Estimated Index Values of Ships 2009-2016

Analysis of the Design Efficiency of Ships that have Entered the Fleet since 2009

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Content

Summary

All ships built after 1 January 2013 need to have an Energy Efficiency Design Index (EEDI). This measure of design fuel efficiency needs to be better than a reference value which depends on the ship type and size. The reference value reflects the average fuel efficiency of ships that have entered the fleet between 1999 and 2008.

The required EEDI is set to become more stringent over time. From 2015, ships have to be 10% more efficient, and every five years the stringency increases by another 10% until 2025. These targets are subject to mid-term reviews. The review of Phase 2, requiring ships from 2020 to be 20% more efficient than the reference value, is ongoing.

This study analyses the development of the design efficiency of ships that have entered the fleet from 2009 to 2016. Because the EEDI of a ship can only be determined in a sea trial, this study uses a simplified version called the Estimated Index Value (EIV). The EIV can be calculated on the basis of publicly available information and the EIVs of ships that entered the fleet between 1999 and 2008 were used to calculate the reference values. The EIV is higher than the EEDI on average, meaning that ships are generally more fuel efficient than the EIV suggests.

This study finds that based on an analysis of EIVs, the average design efficiency of new ships has improved in recent years. However, the efficiency improvements seem to have stalled in 2016. On average, the design efficiency of new bulk carriers, tankers and gas carriers was worse in 2016 than they were in 2015. Also the share of ships below the reference line and the share of ships meeting or exceeding Phase 1, Phase 2 or Phase 3 required EEDI values has decreased in 2016. The design efficiency of container ships and general cargo carriers was more or less at the same level in 2016 as in 2015.

This report has also calculated the estimated EEDI of new ships, using the empirical relation that the EEDI is about 10% lower than the EIV. Amongst the ships built in recent years, there are at least 20% which have an estimated EEDI that is more than 20% below the reference line (i.e. that meet Phase 2 EEDI requirements). For general cargo ships, the share is 40% and for container ships, more than 60% are at least 20% below the reference line. In all but one size categories of ships, ships have been built that are more than 20% below the reference value.

Still, a surprisingly large share of ships that entered the fleet in 2016 had an EIV that is well above the reference line, sometimes more than 50%. This does not appear to be an issue that affects specific ship types: often the variation in EIVs between ships of the same type and a similar size is very large, spanning from values well below the reference line to values well above it. This suggests that there is a large variation in the design efficiency that is not determined by ship type-specific requirements.

1 Introduction

1.1 Policy Context

The Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) adopted the regulation on the Energy Efficiency Design Index (EEDI) in 2011. The EEDI is a measure of a ship's efficiency under standardized conditions, expressed by the amount of CO_2 emissions per tonne mile. The regulations, contained in MARPOL Annex VI Chapter 4, require ships that are built on or after 1 January 2013 to have an EEDI that is better than the required EEDI for that ship. Over time, ships have to meet increasingly stringent limits: between 2015 and 2019, ships need to have an EEDI that is at least 10% better than the reference line; between 2020 and 2024 they have to be 20% better than the reference line and from 2025 onwards 30%. Small ships are either exempted or have a relaxed stringency requirement.

The required EEDI is a function of ship type and size of the ship. It is based on an empirical regression line of the efficiency of ships built between 1999 and 2009 which is called the reference line. The reference lines were calculated by the IMO using publicly available data to construct a simplified version of the EEDI called the Estimated Index Value (EIV).

MEPC 70 reviewed the reduction rate of Phase 2 of the EEDI and decided to retain it, but also to start a thorough review of EEDI Phase 3 requirements and their early implementation, and of the possibility of establishing a Phase 4 in 2017, also considering the possibility to bring Phase 3 forward to 2022 (MEPC, 2016b).

This report is an early contribution to the review. It analyses the EIVs of ships that have entered the fleet between 2009 and 2016 and updates earlier reports (CE Delft, 2015), (CE Delft, 2016). The EIVs have been calculated of 701 ships that have entered the fleet in 2016 and for which sufficient data were available. In total, the analysis is based on over 11,000 ships that have entered the fleet over eight years.

1.2 How the EEDI regulation works

All ships built on or after 1 January 2013 need to attain a value of the EEDI which is better than the required EEDI. The required EEDI is a function of the ship type and the capacity of a ship and can be calculated using the formulas presented in Table 1.

Table 1 Reference line formula for different ship types

Ship type	Reference line value
Bulker	$961.79*(dwt)^{-0.477}$
Gas carrier	$1120*(dwt)^{-0.456}$
Tanker	$1218.8*(dwt)^{-0.488}$
Container ship	$174.22*(0.7*dwt)^{-0.201}$
General Cargo ship	$107.48*(dwt)\text{-}^{-0.216}$
Combination carrier	$1219*(dwt)^{-0.488}$

Source: Resolution MEPC.203(62).

The reference lines have been derived by calculating the Estimated Index Value (EIV), which is a simplified form of the EEDI, for all ships that have entered the fleet between 1999 and 2008, and drawing a regression line (MEPC, 2013).

The required EEDI is expressed as a share of the reference line value for the ship. As shown in Table 2, the stringency increases over time. The reduction factors are the same for all ship types. Small ships, however, are exempted or treated differently, and the threshold varies for different ship types.

Table 2 Reduction factors (in percentage) for the EEDI relative to the EEDI Reference line

	Phase 0 2013-2014	Phase 1 2015-2019	Phase 2 2020-2024	Phase 3 2025 -
Reduction of the required EEDI relative to the reference line	0%	10%	20%	30%

Source: (MEPC, 2011).

1.3 Objectives

The objective of this study is to analyse development of design efficiency of ships that have entered the fleet since 2009 and update the analysis with ships that have entered the fleet in 2016.

Specifically, the report sets out to answer the following questions:
- What share of ships have EIV scores that meet or exceed current and future EEDI limits?
- How have efficiency changes been realised?
- How does the design efficiency of ships that have entered the fleet in 2016 compare to the efficiency of older ships?

1.4 Methodology

This study has calculated the EIV for ships that have entered the fleet between 2009 and 2016. 2009 was the first year after the period over which the reference lines have been calculated. 2016 was the last year available.

The EIV is given by the formula (Resolution MEPC.231(65)):

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

In line with resolution MEPC.231(65) the following assumptions have been made in calculating the EIV:

1. The carbon emission factor is constant for all engines, i.e. CF,ME = CF,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 main engines power and is 75% of the total installed main power (MCR_{ME}).
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 auxiliary power and is calculated according to paragraphs 2.5.6.1 and 2.5.6.2 of the annex to MEPC.212(63).
6. No correction factors on ice class, voluntary structural enhancement, etc. are used.
7. Innovative mechanical energy efficiency technology, shaft motors and other innovative energy efficient technologies are all excluded from the calculation, i.e. P_{AEeff} = 0, P_{PTI} = 0, P_{eff} = 0.
8. Capacity is defined as 70% of dead weight tonnage (dwt) for container ships and 100% of dwt for other ship types.

The EIV is a simplified form of the EEDI. An important difference is that the specific fuel consumption in the EEDI is not constant. Clarksons' World Fleet Register contains the specific fuel consumption of the main engine for 7,992 vessels (87%) of the 9,179 ships built between 2009 and 2014.
The average specific fuel consumption for these ships is close to 175 g/kWh, which is 8% lower than the constant value of 190 g/kWh in the EIV. Other differences are that the EEDI allows ice-classed ships to have larger engines, and that there are correction factors for various ship types and for energy saving technologies.

As a result of the assumptions made in the calculation, the EIV is higher than the EEDI for most ships. In other words, the design efficiency of a ship as shown by its EEDI is usually better than the value of the EIV suggests. An empirical analysis of the relation between the EIV and the EEDI of 154 ships built in or before 2014 showed that the EEDI was on average 10% lower than the EIV (CE Delft, 2016)

1.5 Scope

The analysis includes all ship types for which an EEDI reference line has been defined in 2011: bulk carriers, container ships, tankers, gas carriers, general cargo carriers, and combination carriers.[1]

We have calculated the EIV for all ships that have entered the fleet between 1 January 2009 and 31 December 2016 and for which sufficient data were available in the Clarksons World Fleet Register (WFR) to calculate the EIV: main engine power, speed and deadweight tonnage. There are two differences between the database and the EEDI regulations that need to be taken into account when interpreting the results of this study:

1. The data on main engine power, speed and deadweight tonnage in the WFR need not be the same as those that are used to determine the EEDI. This is especially the case for speed. For the EEDI, the speed at 75% of MCR is relevant while the speed reported in the WFR may be at a different engine power (the MCR rate is not specified in the database). Note, however, that the reference lines have also been calculated without a specific definition of speed.
2. The date of entry in the fleet is not the same as the date that is used to determine whether a ship is subject to the EEDI and if so, which phase applies. The date of entry in the fleet is the date on which the ship is delivered by the yard to the owner. The date for the EEDI is the date of the contract, or in absence of a contract either 6 months before the keel-laying date or 30 months before the delivery of a ship.

Small ships have been excluded from the analysis. The threshold has been set at the cargo capacity above which the reference line applies, which depends on the ship type (see Table 3).

Table 3 Minimum size threshold for inclusion in the analysis

Type	Minimum dwt
Bulk carrier	10,000
Container ship	10,000
Tanker	4,000
Gas carrier	2,000
General cargo ship	3,000
Combination carrier	4,000

Outliers have been excluded from the calculation of the mean and median EIVs and of the calculation of the standard deviation in order to ensure that these values were not affected by ships with atypical designs. They have been defined as ships of which the relative distance to the reference line is more than 100% above the reference line or more than 75% under the reference line. This has excluded less than 0.1% of the ships from the sample.

[1] In 2014, EEDI reference lines have been defined for five additional ship types: LNG carriers, Ro-ro cargo ships (vehicle carriers), Ro-ro cargo ships, Ro-ro passenger ships and Cruise passenger ships having non-conventional propulsion. For these ships, the required EEDI is defined from 1 January 2015. Consequently, very few ships in the fleet at the end of 2015 are subject to the EEDI requirement and for that reason these ships have not been included in this analysis.

2 Design efficiency of ships 2009-2016

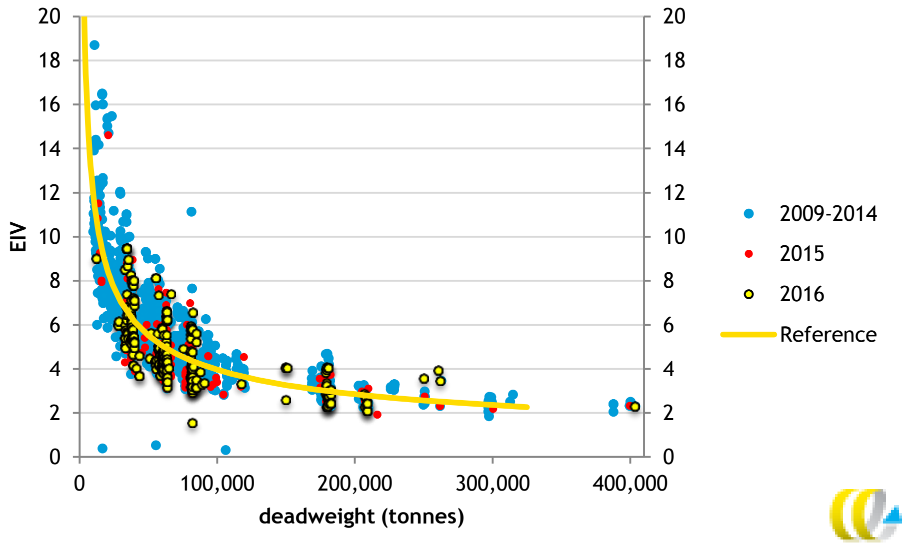
2.1 Introduction

This chapter presents the development of the design efficiency of ships built between 2009 and 2016. It uses two measures for efficiency: the EIV and the distance of a ship's EIV to the reference line for that ship. The development is presented for bulk carriers (Section 2.2), container ships (Section 2.3), tankers (Section 2.4), gas carriers (Section 2.5) and general cargo ships (Section 2.6). For these ship types, the reference line has been defined in 2011. Chapter 3 presents our conclusions.

2.2 Bulk Carriers

The Estimated Index Values of 5,618 bulk carriers that have entered the fleet in the years 2009-2016 have been calculated. Figure 1 illustrates the results for each bulker. Deadweight tonnage is on the horizontal axis, the EIV on the vertical axis. Observations below the continuous yellow curve refer to bulkers of which the EIV is better than the reference line; observations above the same curve imply that the design efficiency of these bulkers is worse than the reference line. Because the EEDI is generally lower than the EIV, bulkers above the reference line may still meet the required EEDI.

Figure 1 EIV of Bulk Carriers built in 2009-2016



Source: CE Delft.

Table 4 provides more detail on the EIV of bulk carriers. While both the mean and median EIV were above the reference line between 2009 and 2012, they have decreased since, indicating that the design efficiency has improved.

About three quarters of the ships built in 2014 – 2016 have EIVs below the reference lines, about half meet the Phase 1 requirement and one fifth meet the Phase 2 requirements. It appears that the average efficiency of new bulk carriers has worsened slightly in 2016: the mean and median EIV are closer to the reference line, and the share of ships below a certain threshold has decreased a little. Note, however, that the changes in the average and mean EIV are small compared to the standard deviation, so that it is not possible to draw firm statistical conclusions.

Table 4 Descriptive statistics for Bulk Carriers 2009-2016

Variable	Built	2009	2010	2011	2012	2013	2014	2015	2016
EIV	Mean	5.7	5.5	5.4	5.4	5.2	4.8	4.7	4.7
%distance to the reference line*	Mean	6%	6%	8%	6%	1%	-6%	-8%	-4%
	Median	6%	7%	8%	6%	-1%	-9%	-13%	-12%
	Standard deviation	12%	12%	13%	14%	15%	17%	19%	21%
Ships	Total number	559	974	1,113	1,048	625	474	489	332
EIV under	With EIVs under reference line (in%)	31%	29%	23%	35%	53%	74%	76%	71%
Reference line	With EIVs 10% under reference line (in%)	10%	8%	8%	11%	23%	46%	58%	53%
	With EIVs 20% under reference line (in%)	2%	1%	1%	1%	3%	17%	23%	19%
	With EIVs 30% under reference line (in%)	0%	0%	0%	0%	0%	2%	6%	5%

Source: CE Delft.

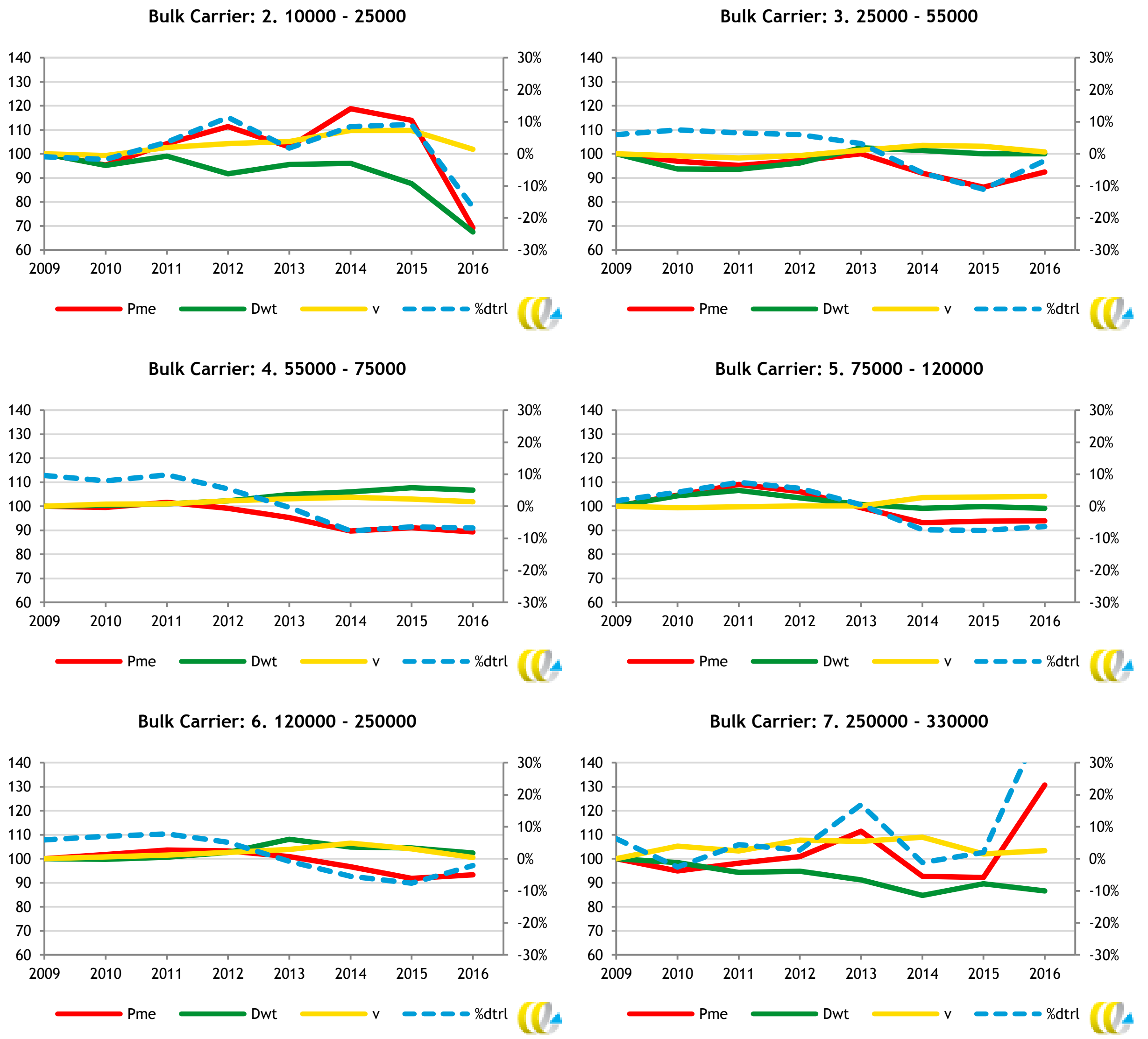
* A negative value signifies an EIV below the reference line (a better design efficiency).

Figure 2 analyses the design efficiency of new bulk carriers for six size categories. For each size category, the average relative distance of the EIV of ships to the reference line (DtRL) has been calculated and the development of the factors that make up the EIV has been analysed (main engine power, ship capacity and speed).

Figure 2 shows that for small bulk carriers (up to 25,000 dwt), the average design efficiency has improved in 2016. For all other categories, the average design efficiency has remained stable or worsened.

The main driver for the change of the EIV has been the change in main engine power. Interestingly, when comparing average 2016 ships with average 2015 ships, the average design speed of the ships has remained more or less constant or moved in the opposite direction of the engine power, which suggests that the hull efficiency, the propeller efficiency or the rudder efficiency have deteriorated so that ships require more power to maintain a certain speed. The opposite was the case in the previous two years.

Figure 2 Development in EIV, engine power, size and speed of Bulk carriers 2009-2016 (2009=100)



Source: CE Delft.

Table 5 shows the Estimated EEDI for bulk carriers (eEEDI), defined as 90% of the EIV value. The results suggest that not all ships that have entered the fleet in 2016 have an attained EEDI that is below the reference line, as they are required to have unless they have obtained a waiver.

Table 5 Estimated EEDI for Bulk Carriers 2009-2016

Variable	Built	2009	2010	2011	2012	2013	2014	2015	2016
eEEDI	Mean	5.1	4.9	4.9	4.9	4.6	4.3	4.2	4.2
%distance of eEEDI to the reference line	Mean	-5%	-4%	-3%	-5%	-9%	-15%	-17%	-14%
	Median	-4%	-4%	-3%	-5%	-11%	-18%	-22%	-21%
	Standard deviation	11%	11%	11%	13%	14%	15%	17%	19%
Ships	Total number	559	974	1,112	1,048	625	474	489	332
eEEDI under	With eEEDI under reference line (in%)	66%	70%	64%	66%	74%	86%	82%	78%
Reference line	With eEEDI 10% under reference line (in%)	31%	29%	23%	35%	53%	74%	76%	71%
	With eEEDI 20% under reference line (in%)	8%	5%	5%	9%	20%	44%	55%	51%
	With eEEDI 30% under reference line (in%)	1%	1%	1%	1%	2%	11%	16%	14%

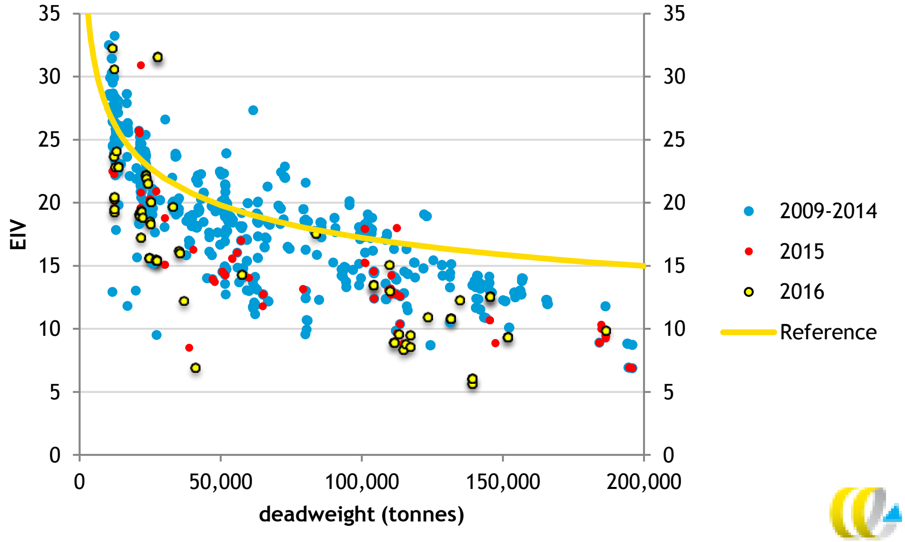
2.3 Container ships

The Estimated Index Values of 1,449 container ships built in the years 2009-2015 have been calculated.

Figure 3 illustrates the outcome for each container ship. Deadweight tonnage is on the horizontal axis, the EIV on the vertical axis. Observations below the continuous yellow curve refer to container ships of which the EIV is better than the reference line; observations above the same curve imply that the design efficiency of these container ships is worse than the reference line.

Most container ships have EIVs below the reference line. Only a few relatively small ships exceed the reference line.

Figure 3 EIV of Container ships built in 2009-2016



Source: CE Delft.

Table 6 provides more detail on the EIV of container ships. Both the mean and median EIV have been below the reference line between 2009 and 2012.
The average design efficiency has improved significantly from 2013. About 90% of the ships built between 2013 and 2016 have EIVs below the reference lines, while over 60% of the ships built in 2014 - 2016 meet the Phase 2 requirements and a little less than 40% Phase 3 requirements.

Table 6 Descriptive statistics for Container ships 2009-2016

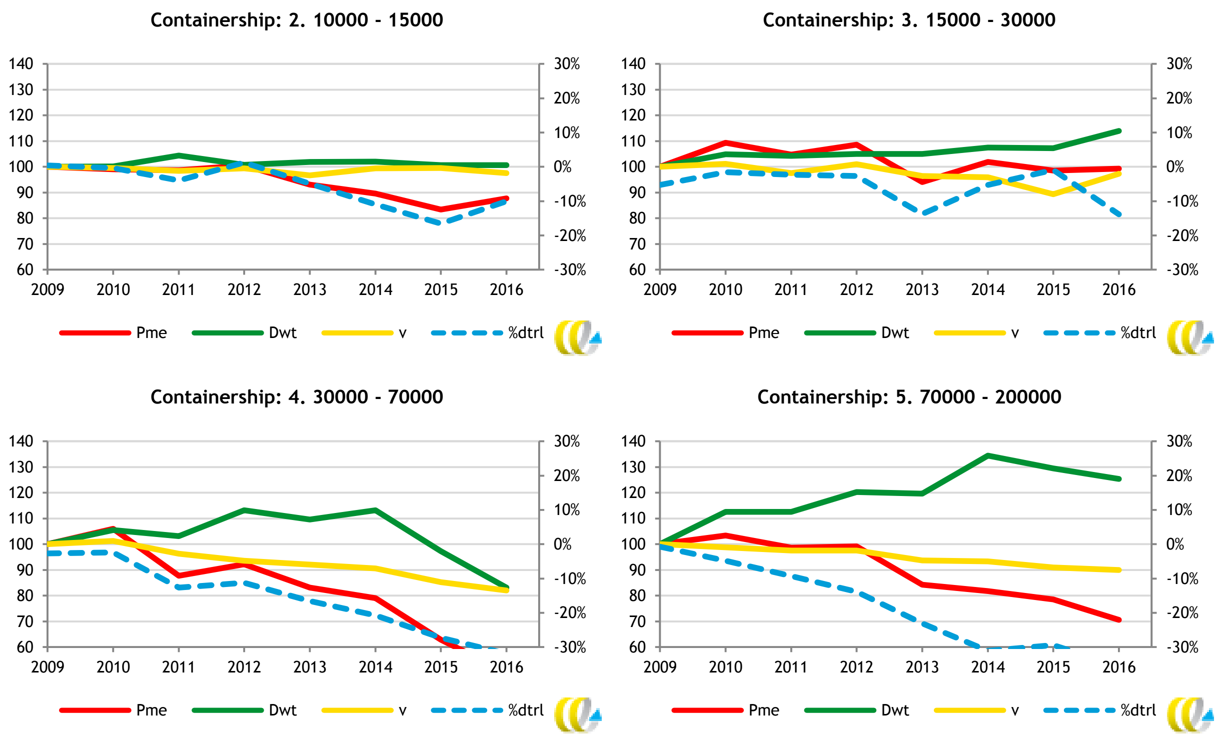
Variable	Built	2009	2010	2011	2012	2013	2014	2015	2016
EIV	Mean	20.2	19.2	17.7	18.2	15.6	14.4	15.1	16.1
%distance to the reference line	Mean	-2%	-3%	-9%	-9%	-19%	-24%	-23%	-24%
	Median	-2%	-1%	-8%	-12%	-22%	-25%	-25%	-23%
	Standard deviation	10%	10%	13%	15%	15%	16%	17%	21%
Ships	Total number	258	253	182	195	194	153	149	65
EIV under	With EIVs under reference line (in%)	63%	58%	67%	74%	87%	93%	89%	94%
Reference line	With EIVs 10% under reference line (in%)	16%	23%	45%	53%	73%	83%	83%	83%
	With EIVs 20% under reference line (in%)	7%	6%	17%	18%	51%	63%	64%	63%
	With EIVs 30% under reference line (in%)	2%	1%	6%	10%	26%	37%	36%	38%

Source: CE Delft.

Figure 4 analyses the design efficiency of new container ships for four size categories. For each size category, the average relative distance of the EIV of ships to the reference line has been calculated and the development of the factors that make up the EIV has been analysed (main engine power, ship capacity and speed).

Figure 4 shows that for most size categories, the average design efficiency has improved in 2016, except for container ships with a dwt 10,000 and 15,000. The main driver for the improvement of the EIV for large container ships has been the reduction in main engine power which has coincided with a decrease in speed. For the two smaller ship categories, speeds have either increased or remained constant. Container ships with a dwt between 15,000 and 30,000 have, on average, been able to improve their design efficiency because they were larger in 2016 than in 2015.

Figure 4 Development in EIV, engine power, size and speed of Container ships 2009-2016 (2009=100)



Source: CE Delft.

Table 7 shows the Estimated EEDI for container ships, defined as 90% of the EIV value.

Table 7 Estimated EEDI for Container ships 2009-2016

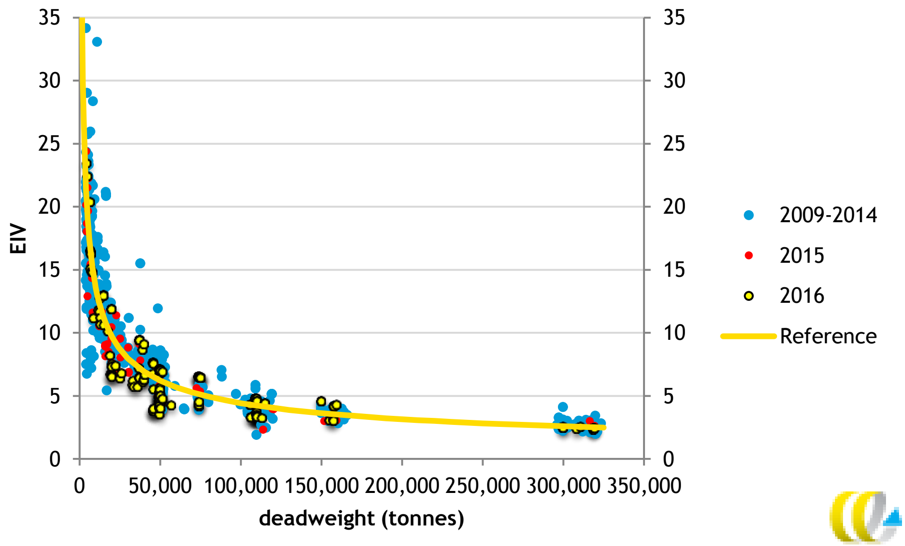
Variable	Built	2009	2010	2011	2012	2013	2014	2015	2016
eEEDI	Mean	18.2	17.3	15.9	16.4	14.0	13.0	13.6	14.5
%distance of the eEEDI to the reference line	Mean	-12%	-13%	-18%	-18%	-27%	-32%	-31%	-31%
	Median	-11%	-11%	-18%	-21%	-30%	-32%	-32%	-31%
	Standard deviation	9%	9%	12%	13%	13%	14%	16%	19%
Ships	Total number	258	253	182	195	194	153	149	65
eEEDI under	With eEEDI under reference line (in%)	90%	93%	95%	88%	95%	99%	99%	94%
Reference line	With eEEDI 10% under reference line (in%)	63%	58%	67%	74%	87%	93%	89%	94%
	With eEEDI 20% under reference line (in%)	14%	19%	40%	52%	72%	82%	82%	80%
	With eEEDI 30% under reference line (in%)	3%	4%	13%	16%	51%	61%	60%	52%

2.4 Tankers

The Estimated Index Values of 2,240 tankers built in the years 2009-2016 have been calculated.

Figure 5 illustrates the outcome for each tanker. Deadweight tonnage is on the horizontal axis, the EIV on the vertical axis. Observations below the continuous yellow curve refer to vessels of which the EIV is better than the reference line; observations above the same curve imply that the design efficiency of these ships is worse than the reference line.

Figure 5 EIV of Tankers built in 2009-2016



Source: CE Delft.

Table 8 provides more detail on the EIV of tankers. While the mean and median EIV have been around the reference line values between 2009 and 2013, 2014 has shown a marked improvement in the EIV values, after which year they have deteriorated slightly. About two thirds of the new ships delivered in 2016 had an EIV below the reference line, while half met the Phase 1 requirements and almost a quarter Phase 2 requirements. In all cases, these shares were lower than in the two preceding years. Note, however, that the changes in the average and mean EIV are small compared to the standard deviation, so that it is not possible to draw firm statistical conclusions.

Table 8 Descriptive statistics for Tankers 2009-2016

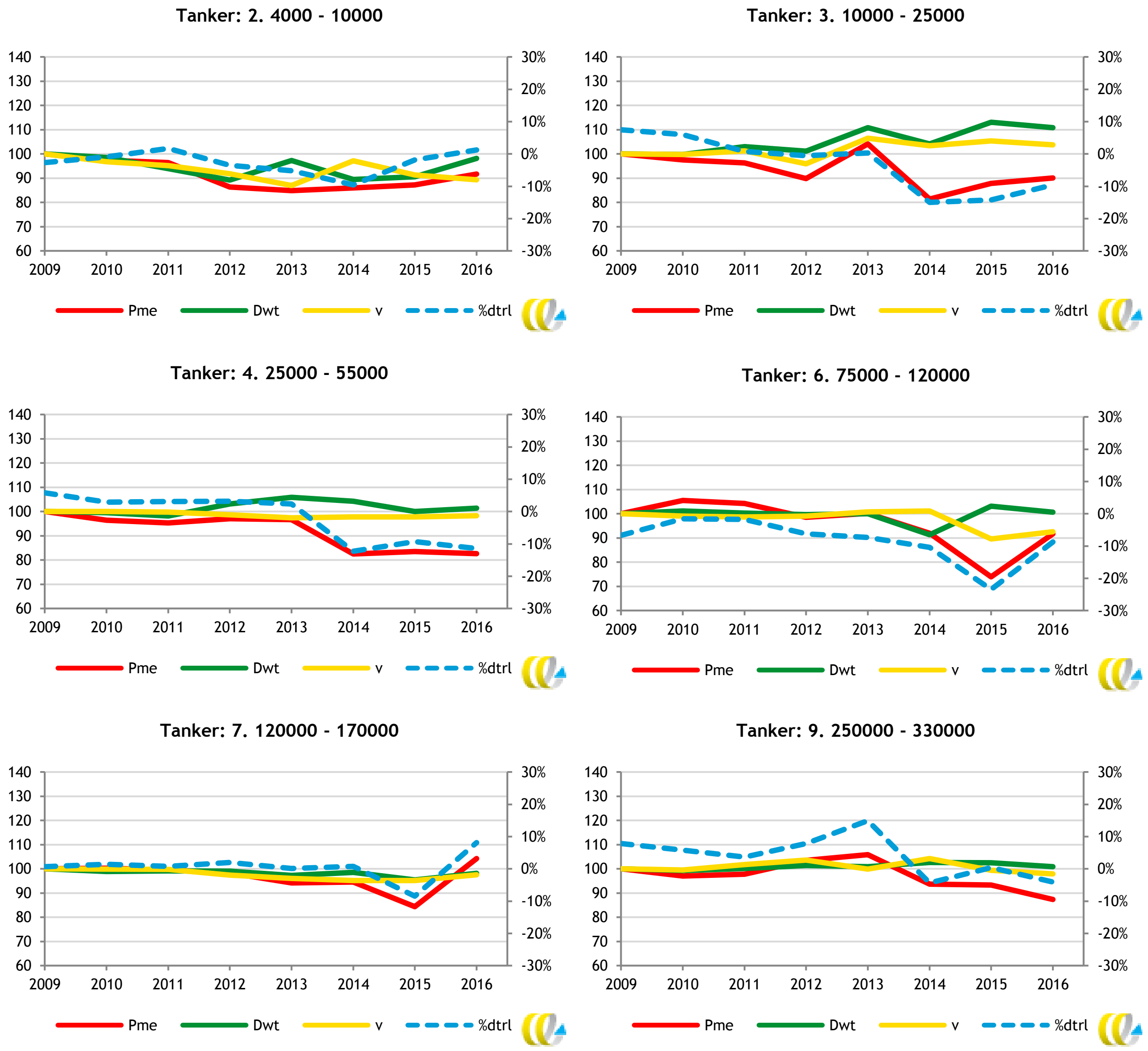
Variable	Built	2009	2010	2011	2012	2013	2014	2015	2016
EIV	Mean	9.0	9.0	8.7	10.1	8.5	8.3	7.4	6.3
%distance to the reference line	Mean	2%	2%	1%	0%	0%	-10%	-9%	-6%
	Median	2%	1%	1%	0%	1%	-14%	-11%	-10%
	Standard deviation	16%	17%	12%	16%	15%	17%	16%	20%
Ships	Total number	691	511	347	233	166	126	177	189
EIV under	With EIVs under reference line (in%)	43%	47%	46%	49%	46%	75%	72%	66%
Reference line	With EIVs 10% under reference line (in%)	15%	14%	15%	18%	16%	57%	56%	50%
	With EIVs 20% under reference line (in%)	4%	2%	2%	6%	6%	25%	26%	34%
	With EIVs 30% under reference line (in%)	1%	1%	0%	3%	3%	9%	7%	11%

Source: CE Delft.

Figure 6 analyses the design efficiency of new tankers for six size categories. For each size category, the average relative distance of the EIV of ships to the reference line has been calculated and the development of the factors that make up the EIV has been analysed (main engine power, ship capacity and speed).

Four out of six size categories have witnessed a deterioration of the EIV in 2016 relative to 2015, as indicated in Figure 6. Only in one case, this development has coincided with an increase in the average speeds, suggesting that hull and propeller efficiency have worsened. Tankers with a dwt between 120,000 and 170,000 had an average EIV that is 20% worse than in 2015.

Figure 6 Development in EIV, engine power, size and speed of Tankers 2009-2016 (2009=100)



Source: CE Delft.

Table 9 shows that the share of tankers with an estimated EEDI that meets Phase 2 or Phase 3 requirements has remained more or less constant in the last two years. Surprisingly, the share of tankers with an eEEDI below the reference line has decreased from over 90% to 72%. It appears that tankers with a design efficiency that just met the requirements have seen their efficiency deteriorate, while the efficient ships have remained as efficient as they were in 2015.

Table 9 Estimated EEDI for Tankers 2009-2016

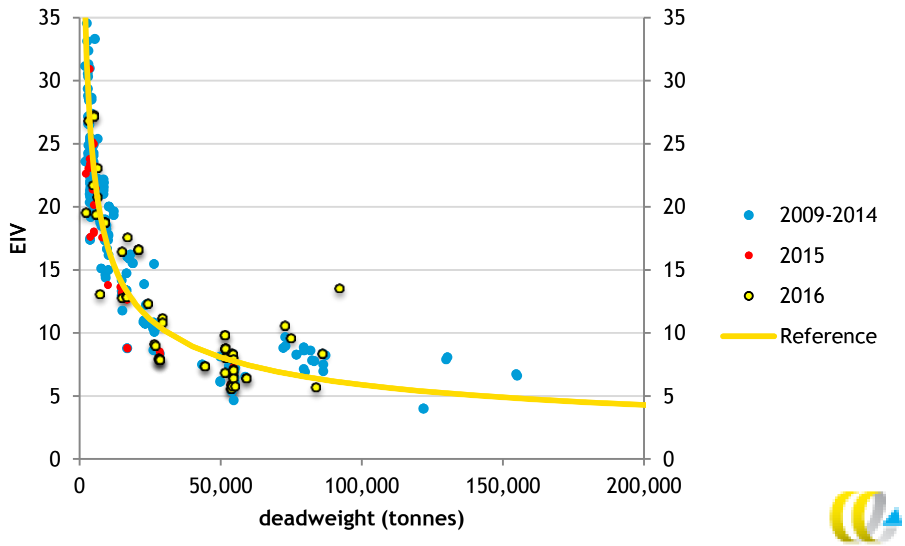
Variable	Built	2009	2010	2011	2012	2013	2014	2015	2016
eEEDI	Mean	8.1	8.1	7.8	9.1	7.6	7.4	6.7	5.7
%distance of the eEEDI to the reference line	Mean	-8%	-9%	-9%	-10%	-10%	-19%	-18%	-16%
	Median	-9%	-10%	-9%	-10%	-9%	-22%	-19%	-19%
	Standard deviation	14%	12%	11%	15%	13%	15%	14%	18%
Ships	Total number	691	508	347	233	166	126	177	189
eEEDI under	With eEEDI under reference line (in%)	81%	85%	85%	85%	87%	92%	92%	72%
Reference line	With eEEDI 10% under reference line (in%)	43%	48%	46%	49%	46%	75%	72%	66%
	With eEEDI 20% under reference line (in%)	12%	10%	12%	17%	15%	54%	49%	48%
	With eEEDI 30% under reference line (in%)	2%	2%	1%	6%	4%	24%	23%	23%

2.5 Gas Carriers

The Estimated Index Values of 381 gas carriers built in the years 2009-2016 have been calculated.

Figure 7 illustrates the outcome for each gas carrier. Deadweight tonnage is on the horizontal axis, the EIV on the vertical axis. Observations below the continuous yellow curve refer to vessels of which the EIV is better than the reference line; observations above the same curve imply that the design efficiency of these ships is worse than the reference line.

Figure 7 EIV of Gas carriers built in 2009-2016



Source: CE Delft.

Table 10 provides more detail on the EIV of gas carriers. While the mean and median EIV have been around the reference line values between 2009 and 2012, the last three years in our analysis show an improvement in the EIV values. 60% or more of the new gas carriers delivered in these years has an EIV below the reference line and in the last two years a quarter or more met Phase 2 requirements. The EEDI is in most cases lower than the EIV (see Section 1.4), so the number of ships with EEDI values better than the threshold is likely to be higher than the shares reported in Table 10.

Table 10 Descriptive statistics for Gas carriers 2009-2016

Variable	Built	2009	2010	2011	2012	2013	2014	2015	2016
EIV	Mean	12.9	16.1	20.1	22.2	17.3	17.5	14.3	11.6
%distance to the reference line	Mean	3%	2%	3%	5%	1%	-9%	-6%	1%
	Median	-4%	-1%	1%	1%	-5%	-13%	-7%	-4%
	Standard deviation	19%	18%	12%	13%	21%	16%	18%	26%
Ships	Total number	59	56	39	33	36	42	57	59
EIV under	With EIVs under reference line (in%)	54%	55%	36%	39%	58%	69%	68%	53%
Reference line	With EIVs 10% under reference line (in%)	22%	29%	5%	3%	25%	57%	39%	37%
	With EIVs 20% under reference line (in%)	12%	11%	3%	0%	11%	26%	26%	20%
Reference line	With EIVs 30% under reference line (in%)	0%	4%	3%	0%	6%	14%	7%	3%

Source: CE Delft.

The EEDI values reported in the interim Report of the Correspondence Group on EEDI review (MEPC 69/5/5) paint a more optimistic picture than this report as it claims that all ships meet Phase 2 requirements (which seems to be disproved by the graph, however). The main reason for the difference is probably the very different sample size. The small sample included in the analysis of the Correspondence Group on EEDI review may have a selection bias. The sample analysed here may include ships that are not required to have an EEDI either because they were not defined as a 'new ship' or because a waiver has been issued by the flag state. Another reason is the difference between the EEDI and the EIV (See Section 1.4).

Table 11 Estimated EEDI for Gas Carriers 2009-2016

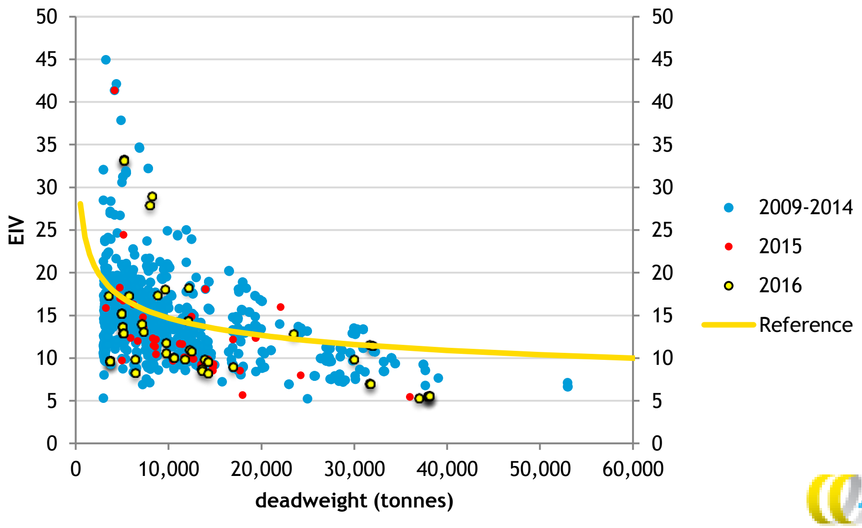
Variable	Built	2009	2010	2011	2012	2013	2014	2015	2016
eEEDI	Mean	11.6	14.5	18.1	20.0	15.6	15.7	12.8	10.4
%distance of the eEEDI to the reference line	Mean	-7%	-8%	-7%	-6%	-9%	-18%	-15%	-11%
	Median	-13%	-11%	-9%	-9%	-14%	-22%	-17%	-14%
	Standard deviation	17%	16%	11%	11%	18%	15%	16%	19%
Ships	Total number	59	56	39	33	36	42	57	58
eEEDI under	With eEEDI under reference line (in%)	69%	70%	82%	76%	78%	88%	88%	79%
Reference line	With eEEDI 10% under reference line (in%)	54%	55%	36%	39%	58%	69%	68%	53%
	With eEEDI 20% under reference line (in%)	19%	25%	5%	3%	25%	52%	35%	38%
	With eEEDI 30% under reference line (in%)	12%	9%	3%	0%	8%	17%	21%	21%

2.6 General Cargo Carriers

The Estimated Index Values of 1,542 general cargo carriers built in the years 2009-2015 have been calculated. Of these, at least 77 are likely to fall under the EEDI regulation because their contract date was on or after 1 January 2013 or their delivery date was on or after 1 July 2015 (see Chapter 4). The EEDI database contained information about 7 general cargo carriers subject to the EEDI requirements on 27 May 2015 (MEPC 69/5/5).

Figure 8 illustrates the outcome for each general cargo carrier. Deadweight tonnage is on the horizontal axis, the EIV on the vertical axis. Observations below the continuous yellow curve refer to vessels of which the EIV is better than the reference line; observations above the same curve imply that the design efficiency of these ships is worse than the reference line.

Figure 8 EIV of General cargo carriers built in 2009-2016



Source: CE Delft.

Table 12 provides more detail on the EIV of general cargo carriers. On average, general cargo ships have had EIVs below the reference line in every year since 2009. The share of ships below the reference line has increased from 70% to 89% with a deterioration between 2009 and 2011 and in general an improvement since. This same U-shaped pattern is visible for the share of ships under the reference line. Since 2013, there has been a marked increase in the share of ships that are more than 20% or more than 30% below the reference line. The EEDI is in most cases lower than the EIV (see Section 1.4), so the number of ships with EEDI values better than the threshold is likely to be higher than the shares reported in Table 12.

Table 12 Descriptive statistics for General cargo carriers 2009-2016

Variable	Built	2009	2010	2011	2012	2013	2014	2015	2016
EIV	Mean	14.5	14.7	14.5	13.7	13.1	13.3	12.2	12.7
%distance to the reference line	Mean	-10%	-6%	-5%	-10%	-9%	-9%	-18%	-15%
	Median	-11%	-9%	-6%	-13%	-15%	-13%	-27%	-24%
	Standard deviation	23%	27%	23%	20%	26%	30%	28%	39%
Ships	Total number	323	317	322	254	136	71	63	56
EIV under	With EIVs under reference line (in%)	70%	68%	61%	69%	79%	77%	87%	77%
Reference line	With EIVs 10% under reference line (in%)	50%	48%	44%	55%	63%	58%	68%	71%
	With EIVs 20% under reference line (in%)	28%	28%	21%	26%	28%	39%	59%	63%
	With EIVs 30% under reference line (in%)	20%	14%	12%	16%	20%	25%	38%	45%

Source: CE Delft.

Table 13 Estimated EEDI for General Cargo Carriers 2009-2016

Variable	Built	2009	2010	2011	2012	2013	2014	2015	2016
eEEDI	Mean	13.0	12.9	12.9	12.3	11.6	12.0	10.6	11.4
%distance of the eEEDI to the reference line	Mean	-19%	-16%	-15%	-19%	-19%	-18%	-28%	-23%
	Median	-20%	-18%	-16%	-22%	-24%	-22%	-35%	-32%
	Standard deviation	20%	21%	19%	18%	21%	27%	19%	35%
Ships	Total number	322	313	320	254	135	71	62	56
eEEDI under	With eEEDI under reference line (in%)	87%	85%	83%	84%	83%	82%	94%	86%
Reference line	With eEEDI 10% under reference line (in%)	70%	68%	62%	69%	79%	77%	89%	77%
	With eEEDI 20% under reference line (in%)	49%	47%	44%	54%	64%	56%	69%	71%
	With eEEDI 30% under reference line (in%)	27%	25%	19%	23%	27%	39%	60%	55%

2.7 Combination Carriers

Between 2009 and 2016, 4 combination carriers have been built according to Clarksons World Fleet Register. This number is too low to make a meaningful analysis.

3 Conclusions

The design efficiency of new ships has improved in recent years. The average EIV of container ships has decreased since 2011, bulk carriers and gas carriers started to decrease in 2013 and tankers in 2014. General cargo ships witnessed improvements in design efficiency in some years on average and deteriorations in other years.

However, the efficiency improvements seem to have stalled in 2016. On average, the design efficiency of new bulk carriers, tankers and gas carriers was worse in 2016 than they were in 2015. Also the share of ships below the reference line and the share of ships meeting or exceeding Phase 1, Phase 2 or Phase 3 required EEDI values has decreased in 2016. The design efficiency of container ships and general cargo carriers was more or less at the same level in 2016 as in 2015.

Note, however, that the changes in the average and mean design efficiency are small compared to the standard deviation, so that it is not possible to draw firm statistical conclusions.

It is surprising that many ships have EIVs well above the reference line in a year in which all new ships that entered the fleet needed to comply with Phase 0 or Phase 1 of the EEDI. This could be caused by the difference between the EIV and the EEDI or it could have been made possibly by relying on waivers for non-compliant ships.

Except for large container ships, design speed has not been a major contributor to changes in the EIV. In most cases, changes in the EIV coincided with changes in engine power that exceeded the change required for average changes in design speeds. This suggests that changes in hull and engine efficiency, and possible innovative technologies, have contributed to changes in the EIV.

The variation in the design efficiency of otherwise very similar ships (same ship type, similar size) is surprisingly large, in some cases more than a factor 3.

4 Refences

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Annex A Data

There were 14,565 ships built in 2009-2016 with a minimum dwt above the reference value (in accordance with MEPC.215(63)) (MEPC, 2012).

Ship type	Minimum dwt
Bulk Carrier	10,000
Combination carrier	4,000
Container ship	10,000
Gas carrier	2,000
General cargo ship	3,000
Tanker	4,000

The number of vessels of the six IHSF ship types included in the calculation of reference lines built in the period 2009-2016 is 11,430. For 3,135 ships that fulfilled the minimum deadweight criterion for their ship type insufficient data was available to calculate the EIV.

Ships that were included in the analysis were Bulk carriers (49%), Container ships (13%), Gas Carriers (3%), General Cargo Ships (13%) and Tankers (21%). 17% of the ships were built in 2009, 18% in 2010, 18% in 2011, 15% in 2012, 10% in 2013, 8% in 2014 8% in 2015 and 6% in 2016.

There are some differences in the database compared to the EIV study of 2016 (CE Delft, 2016), mainly because the data in the Clarksons database has been updated.

Figure 9 Data from Clarksons World Fleet register used in this study 2009-2016

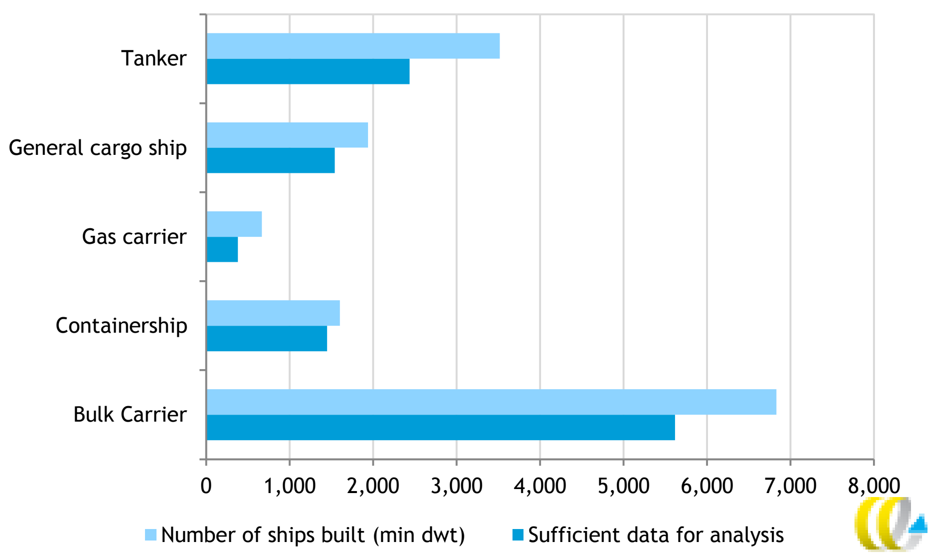

Figure 9 shows the ships that were built in 2009-2016 with a minimum deadweight corresponding with the ship types.