MARINE ENVIRONMENT PROTECTION COMMITTEE
69th session
Agenda item 5

MEPC 69/INF.29
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AIR POLLUTION AND ENERGY EFFICIENCY

Estimated Index Values of Ships 2009-2015: An analysis of the design efficiency of ships that have entered the fleet since 2009

Submitted by Clean Shipping Coalition (CSC)

SUMMARY

Executive summary:	The attached study uses the Estimated Index Value (EIV) to investigate trends in the design efficiency of ships built between 2009 and 2015 and the factors that are contributing to changes in these trends and the underlying EIVs. The study finds that amongst ships built in recent years there are at least 20% which have an EIV 20% below the EEDI reference line; the percentages for general cargo ships and containers are 40% and 60%, respectively. The study further concludes that the most important factor in improving EIVs is better ship design.
Strategic direction:	7.3
High-level action:	7.3.1
Output:	No related provisions
Action to be taken:	Paragraph 5
Related documents:	MEPC 68/INF.25, MEPC 68/3/27; MEPC 69/INF.9 and MEPC 69/5/5

Introduction

1 In 2015 CE Delft carried out a study for CSC members Seas at Risk and Transport & Environment which analysed how the design efficiency of new ships has changed based on a simplified version of the EEDI called the EIV. The study included ships built between 2009 (the first year that ship EIV values were not included in the calculation of the EEDI reference line) and mid-2014 (the last data available for inclusion in the study). That report was submitted to MEPC 68 (MEPC 68/INF.25).

2 By way of follow-up to that study, Seas At Risk & Transport & Environment commissioned the attached further study to:

.1 update the original study with ships that entered the fleet in the second half of 2014 and in 2015; and

.2 investigate the factors behind the changes to the EIV of ships over that time.

3 This new study finds that based on an analysis of EIVs, the average design efficiency of new ships has improved in recent years. The median EIVs of new ships are at least 10% better than the EEDI reference line for all ship types except for gas carriers. Amongst the ships built in recent years, there are at least 20% which have an EIV that is more than 20% below the EEDI reference line. For general cargo ships, the share is 40% and for container ships, more than 60% are at least 20% below the reference line. Because the EEDI is usually lower than the EIV, it is likely that the share of ships that meet or exceed Phase 2 requirements must be larger. In all but one size category of ships, ships have been built that are more than 20% below the reference value.

4 Innovative technologies do not appear to have played a role in lowering the EIV. Speed reduction has contributed in some cases, but there are many ship types and size categories for which the average design speed had not decreased or has even increased even while the design efficiency improved. The most important factor appears to be better ship design. The ratio between the displacement and the engine power has improved over time, and a comparison of the most efficient ships with the least efficient ships shows that this is the most important factor for all ship types. The EIV analysis presented in the report supports a conclusion that innovative technologies are not required to meet the Phase 2 requirements and that the potential of innovative technologies and speed reductions have remained largely untapped in the current improvements in design efficiency.

Action requested of the Committee

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

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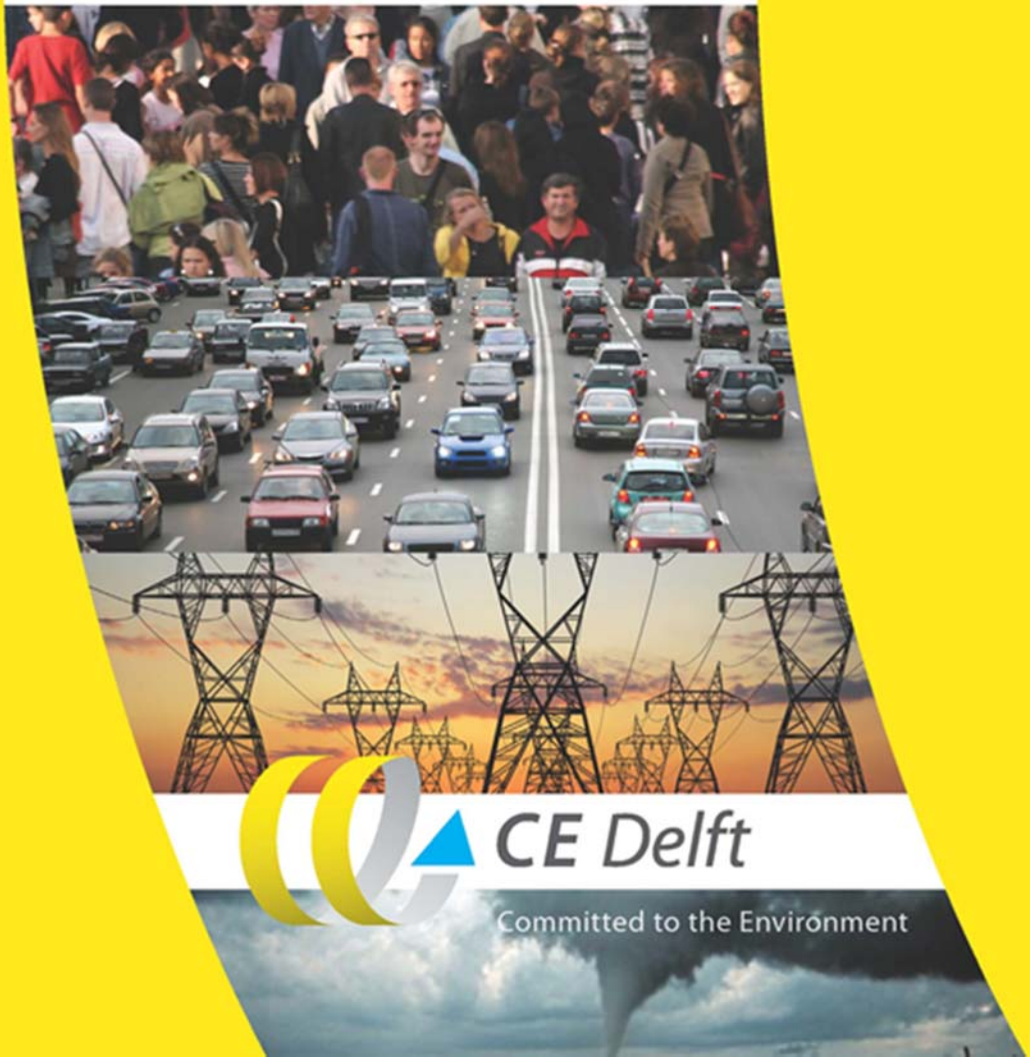
ANNEX

ESTIMATED INDEX VALUES OF SHIPS 2009-2015

Analysis of the design efficiency of ships that have entered the fleet since 2009

Estimated Index Values of Ships 2009-2015

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



CE Delft

Committed to the Environment

Estimated Index Values of Ships 2009-2015

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

This report is prepared by:
Jasper Faber
Maarten ‘t Hoen

Delft, CE Delft, February 2016

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FT: Update

Commissioned by: Seas At Risk and Transport & Environment

CE publications are available from www.cedelft.eu

Further information on this study can be obtained from the contact person, Jasper Faber.

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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 5 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.

The IMO maintains an EEDI database to which classification societies can voluntarily submit information. The number of ships in the database is about half of the number of ships that are required to have an EEDI.

This study analyses the development of the design efficiency of ships that have entered the fleet from 2009 to 2015. 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. The median EIVs of new ships are at least 10% better than the EEDI reference line for all ship types except for gas carriers. Amongst the ships built in recent years, there are at least 20% which have an EIV that is more than 20% below the reference line. For general cargo ships, the share is 40% and for container ships, more than 60% are at least 20% below the reference line. Because the EEDI is usually lower than the EIV, it is likely that the share of ships that meet or exceed Phase 2 requirements must be larger. In all but one size category of ships, ships have been built that are more than 20% below the reference value.

Innovative technologies do not appear to have played a role in lowering the EIV. Speed reduction has contributed in some cases, but there are many ship type and size categories for which the average speed had not decreased or had even increased even while the design efficiency improved. The most important factor appears to be better ship design. The ratio between the displacement and the engine power has improved over time, and a comparison of the most efficient ships with the least efficient ships shows that this is the most important factor for all ship types.

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.

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).

For 2013 and 2014, the EEDI of new ships cannot exceed the reference line; 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.

MEPC 67 decided to conduct a 2015 review of the status of technological developments relevant to implementing Phase 2 of the EEDI regulation as required under regulation 21.6 of MARPOL Annex VI. The Correspondence group submitted an interim report to MEPC 69 in which it presented an analysis of the EEDI of 192 ships. On the basis of this analysis and other considerations, the Group recommends that 'the time period, the EEDI reference line parameters for relevant ship types, and reduction rates set out in regulation 21 of MARPOL Annex VI should be retained' (MEPC 69/5/5, paragraph 32).

The number of ships that have entered the fleet since 2013 is much larger than the number of ships in the EEDI database (there is no obligation to report the EEDI value of new ships to the IMO, which maintains the database). This raises the question whether the conclusions of the Correspondence group also hold when all ships with an EEDI would be analysed.

1.2 How the EEDI regulation works

All ships built on or after 1 January 2013 need to have an EEDI, the so-called attained EEDI, which is better than the required EEDI. As mentioned above, 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	$107.48*(dwt)-^{-0.216}$
Combination carrier	$1219*(dwt)^{-0.488}$

Source: IMO.

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.

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: IMO, RESOLUTION MEPC 203(62).

1.3 Objectives

The objective of this study is to analyse development of design efficiency of ships that have entered the fleet since 2009.

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?
- Do ship types exist for which future EEDI limits are hard to achieve?
- What is the availability of reliable information?

1.4 Methodology

This study has calculated the EIV for ships that have entered the fleet between 2009 and 2015. 2009 was the first year after the period over which the reference lines have been calculated. 2015 was the last year available.

The EIV is given by the formula (MEPC.215(63):

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

In line with resolution MEPC.215(63) (MEPC, 2012), 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 containerships 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.

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 13% lower than the EIV (CE Delft, 2014).

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]

[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.

We have calculated the EIV for all ships that have entered the fleet between 1 January 2009 and 31 December 2015 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 in the WFR is not specified. 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
Containership	10,000
Tanker	4,000
Gas carrier	2,000
General cargo ship	3,000
Combination carrier	4,000

Outliers have also been excluded from the analysis. 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. In total, 21 ships out of 10,571 have been excluded on this ground.

1.6 Outline of the report

The next chapter analyses the design efficiency of five ship types:

– What share of ships of which the EIV meets or exceeds current and future EEDI limits? And how does this share vary over ship types and size categories?
– How have efficiency changes been realised?
– Do ship types exist for which future EEDI limits are hard to achieve?
– What is the availability of reliable information?

2 Design efficiency of ships 2009-2015

2.1 Introduction

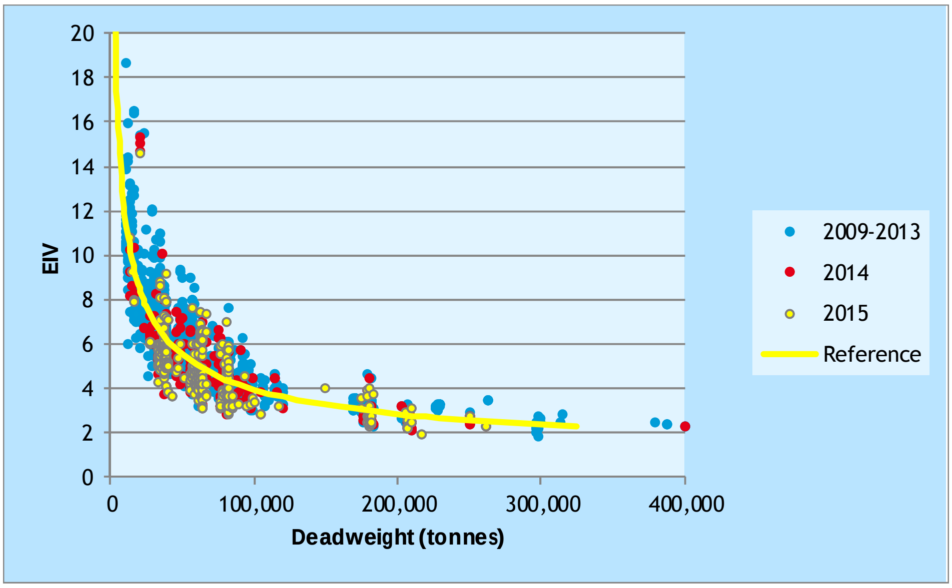
This chapter presents the development of the design efficiency of ships built between 2009 and 2015. It uses two measures for efficiency: the EIV and the distance of a ship's EIV to the reference line for that ship. The development is presented for bulk carriers (Section 2.2), containerships (Section 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. Section 2.8 presents our conclusions.

2.2 Bulk carriers

The Estimated Index Values of 5,237 bulk carriers built in the years 2009-2015 have been calculated. Of these, at least 714 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 128 bulk carriers subject to the EEDI requirements on 27 May 2015 (MEPC 69/5/5).

Figure 1 illustrates the outcome 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.

Figure 1 EIV of Bulk carriers built in 2009-2015



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 and 2015 have EIVs below the reference lines, about half meet the Phase 1 requirement and a quarter of the ships built in 2015 meet the 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 4.

Table 4 Descriptive statistics for bulk carriers 2009-2015

	Built year	2009	2010	2011	2012	2013	2014	2015
EIV	Mean	5.7	5.5	5.4	5.4	5.2	4.8	4.8
%distance to reference line	Mean	5%	6%	8%	6%	2%	-6%	-6%
	Median	6%	6%	8%	6%	-1%	-9%	-12%
	Standard deviation	12%	12%	12%	14%	16%	17%	20%
Number of ships	Total number	559	972	1,110	1,037	623	471	465
EIV under reference line	With EIVs under reference line (in %)	31%	29%	23%	34%	53%	74%	73%
	With EIVs 10% under reference line (in %)	10%	7%	8%	11%	24%	46%	56%
	With EIVs 20% under reference line (in %)	2%	1%	1%	2%	3%	17%	22%
	With EIVs 30% under reference line (in %)	0%	0%	0%	0%	0%	3%	6%

Source: CE Delft.

The EEDI values reported in the interim Report of the Correspondence Group on EEDI review (MEPC 69/5/5) paint a different picture than this report. Of the 128 ships with a compulsory EEDI, 50% are 20% or more below the reference line. 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.

Table 5 and Figure 2 analyse 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).

Table 5 shows that for most size categories, the average design efficiency has improved, sometimes after a deterioration in the first years of the analysis. The average distance to the reference line has only increased for the smallest category, between 10,000 and 25,000 dwt.

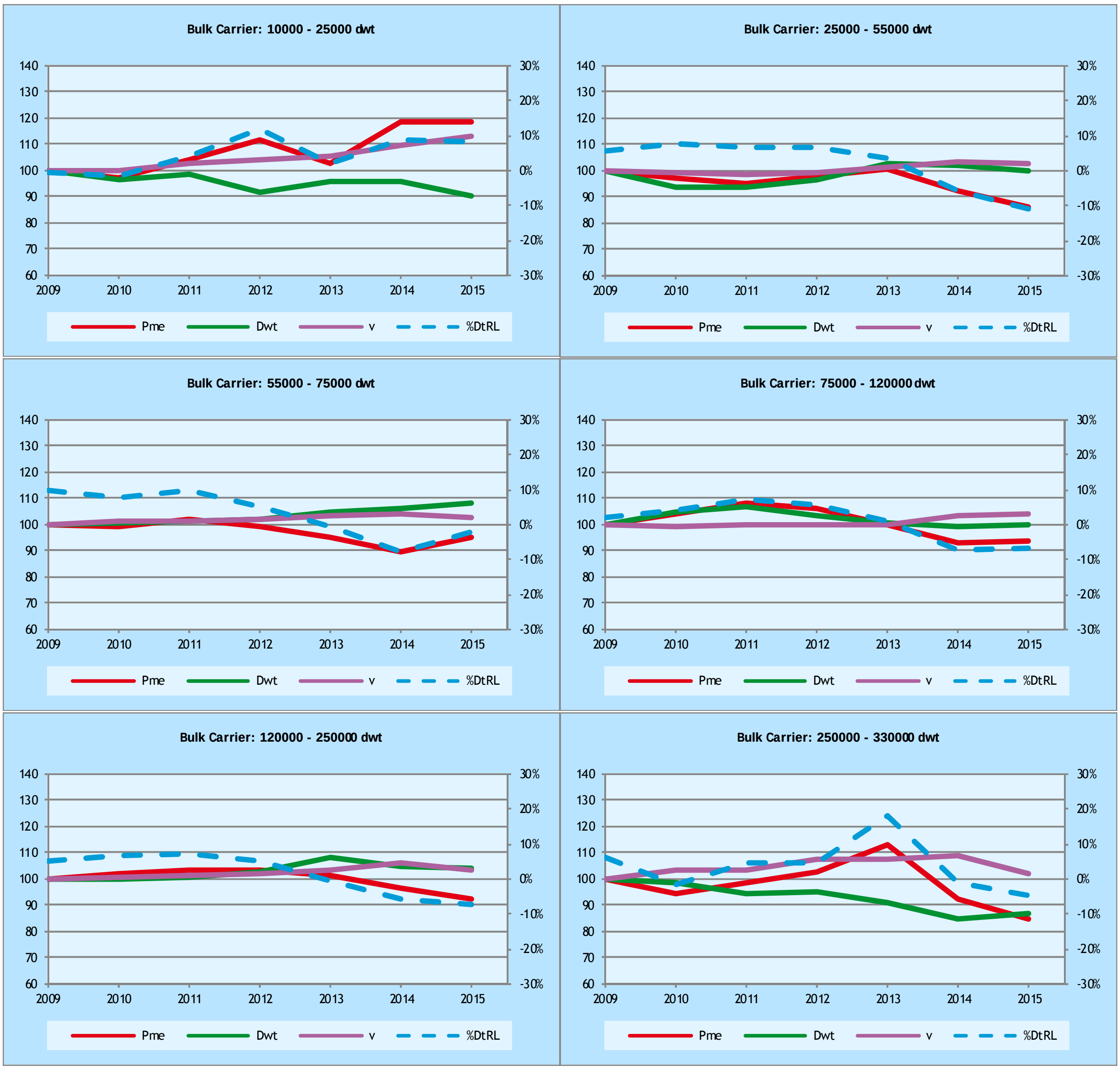
The main driver for the improvement of the EIV has been the reduction in main engine power. Interestingly, the speed of the ships has increased, which suggests that the hull efficiency, the propeller efficiency or the rudder efficiency have improved so that ships require less power to maintain a certain speed.

Table 5 Summary of development in EIV, engine power, size and speed of Bulk carriers, 2009-2015

Size (dwt)	EIV relative to reference line (DtRL)	Main engine power	Size	Speed	Remarks
10,000-25,000	+	+	-	+	
25,000-55,000	-	-	0	0	
55,000-75,000	-	-	+	0+	
75,000-120,000	+, -	+, -	0	+	
120,000-250,000	-	-	+	+	
250,000-330,000	+, -	+, -	-	+	
> 300,000					Too few ships built in 2009-2015 (only 26 of which 20 in 2012-2013)

Source: CE Delft.

Figure 2 Development in EIV, engine power, size and speed of Bulk carriers 2009-2015



Source: CE Delft.

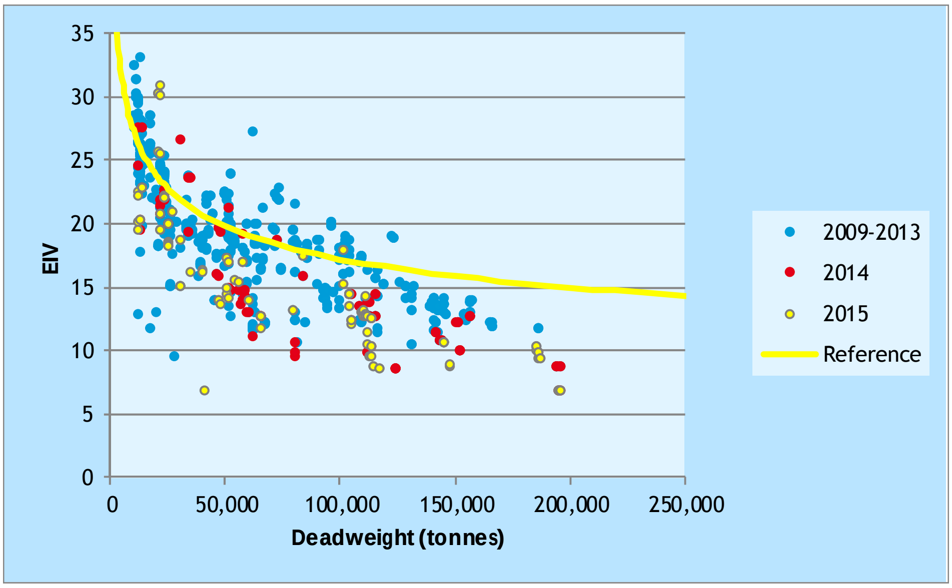
2.3 Containerships

The Estimated Index Values of 1,373 containerships built in the years 2009-2015 have been calculated. Of these, at least 206 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 14 containerships subject to the EEDI requirements on 27 May 2015 (MEPC 69/5/5).

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

Most containerships have EIVs below the reference line. 10 of the 11 ships of approximately 21,000 tonnes deadweight with EIVs above the reference line belong to one shipping company.

Figure 3 **EIV of Containerships built in 2009-2015**



Source: CE Delft.

Table 6 provides more detail on the EIV of containerships. 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 2015 have EIVs below the reference lines, while 60% of the ships built in 2014 and 2015 meet the Phase 2 requirements and 36% Phase 3 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 6.

Table 6 **Descriptive statistics for Containerships 2009-2015**

		2009	2010	2011	2012	2013	2014	2015
EIV	Mean	20.2	19.2	17.7	18.2	15.6	14.6	15.3
%distance to reference line	Mean	-2%	-3%	-8%	-9%	-19%	-23%	-22%
	Median	-2%	-1%	-8%	-12%	-22%	-24%	-24%
	Standard deviation	10%	10%	13%	15%	15%	16%	19%
Number of ships	Total number	259	255	181	195	194	151	138
EIV under reference line	With EIVs under reference line (in %)	63%	58%	66%	73%	87%	93%	91%
	With EIVs 10% under reference line (in %)	16%	22%	43%	53%	73%	83%	86%
	With EIVs 20% under reference line (in %)	7%	6%	17%	18%	51%	60%	64%
	With EIVs 30% under reference line (in %)	2%	1%	6%	10%	26%	36%	36%

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. Of the 14 ships with a compulsory EEDI, all are 20% or more below the reference line and at least 8 are more than 30% below the reference line. 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.

Table 7 and Figure 4 analyse the design efficiency of new containerships 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).

Table 7 shows that for most size categories, the average design efficiency has improved, although the average EIV for ships between 15,000 and 30,000 built in 2015 is higher than the reference line as a result of 11 ships with a very high EIV.

The main driver for the improvement of the EIV has been the reduction in main engine power. For containerships, this has coincided with a decrease in speed.

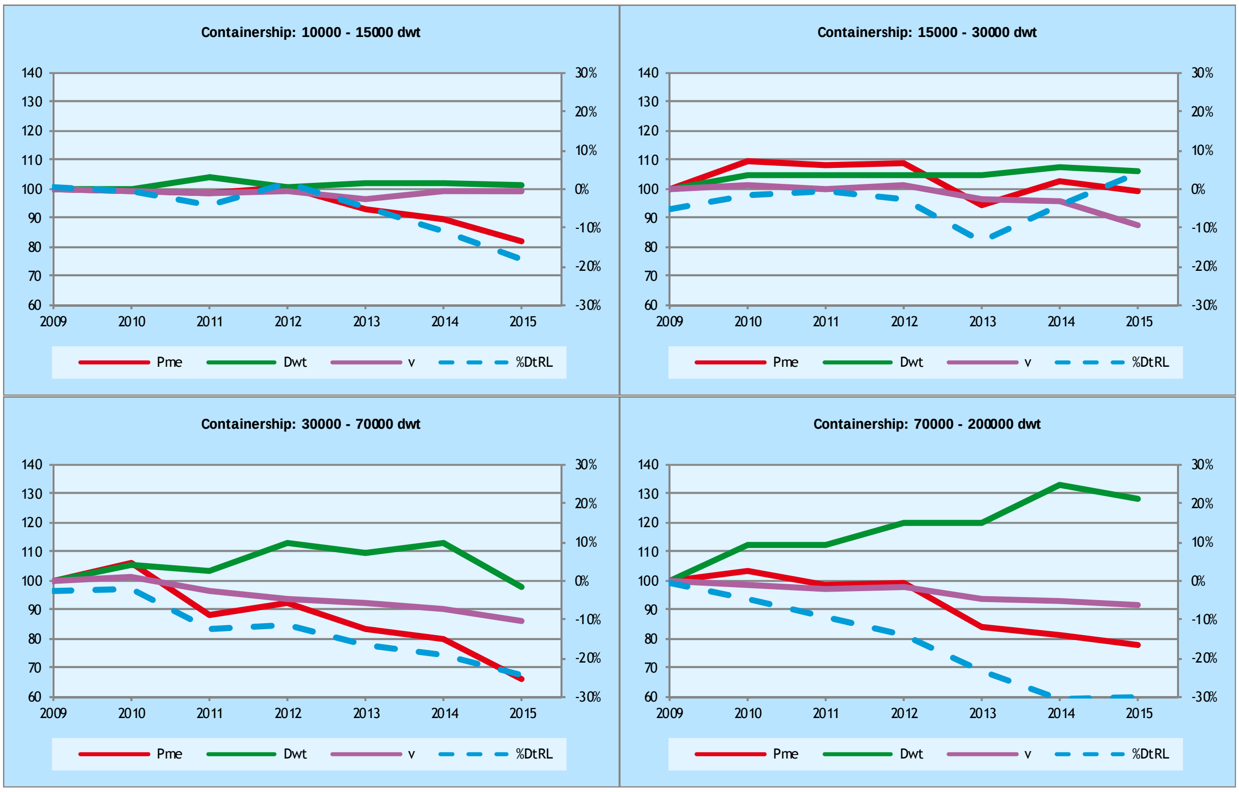
Table 7 Summary of development in EIV, engine power, size and speed of Containerships, 2009-2015

Size (dwt)	Size (TEU)	EIV relative to reference line (DtRL)	Main engine power	Size	Speed	Remarks
10,000-15,000	750-1,100	-	-	0	0	
15,000-30,000	1,100-2,200	-, +	+, 0	+	-	
30,000-70,000	2,200-5,500	-	-	+, 0	-	
70,000-200,000	5,500-20,000	-	-	+	-	

Source: CE Delft.

Note: The TEU capacity is not a factor in the EEDI formula and is presented here for clarification only.

Figure 4 Development in EIV, engine power, size and speed of Containerships 2009-2015



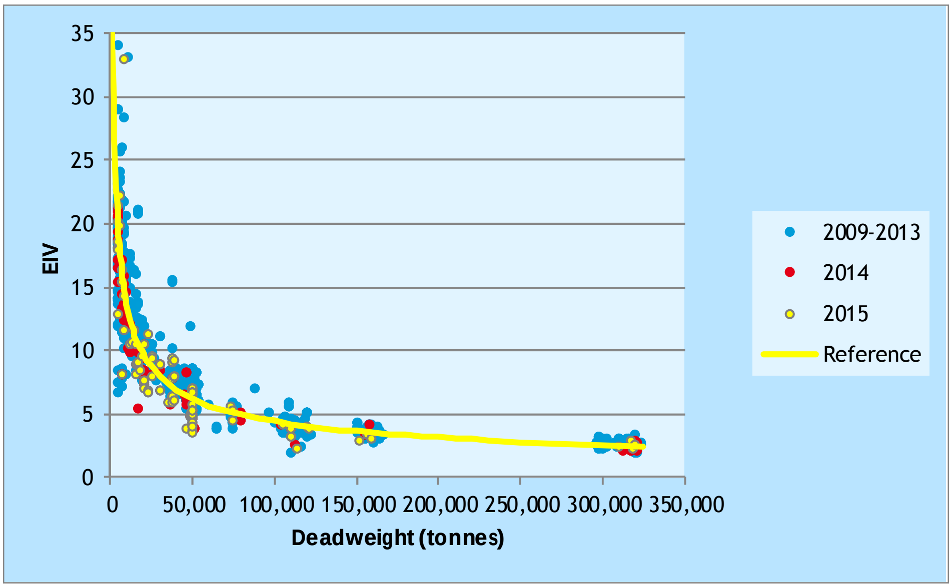
Source: CE Delft.

2.4 Tankers

The Estimated Index Values of 2,210 tankers built in the years 2009-2015 have been calculated. Of these, at least 140 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 26 tankers subject to the EEDI requirements on 27 May 2015 (MEPC 69/5/5).

Figure 5 illustrates the outcome for each containership. 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 2009-2015



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, the last two years in our analysis show an improvement in the EIV values. 70% or more of the new ships delivered in these years has an EIV below the reference line, more than half meet the Phase 1 requirements and almost a quarter 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 8.

Table 8 Descriptive statistics for Tankers 2009-2015

		2009	2010	2011	2012	2013	2014	2015
EIV	Mean	9.0	8.9	8.7	10.2	8.1	8.0	7.3
%distance to reference line	Mean	2%	1%	1%	0%	-1%	-11%	-8%
	Median	2%	0%	1%	0%	0%	-13%	-11%
	Standard deviation	15%	13%	12%	16%	15%	16%	16%
Number of ships	Total number	691	505	345	227	155	119	168
EIV under reference line	With EIVs under reference line (in %)	43%	48%	46%	49%	50%	74%	70%
	With EIVs 10% under reference line (in %)	15%	14%	15%	19%	17%	56%	56%

		2009	2010	2011	2012	2013	2014	2015
	With EIVs 20% under reference line (in %)	3%	2%	2%	7%	6%	24%	24%
	With EIVs 30% under reference line (in %)	1%	1%	0%	3%	3%	9%	7%

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. Of the 26 ships with a compulsory EEDI, 88% already meet Phase 2 requirements (20% or more below the reference line). 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 9 and Figure 6 analyse 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).

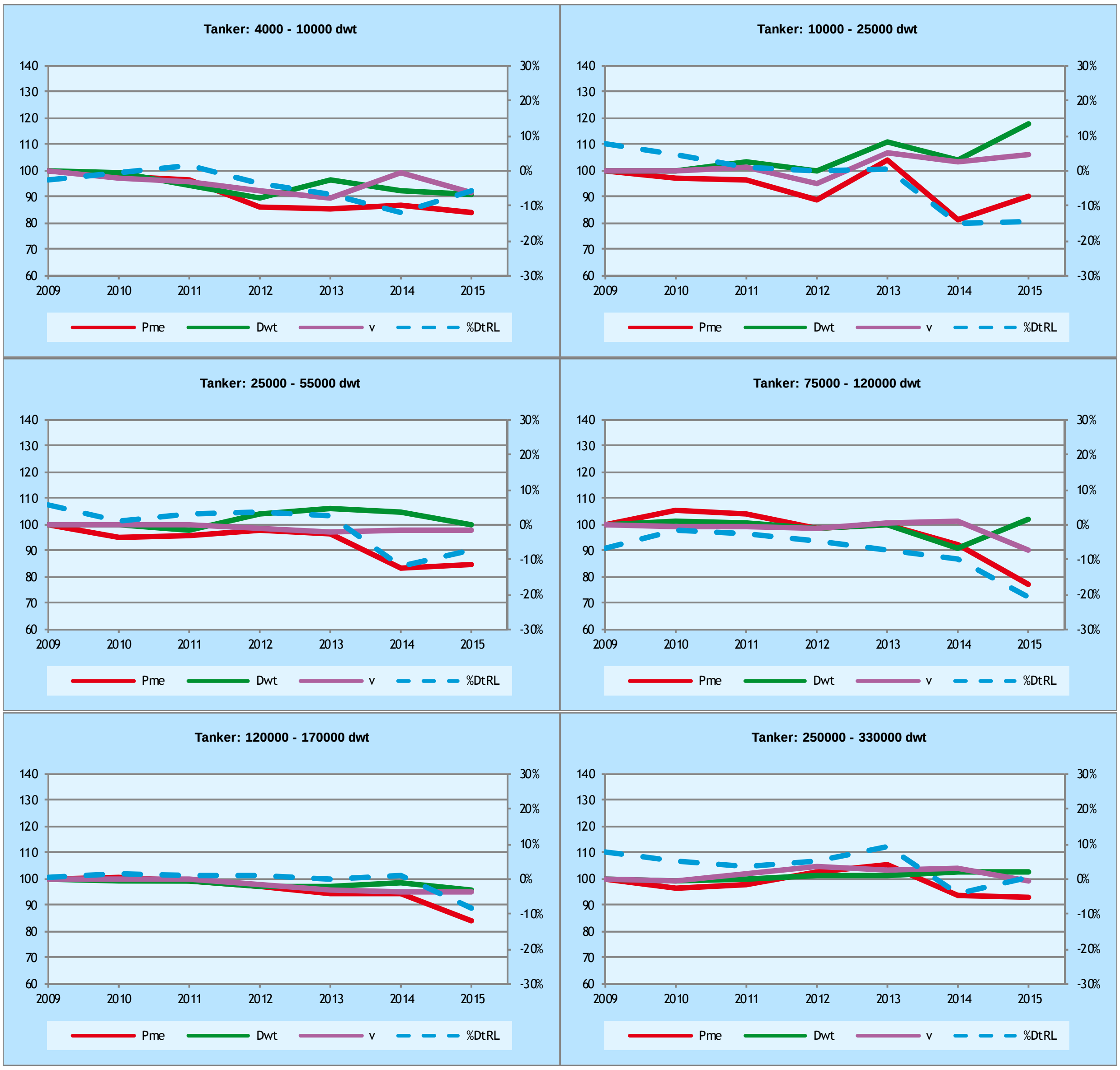
Four size categories has witnessed an improvement in the EIV, as indicated in Table 9. The smallest ships have seen their EIV increase while the largest ships have EIVs that are on average at the reference line. Main engine power has decreased in all size categories. This has sometimes, but not always, coincided with reductions in the average speed. In other cases, the average speed has increased or remained the same. Tankers with a capacity between 55,000 and 75,000 dwt are the only size category in this report in which no ships were built that are 20% or more below the reference line.

Table 9 Summary of development in EIV, engine power, size and speed of Tankers, 2009-2015

Size (dwt)	EIV relative to reference line (DtRL)	Main engine power	Size	Speed	Remarks
4,000-10,000	-, +	-	-	-	
10,000-25,000	-	-	+	+	
25,000-55,000	-	-	+, 0	0	
55,000-75,000	N/a				Very few ships built in 2012-2015
75,000-120,000	-	-	0	0, -	
120,000-170,000	0-	0-	0	-	
170,000-250,000	N/a				No ships built in 2009-2015
250,000-330,000	0	0	0	0	

Source: CE Delft.

Figure 6 Development in EIV, engine power, size and speed of Tankers 2009-2015



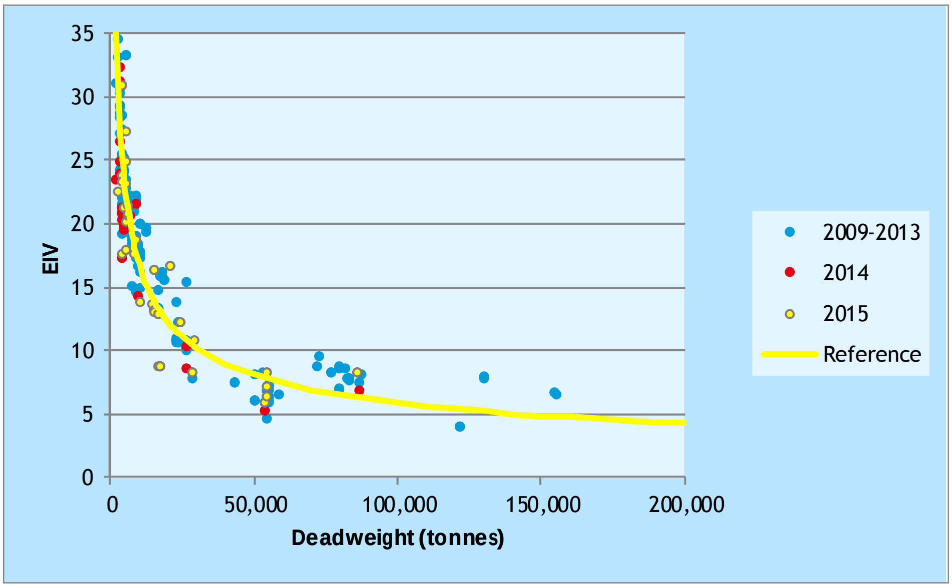
Source: CE Delft.

2.5 Gas Carriers

The Estimated Index Values of 311 gas carriers built in the years 2009-2015 have been calculated. Of these at least 120 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 ships subject to the EEDI requirements on 27 May 2015 (MEPC 69/5/5).

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 2009-2015**



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 ships delivered in these years have 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 2009-2015**

		2009	2010	2011	2012	2013	2014	2015
EIV	Mean	13.0	16.0	19.9	22.2	17.1	17.5	14.8
%distance to reference line	Mean	3%	3%	3%	5%	0%	-9%	-4%
	Median	-4%	-1%	1%	1%	-5%	-11%	-6%
	Standard deviation	19%	18%	12%	13%	20%	16%	19%
Number of ships	Total number	58	55	39	33	35	42	49
EIV under reference line	With EIVs under reference line (in %)	55%	53%	36%	39%	60%	71%	61%
	With EIVs 10% under reference line (in %)	22%	27%	5%	3%	26%	55%	39%
	With EIVs 20% under reference line (in %)	12%	11%	3%	0%	11%	26%	31%
	With EIVs 30% under reference line (in %)	0%	4%	3%	0%	6%	14%	8%

Source: CE Delft.

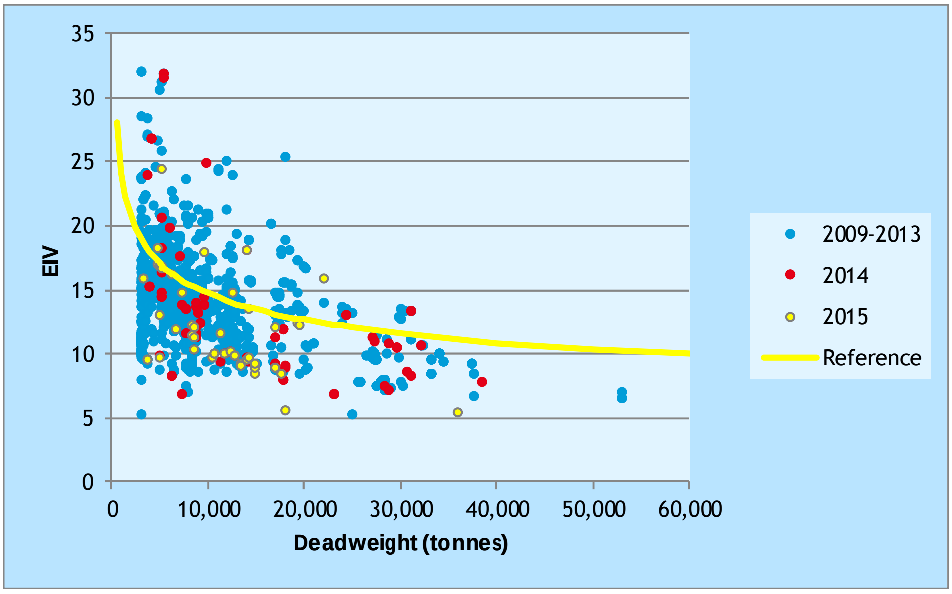
The EEDI values reported in the interim Report of the Correspondence Group on EEDI review (MEPC 69/5/5) paint a more optimistic picture than this report as it claims that all ships meet Phase 2 requirements (which seems to be disproved by the graph, however). The main reason for the difference is probably 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).

2.6 General Cargo Carriers

The Estimated Index Values of 1,466 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 2009-2015



Source: CE Delft.

Table 11 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 11.

Table 11 Descriptive statistics for General cargo carriers 2009-2015

		2009	2010	2011	2012	2013	2014	2015
EIV	Mean	14.4	14.4	14.4	13.8	12.9	13.3	12.1
%deviation from reference line	Mean	-10%	-7%	-5%	-9%	-11%	-9%	-19%
	Median	-11%	-9%	-6%	-13%	-15%	-13%	-26%
	Standard deviation	22%	24%	21%	20%	23%	30%	21%
Number of ships	Total number	322	308	322	253	134	71	56
EIV under reference line	With EIVs under reference line (in %)	70%	68%	61%	68%	80%	77%	89%
	With EIVs 10% under reference line (in %)	51%	47%	44%	55%	64%	58%	66%
	With EIVs 20% under reference line (in %)	28%	28%	21%	26%	28%	39%	57%
	With EIVs 30% under reference line (in %)	20%	14%	12%	16%	20%	24%	38%

Source: CE Delft.

2.7 Combination Carriers

Between 2009 and 2015, 4 combination carriers have been built according to Clarksons World Fleet Register. This number is too low to make a meaningful analysis.

2.8 Conclusions

The analysis shows an improvement in the mean and average EIV for all ship types, especially in the last years. Across all ship types, one fifth or more of ships built in the last years have EIVs that are 20% or more below the reference line. Their EEDI can be expected to be even further below the reference line. And while the share of ships below the reference line is not constant across all size ranges, there are ships that have EIVs at least 20% below the reference lines in all ship type and size categories analysed here.

In most ship type and size categories, the improvements in the average EIV have coincided with a decrease in the average engine power. For bulkers, the reduction of the main engine power occurred when average speeds remained constant or increased somewhat. Tankers have, on average, a speed that is a few percent lower than in 2009. The speed reduction for containerships has been larger. In most size categories, containerships built in 2014 and 2015 had a speed that was on average about 10% lower than in 2009 and 2010.

3 Drivers for efficiency changes

3.1 Introduction

This chapter analyses how changes in the EIV have been realised. It analyses specifically three issues:
1. The extent to which changes in speed have contributed to changes in the EIV, and how the speed of the ships with the best EIV compare with the speed of the ships with the worst EIV. This is analysed in Section 3.2.
2. The extent to which changes in hydrodynamic design of ships have contributed to changes in the EIV. This is the subject of Section 3.3.
3. The extent to which innovative technologies have contributed to changes in the EIV. This is the subject of Section 3.4.

3.2 Reductions in design speed

According to the EIV formula, a higher design speed should result in a lower EIV if all other factors were constant. However, since the main engine power is approximately proportional with the third power of the speed for a given hull form, main engine power and speed cannot be chosen independently. As a result, a 1% higher design speed results in a 3% higher main engine power and hence a 2% higher EIV.

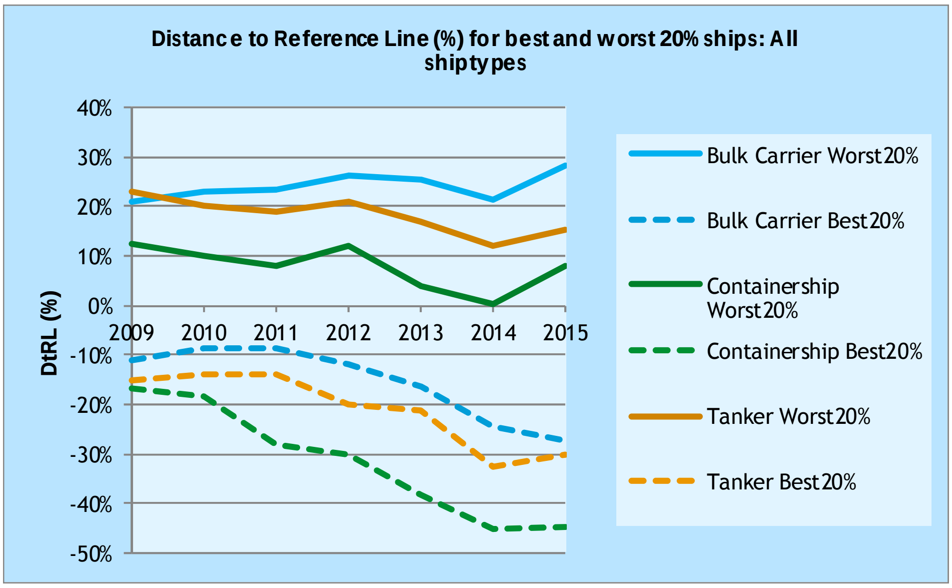
Chapter 2 has shown that in most cases in which the EIV has improved over time, the power of the main engine has decreased. In some cases, this coincided with a decrease in design speed, in other cases, however, it coincided with no changes in the average design speed or even with an increase in design speed. This section applies a different method to analyse the importance of design speed.
- It first calculates the EIV for each ship and determines its relative distance to the applicable reference line.
- Second, it ranks all the ships of a certain type by the relative distance to the reference line. The ships that are relatively far above the reference line are labelled worst ships and the ships that are relatively far below the reference line are labelled best ships.
- Third, it compares the distance to the reference line of the 20% best ships with the 20% worst ships.
- Fourth, it repeats this analysis for the speed and the deadweight.

The results are presented in Figure 9, and Figure 10. Figure 9 shows that the gap between the ships with the best EIV and those with the worst EIV has increased between 2009 and 2015. For all ship types, the best ships have seen their design efficiency improve, while the worst tankers and containerships have improved less and the worst bulk carriers have seen their design efficiency deteriorate.

Figure 10 shows that the speed has not followed the same pattern as the relative EIV scores. The average design speed of the most and least efficient bulk carriers and tankers is not very different. For containerships, the speed difference has increased over time. Interestingly, the most efficient bulk carriers and containerships had, on average, a *higher* design speed than the least efficient ships of the same type.

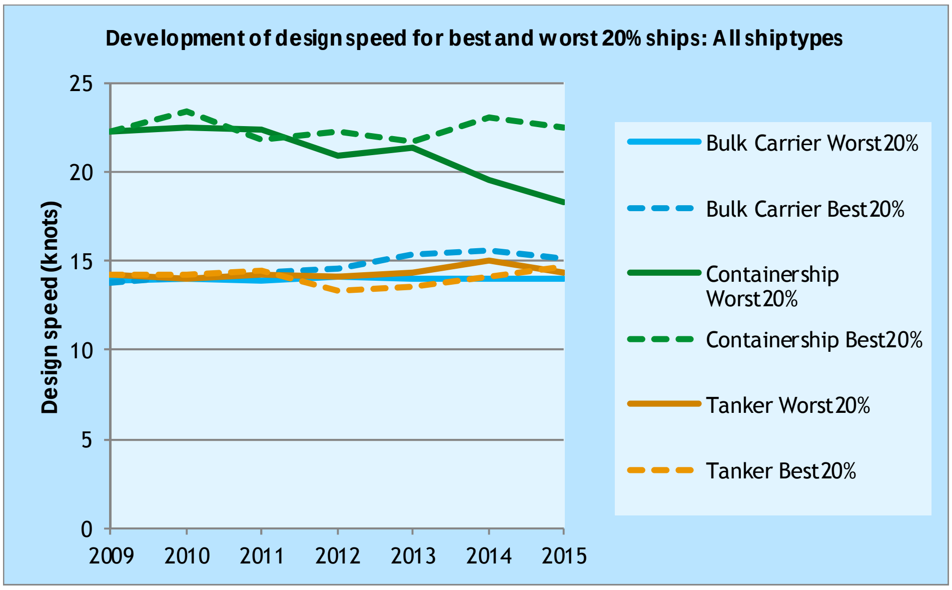
The unexpected effect of the design speed must be due to reductions in the ship resistance. Only when the resistance is reduced, is it possible to have faster ships with lower power. Section 3.3 looks into this relation in more detail.

Figure 9 Relative distance to the reference line of the best and worst ships



Source: CE Delft.

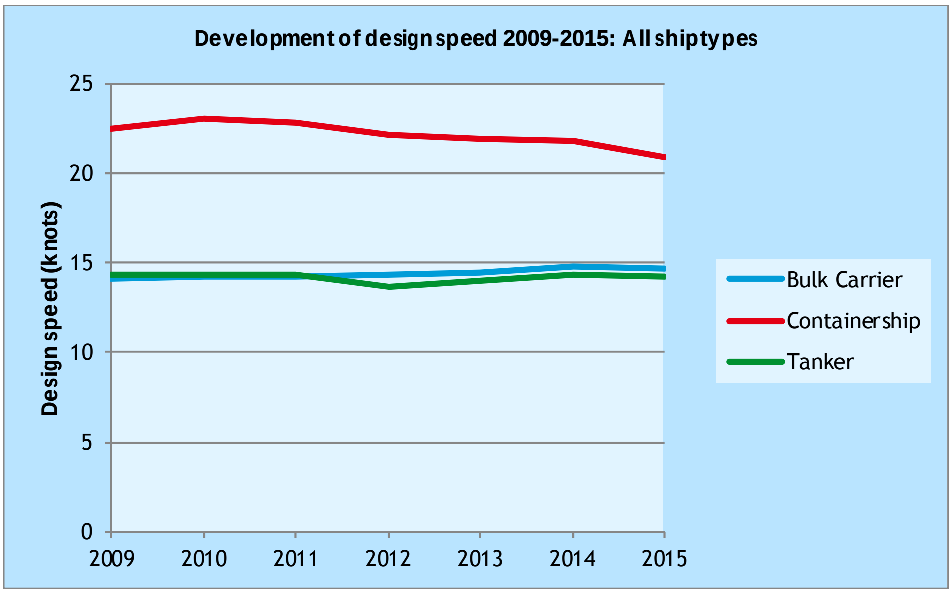
Figure 10 Design speed of the most and least efficient ships



Source: CE Delft.

Figure 11 confirms that the average design speed of bulk carriers and tankers has remained all but constant between 2009 and 2015. Only for containerships it has decreased (about 7%).

Figure 11 Average design speeds of new ships, 2009-2015



Source: CE Delft.

3.3 Ship resistance

The power of a ship is mainly used to overcome resistance and is proportional to the resistance and the speed. The resistance of a cargo ship when moving through the water is approximately proportional to the wetted surface area and the square of the speed. The wetted surface area can be calculated as the displacement to the power of 2/3. Using these relations, the so-called Admiralty coefficient can be defined as:

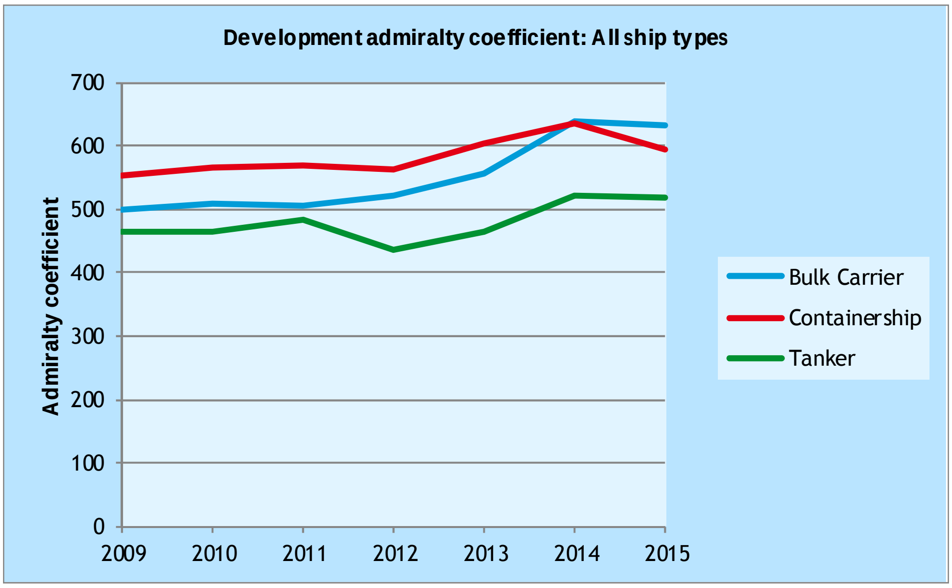
$$AC = \frac{\Delta^{2/3} v^3}{P_{ME}}$$

Where:
AC - the admiralty coefficient
Δ - the displacement of the ship
V - the speed of the ship
P_{ME} - de main engine power of the ship

For a given hull, AC is constant, while ships with a higher AC require less power to move through the water at the same speed and displacement and consequently are more efficient.

Figure 12 shows that the average admiralty coefficient of the three ship types under consideration has increased between 2009 and 2015. This was to be expected as it correlates with the improvement in the EIV.

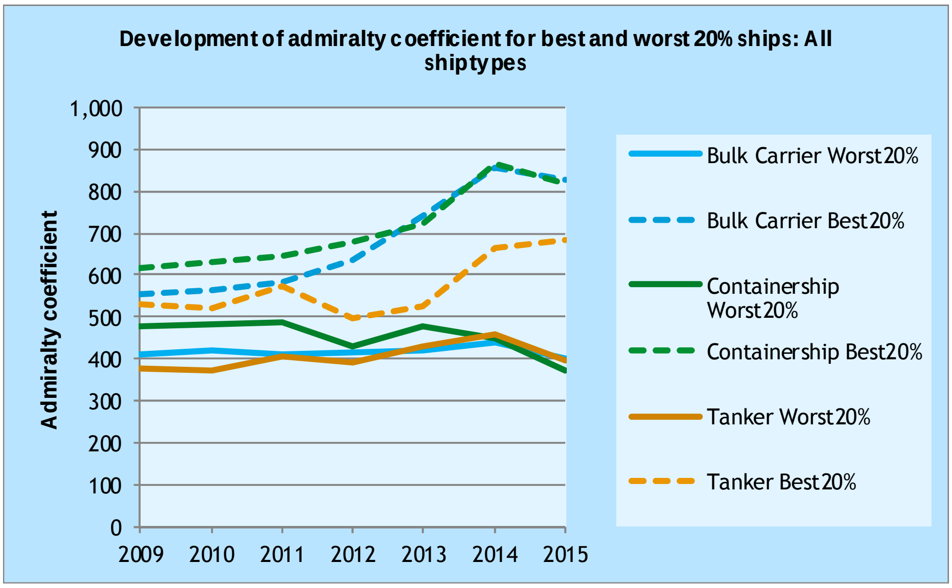
Figure 12 **Development of the average admiralty coefficient, 2009-2015**



Source: CE Delft.

Figure 13 shows that the admiralty coefficient of the 20% least efficient ships has, on average, remained constant or decreased over time. In contrast, the coefficient of the most efficient ships shows an increase between 2009 and 2015 for all ship types.

Figure 13 **Development of the admiralty coefficient of the most and least efficient ships, 2009-2015**



Source: CE Delft.

Section 3.2 concluded that, at least for tankers and bulk carriers, changes in design speed cannot explain the differences in design efficiency between the best and worst ships, nor the development of the design efficiency over time. The analysis of the admiralty coefficient shows that the other terms in the coefficient, i.e. ratio between displacement and power, distinguish the best ships from the worst ships. So the best ships have better hydrodynamic properties, most probably caused by better hull propeller and rudder designs.

3.4 Innovative technologies

The EIV does not account for the use of innovative technologies but the EEDI does. The information on innovative technologies is limited, however. In 2014, the EEDI database (MEPC 67/INF.4) did not include any ships that had used innovative technologies to meet the required EEDI. One year later, MEPC 69/5/5 has analysed the EEDI database and found that none of the ships which currently meet Phase 2 requirements (20% below the reference line) have used innovative technologies to do so.

The EIV analysis presented in this report supports the conclusion that innovative technologies are not required to meet the Phase 2 requirements: while the EIV does not account for the use of innovative technologies, and even though the EIV is generally higher than the EEDI, about a fifth of the ships built in 2014 and 2015 have an EIV that is better than the Phase 2 requirement. It is likely that the share of ships of which the EEDI meets Phase 2 requirements is even larger.

3.5 Conclusions

The evidence presented in this chapter suggests that the design efficiency of tankers and bulkers can be improved considerably without reducing the design speed: the most efficient ships have approximately the same design speed but a much better EIV. This may not be true for containerships.

While some ship type and size categories seem to have improved their average design efficiency through speed reductions, there are also many examples where ship categories have improved their EIV while increasing speed or keeping speed constant. Hence, it cannot be concluded that improvements in design efficiency necessarily require design speed reductions. There is stronger evidence that design efficiency improvements have been achieved through better ship design. The admiralty coefficient suggests that the ratio of displacement and main engine power has improved over time, and that the ratio is better for the most efficient ships than for the least efficient ships. The differences cannot be accounted for by differences in speed or size, at least for bulk carriers and tankers.

These findings suggest that the potential of innovative technologies and speed reductions have remained largely untapped in the current improvements in design efficiency.

4 The EEDI database

MEPC 66 established an EEDI database, maintained by the IMO Secretariat, that records (MEPC 66/21):

1. type of ship;
2. capacity of ship (GT/DWT as appropriate);
3. year of delivery;
4. applicable Phase;
5. required EEDI;
6. attained EEDI; and
7. use of innovative energy efficiency technologies (tick-box indication of whether the fourth and fifth terms of the numerator of the EEDI equation are employed).

IACS can submit information to the database on a voluntary basis.

As of 28 October 2015, the database contained information on 682 ships (MEPC 69/5/5). A report by the Secretariat on the database indicates 131 entries are from non-mandatory EEDIs, i.e. EEDIs of ships that were built before the EEDI became mandatory (MEPC 67/INF.4). Hence, the database contains at most 551 entries of ships with a mandatory EEDI.

According to Clarksons World Fleet register, a total of 1,165 ships were in service in February 2016 that had a contract date on or after 1 January 2013 and were over the size threshold for the EEDI (see Table 12). In addition, there were 65 vessels that had a contract date before 1 January 2015 but a delivery date on or after 1 July 2015 (Table 13).

Table 12 Number of ships larger with a contract date on or after 1 January 2013

Ship type	Minimum dwt	Number of ships
Bulk carriers	10,000	694
Containerships	10,000	194
Tankers	4,000	30 tankers 96 chemical tankers
Gas carriers	2,000	104
General Cargo carriers	3,000	74
Total		1,165

Source: Clarksons World Fleet Register, February 2016.

Table 13 Number of ships with a delivery date on or after 1 July 2015 a contract date before 1 January 2013

Ship type	Minimum dwt	Number of ships
Bulk carriers	10,000	20
Containerships	10,000	12
Tankers	4,000	7 tankers 7 chemical tankers
Gas carriers	2,000	16
General Cargo carriers	3,000	3
Total		65

Source: Clarksons World Fleet Register, February 2016.

There are three possible explanations for the difference between the number of ships in the EEDI database and the number of ships with a contract date on or after 1 January 2013:

1. A large number of ships may have entered the fleet between 28 October 2015 (the last date for which information from the IMO database is available) and February 2016 (the date the WFR was consulted). This may have had an impact but not a large one. When we consider bulk carriers alone, 563 out of 714 had a contract date on or after 1 January 2013 and had been delivered on or before 1 October 2015.
2. A large number of ships may have been issued a waiver. Administrations may waive the requirement to have an EEDI for ships that have a contract date before 1 January 2015. However, when they do so, they must inform the IMO which will circulate the information to Parties to Marpol Annex VI. We have no information that waivers have been granted and do not expect a large number of waivers because shipping organisations like BIMCO have cautioned shipowners against using waivers as this 'could impede the commercial exploitation of such ships'.[2]
3. Many ships with an EEDI are not included in the database, either because of late reporting or because of non-reporting.

This analysis suggests that the current system of voluntary reporting of EEDI values does not result in a database that is complete and up-to-date.

[2] https://www.bimco.org/About/Viewpoint/04_Greenhouse_Gases_and%20Market_Based_Measures.aspx

5 Conclusions

The design efficiency of new ships has improved in recent years. The average EIV of containerships 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.

Amongst the ships built in recent years, there are at least 20% which have an EIV that is more than 20% below the reference line. Because the EEDI is usually lower than the EIV, it is likely that the share of ships that meet or exceed Phase 2 requirements is larger than 20%. This is true for most size categories as well.

Increases in ship size have not played a major role in lowering the average design efficiency. The general trend towards a better design efficiency is also visible for most size classes of ships, and it can also be seen when not the EIV, but the distance of the EIV to the reference line is used as an indicator, thus removing the impact of size. Hence, the improvement is not the result of an increase in the average size of ships.

Speed reductions don't appear to have been the most important factor in improving design efficiency, although they have contributed in some cases. The average speed of tankers and bulkers has remained constant even while the average design efficiency has improved. A comparison of the most efficient ships with the least efficient ships also provides no indication that differences in design speeds have been important to improve the design efficiency. However, for some size categories of tankers and for containerships, improvements of design efficiency have coincided with decreases in design speed.

Ship design has been more important than speed or size in improving the design efficiency of ships. The average admiralty coefficient has increased over time for all ship types, which implies that for bulk carriers and tankers the ratio between displacement and engine power has improved, because the design speed has remained constant for these ship types. Also, the admiralty coefficient for the ships with the best design efficiency is much higher than for the worst ships.

The EEDI database contains only about half of all ships which are subject to the EEDI regulation.

Annex A Data

There were 13,224 ships built in 2009-2015 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
Containership	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 2009-2015 is 10,617. For 2,607 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%), Containerships (13%), Gas Carriers (3%), General Cargo Ships (14%) and Tankers (21%). 18% of the ships were built in 2009, 20% in 2010, 19% in 2011, 16% in 2012, 11% in 2013, 8% in 2014 and 8% in 2015.

Compared to the EIV study of 2015 (CE Delft, 2015) the number of ships included in the calculations for 2014 is higher in this study. This is because only the first half of 2014 was available in the last study. Other differences occur, mainly because the data in the Clarksons database has been updated.

Figure 14 Data from Clarksons World Fleet register used in this study 2009-2015

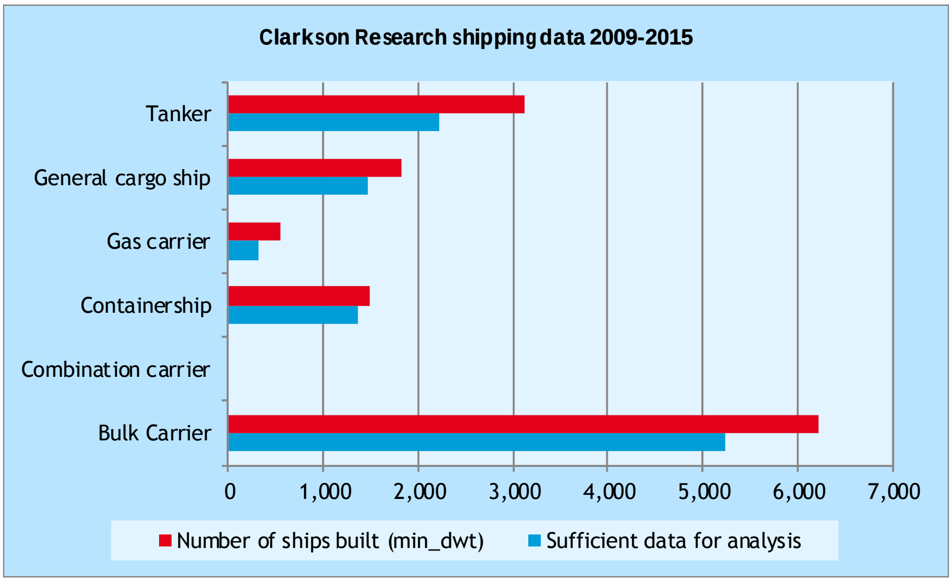


Figure 14 shows the ships that were built in 2009-2015 with a minimum deadweight corresponding with the ship types.