The Fuel Efficiency of Maritime Transport

Potential for improvement and analysis of barriers

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Preface

This report has been written by a team of experts from CE Delft and Marena Ltd. for the Ocean and Policy Research Foundation. It builds upon and includes an earlier report, titled 'Analysis of GHG Marginal Abatement Cost Curves'. The authors thank the maritime stakeholders who have agreed to be interviewed. We acknowledge valuable comments by the project Steering Committee, a German shipowner and a Japanese shipping company on the draft report. The views expressed are those of the authors, not necessarily of the client. All errors are ours.

Jasper Faber

Contents

Summary

Greenhouse gas emissions from maritime transport account for approximately 3% of global emissions and are projected to increase rapidly over the next decades. One of the ways to reduce these emissions is to improve the fuel efficiency of ships. Many measures can be implemented to do so, ranging from weather routing to installing solar cells.

Marginal Abatement Cost Curves (MACC) present measures to reduce GHG emissions in order of their cost-effectiveness. Over the last years, several MACCs have been published that appear to project different abatement potentials. One thing the MACCs have in common is that they project a large cost-effective potential: several measures can be implemented at a net profit. Taking this into account, some projections have shown that GHG emissions could remain at their 2005 levels until around 2020, provided that all available options to reduce emissions are implemented.

The finding that GHG emissions of maritime transport could remain stable over the coming decade depends crucially on three assumptions. First, that the baseline emission projections are consistent with current developments in shipping. Second, on the abatement potential of maritime transport and consequently on the MACCs. The published MACCs differ with regards to the total abatement potential and the costs. As a result, the emission projections may differ, depending on the MACC used. Third, on whether all the measures included in the MACCs can be implemented. Currently, several studies point to the existence of non-market barriers to the implementation of cost-effective measures. If these barriers can be overcome, emissions could stabilise.

On baseline emissions, this report finds that using such a model and using transport work data to project transport demand yields emission projections that would be 6% higher than conventionally assumed. In addition, it finds that due to the increasing size of the largest container ships, ship emissions may be 3-7% lower in 2020 and 6-13% in 2050. On balance, this report finds that maritime transport emission projections should be somewhat lower than previously assumed. It also finds that because ship emission projections depend on shipping activity projections, which in turn depend on trade projections, it would be good if emission projections would be based on trade models.

This report finds that the differences in MACCs can be traced back to differences in the baseline and a larger number of measures that are included. The remaining difference is about 10% and can be attributed to the other methodological differences.

A literature review and interviews with stakeholders has identified seven general **barriers** to the implementation of cost-effective measures to improve the fuel-efficiency of a ship. These are:

1. A split incentive because a ship owner has to invest in the fuel efficiency of a ship while the charterer pays for the fuel. In practice, the owner can earn a higher charter rate for a more fuel efficient ship in most market conditions but the amount by which the charter rate is higher is only a share of the amount by which the fuel consumption is lower. The fact that owners are only able to recoup a share of the benefits of a fuel-efficient ships depends on two factors. First, micro-economic analysis shows that it is rational in an equilibrium market that the benefits are shared between the supplier (i.e. the owner) and the consumer (i.e. the charterer). How large the share for each party is, depends on the price elasticity of demand and the price elasticity of supply. Both depend on market circumstances and are therefore variable. Second, in charter parties the risks of over- and underperformance of a ship are unevenly distributed. While owners bear the risk of underperformance, there is no risk to the charterer in case of overperformance. Both factors combined have the effect that ship owners who invest in a fuel efficient ship, or who invest in improving the fuel-efficiency of their ship, are able to earn back a share of the fuel benefits through higher charter rates. The remaining benefits are for the charterer.
2. A lack of independent data, especially on new technologies, results in a high uncertainty in the business case and prevents ship owners to invest.
3. The transaction costs associated with searching for and evaluating measures to improve the fuel-efficiency of ships may be high, especially for new technologies. This barrier exacerbates the previous one.
4. Financial constraints are caused with market circumstances and by requirements to invest in other technologies, e.g. for ballast water management and emissions control.
5. Yards may be reluctant to implement new and innovative technologies, and they may be reluctant to include these technologies in their warranties. The reluctance varies considerably over yards.
6. In some cases, ship owners and operators may not have good information on the fuel efficiency of a vessel, making it hard to analyse the impacts of efficiency improving equipment.
7. As some retrofits are only feasible when a ship is already in dry dock, and dry docks are planned on regular 4 to 6 year intervals, there may be a time lag between when a measure becomes cost-effective and its implementation.

The first three are the most important in terms of impacts on the cost-effectiveness of measures and hence on the cost-effective abatement potential. The financial constraints are severe but likely to be temporary; while the reluctance of yards and the fuel monitoring system are very case-specific. The time lag for technologies that require drydocking is a universal barrier, albeit one that can hardly be overcome.

The impact of the barriers on the cost-effective abatement potential can only be quantified in a scenario analysis. This report finds that, depending on the scenario, the abatement potential may be reduced by about 25%, with a scenario-dependent range of 13% - 47%.

There are several ways to overcome these barriers. The split incentive can – to some extent – be overcome by providing more detailed information about fuel efficiency of ships, taking the operational profile into account. As a result, the fuel consumption can be more accurately projected and a larger share of efficiency benefits can be appropriated by the ship owner, thus increasing the return on investment in fuel saving technologies. This would also require changes to standard charter parties.

The credibility of information about new technologies can be improved through intensive collaboration between suppliers of new technologies and shipping companies. In order to overcome risk, government subsidies could provide an incentive. This could have the additional benefit that governments could require publication of results.

1 Introduction

Greenhouse gas emissions from maritime transport account for approximately 3% of global emissions and are projected to increase rapidly over the next decades (UNCTAD, 2011). One of the ways to reduce these emissions is to improve the fuel efficiency of ships. Many measures can be implemented to do so, ranging from weather routing to installing solar cells.

Marginal Abatement Cost Curves (MACC) present measures to reduce GHG emissions in order of their cost-effectiveness. Over the last years, several MACCs have been published that appear to project different abatement potentials. One thing the MACCs have in common is that they project a large cost-effective potential: several measures can be implemented at a net profit. Taking this into account, UNCTAD (2011) finds that GHG emissions could remain at their 2005 levels until around 2020, provided that all available options to reduce emissions are implemented.

The finding that GHG emissions of maritime transport could remain stable over the coming decade depends crucially on three assumptions. First, that the baseline emission projections are in line with Buhaug et al. (2009). Second, on the abatement potential of maritime transport and consequently on the MACCs. Several MACCs have been published. They differ with regards to the total abatement potential and the costs. As a result, the emission projections may differ, depending on the MACC used. Third, on whether all the measures included in the MACCs can be implemented. Currently, several studies point to the existence of non-market barriers to the implementation of cost-effective measures. If these barriers can be overcome, emissions could stabilise.

This report analyses the three conditions for stabilisation of maritime transport emissions. Chapter **Fout! Verwijzingsbron niet gevonden.** analyses aseline emission projections. Chapter **Fout! Verwijzingsbron niet gevonden.** presents a comparative analysis of MACCs for the shipping sector and studies the impact of one crucial element, viz. holding times of ships. Chapter **Fout! Verwijzingsbron niet gevonden.** identifies the barriers to the implementation of cost-effective measures and analyses their causes. A tentative quantification of the impact of the barriers on the cost-effective abatement potential is presented in Chapter **Fout! Verwijzingsbron niet gevonden.**. Chapter **Fout! Verwijzingsbron niet gevonden.** develops possible ways to educe barriers. Chapter **Fout! Verwijzingsbron niet gevonden.** concludes.

2 Baseline emission projections

2.1 Introduction

Most Marginal Abatement Cost Curves (MACCs) for the shipping sector assess the curve in a future year, commonly 2020 or 2030. In order to assess the reduction potential in that year, it is necessary to make a projection of emissions and fleet composition. Hence, baseline emission projections are a crucial element of each MACC.

Emission projections take several factors into account:
- Projections in demand for maritime transport. Often, this is based on a relation between seaborne trade and GDP.
- Projections of fleet efficiency. Often, this is broken down to changes in ship type and size, improvements in fuel efficiency of ships (engines and hull forms, other fuel-efficiency improving equipment like waste heat recovery), changes in ship operational or design speed.
- Projections of the carbon content of fuel.

Many MACCs for shipping take the emissions projections from the Second IMO GHG Study (Buhaug et al., 2009) as a basis. These projections have been based on the assumption of a linear relation between total seaborne trade and GDP. Section 2.2 tests whether other data and methods would yield different results.

Since the baselines have been developed in 2008 and 2009, they did not take into account the size increase in the largest containerships that has occurred since then. Because larger ships are more efficient and the largest container ships account for a significant share of maritime transport emissions, this size increase has potentially significant results on the baseline. Section 2.3 analyses this issue.

2.2 The relation between GDP and trade

The Second IMO Greenhouse Gas Study (Buhaug et al., 2009) also demonstrated that total seaborne trade (TST) and CO_2 emissions have been increasing over time, and made projections of 2050 emissions to enable climate impact studies to be performed.

The projection of CO_2 emissions is essentially done by projecting traffic, and then further estimations of ship size, equipped engine power requirements, changes in engine and vessel efficiency, changes in vessel size and changes in carbon content of fuel are all accounted for. Evidently, a number of assumptions have to be made and examples of such a methodology to various degrees of complexity have been employed in previous emission projection studies to 2050 (e.g. Eyring et al., 2005; Eide et al., 2007; Buhaug et al., 2009; Paxian et al., 2010). What has been common in all these studies is an underlying projection of traffic, or seaborne trade, on the basis of a correlation with global GDP. However, all of these aforementioned studies have used TST, rather than individual cargo or ship types. Both individual ship types for different cargos and their underlying market forces differ. These previous studies have extrapolated TST and then disaggregated out again different sectors. In addition, these studies have all assumed a linear relationship between TST and global GDP. In long-term projections of air traffic and emissions, similar methodologies have been used, but have used non-linear regression models (e.g. FESG 1998; IPCC 1999; Owen et al., 2010).

Moreover, since the aforementioned studies have used TST (in tonnes), while emissions are associated with transport work (in tonne-miles), they have implicitly assumed that the average distance over which cargo is transported has remained constant.

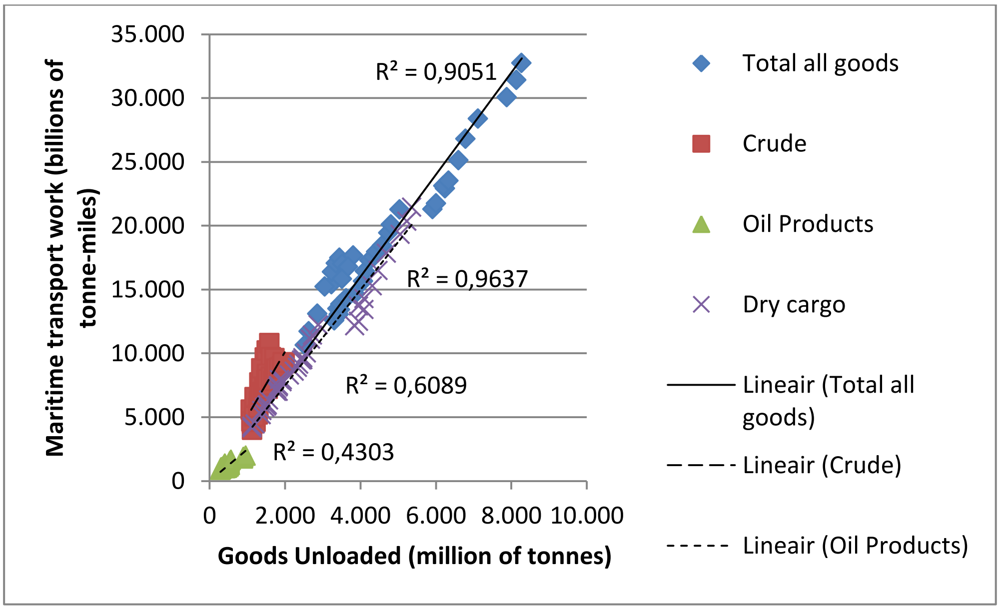
In this section, historical data on maritime transport work from a number of different cargo types from 1970 to 2008 have been used to project future trade in terms of three different types of cargo, and TST out to 2050 using a non-linear regression model. The model used, a Verhulst model of the sigmoid curve type, simulates the three typical phases of economic markets, i.e. emergence, maturation and saturation. Results are presented for the projected growth in seaborne trade to 2020 and discussed in the context of other studies and test results using linear growth assumptions.

2.2.1 Methodology

Data sources

Global data on maritime trade (both seaborne trade and maritime transport work) are produced on a routine basis by the United Nations Conference on Trade and Development (UNCTAD) as part of their annual 'Review of Maritime Transport', which has been produced since 1968 (e.g. UNCTAD, 2009). The UNCTAD Secretariat were approached for digital data and kindly provided annual transport work data back to 1970. Figure 1 shows that TST and maritime transport work are highly correlated, indicating that average transport distances have hardly changed over time which is surprising given emergence of developing economies in the period concerned. This conclusion is valid for total seaborne trade and dry cargoes; for crude oil and oil products, the correlation is much weaker. Probably a regional matrix of transport work would reveal better whether and how trade patterns have shifted. We did, however, not have access to more detailed data.

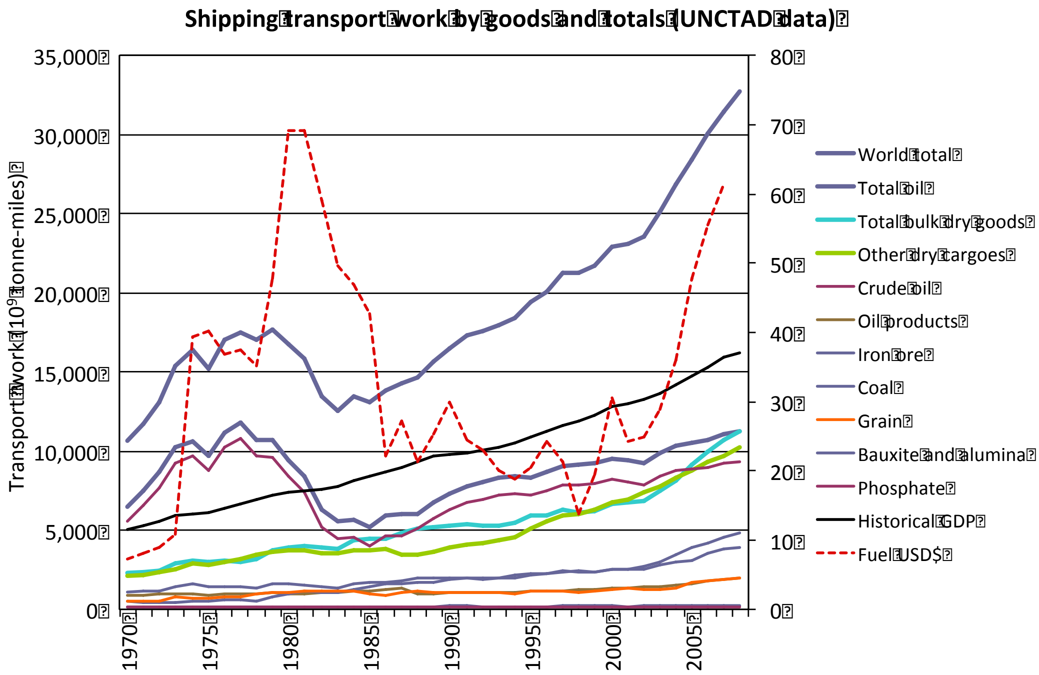
Figure 1 Correlation between seaborne trade and maritime transport work

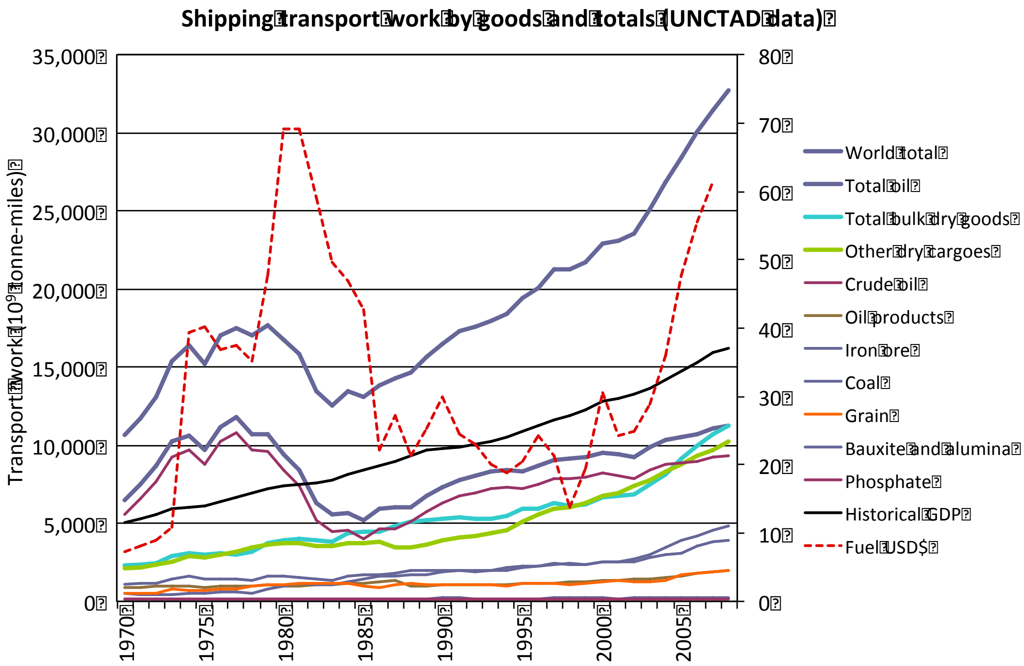


Source: UNCTAD, 2009.

The data included the following cargo types: crude oil, other oil products, iron ore, coal, grain, bauxite and aluminia, phosphate, other dry cargos. By interpretation (with consultation with UNCTAD), these categories can be usefully combined to: total oil, total bulk dry goods, total other dry goods, which are generally transported by three different ship types of tankers, bulk raw material ships, container (and other) ships. These three totals represent the majority of ship types and the changes over time of tonne miles over time are illustrated in Figure 2 along with other influential factors such as fuel price and global GDP.

Figure 2 **Transport work for all categories of cargo provided by UNCTAD, 1970 to 2008 in billion tonne-miles, also illustrated with global GDP and oil prices (right hand axis) in trillion US$ (constant 1990 prices, and constant oil prices (USEIA data).**

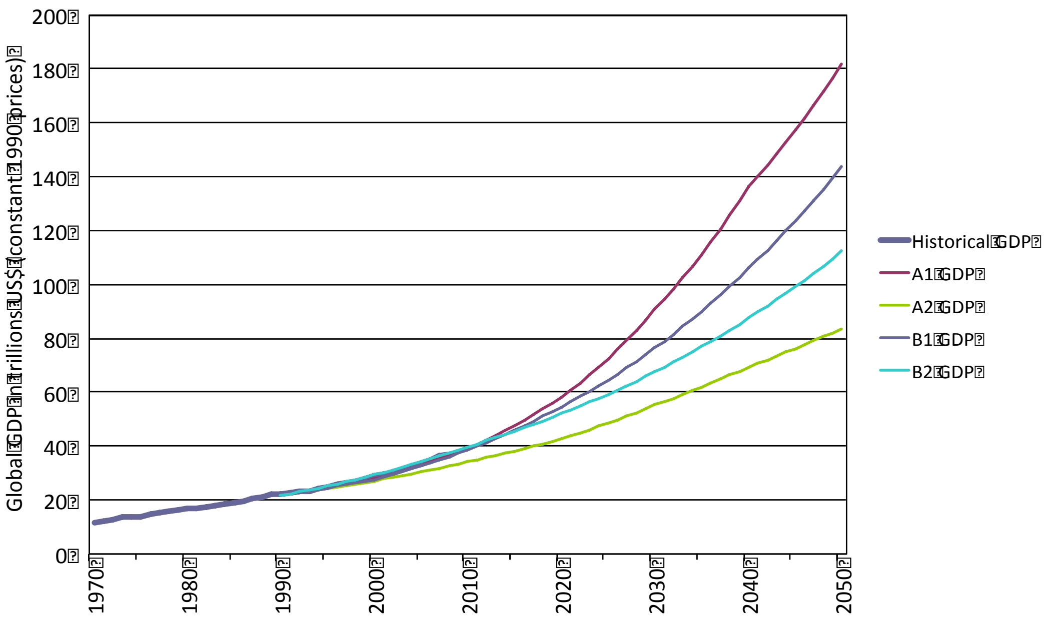




Data for bauxite and aluminia, and phosphate were only available from 1987 on, so have been backfilled in a simplistic manner; bauxite and aluminia from a simple linear trend, and phosphate as an average of the 1987 to 2008 data, as the time-series appears to be stationary.
From Figure 2 it is apparent why the previous studies (Eyring et al., 2005; Eide et al, 2007; Buhaug et al., 2009) have only used TST data from 1985 on; there is an extreme excursion of the TST over the period 1970 to 1985. This excursion in TST is entirely caused by the crude oil seaborne trade and was driven by a number of political and economic factors, some of which are connected with the political situation over oil prices during this period. The volatile situation in the Middle East also led to avoidance of the Suez Canal, and ships also increased dramatically in size such that the Panama Canal became un-navigable for some ships. The outcome for this study is that the period 1970 to 1985 had a particular explanation for the data excursion for tonne-miles of crude oil, so that those data were excluded from the analysis.

Historical data on global GDP were obtained and GDP projection data for the four IPCC SRES scenario families, A1, A2, B1, B2 obtained from the IPCC website, and are described by IPCC (2000). The GDP data are illustrated in Figure 3.

Figure 3 **Historical and future projections (IPCC, 2000) of global GDP in trillions of US$, constant 1990 prices**



Statistical model

The objective of this work was to establish whether a more realistic modelling approach than a linear projection of GDP/TST could be formulated that better simulated established behaviour of markets.
Non-linear statistical models have been used for some time in long-term projections of aviation. The Forecasting and Economic Support Group (FESG) of ICAO produced such a model for the IPCC (1999) assessment, '*Aviation and the Global Atmosphere*' (see IPCC, 1999) and has been used in Owen et al.'s (2010) recent projections of aviation emissions for 2050. Such models are often referred to as 'logistic models', or more simply 'non-linear regression models'. A range of these models exists, such as the Verhulst or Gompertz models, and

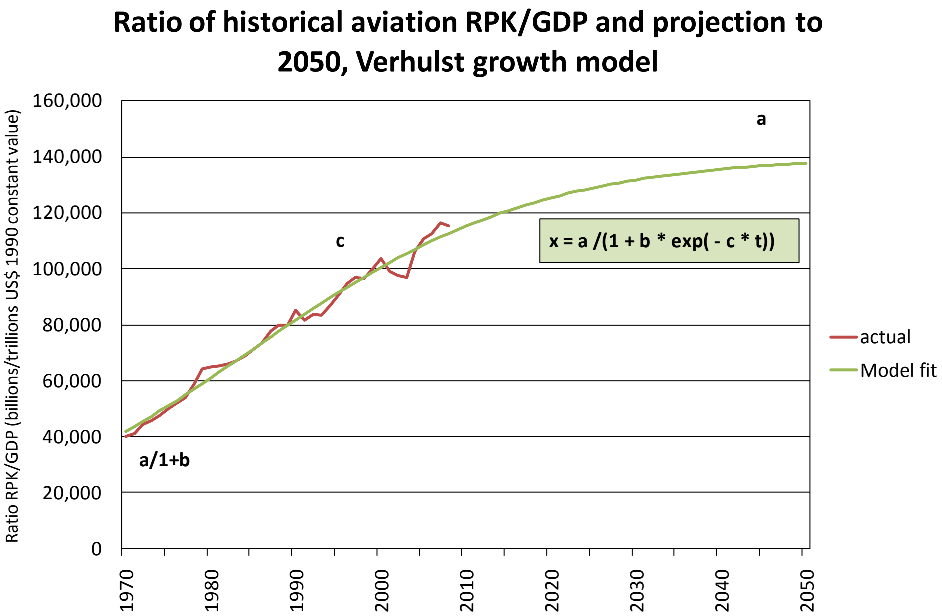
they are commonly used in the econometric literature where the requirement is to simulate some form of market saturation (Jarne et al., 2005).

The sigmoid curve mimics the historical evolution of many markets with three typical phases: emergence, inflexion (maturation), and saturation where the period of expansion and contraction are equal with symmetrical emergent and saturation phases. The phase first involves accelerated growth; the second, approximately linear growth; and the third decelerated growth. Logistic functions are characterised by constantly declining growth rates. The Verhulst function is particularly attractive as it calculates its own asymptote from the data and is described as follows, where x is the future demand and t is time in years and a, b and c are model constants:

$$x = a / (1 + b * \exp(-c * t)) \quad [3]$$

The constants a, b, and c are estimated from initial guesses of asymptote, intercept and slope, and solved by converged iterative solution. PASW v18 provided a suitable program for this model. An application of this model to the aviation sector, where demand is represented by Revenue Passenger Kilometres (RPK), is shown in Figure 4.

Figure 4 Example of application of the Verhulst model to historical RPK/GDP and future IPCC SRES GDPs



The shipping sector, however, is quite different to the aviation sector as the different ship types are quite different in size, power, and market growth rates. The growth rates (see Figure 6) are also potentially more complex than that of aviation. Nonetheless, the Verhulst model was applied to total oil, excluding the 1970 to 1985 period, total bulk dry goods, and other dry goods.

2.2.2 Results

The ratios of maritime transport work to GDP for the three different cargo types (total oil, total bulk dry goods, and other dry goods) are shown in Figure 5.

Figure 5 **Ratios of TST (different sub-types) in billion tonne-miles to historic global GDP in US$ (constant 1990 prices)**

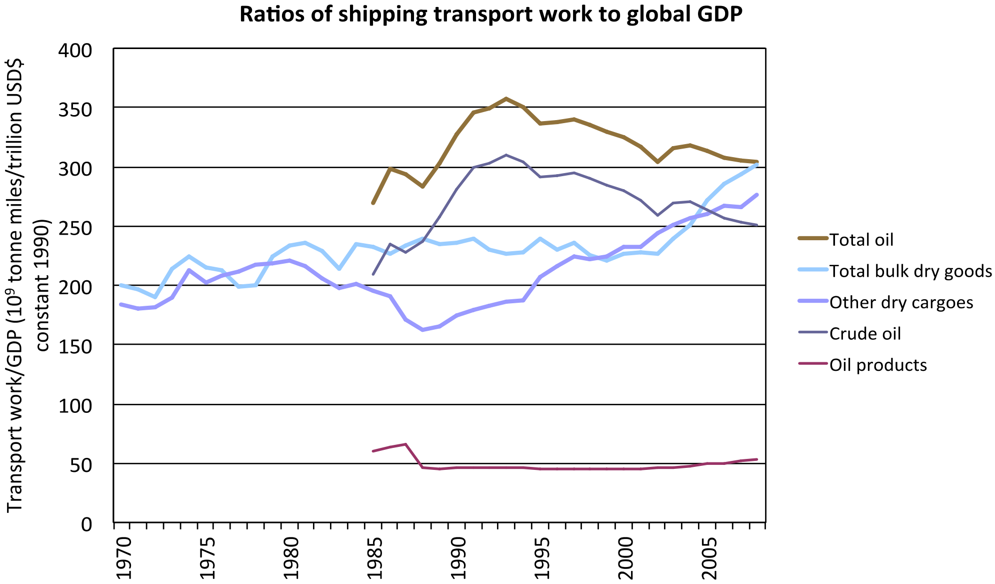


Figure 5 shows a set of more complex signals than the pattern of aviation growth, nonetheless, the patterns of growth of ratios for total bulk dry goods and other dry cargos were particularly promising. Statistically significant and robust Verhulst models were calculated for the three main cargo types, and the future ratios growth curves shown, as calculated, in Figure 6.

Figure 6 **Historical and modelled growth curves to 2050 for ratios of total oil, total bulk dry goods, and other dry cargos. Linear functions have also been calculated and plotted**

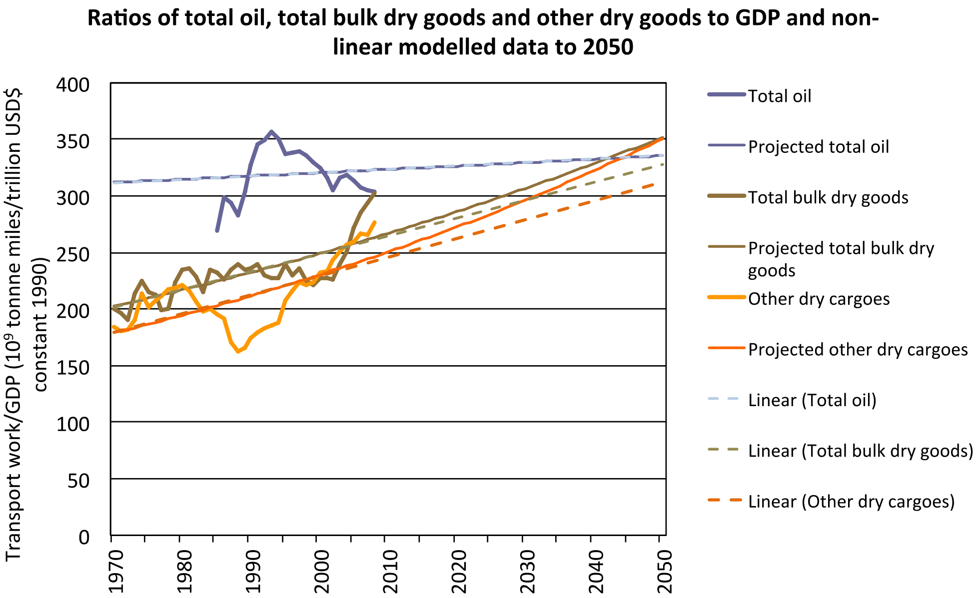
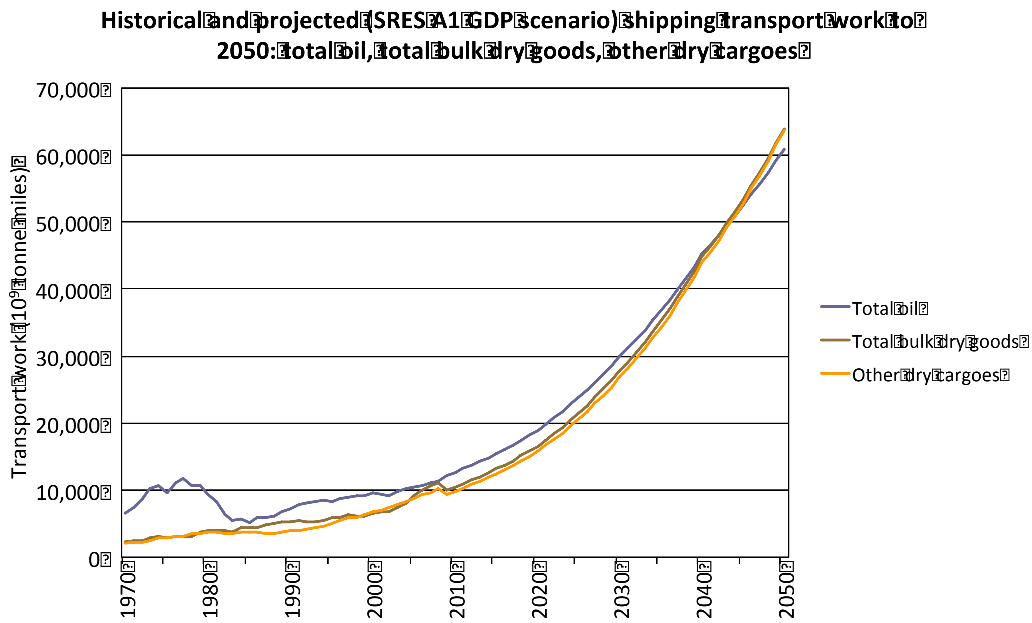


Figure 6 indicates that future growth rates of maritime transport work can be successfully modelled in a non-linear fashion, which is more realistic than the conventional linear model, by three different cargo types. This is a distinct advantage for the next step of assembling a simplified modelling system of future emissions.

2.2.3 Discussion

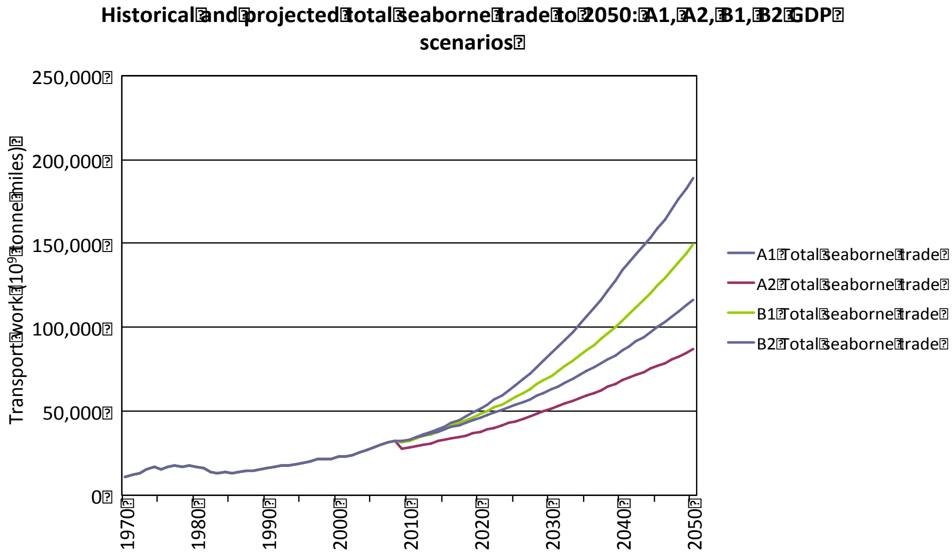
Taking one of the GDP growth scenarios, A1 as an example, the growth in transport work for the three ship cargo types is shown, projected from historical data from the three Verhulst models formulated though to 2050 in Figure 7.

Figure 7 **Historical and projected growth in transport work of total oil, total bulk dry goods and other dry cargoes through to 2050, Scenario A1**



The three ship cargo types have been combined to illustrate total seaborne transport work projections under a range of GDP assumptions, and this is shown in Figure 8. In order to illustrate the TST for the future, the sectors have been added together and illustrated in Figure 8.

Figure 8 Projected global TST in billion tonne-miles for SRES Scenarios A1, A2, B1, B2



The base-case data for the three cargo types in 2008, 2025 and 2050 are given in Table 1.

These data indicate maritime transport work is projected to grow by factors of 1.3 to 1.9 over 2008 levels, depending upon the IPCC GDP scenario projected. By 2050, transport work is projected to grow by between factors of 2.7 to 5.8, the largest growth being demonstrated by the strongest economic Scenario, A1.

As a sensitivity study, Scenario A1 was calculated using individual linear models for the three cargo types (see Figure 3.2) and combined to provide a total linear growth projection for 2050, which was 177,360 × 10^9 tonne miles, some 6% less than the equivalent 2050 growth using the non-linear models, combined, of 188,737 × 10^9 tonne miles. This difference ranged between 0% for total oil, 7% for total bulk dry goods, and 11% for other dry goods.

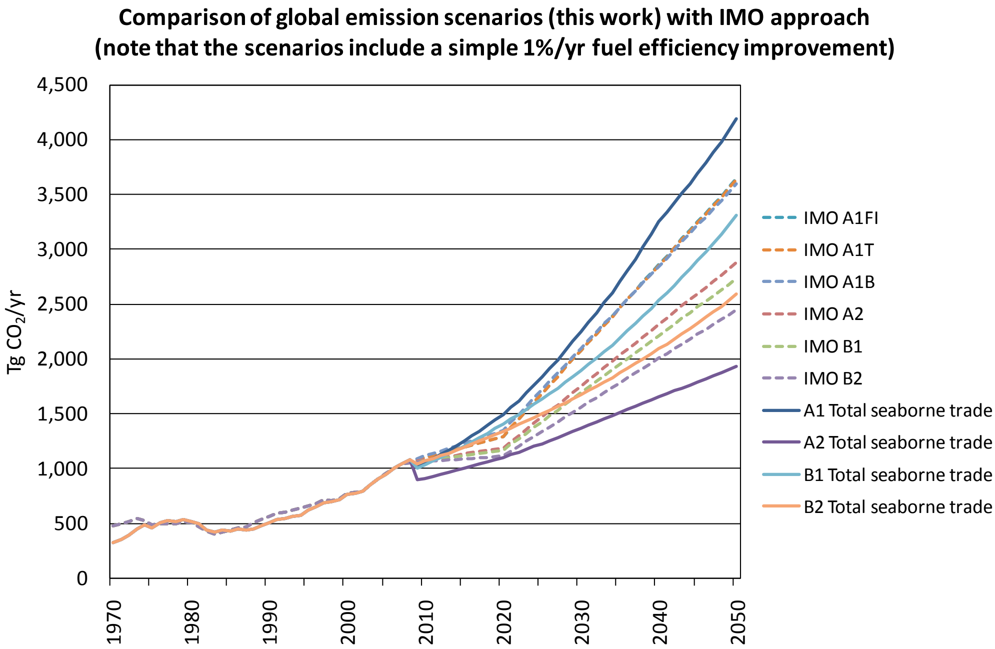
In terms of the linear modelling method, the method utilised here was similar to that used for the non-linear modelling, i.e. a relationship was calculated between the *ratio* of transport work/GDP and a time index, such that a future ratio is calculated and the actual transport work backed out of a ratio substituting global GDP projections. In other studies (e.g., Eyring et al., 2005, Eide et al., 2007, Buhaug et al., 2009, Paxian et al., 2010) it appears that only the relationship between TST and GDP has been calculated. If this method is used, this underestimates 2050 TST in an A1 test case by 13%.

Table 1 Transport work data (10^9 tonne miles) for the three cargo types and TST in 2008, 2025 and 2050 for Scenarios A1, A2, B1 and B2

Year	Total oil	Total bulk dry goods	Other dry cargoes	A1 Total seaborne trade	Total oil	Total bulk dry goods	Other dry cargoes	A1 Total seaborne trade	Total oil	Total bulk dry goods	Other dry cargoes	B1 Total seaborne trade	Total oil	Total bulk dry goods	Other dry cargoes	B2 Total seaborne trade
2008	11,292	11,209	10,245	32,746	11,292	11,209	10,245	32,746	11,292	11,209	10,245	32,746	11,292	11,209	10,245	32,746
2025	23,795	21,490	20,625	65,910	15,935	14,392	13,812	44,139	21,192	19,140	18,369	58,702	19,448	17,565	16,857	53,871
2050	60,972	64,001	63,764	188,737	28,069	29,463	29,354	86,886	48,205	50,600	50,413	149,219	37,685	39,557	39,411	116,652

Although calculation of global emissions is beyond the scope of this project, it is convenient to test whether the global version of the simplified transport projection model is predicting emissions to within the same orders as previous published calculations. In order to do this, a simplified method has been used to calculate emissions. The base year of 2006 has been calibrated against data from the SeaKLIM model (Paxian et al., 2010), itself providing data consistent with the base year of 2007 of the Buhaug et al. (2009) study. By combining the nine ship types of SeaKLIM to the three cargo types represented here, the emissions from the three types are determined and a base case set of emission factors determined, in terms of g CO_2/tonne-mile of approximately 23, 18, and 62 g CO_2 for tankers, bulk dry goods carriers, and other dry goods carriers (largely container ships, reefers, fishing vessels, and 'others', in SeaKLIM). These emission factors are broadly in line with emission factors presented by Buhaug et al. (2009). By applying an overall fleet fuel efficiency factor (set at 1% yr^{-1}), this emulates all the envisaged changes from technology and operational measures in a simplified manner. The results of this calculation are shown in Figure 9, where the results are compared with those of Buhaug et al. (2009).

Figure 9 **Projected global emissions of CO_2 from shipping (this work) to 2050 compared with projections of Buhaug et al. (2009)**



The results show that the projections from this work are broadly in line with those of the work for the IMO (Buhaug et al., 2009) with a somewhat broader spread of results. This initial testing makes further use of the TST model promising that similar results to other studies have been found at a global level but with the advantage of an ability to create scenarios that vary demand by cargo type, and a more sophisticated and econometrically-base extrapolation model that simulates market saturation.

2.2.4 Conclusions

Previous modelling of TST has used truncated data, i.e. 1985 onwards, rather than all the data available from UNCTAD dating back to 1970. This is because of anomalous growth and decline of the tanker sector between 1970 and 1984, which dominated the pattern of TST over this period. Splitting the data into different cargo types (total oil, total bulk dry goods, other dry goods) revealed that the transport work performed by the three types defined was growing at different rates and that amalgamating the data is an unnecessary and potentially over-simplifying assumption, as the three types of cargo are driven by slightly different economics, whilst the overall growth of all three is correlated with global GDP.

In addition to modelling the three different types of cargo separately, we have used transport work instead of total seaborne trade as the former is more directly related to shipping activity and emissions. Also, a more sophisticated non-linear regression model was used as opposed to prior linear regression models. The Verhulst model selected is of the ‘S curve’ type, which more realistically models different growth phases of markets and is often used in econometric statistical modelling.

The particular advantage of splitting the data into three distinct types is that it will facilitate better and more flexible modelling of ship emissions, since the discrimination will allow efficiency parameterisation with assumed increases in vessel size that are specific, rather than for the whole fleet.

Initial testing of the results of the transport work modelling at the global level shows comparable results with other previous studies, when emissions are calculated in a simplified manner, giving confidence in the global modelling approach.

2.3 The increase in size of large container ships

Most MACCs are based on emission projection baselines as developed in Buhaug et al. (2009). These emission baselines are based on projections of transport demand, energy and transport efficiency. The latter comprises ship technology, ship operation and fleet composition. This section focuses on fleet composition.

Fleet composition projections can be broken down in projections of the number of ships and of the average size of ships. These projections are disaggregated to ship type. For each ship type, Buhaug et al. has a number of different size categories (from 1 to 6). Within each category, e.g. crude oil tankers of 80,000 – 199,999 dwt, the average size remains constant over time, but because the number of ships in each size categories may change, the average size of ships of a certain type may change over time.

Table 2 shows the average sizes of the three main ship types and how they are projected to change over time. The increase in average size is the largest for container ships and smaller for tankers and bulkers.

Table 2 Change in average size of different ship types

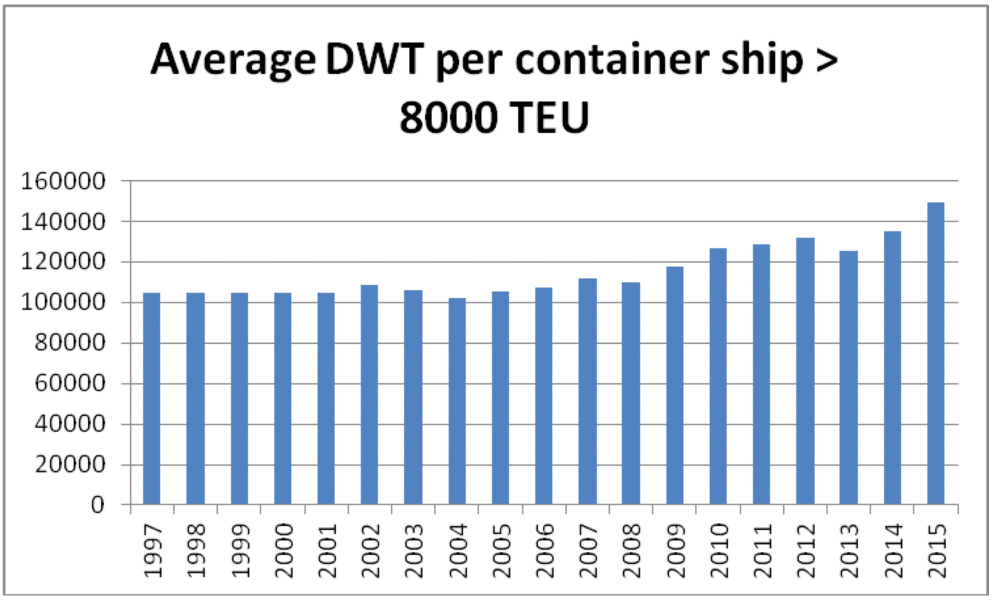
Ship type	Average cargo capacity in 2007 (tonnes of cargo)	Average annual change in size, 2007-2020	Average annual change in size, 2020-2050
Tanker	35,789	-0.29%	0.63%
Bulk carrier	52,574	1.21%	0.16%
Unitised cargo ship	Not available	1.33%	1.39%

Source: CE calculations based on Buhaug et al., 2009.

Containerships account for a significant and increasing share of emissions of maritime transport. In 2007, they accounted for 22% of total maritime transport emissions. The largest size category accounted for 2%. In the A1B Scenario, the share of the largest container ships is projected to increase to 12% of total shipping emissions in 2020 and 22% in 2050. Hence, if the efficiency of these ships changes, the impact on projected emissions may be significant.

Since the publication of Buhaug et al. (2009), the size of the largest container ships (larger than 8,000 TEU) has increased. Buhaug et al. (2009) used an average size for this category of 100,000 dwt, but in 2011 the average new built ship has increased to 125,000 dwt while ships of up to 165,000 dwt have been ordered. Figure 10 shows the development of the size of the largest containerships over time.

Figure 10 The average size of new built 8,000+ TEU container ships has increased 30% between 1997 and 2012



Source: http://www.e-ships.net/ships.htm, accessed January 5th, 2012.

Large ships are more efficient. For container ships, the design efficiency (EEDI) is related to the size by the following formula (MEPC 62/24/Add.1):

$$EEDI = 174.22(dwt)^{-0.201}$$

As a result, a 130,000 dwt containership (carrying approximately 11,000 TEU on average) is 5% more efficient than a 100,000 dwt containership (carrying approximately 8,500 TEU on average). The relation between the EEDI baseline (the average design efficiency) and the size of a ship is presented in Table 3.

Table 3 **The energy efficiency design index of larger container ships is better**

Dwt	EEDI	EEDI improvement over 100,000 dwt
100,000	17.22257	0.0%
110,000	16.89577	1.9%
120,000	16.60285	3.6%
130,000	16.33787	5.1%
140,000	16.09631	6.5%
150,000	15.87463	7.8%

Source: CE Delft, this report.

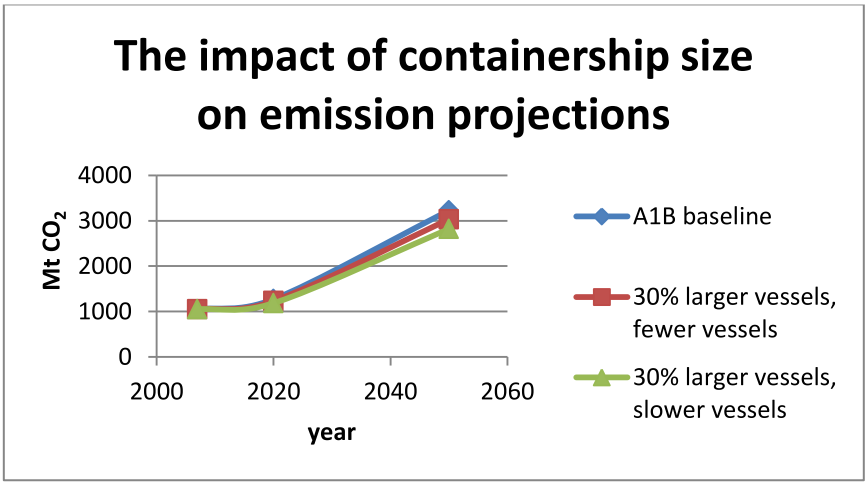
We have modelled the impact of an increase in size of large containerships from 100,000 dwt to 130,000 dwt on average.

In order to assess the impact of larger container ships on emission projections, an assumption has to be made on the relation between the size of these ships and transport demand. We have assumed that transport demand will develop in line with Buhaug et al. (2009). That means that larger containerships create an oversupply of ships. There are broadly two ways how this oversupply can be dealt with:
– There will be fewer, but larger, ships than projected in Buhaug et al. (2009); in this case, the 30% increase in size would result in 23% fewer ships.
– The largest container ships will sail slower to reduce transport work supply; in this case, the 30% increase in size would result in ships sailing 23% slower, which would result in 54% lower fuel consumption per ship.

We have modelled these two possibilities as two distinct scenarios. The slow steaming scenario yields considerably larger emission reductions than the fewer ships scenario. The slow steaming scenario results in large container ships emitting 57% less than in the baseline, the fewer ships scenario results in an emission reduction of 27%.

Depending on the scenario, larger 8,000+ TEU containerships are likely to reduce projected total shipping emissions by 3-7% in 2020 and 6-13% in 2050, relative to a rapidly increasing baseline. Figure 11 shows the emission projections graphically.

Figure 11 **Larger container ships will result in lower emissions**



Source: CE Delft, this report.

2.4 Conclusion

This chapter has analysed ship emission projections and the underlying methodology and assumptions. In particular, it has analysed whether using a saturation model instead of a linear model to project demand would change the emission projections, and it has analysed how larger containerships affect emission projections.

Using a saturation model and transport work data to project transport demand instead of linear models and seaborne trade data yields transport demand projections that are some 6% higher. Using the same assumptions about transport efficiency as in other emission projections, this would imply that projections would be 6% higher.

The size increase of the largest container ships that has become apparent in recent years will have the impact to reduce shipping emission projections. Depending on whether the larger ships will be used to sail slower or to reduce the number of ships, emission projections may be 3-7% lower in 2020 and 6-13% in 2050.

Both factors combined would result in similar to somewhat lower projections of maritime transport emission.

The analysis presented here also points to two other issues. First, since maritime transport activity is driven by trade, and trade is not a simple linear function of GDP, projections could be improved by linking them to trade projections. Second, the relatively large impact of changes in size of container ships, and the fact that these impacts have become apparent only a few years after the Second IMO GHG Study has been published, points to the inherent uncertainty in all these emission projections. Even though commercial shipping has been going on for centuries, the industry is not mature in the sense that its relation to GDP is stable or its current technology can be expected to be stable over a period of decades.

3 Marginal Abatement Cost Curves

3.1 Introduction

Marginal abatement costs curves (MACCs) play an important role in the evaluation of policies to reduce GHG emissions from shipping. They are used as a source of information on the emissions reduction potential, emissions projections and possible future emissions targets.

MACCs indicate how the marginal cost-effectiveness depends on the amount of emissions being reduced, relative to a baseline. Insofar as these curves identify specific technologies, they give an indication of the technologies that can be used to reach a certain emissions target in the most cost-effective manner.

In recent years, several MACCs have been published with apparently different reduction potentials and costs. This chapter seeks to analyse the differences. One crucial assumption in MACCs is the lifetime of technologies. Section 3.6 analyses this factor, the assumptions that have been made in various MACCs and their impacts on MACCs.

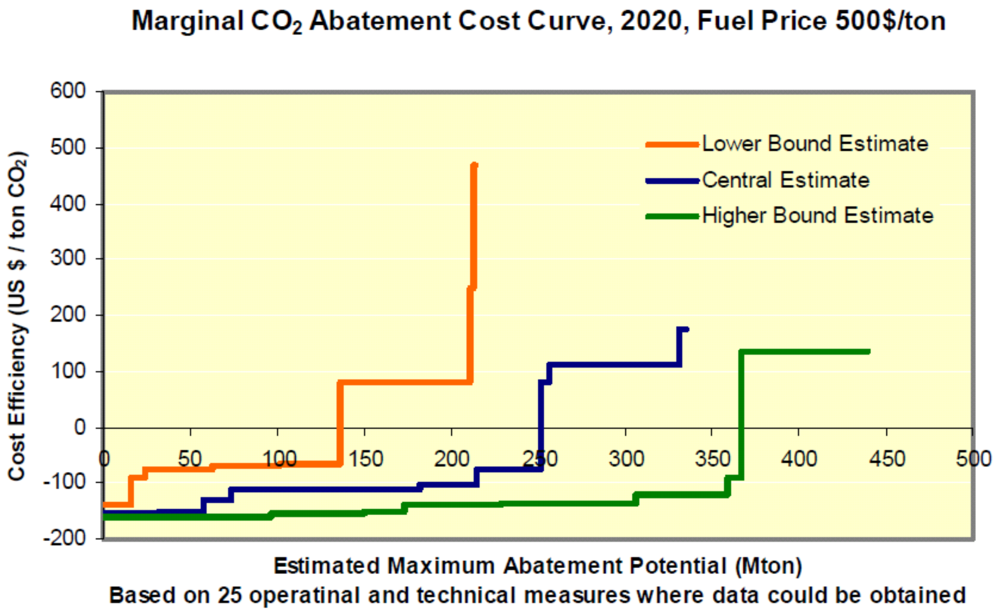
3.2 Overview of published MACCs

To our knowledge, four Marginal CO_2 Abatement Cost Curves of the maritime shipping sector have been published in recent years:

- IMO (2009), Second IMO GHG Study 2009, London (Figure 12);
- DNV (2010), Pathways to low carbon shipping (Figure 13)/Eide et al. (2011), Future cost scenarios for reduction of ship CO_2 emissions;
- IMarEST (2010a), Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measures, MEPC 61/INF. 18 (Figure 14); and
- CE et al. (2009), Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport (Figure 15).

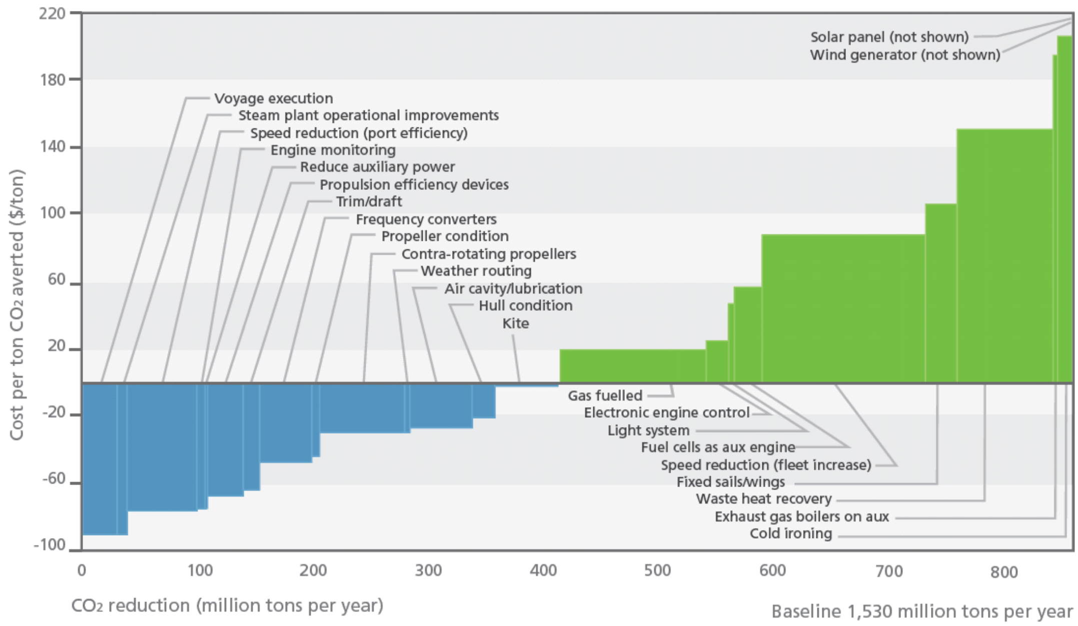
In addition, MACCs have been published in a Norwegian submission to MEPC, IMarEST (2010b) (Updated Marginal Abatement Cost Curves for shipping) and in Annex 10 to the *Full report of the work undertaken by the Expert Group on Feasibility Study and Impact Assessment of possible Market-based Measures* (MEPC 61/INF.2). Both of these were made using the same DNV database as Eide et al. (referenced above) and are therefore not included in the analysis.

Figure 12 Indicative marginal CO_2 abatement costs for 2020



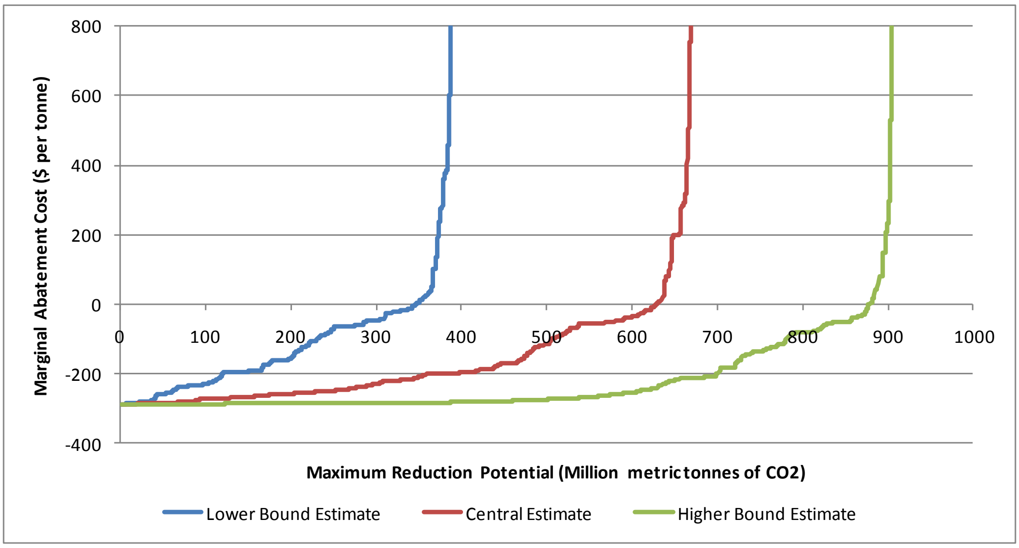
Source: IMO, 2009a.

Figure 13 Average Marginal CO_2 Reduction Cost Per Option - World Shipping Fleet In 2030



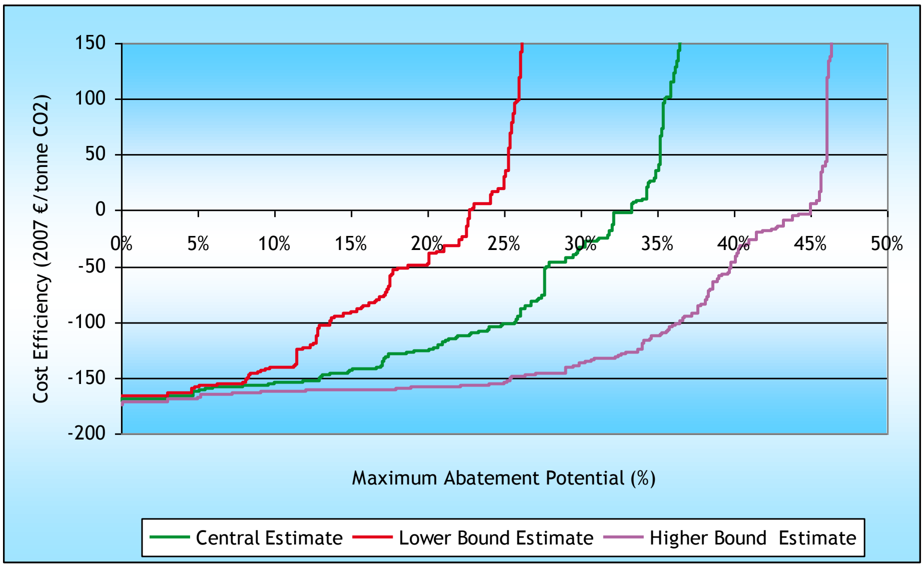
Source: DNV, 2010; Pathways to low carbon shipping. Abatement potential towards 2030.

Figure 14 Aggregated MACC in 2030 with \$900 per ton fuel price and 10% discount rate for all ship types



Source: IMarEST, 2010a.

Figure 15 Marginal CO_2 Abatement Costs for the maritime transport sector in 2030 relative to frozen-technology scenario, range of estimates, US\$ 700/tonne fuel, 9% interest rate



Source: CE et al., 2009.

Previous analysis has shown that MACCs are sensitive to numerous assumptions. The most important assumptions are (IMarEST, 2010a):

- the projected price of fuel;
- the projected fleet;
- the projected fleet renewal rate;
- the abatement measures included in the MACC;
- the discount rate;
- the efficiency of the current fleet;
- the uptake of technologies in the current fleet;
- the future uptake of technologies.

For each of the MACCs studied, we have retrieved the assumptions. We have also assess the extent to which differences in assumptions can explain the differences in the MACCs.

3.3 Descriptive comparison

To our knowledge, the MACC published in IMO (2009a) has been the first MACC for shipping. It has been derived in a collaborative effort of MARINTEK, CE Delft and DNV. The other three MACCs are based on this one.

The main differences between the MACCs presented in IMO (2009a) and the other MACCs are, first, the year of consideration, namely 2020 and not 2030, and, second, the resolution. Whereas the former is presented for fleet average cost-effectiveness values of a limited number of technologies, the latter three include a larger number of technologies and calculate cost-effectiveness for a large number of ship type and size categories. In the following we will compare the three MACCs for 2030, i.e. the MACCs published by Eide et al. (2011), IMarEST (2010a) and CE et al. (2009).

3.3.1 Abatement potential

Table 4 shows a comparison of the main MACCs on both cost-effective and maximum relative abatement potential.

Table 4 **Comparison of cost-efficient and maximum relative abatement potential**

	Eide et al. (2011)	IMarEST (2010a)	CE et al. (2009)
Fuel price in 2030	HFO, LNG: 350 USD/t MDO: 500 USD/t	700 USD/t*	350 USD/t
Discount rate	8% **	10%	9%
Cost-effective relative abatement potential in 2030	~30%	~27%	~25%
Maximum relative abatement potential in 2030	~56%	~34%	~37%

* This is a scenario presented in the sensitivity analysis; in the main scenario a fuel price of 900 USD/t is used.

** This is a scenario presented in the sensitivity analysis; in the main scenario a discount rate of 5% is used and the cost-efficient reduction potential is 11% higher.

In Table 4 the cost-effective and maximum relative abatement potentials derived in the different studies are given for the most comparable scenario.

The cost-effective relative abatement potential in 2030 is assessed to be slightly lower in IMarEST (2010a) and CE et al. (2009) compared to Eide et al. (2011) and the maximum relative abatement potential in 2030 is assessed to be significantly higher in Eide et al. (2011) than in IMarEST (2010a) and in CE et al. (2009).

3.3.2 Framework for the comparative analysis

There are five main factors that determine a Marginal Abatement Cost Curve:
1. The methodology.
2. The scope of the study.
3. The data of the base year.
4. The disaggregation level.
5. Expectations/projections.

These elements are all taken into account in the comparative analysis of the MACCs in Section 3.4. They are illustrated briefly below.

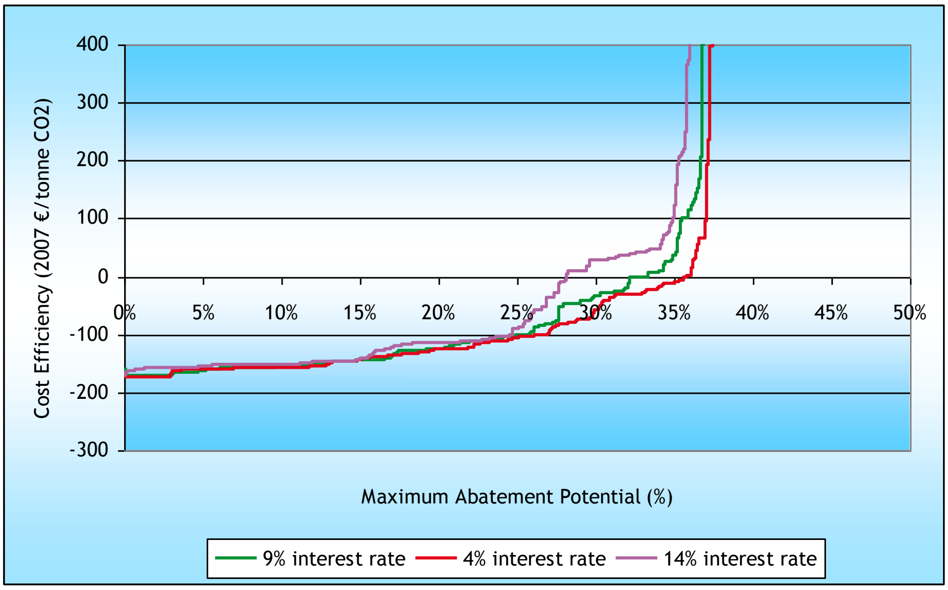
Methodology

There are four major methodological choices to be made when setting up a Marginal Abatement Cost Curve. Choices have to be made regarding:

1. Whether a social or business perspective is taken.
2. Whether and how the abatement measures interact.
3. Whether a frozen technology emission baseline is chosen or a baseline that takes an autonomous efficiency improvement into account. And
4. Which measures are included in the analysis.

A MACC can be set up from two different perspectives, a social or a business perspective. This is mainly reflected in the level of the discount rate that is used to determine the costs that are associated with an abatement measure. The discount rate is higher when a private perspective is chosen, reflecting the fact that companies pay higher interest rates than states. A lower discount rate results in a higher cost-effective abatement potential. The sensitivity analysis carried out in CE et al. (2009) shows that there is indeed a change in the cost-effective abatement potential but that this change can be relatively small:

Figure 16 **Sensitivity analysis w.r.t. discount rate**



Source: CE et al., 2009.

There are CO_2 abatement measures that are not likely to be adopted at the same time or measures that even exclude each other. The abatement potential is overestimated if it is assumed that those measures can be used at large. But even when it is taken into account that not all measures are relevant when determining the abatement potential, MACCs could differ inasmuch as different adoption behaviour can be presumed: different criteria can be used when modelling the choice of the abatement measure from a group of measures that exclude each other. It can, for instance, be assumed that the measure with most advantageous cost-effectiveness will be applied, irrespective of its abatement potential. Alternatively, it could be assumed that the measure with the highest profits or lowest costs is chosen.

The emission baseline can either be modelled as a frozen technology baseline or as an emission baseline with an autonomous efficiency improvement.

Whereas absolute and relative abatement potential presented in the MACC are higher when a frozen technology baseline is used, the emission level that, irrespective of the costs, could be achieved should be the same under both approaches. However, the costs for achieving a certain emission level will be assessed different under these two approaches.

When the probability that an abatement measure will be applied to a ship type/size category is rather low, one might choose not to take this abatement potential into account at all or, alternatively, to take this relative low abatement potential against relative high costs into account. This choice will have an impact on the maximum but not on the cost-effective abatement potential.

Scope of study

The course of a MACC is further determined by the:
- segment of the world fleet under consideration;
- ship types considered;
- ship sizes considered (threshold value); and
- the types of abatement measure that are taken into account (operational and/or technological, established and/or innovative, design and/or retrofit).

Data of base year

The data that is used/is available for the base year is of course crucial for the run of the MACC too. Data is needed w.r.t.:
- the fleet (fuel consumption and (age) structure);
- costs of abatement measures;
- reduction potential of measures;
- diffusion rate of abatement measures.

Disaggregation level

The MACC will have a different run, depending on the disaggregation level with which is worked for setting up the curve. Data can be differentiated w.r.t.:
- ship type/size categories;
- age structure;
- differentiation of cost and reduction potential data w.r.t. the above mentioned categories.

When abatement measures can only be applied to specific ship types and/or size categories, the abatement potential is difficult to determine when aggregated fleet data are used. The cost-efficiency of a certain abatement measure for the average fleet can also deviate strongly from the cost-efficiency for particular fleet segment.

Working with an age structure of a fleet allows, on the one hand, to predict more precisely the number of new ships that enter the market, and allows on the other hand to determine the number of relative old ships in the fleet. The more new ships enter the fleet, the higher the autonomous efficiency improvement. Relative old ships cannot be expected to invest in retrofit measures that have a relative long payback time.

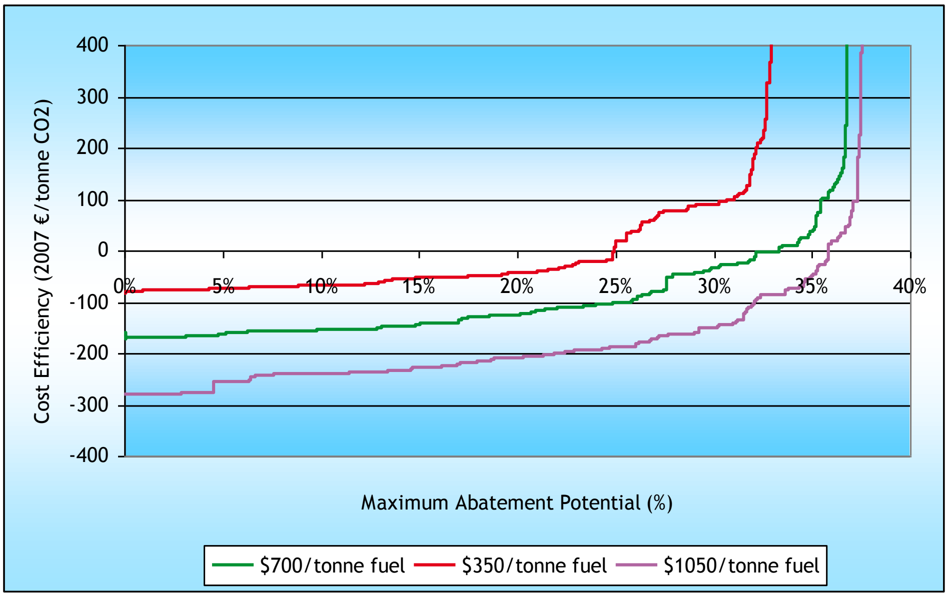
Expectations/projections

The expectations with respect to the following factors have an important impact on the course of the MACC too:
- future fuel price;
- development of fleet structure;
- learning effects w.r.t. abatement measures;

– expected lifetime of measures;
– level of autonomous efficiency improvement.

The level of the fuel price in the year under consideration has a strong impact on the level of the cost-effective abatement potential. Figure 17 illustrates clearly that the higher the fuel price, the higher the cost-effective abatement potential.

Figure 17 Sensitivity of cost-efficient abatement potential w.r.t. future fuel price



Source: CE et al., 2009.

The expected development of the fleet is crucial for the baseline emissions.

Learning effects can have an impact on the future costs as well as on the future reduction potential of an abatement measure. Assuming an increase of the reduction potential over time definitely has an impact on the maximum abatement potential and it can also have an impact on the cost-efficient abatement potential. A decrease of the abatement costs over time leads to an improvement of the cost-effectiveness of the respective measure.

The expected lifetime also has an impact on the cost-effectiveness of a measure. The longer a measure is expected to live, the better its cost-effectiveness.

And finally the expected level of an autonomous efficiency improvement has an impact on both, the abatement potential presented in the MACC and on the assessment of the costs for achieving a certain emission level.

3.4 Comparative analysis

In the previous section, the elements that determine the run of a MACC have been discussed. A comparison of the three studies with respect to these elements shows that the studies differ mainly with respect to nine elements (see Table 5 for an overview).

CE et al. (2009) and IMarEST (2010a) allocate the individual CO_2 abatement measures to measure groups. The measures that are unlikely to be applied together or that exclude each other are thereby allocated to the same measure group. Setting up the MACC, one measure per group is then chosen that is the most likely to be applied to this segment. Eide et al. (2011) take into account that two measures exclude each other, i.e. fuel cells (used as auxiliary engines) and gas fuelled engines.

Table 5 Main differences between the three studies

	Eide et al. (2011)	IMarEST (2010a)	CE et al. (2009)
Modelling interaction between measures	All measures can be combined with each other except for fuel cells (used as auxiliary engines) and gas fuelled engines	Grouping Combination reduces reduction potential in absolute terms	Grouping Combination reduces reduction potential in absolute terms
Baseline emissions	Autonomous efficiency improvement: 2010: 5% 2020: 8% 2030: 10%	Frozen technology baseline	Frozen technology baseline
Baseline emissions in 2030	~1,500 Mt	~2,000 Mt	Reduction potential in rel. terms only (~1,900 Mt)
Coverage of measure types	25 measures	22 measures, 15 groups	28 measures, 12 groups
Cost and reduction potential data in base year	2nd GHG Study data revised and amended	2nd GHG Study data revised	2nd GHG Study data
Fleet (age) structure	2008 fleet composition from LRF; SAI ship building and scrapping forecast for the short-run forecast; heuristic approach for long-term forecast	2007 age structure based on LRF data; 6 age categories of 5 yrs each; max. lifetime of ships = 30 yrs; IMO fleet data and forecast used for total ship numbers	Evenly distributed in 2007; max. lifetime of ships = 30 yrs; IMO fleet data and forecast used for total ship numbers
Fuel price 2030 (sensitivity analysis)	HFO: 350 USD/t MDO: 500 USD/t LNG: 350 USD/t	900 USD/t (700 USD/t, 1,100 USD/t)	700 USD/t (350 USD/t, 1,050 USD/t)
Discount rate (sensitivity analysis)	5% (8%)	10% (4%, 18%)	9% (4%, 14%)
Learning effects	Learning effects applied to several measures in terms of cost reductions and/or reduction potential increase; effect differs per measure	For five innovative technologies, future cost reductions (10-15%) are anticipated for first 5 year period	-

IMarEST (2010a) and CE et al. (2009) work with a frozen technology baseline. More precisely, the two studies work with the A1B Scenario from the Second Greenhouse Gas Study and a sub-scenario that is characterised by a medium demand level and the lowest level of transport efficiency improvement and speed reduction.[1] Baseline emissions in 2030 amount to 1,900 Mt in CE et al. (2009) and to about 2,000 Mt in IMarEST (2010a). In contrast, Eide et al. (2011) work with an autonomous efficiency improvement: "The improvement relative to the average ship in the current fleet is estimated to 5% for ships built in 2010, increasing to 8 and 10% in 2020 and 2030, respectively." This autonomous efficiency improvement is not assigned to specific abatement measures.

IMarEST (2010a) and CE et al. (2009) take almost the same individual abatement measures into account: relative to the latter, IMarEST (2010a) has excluded five individual measures joined two, thus reducing the total number of measures included by five. Compared to CE et al. (2009) in IMarEST (2010a) the measures are allocated to 15 instead of 12 measure groups – it has been assessed that more measures can be combined. In Annex A, Section A.2 a detailed overview is given on these measure groups and the allocation of the individual measures to these groups.

Eide et al. (2011) include a larger number of measures in the cost curve. The following 12 measures are taken into account in Eide et al. (2011) but not in the other two studies:

1. Fuel cells used as auxiliary engines.
2. Electronic engine control.
3. Frequency converters.
4. Gas fuelled engines.
5. Steam plant operation improvements.
6. Engine monitoring.
7. Contra-rotating propeller.
8. Wind power (fixed sails or wings).
9. Speed reduction due to improved of port efficiency.
10. Exhaust gas boilers on auxiliary engines.
11. Wind powered electric generator.
12. Cold ironing.

In contrast, the following 9 measures are covered in IMarEST (2010a) or CE et al. (2009) but not in Eide et al. (2011):

1. 20% speed reduction.
2. Wind engine (Flettner rotor).
3. Main engine tuning.
4. Common-rail technology.
5. Propeller-rudder upgrade.
6. Optimisation water flow hull openings.
7. Hull brushing.
8. Hull hydro-blasting.
9. Dry-dock full blast.

In Annex A, Section A.1 an overview of the coverage of the abatement measures is given for the three studies.

[1] The lowest level is equal to zero in the 2020 forecast. In the 2050 forecast it is zero w.r.t. speed reduction and -0.05 with respect to transport efficiency. For 2030 total ship number have been interpolated.

In all three studies, the cost and reduction potential data that underlies the MACC that is published in the Second IMO Greenhouse Gas Study is used. In IMarEST (2010a) and in Eide et al. (2011) the data has been reviewed by experts and changed slightly. In Eide et al. (2011) data for the extra measures covered has been added.

The fleet (age) structure is determined differently in the three studies. In CE et al. (2009) the annual total number of ships per ship segment is based on the IMO data and IMO forecast. The assumption is made that in the base year (2007) the ships are equally distributed w.r.t. their age per ship segment. Assuming that the maximum lifetime of ships is 30 years and knowing the total number of ships per year, the annual number of ships scrapped and added to the fleet can be derived. In IMarEST (2010a) the annual total number of ships per segment is also based on the IMO data and IMO forecast. However, the age structure of the fleet in the base year is based on the LRF Sea-Web ship database: six age categories of 5 yrs each are differentiated. Thus again the maximum lifetime of a ship is taken to be 30 years. Knowing the total number of ships per year, again the annual number of ships scrapped and new ships can then be derived. In Eide et al. (2011), the fleet composition for 2008 is taken from the LRF database. For the short-run forecast (3-5 yrs) of the fleet structure ship building and scrapping forecasts as published by the Institute of Shipping Analysis (SAI) are used. For the medium- and long-term forecast a heuristic approach is used, assuming in the medium-run a downturn of orders as a consequence of the economic crises. In Table 6 annual scrap and growth rates used in Eide et al. (2011) are given for 5-year averages:

Table 6 **Annual scrap and growth rates used in Eide et al. (2011) (5-year average)**

	Scrap rates (%)	Growth rates (%)					
Year	All ship types	Oil	Dry bulk	Container	LNG	Others	Total fleet
2009	4	12	8	10	29	3	9
2010-2014	3	4	6	4	6	2	4
2015-2019	3	0	0	0	3	1	0
2020-2024	3	1	4	4	3	2	3
2025-2029	3	1	4	3	2	3	3

The three studies also differ as to the expected fuel oil price in 2030. In Eide et al. (2011) the fuel price is expected to be relatively low in 2030. The price for HFO and LNG is assumed to be 350 USD/ton and for MDO 500 USD/ton. CE et al. (2009) expect an average fuel price of 700 USD/ton; a sensitivity analysis is carried out for ± 350 USD/ton. IMarEST (2010a) expect a relative high average fuel price: 900 USD/ton; a sensitivity analysis is carried out for ± 300 USD/ton.

As to the discount rate, different scenarios are presented in each of the three studies. In Eide et al. (2011) the main analysis is carried out for a discount rate of 5%. In a sensitivity analysis results are also presented for a 8% rate. In IMarEST (2010a) and CE et al. (2009) main results are derived for higher, similar discount rates, i.e. 10 and 9% respectively; in a sensitivity analysis results are also derived for 4% in both studies and for 18 and 14% respectively.

The three studies finally also differ with respect to whether and inasmuch learning effects are taken into account. In CE et al. (2009) learning effects are not taken into account. In IMarEST (2010a) learning effects are expected for five innovative technologies: cost reductions of 10-15% are anticipated for the first 5 year period. In Eide et al. (2011) learning effects are applied to several measures in terms of cost reduction and/or increase of reduction potential. The learning effects differ per measure.

3.4.1 Can the differences in assumptions explain the differences in the MACCs?

In Table 4 the cost-effective and maximum relative abatement potential derived in Eide et al. (2011), IMarEST (2010a) and CE et al. (2009) are presented for the most comparable scenario. For these scenarios, the cost-effective relative abatement potential in 2030 is assessed to be slightly lower in IMarEST (2010a) and CE et al. (2009) compared to Eide et al. (2011) and the maximum relative abatement potential in 2030 is assessed to be significantly higher in Eide et al. (2011) than in IMarEST (2010a) and in CE et al. (2009).

When it is taken into account that, compared to CE et al. (2009), the expected average fuel price in 2030 is relatively high in IMarEST (2010a) and is slightly higher in Eide et al. (2011), the assessment the of cost-effective abatement potential can be expected to be the lowest in IMarEST (2010a), and can be expected to be similar in Eide et al. (2011) and CE et al. (2009), but the difference can still be expected to be rather small.

The different expectations with respect to the fuel price however have no impact on the assessment of the maximum relative abatement potential and can therefore not explain the significant difference between Eide et al. (2011) and the other two studies in this respect.

Taking into account that Eide et al. (2011) work with an emission baseline where autonomous efficiency improvement is taken into account, one would even expect that the maximum abatement potential is assessed to be lower. And, if the autonomous efficiency improvement is based on cost-efficient abatement measures, one would also expect the cost-effective abatement potential to be lower. This however is not the case.

A large share of the difference in the maximum abatement potential can be explained by the different abatement measures that are taken into account in the studies. Eide et al. (2011) take 12 abatement measures into account that are not considered in the other two studies. Visual inspection of the average MACC graph shows that these abatement measures account for about 400 Mt abatement potential. This extra abatement potential is also assessed to be relative high, since for most of these measures it is assumed that they can be combined. On the other hand, IMarEST (2010a) and CE et al. (2009) take 9 abatement measures into account that are not considered in Eide et al. (2011). However not all of these 9 measures can be considered as adding to the maximum abatement potential as derived in Eide et al.(2011), since most of these measures would only constitute a substitute for and not complement to measures accounted for in Eide et al. (2011). We estimate that these 9 measures account for 200 Mt extra abatement potential at most.

As to the overlapping abatement measures, which are considered in Eide et al. (2011) as well as in IMarEST (2010a) and CE et al. (2009), cost and reduction potential data for the base year does not seem to be an important source for this difference, since only slight changes have been conducted to the data that is underlying the MACC published in the Second IMO GHG Study. What seems to be much more relevant are the different levels of learning effects that have been assumed. In Eide et al. (2011) learning effects are applied in terms of an increase of reduction potential to several measures, e.g. to waste heat recovery, to exhaust gas boilers, energy efficient lighting and the air cavity system. An increase of the abatement potential of the measures over time has not been assumed in IMarEST (2010a) and in CE et al. (2009).

Figure 18 shows a quantitative comparison of the differences in the maximum abatement potential. Starting from the maximum abatement potential as reported in Eide et al. (2011), we have adjusted it for the baseline. Since CE et al. (2009) have a higher baseline, this results in an increase of the maximum abatement potential from 850 Mt CO_2 in 2030 to 1,040 Mt CO_2. If we subtract the 12 measures that are included in Eide et al. (2011) but not in CE et al. (2009), and add the measures that are included in CE et al. but not in Eide et al., the remaining potential is approximately 760 Mt CO_2. This is approximately 10% more than the maximum abatement potential as reported in CE et al. (2009). Hence, a major share of the difference can be attributed to two factors: a different baseline and a difference in measures. The remaining 10% difference can be attributed to differences in fleet composition and fleet rollover and learning effects of certain technologies.

Figure 18 Quantitative comparison of the differences in the maximum abatement potential

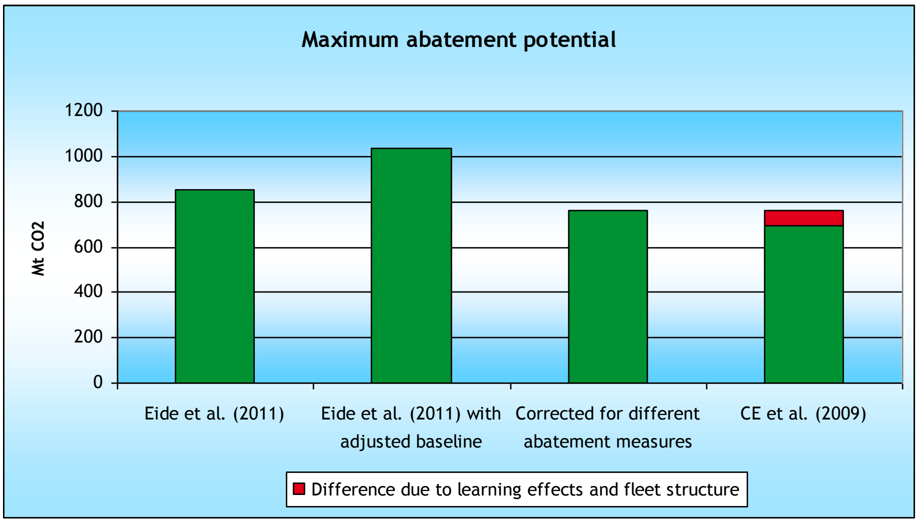
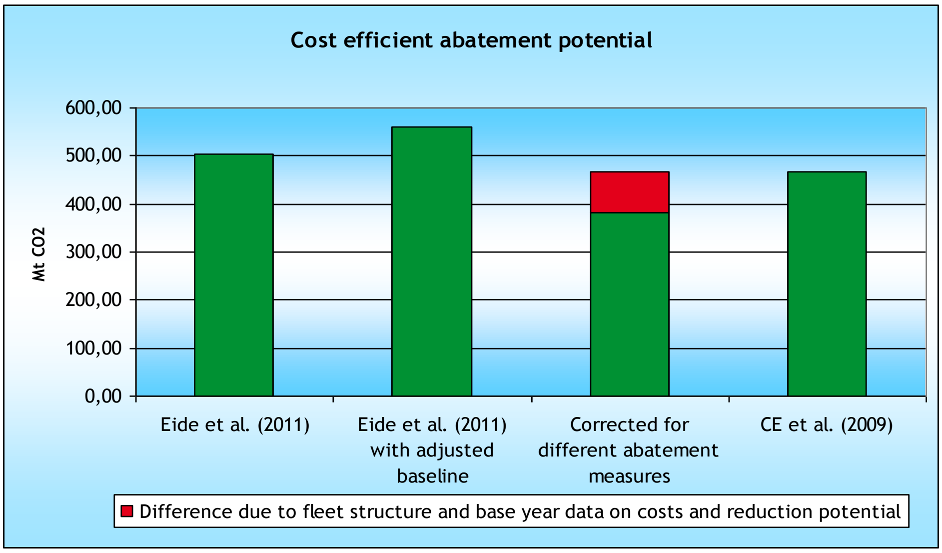


Figure 19 shows a quantitative comparison of the differences in the cost-effective abatement potential. Here, some assumptions have to be made that impact negatively on the quality of the comparison. We had to assume that measures which are cost-effective for a fleet average, are also cost-effective for each ship type and size category. While this is presumably not the case, this was the only way in which we could account for the difference in measures included in the two MACCs.

Starting from a cost-effective abatement potential of a little over 500 Mt CO_2 in the left bar of Figure 19, we again adjusted for the difference in the baseline, increasing the cost-effective potential to 560 Mt CO_2. The cost-effective potential of the measures that both MACCs have in common is shown to be about 380 Mt CO_2 in the third bar from the left. This is approximately 20% less than the cost-effective abatement potential as reported in CE et al. (2009) at the comparable fuel price of USD 350 per tonne of fuel. This difference can be attributed to the fact that some of the measures that are not cost-effective on average are cost-effective on some ship types in Eide et al., differences in fleet composition and fleet rollover and characteristics of certain technologies.

Figure 19 Quantitative comparison of the differences in the cost-effective abatement potential



3.5 Shape of the MACC

All MACCs for shipping have a similar shape: a rather shallow beginning with a negative cost-effectiveness, bending upwards and ending almost vertically (see Figure 12 through Figure 15). This section analyses the reasons for the shape, compares it with other MACCs and draws some general conclusions.

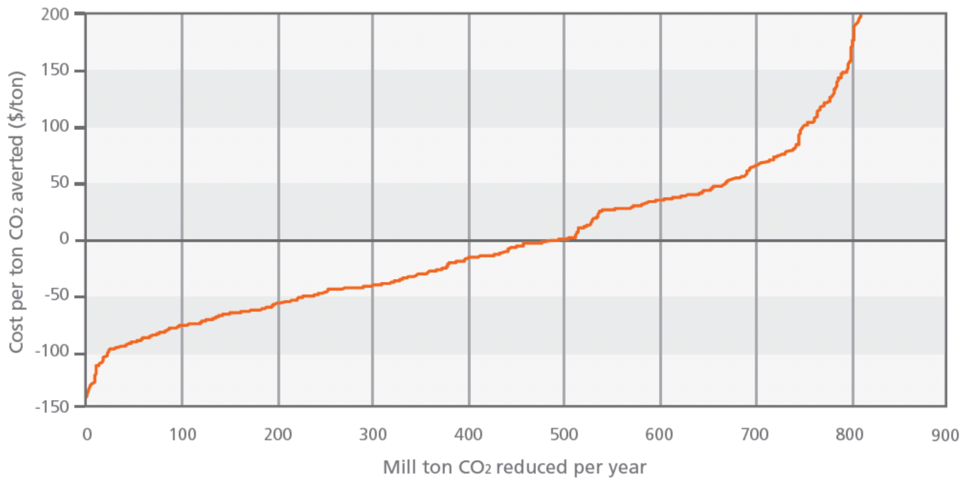
The shape of a MAC curve is to a large extent determined by two factors:
1. The measures included in the curve. And
2. The way in which the curve is represented.

We will discuss both factors subsequently.

The measures included in the curve are an important determining factor of the shape of a MACC. This is especially true for the almost vertical end of the curve. As can be inferred from the DNV curve (Figure 13), which excludes the least cost-effective measures, the end of the curve is dominated by measures like wind generators and solar cells, which have very high costs and a small abatement potential. Excluding these measures yields a significantly flatter curve.

There are several ways in which a curve can be presented. One is to include data on each measure applied to different ship types of different sizes. This yields a curve like in CE et al. (2009) (Figure 15) and IMarEST (2010a) (Figure 14). Another way is to aggregate the data by measure, in other words to present the fleet average cost-effectiveness of specific measures. This yields a curve like Figure 12 and Figure 13. By comparing these two sets, it becomes clear that the latter method yields a much shallower curve. This is also demonstrated by comparing Figure 13 with Figure 20, taken from the same publication, but using a different method to represent the data.

Figure 20 **Detailed Abatement Curves for world shipping fleet 2030**



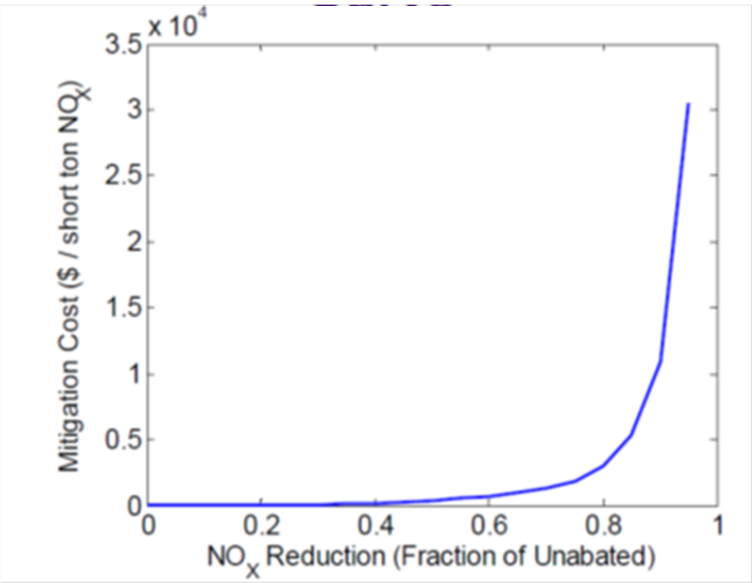
Source: DNV, 2010.

The reason why an aggregated presentation yields a shallower curve is that there can be a significant difference in the cost-effectiveness of a specific measure when applied to different ships. For example, calculations underlying IMarEST (2010a) show that the cost-effectiveness of a 10% speed reduction varies from USD -210 per tonne of CO_2 to USD 1,500 per tonne of CO_2, depending on the ship type and size category. The weighted average cost-effectiveness of this measure is USD -60 per tonne of CO_2. Thus, by aggregating measures across ship types and size categories, the curve becomes shallower.

In summary, the steep end of a curve can be reduced by excluding just a few costly measures and the curve can be made to appear less steep by aggregating data.

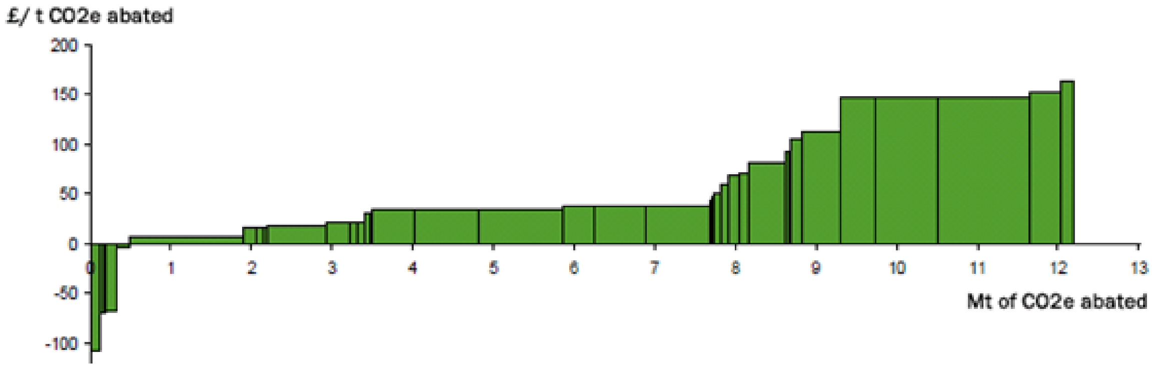
The shape of the shipping MACC is not unique. Figure 21 and Figure 22 show MAC curves for unrelated sectors, NO_x emissions from coal-fired utility boilers and CO_2 emissions from waste processing.

Figure 21 **NO_x Abatement Cost Curves for coal-fired utility boilers**



Source: IIASA, 2006.

Figure 22 Marginal Abatement Cost Curves for the waste sector



Source: Eunomia, 2008.

In many cases, the most costly options are new technologies or technologies that are attractive to niche markets only. This means that technologies which dominate the steep end of the curve are technologies that could be attractive to develop further, e.g. by R&D or innovation support, rather than by market based instruments. The cost-effectiveness of these options can be improved and their potential increased by pushing the technological frontier further (Kesicki, 2010).

3.6 Lifetime of technologies and impacts on cost-effective measures

3.6.1 Introduction

An important parameter in the cost-effectiveness of measures is the lifetime of technologies.

This work package will analyse the different definitions of lifetime (Section 3.6.2), the application of the different definitions to different groups of measures (Section 3.6.3) and the impact of holding times on lifetimes (Section 3.6.4).

3.6.2 Definition of lifetime

There are different definitions of lifetime, such as technical lifetime, economical lifetime, et cetera.

Often lifetime is defined as the period of time during which an individual is alive or as the period of time during which property, an object, a process, or a phenomenon exists or functions.

In case of economical lifetime (or economic life), one refers to the period over which an asset (machine, property, computer system, etc.) is expected to be usable, with normal repairs and maintenance, for the purpose it was acquired, rented, or leased. It is usually expressed in number of years, process cycles, or units produced. Economic life is usually less than absolute physical life for reasons of technological obsolescence, physical deterioration, or product life cycle.

Technical lifetime is defined as the total time for which the equipment is technically designed to operate from its first commissioning. The technical lifetime is often expressed in years or hours of operation. (UNFCC, 2009)
It differs from economic life in the sense that technical life means the period during which a machine is capable of producing, while economic life is related to the depreciation of the machine.

In the shipping industry, the owner can decide to end the economic life of a vessel when the ship's maintenance costs exceeds it's revenues or when the ship has become unattractive for the second hand market. The technical life ends when the ship is broken-down. The owner can sell the ship for dismantling, shipbreaking or ship recycling.

From the owners 'perspective, lifetime of the ship and depreciation of investment is related to the time that the ship is being owned by the owner. Although the lifetime of the ship might be longer, the ship might be sold prematurely. The owner can sell ship in second hand market, but will try to recoup his investment. When energy efficient measures are taken by the owner and when these are reflected in the second hand price, the owner can sell the ship without barriers. However, when these investments are not valuated in the second hand market, the owner might lose his investment. This depends on whether the measures are tied to the ship or not. In case of untied investments, like towing kites, the owner is able to remove the kite and sell the ship without it. However, in case of tied energy efficient measures like a new rudder or air lubrication system, this is not possible. In this case, when the second hand market does not valuate the measures, the investment is lost. The owner can therefore decide not to sell the ship.

3.6.3 Application of the different definitions to different groups of measures

'Lifetime' has a different meaning for different measures. For measures that do not require an investment and that can be discontinued at any time, e.g. biofuels, there are no lifetimes.

For other measures, the annual investment costs vary with lifetime. If there are investments but there is uncertainty about how long a technology will be used, this may also affect the lifetime.

Determining the cost-effectiveness of a ship requires a life cycle perspective where all the costs and benefits are evaluated and compared over it's economic life. Therefore, we will demonstrate an example of how cost-effectiveness is related to lifetime for two cost-efficient measures, waste heat recovery and towing kites[2]. Lifetime runs from 1 to 15 years, while cost-efficiency is expressed in US$ per ton CO_2. Data on cost-efficiency is used from IMarEST (2010)[3].

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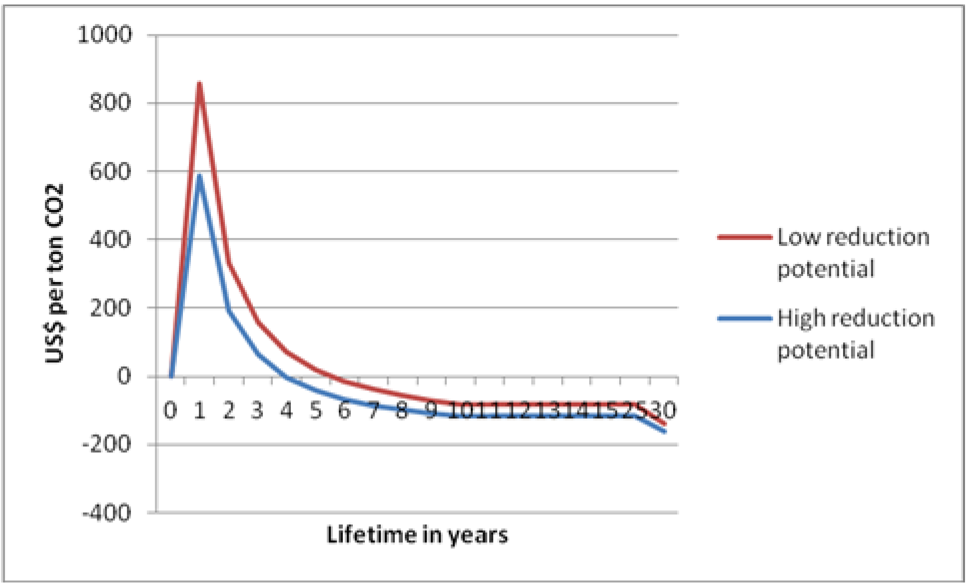
2 A towing kite, as developed by SkySails, is a paraglider-like kite that is attached to the bow of a ship by means of a rope. Wind energy is used to substitute power of the engine.

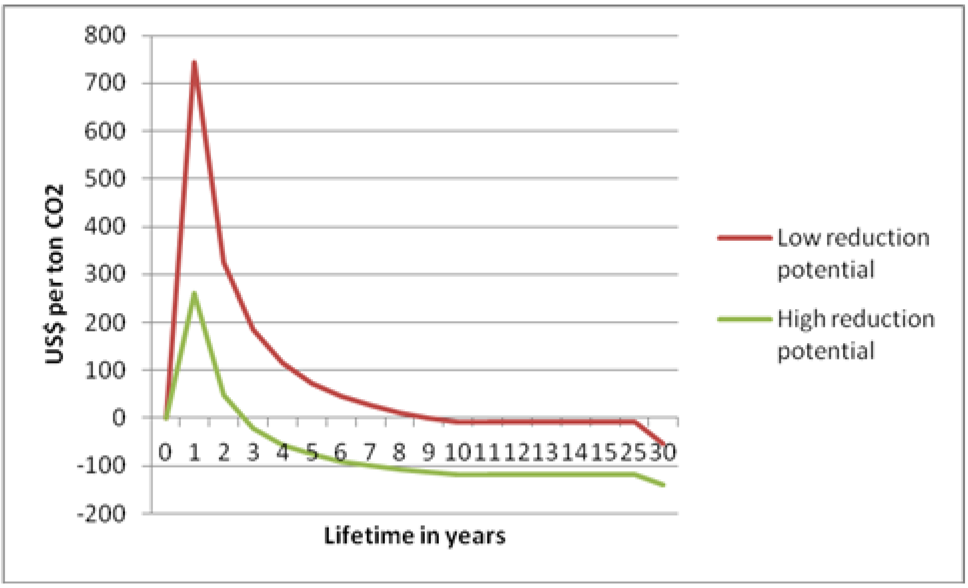
3 Assumptions made: Interest rate in 2030: 9%, bunker fuel price in 2030: US$700/metric ton.

Figure 23 Cost-efficiency of waste heat recovery by lifetime (crude tanker)



This figure shows cost-efficiency (the costs in US$ per reduced amount of CO_2) by waste heat recovery. It shows that the costs of CO_2 efficient measures are high when lifetime is short. For the low and high reduction potential scenario, it is only after respectively 6 and 4 years that the investment in the CO_2 reduction measure has been recouped. When energy efficiency is not reflected in the value of a ship, from a private perspective, economic lifetime of a technology would equal the time a ship is owned by a company. The cost-effective measures are only profitable if the owner owns the ship for several years such that he is able to recoup his investment.

Figure 24 Cost-efficiency of towing kites by lifetime (crude tanker)



This figure shows the cost-efficiency of towing kites by lifetime. It shows that the turning point between the low and high reduction potential scenario is quite large. This can be explained by the large uncertainties with respect to the reduction potential of this measure. For the low reduction scenario, it is estimated that it will take 9 years to recoup the investment, while for the high reduction scenario the payback time is estimated at 3 years.

3.6.4 Impact of holding times on economic and technical lifetimes

There are many estimations regarding lifetime of ships and ship equipment. In the MACCs published in Buhaug et al. (2009) CE et al. (2009) and IMarEST (2010a) a lifetime of 10 year or less is used for equipment (unless in cases such as coating where the lifetime is less) a 30 year lifetime for structural measures on new build ships. The lifetime for equipment is based on the minimum lifetime of installations and environmental equipment in the road and rail sectors according to the HEATCO guidelines (Bickel et al., 2005). These studies used the minimum from the other sectors as equipment in the maritime sector is subject to a more adverse environment. ILO (2009) estimates the average lifetime of a modern vessel at about 20-25 years. OPRF assumes a 10-20 years lifetime for many technologies.

In fact, lifetime of a vessel differs per type of ship, but it also depends on other factors, such as market conditions. When a ship ages, periodic maintenance costs come into play. Repair worthwhile depends on whether the market is strong. If so, the owner squeezes out the maximum economic value out of the ship. If the owner is pessimistic about the future market, he can decide to sell for scrap. Stopford (2009) shows that in a period with general weak market conditions, bulk carriers were scrapped at 25,2 years of age and tankers at 24,7 years (between 1995 and 2000). In 2006, a year of high earnings, the average scrapping age was 28 years for tankers and 30 years for bulk carriers. Specialised ships have longer lives, notably cruise ships which averaged 43,8 years, livestock carriers 33,9 years and passenger ferries 30 years.

Despite the lifetime, a ship owner can decide to sell his ship before the economic or technical lifetime as ended. The period that the owner owns the ship, is indicated as holding time. It is also referred as the real or expected period of time during which an investment is attributable to a particular investor. In a long position, holding period refers to the time between an asset's purchase and its sale (Investopedia, 2011).

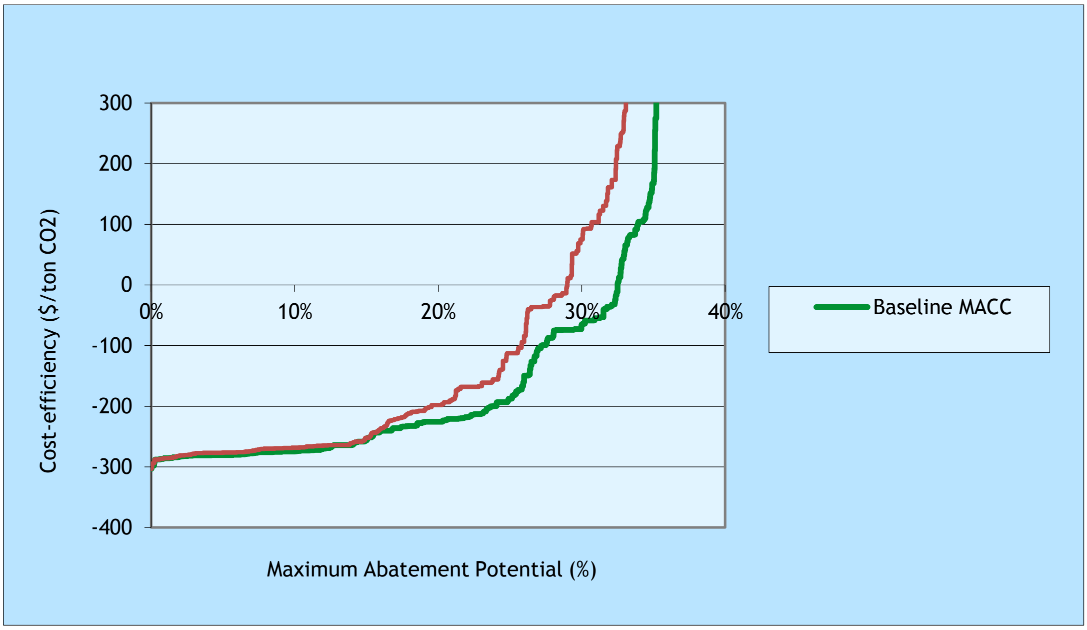
Holding time has no influence on the technical lifetime of a ship, but it does affect economic lifetime. The duration of ownership is related to the way the second hand market valuates energy efficient measures. Furthermore, it depends on whether the investments are tied or untied to the ship and hence can or cannot be removed before the sale (see Section 3.6.2 for a more detailed explanation). Therefore, we can say that holding time will be longer in case of tied investments and in a market that does not reflect energy efficient measures in second hand prices.

Another factor that influences holding time is the way ships are financed. Many ships are financed with bank loans. When revenues are not sufficient to cover the operating and voyage costs, the bank may enforce mortgage rights, seize the ship and sell it to cover the outstanding debt.

Unfortunately, there was no data found in the literature on the average holding period in the shipping industry. It seems that there is no rule of thumb on holding times for shipping companies. The holding time depends on financial contracts but also on the strategy of the individual shipping companies. Therefore, we can not make any numerically statements about holding time.

Figure 25 the change of the cost-efficient abatement potential is illustrated for the case that the economic life of the CO_2 abatement measures is confined to a maximum of 6 years.

Figure 25 Change of maximum abatement potential due to a confinement of the economic lifetime of the abatement measures



Source: CE Delft, this report.

The Marginal Abatement Cost Curves depicted in Figure 25 give the abatement potential of the global fleet in 2030 and are derived for an average bunker fuel price of USD 900 per metric ton as well as for a discount rate of 10%. The baseline scenario is thus comparable to the central scenario in IMarEST (2011).

If the economic lifetime of the measures is restricted to a maximum of 6 years, the MACC curve shifts upwards and the cost-efficient reduction potential is reduced as can be seen in Figure 25. This is due to the fact that the cost-efficiency of those measures deteriorates whose economic lifetime has been assumed to be higher than 6 years in the baseline.

In the case illustrated, the cost-efficient abatement potential is reduced from 32 to 29%. This relative low change of the cost-efficient abatement potential can be explained by the fact that in the baseline the economic lifetime of most of the measures is assumed to be not higher than 10 years. Only for six out of the 26 measures a very high economic lifetime, i.e. the physical lifetime of a ship, has been assumed in the baseline. Such a high economic lifetime is justifiable for the case that the measures have an adequate value on the second hand market or when the investment in these measures will be reflected in the second hand price of the vessels equipped with the measure.

3.7 Conclusion

This chapter has comparatively analysed three Marginal Abatement Cost Curves. The three curves are all based on the MACC as presented in the Second IMO GHG Study, but have been changed afterwards. The methodology is very similar. One study calculates the net present value of the measures if they are implemented in the year for which the MACC is calculated, the other two use annuitised costs. This does not result in significant differences, however.

The MACCs have different assumptions on fuel price and discount rates. These affect the cost-effectiveness of measures and the cost-effective abatement potential, but not the maximum abatement potential. They also have different fleet rollover assumptions.

The MACCs have a different methodology on how measures interact. While two MACCs exclude conflicting measures taken on the same ship (e.g. propeller boss cap fins, nozzles and propeller winglets), the other allows these measures to be taken on the same ship. This could potentially result in an overestimation of the maximum potential.

The MACCs have different business as usual baselines. Two MACCs have a frozen technology baseline with no autonomous efficiency improvements, while the other allows for efficiency improvements over time, which are not attributed to any of the measures in the MACC.

The main differences between the curves is their maximum abatement potential. One MACC has a considerable larger maximum potential than the other two. This can be attributed to a large extent to a difference in the baseline and a larger number of measures that are included. The remaining difference is about 10% and can be attributed to the other methodological differences.

While differences in economic lifetimes can have significant impacts on a number of measures, their overall impact on the MACC is limited. This is because the economic lifetime of most of the measures is assumed to be not higher than 10 years. Only for six out of the 26 measures a very high economic lifetime, i.e. the physical lifetime of a ship, has been assumed in the baseline.

It should be noted that MACCs analyse the cost-effectiveness of measures on a fleet-average (or ship type average) basis. In reality operational profiles of ships vary, as do labour costs, costs of capital, fuel prices, et cetera. As a result, the MACCs are not directly applicable to individual ships or shipping companies.

4 Barriers to the Implementation of Abatement Measures

4.1 Introduction

Most Marginal Abatement Cost Curves (MACCs) for the shipping sector indicate that the sector has a significant potential to improve its fuel-efficiency, and that a large share of this potential can be achieved at negative costs, i.e. at a net profit (Buhaug et al., 2009; CE et al., 2009; IMarEST, 2010a; Eide et al., 2011; Yamaguchi et al., 2012). This finding appears to be at odds with the fact that the actors in the maritime sector are driven by economic considerations, as is pointed out for example by Devanney (2010).

In fact, there are several reasons why the MACCs show a negative potential:
- Most MACCs are for future years, e.g. 2020 or 2030, and most assume fuel prices that are higher than current fuel prices because of a projected increase in crude oil prices and a potential regulatory-driven shift to low sulphur fuels. Because efficiency improvements result in lower fuel consumption, measures become more cost-effective when fuel prices increase.
- Most MACCs show efficiency improvements relative to a frozen technology baseline. In other words, they use the baseline assumption that the efficiency of new built ships in 2020 or 2030 will be the same as in 2007. This assumption is needed in MACC analysis because if an efficiency improvement would be included in the baseline, one would a priory have to exclude the measures which are causing this improvement from the MACC curve. Most studies acknowledge that this assumption is unrealistic, yet necessary for methodological reasons (and quite common in MACCs in other sectors). The only exception to this methodology is Eide et al., 2011, which assumes an autonomous efficiency improvement in the baseline, presumably brought about by technologies not included in the analysis.
- Bottom-up MACCs like the ones analysed here typically evaluate the direct capital and operational costs of certain technologies, as well as their benefits. Risk is usually accounted for by using a discount rate higher than the social discount rate. Other costs, e.g. the costs for searching, evaluating and monitoring new technologies, are not included. To a shipping company, these costs may be high. However, these costs are hard to quantify for the maritime transport sector as a whole because they depend on the technical capabilities of shipping companies, which may vary substantially. Moreover, they depend on the maturity of the technology. Typically, these costs are much higher for new technologies than for mature technologies for which a large amount of information is available.
- Finally, non-financial barriers to the implementation of cost-effective options exist. This chapter analyses these barriers in more detail.

Based on a literature review and interviews with stakeholders (section 4.2), we find that the most important general barriers are the split incentive, the lack of credible information on some technologies, and, in some cases, a principal-agent problem, access to finance, and reluctance of yards to implement new technologies an/or change designs. Other barriers identified in the literature were found to be less important. While in the past shipping companies may have assigned a low priority for fuel-efficiency improvements, rising fuel prices and an increased awareness of the environmental impacts of shipping have changed this. Also, the capacity of retrofit yards is not a major constraint, although for large ships capacity may be scarcer and the current situation may not continue.

Two barriers are considered so important that they merit a further analysis: the split incentive in Section 4.3, and technology-specific barriers including the lack of credible information in Section 4.4.

4.2 Literature review and results from interviews

Several studies have looked into the reasons why not all cost-effective efficiency improvements are being implemented (CE, 2009; IMarEST, 2010a, Devanney 2011; Eide et al., 2011). This section reviews these studies.

In addition, ship owners and other maritime stakeholders were interviewed regarding specific technological and operational measures.
Six different shipping companies were interviewed. Interview partners were the R&D managers and in one case the director of projects and new-building. The shipping companies have some different fleets:
1. Container ships and bulk carriers.
2. Container, Chemical, VLOC and PCTC ships and bulk carriers.
3. Cruise ships.
4. Heavy Lift and Multi-Purpose ships.
5. Bulk carriers, Multi-Purpose vessels and RoRo carriers.
6. Tankers.

Additionally, seven other maritime stakeholders were interviewed covering:
1. A shipyard, mainly for cruise liners.
2. A classification society.
3. An institute for maritime engineering.
4. An international shipping federation.
5. A maritime research institute.
6. An independent international shipping association.
7. A manufacturer of an innovative technology.

The shipping companies were asked which energy efficient measures are already applied and which are planned for the future. Further, they were enquired to give information regarding the expected energy saving potential and the costs of certain technologies, but these answered by none.

The other maritime stakeholders were invited to share their knowledge about the current status, i.e. if the different measures are already applied and their judgement about the future potential.

4.2.1 Split incentive

The most widely identified barrier is the split incentive 'that occurs in much of the industry where fuel is paid by the charterer but technical modifications to a ship are paid for by the owner. Thus the owner is not always in a position to earn back his investments in fuel saving technologies' (CE et al., 2009). The same situation occurs when the second hand value of a ship does not take its fuel-efficiency into account (IMarEST 2010a). Eide et al. (2010) only mention the split incentive as a barrier to the implementation of cost-effective measures, although they also hint at a more general 'lack of responsiveness to economics' in the shipping sector. One reason for this may be that even in market segments where the owner and the operator are the same, shipping companies are sometimes shielded from fuel price increases, e.g. through the application of bunker adjustment factors (CE et al., 2009).

Seminal work by Z.S. Zannetos (1967) showed that in the 1950s and 1960s, time-charter rates were determined in the short run by the size of the ship, the level of the spot rates, the duration of the charter agreement and the lead-time from the point of transaction until delivery. Hence, this work did not directly indicate ship efficiency as a significant factor in charter rates.

An empirical description of how time charter rates were set by a major ship broker around 2000 confirms that efficiency and/or fuel consumption are not among the main determinants of a ship's time charter rate (CE et al., 2009).

On the other hand, Wijnolst and Bartelds (1995) found a clear correlation between fuel consumption and charter rates of bulk carriers in the early 1990s. in their sample, the sum of the fuel cost per day and the time charter rate was roughly equal for almost all the charters. Devanney (2011), citing personal experience, states that time charter rates for tankers from the 1980s until 2005 did take fuel consumption into account.

Some of the apparent contradictions between the two positions are clarified by Veenstra and Van Dalen (2011). Using a database of time charter contracts between 1997 and 2005, predominantly of bulk carriers but also including some tanker contracts, they found that owners underreported the efficiency of their vessels, i.e. they warranted lower speeds than design speeds and higher fuel consumption than design fuel consumption. This suggest that they wanted to avoid bunker and-or speed claims.[4] The analysis also shows that the variations in design ship speed and fuel consumption only partially affect warranted speed and fuel consumption. In other words, if one ship is actually 10% more efficient than another, a charterer is presented with data showing a less than 10% efficiency difference on which he has to base his willingness to pay a certain charter rate. Finally, Veenstra and Van Dalen found that the reported efficiency improved as the market firmed. When demand for ships was high, ship owners were portraying the efficiency of their ships much more positively than when demand was weak. While Veenstra and Van Dalen do not offer an explanation for the relation between market circumstances and reported fuel use, one could understand this when in a firm market there is less of a reputation risk. In a firm market, a ship owner is quite certain that his ship will be chartered again, even if his reputation has been dented by a bunker quantity claim.

The review of the available evidence seems to suggest that charter rates *partially* reflect fuel efficiency. So a ship owner is probably able to command a higher charter price for a more efficient ship, but the benefit of the more efficient ship is generally shared between the owner and the charterer. However, how the benefits are split depends on the market circumstances.

[4] Note that Devanney (2011) states that it can be profitable to overstate the efficiency – this seems to have been a business strategy that served him well but not necessarily a strategy that was generally adopted in the industry.

A related but not identical issue is the relation between freight rates and fuel prices. The empirical evidence shows that freight rates and bunker adjustment factors respond to higher fuel prices (UNCTAD 2011, Notteboom and Cariou, 2009). While this would still give individual operators the possibility to maximise profits by operating optimally efficient ships, it also allows them to meet a certain profit margin target regardless of fuel prices. So if operators have a satisficing strategy rather than a profit maximising strategy, the institutional arrangements that allow them to pass on the variability in fuel prices allows them to continue operating relatively inefficient ships.

Interviewees have, in general, confirmed the existence of a split incentive. Many interviewees have expressed the impression that charterers care little about the fuel efficiency of a ship. Exceptions exist, especially in long term charter markets where ship owners and charterers enter into a long term relationship. Some shipping companies have indicated that they require owners to inform them about the energy efficiency of a ship before they take it on lease.

For ship owners, guaranteeing a certain efficiency can be risky, since they do not always know in advance how a ship will be operated. This makes them reluctant to guarantee a specific efficiency improvement. To arrange the sharing of costs and benefits between owners and charterers if there is a degree of uncertainty is a solution that can be observed in the market but is not common yet.

The split incentive in other sectors

The split incentive is not a strong barrier in most other transport sectors, because the ownership structure is different. In road and rail transport, to our knowledge, transport equipment is usually owned by the operator. Hence, the owner reaps the benefits of fuel efficiency improvements. (In road transport, there may be a barrier as a result of principle-agent relations, where drivers may not have an incentive to drive efficiently, but that is another type of barrier – see Section 4.2.6). In aviation, while the share of leased aircraft is growing, leasing is more a financing construction, comparable to bareboat chartering, than a construction resembling time chartering. Moreover, due to air safety regulations, aircraft owners, whether they are operators or not, are more constrained in the retrofits they can apply.

The only transport sector where the split incentive may present a barrier to the implementation of cost-effective measures is internal waterway transport, where sometimes the barge owner and operator may be different entities, and where similar time charter arrangements can be used as in maritime transport.

Split incentives are an important barrier in the buildings sector, both in office buildings, which are often rented, and in rented residential buildings (Sorrell et al., 2004)[5].

4.2.2 Lack of independent data

As a second barrier to the implementation to cost-effective efficiency improvement technologies, IMarEST (2010a) mentions ‘a lack of information on new technologies’ and the related ‘real or perceived risk of failure of a technology’.

The interviews have confirmed the existence of these barriers. It has been mentioned by shipping companies, research institutes and professional

5 Sorrell, S., E. O'Malley, J. Schleich and S. Scott (2004), The Economics of Energy Efficiency: Barriers to Cost Effective Investment, Edward Elgar, Cheltenham.

societies alike. For non-standard technologies, ship owners and operators have to rely primarily on information from manufacturers and technology service providers. Some ship owners and operators have negative experiences: claims about the effectiveness of certain systems could not be reproduced when tested on their ships. This has often made them sceptical about these claims. Even when technology providers have test reports from independent research organisations, academics or class societies, these are sometimes met with suspicion.

This is especially of importance since the market is characterised by risk aversion with only some first movers that could provide such information. And first movers are not always willing to share their information. Small ship owners have no scope for carrying out their own tests.

Consider for example a supramax bulk carrier. Daily timecharter rates in 2011 ranged from approximately USD 13,000 – USD 17,000.[6] According to Buhaug et al. (2009), such a ship consumes 7,790 tonnes of fuel per year during 262 days at sea. At a price of USD 650 per tonne, this amounts to annual fuel costs of USD 5.1 million. A technology that saves 3% fuel would reduce fuel costs by USD 150,000. If this technology has a chance of breaking down, requiring a ship to go off-hire for ten days, all the benefits would be lost. A risk-averse owner may be willing to forego the opportunity to install the technology.

The relevance of this barrier varies per technology. Section 4.4 provides more details on a number of specific technologies.

4.2.3 Transaction costs

As has been mentioned in Section 4.1 transaction costs are typically not included in MACCs. Still, the costs associated with gathering reliable information on fuel saving technologies may be high, and even more so for technologies that are not applied on a large scale (CE et al., 2009; IMarEST 2010a). This is a barrier that is related to the lack of independent data and like that barrier it is more important for relatively young technologies.

4.2.4 Financial constraints

Even though cost-effective technologies are, by definition, profitable, the may require substantial investments. Also, it may take several years before these investments have been paid back, even in shipping companies that own and operate their own fleet and therefore are not subject to a split incentive barrier (see Section 4.2.1).

Financial constraints may have several causes. IMarEST (2010a) mentions that companies have internal investment appraisal methods which require very short payback times for retrofit technologies. For new technologies, appraisal methods that prescribe a low fuel price in order to account for fuel price uncertainty or because the company has a low fuel price projection for future years.

Interviewees have mentioned that external funding may pose a problem, especially for smaller ship owners. Banks may be reluctant to finance the additional costs of fuel saving technologies because they may consider the technologies to be insufficiently mature. Some smaller shipping companies are able to overcome this problem by developing a ship in close cooperation with a charterer, thus providing additional security to a bank.

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6 http://reports.platou.com/FixtureReport/Pages/BulkFixtures.aspx, accessed February 23rd, 2012.

With changing legislation there are other priorities by shipowners to invest in new technologies. There is MARPOL Annex VI, which forces shipowners to invest in emission reduction technologies to reduce NOx and SO2 emissions (Selective catalytic reduction, exhaust gas cleaning systems like seawater scrubbers and dry exhaust gas cleaning). Further the Ballast Water Convention will soon enter into force. Investments in ballast water treatment systems are in the range of several millions US dollars for large ships. The investments in these high priority technologies will push back the investments in fuel efficient technologies, although there is a lot of room for fuel savings. Ecorys, CE Delft and IDEA (2012) have estimated that the Baltic and North Sea sulphur ECAs could result in an annual additional amount for scrubbers of maximally USD 2 billion – USD 5 billion per annum in the period up to 2020, provided that ship owners will invest in scrubbers rather than use low sulphur fuels. In order to comply with the Ballast water management convention, investments of USD 3-5 billion will be required annually. Since these investments are mandatory, they will probably be prioritised over investments in fuel saving technologies.

Finally, the current market circumstances are unfavourable for investments, as freight rates are low. To the extent that ship owners are affected by bunker prices, these low freight rates coincide with high bunker prices. This may undermine the liquidity and/or the solvency of ship owners, thus creating an additional fi

4.2.5 Reluctance of yards to implement new technologies and capacity constraints

While this has not been mentioned in the literature, ship owner and operators have indicated in the interviews that yards are sometimes reluctant to implement fuel saving technologies. Ship yards offer standard designs and especially smaller owners may have problems with requiring changes to these designs. Some interviewees have the impression that yards have minimised the building cost of a ship, rather than the total costs of ownership. In a period of undersupply of ships changes are also not likely to be called for. Ship yards may be reluctant to make changes because of the warranties they give. Some ship owners indicated that established long term relationships with yards was a way around this problem. Moreover, it was indicated that some yards are much more open to technical change than others.

Only recently shipyards change their minds due to overcapacity in shipbuilding. World orderbook declined to 120M GT at the end of September 2011, the lowest level in five years (CESA, 2011). New ordering remains low in comparison with available capacity as the shipping market is oversaturated with cargo carrying tonnage. Recovery of demand for the specialised vessels is being delayed by the on-going unstable economic situation. Shipyards should begin thinking about new orders by investigating new ship designs and technologies for successful competition.

While the limited capacity of yards to build new ships may have held back innovation in the boom market from 2001 to 2008, this is no longer the case. For most ship types, there appears to be sufficient capacity to build new ships.

The capacity of retrofit, maintenance and repair yards also does not appear to be a barrier, although for very large ships the capacity may be limited. The general situation may deteriorate as yards become increasingly occupied by retrofitting ballast water management systems and possibly scrubbers to comply with MARPOL Annex VI sulphur requirements.

4.2.6 Principle-agent problems

Different actors in the shipping industry may have different incentives with regards to fuel use. Next to the different incentives for ship owners and charterers, discussed in Sections 4.2.1 and 4.3, there may be a split incentive between the crew and the shipping company. Since the crew is hired by the company, this is a typical principal-agent problem where the agent has better information about the fuel consumption of the ship, but not a direct incentive to reduce it as the shipping company has.

It is apparent from several interviews that ship crews systematically overestimate fuel consumption of their ships in their reports to the shipping company. The reasons to do so are diverse. They may wish to have a safety margin in the amount of fuel for unexpected circumstances, e.g. bad weather, need to speed up, et cetera. Some interviewees have also suggested that crews may benefit from having to buy less fuel. Whatever the reasons, if fuel consumption is not reported accurately, it would be hard for a shipping company to accurately assess the efficiency of its ships.

This has an impact on the ability of shipping companies to include efficiency considerations in the charter rate, and on the ability to monitor the effect of fuel saving technologies.

The Ship Energy Efficiency Management Plan (SEEMP) (MEPC.1/Circ.683) requires shipowners, ship operators or any other party concerned, e.g., charterer from 2013 onwards, among others, to improve the energy efficiency of their ships. This includes monitoring of their fuel consumption. As a result, more ships may install equipment that allows them to do so, thus reducing this barrier. Whether this will happen is uncertain, as ships are not required to implement any measures under the SEEMP.

4.2.7 Time lag

CE et al. (2009) has indicated that when there is a constant supply of new technologies, there will often be a time-lag between a measure becoming cost-effective and its implementation due to the fact that some measures can only be implemented when a ship is in drydock. An additional dry docking may reduce the cost-effectiveness of the implementation. Hence, there will always be a natural negative abatement potential.

4.2.8 Low priority in the past

In the past, a low priority may have been given to improvements of fuel efficiency in the past. CE et al. (2009) states that over the past decades, shipping companies have focused on reducing crew costs rather than on reducing fuel costs. As a result, many shipping companies and other stakeholders lacked the knowledge to evaluate efficiency improving measures until recently. This was not irrational per se, as fuel was relatively cheap, so improvements in labour intensity yielded higher benefits than improvements in fuel efficiency. As fuel prices and fuel price forecasts have risen since around 2005, shipping companies and yards have paid more attention to fuel efficiency improvements.

This finding has been confirmed in the interviews. Many interviewees have indicated that, in general, energy efficiency of ships has not been ranked high on the agenda. A number of reasons are given for this, like low bunker fuel costs, a low environmental awareness and, until a few years ago, charter rates that allowed for a profitable operation of almost any ship. However, some interviewees perceive that the market currently is changing and that the awareness with respect to energy-efficiency is increasing.

4.2.9 Conclusion

A literature review and interviews with stakeholders has identified seven barriers to the implementation of cost-effective measures to improve the fuel-efficiency of a ship. These are:

1. A split incentive because a ship owner has to invest in the fuel efficiency of a ship while the charterer pays for the fuel. In practice, the owner can earn a higher charter rate for a more fuel efficient ship in most market conditions but the amount by which the charter rate is higher is only a share of the amount by which the fuel consumption is lower.
2. A lack of independent data, especially on new technologies, results in a high uncertainty in the business case and prevents ship owners to invest.
3. The transaction costs associated with searching for and evaluating measures to improve the fuel-efficiency of ships may be high, especially for new technologies. This barrier exacerbates the previous one.
4. Financial constraints are caused with market circumstances and by requirements to invest in other technologies, e.g. for ballast water management and emissions control.
5. Yards may be reluctant to implement new and innovative technologies, and they may be reluctant to include these technologies in their warranties. The reluctance varies considerably over yards.
6. In some cases, ship owners and operators may not have good information on the fuel efficiency of a vessel, making it hard to analyse the impacts of efficiency improving equipment.
7. As retrofits of certain technologies are only feasible when a ship is already in dry dock, and dry docks are planned on regular 4 to 6 year intervals, there may be a time lag between when a measure becomes cost-effective and its implementation.
8. In the past, shipping companies may have given a low priority to fuel efficiency but this has changed over the last years.

The first two are of prime importance and will be studied in more detail in the next two sections.

4.3 Time charters and the split incentive

As shown in Section 4.2.1, the split incentive is one of the main barriers to the implementation of cost-effective abatement options. It is caused by the fact that ships on time charter are owned by a party that is able to invest in the fuel efficiency of a ship, while it is operated by another party which benefits from potential fuel-efficiency improvements (or suffers from fuel-inefficiency) because it pays for the fuel. The operator is typically not allowed to make changes to the ship.

As concluded in Section 4.2.1, the split incentive is probably not absolute; owners are probably able to command higher charter rates for more fuel-efficient ships, but the increase in the charter rate is lower than the decrease in fuel costs. Moreover, the severity of the split incentive probably depends on the demand for time-chartered ships.

This section analyses the micro-economic and contractual reasons for the impact of the split incentive on the MACC.

4.3.1 Micro-economic analysis of the division of benefits of fuel-efficiency

The micro-economics of the division of the benefits of fuel efficiency is quite complex for two reasons.

First, the outcome can probably best be understood in terms of bargaining, as the market is probably not liquid enough and the variety of vessels and contract terms is too large to analyse this in terms of a perfect market.[7]

Second, there is a significant asymmetry or lack of information. The owner probably knows better then the prospective charterer what the actual efficiency of his ship is. However, as the operational efficiency depends on many factors, and the owner may not have operated the ship, he may not know how efficient the ship actually is. Moreover, as the owner does not know how the charterer will operate the ship, he may not be able to accurately predict the ship's efficiency for the charterer.

Under such imperfect information conditions, bargaining is known to result in a division of the benefits that shares benefits over the two parties engaged in bargaining (Roth 1987).

4.3.2 Types of charter and freight contracts

In the freight market there are 3 types of contractual agreements which are commonly used, namely bare boat charter, time charter and voyage charter.

1. A bare boat charter is a financial arrangement in which the charter hire only covers the financing cost of the ship. The ship owner provides only the ship and gives the charterer complete control, management and operation of the vessel for an agreed leasing period; the charterer has to appoint the crew and pay all operating costs including stores and bunkers.

2. A time charter is for the hire of a ship or charter party for a specified period of time. The charterer pays for the voyage costs, like bunker fuel, port charges, and other costs related to cargo operations. The owner pays for the operating costs and will provide and pay for crew, officers and maintenance.

3. The voyage charter provides transport for a fixed price per ton. The ship owner generally pays all the costs, except possibly cargo handling, and is responsible for managing and planning of the ship and for execution of the voyage. The charterer pays a freight rate per unit of cargo for the carriage of the goods. The owner pays all cost for sea voyages, including fuel. (owner reduces speed and chooses shortest route)

Each type of contract distributes costs and risks differently between the owner and charterer as shown in Table 7.

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7 If the market for ships on time-charter would be a perfect market, there would be an equilibrium price which could change over time depending on the expected amount of demand for maritime transport. This equilibrium price would include both the fuel costs and the charter rate. so in that case, and assuming perfect information about a ship's efficiency, a ship that has USD 1,000 lower fuel costs would have a USD 1,000 higher charter rate.

Table 7 **Contracts, risks and cost distribution**

Type of costs	Bareboat charter	Time charter	Voyage charter
1. Capital cost: Capital, brokerage	Owner	Owner	Owner
2. Operating costs: Wages, provisions, maintenance, repairs, stores and supplies, lube oil, water, insurance, overhead	Charterer	Owner*	Owner*
3. Port costs: Port charges, stevedoring charges, cleaning holds, cargo claims	Charterer	Charterer	Owner*
4. Bunker costs: Canal transit dues, bunker fuel	Charterer	Charterer	Owner*

Source: Stopford (2009).
*Owner: This could also be a subcontractor, or so called the beneficial owner.

The difference in distribution of risk and costs between the owner and charterer might cause a split-incentive and could restrain the owner from making cost-efficient investments, since he is not always the one who benefits from it. Investments in fuel efficiency improving measures (classified as capital costs) are in all cases borne by the owner of the ship, while expenses for fuel are often paid by the charterer (time charter and bareboat charter). In these type of arrangements, the owner is not able to cover his costs and benefit from his cost-effective investment and has therefore no incentive to make these investments.

In a major share of the market, bunker costs are passed on. It is estimated that this may be the case for 70-90% of the bunker fuel consumed (CE et al., 2009). This is hardly surprising for if costs couldn't be passed on, shipping would be unprofitable and there would be no shipping. However, if shipowners have the ability to pass through any increase in cost to their customers in the form of higher freight or term charter rates, this could also be an explanation why fuel efficient measures have not been taken, since there's no point investing in saving. (unless efficiency standards are imposed by law).

The way fuel efficiency is represented in the contractual agreements is studied in Section 4.3.3.

4.3.3 Analysis of charter parties

In this paragraph we study the contracts between the ship owner and charterer. We will focus on the guarantee- and risk structure as laid down in the documents. We will also analyse whether charter parties convey enough information for charterers to value a ship's efficiency and if this is not the case, if it is at all possible to predict a ship's efficiency, given the variability in conditions under which she sails.

Charter parties

Details of the contractual agreement are set out in a charter party, where the responsibilities and costs are defined, as well as how to anticipate when problems arise. A charter party is a private contract between the owner or disponent owner of a vessel and the charterer.

There is a large number of standardised charter-parties for the main trades and routes since it would be too time consuming to develop a new charter-party for every contract. More than 50 charter parties have been approved by the Baltic and International Maritime Council (BIMCO). In addition tot he large number of standard charter parties in use there is also a vast number of private charter parties (in-house charter parties). Both are supplemented by a large number of additional clauses.

The remainder of this Section focuses on the information conveyed in the standardised charter parties which are often used as a basis for specific charter parties.

The Gencon charter party form is the most commonly used general purpose voyage charter form. An example is included in Annex D. Time charters follow the same principles, but include boxes to specify the ships equipment and performance (speed, fuel consumption quantity and prices of bunkers). The most commonly used standard forms for time charters are the Baltime and the New York Produce Exchange Time Charter (NYPE).

With respect to the efficiency of the ship, charter parties in general convey information on:
- fuel consumption (in tonnes per day);
- speed (in knots);
- ship size;
- capacity (container, bunker);
- engine type and power;
- deadweight;
- age of the ship.

Speed and consumption clauses
To reduce uncertainty for the charterer, a charter party often contains a speed ands consumption clause, in which the owner specifies the ship's warranted performance in terms of speed and fuel consumption. This is of particular significance for the time charterer, since the charter is in charge of the commercial operation of the ship and bears the cost and risks.

In the Baltime and NYPE both contain a similar description about the speed and fuel consumption.
- The Baltime 1939 (BIMCO Uniform Time-Charter): provides that the ship shall be "capable of steaming about… knots in good weather and smooth water on a consumption of about … tons oil fuel.
- NYPE 93 (New York Produce Exchange Time Charter): speed about… knots, fully laden, in good weather conditions and up to and including maximum force …. on the Beaufort wind scale, on a consumption of about…. long*/metric* tons of….
- Boxtime (BIMCO Uniform Time Charter Party for container vessels): the vessel's fuel consumption in port and at sea shall not exceed the amounts …., at all times for port consumption and in smooth water with winds snot exceeding Beaufort Scale 4.
- General time charter party: provides speed capability in knots (about), and consumption in m/tons at stated speed (about). Speed and consumption on summer dwt in good weather, max windspeed 4Bft.
- Intertanktime 80 (Tank time charter party): Speed/consumption: the average speed of the vessel will not be less than …. Knots when loaded and …. Knots in ballast on an average daily consumption of no more than ….. metric/long tons of fuel oil having a maximum viscosity of…. Seconds Redwood nr. 1 at 100°F/Centistokes at 50°C and …. Metric/tons diesel oil for main engine and auxiliaries respectively excluding heating of cargo and tank cleaning.

- Gencon (BIMCO Uniform General Charter): no mention about ship efficiency. No warranties on speed or fuel consumption since owner is responsible speed and fuel efficiency.

Devanney (2011) mentions that charter parties often contain speed-consumption curves (i.e. an indication of how the speed of a particular vessel relates to its fuel consumption). The charter parties reviewed here do not contain such information, however: they only provide data for one particular point. It is possible that such information is often added to the standardised charter parties.

If the speed and fuel consumption don't correspond to the indicated specifications in the charter party, the charterer has the right to demand for compensation or an adjustment hire. A claim is effectuated if the difference between the actual and warranted ship speed, and/or between actual and warranted ship fuel consumption is larger than a reasonable margin. In practice this margin is usually 0,5 knots for speed and 5 percent with respect to fuel consumption (Veenstra and Van Dalen, 2011). Good weather conditions often implies smooth water and with winds not exceeding Beaufort Scale 4.

Some charter parties contain specific off-hire provisions in relation to reduced vessel performance on account of speed or excessive fuel consumption. In these provisions it is stated that, in case of poor performance, as a result of a specific defect in the vessel's hull or machinery, compensation is offered by deductions from the hire. For example:

- General time charter party: Off hire clause, but not specific for speed or fuel consumption. Owners shall not be held liable for any reduction in the vessel's speed performance and/or increased bunker consumption nor for any time lost and any other consequences arising as a result of supply of unsuitable fuels.
- NYPE93: In the event of loss of time from deficiency and/or default…, the payment of hire and overtime, if any, shall cease for the time thereby lost…. If upon the voyage the speed be reduced by defect in, or breakdown of, any part of her hull, machinery or equipment, the time so lost, and the cost of extra bunkers consumed in consequence thereof, and all extra proven expenses may be deducted from the hire.
- Intertanker: in the event of loss of time arising from interruption in the performance of the vessel's service or from reduction in the speed of the performance thereof or in any other manner… no hire shall be due or payable in respect of any time lost during which the vessel is unable to perform the service immediately required from her.

We have not found any provisions on adjustment of the charter rates in case a ship consumes less fuel than warranted by the owner.

However, not in all charter parties it is stated clearly what procedure to follow when speed or fuel consumption is higher than warranted in the charter party.

- Boxtime: no mention what to do when consumption is higher or lower than stated in the contract.
- Baltime 1939: no mention what to do when consumption is higher or than stated in the contract. No off-hire clause
- Gencon: - (idem)

It is of course possible that clauses are added to the standardised charter parties on compensation.

Since these provisions are not included in all charter parties and legal understanding and interpretation may differ between them, the Federation of National Associations of Ship Brokers and Agents (Fonasba, 2000) set up a Time Charter Interpretation Code. This Code describes the claim process for time charters and how to interpret existing charter party clauses as well as to assist disputing parties where charter parties are silent or non-determining. In this way many often occurring and avoidable maritime charter party disputes can be eliminated.
Regarding speed and fuel consumption, the Code mentions the following:

> *"If it is found that the vessel's speed has fallen below the warranted speed, hire shall be reduced by an amount equivalent to the loss in time involved at the rate of hire. And if it is found that the vessel's consumption has exceeded the warranted consumption, the additional costs shall be borne by the owners."*

Underperformance in case of speed is calculated by dividing the mileage made good during qualifying periods by the warranted speed and comparing this to the time actually spent. Any excess (apart from the margin) is to be treated as off-hire. Evidence of weather conditions are often taken from the vessel's logs, weather service reports, or weather routing service.

Underperformance with respect to fuel consumption is calculated by multiplying the warranted consumption per day by the recorded qualifying periods, compared to the actual consumption.

> *"In case of any excess, the charterers are be to compensated by the owners for such excess in cost to the charterers calculated at the prices at the last port bunkers were supplied during the time charter, or those at delivery whichever applicable. Such amount may be deducted from hire."*

Again, the Code does not contain references to overperformance of a ship.

To prevent these legal disputes, owners, will try to set warranted speed and consumption as close to actual numbers. Veenstra and van Dalen (2011) investigated these clauses and found out that shipowners engage in strategic behaviour by setting warrant speed levels below design speed and ship fuel consumption levels above design fuel consumption. Setting a relatively high warranted fuel consumption level and a relatively low warranted speed reduces the likelihood of a claim by the charterer.

Hence, our analysis of charter parties shows that the risk for the performance of a ship in terms of speed and fuel consumption lies exclusively with the owner. In case the ship is less efficient than warranted, he has to compensate the charterer. When, on the other hand, the ship is more fuel-efficient than warranted, the charterer benefits but the owner does not.

4.3.4 Conclusion

The fact that owners are only able to recoup a share of the benefits of a fuel-efficient ships depends on two factors.

First, micro-economic analysis shows that it is rational in bargaining that the benefits are shared between the supplier (i.e. the owner) and the consumer (i.e. the charterer) when neither has perfect information about the size of the benefits. How large the share for each party is, depends on the price elasticity of demand and the price elasticity of supply. Both depend on market circumstances and are therefore variable.

Second, in charter parties the risks of over- and underperformance of a ship are unevenly distributed. While owners bear the risk of underperformance, there is no risk to the charterer in case of overperformance.

Both factors combined have the effect that ship owners who invest in a fuel efficient ship, or who invest in improving the fuel-efficiency of their ship, are able to earn back a share of the fuel benefits through higher charter rates. The remaining benefits are for the charterer.

4.4 Barriers for specific technologies

The technology-specific part of the questionnaire was sub-divided into following sections:

1. Technical measures.
   a Reduction of resistance.
   b Engine related measures.
   c Other technical measures.
2. Alternative fuels and power sources.
3. Operational measures.

Outcome
10 out of 12 interview partners answered the questions regarding specific technological and operational measures to improve the efficiency of the fleet. One shipping company did not want to answer the questions, but claimed that they apply nearly all of the proposed technologies and operational measures. However, the data are not included in the analysis, but would change the figures slightly. The results of the interviews are discussed in the next chapter followed by a separate analysis of the four ship owners alone.

4.4.1 Results

4.4.2 Technical measures

Reduction of resistance (see Figure 26)

Optimisation of hull design
There is a strong perception that the optimisation of the hull design is important to improve energy efficiency. E.g. the increase of ship size and the reduction of ballast reduce the fuel consumption per tonne cargo significantly. For certain ships the hull design is optimised continuously e.g. in towing tanks, whereas some say that it is difficult sometimes to get shipyards to accept a new ship design. The latter seems to be the highest barrier for a change in ship design.
New upcoming legislation regarding CO_2 emission reductions like the EEDI will force the shipping industry to improve the ship design and to meet the new standards.

Low friction or alternative hull coatings to reduce roughness and biofouling of wetted surface and thereby reduce the fuel consumption
This technology reduces the resistance in water by reducing surface roughness and biofouling of wetted surface and thereby reduce the fuel consumption. They can be classified as foul-release coatings. Some require frequent cleaning, others rely on speed to wash-off the biofouling.
The awareness and expectations for low friction hull coatings also seem to be very high, however, the savings potential is difficult to prove. Schultz et al. (2007) measured the impact of biofouling on powering of a mid-sized naval surface combatant at 15 knots. The formation of a light slime layer alone

significantly increased the required shaft power by 11% to maintain speed. Heavy calcerous fouling (barnacles, mussels, tubeworms) increased the required power by 86% for this type of ship. Frictional resistance of the hull in water is only a part of total resistance of a ship and on average 90% of fuel is used for ship propulsion. The Clean Shipping Coalition calculated based on several studies that for a typical vessel in a typical trade, the impact of the deterioration in hull and propeller performance is likely to result in a 15 to 20 per cent loss in vessel efficiency on average over a sailing interval (MEPC 63/4/8).

The use of alternative coatings still occurs randomly and is very dependent on the owner. Some ship owners say they prefer to keep the conventional self-polishing antifouling to prevent biofouling of the ship hull, as the alternatives are regarded too expensive. Advanced silicone or fluoropolymer paint systems cause an additional cost of approximately $500,000 (including 2 extra days in dock, full blasting down to steel and associated 2 extra days off hire) for a 4000 TEU container vessel compared to conventional self-polishing antifouling coatings ($150,000). According to a cruise liner shipyard they charge an additional €3 million when the owner wants a silicon coating instead of conventional self-polishing copper containing antifouling coating for a large cruise liner. Another shipyard charges some hundred thousand Euros extra, as they have no choice anyway. They cannot use conventional SPCs anymore due to wastewater regulations. However, the silicon paint is not even twice as expensive as the SCPs, but according to the shipyard it is not the paint itself, which causes the higher costs. During the application of silicon paints the parts of the ship have to be encased to prevent the overspray to cover other parts of the ship or the yard, silicon paints require special pumps and repair work is difficult. On the other hand the silicon paints dry faster (2 coatings per day compared to 2 coatings in 1.5 days) and require less coating layers.

Barriers for the use of alternative antifoulings or foul release coatings are manifold:
- lack of independent performance data and proven savings potential;
- high associated costs (purchase, application, maintenance);
- no impact on the charter rates or second hand price of a ship;
- risk of bunker claims due to increased biofouling.

There is also a risk of bunker claims by the charterer due to increased fuel consumption caused by biofouling. The owner has to pay in case of failure of the foul-release or low friction coating. For this reason the owners tend to use conventional SPCs.

Performance monitoring systems control the growth of biofouling. There are performance monitoring systems on the market, which allow calculating the optimum cleaning or docking intervals. The claimed savings potential vary between 8 and 10% (according to the suppliers).
At least one paint manufacturer is offering a performance monitoring system on ships which use their foul release coating and offer some sort of performance guarantee. However, the claimed 8% savings of one paint manufacturer will not provide such great returns when the ship is slow steaming.
Another biofouling performance monitoring system costs approximately $ 500 per month with a savings potential of 10%. The advantage is that the performance monitoring of antifouling paints between the docking intervals can be controlled or docking intervals can be re-scheduled. For foul-release systems, which require cleaning the timing of cleaning can be distinguished. One interview partner had the experience that the cleaning intervals for a certain foul-release coating are much shorter than claimed by the

manufacturer and can only occur partly during one port stay due to the large areas of the hull.

Barriers for the use of biofouling monitoring systems again the lack of independent data and no impact on the charter rates or second hand price of a ship.

Optimisation of water flow

Optimisation of water flow (transverse thruster openings, grids, etc.) and reduction of structural roughness like e.g. seachests has less importance is a proven technology to improve fuel efficiency, However, there is low awareness and understanding by the ship owners regarding the impact of macro-roughness on ships speed and fuel consumption. Seachests and bow thruster openings cannot be avoided, but they can be optimised in many cases. Mainly cruise liners are optimised regarding less hull openings. For the cruise liner industry this is more or the less state of the art. Further ship design is driven by shipyards that have their standard designs, but some research is going on. Only a few ships are optimised in towing tanks, most ship designs are 20 years old. Optimised flow at transverse thruster openings can result in up to 5% reduced energy consumption with a payback of less than 1 year (Wärtsilä, 2008)

The only barriers identified regarding hull openings is the change of ship designs at the shipyards and low awareness.

Another problem related to thruster channels is that they are close to the water line, which allows a substantial and undesired volume of air to be drawn into the channel when the thrusters are activated. This trapped air results in a substantial reduction in power produced by the thrusters and causes increased vibrations and noise.

Air lubrication

Air lubrication is applied to ships to reduce their frictional resistance in water by an air cavity or by pumping air bubbles under the ship hull and thereby reduce the fuel consumption. There three different systems on the market (Table 8). This technology is limited to ships with a flat, wide bottom and is most suitable for ships with a low Froude number, as with these ships the frictional resistance is very high (mainly tankers and bulkers).

Table 8 The different air lubrication systems on the market

System provider	Product	Savings	Verification	Maturity
DK Group	Air Cavity System	10-15% (tanker/bulker) 5-9% (container)	GL certified small bulk carrier tests in 2009 from company projected savings on a 90 m vessel to larger vessel	Full-scale sea trials in 2008, technology commercially available
Mitsubishi Heavy Industries/NYK	Mitsubishi Air Lubrication System (MALS) Mili-bubbles	13 (net)%	N/a	Trials proceed until 2012
Winged Air Induction Pipe (WAIP)	Micro-bubbles	No proven savings, yet	Ongoing trials	
Stena Bulker	Airmax air cushion system	20-30%	Expectation based on small scale tests	Proceeding to larger scale tests

Reference: http://dkgroup.eu/userfiles/files/Fathom-The-Guide.pdf .

The air cavity system is most suitable for new-builds, but a retrofit version has become available. Microbubbles can be used on new-builds as well as retrofits. Most of the tests have been carried out on inland waters. Therefore, the open question is how these systems behave under rolling and pitching. Another uncertainty is the energy used to generate the compressed air, which could offset the expected savings. According to DK-Group 1% of the saved energy is used for production of the compressed air. According to IMarEST the fuel consumption can be as high as 0.3-05 tons per day.

There is a broad range for the installation costs of the **air lubrication system** in % of the price of a new-build ship:

IMarEST (2010a):	2-3%;
DK Group:	1%;
Damen shipyard:	5% for a 110-metre cargo ship.

Also the abatement potential varies quite significantly:

Tankers:	ca. 15 %	(Wärtsilä, 2008);
Containers:	ca. 7.5%	(Wärtsilä, 2008);
PCTC:	ca. 8.5%	(Wärtsilä, 2008);
Ferry:	ca. 3.5%	(Wärtsilä, 2008)
Cargo ship	15%	(Damen shipyard, NL for 60 m ship on rivers);
Unspecified:	20%	(ref. MARIN, NL).

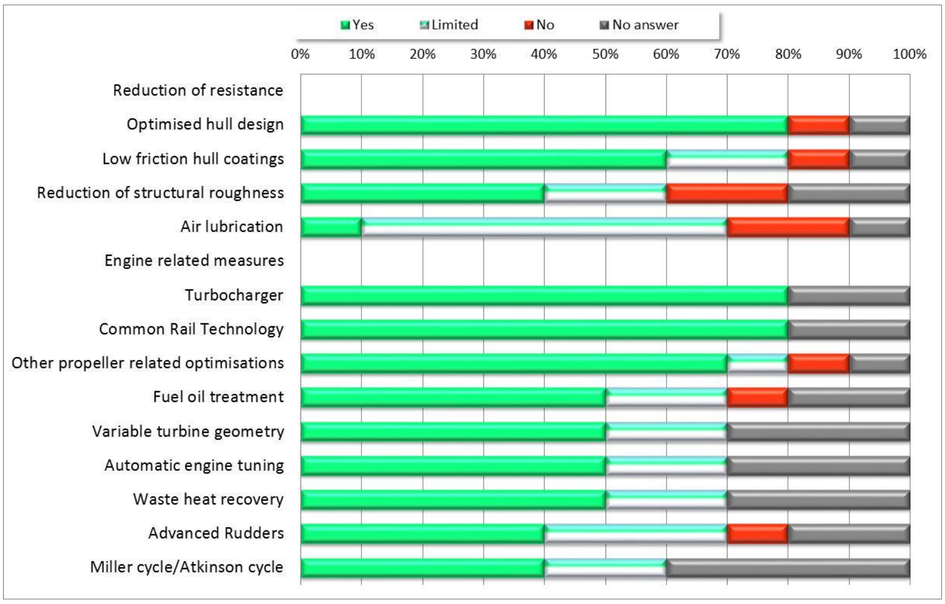
In 2010 Damen shipyards has announced to implement the air lubrication technology starting 2011 and to give licenses to other shipbuilders. Retrofit will last 14 days according to the manufacturer. The estimated payback time is given as 18 months, which will become less with increasing fuel prices.

Micro-bubbles
Micro bubble lubrication requires only a small change to the hull compared to an air-cavity ship. This technology is expected to be suited for moderately fast ships with a target speed range of Froude numbers between 0.05 and 0.15.
In a study carried out by MARIN with during a EU project called SMOOTH on a 109.8 m inland-shipping vessel no appreciable effect was found on resistance,

propulsion and manoeuvring characteristics of a ship by the injection of micro air bubbles. Further, there might be unexpected unforeseen effects on special coatings. They conclude that an ad hoc application of bubble injection for ship hulls is not expected to yield any significant results. (Foeth, 2011). Another study carried out by Maersk (WAIP system) on their container vessel Olivia Maersk did not show any conclusive results in terms of performance gains and associated fuel savings.

From the interviews we identified a very high barrier for the application of **air lubrication**. The interest was very low by all ship owners that have been interviewed, due the complexity, unsuitability for certain ship types and failure during high wave action. There is also huge uncertainty regarding the efficiency. Further, the power consumption to produce compressed air has to be taken into account. However, air lubrication is observed by the maritime stakeholders.

Figure 26 Technical measures: Reduction of resistance and engine related measures already applied



Engine related Measures (Figure 27)

Most of the engine related measures especially **turbo charger, common rail technology and automatic engine tuning or electronic engine control** were regarded as state of the art by the ship owners. There was only one exception where the shipping company only applies turbo chargers and common rail technology and none of the other measures. Also variable turbine geometry, Miller and Atkinson cycle are regarded as proven technologies to improve fuel efficiency, but are also implemented for the reduction of NO_x emissions. Knowledge about the special engine related measures was very low outside the ship owners community. Therefore many other stakeholders did not answer the questions. For the directly engine related optimisations there seem to be little barriers.

Other propeller related optimisations are regarded to have medium impact. Greatest opportunities in the area of propeller optimisation is to optimise the flow around the propeller (e.g. boss fin caps). Ship owners apply flow improvement fins (boss fin caps) and propeller polishing. A lot of research is going on in this area. There are surprisingly little barriers, although the costs can be high (€0.1 – 1.4 M) and there is a risk of high maintenance costs.

E.g. counter rotating propellers cause additional stress on the already a highly stressed shaft. There are safety concerns regarding breakdown.

Waste heat recovery

Waste heat recovery systems can generate electrical energy from the exhaust gas waste heat and can be used in combination with the shaft power generator. Claimed energy savings potential is 10% by the manufacturers with several years pay-back time. This technology raises high interest and is given a high energy savings potential by the interviewed parties (up to 6%). Some ship owners see a high potential especially for cruise liners, others use the waste heat for fuel oil heating only.
The main barrier for the implementation of waste heat recovery was found to be the costs as they are considered to be extremely expensive. One interview partner estimated the costs to be up to 5M€ for a 9000 TEU CV. "Waste heat recovery is fancy to have but very expensive", was another of the statements. Further, the use of waste heat recovery is limited as the vast majority of ships do not have enough power or heat to power the units. Therefore, it is not applicable or suitable for all ship types.

Fuel oil treatment

HFO and MFO contain heavy long-chain hydrocarbons, which are incompletely combusted by marine engines. The consequence is a loss of contained energy and soot formation. However, fuel oil treatment is regarded to have only limited impact on energy efficiency by the interview partners. The saving potential could be 2%. Some additives work by increasing lubrication some do not. One interview partner stated the fuel oil additives are known as "snake oil" and are not used. The biggest barrier (authors knowledge) is engine manufacturers warrantees, as the fuel and lube oil specifications are quite strict. In case of an engine failure due to additives in the fuel the warranty might expire. New innovative technologies like electrolytic treatment of fuel oil to decrease viscosity seem to be unknown in the maritime market. Therefore, the biggest barriers are confidence and lack of information.

Advanced rudders are regarded to be state of art for fast and special ships. The propeller is regarded as most important and improvements pose an advantage, but advanced rudders are very expensive and there is also a risk of introducing new failures especially with cord nozzles. Improvements for propellers are listed in Table 9. The propeller and the shaft are regarded as highly sensitive and highly stressed areas. Therefore, changes in these areas are investigated carefully. A lot of research is going on in the area of advanced rudders, especially for fast ships. The main barrier is the costs, risk of failure and high maintenance.

Table 9 **Improvements of the propellers and the associated fuel savings**

	Possible gain in efficiency	Remarks
Optimum propeller diameter	2%	Consider cavitation, vibrations and noise
Optimum number of blades/optimum area ratio	3%	As above
Pod drives	5%	Only for two-screw arrangements, only with diesel-electric
Kort nozzle	5% 20/30%	Only up to a certain speed and with a high load factor (Wärtsilä, 2008; (Mewis, Hollenbach, 2007)

Other technical measures

The **optimisation of hotelling functions** is well perceived by the maritime industry especially for passenger ships. The energy saving potential for these ship types is huge. The cruise liners use power optimisation programs for air condition, ventilation, light, etc. There is a lower effect on all other ship types, but still this energy saving option is implemented by shipyards and designers. It will also be part of the SEEMP.

Electric propulsion is applied by cruise liners only, as it is very dependent on the operational profile of the ships. For long fixed routes this does not seem to be a solution nowadays. However, electric propulsion is a good measure to optimise and control energy consumption and works well in combination with waste recovery systems. This can improve efficiency, but at higher costs. The expected saving potential is 6-8%.

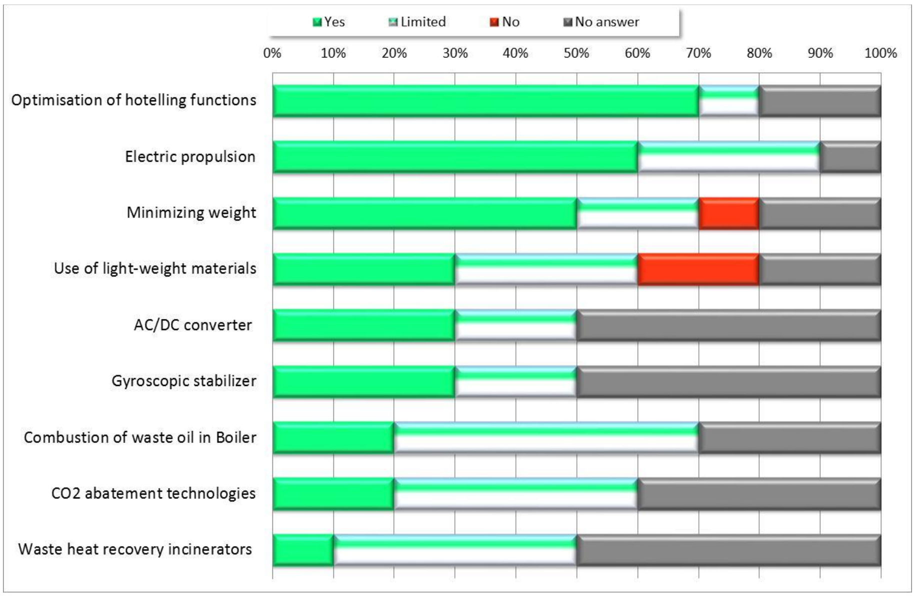
Minimising the weight of the ship and the use of **lightweight materials** represents a huge saving potential for passenger ships, but not so much for other ship types. Weight can only be reduced to a certain extent. In most ships freight constitutes 70-80% of the water displacement. So only limited total weight reductions can be achieved. Moreover, the lifetime of a ship and its strength pose limits. In terms of light weight material one big barrier is the lack of suitable materials and safety aspects. For example high tense steel causes cracking.

AC/DC converters are increasingly used in special ships such as passenger ships, special purpose vessels. They are useful on ships with a high base load like cruise liners. Thyristor controlled rectifiers are used to convert AC to DC power for high power requirements like azipods and electric propulsion, as the energy consumption can be optimised. Savings are also good in terms of space and energy loss through the cables and instruments. However, AC/DC converters are not suitable for all ship types. As a result of the interviews it was found that the general knowledge about AC and DC power is quite low and consequently is regarded as the highest barrier. Only one ship owner applies the thyristor technology.

Combustion of waste oil is not well perceived due to costs (“about 10 times more expensive to burn sludge than land it”), and environmental concerns, as the exhaust gas will contain many pollutants. Further, local regulations limit the combustion of waste oil in certain areas. Only one ship owner has the technical option installed on several ships. The barriers are therefore costs, environmental concerns and legislation.
CO_2 abatement technologies do not increase the fuel efficiency, but reduce GHG emissions of ships. These are in a research and pilot stage at two ship owners, others tend to observe. The main barrier here is the trust in the technology and the conservative behaviour of the maritime scene.

Waste heat recovery of incinerators is not well known as not all ships have waste incinerators. Incinerators waste heat recovery is only used on passenger ships like cruise liners. The barriers therefore are lack waste incinerators, lack of information, but also technical problems which might outbalance the benefit.

Figure 27 Other technical measures already applied



4.4.3 Alternative fuels and power sources

Cold ironing (shore power) does not save energy overall, but reduces fuel consumption of the ship and reduces local emissions. Only one ship owner has installed shore power connections on several ships. There are a number of barriers. The most important is the deficiency in standardisation of power supply (variable frequency, voltage and connectors). The second is that ship owners want to have power from renewable energy sources, but this is not guaranteed by the energy suppliers. Others regard cold ironing as counterproductive, as a highly effective power plant is already on board.

LNG and CNG also do not save energy, but are very interesting as alternative fuel in terms of price and emission limits for NO_x and SO_2. Yet the costs for ship construction increase significantly compared to conventionally fuelled ships, although this does not pose a barrier. The currently increasing demand of LNG and CNG as alternative to oil, especially in Japan, makes the construction of LNG or CNG attractive. Compared to other ship types the new-build orders for gas fuelled ships are relatively high. Barriers are the low availability of LNG and CNG, lack of infrastructure for supply and the size of storage tanks (lack of space). Nowadays these fuels are only attractive for gas carriers and for short sea shipping like ferries. Most of the ship owners are watching the developments carefully.

Recently a new LNG Box ship design has been approved by DNV with a dual fuel engine, which allows variable mixtures of HFO and LNG. In the maximum gas load for the engine (90% LNG and 10%HFO) there is an expected CO_2 emission reduction of 23%. Further the first LNG fuelled tanker has been built for inland shipping (Argonon, 6100 dwt, dual fuel engine Caterpillar).

Fuel cells are regarded a promising technology but not mature enough at the moment. There are a number of research projects going regarding their implementation on ships. The application of fuel cells as auxiliary power is more than 5 years away and as main propulsion more than 30 years. None of the interviewed ship owners apply fuel cells on their ships today, but it is known that fuels cells are used for submarines and for small ferries. The barriers are lack of maturity, but also cost. Fuel cells and hydrogen are very expensive compared to other fuels.

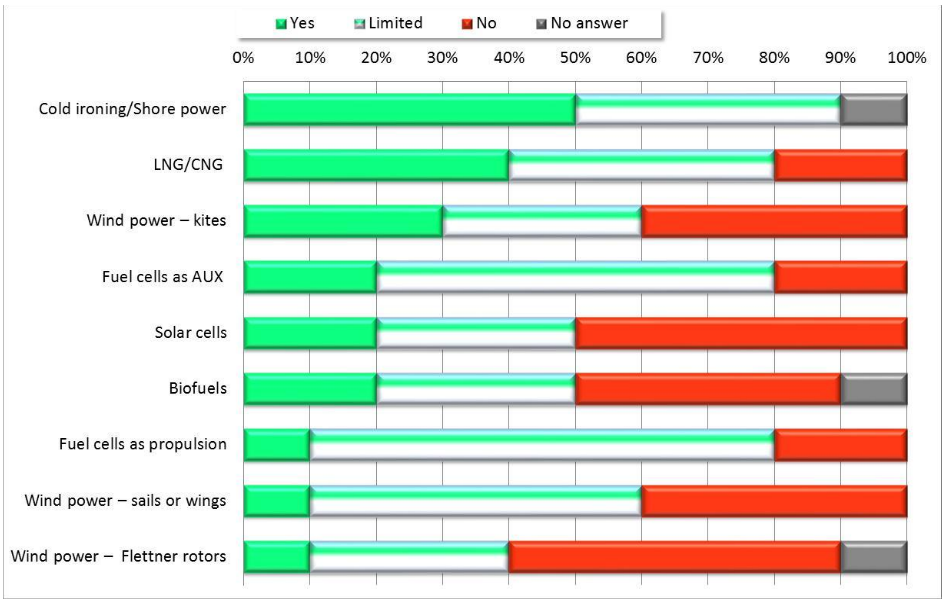
Solar cells are only suitable for a niche market like cruise liners, car carriers and ferries (ships with a large available top surfaces). For example Nissan launched its first energy-efficient coastal car carrier, the Nichioh Maru in January 2012 with an electronically-controlled diesel engine and 281 solar panels fitted to the carrier's deck. Another solar ship is the Turanor PlanetSolar whose deck is covered with 537 square meters of photovoltaic panels. However this is no cargo ship. Most energy efficient ships applying solar panels are in a design stage like the Aquarius Eco Ship, which integrates solar panels in wings to additionally use wind energy or NYK's Eco Ship 2030. For most ships the power generation by solar energy can only be a fragment of total power requirement as the energy produced per square meter is very low. Only two interview partners expect this technology to improve the energy efficiency of ships. One shipowner runs trials on 8 ships. The barriers here are unsuitability for most ship types and low expectations in terms of power generation.

Biofuels do not save energy and do not seem to be an attractive measure in shipping. There is limited supply of biofuels, no cost advantage and the production is regarded to have very negative environmental impacts. The interviewed cruise liner company stopped the use of biofuels due to costs and bad public reputation. The US Navy has made a firm commitment to use substantial quantities and Lloyd's Register has been working with Maersk to understand biofuel performance. Some trials are currently going on. Future designs include a new "Algae Harvester" designed by Wärtsila, which will collect algae from large basins that would float in the sea. The filtered algae can become a significant part of biomass to biofuel conversion. Current barriers are no expected savings potential and bad reputation, but this might change depending on the production process of biofuels.

Wind Propulsion

The interview partners know that all of the three wind propulsion options - sails, kites and flettner rotors - are in a trial stage and observe this. One interviewed ship owner is investigating the impact of wind propulsion systems on ship design. From the three wind power options, the use of kites has the lowest acceptance due to operational limitations, kite durability, replacement costs and difficult handling. A major concern is the safety aspect as e.g. kites could interfere with the ship operation when falling into the sea. One interviewed ship owner is in a trial stage. Flettner rotors could cause some ship stability problems. All three technologies are dependent on wind directions and therefore on the operational profile of the ship. Additionally the kites, wings and sails are only suitable for relatively slow ships (10–15 knots). In summary there is interest, but many limitations. There was a proposal by Germany to the IMO (MEPC 62/5/12) to implement wind propulsion systems in the formula of the EEDI.

Figure 28 Alternative fuels and power supplies already applied



4.4.4 Operational measures

General speed reduction is believed to have the highest impact on energy efficiency. For the current new-build orders like the Maersk Triple-E, the design speed is reduced by 2 knots compared to Emma Maersk, which allows a reduction in power requirements of 19%. However, in general speed reduction is still very market driven and depends on charter contracts (charter rate/day) and fuel prices. Further, the ship has a specified design speed and needs to maintain its flexibility in terms of weather, cargo, etc. Speed is also dependent on weather, cargo, etc. As a rule of thumb, a speed reduction of 10% means 19% fuel saving. However, speed has impact on charter rates, which is calculated for days. Therefore it is crucial to implement this tool in the charter rates. Otherwise, speed reduction is regarded as a very strong tool, probably the most promising.

Weather routing is applied by all ship owners and is well accepted. The saving potential depends on ship routes. Savings can be made especially on North Atlantic and Pacific routes. The indirect saving is the prediction of arrival time and therefore the possibility to run the ship at a constant lower speed instead of driving at full load. One monitoring tool which includes weather routing is the Eniram Technology.
SeaTechnik calculates optimum operation for all speeds and conditions and combines this with voyage planning weather data so that the voyage is executed with minimum energy by sailing to an optimum power/speed profile. The system also ensures arrival on time and automatically controls propulsion machinery to precisely maintain that profile.
There are no identified barriers at all.

Trim optimisation is well accepted in the maritime industry, nearly state of the art. One ship owner started to improve training to raise awareness on the benefits of correct trim in relation to fuel savings. On large containerships savings up to 10% can be achieved. Further improvement would be the combination with ballast water optimisation. Trim optimisation is part of Ship Energy Efficiency Management Plan's (SEEMP) strategic areas for cost-effective and practical measures to increase efficiency of ships in operation and is considered one of the most easily achievable fuel saving practices currently available. There is a number of systems on the market claiming fuel savings

from 4-10%. For example GL`s EcoAssistant helps to optimise the ships trim, which influences its resistance and hence its fuel consumption. The trim strongly depends on the operating parameters of speed, displacement and water depth. ECO-Assistant calculates the optimum dynamic trim for the specific operating condition.
There does not seem to be any barrier, instead there is a medium to high potential for power optimisation.

Voyage optimisation by choosing the optimal route regarding weather conditions and to adjust the speed depending on sea state is another option to reduce fuel consumption (e.g. SeaPlanner). The savings potential is given to be 2% (Info given by SeaPlanner). Voyage optimisation is well known and is applied by most shipping companies. The saving potential is regarded as medium up to high. The barriers are the contracts with charter parties and port mentality. This area has to be developed mutually with charter party.

A lot of effort is put into **the increase of awareness and regular training of the crew.** Awareness is increased by sending monthly environmental bulletins to the crew, increase of competition and comparison of ships regarding fuel efficiency, accidents and emissions. One stakeholder also reported about a propulsion based payment or salary applied in cruise liner industry. Others say that awareness in combination with training decides the most about energy efficiency in shipping. Classification societies support this with a software tool. Some ship owners have environmental officers, which provide on board training for the crew. The saving potential is regarded as very high (up to 20%). There are no barriers at all.

Autopilots generally optimise the steering of a ship under different weather and load conditions. All interviewed ship owners make use of autopilots in their fleet. One ship owner states that the autopilot is part of their SEEMP. The saving potential is very high and there is room for improvements. There is no barrier at all.

Monitoring of energy consumption is applied by two ship owners. The other two can only record fuel consumption by the amount of fuel bunkered after a voyage, but this is not the same. The monitoring of fuel consumption is regarded to have a high potential, especially for crew awareness training. One of the interviewed ship owners uses an energy performance monitoring system, which is looking at the entire ship performance and not only propeller monitoring. The costs are between $50-$80,000/vessel plus an annual subscription fee to web based data portal (cost unknown). The system provides information on trim optimisation, feedback about deviation from set key performance indicators and power management. The savings are more than the claimed savings of 2-4%. Another interviewed shipowner uses the ENIRAM software. Other monitoring systems like
A more precise method would be to look at the life cycle costs of a ship including new technologies like the currently developed BAL.L3C software from BALance. This tool is developed in the EU project BESST and allows comparison of different designs, materials and technologies including variables like fuel and labour costs and exchange rates. The output parameters allow analysis of the return of investments and fuel savings.

No barrier was identified, but the authors view is that active energy monitoring instrumentation and software are very expensive.

Optimised fleet management is currently applied by three of the interviewed ship owners, but there is still space for improvement. The limited information given to this option does not allow identifying any barriers.

Regular hull and propeller cleaning reduces the drag caused by biofouling and is regarded to have a huge saving potential. However, the conventional self-polishing antifouling coatings are not suitable for polishing, as the paint would be polished causing a peak release of biocides into the environment. Only two interviewed shipping companies have implemented the regular propeller and hull cleaning. There is monitoring software available like Propulsion Dynamics, which monitor increased fuel consumption by biofouling and allow determination of cleaning intervals.
Another other problem identified is the local release of invasive species, which can cause the same problems like ballast water. This can be subject to local legislation like in Australia and New Zealand. Here the limited application is due to the type of coatings and possibly due to legislation.

Speed reduction due to port efficiency is sometimes applied by two ship owners and is routinely applied in container shipping, but is generally also dependant on the charter contracts. It is believed that there is a high saving opportunity, but it requires a shift in port mentality (e.g. queues in ports). There is also a potential for short sea shipping on fixed routes.

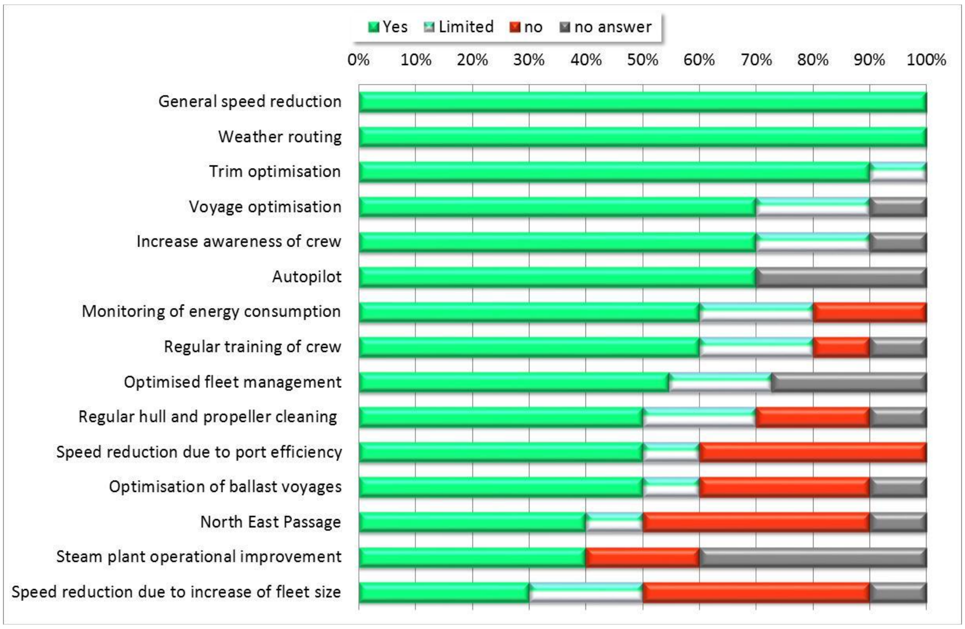
Optimisation of ballast voyages is not applied on cruise liners, as they do not have as much ballast water as other ships and should always carry passengers. Another ship owner currently investigates this option. Otherwise optimisation of ballast voyages is applied and it is well known that ballast water and ballast voyages should be kept at a minimum. The only barrier could be commercial aspects.

North East Passage is a special case of voyage optimisation, but is limited to some months in summer due to ice coverage. Ships sailing the Northern Route require the highest ice class, are guided by ice breakers and require approval from the Russian Authorities. Consequently there are a number of barriers: weather conditions, ships' ice class, costs for ice breakers and time for the Russian approval.

Steam plant operational improvement is regarded as state of the art, but limited to ships that have boilers. Steam plants use the waste heat from the flue gas. Only two of the ship owners apply steam plant optimisation, however some believe that there is a good potential to save energy. The barrier is the principal use of steam plants. Steam as propulsion became very rare.

Speed reduction due to an increase of the fleet size is not applied by any of the interviewed ship owners. The other stakeholders could report that this applied to a limited extent. There a general agreement that this measure offers a huge opportunity to save energy and to increase the effective use of the fleet. The main barrier is that the fuel is still too cheap compared to the cost of a new ship, which is reflected by a careful cost-benefit calculation. There is also the opportunity to increase the size of single ships to reduce the costs per ton of cargo, which more common practise.

Figure 29 Operational measures already applied



Energy performance monitoring/reporting software:

The energy performance monitoring system is looking at the entire ship performance and not only propeller monitoring. The costs are between $50-$80,000/vessel plus an annual subscription fee to web based data portal (cost unknown). The systems provide information on trim optimisation, feedback about deviation from set key performance indicators and power management. The savings are more than the claimed savings of 2-4%.

Ship size

A huge potential for savings is the construction of larger ships with an improved ship weight/total weight ratio and a smaller design speed like the Maersk Triple E-class (400 m, 18 000TEU, 20 orders), which will reduce the CO_2 emissions by 50% compared to the average for vessels operating on the Asia-Europe trade. Large ships are also more fuel efficient because they generate fewer waves. Economies of scale can generate significant fuel savings (see also Section 2.3).

4.4.5 Analysis of ship owners questionnaires (Figure 27)

Four out of five ship owners answered the detailed questions. One shipping company only reported that most of the technological and operational measures are applied in their fleet. However, this information is not reflected by the graphs as no detailed information was given

The most important energy reducing measures are the operational optimisations (Figure 26), which should be reflected in the MACCs to a large extent. The largest impact on MACCs is expected by the general speed reduction and by increasing the environmental awareness of the crew, followed by the frequent training of the crew. All interviewed shipping companies use weather routing, trim and voyage optimisation and make use of autopilots. However the savings potentials are unknown. So far no ship owner increased its fleet size due to reduce speed.

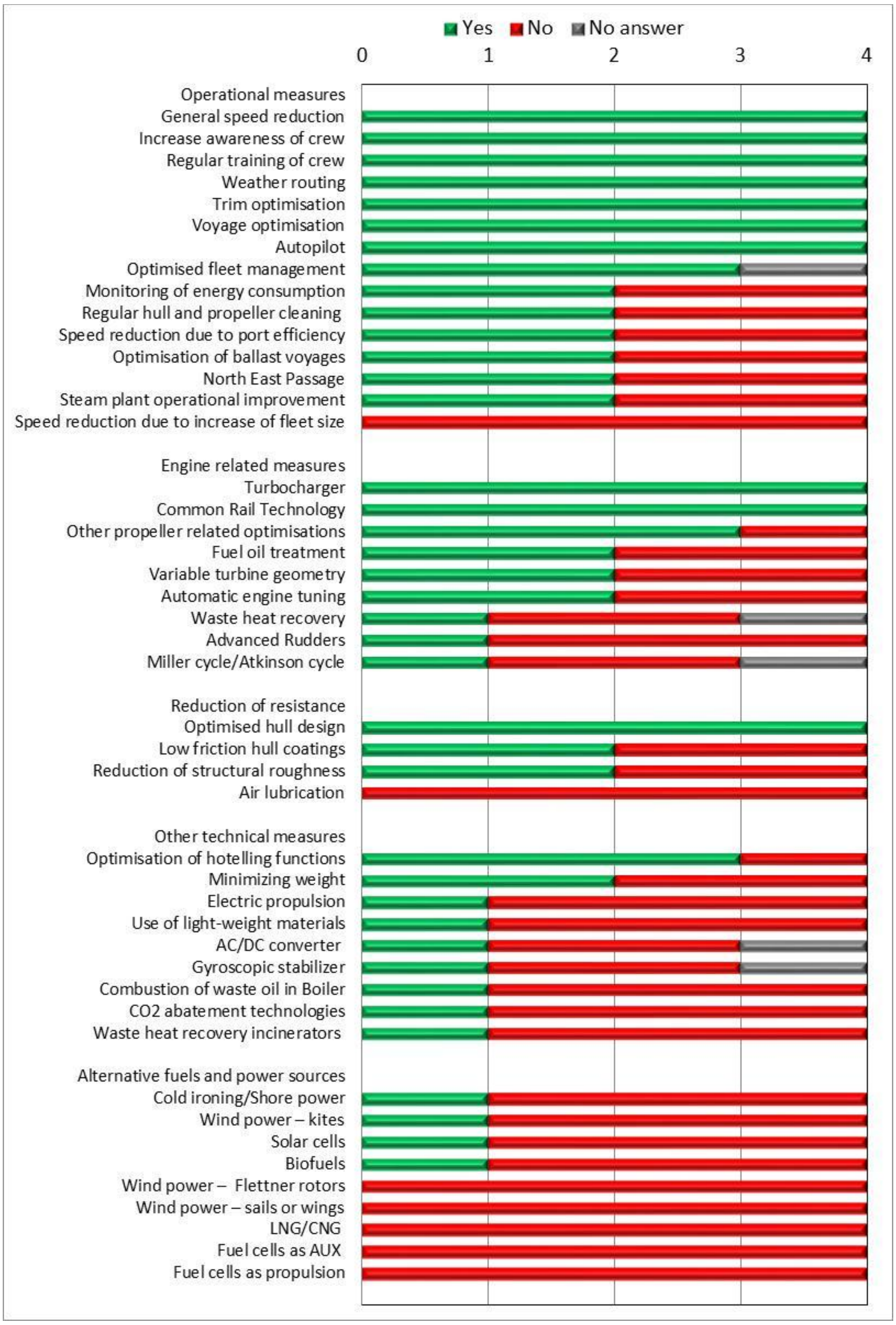
The second important energy measure improvements are engine and propeller related. Most of the engine related measures are state of the art and are implemented. This should be echoed by the MACCs. Most ship owners also try to improve the water flow around the propeller rather than investing in expensive advanced rudders. The reason might be costs and safety aspects.

Reduction of resistance is important as all ship owners optimised their hull design to reduce resistance, whereas reduction of friction by coatings and structural roughness was applied by two ship owners only. The reason is the uncertainty in savings potential and cost-benefit. Air lubrication was not applied at all due to technical constraints and complexity. Four different technologies have been identified in this category with varying savings potentials. The latter technology should appear in the MACCs in the higher end.

Other important energy saving measures are optimisation of hotelling functions and minimising weight. All other measures in this section have less importance or sometimes are unknown and are applied in cruise liners only.
CO_2 abatement technologies are in a trial stage at one ship owner and are currently planned by another shipping company. However this does not reduce the fuel consumption. It only reduces GHG emissions.

The least promising measures are in the section alternative fuels and power sources. There is huge interest in LNG/CNG as future alternative fuel, but there is a lack of infrastructure and ship construction becomes more expensive. However there is a recent trend towards the use LNG/CNG, due to legislation in emission reductions and increasing fuel prices. Wind propulsion is applied by one ship owner on a trial basis but the general view is that this is not suitable for most ships. Fuel cells are not ready for the maritime market, especially not as main propulsion. Solar cells deliver too little energy at high costs. Biofuels were applied by one ship owner in the past, but not anymore due to its bad reputation. The figures surely will change and have an impact on MACCs when fuel prices increase.

Figure 30 Analysis of already applied technologies and measures by the different shipping companies



4.5 Conclusion

There are both general and technology-specific barriers to the implementation of cost-effective abatement options.

A literature review and interviews with stakeholders has identified seven general barriers to the implementation of cost-effective measures to improve the fuel-efficiency of a ship. These are:

1. A split incentive because a ship owner has to invest in the fuel efficiency of a ship while the charterer pays for the fuel. In practice, the owner can earn a higher charter rate for a more fuel efficient ship in most market conditions but the amount by which the charter rate is higher is only a share of the amount by which the fuel consumption is lower. The fact that owners are only able to recoup a share of the benefits of a fuel-efficient ships depends on two factors. First, micro-economic analysis shows that it is rational in an equilibrium market that the benefits are shared between the supplier (i.e. the owner) and the consumer (i.e. the charterer). How large the share for each party is, depends on the price elasticity of demand and the price elasticity of supply. Both depend on marker circumstances and are therefore variable. Second, in charter parties the risks of over- and underperformance of a ship are unevenly distributed. While owners bear the risk of underperformance, there is no risk to the charterer in case of overperformance. Both factors combined have the effect that ship owners who invest in a fuel efficient ship, or who invest in improving the fuel-efficiency of their ship, are able to earn back a share of the fuel benefits through higher charter rates. The remaining benefits are for the charterer.
2. A lack of independent data, especially on new technologies, results in a high uncertainty in the business case and prevents ship owners to invest.
3. The transaction costs associated with searching for and evaluating measures to improve the fuel-efficiency of ships may be high, especially for new technologies. This barrier exacerbates the previous one.
4. Financial constraints are caused with market circumstances and by requirements to invest in other technologies, e.g. for ballast water management and emissions control.
5. Yards may be reluctant to implement new and innovative technologies, and they may be reluctant to include these technologies in their warranties. The reluctance varies considerably over yards.
6. In some cases, ship owners and operators may not have good information on the fuel efficiency of a vessel, making it hard to analyse the impacts of efficiency improving equipment.
7. As retrofits are often only feasible when a ship is already in dry dock, and dry docks are planned on regular 4 to 6 year intervals, there may be a time lag between when a measure becomes cost-effective and its implementation.

The first three are the most important in terms of impacts on the cost-effectiveness of measures and hence on the cost-effective abatement potential. The financial constraints are severe but likely to be temporary; while the reluctance of yards and the fuel monitoring system are very case-specific. The time lag for technologies that require drydocking is a universal barrier, albeit one that can hardly be overcome.

The overall comparison of the different measures showed that the optimisation of operational measures is most important. The reason might be a comparable little effort for the implementation, little technological changes of the ship structure and comparable low investment. Ship owners and other maritime stakeholders both judged these measures as the highest energy saving measure and therefore have a huge impact on the MACCs. In detail the most accepted operational measures are speed reduction, increase of crew awareness and crew training. Awareness is e.g. increased by fuel saving competition between crews and ships.

Engine related measures are well perceived by the ship owners, whereas the knowledge other maritime stakeholders was very low. Most engine related improvements are regarded as state of the art and are also related to reduction of NO_x emissions. They should appear in the MACCs as already applied technologies. Improvements in engine performance are largely dependent on new developments at the engine manufacturers. Barriers for the other technologies are the high costs for e.g. waste heat recovery and advanced rudders. Changes to the propulsion system are not only costly but also regarded as very sensitive in term of ships safety. Therefore there is a strong reluctance for the implementation and should appear in the tail of the MACCs. Fuel oil treatment has the lowest potential and is regarded as very uncertain with little potential and is not implemented on a broad basis.

Reduction of ship hull friction is well accepted as energy saving measure, especially the optimisation of the ship hull design. Optimisation of the ship hull design is state of the art. The only barrier is the acceptance at the shipyards, who do not like changes of designs. The extent of the fuel saving potential is mainly unknown. The barriers for low friction hull coatings are uncertainty of saving potential and high costs. Air lubrication was the least accepted method for a number of technical and operational reasons. Energy savings between 1-10% are possible, but air lubrication is simply not suitable for most ship types and has very limited potential to be implemented. However some tests are carried out currently and some look very promising for certain ship types. Micro- or Milli-bubbles are even suitable for retro-fitting in existing ships.
Other technical measures are less accepted or simply unknown. On the top range are optimisation of hotelling functions and minimisation of weight. The remaining technological measures are mainly applied on cruise liners only and not relevant for other ship types. Here the MACCs should differ significantly for the different types of ships with high impact on cruise liners and less impact for other ship types.

The lowest acceptance was for alternative fuels and alternative power sources. Ship owners largely do not accept alternative power sources and other maritime stakeholders see a limited or no impact at all. Shore power is applied by one ship owner and largely fails due to standardisation of the power supply.

Fuel cells are not regarded as mature for shipping and are only applied in a very small niche market. It will take many years until fuel cells can be implemented in ships, especially as main propulsion. Even when the technical problems are solved, the price of the technology and hydrogen has to be much lower to support the implementation of fuel cells. Wind power is applied by one ship owner only in a ship trial. Kites have the lowest acceptance compared to Flettner rotors, sails and wings. Barriers are the handling, costs for the replacement parts plus the fact that they are only useful on relatively slow ships (<15 knots). However, if wind propulsion is applied, there will be a huge impact on the MAC curve, as the saving potential can be very large. The barriers for the use of LNG and CNG are lack of infrastructure for their global supply, increase of shipbuilding costs and space requirements. All ship owners are very interested in the use of LNG/CNG, but observe the developments only. This alternative fuel again can only be applied in a niche market like gas carriers and short sea shipping. Only recently a LNG ship design has been approved by DNV, but this has still to be built. The first LNG fuelled ship for inland waterways has been built.

Recent developments
Market barriers include a lack of proven technologies, unreliability and low fuel prices. But these barriers are increasingly eroding and the industry is opening its eyes to the possibilities that innovative technologies can bring. However as the charter rates are very low due to high ship availability there will be a further delay for the introduction of energy efficient technologies in the world fleet. The current overcapacity in available ships will not recover till the end of 2012, if at all. This overcapacity e.g. in the container ship market will be held back by the current new-orders of ultra large container ships. The current new orders equate to 25% of the total fleet in service. Possibly the replacement of old ships by the new energy efficient ships will be a driver for the market in terms of GHG reductions of the world fleet.

5 Impact of barriers on MACCs

5.1 Introduction

The MACCs as published by Buhaug et al. (2009), CE et al. (2009), IMarEST (2010a) and Eide et al. (2011) show the reduction potential and costs if all the ships that are in principle able to implement a certain technology do so. In that sense, they could be characterised as idealistic MACCs: they show the maximum achievable reduction and its costs.

As shown in Chapter 4, there are barriers to the implementation of cost-effective technologies. As a result, not all the cost-effective measures are likely to be implemented. This chapter attempts to quantify the impact of these barriers on the MACCs. As such, they could be characterised as realistic MACCs. Examples of MACCs that take barriers into account are scarce. Yamaguchi (2012) is an example of a MACC that takes the barrier of the speed of diffusion of new technologies into account.

A comparison of idealistic and realistic MACCs quantifies the importance of the barriers. From a policy perspective, it indicates whether or not it is important to develop policies to address the barriers. However, it should be noted that the quantification of the barriers is subject to a considerable degree of uncertainty. Therefore, this chapter shows the results of various sets of assumptions representing the envelope of outcomes.

5.2 Scenarios for the quantification of barriers

This section develops scenarios for the quantification of barriers. It builds on the list of barriers analysed in Chapter 4. For each of the barriers identified there, this section argues whether, and of so how, it can be quantified.

As discussed in Chapter 4, barriers are hard to quantify. We have chosen to develop three scenarios for their impacts on the MACC: a low barrier scenario, in which the barriers have a small impact on the likelihood of adoption of technologies, a central scenario, and a high scenario, in which the barriers have severe impacts.

The scenarios relate to three barriers, which chapter 4 found to be the most important. These are the split incentive, which reduces the benefits of investments in fuel saving technologies for ship owners; the lack of independent data which causes ship owners to distrust certain technologies and hence not to invest in them; and transaction costs. With regards to the latter, we have only included transaction costs related to slow steaming in the scenarios. Other transaction costs, e.g. the costs of searching and evaluating new technologies, are sometimes associated with the lack of independent data and often could not be quantified.

Below, more detail on the scenario assumptions is presented.

1. A split incentive. Section 4.3 shows that as a result of the split incentive, ship owners are able to reap a share of the benefits of investments in fuel-efficiency. The share depends on the business cycle and possibly on other parameters, and we have not been able to quantify the share. Hence, we

assume that ship owners are able to appropriate half of the fuel savings caused by investments in fuel efficiency in higher charter rates in the base scenario. In a sensitivity analysis, we use values of 25% and 75%. Of course, this only applies for fuel efficiency improvements which require investments in technology, such as changes to the propeller, rudder, waste heat recovery and wind power. The split incentive applies to all ships on time charter, which, according to CE Delft et al. (2009) is 70-90% of ships. We have assumed that this share is constant over all categories of ships.

2. A lack of independent data, especially on new technologies. We have assumed that a lack of independent data results in ship owners not adopting that technology. In a sensitivity analysis, we have assumed that these technologies are available to half of the ships on which they can be implemented in principle. As shown in Section 4.4, currently the uncertainty on the measures below it the largest.
   a Air lubrication. Uncertainty about the abatement potential and operational costs constitutes a barrier to the implementation of this technology in new build ships;
   b Advanced rudders. The capital expenditures are perceived to be very high while the fuel savings are considered to be uncertain, thus constituting a barrier to the implementation of this technology as a retrofit.
   c Wind power. Kites are considered by many shipowners to be unreliable or unpractical, while Flettner rotors and sails are considered to impact the stability and the structure of a ship.
   d Waste heat recovery. Uncertainty about the applicability and the abatement potential constitute a barrier to the implementation of this technology. Since waste heat recovery is known to be implemented in a number of ships, we only take this barrier into account in one scenario;
3. Transaction costs associated with measures. Transaction costs associated with searching and evaluating information on new technologies is assumed to be part of the barrier of lack of independent data. For slow steaming, there are also transaction costs as charter parties may have to be amended as well as schedules. Some of these changes would involve negotiations with shippers, drafting new legal documents, et cetera, all of which may be costly. Recent experience with slow steaming has shown that shipping lines, especially container lines, have been able to slow down (UNCTAD, 2011, Cariou 2010). Tankers have slowed down on ballast legs and, sometimes, using new arrangements such as virtual arrival (Devanney 2011, Intertanko and OCIMF, 2010). Information on bulkers is more patchy but it seems they have slowed down to some extent (PWC, 2011). To quantify this barrier, we have assumed that half of the non-container ships would not be able to slow down.

Other barriers have not been quantified for various reasons:

4. Financial constraints are not taken into account here as we assume that they are less important over a long time period. While there are good reasons to assume that many shipping companies currently face financial constraints, it is unlikely that this situation will continue until 2030.
5. The reluctance of yards to implement new and innovative technologies is associated with the lack of independent data and transaction costs and not quantified separately as a barrier.
6. The quality of the information that ship owners and operators have on fuel efficiency is assumed to be part of the split incentive problem and quantified as such.
7. The time lag caused by dry dockings is not assumed to be relevant as ships will have had several dry dockings in the period up to 2030.

We have developed three scenarios for which the impact of the barriers on the MACC will be shown.

Table 10 Barrier quantification scenarios

	Central barrier scenario	Low barrier scenario	High barrier scenario
Split incentive: share of benefits reflected in time charter rates	50%	25%	75%
Lack of independent data	Air lubrication, advanced rudders, wind power are not available	Air lubrication, advanced rudders, wind power, applied to 50% of the relevant ships	Air lubrication, advanced rudders, wind power, waste heat recovery are not available
Transaction costs	50% of the non-container ships are not able to slow down	25% of the non-container ships are not able to slow down	75% of the non-container ships are not able to slow down

5.3 Barrier adjusted MACCs

In each of the three barrier scenarios three different barriers are taken into account: the split incentive between the ship owner and the ship operator, the lack of objective data on the reduction potential and/or the costs of the abatement measures, and the transaction costs that are associated with the adoption of abatement measures. The three scenarios however differ in the extent to which the barriers do play a role, resulting in a low, a central and a high barrier scenario.

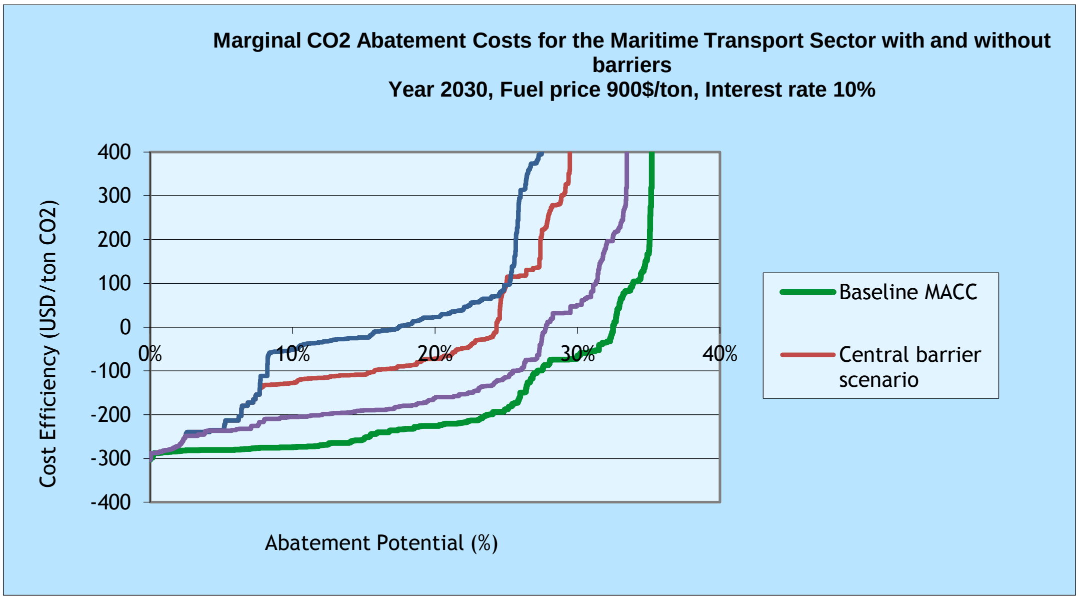
We have quantified the CO_2 abatement potential of the global maritime shipping sector for the three barrier scenarios and compared it to the baseline MACC, i.e. for he case that the three types of barriers are absent.

The three types of barriers have thereby been modelled as follows:
1. When a ship owner has to bare the investment costs for a CO_2 abatement measures whereas he cannot fully profit from the benefit of the investment, which in this case are the reduced fuel expenditures, his investment incentive is naturally reduced due to this **split incentive**. For those CO_2 abatement measures that require an investment of the ship owner we therefore determine the cost-efficiency of the abatement measure without taking the entire fuel expenditure savings into account. In the low barrier scenario 75%, in the central barrier scenario 50%, and in the high barrier scenario 25% of the fuel expenditure savings are considered.
2. The **lack of objective data on the cost-efficiency and/or the abatement potential** of CO_2 abatement measures can be expected to result in a reduced diffusion rate of these measures. A lack of objective data can mainly be expected to play a role for innovative measures for which empirical data is rather scarce. In the low barrier scenario we therefore assume that 50% of the ships that could make use of air lubrication, wind power or an advanced rudder will not do so. In the central barrier scenario we assumed that none the ships that could make use of air lubrication, wind power or an advanced rudder will do so. The high barrier scenario is an extension of the central barrier scenario by assuming on top that none of the ships that could make use of waste heat recovery will do so.

3. **Transaction costs that are associated with the adoption of CO_2 abatement measures** will lead to a lower cost-efficiency and thus also to a lower diffusion rate of these measures. To model the impact of transaction costs exactly, one would have to quantify the transaction costs per measure and take these costs into account when determining the cost-efficiency of the measures. Since it is very difficult or even impossible to determine these transaction costs, we decided to model this barrier just as we modelled the second barrier, i.e. the lack of objective data, by assuming that a certain share of ships will not adopt the respective measure. We thereby implicitly assume that transaction costs are that high that these measures become cost ineffective. Slow steaming is a good example for a measure that is associated with transaction costs that are difficult to quantify, such as the possible adjustment of logistic chains as a result of slow steaming. In the low barrier scenario we assume that 25%, in the central scenario that 50% and in the high scenario that 75% of the ships that are candidates for slow steaming will not do so. Note that due to the way we have modelled this third barrier the maximum abatement potential as shown in Figure 31 will decline due to this third barrier.

In Figure 31 the change of the cost-efficient abatement potential is illustrated for the three barrier scenarios as well as for the scenario in which there are no such barriers, i.e. the baseline MACC. The Marginal Abatement Cost Curves depicted give the abatement potential of the global fleet in 2030 and are derived for an average bunker fuel price of USD 900 per metric ton as well as for a discount rate of 10%. The baseline scenario is thus comparable to the central scenario in IMarEST (2011).

Figure 31 Change of cost-efficient abatement potential for different degrees of barriers



Source: CE Delft, this report.

In the baseline scenario the cost-efficient abatement potential amounts to around 32%. In the central barrier scenario, the cost-efficient abatement potential is reduced to 24 %, whereas in the low and high barrier scenario it is reduced to 28% and 17% respectively.

The split incentive barrier leads to a deterioration of the cost-efficiency of most of the abatement measures, leading to an upward shift of the MACC and thus to a reduction of the cost-efficient abatement potential. The cost-efficiency of abatement measures does also deteriorate when there are transaction costs associated with the adoption of the specific measures. These transaction costs might consist of verifying the reduction potential and/or the costs of the measures. When the cost-efficiency of a measure does deteriorate, the according part of the curve would move more to the upper right part of the curve. Since the transaction costs are very difficult to determine we modelled this effect by implicitly assuming that transaction costs make certain measures cost inefficient for some ship types, and omitted the respective cost-efficient part of the curve without adding a part to the cost inefficient part, resulting in a compressed part of the cost-efficient part of the curve and to a reduction of the total maximum abatement potential. Note that due to the interaction of the abatement measures, the cost-efficiency and the abatement potential of other measures are indirectly affected by the barriers too.

5.4 Conclusion

Barriers to the implementation of cost-effective abatement options can have a significant effect on both the cost-effective abatement potential and the Marginal Abatement Cost Curve. While the impacts are hard to quantify, this chapter shows that under a range of plausible assumptions, the cost-effective abatement potential may be reduced by an eighth to a half. Moreover, while the cost-effectiveness of the cheapest options remains unaffected, the general cost-effectiveness reduces significantly. This is a result of the fact that ship owners are only able to earn back a share of the efficiency improvements through higher charter rates. This means that the business case for many options becomes dependent on fuel price assumptions, requirements about rates of return, et cetera.

Reducing the barriers would potentially improve the scope for abatement in the shipping sector considerably.

6 Ways to reduce barriers

6.1 Introduction

As shown in Chapter 3, there is a considerable potential to improve the fuel-efficiency of ships and reduce GHG emissions relative to the increasing baseline. Although Chapter 2 indicates that this is unlikely to result in an absolute decrease in emissions, implementing the abatement measures, and certainly the cost-effective ones, could slow down the increase in maritime transport emissions (UNEP, 2011).

However, non-financial barriers prevent many of the measures from being implemented, as discussed in Chapter 4. Chapter 5 has attempted to quantify the impact and found that the barriers reduce the cost-effective abatement potential, potentially significantly, and also reduce the cost-effectiveness of the abatement measures from the perspective of the ship owner, who often has to decide on making the investments.

Hence, it could be worthwhile to offer ways to reduce barriers, either through policy or regulation, or through changes in business practices.

Table 11 presents an overview of the barriers and a list of the possible ways to reduce them. From this list, three items have been chosen for further elaboration. Improving ways to convey the fuel efficiency of a ship is a way to overcome the split incentive between the ship owner and the operator. It is analysed in Section 0. Another way to reduce the split incentive, lower dispute settlement costs, is analysed in Section 6.3. Finally, providing credible data about the costs and effectiveness of different fuel saving technologies as a way to increase acceptance of some of the newer measures is analysed in Section 6.4.

Table 11 Barriers and possible ways to reduce them

Barriers identified	Description of the barrier	Relevance of the barrier	Possible ways to reduce the barriers
Low priority	Traditionally, shipping companies have been focussed more on reducing non-fuel cost items (capital costs, labour costs) than on improving the fuel-efficiency of ships.	Diminishing as fuel prices become a larger share of operating costs of ships.	More involvement in R&D projects and funding to increase awareness and trust in efficient technologies. Create pressure by more stringent legislation. Increase pressure by increasing consumer awareness about carbon footprint of international transport.

Barriers identified	Description of the barrier	Relevance of the barrier	Possible ways to reduce the barriers
Split incentives	In many markets, more efficient ships are able to command higher charter rates. However, empirical evidence suggests that ship owners avoid disputes by underreporting the efficiency of their ships. As a result, only a share of the efficiency gains are reflected in higher charter rates. This means that not all cost-effective measures to reduce CO_2 emissions are profitable to ship owners – a share of the benefits spills over to the charterers - , but just the measures that have a cost-effectiveness that exceeds a certain threshold.	Significant.	Lower dispute settlement costs could reduce the dispute avoiding behaviour of ship owners. Better ways to convey information about the efficiency of a ship may create opportunities for ship owners to command higher charter rates for efficient ships. Including fuel costs in the charter rates, possibly adjusted by speed imposed on the ship by the charterer, would increase the incentive for ship owners to improve the efficiency of their ships.
Principle agent problem	Shipping companies may not be able to accurately monitor fuel consumption of their ships if the crew has an incentive to hide it.	Not clear.	Automatic fuel consumption monitoring equipment may reduce the scope for incorrectly reporting fuel consumption data. Labour contracts can be amended in order to provide an incentive for the crew to save fuel, rather than to hoard fuel.
Lack of independent data about measures to improve efficiency	Manufacturers claims of fuel efficiency improvements are often distrusted by shipping companies.	Significant.	Independent tests of fuel saving equipment may provide ship owners assurance about the performance of the equipment. Equipment manufacturers may assume some of the risk by guaranteeing a certain efficiency improvement.

Barriers identified	Description of the barrier	Relevance of the barrier	Possible ways to reduce the barriers
			The leasing of technologies could be another approach: in terms of failure, the risk is with the manufacturer
Reluctance of yards to introduce new technologies	Ship yards may be reluctant to introduce new technologies in new ships for reasons related to the efficiency of the shipbuilding process, warranties, et cetera.	Currently, there seems to be an overcapacity both in new building yards and in maintenance and repair yards	Shipyards should begin thinking about investigating new ship designs and technologies for successful competition. Some designers are searching for yards as partner Improve qualification of yards personnel.
Capacity of yards	Yards may not have sufficient capacity to install fuel saving technologies	Currently, there seems to be an overcapacity both in new building yards and in maintenance and repair yards	Shipyards can manufacture some of the efficient technologies themselves to enter the market. One Singaporian shipyard is following this path. Demand for ship repair and retro-fitting of e.g. ballast water treatments technologies alone will block repair yards over the coming years, especially for large ships. Therefore, the availability of repair yards should be increased.
Access to finance	Freight rates are lower than their long term average while fuel costs have gone up. This has drained the liquidity of some shipping companies.	Currently an issue.	Not analysed.
Route dependency of efficiency	Efficiency of a ship is dependent on many factors and can hardly be presented in a single figure.	Would become an issue if efficiency-dependent charter rates would become the norm.	Shipowners and charterers have to harmonise their fuel calculations.

Barriers identified	Description of the barrier	Relevance of the barrier	Possible ways to reduce the barriers
Low environmental awareness of ship personnel	The ships personnel at these times have no interest to run a ship efficiently.	significant	Theoretical and practical training in ship energy efficiency for the crew and an award scheme for energy savings like mentioned before.

Not all barriers are equally important in all situations.

In situations where conventional technology is applied to new built ships, the split incentive is important, as are financial constraints and reluctance of yards to implement new technologies. Finding independent data is relatively easy for conventional technology and search costs are low.

When applying conventional technologies as retrofits, the split incentive is important, as are financial constraints, especially since other technologies also have to be retrofitted, and the capacity of retrofit yards.

Operational abatement measures may be held back by the split incentive and transaction costs (if they require changes to standard charter parties, for example).

For unconventional technologies, lack of independent data and transaction costs are important barriers, as well as reluctance of yards and the split incentive.

6.2 Improving ways to convey the fuel efficiency of a ship

One of the causes of the split incentive is the fact that current charter parties offer very limited information about the fuel efficiency of a ship (see Section 4.2.1 and 4.3). The information conveyed in the standard charter parties is limited to the warranted speed and fuel consumption. The latter is often presented in tonnes per day, and often rounded to full tonnes.

If fuel efficiency could be more accurately conveyed, this could result in ship owners being able to recoup a larger share of the benefits of more fuel efficient ships. If so, it would reduce the barrier to investments in fuel-efficiency improving technologies caused by the split incentive.

In this section, we explore two ways in which ship owners can give more precise information about the fuel efficiency of their ships. One was is to present the potential charterer with more accurate information about the efficiency under the circumstances that the ship will be used. The other is to use or develop more accurate standardised measures of ship efficiency.

6.2.1 Tailored information about fuel consumption

Many factors are known to affect fuel consumption, including (MEPC.1/Circ.683, IMO, 2009c):

- speed;
- variability of speed;
- cargo, fuel and ballast load;
- trim;
- propeller pitch;
- et cetera.

The impacts of speed, variability of speed and load are potentially large. The fuel consumption of the main engine has a cubic relation to speed. Sailing at constant speeds can save a significant amount of fuel. And ships sailing in ballast consume often up to 15% less fuel than fully laden ships. The other factors may have negligible impacts, but in combination their impact could be significant.

What is perhaps more important is that the impact of each of these factors on fuel consumption can be different for each ship. For example, the precise relation between speed and fuel consumption depends on the auxiliary engines and boilers, the hull form, propeller, et cetera. The difference between fuel consumption when laden and in ballast depends on the hull form, trim, et cetera.

Hence, the warranted fuel consumption at the warranted speed may be of limited relevance to a charterer who envisages to use a ship for a particular trade. He may be more interested in consumption under a particular speed and load profile.

To some extent, tools analysing ship-efficiency and its factors are available on the market. There have been reports that some of these tools are used in charter party negotiations, although we have no confirmation of this in our interviews.[8]

In order to reduce this barrier, providers of standard charter parties could develop tools to assess a ship's fuel consumption for various operational profiles or incorporate the option to use information from existing tools. Development of such tools would require co-operation with ship owners and charterers because it requires use of data that both parties have. Moreover, for the tool to be effective, it has to be trusted by different parties. And finally, the charter party providers need to develop clauses in the parties which allow the use of these tools and which govern dispute settlements when the efficiency of a ship is misrepresented.

6.2.2 Fuel efficiency metrics

Over the past years, a number of ship fuel efficiency metrics have been developed. The *Energy Efficiency Operational Index* (EEOI) has been developed by the IMO to measure the performance of a ship per tonne-mile of transport work performed (MEPC.1/Circ.684, IMO, 2009d). Other operational indices include the BSR Clean Cargo Group Index, which is similar to the EEOI but only applicable to container ships, and the Intertanko Index for tankers, although it is not clear whether the latter is still being used (CE et al., 2006). The *Energy Efficiency Design Index* (EEDI) has been developed to represent the energy

[8] Propulsion Dynamics mentions on its website that its CASPAR system, which analyses the actual speed and fuel consumption performance of the vessel, can be used to generate Actual Obtainable Speed/Consumption Diagrams that can be used in charter negotiations. http://www.propulsiondynamics.com, accessed 23 February 2012.

efficiency of new ships under standardised conditions (MEPC.1/Circ.681, IMO, 2009b).

If any or all of these metrics would reflect the fuel efficiency of a ship more accurately than the fuel consumption figure reported in the charter parties, conveying them could enable ship owners to command a higher charter rate for a more fuel efficient ship and thus earn back a larger share of the fuel savings of more fuel efficient ships.

At this moment, however, it is not clear whether any of these metrics reflects the fuel efficiency more accurately. As for the EEOI and related operational measures, CE et al. (2006) found that the EEOI of a specific ships can show a large variation due to:

- **Density of the cargo.** Bulk carriers can transport weight restricted cargo (high density cargo such as coal or ore) or volume restricted cargo. Since the formula is expressed in mass of CO_2 per tonne-mile of transport work, the former ship would always have a better index than the latter.
- **Business cycle:** Changes in transport demand and fleet size cause changes in relative cargo availability hence efficiency. To be effective, the baseline must be more or less continuously adjusted.
- **Trade specific supply and demand:** Transport efficiency potential depends on location of origin and destination, cargo volumes, ability to find return goods (trade triangles, etc.) type of goods and more.

As a result, the EEOI reported over one period may not be a good indicator of the EEOI in another period, especially when a different type of cargo is transported, the ship will be operated on a different route, et cetera. This conclusion is echoed by shipping companies interviewed in the course of this project (see Section 4.2). They generally see the merit of the EEOI to compare similar ships in the fleet of a company, rather than across companies.

The EEDI is meant for new built ships and will become mandatory from 2013 onwards. Currently, a few ships have a verified EEDI. Hence, nothing is known about the relation between EEDI and actual fuel consumption of ships. Neither is there an analysis of the relation between other design indices and actual fuel consumption. When, from 2013 onward, an increasing number of ships will have an EEDI, more experience can be gained on the relation between the EEDI and the operational efficiency of ships in practice. This will allow the market to evaluate whether the EEDI is suitable as an additional metric for conveying a ship's efficiency in a charter contract.

Shipping companies interviewed in the course of this project (see Section 4.2) have different expectations of whether the EEDI or other design based indices will increase the transparency of the time charter market. Some interviewees thought that the metric would allow for gaming and that it would take a long time for the market to get used to the metric. Others thought is could add transparency if it proved to be a reliable metric. Probably these two views are not that far apart, as they both point to the need to better understand the relation between the EEDI and actual emissions.

It would be worthwhile to explore in detail whether and if so, how, the EEDI can be used to convey information about a ship's efficiency. In addition, shipping companies are required to set a goal related to the energy-efficiency of their ships as part of the Ship Energy Efficiency Management Plan (SEEMP). It is likely that this will result in the coming years in a better understanding of various indicators, including the EEOI.

6.2.3 Conclusion

There is a considerable potential to improve the information exchange in charter parties on the fuel efficiency of a ship. This may reduce the split-incentive barrier to the implementation of cost-effective abatement measures.

One way is for the ship owner to develop a tool that evaluates fuel use of a ship under a range of conditions. Such tools are commercially available. Providers of standard charter parties could consider opening the opportunity to warrant fuel consumption according to the ship-specific tool.

A second way is to develop better fuel-efficiency metrics. Up to now, none of the metrics developed has proven to be able to reduce the split-incentive barrier. It remains to be seen whether the EEDI, which most new ships will have from 2013 onwards, and/or other design based metrics can fulfil this role. It would be good to study the relation between the EEDI and actual fuel consumption to develop a better understanding.

6.3 Lower dispute settlement costs

Section 4.3 has shown that many ship owners are risk averse with regards to bunker quantity claims and as a result underreport the fuel-efficiency of their ships. Moreover, the analysis shows that underreporting is, on average, larger for more efficient ships.

One of the reasons for underreporting appears to be the possibility of bunker claims and the costs of dispute settlement. This led to the idea that lower dispute settlement costs could result in more accurate warranties with regards to fuel consumption and to a decrease of the split incentive barrier.

It appears, however, that the shipping industry has a range of institutions aimed at reducing dispute settlement costs. For example, many ship owners and charterers include speed/consumption clauses in their charter parties, which allow for a swift settlement of differences in fuel consumption. In general, when an owner and a charterer disagree on the amount of bunker consumed, they will first try to reach an agreement. If that fails, they will often appoint an arbitrator. If that fails, a second or sometimes even third arbitrator can be sought. Court cases on bunker claims are seldom as well as costly.

Because of these institutions, it is likely that dispute settlement costs are already low and there is little scope, if any, to reduce them further.

6.4 Increasing the credibility of data on fuel saving equipment

Manufacturers claims of fuel efficiency improvements of specific technologies are often distrusted by shipping companies (see Sections 4.2.2 and 4.4). In many cases, this is even true of reports of third parties paid for by manufacturers. Many interviewees have offered examples of bad experiences with claims that turned out to be exaggerated.

Since this barrier relates primarily to new or improved technologies, one way of interpreting this problem is to analyse it as a diffusion of innovation problem. It is worthwhile to learn from this body of literature. Rogers (2003) finds that there are five qualities that determine the success of an innovation:

1. The relative advantage of a new technology compared to the current alternatives.
2. The compatibility of the technology with existing values and practices;
3. The simplicity and ease of use of the technology.
4. The degree to which an innovation can be experimented with without taking too much risk.
5. The degree to which results (including the relative advantage, the compatibility and the ease of use) are observable.

From the interviews, it is clear that the last two items are often lacking. First, before a measure can be experimented with, a ship owner has to invest and he may run the risk of the new technology interfering with normal operations of the ship, potentially even requiring the ship to be taken off-hire in order to remove the technology. Second, the costs and benefits are often not observable because the information supplied by or on behalf of the manufacturers is often distrusted.
There are a few positive examples of diffusion of innovation in the shipping industry. Waste heat recovery have been available for a long time. After they had generated some interest in the 1970s and early 1980s, lower fuel prices and apparent technology failures reduced interest. It appears that the co-operation of equipment manufacturers and a few shipping lines in the late 1990s and 2000s has revived the interest. Both the shipping lines and the equipment manufacturers have shared their experiences and this seems to have changed how shipping companies view this technology.

In this example, it is clear that experiments have been conducted in collaboration between suppliers and shipping companies, and that these experiments have resulted in observable characteristics of technologies. It is not clear whether and, if so, how the risks have been reduced.

Another example is the Mitsubishi Air Lubrication System. This system is currently being tested on an NYK-line vessel in a programme subsidised by the Japanese government (Tanaka, 2012). In this case, the risk of testing the new technology appears to be reduced by the government subsidy.

These examples show that there are ways to speed up the diffusion of innovation by increasing the credibility of data on fuel saving equipment. The primary means to which this can be achieved is a collaboration between suppliers of technology and shipping companies. Additionally, risk can be reduced through government subsidies.

7 Conclusion

This report has analysed three essential factors in the development of maritime transport emissions. First, it has analysed the baseline emission projections which underlie most analyses of the climate impact of shipping and policies to reduce the impact. Second, it has analysed the abatement potential of maritime transport and the Marginal Abatement Cost Curves which show the costs of achieving certain emission reductions. Third, it has analysed barriers to the implementation of cost-effective abatement options and the ways in which these barriers can be overcome.

This report has applied a saturation model to ship emission projections. It finds that using such a model and using transport work data to project transport demand yields emission projections that would be 6% higher than conventionally assumed. In addition, it finds that due to the increasing size of the largest container ships, ship emissions may be 3-7% lower in 2020 and 6-13% in 2050. On balance, this report finds that maritime transport emission projections should be somewhat lower than previously assumed. It also finds that because ship emission projections depend on shipping activity projections, which in turn depend on trade projections, it would be good if emission projections would be based on trade models.

The main differences between published Marginal Abatement Cost Curves is their maximum abatement potential. This can be attributed to a large extent to a difference in the baseline and a larger number of measures that are included. The remaining difference is about 10% and can be attributed to the other methodological differences.

A literature review and interviews with stakeholders has identified seven general barriers to the implementation of cost-effective measures to improve the fuel-efficiency of a ship. These are:

1. A split incentive because a ship owner has to invest in the fuel efficiency of a ship while the charterer pays for the fuel. In practice, the owner can earn a higher charter rate for a more fuel efficient ship in most market conditions but the amount by which the charter rate is higher is only a share of the amount by which the fuel consumption is lower. The fact that owners are only able to recoup a share of the benefits of a fuel-efficient ships depends on two factors. First, micro-economic analysis shows that it is rational in an equilibrium market that the benefits are shared between the supplier (i.e. the owner) and the consumer (i.e. the charterer). How large the share for each party is, depends on the price elasticity of demand and the price elasticity of supply. Both depend on marker circumstances and are therefore variable. Second, in charter parties the risks of over- and underperformance of a ship are unevenly distributed. While owners bear the risk of underperformance, there is no risk to the charterer in case of overperformance. Both factors combined have the effect that ship owners who invest in a fuel efficient ship, or who invest in improving the fuel-efficiency of their ship, are able to earn back a share of the fuel benefits through higher charter rates. The remaining benefits are for the charterer.
2. A lack of independent data, especially on new technologies, results in a high uncertainty in the business case and prevents ship owners to invest.

3. The transaction costs associated with searching for and evaluating measures to improve the fuel-efficiency of ships may be high, especially for new technologies. This barrier exacerbates the previous one.
4. Financial constraints are caused with market circumstances and by requirements to invest in other technologies, e.g. for ballast water management and emissions control.
5. Yards may be reluctant to implement new and innovative technologies, and they may be reluctant to include these technologies in their warranties. The reluctance varies considerably over yards.
6. In some cases, ship owners and operators may not have good information on the fuel efficiency of a vessel, making it hard to analyse the impacts of efficiency improving equipment.
7. As retrofits are often only feasible when a ship is already in dry dock, and dry docks are planned on regular four to six year intervals, there may be a time lag between when a measure becomes cost-effective and its implementation.

The first three are the most important in terms of impacts on the cost-effectiveness of measures and hence on the cost-effective abatement potential. The financial constraints are severe but likely to be temporary; while the reluctance of yards and the fuel monitoring system are very case-specific. The time lag for technologies that require drydocking is a universal barrier, albeit one that can hardly be overcome.

The overall comparison of the different measures showed that the optimisation of operational measures is most important. The reason might be a comparable little effort for the implementation, little technological changes of the ship structure and comparable low investment. Ship owners and other maritime stakeholders both judged these measures as the highest energy saving measure and therefore have a huge impact on the MACCs. In detail the most accepted operational measures are speed reduction, increase of crew awareness and crew training. Awareness is e.g. increased by fuel saving competition between crews and ships.

Engine related measures are well perceived by the ship owners, whereas the knowledge of other maritime stakeholders was very low. Most engine related improvements are regarded as state of the art and are also related to reduction of NO_x emissions. They should appear in the MACCs as already applied technologies. Improvements in engine performance are largely dependent on new developments at the engine manufacturers. Barriers for the other technologies are the high costs for e.g. waste heat recovery and advanced rudders. Changes to the propulsion system are not only costly but also regarded as very sensitive in terms of ships safety. Therefore there is a strong reluctance for the implementation and this should appear in the tail of the MACCs. Fuel oil treatment has the lowest potential and is regarded as very uncertain with little potential and is not implemented on a broad basis.

Reduction of ship hull friction is well accepted as energy saving measure, especially the optimisation of the ship hull design. Optimisation of the ship hull design is state of the art. The only barrier is the acceptance at the shipyards, who do not like changes of designs. The extent of the fuel saving potential is mainly unknown. The barriers for low friction hull coatings are uncertainty of saving potential and high costs. Air lubrication was the least accepted method for a number of technical and operational reasons. Energy savings between 1-10% are possible, but air lubrication is simply not suitable for most ship types and has very limited potential to be implemented. However, some tests are carried out currently and some look very promising for certain ship types. Micro- or milli-bubbles are even suitable for retro-fitting in some existing ships.

Other technical measures are less accepted or simply unknown. On the top range are optimisation of hotelling functions and minimisation of weight. The remaining technological measures are mainly applied on cruise liners only and not relevant for other ship types. Here the MACCs should differ significantly for the different types of ships with high impact on cruise liners and less impact for other ship types.

The lowest acceptance was for alternative fuels and alternative power sources. Ship owners see little benefit in alternative power sources and other maritime stakeholders see a limited or no impact at all. Moreover, the infrastructure to provide ships with LNG is still emerging and some places prevent the bunkering of LNG on safety grounds. Shore power is applied by one ship owner and largely fails due to standardisation of the power supply.

Fuel cells are not regarded as mature for shipping and are only applied in a very small niche market. It will take many years until fuel cells can be implemented in ships, especially as main propulsion. Even when the technical problems are solved, the price of the technology and hydrogen has to be much lower to support the implementation of fuel cells. Wind power is applied by one ship owner only in a ship trial. Kites have the lowest acceptance compared to Flettner rotors, sails and wings. Barriers are the handling, costs for the replacement parts plus the fact that they are only useful on relatively slow ships (<15 knots). However, if wind propulsion is applied, there will be a huge impact on the MAC curve, as the saving potential can be very large. The barriers for the use of LNG and CNG are lack of infrastructure for their global supply, increase of shipbuilding costs and space requirements. All ship owners are very interested in the use of LNG/CNG, but observe the developments only. This alternative fuel again can only be applied in a niche market like gas carriers and short sea shipping. Only recently a LNG ship design has been approved by DNV, but this has still to be built. The first LNG fuelled ship for inland waterways has been built.

Barriers to the implementation of cost-effective abatement options can have a significant effect on both the cost-effective abatement potential and the Marginal Abatement Cost Curve. While the impacts are hard to quantify, the cost-effective abatement potential may be reduced by an eighth to a half under a range of plausible assumptions. Moreover, while the cost-effectiveness of the cheapest options remains unaffected, the general cost-effectiveness reduces significantly. This is a result of the fact that ship owners are only able to earn back a share of the efficiency improvements through higher charter rates. This means that the business case for many options becomes dependent on fuel price assumptions, requirements about rates of return, et cetera.

Reducing the barriers would potentially improve the scope for abatement in the shipping sector considerably. There are several ways to overcome them. The split incentive can – to some extent – be overcome by providing more detailed information about fuel efficiency of ships, taking the operational profile into account. As a result, the fuel consumption can be more accurately projected and a larger share of efficiency benefits can be appropriated by the ship owner, thus increasing the return on investment in fuel saving technologies. This would also require changes to standard charter parties.

The credibility of information about new technologies can be improved through intensive collaboration between suppliers of new technologies and shipping companies. In order to overcome risk, government subsidies could provide an incentive. This could have the additional benefit that governments could require publication of results.

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Annex A Abatement measures

A.1 Coverage of studies with regard to the individual abatement measures

The following table gives an overview of the different CO_2 abatement measures that underly the MACCs in the different studies. Note thereby that summing up the ticked boxes per column does not give the actual number of measures considered in the studies. This is the case because both a measure group with which is worked in a study is given (e.g. reduced auxiliary power usage) but also single measures which could be subsumed to this group (e.g. speed control of pumps and fans) with which in the other study is worked are given.

Table 12 CO_2 abatement measures underlying the MACCs of the different studies

	Eide et al. (2011)	IMAREST et al. (2010a)	CE et al. (2009)
Main engine tuning	-	x	x
Common-rail	-	x	x
Electronic engine control	x	-	-
Frequency converters	x	-	-
Gas fuelled engines	x	-	-
Steam plant operation improvements	x	-	-
Waste heat recovery	x	x	x
Engine monitoring	x	-	-
Propeller-rudder upgrade	-	x	x
Propeller upgrade (nozzle, tip winglet)	x	x	x
Propeller boss cap fins	x	x	x
Improvement flow to/from propeller	x	x	x
Contra-rotating propeller	x	-	-
Propeller performance monitoring	-	-	x
Propeller polishing	x	x	x
Air lubrication	x	x	x
Hull coating	x	x	x
Hull performance monitoring	-	-	x
Hull brushing	-	x	x
Hull hydro-blasting	-	x	x
Dry-dock full blast (old ships)	-	-	x
Optimisation water flow hull openings	-	x	x
Towing kite	x	x	x
Wind power (fixed sails or wings)	x	-	-
Wind engine (Flettner rotor)	-	x	x
Speed reduction due to improvement of port efficiency	x	-	-
Speed reduction 10% (due to fleet increase)	x	x	x
Speed reduction 20% (due to fleet increase)	-	x	x
Reduced auxiliary power usage (low energy lighting etc.)	x	x	x
Speed control of pumps and fans	x	x	x
Energy efficient light system	x	x	x
Exhaust gas boilers on auxiliary engines	x	-	-
Solar panels	x	x	X
Fuel cells used as auxiliary engines	x	-	-

	Eide et al. (2011)	IMAREST et al. (2010a)	CE et al. (2009)
Wind-powered electric generator	x	-	-
Power management system	-	-	x
Cold ironing	x	-	-
Optimisation trim/draft (based on load condition)	x	x	x
Voyage optimisation using shaft power meter	x	-	x
Voyage optimisation using fuel consumption meter	x	-	x
Voyage execution (const. speed and load; rudder position)	x	-	-
Weather routing	x	x	x
Autopilot upgrade/adjustment	-	x	x

A.2 Measure groups IMAREST (2010a) and CE et al. (2009)

In IMAREST (2010a) and in CE et al. (2009) the individual CO_2 abatement measures are grouped. The measures that are not likely to be used together/that exclude each other are thereby allocated to one group. As can be seen in the following overview, in IMAREST (2010a) five individual measures are taken less into account and two measures were joined, whereas three more measure groups are differentiated. In Table 13 those measure groups that differ are listed first.

Table 13 Comparison of measure groups in IMAREST (2010a) and CE et al. (2009)

IMAREST (2010a)		CE et al. (2009)	
Measure Group	**Individual Measure**	**Measure Group**	**Individual Measure**
Weather routing	Weather routing	**Voyage and operations options**	Weather routing
Autopilot upgrade/adjustment	Autopilot upgrade/adjustment		Autopilot upgrade/adjustment
	-		Optimisation using shaft power meter
	-		Optimisation using fuel consumption meter
Reducing onboard power demand (hotel services)	Low energy lighting	**Auxiliary systems**	Low energy lighting
Speed control of pumps and fans	Speed control of pumps and fans		Speed control of pumps and fans
	-		Power management
Propeller maintenance	Propeller polishing (at regular intervals)	**Propeller maintenance**	Propeller brushing (at regular intervals)
	Propeller polishing (when needed; including propeller performance monitoring)		Propeller brushing (increased frequency)
			Propeller performance monitoring

IMAREST (2010a)		CE et al. (2009)	
Hull coating	Hull coating I	**Hull coating and maintenance**	Hull coating I
	Hull coating II		Hull coating II
	-		Dry dock full blast
	-		Hull performance monitoring
Hull cleaning	Hull brushing		Hull brushing
	Underwater blast		Underwater blast
Speed reduction	10% speed reduction	**Speed reduction**	10% speed reduction
	20% speed reduction		20% speed reduction
Optimisation hull openings	Optimisation water flow of hull openings	**Retrofit hull improvement**	Transverse thruster opening (flow optimisation, grids)
Air lubrication	Air cavity system	**Air lubrication**	Air cavity system
Propulsion upgrade	Propeller-rudder upgrade	**Propeller/propulsion upgrade**	Propeller-rudder upgrade
	Propeller upgrade (nozzle, tip winglets, etc.)		Propeller upgrade (nozzle, tip winglets, etc.)
	Propeller boss cap fins		Propeller boss cap fins
Main engine adjustments	Common rail technology	**Main engine retrofit measures**	Common rail technology
	Main engine tuning		Main engine tuning
Waste heat recovery	Waste heat recovery	**Waste heat recovery**	Waste heat recovery
Wind power	Towing kite	**Wind power**	Towing kite
	Wind engines		Wind engines
Solar power	Solar power	**Solar power**	Solar power

Annex B Questionnaire

Questionnaire for maritime stakeholders

This questionnaire helps to identify the efforts of the maritime industry to reduce GHG emissions. The results will feed into a GHG study and will help to identify the differences in the various published marginal CO2 abatement cost curves. The study is carried out by CE Delft and Marena Ltd for the Ocean Policy Research Foundation, Japan. Names of companies and individuals will be treated confidential and are only classified into major groups, unless agreed otherwise. We thank all parties for their contribution.

1. Barriers to the implementation of energy saving measures

Several studies have indicated that shipping companies can increase the energy efficiency of their ships at no costs or even at a profit. DNV, for example, has estimated that on average, ships can improve their energy efficiency by 10% while at the same time reducing their costs. What is your opinion about these studies?

1.1 Several studies have looked into the reasons why not all cost-effective efficiency improvements are being implemented. IMarEST (2010) has identified a number of reasons:

1. Technological barriers
   a. real or perceived risk of failure of a technology
   b. incompatibility of certain technologies with the ship and/or the routes where it sails

2. Institutional barriers
   a. split incentive in which the ship owner has to make an investment in a new technology while the charterer receives the benefit of lower fuel consumption
   b. the split incentive combined with the fact that neither the charter market nor the second hand market pay a premium for fuel efficient ships
   c. bunker adjustment factors and other financial arrangements which shield the ship operator from the costs of fuel and thus make investments in energy saving less profitable
   d. lack of information on new technologies and/or the costs associated with finding out about new technologies

3. Financial
   a. investment appraisal methods in shipping companies which require very short payback times for retrofit technologies
   b. investment appraisal methods that prescribe a low fuel price in order to account for fuel price uncertainty

Questions

1.1.1. Do you think these barriers exist?

1.1.2 Do you think other barriers are also important? If so, which?

1.1.3. Which barrier or barriers are the most important in your opinion?

1.2 Many stakeholders have perceived the split incentive to be an important reason why not all cost-effective technologies are implemented. This means that a charterer will not pay a premium for a more fuel efficient ship, even though he has to pay less for the fuel.

1.2.1 Is this true, in your opinion, and if so, why isn't the fuel-efficiency reflected in the charter rate?

1

1.2.2 If you charter a ship, do you assess its fuel efficiency and if so, how?

1.2.3 Will the increased transparency in the market (e.g. EEDI and EEOI) change this situation?

1.2.4 Are some technologies perhaps regarded as risky so that they actually result in lower charter rates? If so, which?

1.2.5 How do you think that innovative technologies affect the second hand price of a ship?

1.2.6 Do the classification societies approve all technologies?

1.2.7 Do you have a specific fuel price in mind when assessing different technologies?

1.2.8 **In general,** do you think the general mentality is to watch others before taking action?

1.2.1 do shipowners wait for the legislation to be in place before applying an energy saving measure?

2

2. Energy Efficiency Measures: State of the Art/Plans for the Future

Which energy efficiency measures do you believe is already applied and accepted by shipowners and which are most promising from your point of view? Under comments the measures can be related to certain ship types.

2.1 Technical measures

No.		Already applied	Application planned	(Expected) Energy saving (%)	Costs	Comments
1	**Reduction of resistance**					
2	Low friction hull coatings to reduce roughness of wetted surface					
3	Reduction of structural roughness (e.g. less hull openings					
4	Optimised hull design to reduce wave resistance					
5	Air lubrication					
6	Electric propulsion					
	Engine related measures					
7	Turbocharger					
8	Common Rail Technology					
9	Variable turbine geometry					
10	Miller cycle/Atkinson cycle					
11	Automatic engine tuning					
12	Waste heat recovery					
13	Fuel oil treatment e.g.					
14	Advanced Rudders					
15	Other propeller related optimisations					
	Other technical measures					
16	AC/DC converter For the propeller and generator					
17	Optimisation of hotelling functions					

3

No.		Already applied	Application planned	(Expected) Energy saving (%)	Costs	Comments
18	Minimizing weight					
19	Use of light-weight materials in ship construction					
20	Waste heat recovery incinerators					
21	CO_2 abatement technologies					
22	Gyroscopic stabiliser					
23	Combustion of waste oil in Boiler					
24	Others					

2.2 Alternative fuels and power sources

No		Already applied	Future potential	(Expected) Energy saving (%)	Costs	Comments
1	Cold ironing/Shore power					
2	Fuel cells as AUX (hybrid auxiliary power generation)					
	Fuel cells as propulsion					
3	LNG/CNG					
4	Biofuels					
6	Wind power – kites					
7	Wind power – sails or wings					
8	Wind power – wind generators (Flettner rotor)					
9	Solar cells					
10	Others					

4

2.3 Operational measures

No		Already applied	Future potential	(Expected) Energy saving (%)	Costs	Comments
1	General speed reduction					
2	Speed reduction due to port efficiency					
3	Speed reduction due to increase of fleet size					
4	Weather routing					
5	Voyage optimisation					
6	Steam plant operational improvement					
7	North East Passage					
8	Trim optimisation					
9	Optimisation of ballast voyages					
10	Monitoring of energy consumption					
11	Autopilot					
12	Regular hull and propeller cleaning					
13	Increase awareness of crew					
14	Regular training of crew					
15	Optimised fleet management					
16	Others					

Annex C Discounting effects in cost-effectiveness analysis

C.1 Introduction

The MACC for CO_2 abatement measures in the shipping sector compares the cost-effectiveness of measures with different lifetimes. As a result, the period over which the emissions are reduced varies over measures.

The cost-effectiveness analysis compares the costs per unit of CO_2 reduced. Some MACCs express cost-effectiveness in annual CO_2 reductions per annualised costs, others use the CO_2 emission reductions over the lifetime of the measure divided by the net present value of the costs. In the latter case, the results depend on whether future emission reductions are discounted or not, and if so, at the same rate as future costs or not ().

Table 14 illustrates this point. The table compares three measures that have the same absolute effect, a reduction of 100 units of CO_2, and the same costs, 100 units, but a different lifetime. When effects are not discounted, each measure has the same effectiveness, of course. When either annualised costs are used, or effects are discounted, the measure with the longest lifetime has the lowest cost-effectiveness.

Table 14 Comparison of different ways to calculate cost-effectiveness

Capital Costs	Lifetime	Annual CO_2 emission reductions	Discount rate	Cost-effectiveness if costs are expressed in NPV and effects are discounted (€)	Cost-effectiveness if costs are expressed in NPV and effects are not discounted(€)	Cost-effectiveness if costs are annualised (€)
100	10	10	10%	1.63	1.00	1.63
100	5	20	10%	1.32	1.00	1.32
100	1	100	10%	1.10	1.00	1.10

So the order of the cost-effectiveness of different measures depends on the method to determine cost-effectiveness, and especially on discounting effects or not.

Many studies of cost-effectiveness of environmental measures use annualised costs and effects, which has the same effect as discounting future effects (e.g. Blok, 2001; AEA, 2001; INFRAS, 2006). However, other studies use net present values of costs and undiscounted effects (TNO 2006; Lutsey 2008).

Many guidelines for project appraisal in either environmental economics and transport economics do not specifically recommend either discounting physical effects or not (Treasury Board of Canada, s.a.; HM Treasury, s.a.; Florio et al., 2008). In most cases, these guidelines focus on cost-benefit analysis and discuss cost-effectiveness analysis only in passing.

In contrast, the issue of discounting in cost-effectiveness analysis is discussed in much detail in health economics. The World Health Organisation, in its guidelines, states that ‘It is standard practice in most cost-effectiveness studies to discount future health benefits at the same rate as costs’, although ‘the practice is widely debated’. It cites three reasons to discount health effects:

1. People value current health over future health, hence there is a time preference in the health effect;
2. People trade current welfare for future health, hence there are opportunity costs associated with investments in future health improvements.
3. There is a eradication/research paradox: if one compares an investment in health improvement with an investment in research that has a chance of resulting in an eradication of a disease, a zero discount rate would suggest to invest all the funds in research, as it has an infinite revenue stream.

Some of these arguments are valid for investments in CO_2 abatement as well. People may value current abatement (i.e. current reduction of pollution) over future abatement. And the eradication/research paradox exists in CO_2 abatement as well.

In addition, there is another argument in favour of discounting (Weikard and Zhu 2005). Because CO_2 has a very long lifetime, and assuming that climate change reduces productivity, emitting CO_2 will lower productivity and economic growth. One unit emitted now has a stronger impact on future growth than one unit in the future, since it sets the economy on a lower growth path starting today. Hence, it would be right to discount the physical effects.

A different but related question is whether the discount rate for the physical effects should be the same as the discount rate for costs or not. We have not analysed this question in detail. All the studies reviewed that discount future physical effects use the same discount rate. However, they do not present a theoretical argument for doing so. In our analysis, we have chosen to stick with this convention.

Annex D Gencom Charter Party Form

1. Shipbroker	RECOMMENDED THE BALTIC AND INTERNATIONAL MARITIME COUNCIL UNIFORM GENERAL CHARTER (AS REVISED 1922, 1976 and 1994) (To be used for trades for which no specially approved form is in force) CODE NAME: "GENCON" Part I 2. Place and date
3. Owners/Place of business (Cl. 1)	4. Charterers/Place of business (Cl. 1)
5. Vessel's name (Cl. 1)	6. GT/NT (Cl. 1)
7. DWT all told on summer load line in metric tons (abt.) (Cl. 1)	8. Present position (Cl. 1)
9. Expected ready to load (abt.) (Cl. 1)	
10. Loading port or place (Cl. 1)	11. Discharging port or place (Cl. 1)
12. Cargo (also state quantity and margin in Owners' option, if agreed; if full and complete cargo not agreed state "part cargo") (Cl. 1)	
13. Freight rate (also state whether freight prepaid or payable on delivery) (Cl. 4)	14. Freight payment (state currency and method of payment; also beneficiary and bank account) (Cl. 4)
15. State if vessel's cargo handling gear shall not be used (Cl. 5)	16. Laytime (if separate laytime for load. and disch. is agreed, fill in a) and b). If total laytime for load. and disch., fill in c) only) (Cl. 6)
17. Shippers/Place of business (Cl. 6)	a) Laytime for loading
18. Agents (loading) (Cl. 6)	b) Laytime for discharging
19. Agents (discharging) (Cl. 6)	c) Total laytime for loading and discharging
20. Demurrage rate and manner payable (loading and discharging) (Cl. 7)	21. Cancelling date (Cl. 9)
	22. General Average to be adjusted at (Cl. 12)
23. Freight Tax (state if for the Owners' account) (Cl. 13 (c))	24. Brokerage commission and to whom payable (Cl. 15)
25. Law and Arbitration (state 19 (a), 19 (b) or 19 (c) of Cl. 19; if 19 (c) agreed also state Place of Arbitration) (if not filled in 19 (a) shall apply) (Cl. 19)	
(a) State maximum amount for small claims/shortened arbitration (Cl. 19)	26. Additional clauses covering special provisions, if agreed

It is mutually agreed that this Contract shall be performed subject to the conditions contained in this Charter Party which shall include Part I as well as Part II. In the event of a conflict of conditions, the provisions of Part I shall prevail over those of Part II to the extent of such conflict.

Signature (Owners)	Signature (Charterers)

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PART II

"Gencon" Charter (As Revised 1922, 1976 and 1994)

1. It is agreed between the party mentioned in Box 3 as the Owners of the Vessel named in Box 5, of the GT/NT indicated in Box 6 and carrying about the number of metric tons of deadweight capacity all told on summer loadline stated in Box 7, now in position as stated in Box 8 and expected ready to load under this Charter Party about the date indicated in Box 9, and the party mentioned as the Charterers in Box 4 that:
The said Vessel shall, as soon as her prior commitments have been completed, proceed to the loading port(s) or place(s) stated in Box 10 or so near thereto as she may safely get and lie always afloat, and there load a full and complete cargo (if shipment of deck cargo agreed same to be at the Charterers' risk and responsibility) as stated in Box 12, which the Charterers bind themselves to ship, and being so loaded the Vessel shall proceed to the discharging port(s) or place(s) stated in Box 11 as ordered on signing Bills of Lading, or so near thereto as she may safely get and lie always afloat, and there deliver the cargo.

2. **Owners' Responsibility Clause**
The Owners are to be responsible for loss of or damage to the goods or for delay in delivery of the goods only in case the loss, damage or delay has been caused by personal want of due diligence on the part of the Owners or their Manager to make the Vessel in all respects seaworthy and to secure that she is properly manned, equipped and supplied, or by the personal act or default of the Owners or their Manager.
And the Owners are not responsible for loss, damage or delay arising from any other cause whatsoever, even from the neglect or default of the Master or crew or some other person employed by the Owners on board or ashore for whose acts they would, but for this Clause, be responsible, or from unseaworthiness of the Vessel on loading or commencement of the voyage or at any time whatsoever.

3. **Deviation Clause**
The Vessel has liberty to call at any port or ports in any order, for any purpose, to sail without pilots, to tow and/or assist Vessels in all situations, and also to deviate for the purpose of saving life and/or property.

4. **Payment of Freight**
(a) The freight at the rate stated in Box 13 shall be paid in cash calculated on the intaken quantity of cargo.
(b) *Prepaid.* If according to Box 13 freight is to be paid on shipment, it shall be deemed earned and non-returnable, Vessel and/or cargo lost or not lost.
Neither the Owners nor their agents shall be required to sign or endorse bills of lading showing freight prepaid unless the freight due to the Owners has actually been paid.
(c) *On delivery.* If according to Box 13 freight, or part thereof, is payable at destination it shall not be deemed earned until the cargo is thus delivered. Notwithstanding the provisions under (a), if freight or part thereof is payable on delivery of the cargo the Charterers shall have the option of paying the freight on delivered weight/quantity provided such option is declared before breaking bulk and the weight/quantity can be ascertained by official weighing machine, joint draft survey or tally.
Cash for Vessel's ordinary disbursements at the port of loading to be advanced by the Charterers, if required, at highest current rate of exchange, subject to two (2) per cent to cover insurance and other expenses.

5. **Loading/Discharging**
(a) Costs/Risks
The cargo shall be brought into the holds, loaded, stowed and/or trimmed, tallied, lashed and/or secured and taken from the holds and discharged by the Charterers, free of any risk, liability and expense whatsoever to the Owners. The Charterers shall provide and lay all dunnage material as required for the proper stowage and protection of the cargo on board, the Owners allowing the use of all dunnage available on board. The Charterers shall be responsible for and pay the cost of removing their dunnage after discharge of the cargo under this Charter Party and time to count until dunnage has been removed.
(b) Cargo Handling Gear
Unless the Vessel is gearless or unless it has been agreed between the parties that the Vessel's gear shall not be used and stated as such in Box 15, the Owners shall throughout the duration of loading/discharging give free use of the Vessel's cargo handling gear and of sufficient motive power to operate all such cargo handling gear. All such equipment to be in good working order. Unless caused by negligence of the stevedores, time lost by breakdown of the Vessel's cargo handling gear or motive power - pro rata the total number of cranes/winches required at that time for the loading/discharging of cargo under this Charter Party - shall not count as laytime or time on demurrage. On request the Owners shall provide free of charge cranemen/winchmen from the crew to operate the Vessel's cargo handling gear, unless local regulations prohibit this, in which latter event shore labourers shall be for the account of the Charterers. Cranemen/winchmen shall be under the Charterers' risk and responsibility and as stevedores to be deemed as their servants but shall always work under the supervision of the Master.
(c) Stevedore Damage
The Charterers shall be responsible for damage (beyond ordinary wear and tear) to any part of the Vessel caused by Stevedores. Such damage shall be notified as soon as reasonably possible by the Master to the Charterers or their agents and to their Stevedores, failing which the Charterers shall not be held responsible. The Master shall endeavour to obtain the Stevedores' written acknowledgement of liability.
The Charterers are obliged to repair any stevedore damage prior to completion of the voyage, but must repair stevedore damage affecting the Vessel's seaworthiness or class before the Vessel sails from the port where such damage was caused or found. All additional expenses incurred shall be for the account of the Charterers and any time lost shall be for the account of and shall be paid to the Owners by the Charterers at the demurrage rate.

6. **Laytime**
* *(a) Separate laytime for loading and discharging*
The cargo shall be loaded within the number of running days/hours as indicated in Box 16, weather permitting, Sundays and holidays excepted, unless used, in which event time used shall count.
The cargo shall be discharged within the number of running days/hours as indicated in Box 16, weather permitting, Sundays and holidays excepted, unless used, in which event time used shall count.
* *(b) Total laytime for loading and discharging*
The cargo shall be loaded and discharged within the number of total running days/hours as indicated in Box 16, weather permitting, Sundays and holidays excepted, unless used, in which event time used shall count.
(c) Commencement of laytime (loading and discharging)
Laytime for loading and discharging shall commence at 13.00 hours, if notice of readiness is given up to and including 12.00 hours, and at 06.00 hours next working day if notice given during office hours after 12.00 hours. Notice of readiness at loading port to be given to the Shippers named in Box 17 or if not named, to the Charterers or their agents named in Box 18. Notice of readiness at the discharging port to be given to the Receivers or, if not known, to the Charterers or their agents named in Box 19.
If the loading/discharging berth is not available on the Vessel's arrival at or off the port of loading/discharging, the Vessel shall be entitled to give notice of readiness within ordinary office hours on arrival there, whether in free pratique or not, whether customs cleared or not. Laytime or time on demurrage shall then count as if she were in berth and in all respects ready for loading/discharging provided that the Master warrants that she is in fact ready in all respects. Time used in moving from the place of waiting to the loading/discharging berth shall not count as laytime.
If, after inspection, the Vessel is found not to be ready in all respects to load/discharge time lost after the discovery thereof until the Vessel is again ready to load/discharge shall not count as laytime.
Time used before commencement of laytime shall count.
* *Indicate alternative (a) or (b) as agreed, in Box 16.*

7. **Demurrage**
Demurrage at the loading and discharging port is payable by the Charterers at the rate stated in Box 20 in the manner stated in Box 20 per day or pro rata for any part of a day. Demurrage shall fall due day by day and shall be payable upon receipt of the Owners' invoice.
In the event the demurrage is not paid in accordance with the above, the Owners shall give the Charterers 96 running hours written notice to rectify the failure. If the demurrage is not paid at the expiration of this time limit and if the vessel is in or at the loading port, the Owners are entitled at any time to terminate the Charter Party and claim damages for any losses caused thereby.

8. **Lien Clause**
The Owners shall have a lien on the cargo and on all sub-freights payable in respect of the cargo, for freight, deadfreight, demurrage, claims for damages and for all other amounts due under this Charter Party including costs of recovering same.

9. **Cancelling Clause**
(a) Should the Vessel not be ready to load (whether in berth or not) on the cancelling date indicated in Box 21, the Charterers shall have the option of cancelling this Charter Party.
(b) Should the Owners anticipate that, despite the exercise of due diligence, the Vessel will not be ready to load by the cancelling date, they shall notify the Charterers thereof without delay stating the expected date of the Vessel's readiness to load and asking whether the Charterers will exercise their option of cancelling the Charter Party, or agree to a new cancelling date.
Such option must be declared by the Charterers within 48 running hours after the receipt of the Owners' notice. If the Charterers do not exercise their option of cancelling, then this Charter Party shall be deemed to be amended such that

PART II

"Gencon" Charter (As Revised 1922, 1976 and 1994)

the seventh day after the new readiness date stated in the Owners' notification to the Charterers shall be the new cancelling date.

The provisions of sub-clause (b) of this Clause shall operate only once, and in case of the Vessel's further delay, the Charterers shall have the option of cancelling the Charter Party as per sub-clause (a) of this Clause.

10. Bills of Lading

Bills of Lading shall be presented and signed by the Master as per the "Congenbill" Bill of Lading form, Edition 1994, without prejudice to this Charter Party, or by the Owners' agents provided written authority has been given by Owners to the agents, a copy of which is to be furnished to the Charterers. The Charterers shall indemnify the Owners against all consequences or liabilities that may arise from the signing of bills of lading as presented to the extent that the terms or contents of such bills of lading impose or result in the imposition of more onerous liabilities upon the Owners than those assumed by the Owners under this Charter Party.

11. Both-to-Blame Collision Clause

If the Vessel comes into collision with another vessel as a result of the negligence of the other vessel and any act, neglect or default of the Master, Mariner, Pilot or the servants of the Owners in the navigation or in the management of the Vessel, the owners of the cargo carried hereunder will indemnify the Owners against all loss or liability to the other or non-carrying vessel or her owners in so far as such loss or liability represents loss of, or damage to, or any claim whatsoever of the owners of said cargo, paid or payable by the other or non-carrying vessel or her owners to the owners of said cargo and set-off, recouped or recovered by the other or non-carrying vessel or her owners as part of their claim against the carrying Vessel or the Owners. The foregoing provisions shall also apply where the owners, operators or those in charge of any vessel or vessels or objects other than, or in addition to, the colliding vessels or objects are at fault in respect of a collision or contact.

12. General Average and New Jason Clause

General Average shall be adjusted in London unless otherwise agreed in Box 22 according to York-Antwerp Rules 1994 and any subsequent modification thereof. Proprietors of cargo to pay the cargo's share in the general expenses even if same have been necessitated through neglect or default of the Owners' servants (see Clause 2).

If General Average is to be adjusted in accordance with the law and practice of the United States of America, the following Clause shall apply: "In the event of accident, danger, damage or disaster before or after the commencement of the voyage, resulting from any cause whatsoever, whether due to negligence or not, for which, or for the consequence of which, the Owners are not responsible, by statute, contract or otherwise, the cargo shippers, consignees or the owners of the cargo shall contribute with the Owners in General Average to the payment of any sacrifices, losses or expenses of a General Average nature that may be made or incurred and shall pay salvage and special charges incurred in respect of the cargo. If a salving vessel is owned or operated by the Owners, salvage shall be paid for as fully as if the said salving vessel or vessels belonged to strangers. Such deposit as the Owners, or their agents, may deem sufficient to cover the estimated contribution of the goods and any salvage and special charges thereon shall, if required, be made by the cargo, shippers, consignees or owners of the goods to the Owners before delivery.".

13. Taxes and Dues Clause

(a) On Vessel -The Owners shall pay all dues, charges and taxes customarily levied on the Vessel, howsoever the amount thereof may be assessed.

(b) On cargo -The Charterers shall pay all dues, charges, duties and taxes customarily levied on the cargo, howsoever the amount thereof may be assessed.

(c) On freight -Unless otherwise agreed in Box 23, taxes levied on the freight shall be for the Charterers' account.

14. Agency

In every case the Owners shall appoint their own Agent both at the port of loading and the port of discharge.

15. Brokerage

A brokerage commission at the rate stated in Box 24 on the freight, dead-freight and demurrage earned is due to the party mentioned in Box 24.

In case of non-execution 1/3 of the brokerage on the estimated amount of freight to be paid by the party responsible for such non-execution to the Brokers as indemnity for the latter's expenses and work. In case of more voyages the amount of indemnity to be agreed.

16. General Strike Clause

(a) If there is a strike or lock-out affecting or preventing the actual loading of the cargo, or any part of it, when the Vessel is ready to proceed from her last port or at any time during the voyage to the port or ports of loading or after her arrival there, the Master or the Owners may ask the Charterers to declare, that they agree to reckon the laydays as if there were no strike or lock-out. Unless the Charterers have given such declaration in writing (by telegram, if necessary) within 24 hours, the Owners shall have the option of cancelling this Charter Party. If part cargo has already been loaded, the Owners must proceed with same, (freight payable on loaded quantity only) having liberty to complete with other cargo on the way for their own account.

(b) If there is a strike or lock-out affecting or preventing the actual discharging of the cargo on or after the Vessel's arrival at or off port of discharge and same has not been settled within 48 hours, the Charterers shall have the option of keeping the Vessel waiting until such strike or lock-out is at an end against paying half demurrage after expiration of the time provided for discharging until the strike or lock-out terminates and thereafter full demurrage shall be payable until the completion of discharging, or of ordering the Vessel to a safe port where she can safely discharge without risk of being detained by strike or lock-out. Such orders to be given within 48 hours after the Master or the Owners have given notice to the Charterers of the strike or lock-out affecting the discharge. On delivery of the cargo at such port, all conditions of this Charter Party and of the Bill of Lading shall apply and the Vessel shall receive the same freight as if she had discharged at the original port of destination, except that if the distance to the substituted port exceeds 100 nautical miles, the freight on the cargo delivered at the substituted port to be increased in proportion.

(c) Except for the obligations described above, neither the Charterers nor the Owners shall be responsible for the consequences of any strikes or lock-outs preventing or affecting the actual loading or discharging of the cargo.

17. War Risks ("Voywar 1993")

(1) For the purpose of this Clause, the words:

(a) The "Owners" shall include the shipowners, bareboat charterers, disponent owners, managers or other operators who are charged with the management of the Vessel, and the Master; and

(b) "War Risks" shall include any war (whether actual or threatened), act of war, civil war, hostilities, revolution, rebellion, civil commotion, warlike operations, the laying of mines (whether actual or reported), acts of piracy, acts of terrorists, acts of hostility or malicious damage, blockades (whether imposed against all Vessels or imposed selectively against Vessels of certain flags or ownership, or against certain cargoes or crews or otherwise howsoever), by any person, body, terrorist or political group, or the Government of any state whatsoever, which, in the reasonable judgement of the Master and/or the Owners, may be dangerous or are likely to be or to become dangerous to the Vessel, her cargo, crew or other persons on board the Vessel.

(2) If at any time before the Vessel commences loading, it appears that, in the reasonable judgement of the Master and/or the Owners, performance of the Contract of Carriage, or any part of it, may expose, or is likely to expose, the Vessel, her cargo, crew or other persons on board the Vessel to War Risks, the Owners may give notice to the Charterers cancelling this Contract of Carriage, or may refuse to perform such part of it as may expose, or may be likely to expose, the Vessel, her cargo, crew or other persons on board the Vessel to War Risks; provided always that if this Contract of Carriage provides that loading or discharging is to take place within a range of ports, and at the port or ports nominated by the Charterers the Vessel, her cargo, crew, or other persons onboard the Vessel may be exposed, or may be likely to be exposed, to War Risks, the Owners shall first require the Charterers to nominate any other safe port which lies within the range for loading or discharging, and may only cancel this Contract of Carriage if the Charterers shall not have nominated such safe port or ports within 48 hours of receipt of notice of such requirement.

(3) The Owners shall not be required to continue to load cargo for any voyage, or to sign Bills of Lading for any port or place, or to proceed or continue on any voyage, or on any part thereof, or to proceed through any canal or waterway, or to proceed to or remain at any port or place whatsoever, where it appears, either after the loading of the cargo commences, or at any stage of the voyage thereafter before the discharge of the cargo is completed, that, in the reasonable judgement of the Master and/or the Owners, the Vessel, her cargo (or any part thereof), crew or other persons on board the Vessel (or any one or more of them) may be, or are likely to be, exposed to War Risks. If it should so appear, the Owners may by notice request the Charterers to nominate a safe port for the discharge of the cargo or any part thereof, and if within 48 hours of the receipt of such notice, the Charterers shall not have nominated such a port, the Owners may discharge the cargo at any safe port of their choice (including the port of loading) in complete fulfilment of the Contract of Carriage. The Owners shall be entitled to recover from the Charterers the extra expenses of such discharge and, if the discharge takes place at any port other than the loading port, to receive the full freight as though the cargo had been

carried to the discharging port and if the extra distance exceeds 100 miles, to additional freight which shall be the same percentage of the freight contracted for as the percentage which the extra distance represents to the distance of the normal and customary route, the Owners having a lien on the cargo for such expenses and freight.

(4) If at any stage of the voyage after the loading of the cargo commences, it appears that, in the reasonable judgement of the Master and/or the Owners, the Vessel, her cargo, crew or other persons on board the Vessel may be, or are likely to be, exposed to War Risks on any part of the route (including any canal or waterway) which is normally and customarily used in a voyage of the nature contracted for, and there is another longer route to the discharging port, the Owners shall give notice to the Charterers that this route will be taken. In this event the Owners shall be entitled, if the total extra distance exceeds 100 miles, to additional freight which shall be the same percentage of the freight contracted for as the percentage which the extra distance represents to the distance of the normal and customary route.

(5) The Vessel shall have liberty:-

(a) to comply with all orders, directions, recommendations or advice as to departure, arrival, routes, sailing in convoy, ports of call, stoppages, destinations, discharge of cargo, delivery or in any way whatsoever which are given by the Government of the Nation under whose flag the Vessel sails, or other Government to whose laws the Owners are subject, or any other Government which so requires, or any body or group acting with the power to compel compliance with their orders or directions;

(b) to comply with the orders, directions or recommendations of any war risks underwriters who have the authority to give the same under the terms of the war risks insurance;

(c) to comply with the terms of any resolution of the Security Council of the United Nations, any directives of the European Community, the effective orders of any other Supranational body which has the right to issue and give the same, and with national laws aimed at enforcing the same to which the Owners are subject, and to obey the orders and directions of those who are charged with their enforcement;

(d) to discharge at any other port any cargo or part thereof which may render the Vessel liable to confiscation as a contraband carrier;

(e) to call at any other port to change the crew or any part thereof or other persons on board the Vessel when there is reason to believe that they may be subject to internment, imprisonment or other sanctions;

(f) where cargo has not been loaded or has been discharged by the Owners under any provisions of this Clause, to load other cargo for the Owners' own benefit and carry it to any other port or ports whatsoever, whether backwards or forwards or in a contrary direction to the ordinary or customary route.

(6) If in compliance with any of the provisions of sub-clauses (2) to (5) of this Clause anything is done or not done, such shall not be deemed to be a deviation, but shall be considered as due fulfilment of the Contract of Carriage.

18. General Ice Clause

Port of loading

(a) In the event of the loading port being inaccessible by reason of ice when the Vessel is ready to proceed from her last port or at any time during the voyage or on the Vessel's arrival or in case frost sets in after the Vessel's arrival, the Master for fear of being frozen in is at liberty to leave without cargo, and this Charter Party shall be null and void.

(b) If during loading the Master, for fear of the Vessel being frozen in, deems it advisable to leave, he has liberty to do so with what cargo he has on board and to proceed to any other port or ports with option of completing cargo for the Owners' benefit for any port or ports including port of discharge. Any part cargo thus loaded under this Charter Party to be forwarded to destination at the Vessel's expense but against payment of freight, provided that no extra expenses be thereby caused to the Charterers, freight being paid on quantity delivered (in proportion if lumpsum), all other conditions as per this Charter Party.

(c) In case of more than one loading port, and if one or more of the ports are closed by ice, the Master or the Owners to be at liberty either to load the part cargo at the open port and fill up elsewhere for their own account as under section (b) or to declare the Charter Party null and void unless the Charterers agree to load full cargo at the open port.

Port of discharge

(a) Should ice prevent the Vessel from reaching port of discharge the Charterers shall have the option of keeping the Vessel waiting until the re-opening of navigation and paying demurrage or of ordering the Vessel to a safe and immediately accessible port where she can safely discharge without risk of detention by ice. Such orders to be given within 48 hours after the Master or the Owners have given notice to the Charterers of the impossibility of reaching port of destination.

(b) If during discharging the Master for fear of the Vessel being frozen in deems it advisable to leave, he has liberty to do so with what cargo he has on board and to proceed to the nearest accessible port where she can safely discharge.

(c) On delivery of the cargo at such port, all conditions of the Bill of Lading shall apply and the Vessel shall receive the same freight as if she had discharged at the original port of destination, except that if the distance of the substituted port exceeds 100 nautical miles, the freight on the cargo delivered at the substituted port to be increased in proportion.

19. Law and Arbitration

* (a) This Charter Party shall be governed by and construed in accordance with English law and any dispute arising out of this Charter Party shall be referred to arbitration in London in accordance with the Arbitration Acts 1950 and 1979 or any statutory modification or re-enactment thereof for the time being in force. Unless the parties agree upon a sole arbitrator, one arbitrator shall be appointed by each party and the arbitrators so appointed shall appoint a third arbitrator, the decision of the three-man tribunal thus constituted or any two of them, shall be final. On the receipt by one party of the nomination in writing of the other party's arbitrator, that party shall appoint their arbitrator within fourteen days, failing which the decision of the single arbitrator appointed shall be final.

For disputes where the total amount claimed by either party does not exceed the amount stated in Box 25** the arbitration shall be conducted in accordance with the Small Claims Procedure of the London Maritime Arbitrators Association.

* (b) This Charter Party shall be governed by and construed in accordance with Title 9 of the United States Code and the Maritime Law of the United States and should any dispute arise out of this Charter Party, the matter in dispute shall be referred to three persons at New York, one to be appointed by each of the parties hereto, and the third by the two so chosen; their decision or that of any two of them shall be final, and for purpose of enforcing any award, this agreement may be made a rule of the Court. The proceedings shall be conducted in accordance with the rules of the Society of Maritime Arbitrators, Inc..

For disputes where the total amount claimed by either party does not exceed the amount stated in Box 25** the arbitration shall be conducted in accordance with the Shortened Arbitration Procedure of the Society of Maritime Arbitrators, Inc..

* (c) Any dispute arising out of this Charter Party shall be referred to arbitration at the place indicated in Box 25, subject to the procedures applicable there. The laws of the place indicated in Box 25 shall govern this Charter Party.

(d) If Box 25 in Part 1 is not filled in, sub-clause (a) of this Clause shall apply.

* *(a), (b) and (c) are alternatives; indicate alternative agreed in Box 25.*

** *Where no figure is supplied in Box 25 in Part 1, this provision only shall be void but the other provisions of this Clause shall have full force and remain in effect.*