)*	Total CO_2 emission (ton)
Semi-trailers	59	1800	1100	117
Passenger cars	98	1800	170	30
Air	Persons	Distance by air (km)	CO_2 emission (g/person km)***	Total CO_2 emission (ton)
Passengers**	1955	260	257	131
			Total CO_2 emission by road and air (ton)	**278**

*Average in Finland 2009 (source: VTT, available at: http://lipasto.vtt.fi/).

**The passengers travelling by road are decreased. Values 1 person per trailer and 1,9 persons per passenger car are used (source: VTT, available at: http://lipasto.vtt.fi/).

***Short flights in Europe 2008 (source: VTT, available at: http://lipasto.vtt.fi/).

The distribution of the emissions is demonstrated in Figure 56. The same allocation principles are used as before, which means that the emissions of a typical ferry in this route can be divided so that 54 % of them are allocated to passengers (including passenger cars) and the rest to the cargo. The outcome is that ferry emissions allocated to passenger cars are 0,2 x (0,54 x 98 tons) = 11 tons and for air passengers, 0,8 x (0,54 x 98 tons) = 42 tons. The remaining 98 tons of ferry CO_2 emissions are allocated to truck cargo which results in 45 tons of carbon dioxide. When changing from ferries to the alternative transportation modes, the total emissions are increased by approximately 160% to 212%. The total emission difference is 183% for the benefit of the ferry. Thus it is clearly seen that if the sea route shortens the travel distance significantly, marine transportation is the most efficient way of moving cargo and passengers (when only looking at the CO_2 emissions).

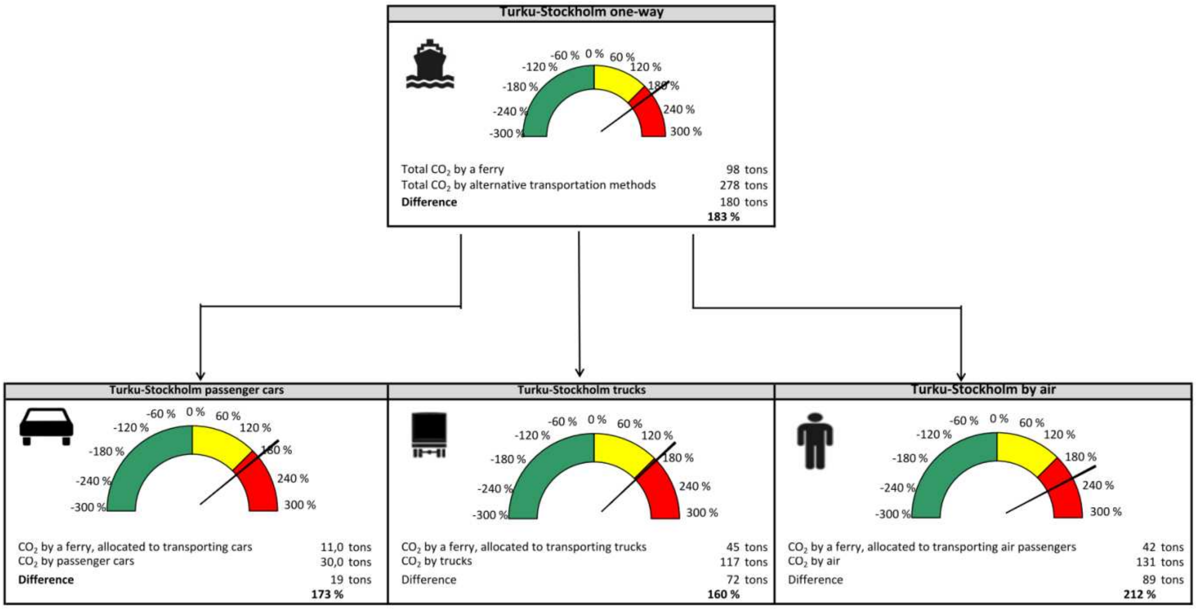


Figure 56 - Turku - Stockholm emission comparison

5.2.1.2. Dover - Calais

The second case example is a transportation task over the English Channel, between Dover, United Kingdom and Calais, France. Although the area experiences heavy ferry traffic, there is also the option to transport goods by train. The train tunnel starts from Folkestone, 15km from Dover and ends near Calais in France. Air connection is not used in this comparison because there are no commercial airports near to Dover. Route details are presented in Figure 57.

Figure 57 - Route options between Dover and Calais

The data for the ferry is from Deltamarin's database and the train emissions are based on Finnish statistics from VTT LIPASTO. The ferry in this one-way route emits 20 tons of CO_2 per trip. The same transport operation for a train causes CO_2 emissions of 4 tons. The calculations are summarized in Table 28.

Table 28 - Dover-Calais one-way trip CO2 emissions by different means of transportation

Dover-Calais, one-way				
Sea	Semi-trailers	Cars	Passengers	Total CO_2 emission by sea per one-way trip (ton)
Ferry	161	200	2000	**20**

Train	Pc.	Distance by train (km)	CO_2 emission (g/km)	Total CO_2 emission (ton)
Semi-trailers*	161	50,5	170	1,386
Passenger cars**	200	50,5	32	0,323
Passenger***	2000	50,5	24	2,424
			Total CO_2 emission by train (ton)	**4**

*Average per a trailer in a train which carries 18 trailers and 6 truck+trailer combinations (source: VTT, available at: http://lipasto.vtt.fi/).

**Average per 2 tons of cargo in Finland 2007 (source: VTT, available at: http://lipasto.vtt.fi/).

***Average per person in Finland 2007 for a long distance electric train (source: VTT, available at: http://lipasto.vtt.fi/).

The total CO_2 emissions from a train are calculated to be 80 % lower than the emissions from a ferry. When allocating the ferry emissions for different types of cargo, the same method is used as in the previous Turku – Stockholm route. For a ferry operating in the Channel, the passenger – passenger car –relation is now 0,323 / 2,424 (Table 28) and the distribution of passenger / cargo –emissions is 19 % / 81 % (same allocation principles used as in the previous case). These values lead to results presented in Figure 58. It is important to note that transporting the same amount of cargo by both ferries and trains is impossible, as there is only one rail going to each direction. The traffic volumes are compared according to data by Eurostar and Port of Dover and the results are shown in Table 29. Unfortunately the Dover port data includes all the ferry cargo, not just for Calais, but the volumes between the two are the largest and the magnitudes are clear.

Table 29 - Tunnel and ferry comparison, Dover - Calais

	Freight [mt]	Passengers	
Tunnel	15,3	17 000 000*	*estimate
Ferries (Dover)	52,3*	13 154 638	*25t average truck weight

Even though the trains would not be fully loaded, the capacity of them most probably cannot be quadrupled due to the physical limitations of the tunnel. Instead, the cargo carrying capacity of ferries can be increased considerably. Therefore ferries remain as the main transportation method for ro-ro cargo over the English Channel. However, for passengers the train is more convenient, as it is the fastest way to travel.

The CO_2 emissions allocated for each cargo type is shown in Figure 58.

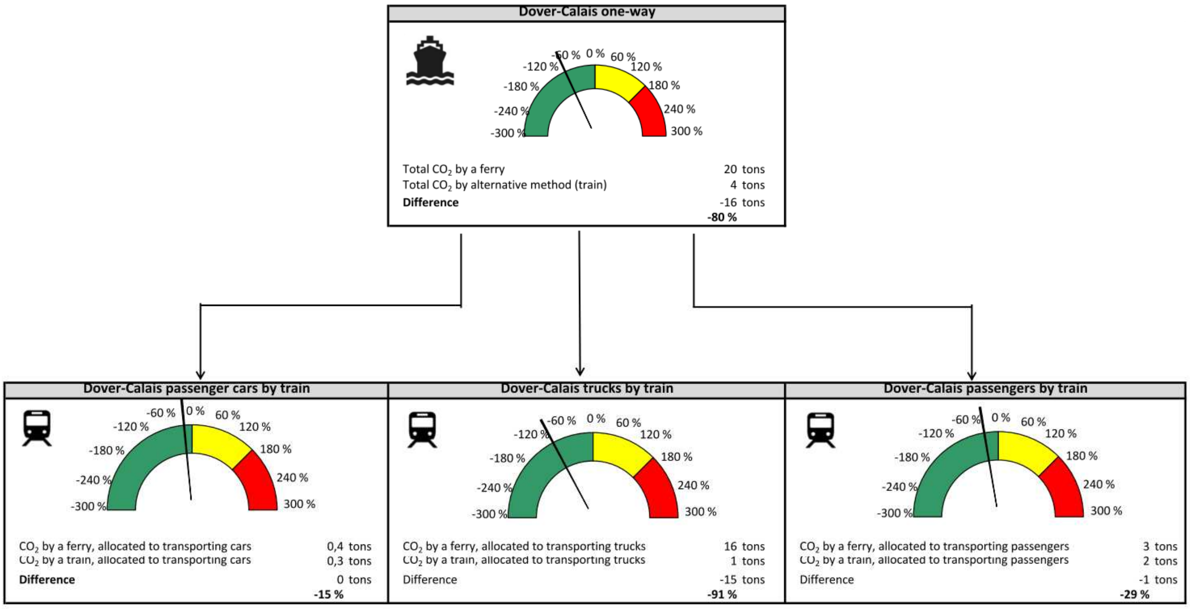


Figure 58 - Dover - Calais emission comparison

5.2.1.3. Piraeus – Mykonos

The third example of a transportation task is the Greece archipelago, where a trip from Piraeus, main land to Mykonos is examined. The example ferry does not have a direct connection between these two destinations, instead it makes stops in Syros and Tinos before it arrives to Mykonos. It is obvious that there are no other competitors for this ferry than an airplane. The nearest airport to Piraeus is in Athens. The destination location of Mykonos has an airport on the same island. The map of the area with the optional travel details is presented in Figure 59.

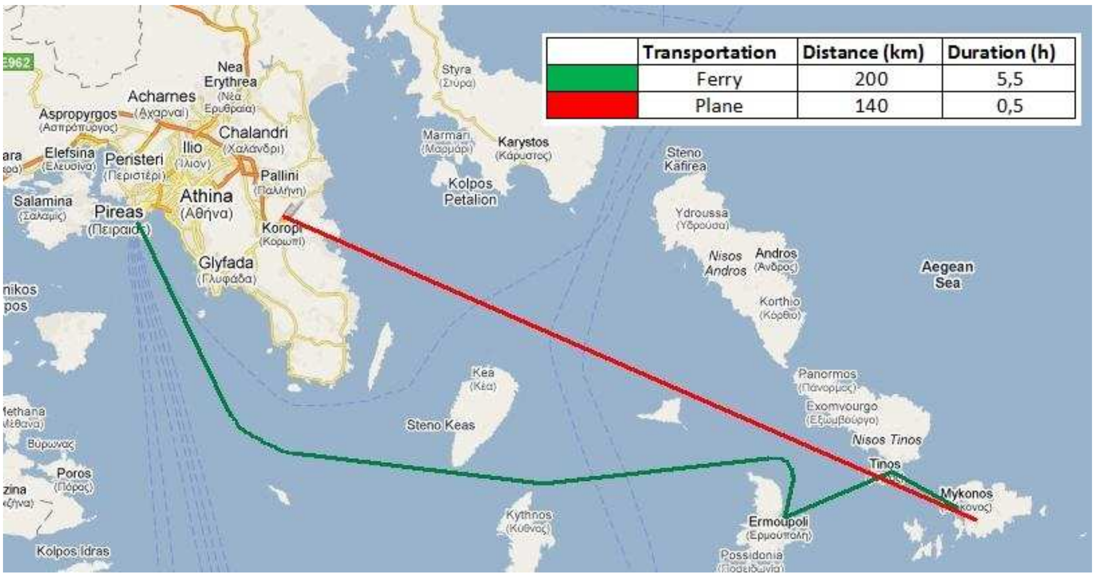


Figure 59 - Route options between Piraeus and Mykonos

According to Deltamarin's database, a high-speed ferry typical to the operation area emits 56 tons of CO_2 during a one-way voyage from Piraeus to Mykonos. It can transport 21 semi-trailers, or in other words 525 tons of cargo. When calculating the emissions for an airplane, the 199 passenger cars carried by ferry are assumed to stay on shore and only the passengers and other cargo are transported by air. According to the statistics from VTT LIPASTO, transportation by air causes CO_2 emissions of 157 tons. Calculations are shown in Table 30.

Table 30 - Piraeus-Mykonos one-way trip CO2 emissions by different means of transportation

Piraeus-Mykonos, one-way				
Sea	Semi-trailers	Cars	Passengers	**Total CO_2 emission by sea per one-way trip (ton)**
Ferry	21	199	1500	**56**

Air	Pc.	Distance by air (km)	CO_2 emission (g/km)	Total CO_2 emission (ton)
Passengers*	1500	140	257	54
Cargo**	525	140	1404	103
			Total CO_2 emission by air (ton)	**157**

*Short flights in Europe 2008 (source: VTT, available at: http://lipasto.vtt.fi/).

**2009 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting (source: VTT, available at: http://lipasto.vtt.fi/).

The emission difference between a ferry and an airplane is significantly beneficial for the ferry. The percentage is 180 % even without taking into account emissions from passenger cars connected with air travel. When allocating the emissions to different cargo types, the previously used method is implemented again. The ratio between passenger and cargo emissions from the ferry is 20/80 (according to the Deltamarin database). Therefore, the CO_2 emissions from the ferry for the passengers are 44,8 tons and for cargo 11 tons. By these calculations the difference of emissions of carbon dioxide allocated to the passengers is 382 %. This proves the efficiency of the ferry, when compared to the airplane transporting passengers and cargo. The distribution is demonstrated in Figure 60. Again, it is important to note that the numbers presented only apply for this case example.

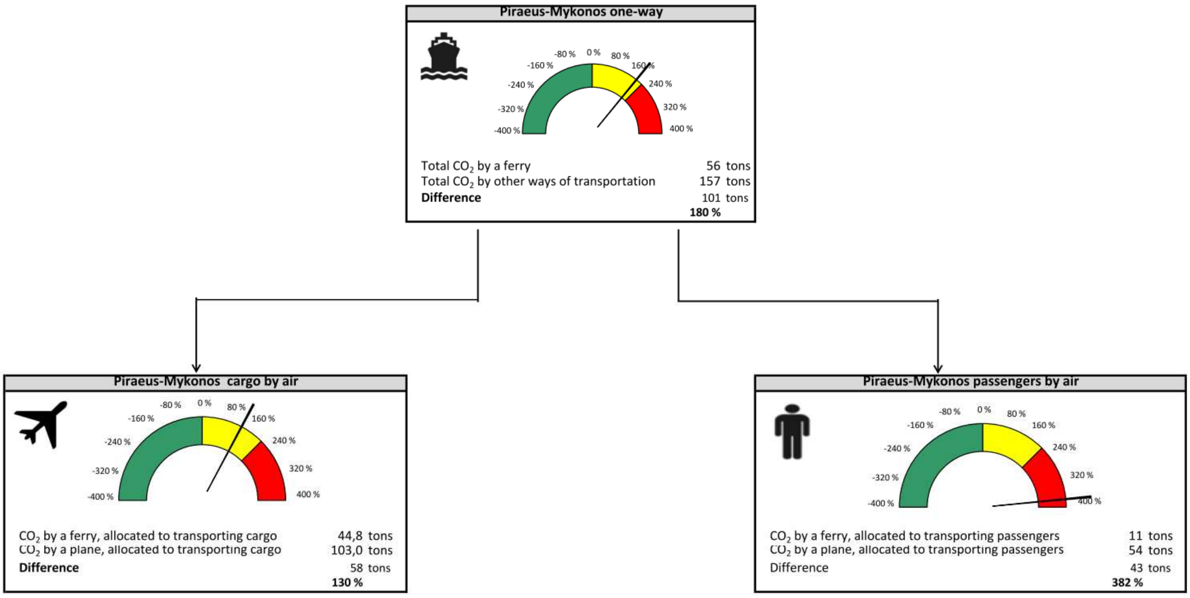


Figure 60 - Piraeus - Mykonos emission comparison

5.2.2. Conclusions on the energy efficiency of alternative transportation modes

The ferry proved to be undoubtedly the most environmentally friendly method of transportation in two out of the three examples when measuring by the amount of consumed fuel (in other words the amount of emitted CO_2) per carried cargo ton and per passenger. As only the CO_2 emissions were compared, it is recommended to make a thorough study with focus on also other aspects of the different transportation methods in order to determine which transportation mode is "best" in each case.

Overall it can be concluded that the RoRo cargo vessels and RoPax vessels are usually more efficient than the competing transport methods on typical short-sea shipping routes and that the volume or capacity of the ferry transportation is superior to the capacity of the competing methods. This argument should be kept in mind when defining legislation that may limit the operative effectiveness of RoRo and RoPax vessels.

6. EEDI applicability for purpose built / specialized vessels

6.1. Vessel categories in the EEDI

Cargo carrying ships are currently included in the EEDI approach. These ships are vessels that can be categorized easily and that intended for continuous operation at or near a single design point (i.e. service speed). In addition to these "conventional vessels", more specialized vessels such as RoRo and RoPax vessels are to be included into the EEDI at a later stage, provided that a suitable method can be found. However, in addition to these vessels, a large number of purpose-built, specialized vessels exist that are currently excluded from the EEDI scope. These excluded vessels include yachts, offshore supply vessels, service vessels and fishing vessels to name a few.

The vessels included in the current EEDI approach are listed in Table 31 and the vessels excluded from the current EEDI approach in

Table 32. The relative GHG-emission estimations are also presented in the tables. The emission estimations are from the IMO GHG study from 2009.

Table 31 - Current EEDI coverage (MEPC 60/WP5)

Covered by the current EEDI approach			
Ship Types	**Total CO_2 emissions**	**% of total**	**Cumulative**
Crude oil tanker	112,769,764	10.1%	10.1%
Products tanker	43,378,360	3.9%	14.0%
Chemical tanker	64,139,731	5.7%	19.7%
LPG tanker	14,334,344	1.3%	21.0%
LNG tanker	33,250,235	3.0%	24.0%
Other tanker	2,377,084	0.2%	24.2%
Bulk	178,176,226	15.9%	40.1%
General cargo	95,915,792	8.6%	48.7%
Other dry-Reefer	19,220,666	1.7%	50.4%
Other dry-Special	1,050,811	0.1%	50.5%
Container	263,976,591	23.6%	74.1%
Vehicle	27,416,137	2.5%	76.6%
Roro	18,250,134	1.6%	78.2%
Ferry-Pax	17,648,095	1.6%	79.8%
Ferry-RoPax	64,188,634	5.7%	85.5%
Cruise	21,307,727	1.9%	87.4%
Total EEDI coverage	977,400,330	87.4%	

Table 32 - Ship types not covered by the current EEDI approach (MEPC 60/WP5)

Not covered by the current EEDI approach			
Ship Types	**Total CO_2 emissions**	**% to total**	**Cumulative**
Yacht	2,961,512	0.3%	87.7%
Offshore-Anchor handling T/S	343,305	0.0%	87.7%
Offshore-Crew/supply vessel	2,016,424	0.2%	87.9%
Offshore-Pipe(various)	1,694,125	0.2%	88.0%
Offshore-Platform supply	7,847,436	0.7%	88.7%
Offshore-Support/safety	1,287,720	0.1%	88.9%
Offshore-Tug supply	4,867,580	0.4%	89.3%
Service-Dredging	5,454,387	0.5%	89.8%
Service-Other	9,084,457	0.8%	90.6%
Service-Research	4,559,833	0.4%	91.0%
Service-SAR & patrol	2,399,215	0.2%	91.2%
Service-Tug	36,548,686	3.3%	94.5%
Service-Workboats	839,629	0.1%	94.6%
Miscellaneous-Fishing	22,606,670	2.0%	96.6%
Miscellaneous-Other	718,334	0.1%	96.6%
Miscellaneous-Trawlers	37,513,822	3.4%	100.0%
Total Non-EEDI coverage	**140,743,136**	**12.6%**	

The ship categories listed in the tables include all propulsion solutions, and thus the vessels currently excluded from the EEDI by guidelines (smallest ships, ships with diesel-electric propulsion or hybrid / gas-turbine machinery) are also included in the tables. However, although the amount of the ships outside the current EEDI scope is roughly one third of the 12,6% share of the total global GHG emissions from shipping, even they have been included in the scope of this study.

6.2. Purpose built / specialized vessel categories

The purpose built / specialized vessels consist of four main groups - yachts, offshore vessels, service vessels and miscellaneous vessels. As the scatter of the various specialized ship groups is large, there are multiple subgroups in the four main groups. However, the absolute number of ships in these subgroups might be relatively low for defining separate EEDI approaches for them.

Yacht ship group

Yachts are recreational vessels and can be considered to be “mini-cruisers”, meaning that their main purpose is to offer a “floating holiday”. These vessels do not have any specific itineraries or schedules, thus defining a transportation task for them impossible.

The estimated CO_2 emissions from yachts are 0,3% of total shipping CO_2 emissions, roughly the same absolute amount when compared to the "other tanker" - group in the current EEDI approach. The total number of yachts in the IHSF database is 1735 (out of which 911 (or 52,5%) are below 400GT), whereas the number of "other tankers" is only 182. This demonstrates the huge difference when comparing the absolute emissions to the number of vessels. A typical yacht is presented in Figure 61.

Figure 61 - Yacht "Lionheart"

Yachts have high-speed four stroke diesel engines and two propulsion drivers, connected either to controllable or fixed pitch propellers. The common measure for capacity for a yacht is its gross tonnage or the length of the vessel. However, gross tonnage describes the absolute size of the vessel in a more accurate way and thus it will be used within this study as the capacity for yachts. The installed power and thus the maximum speed vary considerably, as shown in Figure 62.

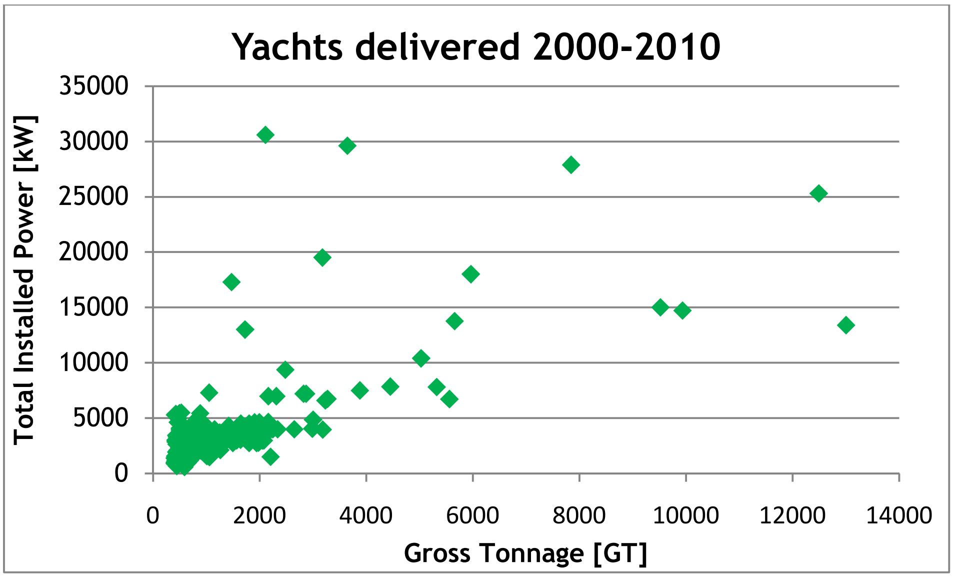


Figure 62 - Yacht gross tonnage vs. total installed power

Offshore ship group

The offshore vessel group consists of various platform supply and service vessels, such as anchor handling vessels, crew/supply vessels bringing ratios and crews to and from platform, various pipe laying / service vessels, pure platform supply vessels performing various maintenance and construction operations, stand-by support/safety vessels equipped with heavy fire-fighting equipment and tug supply vessels helping large tankers manoeuvre near the platforms and moving floating platforms as necessary.

The various subgroups in the offshore vessel group are shown in Table 33, where it can be seen that the "anchor handling / tug / supply" and "supply vessels" groups are the two largest groups forming roughly 80% of the total group size.

Table 33 - Offshore vessel subgroups

Ship type	PCS	% of total
Anchor handling / tug / supply	774	51,4 %
Crewboat	56	3,7 %
Diving support vessel	47	3,1 %
Offshore construction vessel	12	0,8 %
Offshore maintenance / utility vessel	42	2,8 %
Offshore support vessel	18	1,2 %
Other offshore vessels	18	1,2 %
Safety standby vessel	78	5,2 %
Supply vessels	443	29,4 %
Survey ship ROV support	19	1,3 %
Total:	1507	100,0 %

The size and power distribution of offshore vessels is shown in Figure 63.

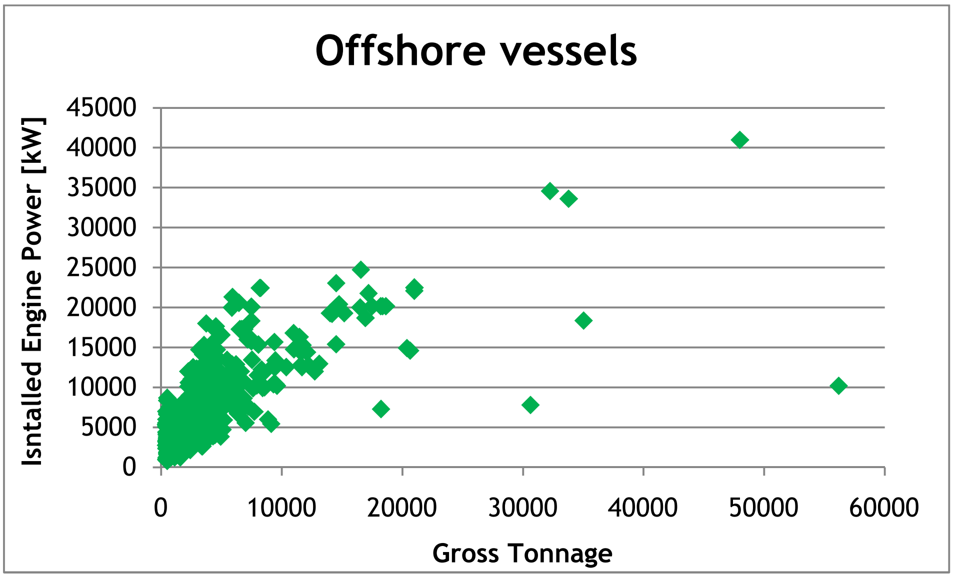
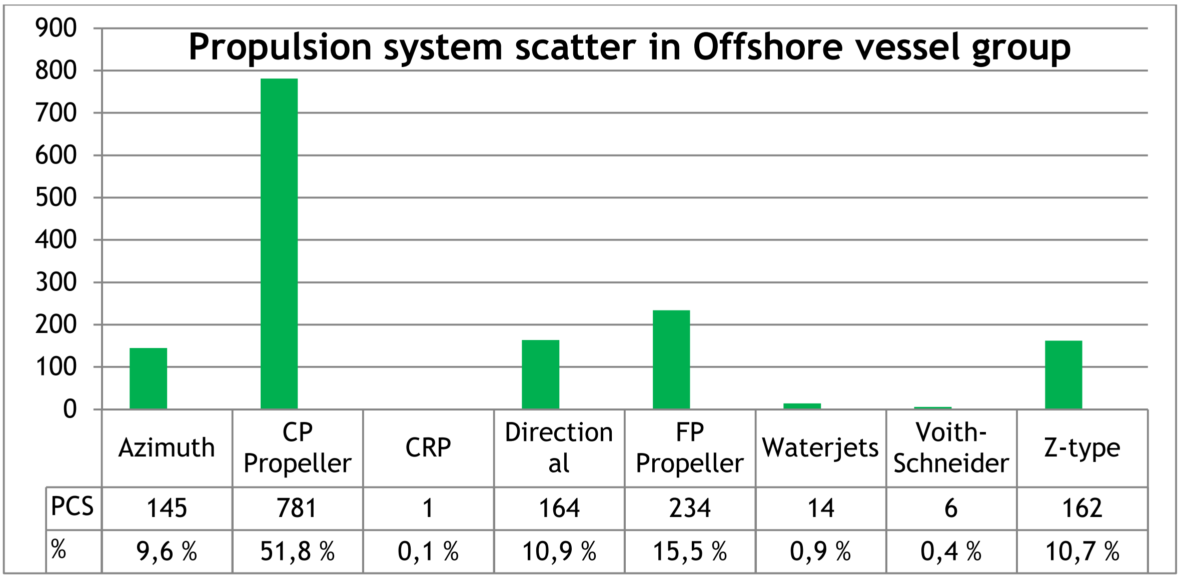


Figure 63 - Installed engine power vs. GT on offshore vessels

As the operations for which the vessels have been designed for varies a lot, so too do the propulsion systems of these vessels. The propulsion alternatives for the ships in question are shown in Figure 64.



	Azimuth	CP Propeller	CRP	Directional	FP Propeller	Waterjets	Voith-Schneider	Z-type
PCS	145	781	1	164	234	14	6	162
%	9,6 %	51,8 %	0,1 %	10,9 %	15,5 %	0,9 %	0,4 %	10,7 %

Figure 64 - Offshore vessel group propulsion systems

Controllable Pitch propeller is the most common propulsion solution, though azimuthing systems (both electrical and Z-drive) are also common. Due to redundancy reasons, the offshore vessels have usually two or more medium- or high-speed four-stroke diesel engines. Ice-class is common for offshore vessels; out of the sample of 1507 vessels 167 (~11%) have an ice-class. The number of propulsion units is typically two or more, as illustrated in Table 34.

Table 34 - Propulsion unit number in offshore vessels

	Pcs	% of total
1 propulsion unit	22	1,5 %
2 propulsion units	1354	89,8 %
3 or more propulsion units	131	8,7 %

Altogether the various offshore vessels are estimated to contribute only 1,6% of the total CO_2 emissions from shipping, roughly a similar amount as RoRo cargo vessels. There are 7423 offshore vessels (out of which 1720, or 23% are below 400GT) and 2776 RoRo vessels in the IHSF Fairplay database. From this data it can be assumed that a single RoRo vessel creates roughly three times as much of CO_2 emissions as one offshore vessel. A typical offshore supply vessel is shown in Figure 65.

Figure 65 - Offshore supply vessel

The offshore vessels have extremely varying operation tasks, which can change on a day-to-day basis. Typical operational requirements for an anchor handling tug supply (AHTS) vessel are;

- Transport fresh water, diesel oil, deck cargoes, bulk cargoes (cement / Barites / Bentonite) liquid mud, stores, materials & equipment
- Two / move Rigs
- Anchor handling
- External fire fighting
- Transportation of passengers to and from Oil field, located offshore
- To berth and/or hold station near offshore platforms to safely transfer passengers, liquids, deck and bulk cargoes
- Rescue personnel fallen overboard and pollution control
- Helicopter hoisting facilities
- Operation to be 24-hours/day continuous operations, capable of remaining on station for a minimum of 15 days

The redundancy of the vessels is of utmost importance to ensure the safe and efficient operation of these vessels, as typical operation areas and environmental conditions are extremely challenging. In addition, many of the platforms that the vessels service are designed to be built according to arctic conditions, thus requiring sufficient ice-performance from the supply vessels.

Service ship group

The service ship group consists of dredgers, research vessels, search and rescue / patrol boats, tugs and workboats. What is common for all of these vessels is that they do not have any specific measurable transportation tasks, but as the name suggests, they serve a specific purpose. This purpose can then vary from dredging to harbour service or fire-fighting, etc. Altogether it can be said that no common design criteria or measurable task exists for this ship group. The largest subgroup in the service vessel group consists of various tugs. All service ship subgroups are presented in Table 35.

Table 35 - Service vessel group subgroups

Ship type	PCS	% of total
Anchor handling / salvage / supply	8	0,9 %
Anti-pollution vessel	11	1,3 %
Buoy tender	15	1,7 %
Cable / Cable repair ship	17	2,0 %
Hopper barge	23	2,6 %
Ice breaker	7	0,8 %
Other vessels	54	6,2 %
Patrol / Pilot vessel / SAR vessel	43	4,9 %
Research vessel	17	2,0 %
Various Dredgers	111	12,8 %
Various Tugs	563	64,8 %
Total:	869	100,0 %

The size and power distribution of offshore vessels is shown in Figure 66.

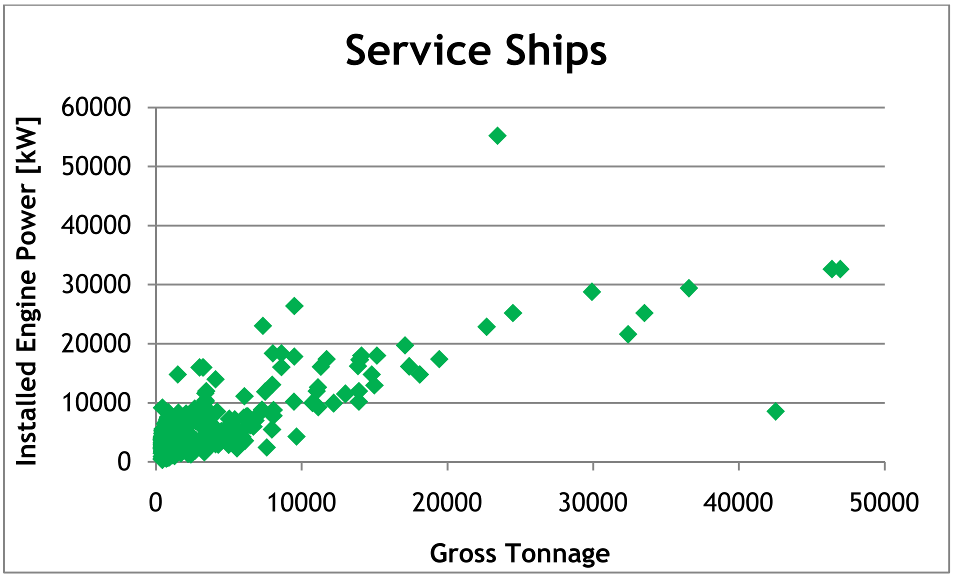
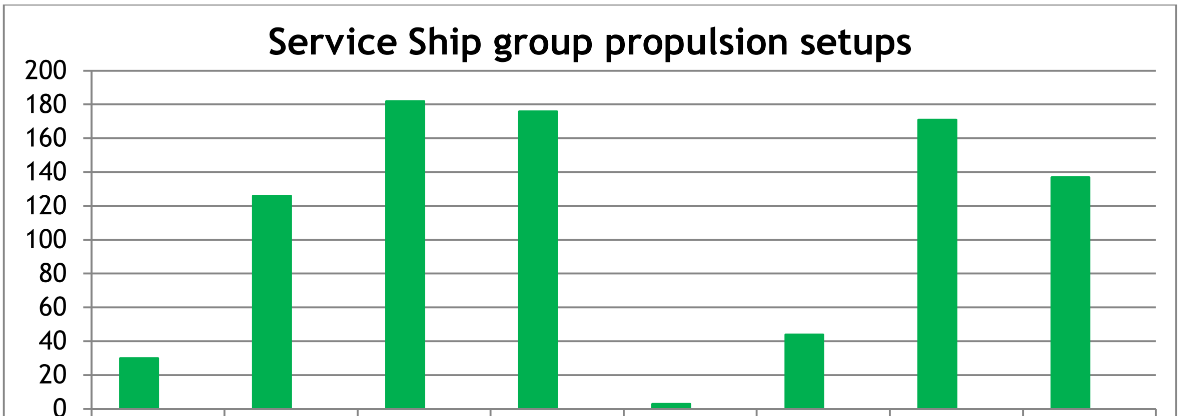


Figure 66 - Installed engine power vs. GT on Service Ships

Due to highly varying operation tasks and thus designs, also the propulsion methods vary greatly in this service ship group. Usually these service ships have two medium- or high-speed four-stroke marine diesel engines and the most common propulsion types are controllable or fixed pitch propeller, Z-type or directional propulsion as shown in Figure 67.



	Azimuth	CP Propeller	Directional	FP Propeller	Waterjets	Voith-Schneider	Z-Type	Unknown
PCS	30	126	182	176	3	44	171	137
%	3,5 %	14,5 %	20,9 %	20,3 %	0,3 %	5,1 %	19,7 %	15,8 %

Figure 67 - Propulsion setups on service ships

As such, the service vessels are estimated to contribute 5,3% of the CO_2 emissions from shipping, with 21 505 vessels in the IHSF database. Tugs are the single largest group, making up roughly 70% of all the vessels in the service ship group. Tugs contribute an estimated 3,3% of the CO_2 emissions from shipping, which is roughly a similar amount to LNG - tanker GHG emissions (1 744 vessels in IHSF database). If this widely scattered group of service vessels would be regulated, it should concentrate on tugs and disregard the other subgroups due to the huge differences in vessel design.

Tugs do not serve a specific transport task, but support other large vessels in harbours. They move vessels that either should not move themselves (like large ships in narrow channels or harbours) or vessels that cannot move themselves (barges, disabled ships, platforms). Some tugs might have other special purposes, like fire-fighting or moving barges in inland-waterways. A typical tug is presented in Figure 68.

Figure 68 - Typical service vessel (tug)

The “capacity” of tugs is measured commonly in bollard pull (the capability to tow and push floating objects), which is directly connected to the installed engine power. As the average size of ships in other classes keeps growing, it will also increase the requirements of the bollard pull of tugs in order to maintain and enhance the performance of harbour services. Therefore, the installed power of tugs is likely to increase in the future; making any limitations to it dangerous and inefficient.

Miscellaneous ship group

The “miscellaneous ship group” consists mainly of fishing vessels and trawlers, as shown in Table 36. The variety of fishing vessels and trawlers is large, ranging from seiners, trawlers and line vessels to “floating factories”. The characteristics of a fishing vessel depend mainly on the ability to process and conserve the cargo on the vessel.

Table 36 - Miscellaneous ship group subgroups

Vessel type	PCS	% of total
Fisheries protection vessel	23	7,8 %
Fishing vessel	129	43,6 %
Live fish carrier	23	7,8 %
Other fishing vessels	12	4,1 %
Refrigerated fish carrier	11	3,7 %
Trawler	98	33,1 %
Total:	296	100,0 %

The size and power distribution of offshore vessels is shown in Figure 69.

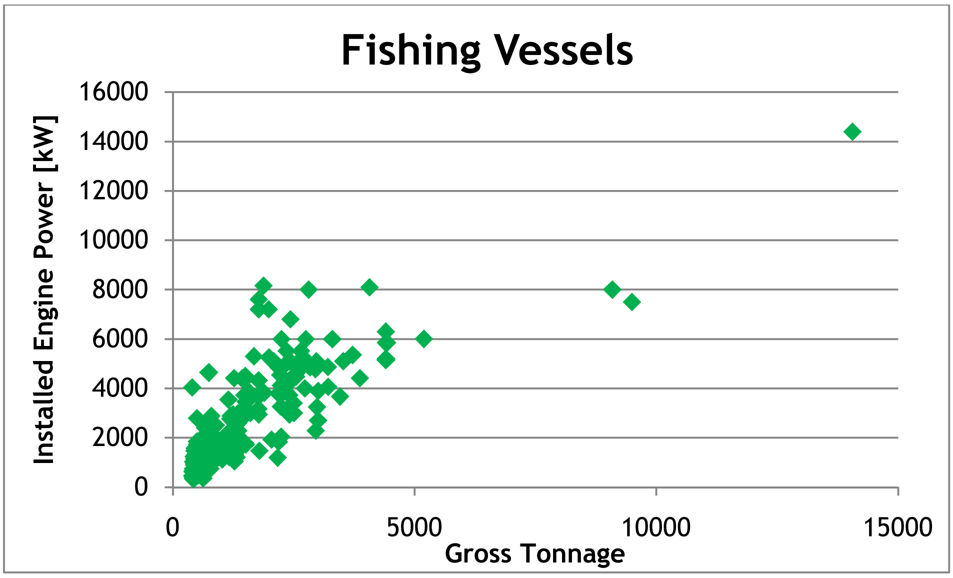


Figure 69 - Installed Engine power vs. GT of Fishing Vessels

Typical propulsion machinery on these vessels consists of one medium- or high-speed four-stroke main engine and single controllable or fixed pitch propeller. The required auxiliary engine power varies depending mainly on the amount of ice/refrigeration capacity and fish processing machinery onboard.

Altogether the miscellaneous vessel group (25 659 vessels, out of which 18 964 (74%) are below 400GT and thus excluded from MARPOL) is estimated to contribute to 5,5% of the total CO_2 emissions from shipping, which is roughly a similar amount to chemical tankers (5354 vessels). A typical fishing vessel is presented in Figure 70.

Figure 70 - Typical fishing vessel

The operation of the various fishing vessels depends on the subcategory of the vessel, but what is common to all of the vessels is that the operation profile varies considerably. For example, a typical trawler transit speed is 12kn whereas the trawling speed is around 4kn in normal weather conditions. The required propulsion power is roughly doubled in the trawling mode in good conditions, whereas in extreme conditions the required propulsion power is almost two times higher compared to transit speed propulsion power requirement, as illustrated in Table 37.

Table 37 - Typical trawler operation profile ("The Next Gen., SINTEF Norway)

		Typical operation profile stern trawlers, double trawl						
Operating days	340	Steaming to/from Hs<1m	Steaming at fish ground Hs<1m	Trawling good weather Hs<1m	Trawling normal weather Hs=1,5m	Trawling bad weather Hs=2,5m	Production normal weather Hs=1,5m	Trawling extreme load Hs=5,0m
Time consumed	100 %	11 %	7 %	25 %	36 %	10 %	10 %	1 %
Time consumed, days	340	37	24	85	122	34	34	3
Rudder resistance in percent of propulsion power		0 %	0 %	2 %	5 %	15 %	0 %	40 %
Speed	[knots]	12	12	4	4	4	2	4
"State of the art" trawler								
Average propulsion power demand	[kW]	1200	1200	2450	2600	2900	300	3450
Rudder resistance	[kW]	0	0	49	130	435	0	1380
Electric power demand	[kW]	300	400	450	500	550	500	1000
Total power	[kW]	1500	1600	2949	3230	3885	800	5830
Engine load	[%]	26 %	27 %	51 %	55 %	67 %	14 %	100 %
Fuel consumption	[tons]	256	174	1143	1803	602	124	90
Total fuel consumption per year	[tons]				Per day:	12,33	Per year:	4192

As noted in the table, the propulsion power requirements of varying fishing vessels are heavily dependent on the weather conditions and exceed the normal transit speed propulsion power requirements significantly.

6.3. Possible modifications to EEDI to include specialized vessels

In order to also include purpose built / specialized vessels into the EEDI baseline approach, multiple options for the vessel groups were tested. The EEDI calculation guidelines have not been targeted at these four ship groups as there is no clear transportation task defined for these vessels However, the conventional EEDI calculation guidelines (see Appendix 2) are used in the tested approaches. The source data used is from the IHS Fairplay (register 10.01, Shippax 3.3.57), similarly as for RoRo and RoPax vessels in this study.

6.3.1. Yachts

The yacht group consists of the IHSF Fairplay "Non-Merchant" subgroup "Yachts". The size of the group for vessels built in 2000-2010 is relatively small, consisting of 348 vessels as shown in Table 38.

Table 38 - Yacht group size

	Number of ships	% remaining
Yachts built 2000-2010. GT < 400 removed	473	-
Missing power, speed and L_{BP} removed	348	73,5 %

The conventional EEDI calculation guidelines are used with the following assumptions:

- The capacity is defined as the gross tonnage
- 75% of total installed engine power (P_{ME} + P_{AE}) and specific fuel oil consumption of 215g/kWh were used
- Speed was defined as 91% of the speed reported in IHSF database as reasoned in Chapter 3.5

Based on these assumptions, the EEDI values for yachts are calculated and presented in Figure 71.

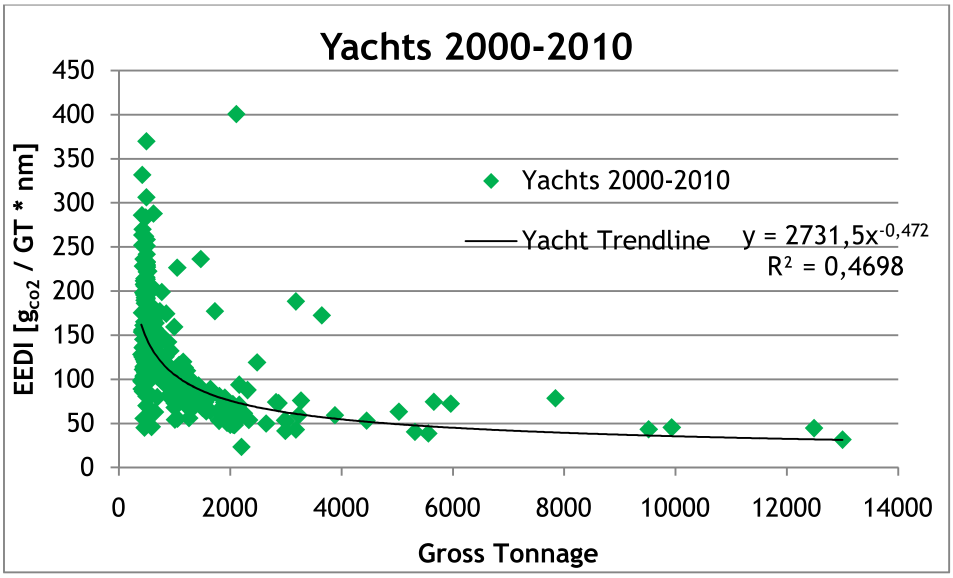


Figure 71 - Yachts in EEDI

The scatter of the data points is very large, especially with the smaller vessels, similarly to other ship groups already included in the EEDI approach. There are some larger vessels that seem to comply relatively well with the EEDI method in the 4 000 - 12 000 GT range. These largest yachts could possibly be included into the passenger ship group for the EEDI. However, as the size and number of large yachts suitable to the passenger ship group is very small (e.g. in the 20th century only 10 yachts over 5000 GT have been built), developing specific correction factors for this small number of ships seems highly unfeasible as the absolute benefit would be negligible.

In case a strict EEDI approach would be applied to yachts, it would lead to limiting the "luxury level" and maximum speed of the vessels by limiting the total installable engine power. However, these vessels are often built to be capable of extremely high speeds compared to normal operating speeds. In addition, the auxiliary engine powers / hotel load are high due to the high electricity demand of all the amenities onboard. Limiting the "luxury level" does not seem feasible at all, as the very purpose and design criteria for yachts is to provide a luxurious experience.

One example of a vessel that has an EEDI value in the range of 400 g_{co2}/GT*nm in the previous chart is "Ecstasea", a super yacht designed to do 25kn with its conventional diesel engines onboard. In addition to the diesel engines, there is also a gas turbine installed onboard which enables speeds over 30kn. This vessel is a good example to indicate how there are many solutions on these vessels that would not be financially feasible, as the main focus on these vessels is ultimate luxury, comfort and exclusivity. Therefore it is proposed that instead of a strict EEDI approach, a more feasible approach to enhance the energy efficiency on these vessels would be to regulate the specific fuel oil consumption of the engines onboard or by implementing a fuel tax (market based measures). These alternative methods are discussed in more detail in Chapter 6.4.

6.3.2. Offshore vessels

The offshore vessel group consists of IHSF Fairplay "offshore" - group, excluding drill ships, drill barges, FPSO's and ice breakers. Ships built in 2000-2010 are shown in Table 39.

Table 39 - Offshore vessel filtering

	Number of ships	% remaining
Vessels delivered 2000-2010	3066	-
Drillships, drill barges, FPSO's and ice breakers removed	2984	97,3 %
Missing power, speed, Lbp, DWT, GT < 400 removed	1633	53,3 %
Missing propulsion type removed	1507	49,2 %

In order to find out if the conventional EEDI approach could also be used for offshore vessels, the calculation guidelines attached as Appendix 2 to this document were used with the following assumptions:

- The capacity was defined as the deadweight of the vessel
- 75% of the total installed engine power (P_{ME} + P_{AE}) and specific fuel oil consumption of 215g/kWh were used
- Speed was defined as 91% of the speed reported in IHSF database as reasoned in Chapter 3.5

Based on these assumptions, the EEDI values were calculated to the offshore vessel group as presented in Figure 72.

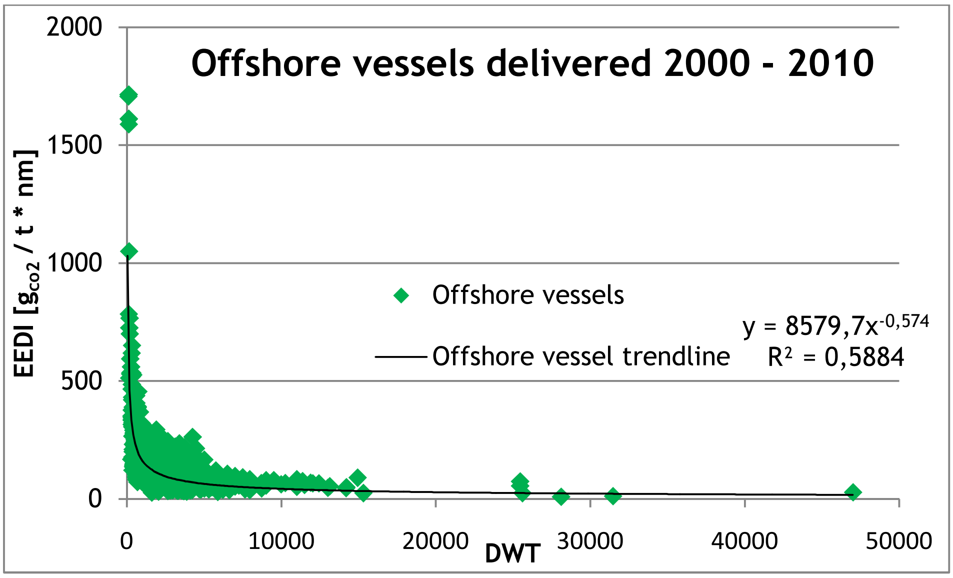


Figure 72 - Offshore vessels in EEDI

The variety in the sizes and EEDI values of the offshore vessels is extremely large. The deadweight of the vessels varies from near-zero all the way to almost 50 000. A closer look is paid on vessels with a DWT < 10 000 and an EEDI value < 500. The results are presented in Figure 73. The vessels are divided according to Table 33.

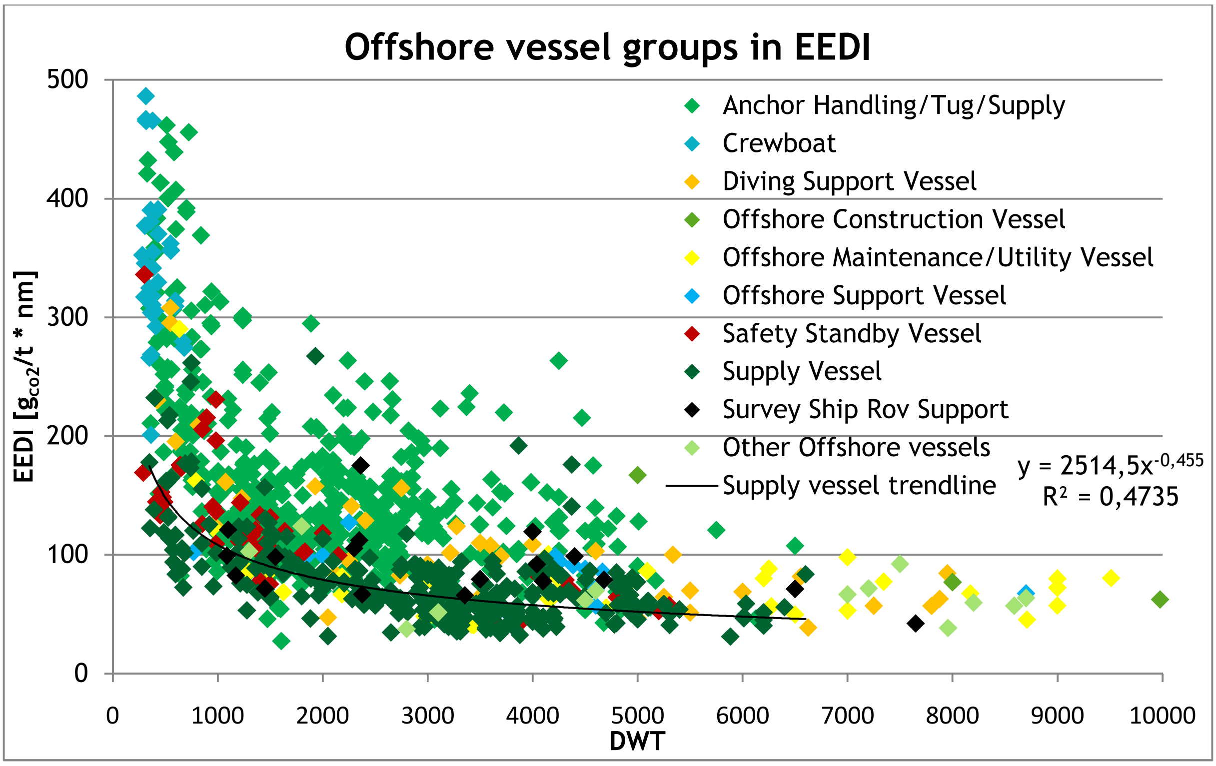


Figure 73 - Offshore vessel groups and EEDI

Virtually all of the subgroups have a very large scatter of EEDI values and capacities. Especially the index values from the largest group, the AHTS vessels, are very scattered. Although the second largest group "Supply Vessels" seems to be a more coherent subgroup, it is not. As can be seen from the figure above, a regression curve was calculated for the "Supply Vessel" group only. The regression curve shows that the standard deviation of this subgroup is approximately 0,47, reflecting the high inconsistency and varying design criteria of these vessels.

One of the most important design properties of the AHTS vessels is the amount of bollard pull the ship is capable of. Bollard pull is directly connected to the installed engine power; the greater the required bollard pull the higher the required engine power will be. The bollard pull of AHTS vessels is plotted against the total installed engine power in Figure 74. The relation between bollard pull and the total installed engine power stays relatively constant. This implicates that the designs are relatively similar from the efficiency point of view, as the bollard pull is one of the most important values that is optimized in AHTS vessel design.

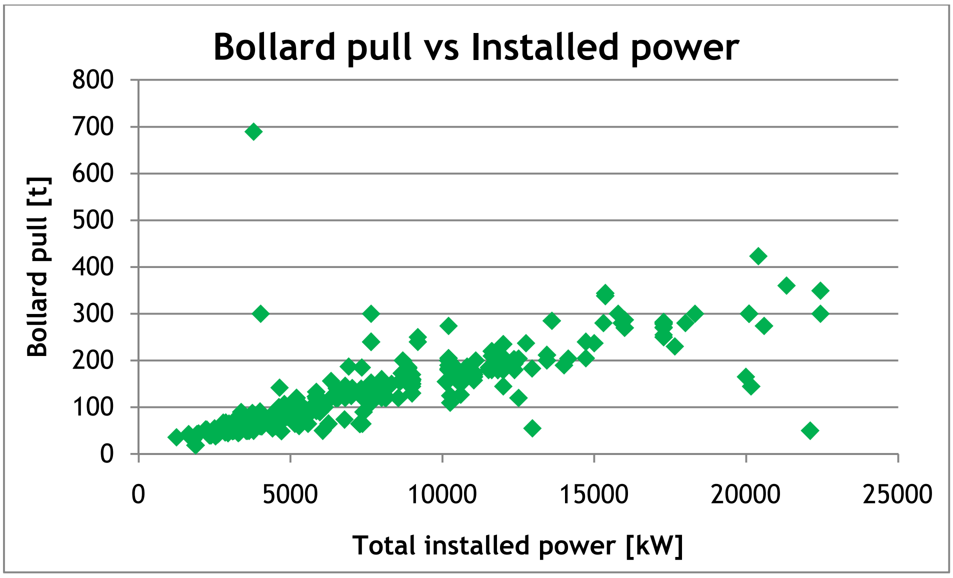


Figure 74 - Bollard pull vs. Installed power in "Anchor handling / tug / supply" offshore vessel subgroup

Including the two largest offshore vessel subgroups into the EEDI approach is highly unfeasible as the vessels do not have any common measurable transportation tasks. In addition, as shown in the previous figures, the relatively large amount of installed engine power in the largest offshore vessel group, namely the AHTS vessels, is due to the function and operability of the vessels and not for reaching high speeds.

Limiting the power of these vessels also poses various risks to their operation. Many oil platforms are located in harsh marine environments and thus the requirements for the offshore vessels regarding engine power, redundancy, power reserves and safety margins are justifiable. In addition, a growing number of oil and gas platforms are designed to be built for arctic conditions, requiring extremely good ice-performance from the supply vessels in order to ensure safe and efficient operation of the platforms.

It can be concluded that also the offshore vessels should be excluded from the EEDI approach and alternative methods are to be used for regulating the energy efficiency of these vessels. These methods could be for example by requiring specific bollard pull efficiency from the AHTS vessels or by limiting the specific fuel oil consumption of the engines onboard. These alternative methods are discussed further in Chapter 6.4.

6.3.3. Service ships

The “service ship” - vessel group consists of “Miscellaneous” - ship group in the IHSF database, the amount of ships are shown in Table 40.

Table 40 - Service ship filtering

	Number of ships	% remaining
Vessels built 2000-2010	6186	-
GT < 400 removed	1573	25,4 %
Missing power, speed and L_{BP} removed	1359	21,9 %
Blank speeds, offshore and tanker vessels removed	869	14,0 %

When using deadweight as the capacity, the size of the vessel group was reduced as all of the ships in the "service vessel" group do not have deadweight capacity. The ships used in the EEDI calculations with DWT as the capacity are presented in Table 41.

Table 41 - Service vessels group sizes when capacity is defined in DWT

Ship type	PCS	% of total
Anti-pollution vessel	10	1,4 %
Buoy tender	15	2,1 %
Cable / Cable repair ship	17	2,4 %
Hopper barge	21	3,0 %
Ice breaker	7	1,0 %
Other vessels	52	7,4 %
Patrol / Pilot vessel / SAR vessel	40	5,7 %
Research vessel	14	2,0 %
Various Dredgers	106	15,0 %
Various Tugs	423	60,0 %
Total:	705	100,0 %

The two largest subgroups are tugs (60%) and dredgers (15%). Tugs do not usually have a specific deadweight, as their function is pushing and towing different types of floating vessels. For dredgers on the other hand, deadweight is one of the important design criteria as it defines the vessel's capacity. For both of the vessels, speed is not important, as the absolute distances travelled are short and the engine power is used for other functions.

In order to find out if the conventional EEDI approach could also be used for service vessels, the calculation guidelines attached as Appendix 2 to this document were used with following assumptions:

- The capacity was defined both in deadweight and gross tonnage for the vessels
- 75% of total installed engine power (P_{ME} + P_{AE}) and specific fuel oil consumption of 215g/kWh were used
- Speed was defined as 91% of the speed reported in IHSF database as reasoned in Chapter 3.5

Based on these assumptions, the EEDI values were calculated for the service vessel group as presented in Figure 75. Due to the high scale of the EEDI and DWT values, vessels with EEDI value > 1000 or DWT > 10 000 are excluded and the remaining vessels are shown in Figure 76. As can be seen, most dredgers have low EEDI values with high capacities, whereas tugs have low capacities and high EEDI values in general. The scatter of the EEDI values for tugs is extremely high, due to the variations in bollard pull values (the total installed power).

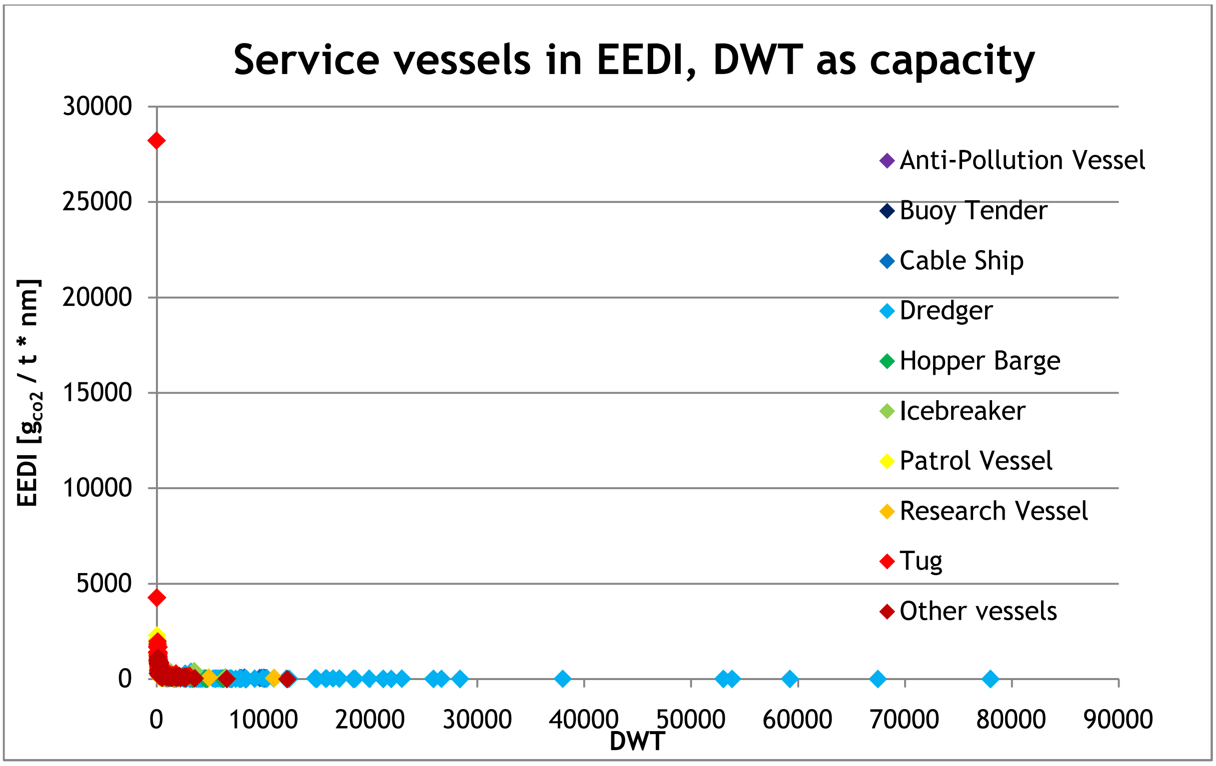


Figure 75 - Service vessels in EEDI, DWT as capacity

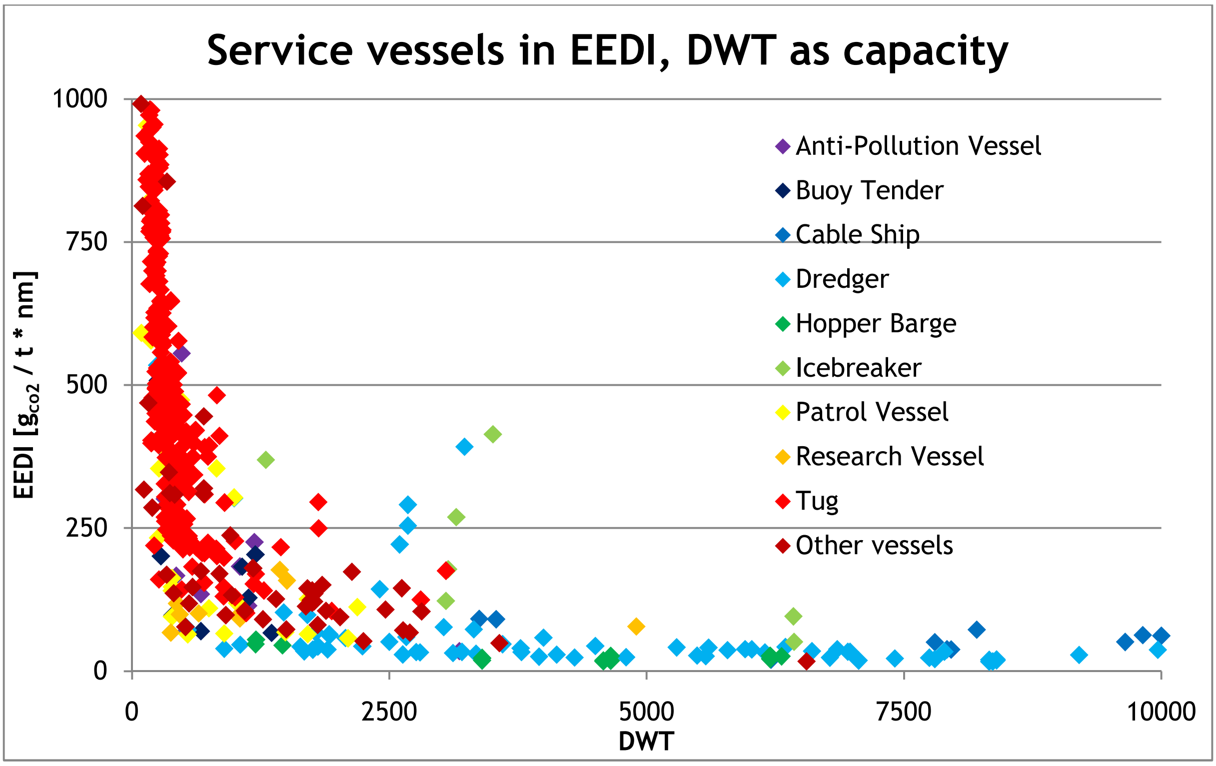


Figure 76 - Service vessels in EEDI, DWT as capacity, zoomed

As can be noticed the scatter of the vessels both in the calculated EEDI values and deadweight capacities of the vessels is very high. This is due to the highly varying operation tasks and thus different design criteria.

When using gross tonnage as the capacity for the "service vessel" subgroups, as shown in Table 42, the results were relatively similar as when using deadweight as capacity. The calculated EEDI values are shown in Figure 77 and Figure 78. As seen from the figures, the scatter and subgroup tendencies remain similar compared to defining the capacity in DWT. Tugs and dredgers are the two largest groups.

Table 42 - Service vessel subgroups, capacity defined in GT

Ship type	PCS	% of total
Anti-pollution vessel	11	1,3 %
Buoy tender	15	1,7 %
Cable / Cable repair ship	17	2,0 %
Hopper barge	23	2,6 %
Ice breaker	7	0,8 %
Other vessels	62	7,1 %
Patrol / Pilot vessel / SAR vessel	43	4,9 %
Research vessel	17	2,0 %
Various Dredgers	111	12,8 %
Various Tugs	563	64,8 %
Total:	869	100,0 %

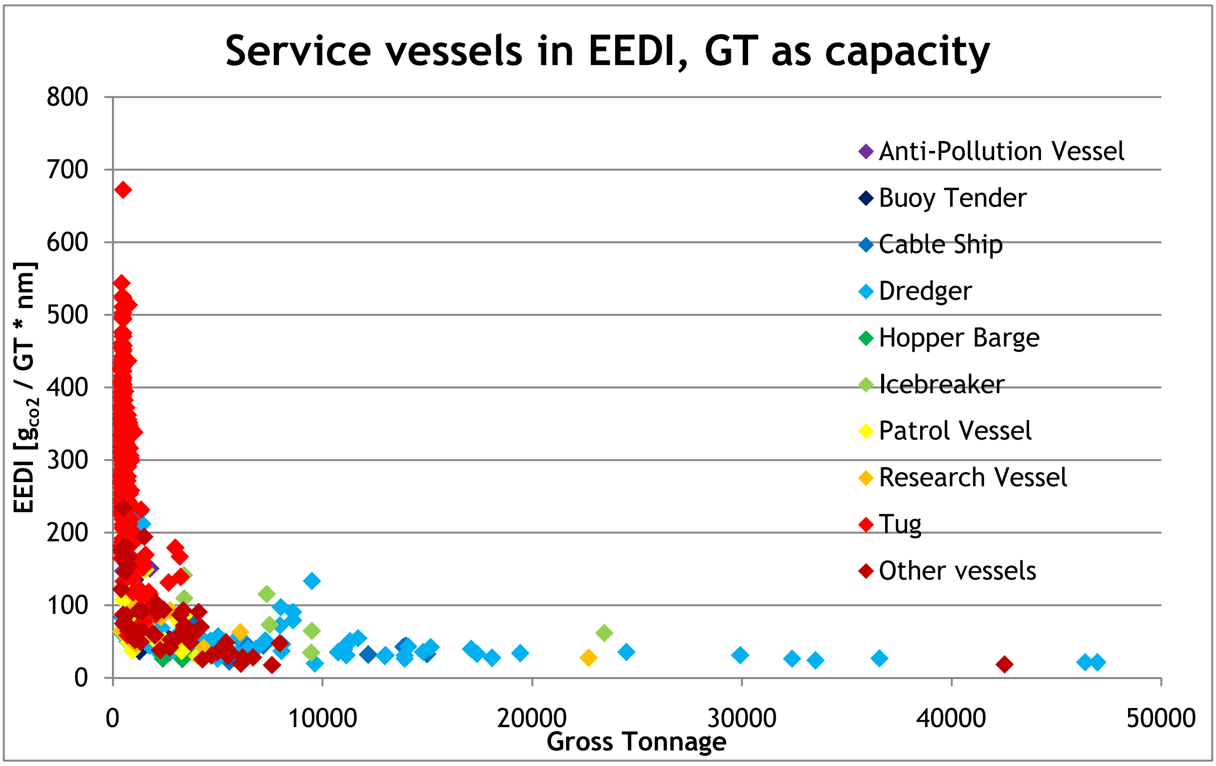


Figure 77 - Service vessels in EEDI, capacity as GT

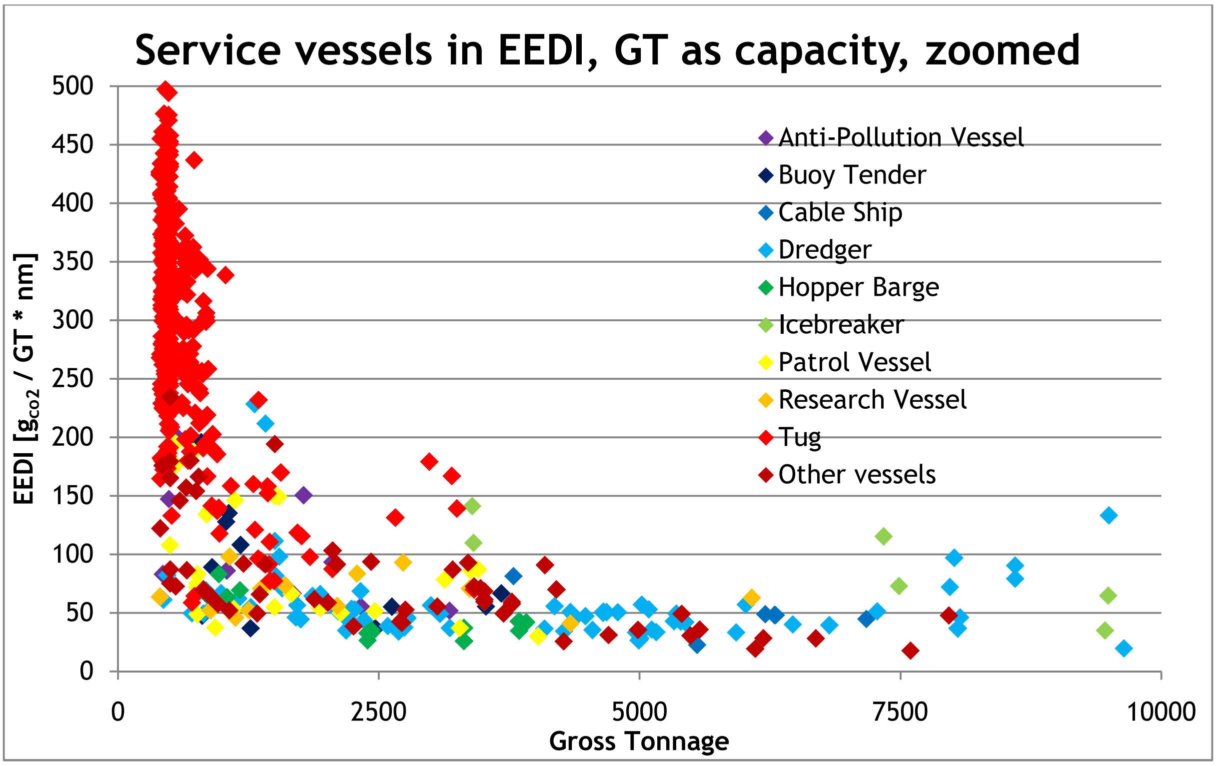


Figure 78 - Service vessels in EEDI, capacity as GT, zoomed

When vessels that have an EEDI value over 500 and vessels with a GT over 10 000 are excluded, the different subgroups and their typical EEDI values can be seen to be similar as when using DWT as capacity.

If the EEDI would be broadened to also include "service vessels", it should only be applied for tugs, as they are the single largest subgroup and make up 60-70% of the total "service vessel" – group.

The most important design value of tugs is the bollard pull, as it describes the vessels' ability to move floating objects. The bollard pull of tugs is plotted against the installed power in Figure 79, where one can readily notice that the relation is relatively linear and extreme variations in general do not exist.

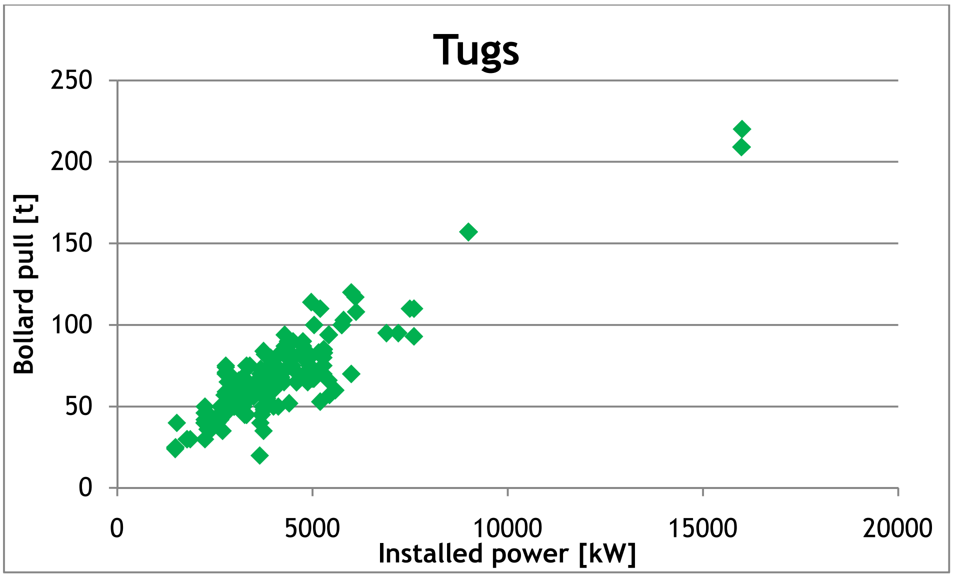


Figure 79 - Tugs, Bollard pull vs. Installed power

Tugs also serve other purposes than moving floating objects. These tasks include fire fighting and various maintenance purposes in harbors. The operation profile of tugs is such that it uses its maximum power only for very short periods of time (e.g. 5% of time with over a 67% engine loadings, 60% of the time with engine loads below 20%). However, this maximum power is required in order to move the largest ships in an efficient, and more importantly, safe manner in harbors.

Even though the relative amount of CO_2 emissions from tugs is roughly as large as the CO_2 emissions from product or LNG tankers, including tugs into the EEDI baseline approach does not seem feasible. This is due to the fact that the variety in size, powering and overall design of different tugs is huge. Also the absolute number of individual ships is very large: 15 095 vessels, out of which 12 788 (85%) are under 400GT. Tugs are clearly more numerous when compared to LNG tankers (396 vessels) or product tankers (5859 vessels). All these numbers are from the IHSF database and also include small vessels.

Including tugs into the strict EEDI approach and thus limiting the maximum power of the vessels would pose challenges in harbours as the average ship size will continue to increase in the future. Limiting the power of tugs could cause safety issues, as there would be limitations in moving the largest ships in rough weather. In addition, when forced to keep both full and empty ships in the harbour due to inefficient tugs, the absolute emissions would in fact be increased.

Altogether, as the number of individual tugs is huge and it is very difficult in any case to include the smallest vessels into the EEDI approach, it can be concluded that if the energy efficiency of tugs or service vessels in general is to be regulated, it should be done with another method than with the EEDI. These methods could be for example by specifying minimum bollard pull performance per installed kilowatt, or by limiting the specific fuel oil consumption of the engines. These alternative methods are discussed in more detail in Chapter 6.4.

6.3.4. Miscellaneous ships (fishing vessels)

The miscellaneous ship group consists mainly of the "Fishing" - vessel group in IHSF Fairplay database as shown in Table 43. The subgroups with sizes are shown in Table 44.

Table 43 - Miscellaneous ship group filtering

	Number of ships	% remaining
Ships delivered 2000-2010, GT < 400 removed	706	-
Missing speed and power removed	296	41,9 %

Table 44 - Miscellaneous vessel subgroup sizes when GT used as capacity

Vessel type	PCS	% of total
Fisheries protection vessel	23	7,8 %
Fishing vessel	129	43,6 %
Live fish carrier	23	7,8 %
Other fishing vessels	12	4,1 %
Refrigerated fish carrier	11	3,7 %
Trawler	98	33,1 %
Total:	296	

In order to find out if the conventional EEDI approach could be used for miscellaneous vessels (fishing vessels), the calculation guidelines attached as Appendix 2 to this document were used with following assumptions:

- The capacity was defined both in deadweight and gross tonnage of the vessel
- 75% of total installed engine power (P_{ME} + P_{AE}) and specific fuel oil consumption of 215g/kWh were used
- Speed was defined as 91% of the speed reported in IHSF database as reasoned in Chapter 3.5

Based on these assumptions, EEDI values were calculated to the vessel group as presented in Figure 80 and Figure 81. As seen from the plotted EEDI values, there is a large scatter in the data, even though the design criteria of these vessels are somewhat uniform. The variation between the vessels is large as the gross tonnage does not describe these vessels in a reliable manner.

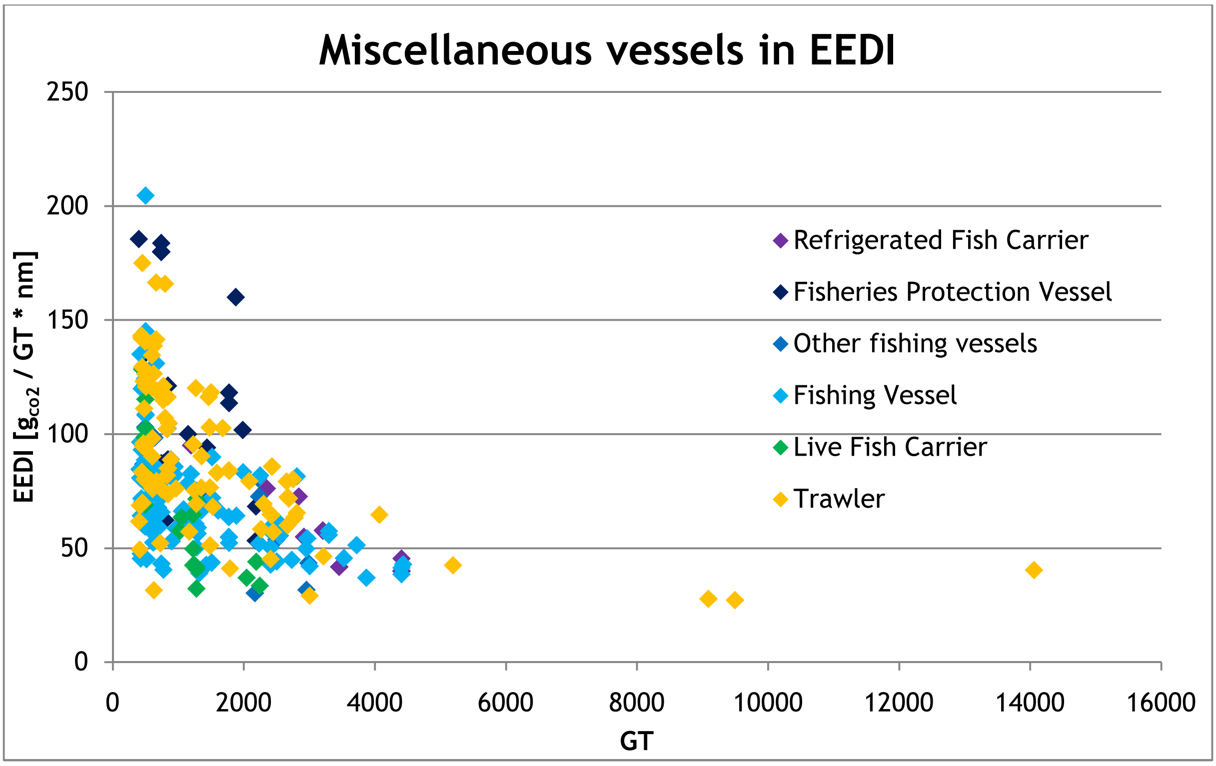


Figure 80 - Miscellaneous vessels in EEDI, capacity in GT

When excluding the vessels with an EEDI value over 150 and a GT over 5 000, the scatter between the different vessels can be seen more clearly. Variations in the range of 200% are typical.

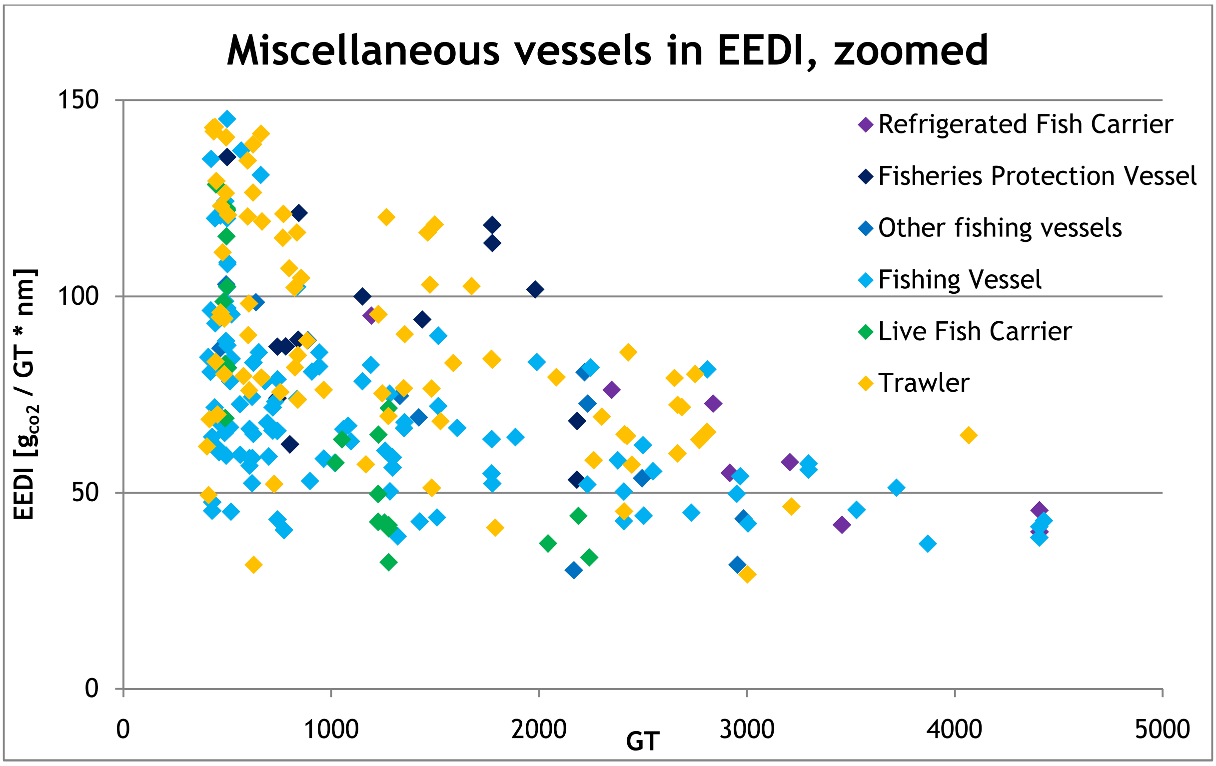


Figure 81 - Miscellaneous vessels in EEDI, capacity in GT, zoomed

When using the deadweight of the vessels as the capacity, it can be noticed that the scatter of the data is reduced and correlation enhanced. However, as many of the vessels in the "miscellaneous vessels" group have deadweight of zero, a large part of the group will be excluded as shown in Table 45.

Table 45 - Miscellaneous vessel subgroups when capacity measured in DWT

Vessel type	PCS	% of total
Fisheries protection vessel	21	10,6 %
Fishing vessel	75	37,9 %
Live fish carrier	20	10,1 %
Other fishing vessels	11	5,6 %
Refrigerated fish carrier	11	5,6 %
Trawler	60	30,3 %
Total	198	

The EEDI values are plotted against the deadweight and shown in Figure 82. However, the variations both in the EEDI values and the DWT of the vessels are still quite significant.

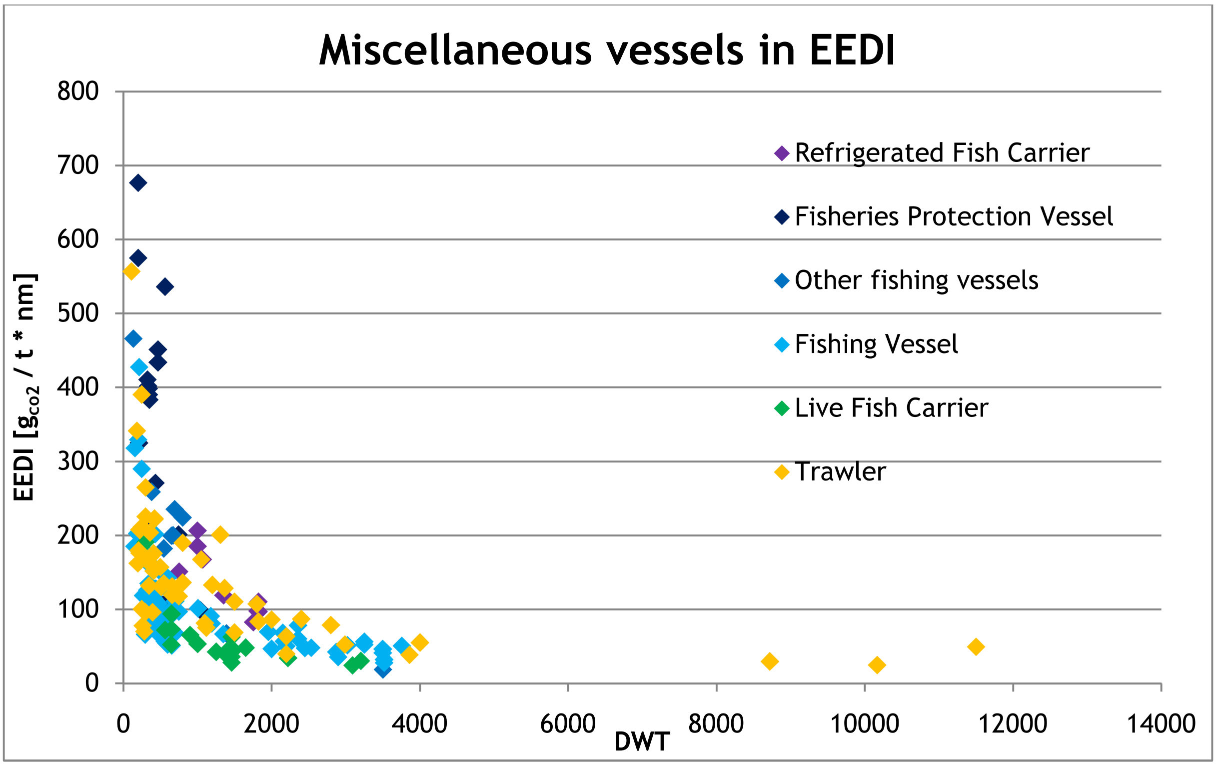


Figure 82 - Miscellaneous vessels in EEDI, capacity in DWT

When vessels with deadweight over 5000 DWT and vessels with an EEDI value over 500 are excluded, the different subgroups become more visible. The scatter in the groups is smaller than with GT and thus it is possible to draw trend lines for two of the largest subgroups (fishing vessels, trawlers) with a standard deviation of 0,64-0,68 as shown in Figure 83.

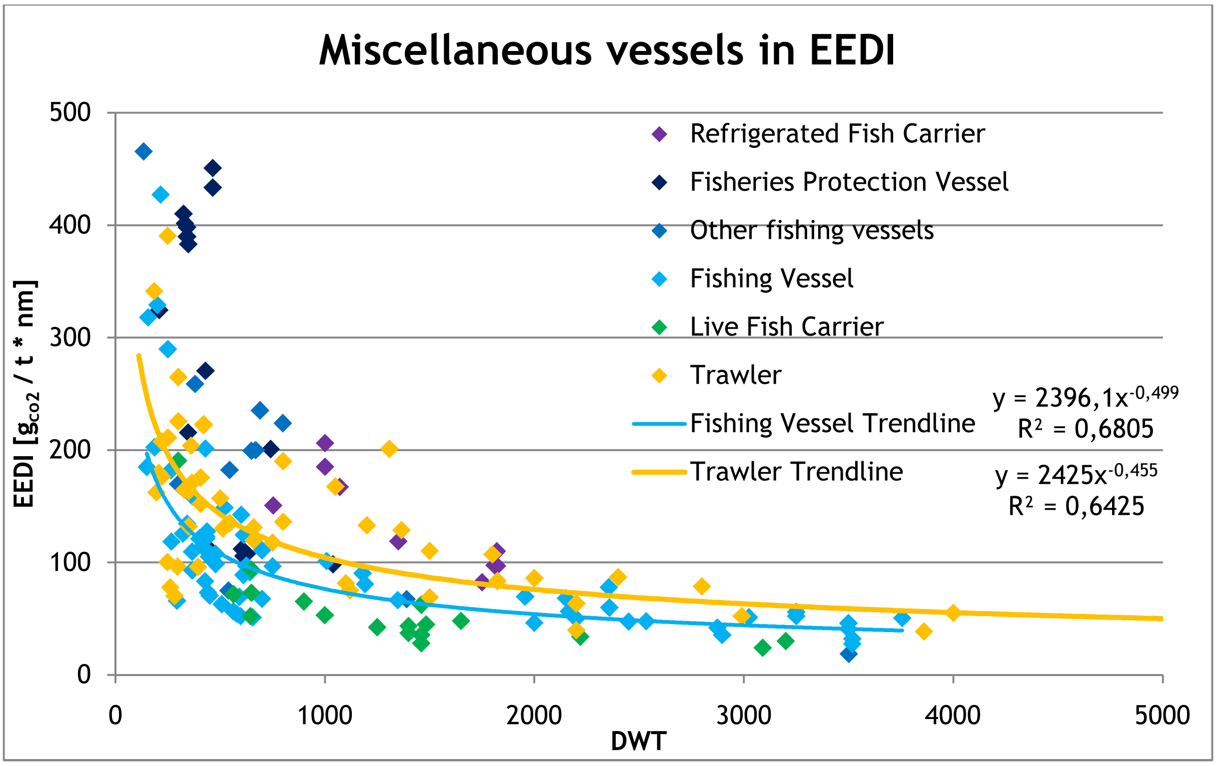


Figure 83 - Miscellaneous vessels in EEDI, capacity in DWT

However, the defining factor for the installed engine power of fishing vessels and trawlers is not for the transit speed, which is used in the EEDI definition, but for fishing operations. These operations require a significantly higher power than the transit speed. This was already discussed earlier and presented in Table 37.

As was the case with the differences between RoRo weight and volume carriers, the differences between fishing vessels and trawlers cannot be clearly tied to any one design value. Therefore there will be a risk of creating a potential loophole by defining two separate baselines for two ship groups that are in fact very similar with each other. Including the various fishing vessels and trawlers into the EEDI baseline approach seems unfeasible due to the potential loopholes and the problems in defining the required propulsion power of the vessels in a justified and reliable way.

If one would implement a strict EEDI approach for these vessels, it would inevitably result in reducing the installed engine power. This would then lead to a situation where the fishing capacity of the vessels would likewise be reduced to a certain level. And as with other ship groups, limiting the engine power may lead to an increased safety risk when operating in difficult weather conditions. With a strict EEDI approach, also the auxiliary engine power and the capacity of the refrigeration machinery will be affected. This would not allow the vessel to spend long times at sea, which will lead to an increase of cargo transportation time.

As with other specialized vessels, an alternative method of regulating the specific fuel oil consumption of the installed engines is seen as a more feasible approach than implementing the EEDI for these vessels. The alternative methods are discussed in more detail in Chapter 6.4.

6.3.5. Conclusions on the applicability of the EEDI

Purpose built / specialized vessels are ships without a specific transportation task. In addition, these vessels are highly flexible and have variable operation profiles and services that can change on a day-to-day basis. In contrast, the EEDI is a measure of the transportation efficiency for vessels operating with fixed operation profiles and tasks.

Regarding purpose built / specialized vessels and the basic principle of the EEDI formula, there is a clear discrepancy. The EEDI formula can be simplified to stand for "impact over benefit", where impact = engine power * SFOC * carbon conversion factor, and the "benefit" for society, which is tied to the ship's service. However, for purpose built / specialized vessels, the "benefit" stands for the installed power of the vessels allowing for the execution of the given task in all conditions with certain margins for safety. Since purpose built / specialized vessels will have their installed engine power as both the "impact" and "benefit", the EEDI formula with requirements will clearly not work for them.

Besides to the problems arising from the fundamental differences between the EEDI idea and purpose built / specialized vessel group, a strict EEDI approach to these vessels would potentially lead to the following severe problems:

- Increased safety risks through reduced redundancy, maneuverability and insufficient propulsion power in vessels operating in very severe environmental conditions (offshore vessels, ice breakers, trawlers, fishing vessels)
- Increased GHG emissions by limiting the propulsion power of e.g. tugs and ice breakers, thus leading to inefficient harbor / ice breaking operations
- Decreased overall operative efficiency by limiting the propulsion power (tugs, offshore AHTS, fishing vessels)

If the EEDI would be applied for purpose built / specialized vessels, the verification process would be the same as it is for conventional ships – according to the guidelines MEPC 1/circ.682, attached as Appendix 3 to this document. However, since the EEDI approach is not considered feasible for purpose built / specialized vessels, the alternative method to be developed should also include an efficient and separate verification process.

As the target of the EEDI is to reduce GHG emissions while not jeopardizing safe and efficient marine operations, it can be concluded that the current EEDI approach cannot be considered feasible for any of the purpose built / specialized vessel groups. Due to the huge variation in the services (different tasks requiring different engine power) that these vessels provide, an energy efficiency approach based on design criteria, such as the EEDI, will not be applicable to these vessel types, no matter how many correction factors are implemented. Instead an alternative method for regulating the energy efficiency of these vessels should be considered.

6.4. Alternative methods to evaluate the energy efficiency of specialized vessels

As discussed in earlier chapters, the current EEDI approach is not considered feasible for purpose built / specialized vessels as they do not have any specific transportation task that could be measured. Limiting the installed propulsion power also creates multiple problems and safety concerns. Therefore, alternative methods to evaluate and regulate the energy efficiency of these vessels during the design stage will be considered. The alternative methods discussed are:

- Limiting the specific fuel consumption of the engines,
- Regulating bollard pull performance and
- Requiring the vessels to be able to serve multiple purposes.

Limiting the specific fuel oil consumption of the engines

One possible method to evaluate and regulate the energy efficiency of purpose built / specialized vessels could be to regulate the energy efficiency of the engines by specifying a maximum value for the specific fuel oil consumption. As the usage of the engines onboard these vessels is extremely variable, no common operation profile can be developed for the engines and vessels in question.

The SFOC of the main and auxiliary engines could be limited to a predetermined limit, which could be certified in the mandatory Engine International Air Pollution Prevention (EIAPP) - certificate. The EIAPP certificate already contains most of the important engine parameters as the main purpose of the certificate is to report and verify the NO_x emissions of the engine. However, there are multiple challenges regarding limiting the SFOC to a certain level:

- The engine lay-outs and thus efficiency on a specific load point differ considerably, depending on which load range and purpose the engine is optimized to.
- The upcoming air emission limits cause the absolute efficiency of the engines to decrease slightly due to the physical properties of NO_x formation; “trade-off between fuel economy and NO_x emissions”.
- The engines in purpose built / specialized vessels are used on a wide load-range, thus they are not optimized for a single specific load point but instead a wider range should be considered. Specifying e.g. 10 measurement points for a large variety of different engines is challenging both from the legislative and manufacturer point of view.
- Challenges exist in taking different fuel saving technologies such as waste heat recovery into account, as they often increase the absolute engine fuel consumption but decrease the overall fuel consumption. These systems should be treated as a single unit and not separately in the engine test bench.

Typical engines used in the purpose built / specialized vessels are listed in Table 46. As can be seen there are relatively large differences between the engines regarding specific fuel oil consumption, highlighting the differences in the engine layouts and physical principles. The high-speed engines (MTU, Caterpillar) are designed to be flexible and to be used on a wide load-range, whereas the larger engines (MaK, Wärtsilä) are designed to be extremely efficient near a limited number of design-points and thus are usually optimized for the design point.

Table 46 - Example of typical engines in purpose built / specialized vessels

Engine	Power [kW]	Speed and RPM	Fuel consumption [l/h]	SFOC [g/kWh]
Yacht				
MTU 16VM2000M72	1440	High (2300)	358	215,0
MTU 12VM4000M63	1500	High (2000)	358	206,4
Caterpillar 3512B	1678	High (1200)	415	213,9
Caterpillar 3516B	1491	High (1600)	393	228,0
Offshore				
Engine	**Power [kW]**	**Speed and RPM**	**Fuel consumption [l/h]**	**SFOC [g/kWh]**
MaK 8M32C	3800	Medium (600)	-	177,0
Wärtsilä 9 L20	1800	High (1000)	-	189,0

Altogether it can be concluded that limiting the SFOC of the engines has multiple challenges. One of the challenges is in defining a fair "operation profile" for the engine(s). The profile(s) could be similar or different to all engines depending on the type of vessel the engine is intended for. Another problem is the measurement and certification, as the engines are often upgraded and maintained during their life-cycle, thus affecting their absolute fuel consumption.

Regulating bollard pull performance

One option to direct energy efficiency requirements of the largest purpose built / specialized vessel subgroups, namely the AHTS vessels and tugs, could be to require specific bollard pull performance compared to the installed propulsion power. The bollard pull performance is a vessel-specific property that can be optimized with design measures, such as propeller and nozzle optimization. As noted in the earlier chapters (6.3.2 and 6.3.3), the bollard pull of these vessels is relatively linearly comparable to the installed power.

The bollard pull performance of AHTS vessels was plotted against the total installed power in Figure 84. As can be seen the correlation of the data to the linear trend line was relatively good, though differences in the range of 100% did exist. These variations are due to differences in the vessel design, especially for the largest vessels where other parameters than bollard pull are dominant, such as cargo carrying capacity or open-water performance. Due to these differences, a cut-off limit for bollard pull (e.g. 200t) and / or installed power (e.g. 10 000kW) could be implemented in order to enhance the feasibility of such an approach.

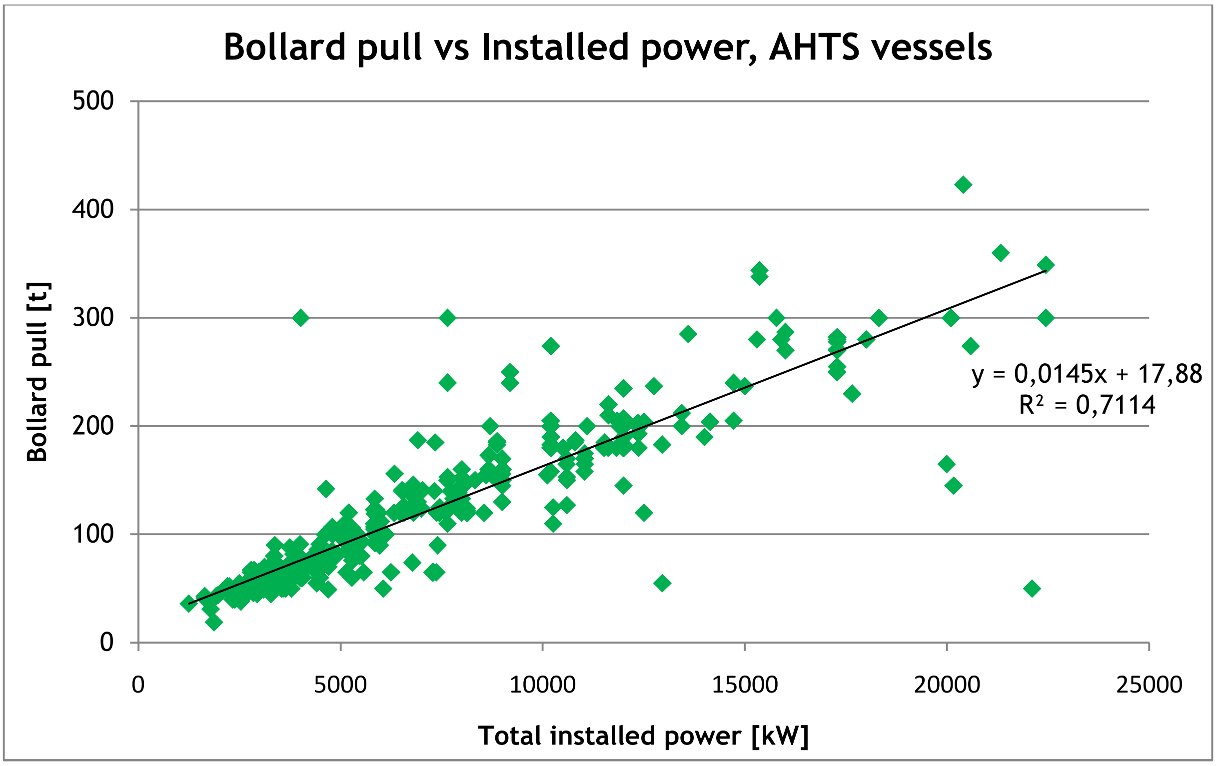


Figure 84 - AHTS bollard pull

Verifying the bollard pull reliably is challenging as the environmental conditions (currents, tide and wind) can have a significant effect on the performance. Limiting the allowed power for a specific bollard pull with cut-off limits could cause vessels with “too high” bollard pull / installed power to be built, thus leading to undesirable results for efficiency improvements. On the other hand, limiting the power of the largest tugs according to bollard pull is unfeasible as those vessels are often designed for other purposes as well, and bollard pull is only an additional feature that is utilized occasionally.

Requirement of multi-purpose functions and the reduction of stand-by times

The basic idea behind a multi-purpose vessel would be that all of the vessels in the “service ship” or “offshore vessel” categories would be required to be able to serve multiple purposes. The reasoning is that as these vessels operate with widely varying profiles on a day-to-day basis and spend long times in idle / stand-by mode, these “non-productive” times could be minimized by requiring that each vessel would have two or more possible functions they could serve. For example a tug could be designed to be a combined tug / fire fighting / maintenance vessel, or an offshore vessel could act as a tug, supply vessel and fire-fighting vessel at the same time.

An example multi-purpose support vessel, MSV Botnica, is presented in Figure 85. As opposed to traditional ice breakers that are laid up for the summer time, MSV Botnica is an ice-breaker that can be used as a support vessel at oil fields during the summer time.

Figure 85 - MSV Botnica

However, almost all of the offshore vessels are already designed to serve multiple purposes. In addition, many tugs are equipped with at least some fire-fighting equipment, thus already serving multiple purposes. If these vessels would be equipped with additional equipment in order to be able to serve additional tasks or operations, such as maintenance or construction, at least the weight of the vessels would be increased, which would reduce the efficiency of its main operations. There is also the question of can a vessel serve two or more purposes at the same time without decreasing the efficiency of its normal operations. Would it be more efficient to build a separate ship for each purpose even though these vessels would be laid-up or used in stand-by mode for more than 50% of their total annual operation time?

7. Workshop

7.1. Background

Deltamarin and EMSA held a workshop dedicated for evaluating the suitability of the EEDI for RoRo and RoPax vessels on April 19-20, 2011 in Helsinki, Finland. The event consisted of Deltamarin presenting the current state of its research, including the findings and alternative solutions/approaches concerning the EEDI for RoRo and RoPax vessels. As the study was still underway during the workshop, participants were encouraged to discuss, give input and estimate the feasibility of each proposal in order to develop them further. There were also possibilities to share thoughts on other EEDI-related issues on RoRo and RoPax vessels that other parties were currently working on. In order for the workshop to be a success, the main focus was on open discussions and the exchanging of ideas.

The workshop had a wide variety of participants and virtually every facet from the European maritime segment and industry were present:

- Belgian Flag State
- Danish Maritime Authority
- Deltamarin
- EMSA
- Finnish Shipowners' Association
- Finnlines
- Flensburger Schiffbaugesellschaft
- HSVA
- International Chamber of Shipping
- Lloyd's Register
- MAN
- Meyer Werft
- Stena Rederi
- Swedish Shipowners' Association
- Swedish Transport Agency
- Technical University of Denmark
- TraFi
- TUHH
- UECC
- Viking Line
- Wärtsilä

Deltamarin's findings and proposals for discussion were presented during the first day (see agenda below). The findings and conclusions presented by Deltamarin were based on and are detailed in this written study. During the second day, the emphasis was on alternative methods and other findings on the EEDI by other parties in the maritime segment.

Day 1 Tuesday, April 19

0900	Registration	
0915	Introduction and welcome	Deltamarin
0930	Project background and goals	Carlos Pereira, EMSA
0945	Current state of EEDI and IMO submissions	Deltamarin
1045	Coffee break	
1100	GHG reduction potential, analysis of source data, ship categorization	Deltamarin
	Discussion	
1200	Lunch	
1300	Findings on EEDI correction factors, baselines and possible modifications for **RoRo** vessels	Deltamarin
	Discussion	
1500	Coffee break	
1530	Findings on EEDI correction factors, baselines and possible modifications for **RoPax** vessels	Deltamarin
	Discussion	
1700	End of Day 1	
1830	Dinner	

Day 2 Wednesday, April 20

0900	EUROCAG: Status and background of EEDI integration for RoRo vehicle carriers	Inge Sandaas, UECC
	Discussion	
0945	Swedish Shipowners' Association EEDI work for the Swedish Transport Agency	Jan Bergholtz, SSA
	Discussion	
1030	Coffee break	
1045	CESA: Status and background of EEDI for RoRos	Rolf Nagel, FSG
	Discussion	
1115	EEDI Challenges for RoRo vessels	Lennart Pundt, TUHH
	Discussion	
1200	Lunch	
1300	CESA: Status of EEDI for DE cruise ships	H-J Mammes, Meyer
	Discussion	
1400	Alternative methods for evaluating energy efficiency of RoRo and RoPax vessels	Deltamarin
	Discussion	
1445	Workshop conclusions and end remarks	Deltamarin
1500	Coffee break	
1530	Discussion and open issues	
1700	End of Day 2	

7.2. EEDI findings and discussions

EEDI in its current state will make designing and building fast RoRo and RoPax vessels very difficult in the future. This may inevitably lead to the removal of certain services and shipping routes and will move the cargo to be transported by other means - not necessarily more environmental friendly than shipping.

As has been shown in this report, the EEDI values for RoRo and RoPax vessels result in a huge scatter mainly due to the variations in service speeds between vessels of similar size. This will then result in a calculated baseline, which will be very difficult to reach for certain ships on specific service routes. As the setting of the baseline is a political decision in the end, ship types with a large scatter could simply have their baselines set markedly higher from the calculated average regression line.

During the course of the two days, it was clear that the European RoRo and RoPax operators, yards, flag states, classification societies and research institutions all recognized and agreed on what the main EEDI shortcomings for the vessel types were. All of the participants shared the common goal of identifying and modifying the EEDI in order for it to accurately evaluate the energy efficiency of short-sea shipping by taking into account the special properties and criteria that can be attributed to these vessels.

During the discussions it was also apparent that the main problem areas that lead to a large scatter within the EEDI were:

- A wide variety in vessel service speed and therefore power requirements and
- The necessity for a certain level of reserve power.

Data inconsistencies and other errors in the source data set (IHS Fairplay database) were discussed multiple times, but it was agreed that although they are present, they are not critical for evaluating the EEDI methodology at this point.

7.3. Workshop conclusions

During the event there was nothing to indicate that any significant proposals dealing with EEDI correction factors, baselines or alternative methods would be made for MEPC 62.

If the EEDI would be adopted at MEPC 62, the industry should make sure that possible modifications to the EEDI methodology to better include RoRo and RoPax vessels in it should be possible to develop at a later stage. There should also be an option to develop alternative methods for energy efficiency if no EEDI modifications were to be agreed upon.

The four main areas to be touched in further work for developing the EEDI approach for RoRo and RoPax vessels are:

- The allowable amount of installed reserve power (by developing a correction factor for P_{ME}, or by other methods)
- The level of required service speeds (by developing speed dependant baselines, or by other methods)
- Inclusion of auxiliary engine power as defined by e.g. Electric Power Tables (EPT)
- Incorporation of the oil fired boiler into the formula to take into account waste heat recovery, etc.

The current situation is as such that although the short-sea maritime segment shares common goals for developing the EEDI to better suit RoRo and RoPax vessels, there exists various alternative approaches to improve the EEDI methodology. To make an effective proposal to the IMO on the required adjustments and modifications to the EEDI methodology, the industry should start to converge on a common improvement proposal. It remained unclear to whom such a responsibility should fall on. Finally, there was still some question whether the focus should remain on improving the EEDI or whether development should start on entirely new alternative methods.

8. Final conclusions

8.1. The key principles behind EEDI

When the IMO committed to develop methods to reduce future CO2 levels, there was a consensus that developing such regulations should follow the following key principles:

1. Effectively reduce CO2 emissions
2. Be binding and include all flag states
3. Be cost effective
4. Not distort competition
5. Be based on sustainable development without restricting trade and growth
6. Be goal-based and not prescribe particular methods
7. Stimulate technical research and development in the entire maritime sector
8. Take into account new technology
9. Be practical, transparent, free of fraud and easy to administer

Therefore it is imperative to comply with these core foundations when developing methods such as the EEDI and applying them on different types of marine vessels. If one or more of the listed principles are not fulfilled, then the methodology in question is invalid and should be subject to further development.

8.2. General findings on RoRo and RoPax vessels

The current EEDI methodology intends to drive ship sizes upwards while lowering the service speeds. For ocean going (deep-sea) vessels this may work, but for short sea shipping it is neither economical nor sustainable. This is due to the fact that in many cases even though a larger vessel could enter into operation, it will be impossible to increase the cargo (e.g. passengers) volumes on that specific route, leaving the new, larger vessel to operate at partial capacity.

The EEDI as such is a simple, yet effective method to measure the CO2 efficiency of a transportation task at one design point. However, short sea shipping vessels, such as RoRo and RoPax vessels, are highly dependent on the following factors:

- Main engine reserve power
- Service speeds
- Auxiliary power for the hotel and/or maneuvering

The EEDI in its current form will in practice limit the installed engine power for marine vessels and as such will restrict all of the operating criteria mentioned above. Restricting any of these attributes will impede the effectiveness of short-sea shipping, make certain routes and services impractical and create serious restrictions for designing new RoRo and RoPax vessels for the required (current) transportation tasks.

As the clear majority of short-sea shipping vessels in the world are RoRo and RoPax vessels operating inside the EU, the problem with the current EEDI approach will mainly be a problem for most of the European RoRo and RoPax fleet.

Listed below are justified reasons for the required operating features and design criteria for short-sea shipping vessels.

8.2.1. Justifications for installed reserve power

To ensure safe, economic and efficient operations, short-sea vessels in many cases have installed a certain level of additional engine power as a reserve. Reasons for a certain level of reserve power have been given below:

1. **Varying environmental conditions.**
   Ships operating in European waters must be designed to operate in areas with many different and changing environmental conditions. Some examples include strong ocean currents or head winds when sailing in one direction on a route; keeping the schedule and service speeds even in shallow water conditions, where the power required to maintain a certain service speed may be increased significantly; and operating in winter, when ice conditions may vary a lot depending on the area and year.

   The ice class is also an important factor for the EEDI approach, since the majority of RoRo and RoPax vessels have an ice class due to the operation in areas with winters, such as the Baltic Sea. The ice class has not been taken into account in this study, but it is recognized that further work on it has to be done as soon as the common approach method for RoRo cargo and RoPax vessels regarding EEDI has been agreed on.

2. **Operative reliability.**
   As RoRo and RoPax vessels are required to keep their schedules (part of a logistics chain or transporting passengers at a predetermined service level), many operators have designed their ships to have two shaft lines with two engines per line. This configuration makes engine repair and maintenance possible during normal operations and allows the operator to maintain the service speed with either two or three engines. In many cases, all of the engines are very rarely being operated simultaneously to attain high speeds, thus the engine configuration will not contribute towards high CO_2 emission. However, such configurations increase service reliability considerably.

3. **Safety and SRTP.**
   Safe-return-to-port (SRTP) requirements only apply to RoPax vessels over 120 meters, but safety issues are nonetheless extremely important for both RoRo and RoPax vessels. In addition to operating in heavy weather conditions, these ships require a high level of operative flexibility, which in many cases require excellent manoeuvrability especially at port. This extra manoeuvrability or engine configurations required by SRTP guidelines translate directly to additional installed engine power that are not used in normal operating conditions.

4. **Flexible cargo capacity for both volume and weight.**
   Many of the RoRo vessels have been designed for carrying multiple types of cargo and thus more emphasis has been put on versatility. In other words this means that a specific vessel might be carrying light cargo most of its time, but a few times a

month must also carry more heavy cargo with a tighter schedule. Such a task naturally requires more power from the engines. It is economically and environmentally more efficient to have one multipurpose vessel in such a case than have two different ships on demand.

5. **Changes in the operation profile.**
   The operation profile and speed profile may change according to the cargo type, requiring more speedy deliveries than normally. Some vessels may also have their operating routes changed according to the charterer. Such operative flexibility is part of normal RoRo operations, which is why there should not be requirements that will prohibit “normal” operation variations.

8.2.2. Justifications for service speeds

The EEDI is quite focused on the burden side of marine ships. Not much focus is given on the speed as the quality of service. It could be argued that in the case of RoRo and RoPax vessels, speed is a clear "benefit for the society". The marine segment should put more emphasis on this beneficial side of fast and reliable transportation work.

It is also important to understand that usually there is a real reason behind the selected service speed - whether low or high. Also, the design speed of RoRo and RoPax vessels may be far (higher) from the actual service speeds utilized on the route.

1. **"Benefit for the society".**
   The benefit for the society has been included as an integral part of the EEDI as the carried cargo quantity. However, for RoRo and especially RoPax ships, it can be said that the “benefit for the society” is also in part the service speed. Therefore some ships on specific routes with specific cargo types or passengers, should be allowed to operate at a certain speed, even if that speed is higher than the average value for the given ship size. When passengers or charterers pay for a service, they also expect a certain level of “added value” for their high-value cargo, be it for quality, reliability or swiftness of the transportation task.

2. **Specific operation profiles.**
   Many routes and services must be completed within a certain time frame e.g. 8h, 24h, etc. to be feasible and allow for a certain number of crossings within a day. For bulk cargo the situation is different as the transportation tasks may take even weeks or months and the cargo is not in a hurry or tied to a specific schedule. But for passengers or other roll-on cargo part of a logistics chain or highway network, a certain transportation route must be completed within a certain timeframe and schedule; and in some cases, such routes may require high service speeds.

3. **High speed transportation demand.**
   Very high speeds are usually utilized by small ferries carrying people and cars or expiring goods over short distances. Such a service is expected by the customers and they are willing to pay for it. If the EEDI would for some reason prevent such speeds for marine vessels, in many cases the alternative would be to shift using air

traffic, which is significantly more expensive for passengers and is much more taxing to the environment.

4. **Scheduled traffic.**
   As mentioned above, due to special requirements from route or ship design criteria, many RoRo and RoPax vessels are operating at medium to high speeds on very tight schedules. In some areas, such tight schedules are highly prone to heavy traffic conditions, difficult ice conditions or other complications. The only solution may be to make up for the lost time (due to unavoidable circumstances) by temporarily increasing the speed while on route. Such short periods of higher speeds naturally require some level of additional power.

5. **Operation part of a logistics chain.**
   Similarly as with scheduled passenger traffic, certain cargo types are required to be picked up and delivered at a specific time. The timeframe may in many cases be quite small, which will require fast speeds on a route as well as the capability to make up for lost time while in transit. Restricting speeds for such vessels will not only affect these ships, but the entire logistics chain: warehouses, factories, assembly plants, etc. In the majority of cases, making drastic changes to the entire logistics chain is not in any way possible.

8.2.3. Justifications for auxiliary power

1. **Varying hotel loads.**
   RoPax vessels come in a large variety of different sizes and configurations. Some vessels might have a very low number of passengers and others a very high. In addition, the luxury or comfort level may be very different between ships of the same size and capacity. Therefore some ships will clearly have very different hotel loads and should not be penalized for having different levels of passenger services and comfort levels.

2. **Manoeuvrability.**
   Even though manoeuvrability in certain harbour does not experience strong weather conditions and the argument for safety does not exist, many RoRo and RoPax vessels will still have high requirements for manoeuvrability. Many harbours may be small or otherwise congested traffic areas, requiring RoRo and RoPax vessels to move in and out efficiently. Vessels may be required to turn 180 degrees in tight spaces, or come to a full stop within a short distance. Also, these vessel types are designed for independent operations and should not be required to rely on tug services etc.

8.3. General findings on purpose built / specialized vessels

As the target of the EEDI is to reduce GHG emissions without jeopardizing safe and efficient marine operations, it can be concluded that the current EEDI approach cannot be considered feasible for purpose built / specialized vessels. After the characteristics of these vessels were reviewed, it can be concluded that the following reasons support this claim.

1. **Huge scatter in EEDI values.**
   As purpose built / specialized vessels serve a specific service function, the ships come in a wide variety of different ship sizes and engine powers suited for different tasks. This naturally leads to a huge scatter in the EEDI values – even for ships with similar services. Also, as conventional vessel types are increasing size, so too will the engine power of certain ships (e.g. tugs) increase in order to continue to maintain the required level of service.

2. **No clear transportation task, fixed schedules or operation profiles**.
   Purpose built / specialized vessels are vessels without a specific transportation task. In addition, these vessels are highly flexible and have variable operation profiles that can change on a day-to-day basis. At the same time, the EEDI is a measure of transportation efficiency for vessels operating continuously with a uniform operation profile. Due to these reasons, the EEDI is not suitable for these vessels.

3. **Service = engine power**
   The EEDI formula discusses the concepts of "impact on the environment" and "benefit of the service", but for purpose built / specialized vessels they are both the same: engine power. Limiting the propulsion power of these vessels would create safety risks through decreased redundancy and maneuverability and insufficient propulsion power in certain conditions. Continuing such services with limited engine power would make all operations inefficient and would most likely increase the overall GHG emissions.

9. Possible impacts in the future due to the EEDI

9.1. EEDI impacts on vessel design and construction

The main goal of the EEDI is to prevent the design of the most inefficient ships by setting certain energy efficiency requirements. In practice this will result in a reduction of installed engine power, which will reduce the service speeds of the majority of vessels. However, with RoRo and RoPax vessels, the “excessive” power is mainly used for redundancy and making journeys in the allocated time frame.

EEDI is intended to be a design index, and thus the main emphasis of it is to the design of the vessels. However, the design of the vessel influences directly also the operation of the vessels.

The possible impact of a strict EEDI approach to RoRo and RoPax vessels would be limiting the installable propulsion power and thus the maximum speeds by a certain amount. In case the separate groups for RoRo weight and RoRo volume carriers were retained, a risk of artificially designing weight carriers to volume carriers exists as the threshold value is not based on any specific design criteria. The motivation would be that the EEDI value for volume carriers allows for significantly higher engine power to be installed, when compared to the possible engine size for weight carriers. These artificial designs are closely tied to the amount of lane meters on a vessel, as a standardized definition does not exist. For example, if a weight carrier that has DWT / LM of 4,25t/lm would artificially create more lane meters to get under the 4t/lm threshold value, it would be classified as a volume carrier by the EEDI and thus be allowed a higher EEDI value.

The impact on RoPax vessel design could be that artificially large superstructures are designed in order to increase the gross tonnage of the vessel in order to decrease the attained EEDI value. On the other hand, the port and fairway dues are commonly allocated according to the GT of the vessel, so a suitable equilibrium between the EEDI value and operational cost would need to be determined.

The future reduction targets will cut down the speeds of RoRo and RoPax vessels even further, as there are no other realistic technical solutions to meet the targets of 20-30% emission reductions by the year 2025.

In case purpose built / specialized vessels would be included into a strict EEDI approach, also the propulsion power on them would be limited to a certain level. It would be clear that for these vessels the maximal amount of power would be installed to each and every vessel, as their efficiency and “benefit to the society” is directly connected to the installed power onboard and not on the speed of the vessel. This “automatic” power maximizing will inevitably lead to a number of over-powered vessels that will emit a relatively larger amount of CO_2 emissions when operating at partial engine loads.

9.2. Technical and operational aspects in the future

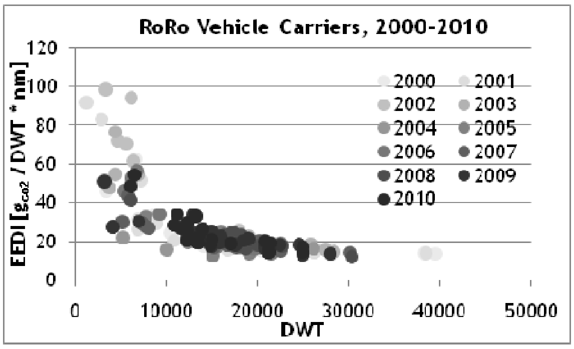
The fundamental principle behind the EEDI methodology is to measure and regulate the energy efficiency of a marine vessel at a single design point. This single point has been selected as 75% of propulsion power, corresponding to a certain speed at maximum loading conditions. However, for short-sea shipping, the operative principle is much more flexible and therefore also the design criteria are more complex than simply optimizing the vessel's operation to one single point only.

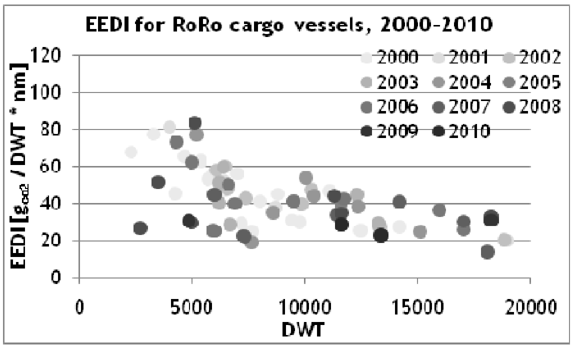
If the EEDI would be implemented to short-sea shipping (RoRo and RoPax vessels) without any changes, the impact would be that the reserve power of the vessels would be cut down, leading to significant changes in the ships' operations. There would no longer be a possibility to keep tight schedules, down-time due to maintenance would start to play an important role, and operating in challenging weather conditions would become unreliable and unsafe. At the same time overall GHG emissions would increase, as the vessels would have to stay in harbours for longer times due to various reasons, or require more assistance from icebreakers, tugs, etc. Because entire shipping routes and schedules would have to be redefined completely, the "benefit to the society" would be diminished considerably. Additionally, on certain high speed routes, some of the cargo would most likely shift to other means of transportation, likely further increasing the overall GHG emissions.

The discussed tendencies are even more apparent when considering the EEDI approach for purpose built / specialized vessels. For these vessels redundancy and safety are of utmost importance. For many of the vessels in this group, limiting the engine power will create more problems than it will solve.

9.3. Green House Gas reduction potential

One important aspect to review is to see how much the energy efficiency of ships has in fact improved during the past 10 years (the EEDI scope for determining baselines). Looking at the EEDI values for RoRo and RoPax vessels built in the last 10 years (Figure 86), no clear reduction tendency in the index values can be identified. This however does not mean that no improvements in energy efficiency have been reached. Most likely energy efficiency has been improved on the operational side as well as with small technical improvements for onboard machinery. These however do not show up in the EEDI value, which is based only on a few ship design values.





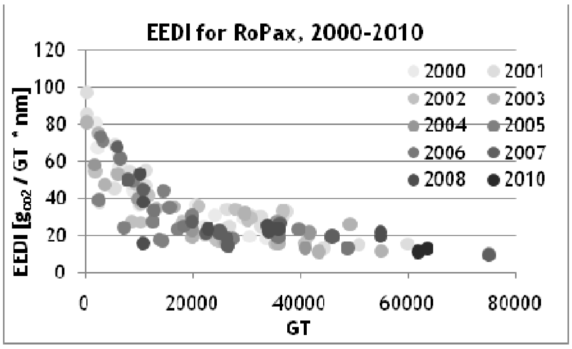


Figure 86 – EEDI values for ships delivered in the last 10 years

Since no reductions in the EEDI value have been identified, it is questionable what level of actual reductions is even possible for new ships in the RoRo/RoPax categories. Considering the aforementioned trend with the proposed EEDI reductions by the IMO (-10%, -20% and -30% by 2025 respectively), it can be concluded that fulfilling the reduction targets with these ships will be at least a huge challenge, if not totally impossible.

As RoRo vessels make up ~4% and RoPax vessels ~7% of global CO_2 emissions, the reduction potential from them is obviously lower than the rest of the global fleet. The table below shows a very rough generalization on how emissions from shipping will increase in the future. The projected increase is based on the IMO GHG study, with the presumption that all ship types exhibit the same rate of change. If the first EEDI reductions of -10% were possible for RoRo and RoPax vessels, the numbers in red give the absolute values in Mt of CO_2 per year. The last column shows the amount of Mt of CO_2 that the EEDI would "remove". The percentages in the last column show what the ratio of reduced CO_2 emissions from RoRo and RoPax vessels is when compared to global CO_2 emissions from international and domestic shipping. Clearly the absolute amount of CO_2 reductions is very small, when compared to both the total CO_2 emissions from shipping and the possible CO_2 reductions from conventional vessels.

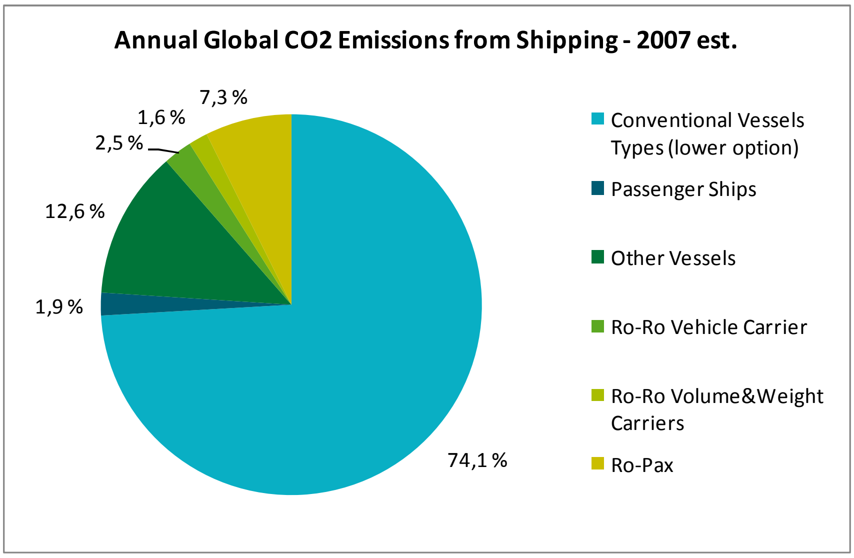


Figure 87 - Annual CO_2 emissions from shipping in 2007

Table 47 – Estimated total CO_2 reduction due to future EEDI limits

Annual Global CO2 Emissions from Shipping 2007	CO2 [Mt]	CO2 [%]	total 2015 +25% *	total 2019 +40% *	change '15-19	EEDI '15-19 -10%	
Conventional Vessels Types (lower option)	829	74,1 %	1036	1160	124	12,429	
Passenger Ships	21	1,9 %	27	30	3	0,320	
Other Vessels	141	12,6 %	176	197	21	2,111	
Ro-Ro Vehicle Carrier	27	2,5 %	34	38	4	0,411	0,027 %
Ro-Ro Volume&Weight Carriers	18	1,6 %	23	26	3	0,274	0,018 %
Ro-Pax	82	7,3 %	102	115	12	1,228	0,079 %
			*) compared to current				
Total	**1118**		**1398**	**1565**			
Total due to EEDI reduction for new ships				**1549**			

If the simple EEDI approach is applicable for the majority of the global fleet (bulk carriers, tankers, containers), could the EEDI be implemented for them exclusively, as the majority of CO_2 (~74%) would be included within the EEDI scope. There is no need to scrap the entire EEDI development process just because the simple EEDI approach with 1 baseline does not fit for short-sea shipping vessels.

The potential reduction in future green house gases was estimated only for RoRo and RoPax vessels. As indicated in previous chapters, since the EEDI approach will not yield any CO_2 reductions from purpose built / specialized vessels, these groups have been left out from this analysis.

10. Recommendations

10.1. General recommendations

This study tested various different capacity factors for both the EEDI formula and baseline definition for both RoRo and RoPax vessels. With each different approach, the resulting scatter was no better than the current EEDI approach. Therefore it was concluded that capacity factors and baseline calculation should remain the same as indicated by the current EEDI approach. Regarding RoRo and RoPax vessels, there were two main issues to be solved: how to take into account the various service speeds used and how to allow a certain level installed reserve engine power.

Speed dependant baselines would provide one solution for taking into account the required service speeds of RoRo and RoPax vessels. The EEDI methodology as such would only require fast ships to drop their speed to become compliant with the EEDI, in other words reducing CO_2 emissions only from the fastest vessels. However speed dependant baselines would require all future vessels with different design speeds to reduce CO2 emissions according to the IMO reductions.

As for taking into account the level of reserve power on these vessels, one approach could be that the EEDI will be implemented as such also for RoRo and RoPax vessels, but the EEDI baseline would be shifted upwards by a significant amount so the special properties of short sea shipping could be allowed in the future as well. In the end, this would be a political decision. A more technical approach, although with a similar effect, would be to define a certain “power factor” for RoRo and RoPax vessels. This power factor would only apply to new vessels, where it would reduce the amount of installed power used in the EEDI formula.

As with conventional vessel types, all RoRo and RoPax ships also result in a large scatter for smaller ship sizes. Due to this reason, lower cut-off limits should be developed for the RoRo and RoPax vessel groups as well.

Finally, ice classes should be taken into account in the EEDI for all RoRo and RoPax vessels. The approach should be similar as to the ice-class correction factors developed for conventional vessels, although power requirements due to class-requirements are most likely already met with ships with high service speeds (circa >18 knots). The definition should be made based on how much LW, displacement and eventually power the ice classes will demand.

The alternative approaches shortly presented in this study are an attempt to include the operative energy efficiency of vessels by applying the design data in more detail. These approaches however have not been studied further, as Deltamarin still believes that instead effort should be directed in getting the EEDI to function appropriately for RoRo and RoPax vessels in general.

10.2. Recommended action for RoRo vehicle carriers

EEDI for vehicle carriers results in a fairly low scatter. There is a fair bit of scatter with smaller and short-sea shipping vessels, most likely due to a twin-screw propulsion configuration. The recommendation is to keep the EEDI as is for the vessels operating in deep sea areas and try to adjust the scatter by either correction factors taking into account short-sea shipping characteristics or by setting a lower cut-off limit. The capacity could be changed to lane meters, though currently DWT as the capacity seems to give sufficient results.

10.3. Recommended action for RoRo cargo vessels

This study has shown no clear distinction between RoRo weight and volume carriers and therefore it is recommended to recombine these two subgroups into one RoRo cargo vessel group. However, since there are vessels dedicated for heavy or light cargo exclusively and multipurpose vessels capable of transporting different cargo types as required, the EEDI formula should allow for some amount of "additional" engine power. This would be possible with the “power factor” for P_{ME} mentioned above.

An alternative, and a more complex method, to the “power factor”, would be to have two power levels for RoRo ships (i.e. a power scaling factor). The lower power limit (baseline) would be for normal vessel operations at its service speed on a typical route and weather conditions. The second power level would take into account special vessel or route characteristics (e.g. cargo type changes to heavy, temporary logistics chain changes requiring faster operating speeds, etc...). More work is needed to develop this approach and define the levels of engine MCR for each operating point.

The recommended way forward is to utilize speed dependant baselines, where the required (or allowed) EEDI value of a ship would depend on the design speed of the vessel. This approach would continue to allow the building of both fast and slow vessels in the future, thus enhancing the energy efficiency of short-sea shipping in general.

10.4. Recommended action for RoPax vessels

Due to carrying both roll-on cargo and passengers, RoPax vessels come in all sizes and service speeds. The ratio between roll-on cargo and passengers as well as vessel characteristics varies a lot. Due to such a large variation and scatter of the resulting EEDI data, finding suitable correction factors for RoPax vessels is extremely difficult.

If the EEDI approach is to be applied for RoPax vessels, in addition to the recommendations mentioned in the general and RoRo sections, the following issues should also be addressed:

- Definition of P_{AE}. Take hotel loads and auxiliary power into account by developing electric power tables (EPT)
- PTO power reduction should be made according to the real sea load, not based on the installed PTO size, as they are most commonly used for powering thrusters.
- Emissions from oil fired boiler should be included in the EEDI formula, as it does not currently encourage maximum utilization of the fuel heat value (i.e. waste heat recovery).

10.5. Recommended action for purpose built and specialized vessels

As was concluded previously, a strict EEDI approach as such will not be feasible for purpose built / specialized vessels. Instead of the typical EEDI approach, alternative methods for regulating the energy efficiency of these vessels should be considered.

Recommended alternatives for purpose built / specialized vessels, excluding yachts

- Limit the specific fuel consumption of the engines to a predetermined limit. Thus the energy efficiency would be enhanced by preventing the use of inefficient engine designs. However, multiple challenges regarding the real operation profile of the engines and the principle differences in the engine layouts exist.
- Requiring specific bollard pull performance according to the installed engine power in tugs and offshore AHTS vessels (the two largest groups). However, cut-off limits are required as the largest vessels should not be included in this approach. These cut-off limits also present risks of creating a loophole as then vessels could be designed “too large” and thus the absolute energy efficiency would be reduced.
- Service and offshore vessels could be required to be designed and built to serve as multiple purposes, thus reducing lay-up and stand-by times.

Recommendations for yachts

As yachts stand out from the other ship types in the purpose built / specialized vessels group, in addition to the SFOC limitations discussed above, there are some additional options that could be applied for these luxury ships.

- One option would be to include yachts in the passenger vessel group for including them in the standard EEDI approach. This could be a feasible option, as yachts (especially the larger individuals) have certain operational aspects in common with other ships in the group. However, creating correction factors and additional modifications to the EEDI formula is not seen feasible as the absolute amount of different yachts that could be included into the passenger vessel group is very small and thus the achievable GHG reductions would be minimal and would not be justified by the additional regulative work required.
- Another option would be to concentrate on the operation side, and develop market based measures such as a fuel tax for yachts exclusively. This would put more pressure to reduce fuel consumption and thus GHG emissions.

Altogether it can be concluded that the current EEDI approach is not seen as feasible for purpose built / specialized vessels and instead an alternative method should be developed. The presented proposals for alternative methods require additional research and development in order to evaluate if and how they could be implemented.

11. List of figures

12. List of tables

13. List of Appendices

Appendix 1 - EEDI baseline calculation guidelines (MEPC 61/5/3 - Annex 4)

Appendix 2 - EEDI calculation guidelines (MEPC.1/Circ.681)

Appendix 3 - EEDI verification guidelines (MEPX.1/Circ.682)

ANNEX 4

GUIDELINES FOR CALCULATION OF REFERENCE LINES FOR USE WITH THE ENERGY EFFICIENCY DESIGN INDEX

1 MEPC 59 agreed that the reference lines should be established for each ship type defined in the Interim Guidelines on the Method of Calculation of the Energy Efficiency Design Index (EEDI) for new ships (MEPC.1/Circ.681). The purpose of the EEDI is to provide a fair basis for comparison, to stipulate the development of more efficient ships in general and to establish the minimum efficiency of new ships depending on ship type and size. Hence, the reference lines for each ship type must be calculated in a transparent and robust manner.

2 The annex to MEPC.1/Circ.681, as amended by the decisions agreed at MEPC 60, defines the ship types and the method of calculation for the attained EEDI.

Calculation of reference lines

Definition of a reference line

3 A reference line is defined as a curve representing an average index value fitted on a set of individual index values for a defined group of ships.

4 One reference line will be developed for each ship type defined in MEPC.1/Circ.681, as amended, ensuring that only data from comparable ships are included in the calculation of each reference line.

5 The reference line value is a function of the ship's Capacity, as defined in MEPC.1/Circ.681, and formulated as $Reference\ line = a\ Capacity^{-c}$ where a and c are constants determined from the regression curve fit. It is noted that the format of the reference line has not been agreed for ro-ro cargo ship volume carriers and ro-ro cargo ship weight carriers as well as for ships with unconventional propulsion.

6 Input data for the calculation of the reference lines is filtered through a process where data deviating more than two standard deviations from the regression line are discarded. The regression is then applied again to generate a corrected reference line. For the purpose of documentation, discarded data should be listed with the ships IMO number.

Data sources

7 Lloyd's Register Fairplay (IHSF) database is agreed as the standard database delivering the primary input data for the reference line calculation. For the purpose of the EEDI reference line calculations, a defined version of the database is archived as agreed between the Secretariat and IHSF.

8 For the purpose of calculating the reference lines, data relating to existing ships of 400 GT and above from the IHSF database delivered in the period from 1 January 1999 to 1 January 2009 are used.

9 The following data from the IHSF database on ships with conventional propulsion systems should be used when calculating the reference lines:

.1 data on the ships' capacity should be used as *Capacity* for each ship type as defined in MEPC.1/Circ.681, as amended;

.2 data on the ships' service speed should be used as reference speed V_{ref}; and

.3 data on the ships' total installed main power should be used as $P_{ME(i)}$.

10 For passenger ships and ro-ro passenger ships with conventional propulsion, the following data should also be used when calculating the reference line:

.1 data on the total installed auxiliary power.

11 For some ships, some data entries may be blank or contain a zero (0) in the database. Datasets with blank power, capacity and/or speed data should be removed from the reference line calculations. For the purpose of later references, the omitted ships should be listed with their IMO number.

12 When calculating the reference lines, passenger ships and ro-ro passenger ships with a reference speed below 15 knots should be removed from the calculations. For the purpose of later references, the omitted ships should be listed with their IMO number.

13 To ensure a uniform interpretation, the association of ship types defined in MEPC.1/Circ.681, as amended, with the ship types given by the IHSF database and defined by so-called Stat codes, is shown in the appendix to this guideline. Table 1 in the appendix lists the ship types from IHSF to be used for the calculation of reference lines. Table 2 lists the IHSF ship types which should not be used when calculating the reference line.

Calculation of reference line

14 To calculate the reference line, an index value for each ship contained in the set of ships per ship type is calculated using the following assumption:

.1 the carbon emission factor is constant for all engines,
i.e. $C_{F,ME} = C_{F,AE} = CF$ = 3.1144 g CO_2/g fuel;

.2 the specific fuel consumption for all ship types is constant for all main engines, i.e. $SFC_{ME} = 190$ g/kWh;

.3 $P_{ME(I)}$ is the installed main power as defined in MEPC.1/Circ.681;

.4 the specific fuel consumption for all ship types is constant for all auxiliary engines, i.e. $SFC_{AE} = 215$ g/kWh;

.5 P_{AE} is the installed auxiliary power and for cargo ships it is calculated according to paragraphs 2.5.6.1 and 2.5.6.2 of the annex in MEPC.1/Circ.681. For passenger ships with the conventional propulsion systems, P_{AE} is calculated as the total installed auxiliary power according to the information in the IHSF database multiplied by 0.35;

.6 all correction factors f_j, f_i and f_w are set to 1; and

.7 innovative mechanical energy efficiency technology, shaft motors and other innovative energy efficient technologies are all excluded from the reference line calculation, i.e. $P_{AEeff} = 0$, $P_{PTI} = 0$, $P_{eff} = 0$.

15 The equation for calculating the index value for each ship is then as follows:

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

Documentation

16 For purposes of transparency, the ships used in the calculation of the reference lines should be listed with their IMO numbers and the nominator and denominator of the index formula, as given in paragraph 15. The documentation of the aggregated figures preserves the individual data from direct access but offers sufficient information for possible later scrutiny.

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Ref. T5/1.01

MEPC.1/Circ.681
17 August 2009

INTERIM GUIDELINES ON THE METHOD OF CALCULATION OF THE ENERGY EFFICIENCY DESIGN INDEX FOR NEW SHIPS

1 The Marine Environment Protection Committee, at its fifty-ninth session (13 to 17 July 2009), recognized the need to develop an energy efficiency design index for new ships in order to stimulate innovation and technical development of all elements influencing the energy efficiency of a ship from its design phase. The Committee, being mindful that the applicability of the EEDI formula to all categories of ships and the feasibility and applicability of the technical parameters (i.e. $f_{eff(i)}$ and f_w) in the EEDI formula need to be further refined to improve the method of calculation of the EEDI; agreed to circulate the Interim Guidelines on the method of calculation of the energy efficiency design index for new ships, as set out in the annex.

2 Member Governments and observer organizations are invited to use the interim guidelines, for the purpose of test and trials on a voluntary basis:

.1 for ships with conventional propulsion systems (main engine mechanical drive); and

.2 to the extent possible, for ships with non-conventional propulsion systems (e.g., diesel-electric propulsion, turbine propulsion or hybrid propulsion systems).

3 Member Governments and observer organizations are also invited to provide the outcome and experiences in applying the interim Guidelines to future sessions of the Committee for further improvement of the method of calculation of the EEDI for new ships.

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ANNEX

INTERIM GUIDELINES ON THE METHOD OF CALCULATION OF THE ENERGY EFFICIENCY DESIGN INDEX FOR NEW SHIPS

1 Definitions

For the purpose of these Guidelines, the following definitions should apply:

.1	Passenger ship	a ship which carries more than 12 passengers as defined in SOLAS chapter 1, regulation 2
.2	Dry cargo carrier	a ship which is constructed generally with single deck, topside tanks and hopper tanks in cargo spaces, and it is intended primarily to carry dry cargo in bulk, and includes such types as ore carriers and combination carriers, as defined in SOLAS chapter IX, regulation 1
.3	Gas tanker	a gas carrier as defined in SOLAS chapter II-1, regulation 3
.4	Tanker	an oil tanker as defined in MARPOL Annex I, regulation 1 or chemical tanker and a NLS tanker as defined in MARPOL Annex II, regulation 1
.5	Containership	a ship designed exclusively for the carriage of containers in holds and on deck
.6	Ro-ro cargo ship: Vehicle carrier	A multi deck ro-ro cargo ship designed for the carriage of empty cars and trucks
.7	Ro-ro cargo ship: Volume carrier	A ro-ro cargo ship, with a deadweight per lanemetre less than 4* tons/m, designed for the carriage of cargo transportation units
.8	Ro-ro cargo ship: Weight carrier	A ro-ro cargo ship, with a deadweight per lanemetre of 4* tons/m or above, designed for the carriage of cargo transportation units
.9	General cargo ship	A ship with a multi-deck or single-deck hull designed primarily for the carriage of general cargo
.10	Ro-ro passenger ship	A passenger ship as defined in SOLAS chapter II-1, Part A, regulation 2.23

Ships falling within more than one of the ship types should be considered as being the ship type with the lower baseline.

* The value should be further investigated during the period of voluntary use of the EEDI.

2 Energy Efficiency Design Index (EEDI)

The attained new ship Energy Efficiency Design Index (EEDI) is a measure of ships CO_2 efficiency and calculated by the following formula:

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

* If part of the Normal Maximum Sea Load is provided by shaft generators, SFC_{ME} may – for that part of the power – be used instead of SFC_{AE}

Note: This formula may not be able to apply to diesel-electric propulsion, turbine propulsion or hybrid propulsion system.

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(s) respectively. C_F corresponds to the fuel used when determining *SFC* listed in the applicable EIAPP Certificate. The value of C_F is as follows:

Type of fuel	**Reference**	**Carbon content**	**C_F (t-CO_2/t-Fuel)**
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.75	2.750000

.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 shaft power 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:

.3.1 For dry cargo carriers, tankers, gas tankers, containerships, ro-ro cargo and general cargo ships, deadweight should be used as *Capacity*.

.3.2 For passenger ships and ro-ro passenger ships, gross tonnage in accordance with the International Convention of Tonnage Measurement of Ships 1969, Annex I, regulation 3 should be used as *Capacity*.

.3.3 For containerships, the capacity parameter should be established at 65% of the deadweight.

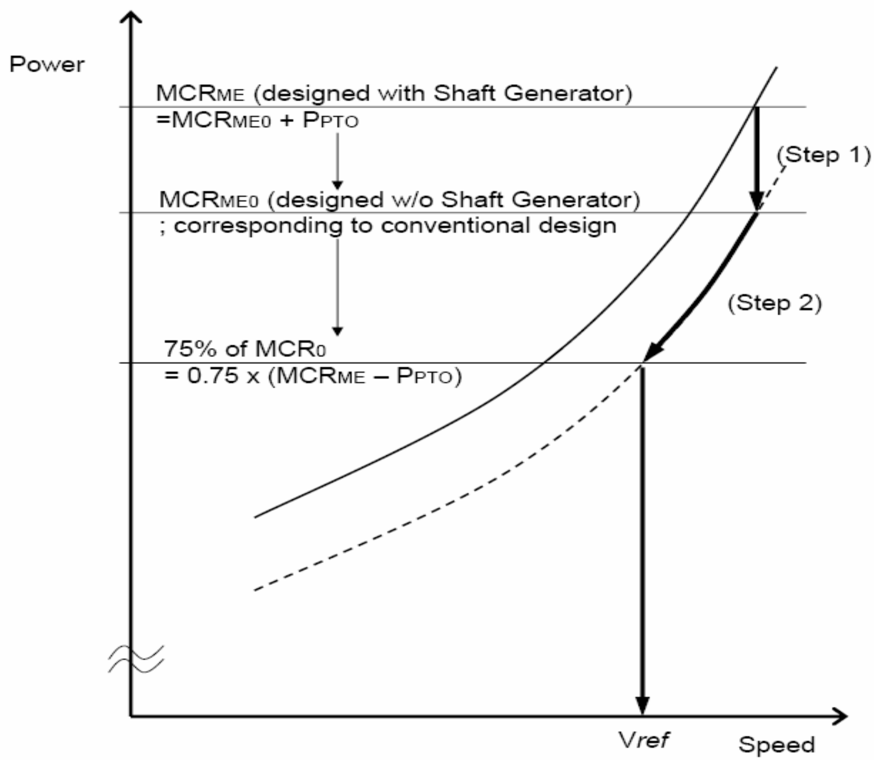
.4 *Deadweight* means the difference in tonnes between the displacement of a ship in water of relative density of 1,025 kg/m^3 at the deepest operational draught and the lightweight of the ship.

.5 *P* is the power of the main and auxiliary engines, measured in kW. The subscripts $_{ME}$ and $_{AE}$ refer to the main and auxiliary engine(s), respectively. The summation on *i* is for all engines with the number of engines (^{nME}). (See the diagram in the Appendix.)

.5.1 $P_{ME(i)}$ is 75% of the rated installed power (MCR) for each main engine (*i*) after having deducted any installed shaft generator(s):

$$P_{ME(i)} = 0.75 \times \left(MCR_{MEi} - P_{PTOi}\right)$$

The following figure gives guidance for determination of $P_{ME(i)}$:



.5.2 $P_{PTO(i)}$ is 75% output of each shaft generator installed divided by the relevant efficiency of that shaft generator.

.5.3 $P_{PTI(i)}$ is 75% of the rated power consumption of each shaft motor divided by the weighted averaged efficiency of the generator(s).

In case of combined PTI/PTO, the normal operational mode at sea will determine which of these to be used in the calculation.

Note: The shaft motor's chain efficiency may be taken into consideration to account for the energy losses in the equipment from the switchboard to the shaft motor, if the chain efficiency of the shaft motor is given in a verified document.

.5.4 $P_{eff(i)}$ is 75% of the main engine power reduction due to innovative mechanical energy efficient technology.

Mechanical recovered waste energy directly coupled to shafts need not be measured.

.5.5 $P_{AEeff\,(i)}$ is the auxiliary power reduction due to innovative electrical energy efficient technology measured at $P_{ME(i)}$.

.5.6 P_{AE} is the required auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodation, e.g., main engine pumps, navigational systems and equipment and living on board, but excluding the power not for propulsion machinery/systems, e.g., thrusters, cargo pumps, cargo gear, ballast pumps, maintaining cargo, e.g., reefers and cargo hold fans, in the condition where the ship engaged in voyage at the speed (*Vref*) under the design loading condition of *Capacity.*

.1 For cargo ships with a main engine power of 10000 kW or above, P_{AE} is defined as:

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

.2 For cargo ships with a main engine power below 10000 kW, P_{AE} is defined as:

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

.3 For ship types where the P_{AE} value calculated by .1 or .2 above is significantly different from the total power used at normal seagoing, e.g., in cases of passenger ships, the P_{AE} value should be estimated by the consumed electric power (excluding propulsion) in conditions when the ship is engaged in a voyage at reference speed (V_{ref}) as given in the electric power table[*], divided by the weighted average efficiency of the generator(s).

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[*] **Note:** The electric power table is often verified and approved by the Administration/Recognized Organization as documentation relating to SOLAS chapter II-1, Part D, regulation 40.1.1. The electric power table shows a generator load summary in kW and lists generators in service at different conditions of ship operation, e.g., "normal seagoing at full passenger load", where the ambient conditions are as follows: outside temperature is 35°C, the relative humidity is 85% and the seawater temperature is 32°C.

.6 V_{ref}, *Capacity* and *P* should be consistent with each other.

.7 *SFC* is the certified specific fuel consumption, measured in g/kWh, of the engines. The subscripts $_{ME(i)}$ and $_{AE(i)}$ refer to the main and auxiliary engine(s), respectively. For engines certified to the E2 or E3 duty cycles of the NO_x Technical Code 2008, the engine Specific Fuel Consumption ($SFC_{ME(i)}$) is that recorded on the EIAPP Certificate(s) at the engine(s) 75% of MCR power or torque rating. For engines certified to the D2 or C1 duty cycles of the NO_x Technical Code 2008, the engine Specific Fuel Consumption ($SFC_{AE(i)}$) is that recorded on the EIAPP Certificate(s) at the engine(s) 50% of MCR power or torque rating.

For ships where the P_{AE} value calculated by 2.5.6.1 and 2.5.6.2 is significantly different from the total power used at normal seagoing, e.g., conventional passenger ships, the Specific Fuel Consumption (SFC_{AE}) of the auxiliary generators is that recorded in the EIAPP Certificate(s) for the engine(s) at 75% of P_{AE} MCR power of its torque rating.

SFC_{AE} is the weighted average among $SFC_{AE(i)}$ of the respective engines *i*.

For those engines which do not have an EIAPP Certificate because its power is below 130 kW, the *SFC* specified by the manufacturer and endorsed by a competent authority should be used.

.8 f_j is a correction factor to account for ship specific design elements.

The f_j for ice-classed ships is determined by the standard f_j in Table 1.

Table 1

Correction factor for power f_j for ice-classed ships

For further information on approximate correspondence between ice classes, see HELCOM Recommendation 25/7*

Ship type	f_j	Limits depending on the ice class			
		IC	IB	IA	IA Super
Tanker	$\frac{0.516 L_{PP}^{1.87}}{\sum_{i=1}^{nME} P_{iME}}$	$\begin{cases} max\ 1.0 \\ min\ 0.72 L_{PP}^{0.06} \end{cases}$	$\begin{cases} max\ 1.0 \\ min\ 0.61 L_{PP}^{0.08} \end{cases}$	$\begin{cases} max\ 1.0 \\ min\ 0.50 L_{PP}^{0.10} \end{cases}$	$\begin{cases} max\ 1.0 \\ min\ 0.40 L_{PP}^{0.12} \end{cases}$
Dry cargo carrier	$\frac{2.150 L_{PP}^{1.58}}{\sum_{i=1}^{nME} P_{iME}}$	$\begin{cases} max\ 1.0 \\ min\ 0.89 L_{PP}^{0.02} \end{cases}$	$\begin{cases} max\ 1.0 \\ min\ 0.78 L_{PP}^{0.04} \end{cases}$	$\begin{cases} max\ 1.0 \\ min\ 0.68 L_{PP}^{0.06} \end{cases}$	$\begin{cases} max\ 1.0 \\ min\ 0.58 L_{PP}^{0.08} \end{cases}$
General cargo ship	$\frac{0.0450 \cdot L_{PP}^{2.37}}{\sum_{i=1}^{nME} P_{iME}}$	$\begin{cases} max\ 1.0 \\ min\ 0.85 L_{PP}^{0.03} \end{cases}$	$\begin{cases} max\ 1.0 \\ min\ 0.70 L_{PP}^{0.06} \end{cases}$	$\begin{cases} max\ 1.0 \\ min\ 0.54 L_{PP}^{0.10} \end{cases}$	$\begin{cases} max\ 1.0 \\ min\ 0.39 L_{PP}^{0.15} \end{cases}$

For other ship types, f_j should be taken as 1.0.

* HELCOM Recommendation 25/7 may be found at http://www.helcom.fi.

.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:

.9.1 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.

.9.2 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 data of actual speed reduction of as many existing ships as possible under representative sea conditions.

.9.3 f_w should be taken as one (1.0) until the Guidelines for the ship-specific simulation (paragraph .9.1) or f_w table/curve (paragraph .9.2) becomes available.

.10 $f_{eff(i)}$ is the availability factor of each innovative energy efficiency technology. $f_{eff(i)}$ for waste energy recovery system should be one (1.0).

.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.

f_i for ice-classed ships is determined by the standard f_i in Table 2.

Table 2

Capacity correction factor f_i for ice-classed ships

For further information on approximate correspondence between ice classes, see HELCOM Recommendation 25/7*

Ship type	f_i	Limits depending on the ice class			
		IC	IB	IA	IA Super
Tanker	$\frac{0.00115 Lpp^{3.36}}{capacity}$	$\begin{cases} max\, 1.31 Lpp^{-0.05} \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 1.54 Lpp^{-0.07} \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 1.80 Lpp^{-0.09} \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 2.10 Lpp^{-0.11} \\ min\, 1.0 \end{cases}$
Dry cargo carrier	$\frac{0{,}000665 \cdot Lpp^{3.44}}{capacity}$	$\begin{cases} max\, 1.31 Lpp^{-0.05} \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 1.54 Lpp^{-0.07} \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 1.80 Lpp^{-0.09} \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 2.10 Lpp^{-0.11} \\ min\, 1.0 \end{cases}$
General cargo ship	$\frac{0{,}000676 \cdot Lpp^{3.44}}{capacity}$	1.0	$\begin{cases} max\, 1.08 \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 1.12 \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 1.25 \\ min\, 1.0 \end{cases}$
Containership	$\frac{0.1749 \cdot Lpp^{2.29}}{capacity}$	1.0	$\begin{cases} max\, 1.25 Lpp^{-0.04} \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 1.60 Lpp^{-0.08} \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 2.10 Lpp^{-0.12} \\ min\, 1.0 \end{cases}$
Gas tanker	$\frac{0.1749 \cdot Lpp^{2.33}}{capacity}$	$\begin{cases} max\, 1.25 Lpp^{-0.04} \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 1.60 Lpp^{-0.08} \\ min\, 1.0 \end{cases}$	$\begin{cases} max\, 2.10 Lpp^{-0.12} \\ min\, 1.0 \end{cases}$	1.0

For other ship types, f_i should be taken as 1.0.

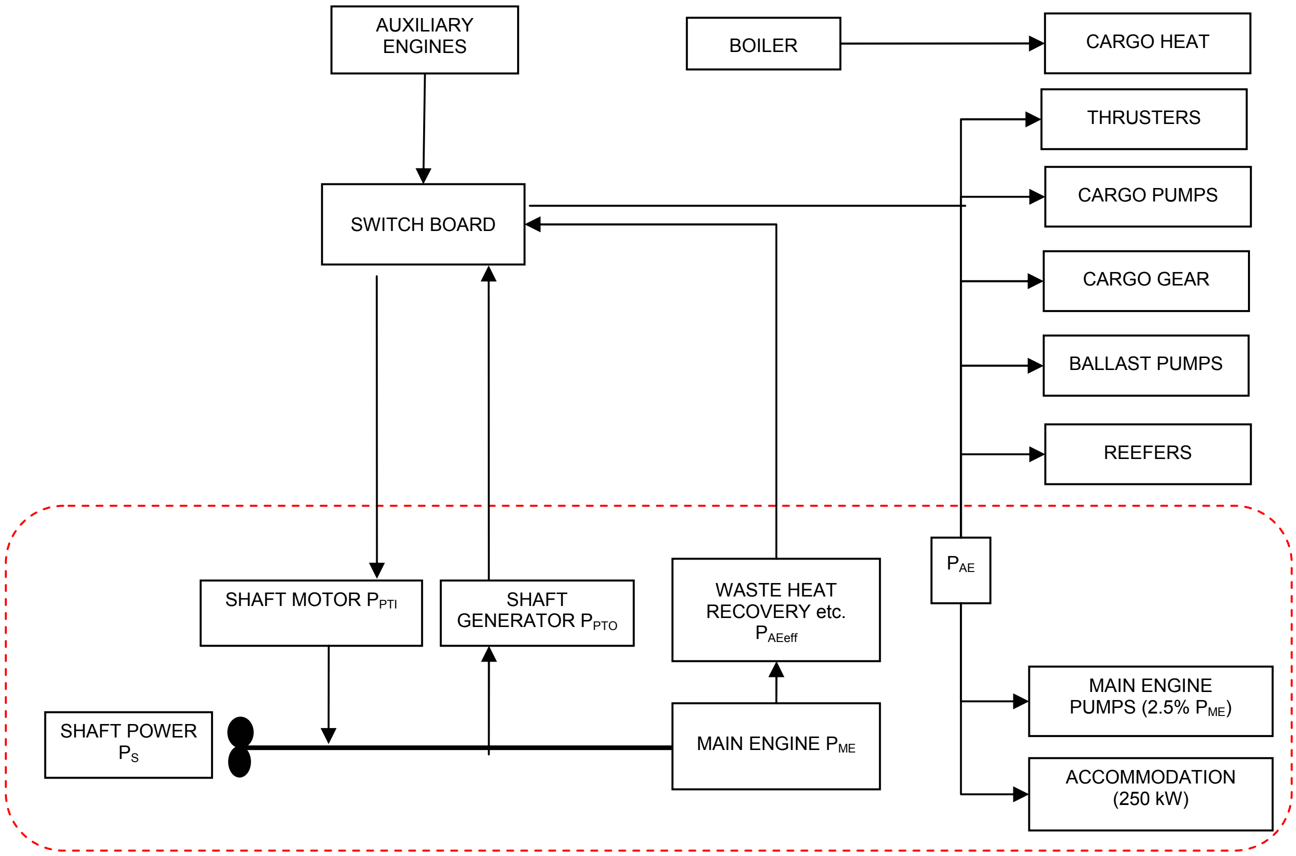
.12 *Length between perpendiculars*, *Lpp* means 96 per cent of the total length on a waterline at 85 per cent of the least moulded depth measured from the top of the keel, or the length from the foreside of the stem to the axis of the rudder stock on that waterline, if that were greater. In ships designed with a rake of keel the waterline on which this length is measured shall be parallel to the designed waterline. The length between perpendiculars (L_{pp}) shall be measured in metres.

* * *

* HELCOM Recommendation 25/7 may be found at http://www.helcom.fi.

Appendix

A generic and simplified marine power plant



Note 1: Mechanical recovered waste energy directly coupled to shafts need not be measured.

Note 2: In case of combined PTI/PTO, the normal operational mode at sea will determine which of these to be used in the calculation.

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MEPC.1/Circ.682
17 August 2009

INTERIM GUIDELINES FOR VOLUNTARY VERIFICATION OF THE ENERGY EFFICIENCY DESIGN INDEX

1 The Marine Environment Protection Committee, at its fifty-ninth session (13 to 17 July 2009), recognizing the need to develop a method for voluntary verification of the energy efficiency design index for new ships in order to promote uniform use of the Interim Guidelines on the method of calculation of the energy efficiency design index for new ships (MEPC.1/Circ.681), agreed to circulate the Interim Guidelines on voluntary verification of the energy efficiency design index, as set out in the annex.

2 Member Governments are invited to use the annexed Interim Guidelines for the purpose of tests and trials on a voluntary basis.

3 Member Governments and observer organizations are also invited to provide the outcome and experiences in applying the Interim Guidelines to future sessions of the Committee for further improvement of the Interim Guidelines.

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ANNEX

INTERIM GUIDELINES FOR VOLUNTARY VERIFICATION OF THE ENERGY EFFICIENCY DESIGN INDEX

1 GENERAL

The purpose of these Guidelines is to assist verifiers of Energy Efficiency Design Index (EEDI) of ships in conducting the verification, on a voluntary basis, of the EEDI which should be calculated in accordance with the Interim Guidelines on the Method of Calculation of the EEDI for New Ships ("EEDI Guidelines", hereafter), and assist shipowners, shipbuilders and manufacturers being related to the energy efficiency of a ship and other interested parties in understanding the procedures of the voluntary EEDI verification.

2 DEFINITIONS[1]

2.1 *Verifier* means an organization which conducts the voluntary EEDI verification in accordance with these Guidelines, including Administrations, classification societies and other organizations which possess technical expertise necessary for conducting the EEDI verification.

2.2 *Ship of the same type* means a ship of which hull form (expressed in the lines such as sheer plan and body plan) excluding additional hull features such as fins and of which principal particulars are identical to that of the base ship.

2.3 *Ship of a similar type* means a ship of which hull form (expressed in the lines such as sheer plan and body plan) excluding additional hull features such as fins and of which principal particulars are largely identical to that of the base ship.

2.4 *Tank test* means model towing tests, model self-propulsion tests and model propeller open water tests. Numerical tests may be accepted as equivalent to model tests if they are performed under documented conditions agreed by the shipbuilder and shipowner.

3 APPLICATION

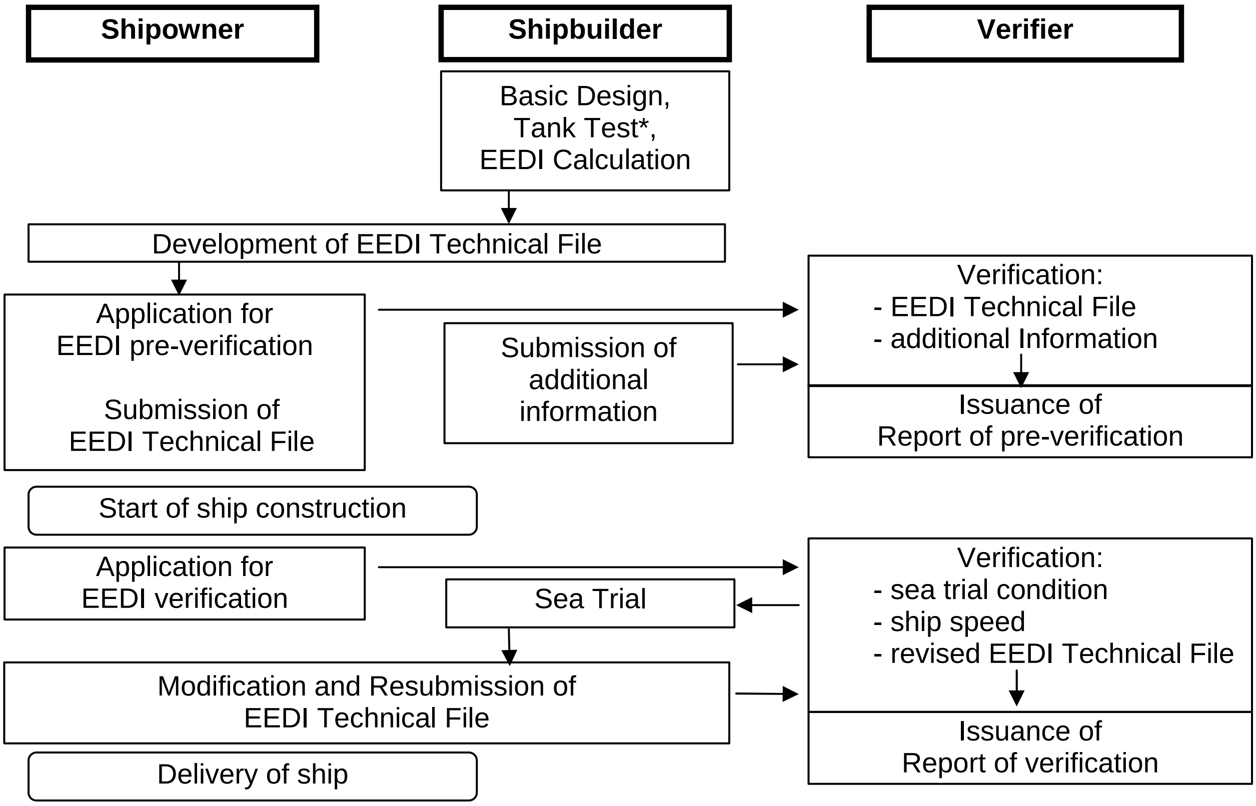
These Guidelines should be applied on a voluntary basis to new ships for which an application for an EEDI verification has been submitted to a verifier.

4 PROCEDURES FOR VERIFICATION

4.1 General

Attained EEDI should be calculated in accordance with the EEDI Guidelines. Voluntary EEDI verification should be conducted on two stages: preliminary verification at the design stage, and final verification at the sea trial. The basic flow of the verification process is presented in Figure 1.

[1] Other terms used in these guidelines have the same meaning as those defined in the EEDI Guidelines.



* To be conducted by a test organization or a shipbuilder itself.

Figure 1 – Basic Flow of Verification Process

4.2 Preliminary verification at the design stage

4.2.1 For the preliminary verification at the design stage, a shipowner should submit to a verifier an application for the verification and an EEDI Technical File containing the necessary information for the verification and other relevant background documents.

4.2.2 EEDI Technical File, which is to be developed by either a shipowner or a shipbuilder, should include at least but not limited to:

.1 deadweight (DWT) or gross tonnage (GT) for passenger and ro-ro passenger ships, the shaft power of the main and auxiliary engines, the ship speed on deep water in the maximum design loaded conditions at the 75% of the maximum continuous rate (MCR) for the main engine, the specific fuel consumption (SFC) of the main engine at the 75% of MCR power, the SFC of the auxiliary engines at the 50% MCR power, and the electric power table for certain ship types, as necessary, as defined in the EEDI Guidelines;

.2 power curves (kW – knot) estimated at design stage under fully loaded condition and sea trial condition;

.3 principal particulars and the overview of propulsion system and electricity supply system on board;

.4 estimation process and methodology of the power curves at design stage;

.5 description of energy saving equipment; and

.6 calculated value of the Attained EEDI.

4.2.3 Sea trial conditions should be set in fully loaded condition, if possible – e.g., in case of tankers.

4.2.4 The SFC of the main and auxiliary engines should be quoted from the approved NO_x Technical File. For the confirmation of the SFC, a copy of the approved NO_x Technical File should be submitted to the verifier. In case NO_x Technical File has not been approved at the time of the application for preliminary verification, the test reports provided by manufacturers should be used. In this case, at the time of the sea trial verification, a copy of the approved NO_x Technical File should be submitted to the verifier.

Note: SFC in the NO_x Technical File are the values of a parent engine, and the use of such value of SFC for the EEDI calculation for member engines may have the following technical problems for further consideration:

- The definition of "member engines" given in NO_x Technical File is broad and specification of engines belonging to the same family group may vary; and

- The rate of NO_x emission of the parent engine is the highest in the group/family – i.e. CO_2 emission, which is in the trade-off relationship with NO_x emission, can be lower than the other engines in the group/family.

Thus, for member engines of which specifications are different from the parent engine, how to determine SFC should be considered further. For instance, measured values of SFC at test bed of manufacturers could be used.

4.2.5 The power curves used for the preliminary verification at the design stage should be based on reliable results of tank test. A tank test for an individual ship may be omitted based on technical justifications such as availability of the results of tank tests for ships of the same/similar type.

4.2.6 The verifier may request the shipbuilder for additional information on top of those contained in Technical File, as necessary, to examine the calculation process of the Attained EEDI. The estimation of the ship speed at the design stage much depends on each shipbuilder's experiences, and it may not be practicable for any person/organization other than the shipbuilder to fully examine the technical aspects of experience-based parameters such as the roughness coefficient and wake coefficient. Therefore, the preliminary verification should focus on the calculation process of the Attained EEDI that should follow the EEDI Guidelines.

Note: A possible way forward for more robust verification is to establish a standard methodology of deriving the ship speed from the outcomes of tank test, by setting standard values for experience-based correction factors such as roughness coefficient and wake coefficient. In this way, ship-by-ship performance comparison could be made more objectively by excluding the possibility of arbitrary setting of experience-based parameters. If such standardization is sought, this would have an implication on how the ship speed adjustment based on sea trial results should be conducted in accordance with paragraph 4.3.8 of these Guidelines.

Note: For ensuring the quality of tank tests, it would be desirable in the future that an organization conducting a tank test be authorized by the Administration or an organization recognized by it in accordance with the guidelines developed by the Organization.

4.2.7 Additional information that the verifier should request the shipbuilder to provide directly to it (i.e. not to be contained in Technical File) includes but not limited to:

.1 descriptions of a tank test facility; this should include the name of the facility, the particulars of tanks and towing equipment, and the records of calibration of each monitoring equipment;

.2 lines of a model ship and an actual ship for the verification of the appropriateness of the tank test; the lines (sheer plan, body plan and half-breadth plan) should be detailed enough to demonstrate the similarity between the model ship and the actual ship;

.3 lightweight of the ship and displacement table for the verification of the deadweight;

.4 detailed report on the method and results of the tank test; this should include at least the tank test results at sea trial condition and at fully loaded condition;

.5 detailed calculation process of the ship speed, which should include the estimation basis of experience-based parameters such as roughness coefficient, wake coefficient; and

.6 reasons for exempting a tank test, if applicable; this should include lines and tank test results of the ships of same/similar type, and the comparison of the principal particulars of such ships and the ship in question. Appropriate technical justification should be provided for regarding the tank test unnecessary.

4.2.8 Such additional information may contain shipbuilders' confidential information. Therefore, after the verification, the verifier should return all or part of such information to the shipbuilder at its request.

4.3 Final verification of the Attained EEDI at sea trial

4.3.1 Prior to the sea trial, a shipowner should submit the application for the verification of EEDI together with the final displacement table and the measured lightweight, or a copy of the survey report of deadweight, as well as a copy of NO_x Technical File as necessary.

4.3.2 The verifier should attend the sea trial and confirm:

.1 propulsion and power supply system, particulars of the engines, and other relevant items described in the EEDI Technical File;

.2 draft and trim;

.3 sea conditions;

.4 ship speed; and

.5 shaft power of the main engine.

4.3.3 Draft and trim should be confirmed by the draft measurements taken prior to the sea trial. The draft and trim should be as close as practical to those at the assumed conditions used for estimating the power curves.

4.3.4 Sea conditions should be measured in accordance with ISO15016:2002 or the equivalent.

4.3.5 Ship speed should be measured in accordance with ISO15016:2002 or the equivalent and at more than two points of which range includes the 75% of MCR power.

4.3.6 The shaft power of the main engine should be measured by shaft power meter or estimated by fuel rack. Otherwise, it should be measured by a method which the engine manufacturer recommends and the verifier approves.

4.3.7 The shipbuilder should develop power curves based on the measured ship speed and the measured shaft power of the main engine at sea trial. For the development of the power curves, the shipbuilder should calibrate the measured ship speed, if necessary, by taking into account the effects of wind, tide and waves in accordance with ISO15016:2002 or the equivalent.

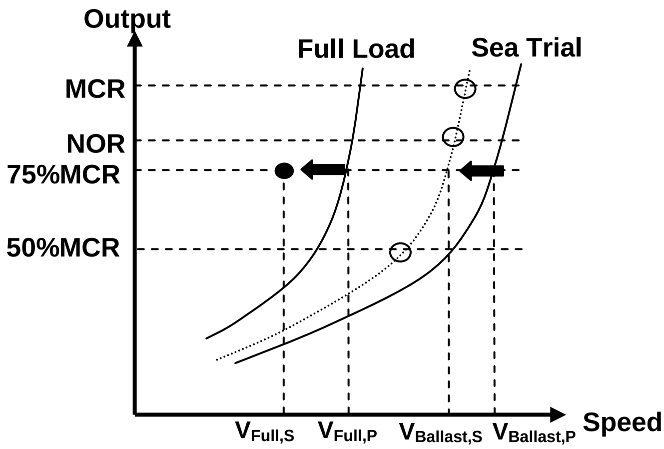
4.3.8 The shipbuilder should compare the power curves obtained as a result of the sea trial and the estimated power curves at the design stage. In case differences are observed, the Attained EEDI should be recalculated, as necessary, in accordance with the following:

.1 for ships for which sea trial is conducted in fully loaded condition (e.g., tankers): the Attained EEDI should be recalculated using the measured ship speed at sea trial at 75% of MCR power; and

.2 for ships for which sea trial cannot be conducted in fully loaded condition (e.g., dry bulkers): if the measured ship speed at 75% of MCR power of the main engine at the sea trial conditions is different from the expected ship speed on the power curve at the corresponding condition, the shipbuilder should recalculate the Attained EEDI by adjusting ship speed in fully loaded condition by an appropriate correction method that is agreed by the verifier.

An example of possible methods of the speed adjustment is given in Figure 2:

Note: Further consideration would be necessary for speed adjustment methodology in 4.3.8.2. One of concerns relates to a possible situation where the power curve for sea trial condition is estimated in excessively conservative manner (i.e. power curve is shifted in a leftward direction) with the intention to get an upward adjustment of the ship speed by making the measured ship speed at sea trial easily exceed the lower-estimated speed for sea trial condition at design stage.



$$V_{Full,S} = V_{Full,P} \times (V_{Ballast,S}/V_{Ballast,P})$$

$V_{Ballast,P}$:estimated ship speed at sea trial conditions on the power curve estimated at design stage
$V_{Ballast,S}$:ship speed obtained as a result of the sea trial
$F_{Full,S}$: adjusted ship speed by the results of sea trial, in fully loaded condition
$F_{Full,P}$:estimated ship speed in fully loaded condition at design stage.

Figure 2 – An Example of Possible Ship Speed Adjustment

4.3.9 In case where the Attained EEDI is calculated at the preliminary verification by using SFC based on the manufacturer's test report due to the non-availability at that time of the approved NO_x Technical File, the shipowner or the shipbuilder should recalculate the Attained EEDI by using SFC in the approved NO_x Technical File.

4.3.10 The shipowner or the shipbuilder should revise an EEDI Technical File, as necessary, by taking into account the results of sea trial. Such revision should include, as applicable, the adjusted power curve based on the results of sea trial (namely, modified ship speed at 75% of MCR power of the main engine at full-loaded condition) and SFC described in the approved NO_x Technical File, and the recalculated Attained EEDI based on these modifications.

4.3.11 The EEDI Technical File, if revised, should be submitted to the verifier for the confirmation that the (revised) Attained EEDI is calculated in accordance with the EEDI Guidelines.

5 ISSUANCE OF THE EEDI VERIFICATION REPORT

5.1 The verifier should issue the Report on the Preliminary Verification of EEDI after it verified the Attained EEDI at design stage in accordance with Sections 4.1 and 4.2 of these Guidelines.

5.2 The verifier should issue the report on the Verification of EEDI after it verified the Attained EEDI after the sea trial in accordance with Sections 4.1 and 4.3 of these Guidelines.

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