Are the new fuel-efficient bulkers a threat to the old fleet?

Jeroen Pruyn
Department of Maritime and Transport Technology, Delft University of Technology, Delft, The Netherlands

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Abstract

Purpose – The purpose of this paper is to investigate whether the headlined eco-bulkers ordered in 2012 and 2013 are posing a threat to the less-efficient ships ordered at the end of the boom in 2008 and 2009.

Design/methodology/approach – This paper will first investigate the drivers for the interest in such low-emission, low-speed bulker as well as the more general history of bulker designs. This is followed by a study on the vessels delivered between 2005 and 2014, based on eight parameters representing fuel efficiency, speed and hydromechanics properties. Within these results, evidence is sought for a significant change in the qualities of the vessels delivered after the last boom.

Findings – The data showed that at least till present, no significant changes could be discovered between 2014 and the earlier years. This indicates that either because of the long delivery times at the end of the boom, such vessels are still to be delivered, or that they were not ordered in an amount large enough to change the trend. For the future, this fact and the changes in vessel design resulting from the introduction of the energy efficiency design index (EEDI) in 2017 and the large fluctuations in the fuel prices will be interesting to keep monitoring the developments in the eight studied parameters.

Originality/value – This paper extends (in time) and improves (number of variables studied) a number of earlier studies on average qualities of the world fleet. It studies both the composition and the changes in average properties of the ships produced each year. It allowed the author to discover and explain the trends that would not have been evident when studying ships as single units or as the result of a business opportunity optimisation. Most important of which is the fact that, on average, ships produced are optimised for the current economic conditions and are not taken into consideration for future trends and scenarios.

Keywords Dry bulkers, Ecologic design, EEDI, Fleet development, Newbuilding development

Paper type Research paper

Introduction

In 2012 and 2013, a number of articles in various newspapers (gcaptain, 2013; MTI, 2014; S and B, 2013; Ship and Offshore, 2012; Tradewinds, 2013; Ultrabulk, 2012; WMN, 2013) were discussing eco-designed bulk carriers. These bulkers would have much lower fuel consumptions and would reach the same speed or at least the current economic speed. At that time, bunker prices were extremely high, on an average of US$600-700 per ton for heavy fuel oil (Bunkerindex, 2015) (Figure 1). Also as the result of the crisis freight rates were quite low, making savings on fuel was a key element in competitiveness. At the same time, the bulker order book was decreasing at a high rate (UNCTAD, 2015) making yards eager for new orders (Figure 2). Finally, the IMO was discussing the introduction of the energy efficiency design index (EEDI) for new build vessels, together with emission control areas

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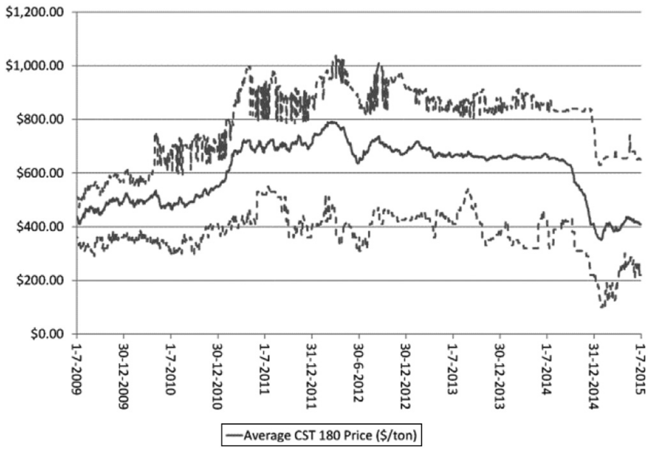
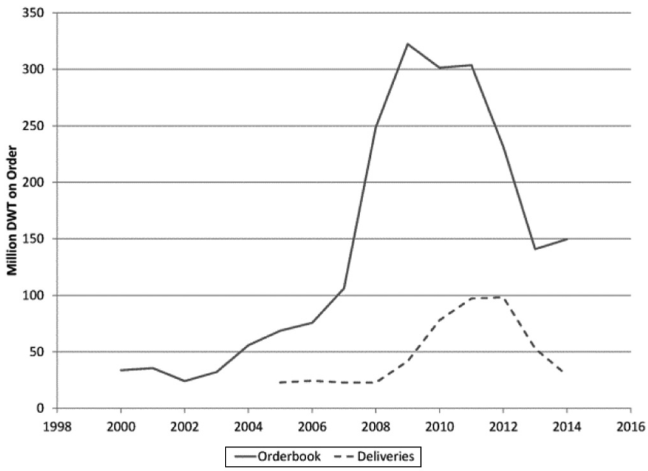


Source: Author based on Bunkerindex (2015)

Figure 1.
Bunker prices for the past five years

(ECAs) used to force the industry to focus on reducing greenhouse gas (GHG) emissions (Buhaug *et al.*, 2009; Smith *et al.*, 2014; Dulebenets, 2016).

The cheaper, both relative to the high-priced bulkers of the boom and in the operational aspect, eco-designed bulkers were, therefore, a recurring topic in newspapers. Taking into consideration a building time of 1-3 years, these new bulkers should be entering the market in 2014 and 2015. It is, therefore, a good moment to check if they are really such a danger to the existing fleet and most of all if they are the success number that the newspapers claimed they will be. This paper begins with investigating the existing design trends for bulk



Source: Author based on data from Traffic (2015), UNCTAD (2015) and Vesselfinder vessel information (2015)

Figure 2.
Order book and delivery development

carriers, followed by a section on the impact of the crisis. Then the effects of EEDI on vessel designs will be discussed. As both the crisis and EEDI induce slow steaming, a section will be devoted to the effects of this measure. This leads to a discussion on the actual eco-bulkers design features and costs. Finally, the vessels build in ten years from 2005 to 2014 will be studied to see the effects of the eco-designed vessels on the average qualities of the fleet of bulkers.

Historical trends in bulker design

As part of the International Maritime Organization's (IMO) research (Buhaug *et al.*, 2009) on GHG emissions from shipping, the historic emissions from shipping were researched (Endresen *et al.*, 2007) for the period 1925-2007. The emissions are based on fuel sales for the period 1925-2002 and on the estimation of fuel consumption for the period 2000-2007. An important conclusion is that the latter is very sensitive to the variable "days at sea", as this will highly influence the final fuel consumption. Endresen *et al.* was able to match the period 2000-2002 for both calculations by manipulating the days at sea variable.

Kristensen and Lützen (2012) researched tankers and bulkers delivered between 1990 and 2010. They looked at the EEDI values and the design parameters relevant for resistance (block coefficient, length-displacement ratio and Froude number) and concluded that these have deteriorated since the start of the last boom (2000-2009) in shipping. They assume that the economic benefit of transporting more cargo, even at higher fuel costs, was beneficial at that time. Faber and 't Hoen (2015) studied an estimation of the EEDI value for the three major ship types (tankers, bulkers and container vessels) for the period 1960-2008. Vessels were grouped into types and decades. For bulkers, a clear improvement was seen between 1960, 1970 and 1980. They also showed that the rising oil price in the 1970s clearly had an effect on efficiency. However, after the 1980s, the EEDI value seems to deteriorate slightly, but as data spreads are not provided, this could just as well be an estimation uncertainty. This uncertainty is increased by the extension of the ordinary least square (OLS)-estimated power curves far beyond the estimation range. All lines go to 400,000 deadweight (DWT), but the vessels of that size were constructed only in the past decade. Before the past decade, vessels were generally not more than 200,000 DWT, with very few exceptions. In their conclusion, it is mentioned that the amelioration and deterioration of the hull form (fuller, less hydrodynamic ships) were not able to explain all the gained efficiency. They suspect that advances in propulsion were also made. This is supported by other research (Górski and Giernalczyk, 2010; Giernalczyk *et al.*, 2010) that shows a decrease in installed power. Total power may still increase as auxiliary power demands have increased because of the increase in technology and luxury (e.g. TV's, computers, bow thrusters, etc.). This could indicate that the assumption used in the research by Faber and 't Hoen (2015) that auxiliary power is a fixed percentage of installed power might have led to overestimating past emissions. This would, however, only increase the drop in EEDI seen now.

Based on the research, the conclusion can be drawn that higher fuel prices have a positive effect on efficiency. However, if the earnings grow faster than fuel expenses, efficiency might deteriorate nonetheless. This makes sense as it can be easily shown that the optimal speed is dependant on the ratio between bunker costs and spot rate (Devanney, 2010c). The last crisis should, therefore, provide a new wave of more efficient ships than before the crisis as both freight rates dropped and bunker prices increased. However, this effect is not instant, especially with a large order book (backlog) as shown in Figure 2. It will take several years before the more efficient ships are delivered. Year 2010 was simply too early to see this effect.

The 2009 crisis in shipping

Results of the 2009 crisis are described by many authors. De Monie *et al.* (2010) focused on the build-up of the crisis. They also highlighted how a banking crisis, through asset financing, but more importantly international transaction financing, can have such a large impact on shipping. This setting is used in the next chapter (Notteboom *et al.*, 2010) to explain the impact on liner shipping and port industry. Počuča and Zanne (2009) tried to show the impact of the crisis on a single 55,000-DWT bulker. Unfortunately for the tramp option, they did not take into account the likeliness of an empty voyage back; hence, the income of the bulker is much higher than in reality. Ionescu (2011) studied the impact of the crisis on shipbuilding, but at a country level. His main conclusion is that if the shipbuilding in a country is largely navy related, the impact of the crisis is reduced. Jiang and Lauridsen (2012) focused on the price forming of yards and its dependence on the time charter (TC) rates; other variables are cost price, capacity and profit margin. Pruyn (2013) also showed that price is mostly dependant on TC rates, and used proxies for cost price, capacity and size. So prices of vessels are related to the current economic situation and not based on long-term strategies. This is further supported by Gkochari (2015) who showed with a real options investment model with game theory, that the time to build delay is the major force behind the boom–bust scenarios in shipping.

All authors further agree that because of the unprecedented boom preceding this crisis, there is a large change; the crisis will be longer than usual as well. The large order book, which would increase the existing fleet by 50 per cent, was only recently delivered to the market, ensuring a situation of oversupply and thus maintaining low freight rates for the past five years, which will continue in the near future. As can be seen in Figure 1, the bunker prices dropped since the beginning of 2015 and are still not close to the pre-crisis levels. On top of this, new regulation on emissions from the IMO is implemented and forces yards and owners to reduce the emissions.

Energy efficiency design index and ship emissions

As of January 1, 2013, the EEDI of new ships should be roughly 10 per cent below the baseline (though allowing a grace period of four years for enforcement). The baseline is a power curve established using vessels build in the period 2000-2009. As was discussed in the sections on historical trends, these vessels are seen as the worst performers of the last 30 years.

Several studies have tried to estimate the CO_2 emissions of ships (Corbett and Koehler, 2003; Buhaug *et al.*, 2009; Psaraftis and Kontovas, 2009; Smith *et al.*, 2014), and the main issue with almost all of them is the sensitivity to assumptions or industry feedback variables such as the ratios active/idle, days at sea/days in port, speed sailed/design speed, total fuel consumption, etc. For a single ship, the equations are easy and straightforward, but when aggregating these values for the world fleet, a small deviation can have a major impact on CO_2 emissions calculated.

This not only affects the current estimations but also influences the reduction and cost of CO_2 reductions calculated in a number of papers (Crist, 2009; Eide *et al.*, 2009; Longva *et al.*, 2010; Eide *et al.*, 2011). Almost all came up with a marginal abatement cost curve (MACC). This is a ranking of the researched measures to reduce emissions from lowest marginal costs to highest marginal costs. It very clearly shows that several measures have a negative cost per CO_2 reduction, meaning that the benefits (profits or cost reductions) are larger than the investment. In other words, the net present value is larger than zero and owners should consider implementing it as it will save money in all circumstances. It also seems that not all options researched are as independent as assumed for the calculation. Using both sail and kite would be difficult and conventional sails might also block the sun from the solar panels installed (another reduction option). Lastly, it is not clear if lightweight (LDT) increases, or in other words if cargo capacity decrease is taken into account as well. Anyway as already stated, the outcome of the MACC is very dependant on the assumptions made, in these cases the bunker costs especially. Also the curves are calculated for individual vessel type and size groups; however, the way the fleet will grow may have a large influence on the total effect as well because of the economies of scale. If we build larger vessels, the total emissions per ton-mile will reduce, but the effect on the EEDI is unclear as it is size dependent.

There is still a lot of debate about the EEDI (Devanney, 2010a, 2010b; Randers, 2012; Papanikolaou, 2014). On the need of it as shipping is still much cleaner than other modes of transport. On the safety of it as it pushes designs of vessels in the direction of low-speed and low-power engines on one side; which in cases of severe weather might not be enough to keep ships on their course and out of trouble. On the other side, it promotes light structures to increase cargo capacity, which in turn could result in insufficient strength later in the life of the vessel. Ultimately, more ships are required to be built. Still, there is no clear indication on how to divide the costs of the reduction fairly. The rules for calculating the EEDI, however, favour slow steaming; the next section will discuss how slow steaming can alleviate some of the pain and reduce oversupply that is the result of the current crisis.

Slow steaming in shipping

In several newspaper articles (Tradewinds, 2009, 2010), Maersk is shown to test the limits of slow steaming for container vessels and very large crude carrier (VLCC) tankers, going as low as 10 per cent engine load, after installing the proper kits. As the IMO research on GHG (Buhaug *et al.*, 2009) coincides with the crisis, many papers on slow steaming focus more on the reduction in CO_2 emissions than the reduction in costs, or even the increase in profits. As the focus of this paper is on the design of eco-bulkers after the boom, only papers related to these events will be discussed here.

Corbrett *et al.* (2009) used a highly simplified model (no return trip, utilization rate is 1) to test two different scenarios for slow steaming in liner shipping. In the first scenario, more vessels enter the service to compensate the loss in supply, and in the second scenario, bigger vessels are used to compensate the loss in supply. The latter is much more beneficial from a CO_2 emission point of view. Lindstad *et al.* (2012) later confirmed the importance of upsizing to achieve the targets for GHG reductions the IMO sets itself, especially in the scenarios where trade will triple between now and 2050 (Buhaug *et al.*, 2009). Yet the EEDI formula does not take average fleet size into account and will thus probably result in the situation of more and slower ships.

Psaraftis and Kontovas (2010) investigated the risk of modal shift as an effect of slow steaming, especially for short sea shipping and high-value goods. This shift could be substantial, but for bulk cargo under investigation here, this risk is irrelevant. Devanney (2010c) investigated the relation between slow steaming and spot rate and established the earlier mentioned ratio of bunker prices per spot rates as a key factor in determining optimal speed. Cariou (2011) investigated slow steaming in liner operations further. The operational expenses of extra vessels are taken into account and costs are minimized, but not CO_2 emissions. However, one could argue that in a model with fixed income (from a fixed amount of cargo to be transported), the owner should maximize profit, not minimize costs, as the costs of ships not sailing should than also be taken into account.

Kontovas and Psaraftis (2011) added the concept of virtual arrival, where the owner and the port are rewarded for providing an instant unloading spot for the vessel that voluntary reduces speed to arrive at the designated time. They argued that although it helps to minimize costs and CO_2 emissions if you optimize speed, it does not help if this period is followed by waiting outside the harbour, burning (expensive) the fuel in an ECA zone.

Lindstad *et al.* (2011) started with a good overview of papers on speed reduction between 2000 and 2010, after which they made the most complex model for calculating the optimal speed, which includes not only still water consumption, but also added resistance in waves, port time and the costs for the cargo owner. Typical routes for each vessel type and size were investigated and CO_2 reductions were maximized. With no extra costs and compared to the same design speed, a 14 per cent reduction is possible. However, sailing at minimal costs (the case in the current crisis), the reduction is already ± 10 per cent, leaving only 3.5 per cent as an extra reduction to be obtained by applying their model. This model is further extended in Lindstad (2013), where several vessels with the same cargo capacity are compared. However, as all new options are post-Panamax vessels, which are able to sail through the new (not yet existing) Panama Canal locks, the comparison is biased because of the scale effects benefits of the new vessels.

Faber (2012) approached it from a different angle and tested to what extent the current inactive fleet of vessels could be used to reduce CO_2 emissions. Engine limits and specific fuel consumption at different loads are taken into account. Of course this model is limited. When international trade picks up, this overcapacity is needed for regular trade, and to keep at the low emission level, extra vessels will need to be built and maintained.

Psaraftis and Kontovas (2013) gave a very good classification of the options for slow-steaming models. They created a list based on earlier researches that contains all aspects a good speed reduction model should take into account: profit optimization, cargo owner as decision-maker, fuel price as an input, freight rate as an input, a relevant fuel consumption function (cubic for bulkers and tankers higher order for container vessels), optimization of speed per leg and pay load (ballast, laden, partially laden), multiple ships for consideration, ability to add more ships (at a cost), inclusion of inventory costs of the cargo owner as well as ports and consideration of emissions and modal split if relevant. Based on Lindstad *et al.* (2011), consumption in waves is still missing from their taxonomy and no model has yet included all these aspects.

In general, the conclusions of all papers are that speed reductions (and size increase) are useful to reduce both costs and emissions. The optimal speed differs depending on the ratio of bunker costs divided by income and the power with which consumption is related to the speed (cubic or higher).

Eco-bulker designs

With the EEDI and slow steaming in mind, options to create the economically best environmentally friendly ship can be tested and judged. What should such an eco-bulker look like? DNV through a number of authors (Crist, 2009; Eide *et al.*, 2009; Longva *et al.*, 2010; Eide *et al.*, 2011) already tried to rank the (soon) available options as best as possible. These rankings show that the operational options especially will result in lower emissions and lower costs, whereas the options to be implemented during newbuilding make the lifetime costs of the vessel higher. Other authors (Boulougouris *et al.*, 2011; Chen *et al.*, 2011; Hollenbach and Reinholz, 2011; He and Ikeda, 2013; Ölçer and Ballini, 2015) have looked at how to design the optimal bulker, most of them taking the environmental parameters into account as well. None, however, came up with a bulker design or a list of suitable measures according to their design framework.

Minchev *et al.* (2013) are the only ones so far who have described the steps and considerations for an eco-bulker design. With the current technology, they are able to reduce the EEDI base value by 19 per cent, without a speed loss for a 350,000-DWT bulk carrier. Earlier, the same vessel was tested in reality by Greenship (2009), and while the NO_x and SO_x emissions were reduced to almost zero, CO_2 emissions were only reduced by 7.2 per cent. One of the reasons was that the reduction of the other two gasses requires extra power and thus increases the CO_2 emissions. The costs of all these measures amounted to US$3.5m or 20 per cent of the investment costs at that time. All reductions are compared to the original vessel. The difference in CO_2 reduction between the two publications is remarkable. It could very well be that the base vessel is already below the EEDI baseline, creating an extra reduction, or that CO_2 measured versus CO_2 calculated by the EEDI creates a larger difference. Also, some further optimisation might have taken place and finally the NO_x and SO_x reduction measures might not have been implemented to save more CO_2, as they are not required for the EEDI.

In any case, these eco-bulkers have been sold to ship owners in 2012 and 2013, as described in the introduction of this paper. It was suggested in the newspaper articles that other yards have followed this trend. This should result in vessels with lower emissions and consumption being built in the past three years. If this segment was large enough, this will be visible in the vessels delivered in 2014 and perhaps already those from 2013, depending on the order book size and building/delivery time.

The main goal of this paper is to test if these eco-bulkers are already forming a major part of the vessels delivered in 2014. To investigate this, a number of parameters for 2014 vessels will be investigated in this section. Based on the literature discussed before, they should be larger on average to take advantage of the economies of scale, should have a lower design and/or service speed and should most certainly have a lower power installed or higher efficiency (power-to-speed ratio). If the reduction in installed power is not achieved by slow steaming, the hull shape should be less full, thus the hull shape expressed by the block coefficient, length–DWT ratio, Froude number and length-to-beam ratio should reflect this.

To calculate these values, the following dimensions of the ship are required: DWT, LDT, length (L), beam (B), depth (D), draught (T), main engine power (type and cylinders will help in establishing this if absent), design speed and service speed. Unfortunately, some data are hard to obtain, especially LDT, speed and engine power (in descending order). Therefore, a large number of databases (UNCTAD, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014; Bunkerindex, 2015; Shipvault, 2015; Traffic, 2015; UNCTAD, 2015; Veritas, 2015; Vesselfinder vessel information, 2015; Fairplay, 2015) have been searched to get the most complete data set possible; this, however, means that the best choice has to be made when there are conflicts in the data. To this end, both the source and values for comparable ships were considered to try and select the best data. This way many outliers caused by errors in the data entry were already corrected. However, all remaining outliers were reviewed as well. If the value was physically unlikely, it was removed. However, for the year 2014, it was noted that several vessels had a lower, but not unrealistic design speed. This seemed to be related to the source being almost all related to less reputable automatic identification system (AIS) data (Shipvault, 2015; Traffic, 2015; Vesselfinder vessel information, 2015). As this was the only variable slightly deviating from normal, it was decided to leave these values in for testing, as otherwise not many ships would remain to do the statistics on. The United Nations Conference on Data and Trade (UNCTAD) data have mostly been used to check if all bulk carriers delivered were identified. The other sources were used for retrieving the data mentioned. In Table I, the count of values found and the value of vessels expected based on UNCTAD reports are presented. However, as of 2009, the number of vessels was not published anymore by UNCTAD and was to be estimated based on the DWT delivered for the given years, and these values are denoted with asterisk.

From Table I, it is immediately clear that almost all bulkers were identified; however, as soon as the speed and the installed power are involved in a parameter, the numbers drop significantly. As design and service speed have the same number of observations, design speed will be used in all calculations where speed is required. The displacement data (block coefficient) are only available for 1-20 per cent of the vessels. This observation is insufficient for the statistical purposes intended here. Hence, DWT has been used as a proxy for the displacement. DWT is the closest to displacement, usually making up 80-85 per cent of the displacement. This brings in a small bias caused by the variation in LDT, but as this is about a factor 4 smaller than DWT, this is deemed acceptable. This does mean that the values calculated are unconventional and should not be compared with normal design data values. Trends over time are still visible. A benefit is that DWT, more closely, represents the trading capacity of the ship.

As for the tests itself, unless indicated otherwise, a power function in the form of $Y = a \times X^b$ has been assumed, estimated using OLS by taking the natural logarithms of both Y and X. This transforms the function into $\mathrm{Ln(Y)} = \mathrm{Ln(a)} + \mathrm{b} \times \mathrm{Ln(X)}$. This has been done for the data of each year to compare the trends and establish the significance in the difference of these lines. ANCOVA [analysis of covariance (Maxwell and Delaney, 2003)] was used to test the hypothesis if all the slopes (b) are equal and all the elevations are equal at a 95 per cent confidence level. Elevations are used, as the test considers if the difference between the lines is significant, so if one line is above the other, or should be considered as being on the same height. Of course the elevations test only makes sense if the hypothesis of the slopes being equal is accepted. In the results, the test outcome is always given, but the particular result is put in *italic* if it should not be considered.

If the hypothesis of equality for the slopes was rejected in the ANCOVA test, the Student–Newman–Keuls stepwise comparison (SNK) (De Muth, 2006) was used to identify the slopes that are equal and the ones that are not, by testing the same hypothesis, that the slopes are equal. This test is done pairwise on the entire set of equations to see if the two means should be considered equal or not. It is slightly more lenient than the ANCOVA test, which could result in a false positive, when the degrees of freedom are close to the next bracket of values. However, as the relevant degrees of freedom for each equation are far above 120, there is no next bracket and, therefore, a false positive should not occur. The

Variable	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
# UNCTAD	308	307	312	355	469*	949*	1107*	1133*	721*	N/A
# Vessels	308	299	293	323	557	984	1175	1195	648	364
DWT	308	299	293	323	554	982	1175	1195	648	364
Design speed	302	296	293	323	543	960	1140	1171	636	348
Service speed	302	296	293	323	543	960	1140	1171	636	348
Engine power	270	262	251	270	427	759	821	994	520	253
Admiralty	265	260	251	270	415	748	806	973	495	226
EEDI proxy	267	261	251	270	425	757	819	993	519	247
Froude number	297	295	293	323	530	950	1123	1148	607	317
Length–DWT ratio	301	298	293	323	541	963	1134	1161	608	321
Block coefficient	69	67	49	30	92	201	93	59	28	3
DWT coefficient	297	292	289	319	529	941	1118	1137	598	307

Note: *Indicates that the value was estimated and not reported directly anymore

Table I. Numbers of observation for each variable benefit of the SNK procedure over a pairwise ANCOVA comparison is that it can be more easily performed on a set of equations using the data from the combined ANCOVA test. If the slopes were equal, but the elevation failed the equality test, the SNK test was also used to identify the combination of elevations that was not equal.

To not clutter the paper with data and tables, the focus will be on the comparison of the years 2006, 2010 and 2014. Each year represents a different situation. Year 2006 is the time before the boom, 2010 is the noticeable end of the boom and 2014 is the first year when eco-bulkers are expected to arrive in the market. For also the research itself, all years were compared, so when needed, these results are also mentioned in the discussion of the results.

Bulk carrier design trends for 2005-2014

This section will discuss the results from the data studied. All data points, as well as trend lines for 2006, 2010 and 2014 will be provided.

The discussion of the results is divided in four parts. The first part will focus on the speed and power of the vessels, the main parameters. The second part will focus on the efficiency expressions, relating speed to power. The third part will discuss four coefficients that express the vessel shape. The final part will look for a significant shift in the size of the vessels ordered.

Speed–power

While Figure 3(a) does show that the speed of the bulk designs have been reduced, in line with the slow steaming approach, the corresponding data in Table II show that the fit (R^2) is relatively low. From the graph this is understandable, as vessels come in certain size classes, but their speed has a wide range within that size class, resulting in vertical groups in the graph. This also results in relatively large mean errors. The ANCOVA test identified that the slopes (a) of the three lines are not equal. The SNK test results for the slopes show that 2006 and 2010 are not equal to 2014. Therefore, the results of the elevation tests are put in *italics* and have no meaning because of this. This means that the speed trend line for vessels in 2014 is significantly lower than those of 2006 and 2010. However, there is some uncertainty about these data, as mentioned in the methodology section, so further tests are required. Not shown in the table, but good to mention is that the SNK tests for 2006 against 2010 showed equal slopes but different elevations.

For Figure 3(b), the lower speed should result in a reduction of power installed. However, the trend lines for 2010 and 2014 seem close to each other and definitely higher than the that of 2006. The corresponding results in Table II indicate that the R^2 is quite high (around 0.9); however, the slopes of the trend lines of 2010 and 2014 are not equal, and only those of 2006 and 2014 are equal. However, here the elevation is not equal so the lines are still different. This means that the installed power for 2014 is significantly higher than that of 2006. As for the trend lines of 2010 and 2014, they cross each other around 250,000 DWT, below that value 2014 is higher, above 2010 is higher. Still it is clear that the expected reduction in installed power did not occur.

The fact that the largest vessels were not constructed before 2009 might influence the trend lines as well. This was also tested but was found to not result in different conclusions other than mentioned above.

Efficiency

EEDI is a representation of transport efficiency. It relates the capacity expressed by the cargo volume times the speed with the required power. The power is then converted into consumption, which is in turn converted into CO_2 emissions. In most researches on the subject, the conversion factors are constants and are, therefore, left out of the trend analysis

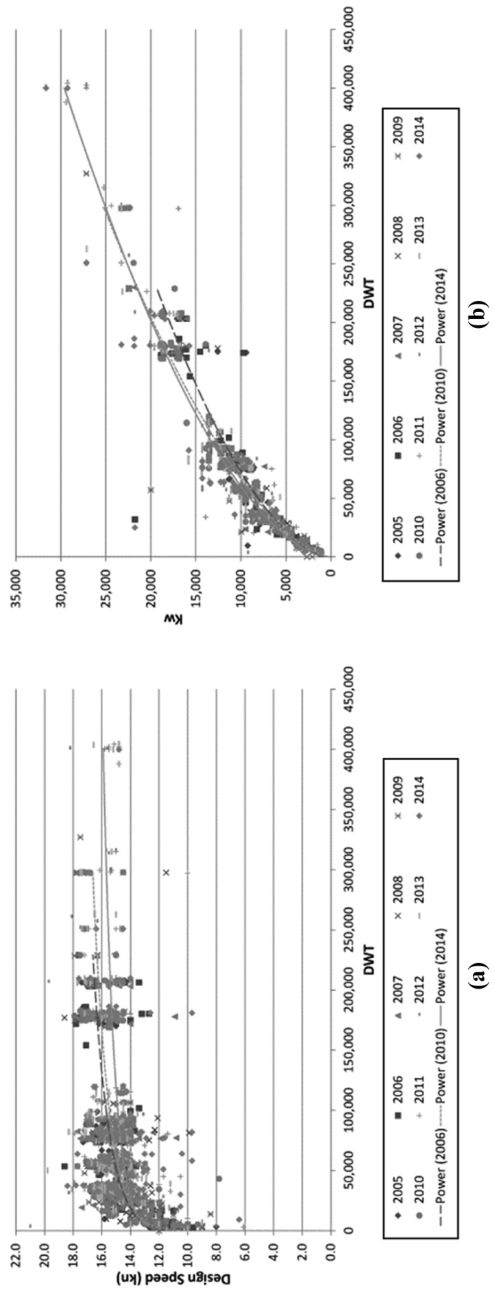


Figure 3.
Speed (a) and power (b) against DWT

in this research, as they do not change the trends visibly [see also equation (1.1)]. In marine engineering, there is also a much older constant in use relating these same aspects with each other, the admiralty constant or coefficient developed by the British Admiralty (Papanikolaou 2014). As displacement is not available in sufficient number, it has been replaced by DWT [see equation (1.2)]:

$$EEDI_{proxy} = \frac{P_{ME}}{DWT \times V_{Design}} \tag{1.1}$$

$$Adm_{proxy} = \frac{DWT^{2/3} \times V_{Design}^{3}}{P_{ME}} \tag{1.2}$$

The difference between the two formulas is significant. The older admiralty constant is used for roughly estimating the required power using ships of similar size and speed. The fact that required power related to speed to at least the power of 3 is used here makes the formula speed-independent for bulkers (where the relation is almost cubic). The peculiar power of 2/3 on displacement is an estimation of the wetted surface of the hull, a factor relevant for the prediction of resistance in still water. Hence, the entire formula has a physical background. The EEDI formula divides power by the transport capacity. This is an economic formulation of the relation. Replacing the engine power by the cubic power of speed multiplied by a constant, it is easy to see that a reduction in speed will lead to a quadratic reduction in EEDI, whereas increasing DWT will only decrease the EEDI linearly.

The results for EEDI are presented in Figure 4(a). The trend lines seem close together, though the 2014 line is the highest, which means more pollution per ton*mile. The corresponding results in Table III show that R^2 is reasonably high, and although the ANCOVA for all three slopes being equal is rejected, the slopes of 2006 and 2010 are both equal to 2014. Not shown is that the rejection is based on the fact that 2006 and 2010 are not equal. In this case, the SNK tests of the elevations are relevant and these show a significant difference. So overall as the slopes are not significantly different, the conclusion should be based on the elevations, which are significantly different, where the slopes of 2014 is slightly lower than 2006, but a lot higher than that of 2010. This is different than that taken from the graph as it includes the entire line. Nonetheless, it is clear that at least no large improvement has been made as compared to 2010 or 2006, especially not in absolute values.

Table II. Speed and power estimations and significance of the trend lines

Speed	2006	2010	2014	Power	2006	2010	2014
N	296	960	348		262	759	253
R^2	0.336	0.405	0.106		0.907	0.958	0.861
b	0.069	0.066	0.048		0.573	0.617	0.573
ME 95%	0.011	0.005	0.015		0.022	0.009	0.029
SNK test	Reject	Reject	ANCOVA: Reject		Accept	Reject	ANCOVA: Reject
a	7.098	7.220	8.557		16.332	10.606	18.355
ME 95%	0.123	0.056	0.164		0.250	0.102	0.318
SNK test	*Reject*	*Reject*	*ANCOVA: Reject*		Reject	*Reject*	ANCOVA: Reject

Note: The italic terms represent the fact that this test does not need to be executed as the test on *b* has already rejected the hypothesis

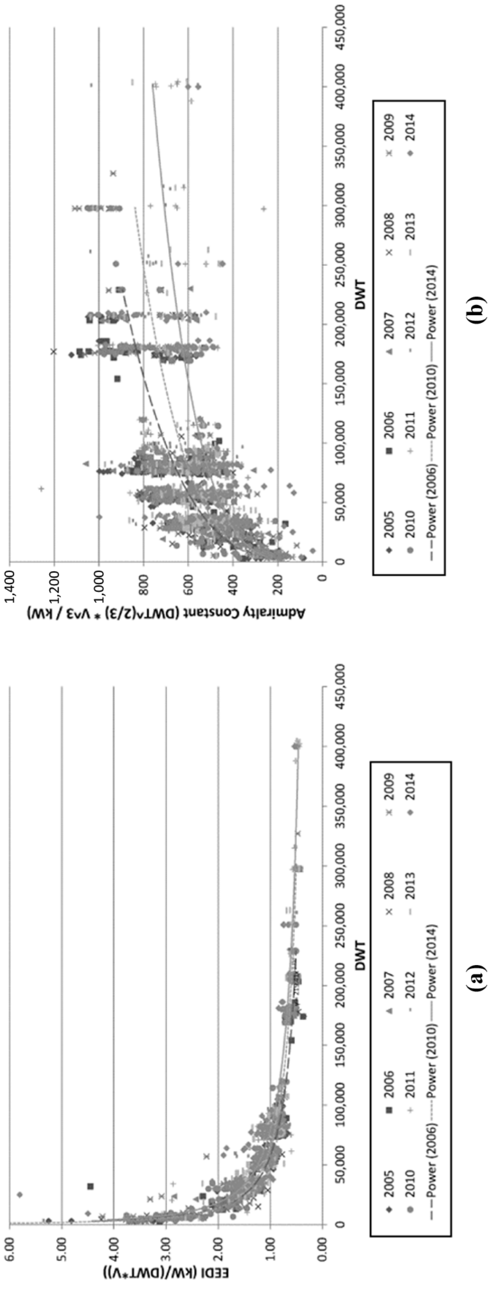


Figure 4.
EEDI (a) and admiralty (b) values against DWT

For the admiralty constant, the results are shown in Figure 4(b). Here a higher trend line would indicate a more efficient vessel. On first inspection, the trend line of 2014 seems the worst line of them all. The corresponding results in Table III show that R^2 is not very high, the influence of speed is large here because of its third power and this is in line with the results obtained for the speed above. This might have also helped to generate the acceptance of all slopes being equal in the ANCOVA test. Still the elevations are rejected as being equal; here, the SNK test shows that both are rejected. Although the visual results of the trend lines might indicate differently, statistically the slopes are equal and based on the elevation differences (not taken up in the tables), and 2010 and 2014 are significantly lower than 2006. This is opposite to the intercepts, as elevation is related to the means of the data and the differences of the slopes. So this would indicate a (small) deterioration compared to 2006 and an even smaller step down compared to 2010. This is in line with the earlier results.

Vessel shape

Kristensen and Lützen (2012) have discussed this deterioration of efficiency, for which EEDI and admiralty both are measures, as well. Ships are sailing slightly slower but require a higher engine power. This contradicts the physical link represented by the cubic speed–power curve. They show that the vessels have become fuller, especially those that have limitation to their size (e.g. Panama Canal). On the other hand, measures to reduce NO_x and SO_x emissions might have been installed on these vessels, requiring power but reducing the environmental load of the vessel. To investigate this, the block coefficient, Froude number, length–DWT ratio and length-to-beam ratio are investigated next. In all cases, displacement has been replaced by DWT and all other values have been maintained. For completeness, the formulas are presented below [equations (1.3) to (1.6)]:

$$C_{b,proxy} = \frac{DWT}{L \times B \times T} \tag{1.3}$$

$$Fr = \frac{V}{\sqrt{g \times L}} \tag{1.4}$$

$$L - ratio_{proxy} = \frac{L}{DWT^{1/3}} \tag{1.5}$$

Table III.
EEDI and admiralty constant estimations and significance of the trend lines

EEDI	2006	2010	2014	Admiralty	2006	2010	2014
N	261	757	247		261	757	247
R^2	0.882	0.916	0.747		0.466	0.515	0.209
b	−0.492	−0.450	−0.475		0.289	0.251	0.243
ME 95%	0.022	0.010	0.035		0.038	0.017	0.059
SNK test	Accept	Accept	ANCOVA: Reject		Accept	Accept	ANCOVA: Accept
a	219.411	147.230	211.482		25.168	35.251	33.145
ME 95%	0.244	0.107	0.387		0.421	0.192	0.661
SNK test	Reject	Reject	ANCOVA: Reject		Reject	Reject	ANCOVA: Reject

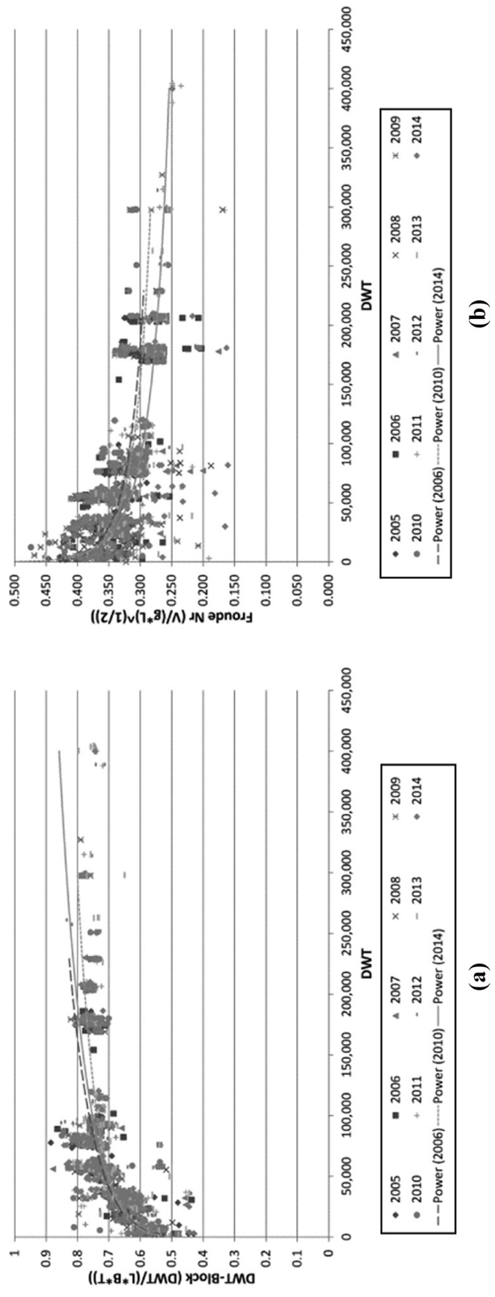


Figure 5.
Block coefficient proxy (a) and Froude number (b) values against DWT

$$L/B - ratio = \frac{L}{B} \tag{1.6}$$

Figure 5(a) shows the results for the block coefficient based on DWT. The trend line for 2014 seems to be in between those of 2006 and 2010. The corresponding results in Table IV show that R^2 is relatively low, despite the fact that speed is not involved in this value. Figure 5(a) shows a rather large spread for the smaller numbers, which leads to the suspicion that for smaller vessels, the effect of ice-class and gear amongst others on the remaining DWT is relatively large. This effect would not be there when displacement would be used, so DWT is perhaps the best proxy and leads to a deterioration of the results. As for the comparison of the slopes, the slope of the trend line for 2006 is equal to that of 2014 and the one for 2010 is not. As for the elevation, these are significantly different, so based on the elevations, 2006 is slightly higher than 2014. This should be interpreted as 2014 having slightly more shaped vessels than 2006, but bulkier vessels compared to 2010.

The Froude number is a dimensionless representation of speed and plays an important role in predicting the wave making resistance of a vessel. The higher the number, the more wave resistance, so lower numbers are better for and would indicate lower power requirements. The trend lines shown in Figure 5(b) indicate again a suspicion of a lower speed for vessels delivered in 2014 compared to those delivered earlier. The R^2 in this case is below 0.5, which is really low. The equality of all slopes tested with the ANCOVA test is rejected; however, the SNK test shows that the slopes of 2006 and 2014 are equal, but their elevations are not. Based on the elevations, 2006 lies above 2014. So 2014 can be seen as having the lowest speed. Even when considering the data of the other lines, 2014 is the lowest line. Again here the fact that the speed is based primarily on AIS data may play a role as there is no evidence of lower power in the other comparisons.

The last two parameters to discuss are both related to the slenderness of the vessel. If the length increases, the vessel is more slender and has less resistance than another vessel with comparable volume but shorter length. In Figure 6(a), the results for slenderness are presented. It is hard to see a difference in the three trend lines. The details and comparison of the trend lines in Table V show that R^2 is below 0.2 and results should not be seen as very relevant. Changing the type of trend line (e.g. linear or exponential) does not improve the results. This low fit and consequent large mean error value for the coefficients results in the ANCOVA test accepting the slopes of the trend lines as equal. However, the elevation of the lines is not equal, and based on the elevation, 2014 has the highest elevation, followed by 2010. This would indicate that

Table IV. DWT block and Froude number estimations and significance of the trend lines

DWT block	2006	2010	2014	Froude	2006	2010	2014
N	292	941	307		295	950	317
R^2	0.587	0.534	0.470		0.312	0.478	0.310
b	0.096	0.076	0.095		−0.084	−0.084	−0.109
ME 95%	0.009	0.005	0.011		0.014	0.006	0.018
SNK test	Accept	Reject	ANCOVA: Reject		Accept	Reject	ANCOVA: Reject
a	6.843	6.980	7.163		0.832	0.822	1.042
ME 95%	0.104	0.050	0.127		0.159	0.062	0.202
SNK test	*Reject*	*Reject*	*ANCOVA: Reject*		Reject	*Reject*	ANCOVA: Reject

Note: The italic terms represent the fact that this test does not need to be executed as the test on b has already rejected the hypothesis

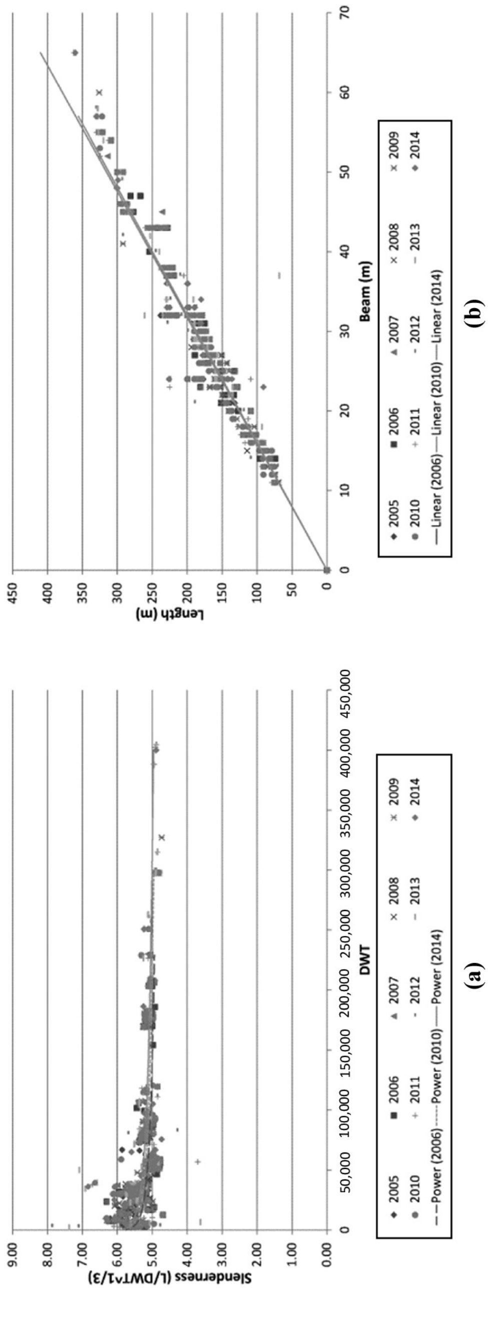


Figure 6.
Length–displacement ratio proxy (a) and L/B ratios (b) values against DWT

over time, vessels have become more slender. A result that may seem to contrast with the earlier discussed increase in block coefficient of the vessel when resistance is considered. Perhaps the lowering of resistance is exactly the reason to move to more slender ships, as it offsets the effects of the larger block coefficient. Finally it might just be the result of chance, given the low R^2 score.

For L/B, a linear trend line was used instead of a power curve. This is a common practice in ship design. The fact that for a given beam (width of the vessel), there is a range of lengths is because of the fact that vessels are designed to deal with several locks and canal restrictions. Especially around 32 metres, a lot of variation is noticeable, which is because of the locks of the Panama Canal. On first inspection, the lines seem to be almost equal. Table V further indicates that R^2 is high above 0.8; however, the ANCOVE test and the SNK test show that slopes should be considered different, thus the elevation results are irrelevant. So using the intercept as well as the slope, it can be stated that below 40-45 metres, the ships build in 2014 are more slender and above that length, the ships build earlier are more slender. Though for this result the difference in the spread of vessel sizes might be more important, than really indicating a minor change in trends. To make sure that the linear approach is valid, the power trend line was also investigated. All trend lines showed values for b of almost 1 and were all seen as equal by the ANCOVA test. The results from the elevations indicated a difference, putting 2014 slightly above 2010 and 2006. This means vessels in 2014 were slightly more slender on average.

Size shift

The last element to look at is a shift in sizes of the vessels ordered. Although this will not improve the EEDI, it will reduce the greenhouse gas emissions of the fleet when sailing slower and bigger vessels and more importantly will also reduce the cost per ton cargo transported (Lindstad *et al.*, 2012).

As can be clearly seen in Figure 7(a), the average size of ordered vessels varies slightly, the main reason seems to be the (re)introduction of bulkers of more than 250,000 DWT in 2008. Within each size group, the changes are minimal. Figure 7(b) shows the fraction of deliveries per year for each size group. The only striking difference is the fact that in the period 2009-2011, a significantly larger fraction of 175.000-200.000 DWT vessels was delivered. Table I shows that the number of deliveries in 2009-2013 was two to four times higher than normal. The amount of other vessels did not reduce but the amount in this particular size group increased significantly. The peak in 2012 and 2013 was lower, only because even smaller vessels

Table V. Slenderness and L/B–ratio estimations and significance of the trend lines

Slenderness	2006	2010	2014	L/B ratio	2006	2010	2014
N	298	963	321		298	964	321
R^2	0.198	0.194	0.169		0.885	0.931	0.833
b	−0.026	−0.027	−0.028		6.003	6.145	5.669
ME 95%	0.006	0.003	0.007		0.248	0.106	0.279
SNK test	Accept	Accept	ANCOVA: Accept		Reject	Reject	ANCOVA: Reject
a	1.923	1.943	1.969		8.480	3.345	22.929
ME 95%	0.067	0.039	0.077		8.521	3.644	9.799
SNK test	Reject	Reject	ANCOVA: Reject		*Reject*	*Reject*	*ANCOVA: Reject*

Note: The italic terms represent the fact that this test does not need to be executed as the test on *b* has already rejected the hypothesis

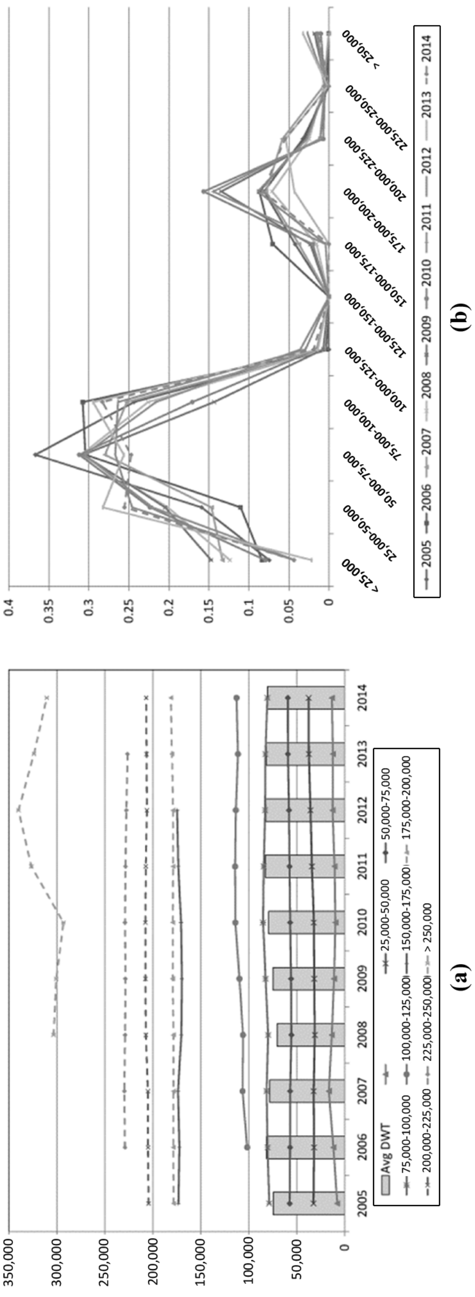


Figure 7.
Average size variation (a) and (b) fraction of size group delivered

were delivered. The author is not aware of any particular reason for the interest in this size class, other than a booming economy and high demands for raw materials

Based on the inspection of eight parameters summarised in Table VI, it can be concluded that there is a difference between vessels delivered in 2014 and those in the nine years before. There is a small reduction in design speed, as a well as an increase of the hydromechanical properties, such as slenderness and Froude number. However, for the block coefficient, the results are already mixed. For the parts on power, the performance is actually worse for the vessels of 2014, in spite of the improvements on the factors important for the required power. The measures to reduce NO_x and SO_x are not coming into force before January 2016, so this does not explain an increase in power compared to speed. The only remaining option is that the speed data are not always correct. Given the multitude of sources and the fact that speed data are often missing from classification information, it seems the most logical explanation for this peculiarity. A review of the data shows only 30 per cent of the speed is coming from the more reliable sources; the rest is substituted with maximum AIS speeds, which are not the most reliable, especially for young vessels, and often closer to service speed. As for the slenderness, the increase in size could also play a role in the improvement of these values. In any case, there is not a clear indication that the ships built in 2014 are more eco-friendly.

Conclusions

Considering the literature research, there are major forces both economically and regulatory that will force owners to consider sailing at slower speed. While the economic forces can be satisfied with proper engine adaptations, the regulatory forces will make sure that the total installed power will also be reduced. Several companies, shippers and yards were reported to already explore this opportunity; however, the data analysis shows that either in 2014, mostly pre-crisis vessels were still being delivered or that the announced wave of eco-bulkers was created more by the media than by the owners, as no proof of a noticeable improvement was found in the data on vessels delivered between 2005 and 2014.

The only thing that could be noticed was a slight reduction in design speed; however, this is most likely the result of the data used, not a real change of design as it was not accompanied by a reduction in installed power. It makes the efficiency ranking seem worse than any of the previous years. All these differences were marginal, though statistically significant (95 per cent confidence level). Furthermore, no proof was found of better hydrodynamic properties of the vessels or any other adaptation of the improvements mentioned by DNV and the eco-bulk designers.

Nevertheless, in the near future, these ships will be appearing on the stage, as of the start of 2017, the first phase of the EEDI has come into force. It would be interesting to

Table VI. Summary of eco-friendliness for all parameters

Comparison	Speed	Power	EEDI	Admiralty	DWT block	Froude no.	Slenderness	L/B ratio
2014 vs 2006	2014	2006	2014	2006	2014	2014	2014	2014
2014 vs 2010	2014	2010 (<250,000 DWT)	2010	2010	2010	2014	2014	2014

follow the development of these design parameters and to see how these new ships would compete with the current fleet of ships, as in crisis they have an advantage, but in a boom their capacity to speed up is limited.

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Corresponding author
Jeroen Pruyn can be contacted at: j.f.j.pruyn@tudelft.nl