Comparative analysis of ship efficiency metrics

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1 Introduction

1.1 Policy context

Greenhouse gas emissions of maritime transport accounts for approximately 3% of global greenhouse gas emissions and the emissions are projected to double in the period up to 2050 (2014 IMO GHG Study). The Marine Environment Protection Committee (MEPC of the International Maritime Organization (IMO) has been working on policies to address these emissions since 1996. In 2012, it has adopted the Energy Efficiency Design Index, which sets increasingly stringent limits to the design efficiency of new ships. It is currently discussing further technical and operational measures for enhancing energy efficiency of international shipping, with the aim of improving the energy efficiency of all ships, not just new ships.

There have been four proposals of metrics that could be used in these technical and operational measures. These are:

1. The Fuel Oil Reduction Scheme (FORS), which measures the annual fuel consumption of a ship and compares it to a reference value calculated from the engine power of a ship and the operational profile of the ship type to which the ship belongs in 2007.
2. The Annual Efficiency Ratio (AER), which divides the annual carbon dioxide emissions of a ship by the product of the distance sailed and the deadweight of the ship.
3. The Individual Ship Performance Index (ISPI), which divides the annual carbon dioxide emissions of a ship by the distance sailed, and sets an improvement target which takes into account the design efficiency of the ship.
4. The as yet unnamed US proposal (abbreviated here as USP), which divides the annual energy consumption of a ship by the number of hours in service.

Up to know, the discussion of the metrics has been based primarily on theoretical evaluation of the formulae. This study aims to add a new element to the discussion by presenting, for the first time, a comparative analysis of the metrics using empirical data of ships. This allows us to analyse how the scores on the different metrics reflect the efficiency of the ships. We do so in two ways. First, we analyse whether improvements in the scores of ships on the four metrics are correlated, which could indicate that they are all based on a common element of efficiency. Second, we analyse how the four metrics change when the average speed of ships change, which indicates how they respond to the only operational measure to reduce emissions that is observable in our dataset.

1.2 Method and data

We have received empirical data on fuel use, distance sailed, hours and days in service, deadweight, engine power and reference speed for 23 vessels in 2012 and 2013. The sample contains 10 container ships, 8 bulkers, 3 RoPax and 2 product tankers. For each ship, FORS, AER, ISPI and USP have been calculated for 2012 and 2013 using the formulae presented in MEPC 66/4/6 (FORS, AER and ISPI) and MEPC 65/4/19 (USP).

2 Analysis of the ship efficiency metrics

This chapter presents a comparative analysis of the scores of the ships on the efficiency metrics. First, it shows and compares the year-on-year differences in the scores on each of the metrics. If the differences are correlated, i.e. if improvements in one metric coincide with improvements in the other metrics, the metrics reflect the same aspect of efficiency. If, on the other hand, the correlation is weak, the metrics reflect different aspects of efficiency.

Second, it analyses the relation between year-on-year changes in the average speed of ships and the scores on the metrics. Since speed reduction is generally assumed to improve the fuel efficiency of ships, one would expect that a decrease in the average annual speed results in an improvement of the score on each of the metrics.

2.1 Year-on-year differences in scores

Table 1 shows the changes in the scores for the 23 ships between 2012 and 2013. Assuming that the reference lines or baselines remain constant over time, an decrease in the value of a metric indicates a decrease in fuel use and emissions (per se or per unit of activity) and therefore an improvement in the score.

The year-on-year changes can be quite large in any metric. FORS values in the sample show changes ranging from a decrease of 61% to an increase of 32%. The maximum increases in AER and ISPI are similar to FORS, but the maximum decreases are lower, 14 and 20% respectively. The changes in the USP range from a decrease of 33% to an increase of 15%.

In many cases, ships either improve or worsen their score on all metrics. However, there are five cases in which AER and ISPI have a different sign than FORS and USP, three cases in which FORS has a different sign and one case in which USP has a different sign. Even in this small sample, the reasons for different signs are diverse, may have to do with higher or lower aux engine use, cargo load, sea conditions and other parameters which are not observed here.

The largest changes in FORS often coincide with large changes in the activity of ships, measured either in the number of days at sea or the number of hours in service. Such changes in activity do not always result in large changes in scores on the other metrics.

Table 1 **Changes 2012-2013 for different metrics (negative values mean lower emissions, lower emissions per tonne-mile, per mile or per service hour)**

Ship	FORS	AER	ISPI	USP
Ship 1	-9%	-6%	-6%	-4%
Ship 2	4%	12%	12%	15%
Ship 3	4%	0%	0%	12%
Ship 4	6%	1%	1%	7%
Ship 5	-26%	6%	6%	-18%
Ship 6	3%	-4%	-4%	-7%
Ship 7	-41%	-8%	-20%	-33%
Ship 8	-28%	-10%	-10%	-15%
Ship 9	32%	14%	14%	1%
Ship 10	-16%	3%	3%	-5%
Ship 11	3%	31%	31%	3%
Ship 12	-61%	8%	8%	7%
Ship 13	-4%	-1%	-1%	-2%
Ship 14	-6%	-5%	-5%	-7%
Ship 15	-8%	-9%	-9%	-9%
Ship 16	10%	-4%	-4%	5%
Ship 17	-4%	0%	0%	-5%
Ship 18	6%	-1%	-1%	0%
Ship 19	-12%	-14%	-14%	-6%
Ship 20	-15%	-2%	-2%	-10%
Ship 21	-6%	16%	16%	5%
Ship 22	9%	3%	3%	7%
Ship 23	2%	3%	3%	-7%

Correlation of scores: which metrics are alike?

This section analyses the correlation of the year-on-year charges in the scores. The sign of the correlation coefficient indicates whether the scores move in the same direction or not. The value of the correlation coefficient indicates how strong the correlation is. If changes in one metric were fully mirrored by changes in another, the coefficient would be 1. A lower value indicates a weaker correlation.

The correlation coefficients are presented in Table 2. As all the signs are positive, the results show that the trend in this sample is that an improvement in either metric will often coincide in an improvement in other metrics. The correlation is especially strong between AER and ISPI. The correlation between the other metrics is weaker. This suggests that these metrics convey different aspects of efficiency.

Table 2 **Correlation coefficients between the changes in the values of the metrics**

	AER	ISPI	USP
FORS	0.24	0.31	0.47
AER		0.97	0.46
ISPI			0.58

If the outlier in FORS (ship 12) is removed from the sample, the correlation coefficients between FORS on the one hand and the other metrics increase significantly. For example, the correlation coefficient between FORS and the USP increases from 0.47 to 0.77.

2.2 Speed

Speed reduction is one way to reduce the fuel consumption of ships.
Our dataset does not contain information on operational or technical measures that may have been implemented in order to reduce the emissions of the ships in the sample, except for changes in the average speed (nautical miles per hour in service). This allows for an evaluation of the impact of changes in the average annual speed on each metric.

As a rule of thumb, there is a square relation between the speed of a ship and her fuel consumption per unit of distance. When a ship sails at a slower speed, it covers less distance per year and spends more time at sea as the number of voyages decreases, and therefore the time in port. As a result, one would expect that the USP would react strongly to changes in speed, as a reduction in speed results in less energy used and more time at sea. ISPI and AER would be impacted less, since the emissions would decrease, but so would the distance. FORS would fall in between these groups (CE Delft, 2014).

In our sample, speed is positively correlated with FORS and USP (a reduction in speed results in an improvement in the metric), as shown in Figure 1 and Figure 2, although the correlation is weak (removal of the outlier ship 12 improves the correlation for FORS to a coefficient of 0.2). The low correlations indicate that there are many other factors that influence the metric, which are not observed in our dataset. These factors could include weather and sea conditions, cargo load conditions, and speed profiles (as opposed to average annual speed).

Figure 1 **A reduction in the average annual speed results in an improvement of FORS, although the correlation is weak**

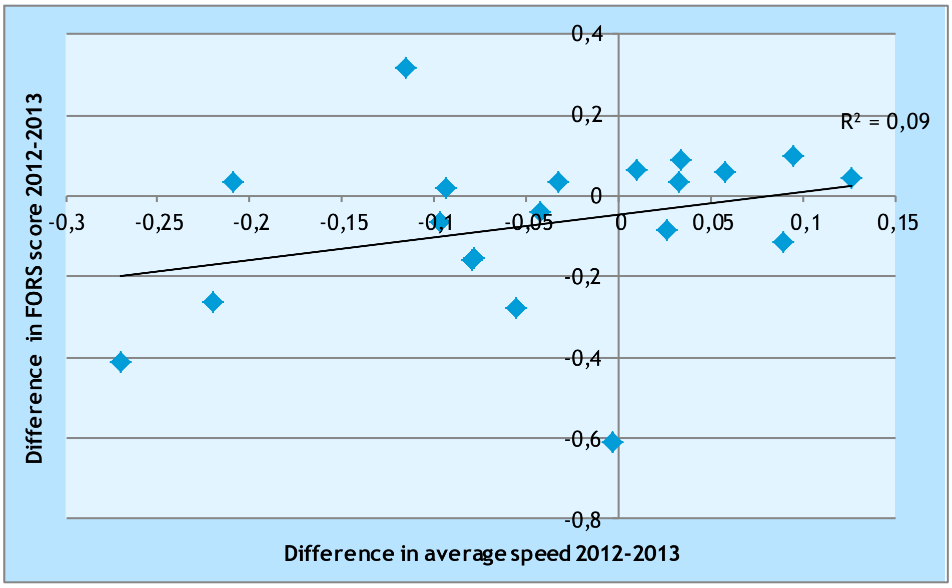
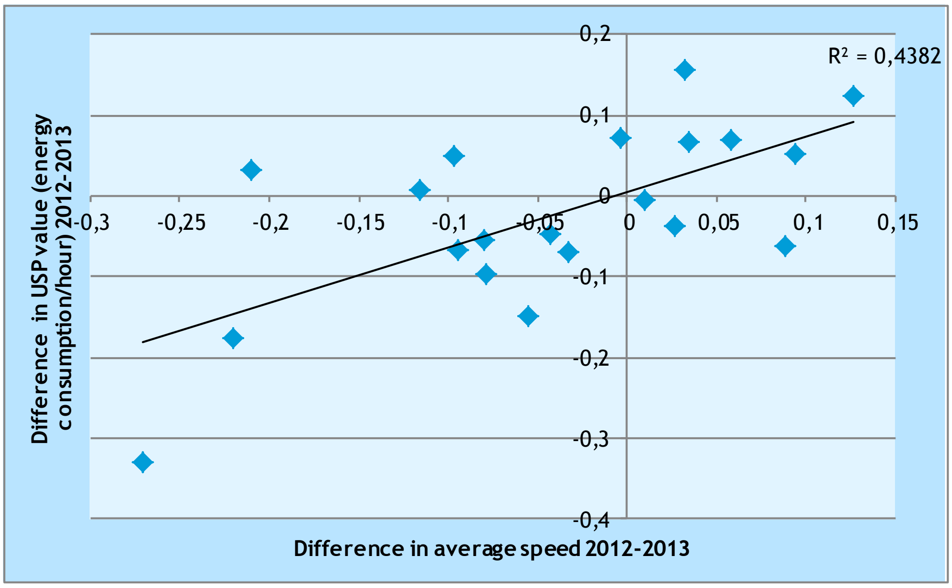


Figure 2 A reduction in the average annual speed results in an improvement of USP



Unexpectedly, speed is negatively correlated with ISPI and the AER in this sample, although the correlations are weak. As argued above, this is not expected and probably shows that other factors than speed dominate in this sample. Figure 3 and **Figure 4** show the correlations. These results show the need for a more thorough analysis including a larger dataset in order to assess whether other factors should also be taken into account.

Figure 3 In this sample, a reduction in the average annual speed results in a worse AER value, although the correlation is weak

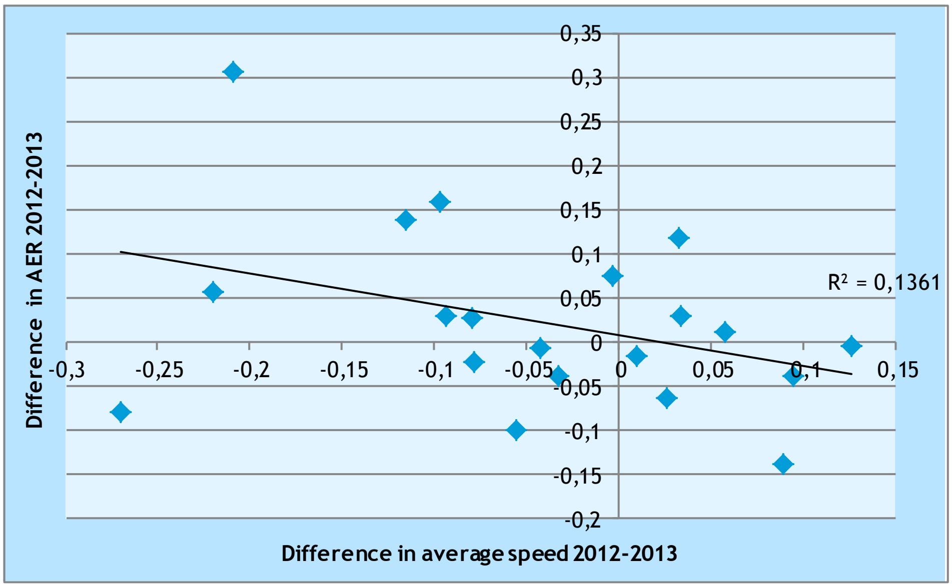
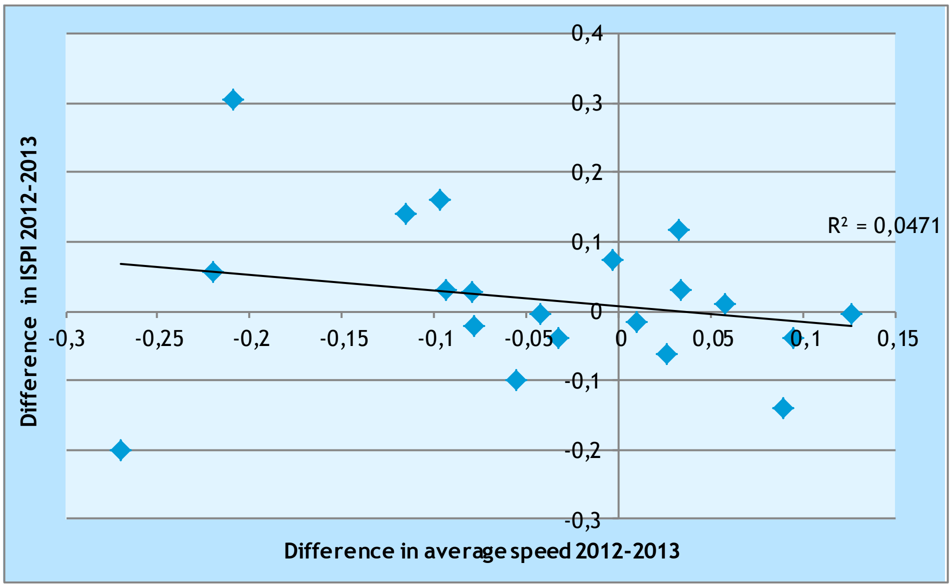


Figure 4 **In this sample, a reduction in the average annual speed results in a worse ISPI value, although the correlation is weak**



3 Conclusions

As this study is based on a limited sample of 23 ships, it is not possible to draw conclusions that are valid for the entire fleet. However, these conclusions can guide further research, preferably with a much larger and more representative sample of ships.

FORS is the only metric that has a reference value. As a result, we can presently analyse how ships would score relative to the FORS reference value, but we cannot do the same analysis for other metrics. In this sample, bulkers are on average the most efficient ships, containers have about the average efficiency score and product tankers shore above the average. If other metrics would have reference lines, we could analyse whether the efficiency scores are correlated across the four metrics, but lacking reference lines, this is not possible.

This paper has analysed the year-on-year changes of the scores in the four metrics of the ships in the sample, as well as the year-on-year changes in the average annual speed of the ship (in nautical miles per hour). Assuming that the reference lines of AER, ISPI and the USP are constant in time, a decrease in the metric would also result in a decrease of the score (or an improvement in the efficiency).

The variation in the year-on-year changes in this sample are larger for FORS than for the other metrics. Ships with a large difference in scores between 2012 and 2013 are often ships that have a considerable difference in days at sea over the years. This may be caused by maintenance, or by ships being laid up.

The year-on-year changes across all metrics are correlated, although the correlation coefficients are low. In other words, the trend in this sample is that an improvement in either metric will often coincide in an improvement in other metrics, but the size of the difference and in some cases even the sign may be different for individual ships. ISPI and AER have a high correlation coefficient, indicating that in this sample, year-on-year changes in the AER have almost always the same value as the year-on-year changes in ISPI. Changes in FORS and USP almost always have the same sign and when the outliers in FORS are eliminated, the correlation coefficient becomes large.

There are many factors that influence the scores in all metrics apart from average annual speed and days at sea. In some cases, the scores changed because of large increases or decreases in the use of MDO, which could indicate changes in the use of auxiliary engines, or because differences in fuel use that cannot be related to changes in average speed or hours in service. These could be caused by unobserved factors like differences in loading conditions, weather and sea conditions and speed profiles (as opposed to average speed).

In this sample, we see a positive correlation between speed and the US proposal, and a weak positive correlation between speed and FORS. This means that if ships reduce their average annual speed, in general their USP score improves, and their fuel consumption reduces (removing outliers with large changes in the number of operating days improves the strength of the correlation for FORS). This is to be expected, because slow steaming reduces emissions and improves the efficiency of ships.

Unexpectedly, this sample shows a negative correlation between speed changes and changes in the AER and ISPI. These correlations are very weak, so they may not mean very much, and they may not be representative. After all, there is no theoretical reason to assume that slow steaming would not be rewarded in the AER or ISPI, although it is rewarded to a lesser extent than in FORS and especially in the USP. The sample results indicate that the impact of efficiency improving operational changes such as slow steaming on the AER and ISPI requires further analysis.

Annex A Scores of ships on each metric

The results of the metric calculation are presented in Table 3. FORS is the only metric for which the proposal contains a reference value, which allows us to evaluate how ships score, except for RoPax for which a baseline is not available. For the other metrics, we can calculate the metric, but not evaluate how ships score relative to a target.

Table 3 Results metric calculation

Ship ID	Ship type	DWT	2012					2013				
			FORS	FORS score	AER	ISPI	USP	FORS	FORS score	AER	ISPI	USP
1	Product tanker	72,650	32,725	102%	7.1	0.94	85	29,943	93%	6.6	0.88	82
2	Product tanker	72,650	28,293	88%	7.4	0.98	90	29,322	91%	8.3	1.10	104
3	Container	13,750	24,885	78%	24.5	0.53	58	25,930	81%	24.5	0.53	65
4	Container	28,520	30,961	44%	16.0	0.72	70	32,770	46%	16.1	0.73	74
5	Container	33,800	52,467	75%	12.8	0.58	101	38,604	55%	13.5	0.61	83
6	Container	33,891	32,590	44%	11.2	0.58	63	33,672	45%	10.8	0.56	59
7	Container	39,330	37,827	42%	11.9	0.79	114	22,225	25%	10.9	0.63	76
8	Container	66,975	82,380	84%	9.7	0.86	112	59,671	61%	8.7	0.77	95
9	Container	80,398	54,454	31%	7.9	1.02	131	71,811	41%	9.0	1.16	132
10	Container	103,800	80,896	60%	8.2	1.11	127	68,058	50%	8.5	1.13	120
11	Bulker	118,000	21,217	44%	2.7	0.4	45	21,899	45%	3.5	0.62	47
12	Bulker	53,450	21,805	61%	7.4	0.66	58	8,475	24%	8.0	0.70	63
13	RoPax	6,450	45,936	n.a.	89.4	8.18	108	43,999	n.a.	88.1	8.06	105
14	RoPax	6,300	32,995	n.a.	67.4	3.90	88	30,953	n.a.	64.3	3.72	83
15	RoPax	6,300	32,724	n.a.	79.5	2.71	88	30,081	n.a.	72.5	2.47	80
16	Container	8,168	17,371	82%	27.1	0.49	37	19,095	90%	26.0	0.47	39
17	Container	8,400	19,612	108%	26.0	0.41	40	18,817	104%	25.9	0.41	38
18	Bulker	227,183	38,938	80%	2.7	0.63	98	41,371	85%	2.6	0.62	98
19	Bulker	32,253	15,254	63%	8.2	0.39	40	13,488	56%	7.0	0.34	37
20	Bulker	32,189	15,488	64%	7.2	0.34	39	13,101	54%	7.0	0.34	35
21	Bulker	169,230	28,655	52%	2.6	0.61	69	26,802	48%	3.0	0.71	72
22	Bulker	70,034	24,647	50%	5.8	0.73	66	26,847	55%	6.0	0.75	70
23	Bulker	37,504	15,203	65%	6.9	0.37	42	15,522	66%	7.1	0.38	39