A study to estimate the benefits of removing market barriers in the shipping sector

Final report

Written by ICF, UCL Consultants, Lloyd's Regi
Lloyd’s List Intelligence and Sintef Ocean
March 2019

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A study to estimate the benefits of removing market barriers in the shipping sector

Final report

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Directorate-General for Climate Action

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Contents

1 Introduction

This report presents the results from a study to estimate the benefits of removing market barriers in the shipping sector, including with the use of a transparent monitoring, reporting and verification (MRV) system. It has been commissioned by DG Climate Action in support of its work to assess potential revisions to the Regulation for the MRV of CO_2 emissions from maritime transport[1] ("the EU MRV Regulation").

The work was carried out by a team led by ICF and comprising UCL Consultants, Lloyd's Register, Lloyd's List Intelligence and Sintef Ocean, between October 2017 and May 2018.

1.1 Study objectives

The main objectives of the study were two-fold.

Firstly, to examine the different market barriers related to energy efficiency investments in shipping, in particular across different categories of ship, and explain how the EU MRV Regulation can help address these market barriers, compared to requirements set out under the International Maritime Organization (IMO) Data Collection System (DCS)[2].

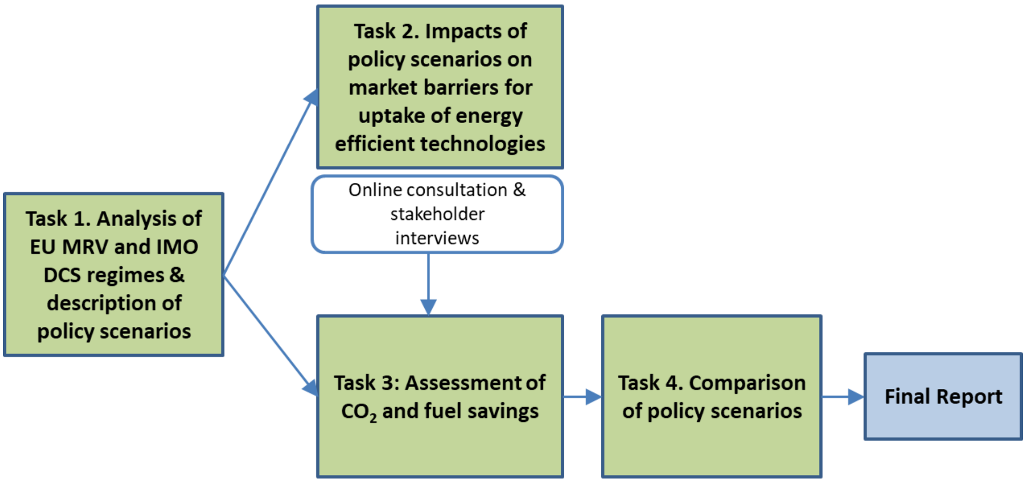
Secondly, to model two specific scenarios: i) use of the EU MRV system, ii) use of an MRV system equivalent to the IMO DCS system; and for each scenario, to identify impacts in terms of CO_2 and fuel savings.

1.2 Summary of approach

Figure 1 provides an overview of the study method, reflecting the following tasks:

- Task 1: Analysis of the EU MRV and IMO DCS requirements and description of the two defined policy scenarios;
- Task 2: Assessment of the impacts of these policy scenarios on market barriers for the uptake of energy efficiency technologies;
- Task 3: Assessment of CO_2 and fuel savings from the two policy scenarios; and,
- Task 4: Overall comparison of the two policy scenarios and conclusions.

Figure 1. Overall methodology designed to meet all the requirements set out in the service request



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[1] EU Regulation 2015/757 (as amended by Delegated Regulation 2016/2071) on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport

[2] Introduced under the IMO's Marine Environment Protection Committee (MEPC) amended International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI by resolution MEPC.278(70), that entered into force on 1 March 2018(MEPC)

1.3 Structure of this report

This report continues in the following sections:

Section 2 provides an overview of the EU MRV and IMO DCS requirements, as well as a summary comparison of both, in order to illustrate key differences in the regimes. It also sets out the two policy scenarios which the study team worked with.

Section 3 presents the different market barriers related to energy efficiency investments in shipping (e.g. per ship category) and explains how the EU MRV Regulation can help address these market barriers.

Section 4 explains the background to the model which has been used to underpin the study analysis, how it functions and how it can be used to estimate the impact of different MRV approaches. It describes how refinements were made to the model, specifically the barrier factors, based on literature review and industry consultations (using both an online survey and structured face-to-face and telephone interviews), for which high level summary results are included.

Section 5 presents and compares the results of the model for the two specific scenarios: i) use of the EU MRV system, ii) use of an MRV system equivalent to the IMO DCS system. For each scenario, results are presented as a range of impacts in terms of fuel savings, carbon dioxide (CO_2) emission reductions and reductions of other emission species (i.e. sulphur dioxide (SOx), nitrous oxide (NOx) and particulate matter (PM)). The section also provides an explanation of the so-called rebound effect which can result from investments in energy efficiency and sets out the limitations of the modelling exercise.

Section 6 summarises the main conclusions from the study.

2 Overview of the EU MRV and IMO DCS requirements and the proposed policy scenarios investigated by this study

The following sections provide a snapshot of the key requirements under the EU MRV and IMO DCS, in order to help illustrate the major differences between the two regimes. They also set out the two policy scenarios which the study team worked with.

2.1 The EU MRV Regulation

2.1.1 Introduction

Regulation (EU) 2015/757 (complemented by Delegated Regulations 2016/2071 and 2016/2072) on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport entered into force on 1 July 2015. Under the EU MRV Regulation, shipping companies (ship owners or other entities responsible for a ship) must monitor at ship level the fuel consumption, CO_2 emissions and energy efficiency of their ships above 5000 GT, within and on voyages to and from European Economic Area (EEA) ports on an annual basis. They must also report annual aggregated data in the following year to the Commission and the relevant Flag States. The monitoring requirements are based on already existing information requirements and data available on board of ships. Accredited independent verifiers ensure that monitoring plans and emissions reports are correct and thereby safeguard the robustness of the data[3].

The key dates and recurring obligations that the shipping sector must adhere to are set out below and require that:

- Existing ships are issued with a ship-specific Monitoring Plan, which are used to collect and monitor data. The Monitoring Plan needed to be submitted for assessment to an approved third party accredited verifier by 31 August 2017 and it must have been completed by 1 January 2018;
- From 1 January 2018, and for each calendar year, each ship has to monitor data on the required parameters (as per Article 9 of Regulation (EU) 2015/757);
- From 30 April 2019, and by 30 April each year, the following requirements have to be fulfilled:
  a) the Company submits its collected data to the third party accredited verifier;
  b) the third party accredited verifier verifies the data; and,
  c) the Company submits to the European Commission and to the authorities of the Flag States concerned a verified emissions report for the past calendar year.
- From 30 June 2019, and by 30 June each year, a valid Document of Compliance has to be present on board of each ship.

The European Maritime Safety Agency (EMSA) has developed a dedicated module (THETIS-MRV) within the original THETIS information system to enable companies responsible for the operation of large ships using EEA ports to report their CO_2 emissions and other relevant information under the MRV Regulation. This web-based application enables all relevant parties to fulfil their monitoring and reporting obligations in a centralised and harmonised way. THETIS-MRV includes a mandatory module (generating emission reports for assessment by verifiers who will issue a Document of Compliance in system) and a voluntary module (enabling companies to draft monitoring plans, which are made available for verifiers to assess). This process is summarised in the graphic in Figure 2 below.

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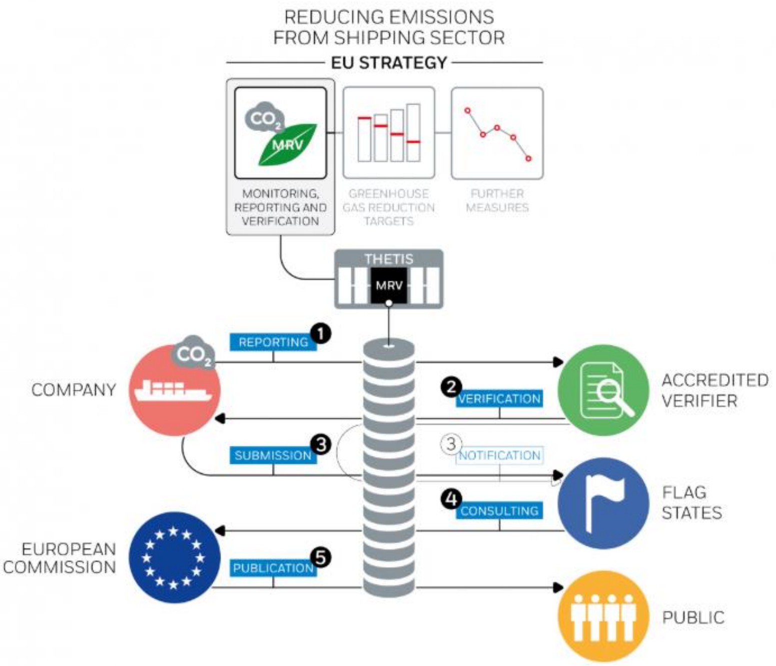
[3] Note that a similar verification approach is applied to the sectors covered by the EU's Emissions Trading System

The European Commission will publish annually details of the identity of each ship, its technical efficiency, annual CO_2 emissions, annual total fuel consumption for voyages, annual average fuel consumption and CO_2 emissions per distance travelled, annual average fuel consumption and CO_2 emissions per distance travelled and cargo carried, annual total time spent at sea in voyages, monitoring method, date of issue and expiry date of the document of compliance, and identity of the verifier, as specified in Article 21.2 of the Regulation. The Commission will also make publicly available the information on CO_2 emissions reported in the emissions reports.

Figure 2. The flow of data under the EU MRV Regulation and public disclosure process, facilitated by the THETIS-MRV system managed by EMSA



Source: EMSA http://www.emsa.europa.eu/infographics/item/3080-thetis-mrv.html

2.2 The IMO Data Collection System (DCS)

2.2.1 Introduction

The IMO DCS was introduced in October 2016 and requires shipping companies to collect global data on the fuel consumption and other relevant data for all their international voyages of their ships of 5000GT and above and to report the aggregated data to their respective Flag State after the end of each calendar year. Flag Administrations must verify, in accordance with their national rules and taking into account IMO guidelines, the data submitted to them by the ships registered under their flag. Flag Administrations, after having determined that the data has been reported in accordance with MARPOL Annex VI, must transfer the data to the IMO Ship Fuel Oil Consumption Database, which is accessible to IMO Member States and the IMO Secretariat. IMO will produce an annual report to MEPC, summarising the aggregated data collected.

The new amendments require that the existing Ship Energy Efficiency Management Plan (SEEMP) is enhanced with a new Part II 'Ship Fuel Oil Consumption Data Collection Plan'. The Administration (or any organisation duly authorised by it, the 'Recognised Organisation'[4] (RO)) is asked to ensure that the SEEMP complies with regulation 22.2 before the ship starts collecting data (by 31 December 2018).

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[4] http://www.imo.org/en/ourwork/msas/pages/recognizedorganizations.aspx

Guidelines for the SEEMP Part II development are found in resolution MEPC.282(70). There are also verification guidelines regarding what verification should include.

The key dates and recurring obligations that the shipping sector must adhere to are that:

- From 1 January 2019, and for each calendar year, the ship collects and reports the required data (as per Appendix 10 to MEPC.278(70)) using a standardised format by IMO.
- The ship reports the collected data to the Administration (or RO) by 31 March each year.
- The Administration (or RO) verifies the reported data and upon successful verification issues a Statement of Compliance to the ship by 31 May each year, following Guidelines found in MEPC.293(71).
- The Administration (or RO) transfers the verified data to the IMO Ship Fuel Oil Consumption Database via electronic communication and using a standardised format, no later than one month after issuing the Statement of Compliance.

2.3 Comparison of the EU MRV and the IMO DCS requirements

Both EU MRV and IMO DCS requirements are mandatory. As described above, they have established processes to collect and analyse emissions data related to the shipping sector. While some elements of the systems are already very similar in their scope and requirements on the shipping sector[5], the main differences relate to the data to be monitored, reporting rules, verification and disclosure. A summary comparison of the EU MRV and IMO DCS is shown in Table 1. It demonstrates where there are key differences, notably in the focus on the actual cargo carried as a core parameter in the EU MRV, as well as its emphasis on the public disclosure of data. This compares to the IMO DCS where the design deadweight tonnage (DWT) – or the cargo carrying capacity of a ship - is the parameter used in MRV and the resulting data being generated across fleets is kept confidential.

Table 1. Summary comparison of the EU MRV and IMO DCS

	EU MRV	**IMO DCS**
Enters into force	1 July 2015	1 March 2018
First monitoring period	Calendar year 2018	Calendar year 2019
Application	Ships of 5,000 GT and above on commercial voyages into, out of and between EU ports	Ships of 5,000 GT and above on international voyages
Fuel monitoring methods	4 methods	4 methods
Monitoring plan	Yes – standardised template	Included in SEEMP
Data Quality	Completeness, accuracy, relevance, control measures	2 processes required on data gaps
Parameters	• Fuel and CO_2 • Actual cargo carried • Distance	• Fuel • Design DWT (i.e. cargo carrying capacity) • Distance

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[5] Based on an in-depth, line-by-line analysis of the requirement of EU MRV and IMO DCS conducted by the study team as part of the desk review underpinning this study

	• Time at sea and in port	• Hours underway
Operational situations	For example, Search & rescue, STS transfer	
Annual Emission Report	Yes – standardised template	Yes – standardised template
Reports to	European Commission and concerned flag States	Flag Administration
Verification Rules	Standardised and prescriptive approach designed to ensure accuracy and reliability of data	Verification rules are less detailed and prescriptive
Disclosure	Public	Confidential

2.4 Background on the policy need for this current study

Under the EU MRV Regulation (Art 22), in the event of an international agreement on a global MRV system for GHG emissions being reached, the European Commission was required to review the EU MRV Regulation, and, if appropriate, propose amendments to the Regulation in order to ensure alignment with that international agreement. Since March 2018 (entry into force), as set out above, there is now an international legal framework in place. The current study compared the two systems and evaluated the impacts of alternative policy scenarios involving the application of each.

2.5 Policy scenarios which have been scrutinised in this study

Considering the limitations of the modelling exercise, the study team was given two policy scenarios by DG CLIMA, described below:

Scenario A – Use of the EU MRV System

Under this Scenario A, the EU MRV Regulation would remain unchanged. This would mean that the current parameters for monitoring, reporting and verification of data under the EU MRV Regulation would continue to apply irrespective of the existence of additional IMO DCS requirements.

Ships of above 5000 GT transporting passengers or cargo for commercial purposes using EEA ports, that have to monitor and report their CO_2 emissions from international maritime transport activities under both systems would therefore have to comply with partially different rules to the IMO DCS requirements.

Scenario B – Use of an MRV System Equivalent to IMO DCS

Under Scenario B, the EU would replace the requirements of the EU MRV Regulation with those of IMO DCS.

The EU would adopt the IMO DCS's requirements on monitoring, reporting and verification. The same data collected for the purpose of the IMO DCS would be used in the EU MRV system, subject to similar rules. This means that the data might not be verified by independent third parties, but instead it would be checked in accordance with the IMO DCS guidelines.

Regarding the scope, information on voyages from or to an EEA port would still be monitored and collected, independent of flag State, but domestic and in-port emissions would no longer be covered. The reporting of voyages to EEA port information is not covered under IMO DCS, as there the reporting is based on flag State. In order to be able to track this type of information, some monitoring parameters would therefore remain as now being recorded under the EU MRV Regulation.

3 Market barriers related to energy efficiency investments in shipping and the potential benefits of the EU MRV Regulation

3.1 Introduction to the challenge of adopting energy efficient technologies in the shipping sector

Numerous cost-effective energy efficiency options (technologies for new and existing ships and operations) have been identified for improving the energy efficiency of ships (e.g. Bouman et al. 2017, Smith et al. 2016). According to the literature, there remains substantial unrealised abatement potential using options that often appear to be cost-negative at current fuel prices. Rehmatulla, Calleya and Smith (2017) show that only a few technology options are implemented by a substantial proportion of shipowners and Rehmatulla (2014) shows low uptake of operational options, despite the easy and instantaneous savings in energy use and emissions. The low uptake of these options, and therefore the 'energy efficiency gap' (Jaffe & Stavins, 1994), which has been evidenced in other sectors (e.g. Rohdin, Thollander, & Solding, 2007 and Schleich & Grubber, 2008), suggests the existence of market failures and non-market failures in shipping.

Market failures occur when markets operate inefficiently, meaning that it is possible to improve society's welfare by altering the way in which goods are produced or consumed (Krugman and Wells, 2012). For example, in shipping, typical market failures might relate to the availability of good information about the range of cost-effective abatement options. Such inadequate (or 'imperfect') information could lead to decisions which do not deliver the best outcome for society. In addition, shipping emissions (greenhouse gases and air pollutants) impose costs on society that the sector itself does not have to bear (Brown, 2001), for example, the costs to human health associated with air pollutant emissions (Smith et al., 2014). This is known as a negative externality. The ship operator or owner, as the party purchasing and consuming the fuel and therefore generating the emissions, does not bear all the costs of those emissions. Without intervention to address these externalities, the sector would not take them into account when making its operational decisions.

Market failures, particularly relevant to preventing the uptake of energy efficient technology, occur because of split incentives, imperfect information, and asymmetric information. Split incentives arise because of contractual or organizational arrangements, while the latter two barriers are associated with informational problems. Split incentives to invest can occur when the costs of investing in an abatement option are incurred by one party but the benefits accrue to another (IEA, 2007). Ship owners are generally responsible for making investments in new technology given they own the capital asset (i.e. the ship). However, they may not realise all of the associated benefits, such as lower fuel costs, because under certain types of contract it is the charterer that pays for the fuel. Therefore, cost-effective abatement options may not be taken up (Rehmatulla, 2014, Faber, Behrends & Nelissen, 2011).

Prakash et al. (2016), using the Rightship GHG rating as a proxy for energy efficiency, show that little to no evidence of a preference for ships with better GHG Ratings is detected in time charter rates in the period 2005-2015, ceteris paribus. Furthermore, using Automatic Identification System (AIS) data, they find that no significant difference is observed in terms of productivity (time spent loaded/ballast and number of loaded voyages, for example) for ships with better GHG Ratings. Similarly, Agnolucci, Smith, & Rehmatulla (2014) and Adland, Alger, Banyte, & Jia (2017) show that shipowners in the drybulk shipping market fail to recoup investments or obtain a premium as a result of energy efficiency. This is an important finding as it shows that there is a lack of incentives for shipowners to invest in energy efficiency, since the market is not sufficiently rewarding investments in energy efficiency. This finding highlights that imperfect and asymmetric information are impeding implementation of energy efficiency measures in shipping and thus the need for corrective policies.

Informational problems in shipping emanate from two key market failures around information:

1. **Imperfect information on energy efficiency technologies** refers either to the lack of reliable information on costs and savings of a particular technology or the lack of trusted and accurate data on energy efficiency and low emissions technology from an independent third party, which cause a market failure (Golove & Eto, 1996). Typically, manufacturers of technology conduct trials and report on efficiency gains. Often, manufacturers' claims are perceived to be overly optimistic and therefore are not trusted (Faber, Behrends, & Nelissen, 2011). The costs of obtaining reliable, accurate and trusted information may be prohibitive and could lead to sunk costs making the investment not worthwhile. The lack of verifiable performance data and standards monitoring protocols causes an informational gap which in turn leads to a market failure (Stern & Aronson, 1984).
2. **Imperfect/asymmetric information between a shipowner and the charterer** refers to the situation where different levels of information are held by contracting parties. For example, ship owners may have the incentive to misrepresent the fuel efficiency of their fleet to a potential customer to make their ships more attractive (Veenstra & Dalen, 2011). However, the information asymmetry may not necessarily arise due to agent opportunism; it may well be that one party may have relevant information on the costs and benefits of an energy efficiency investment, but may find this difficult to convey to the other party. This asymmetry in information could lead to mistrust between charterers and owners. Charterers would therefore be unwilling to pay a premium for energy efficient ships (Adland, et al., 2017; Agnolucci, et al., 2014) as they struggle to differentiate between more and less efficient vessels. As a result, owners could be less confident that they will be rewarded for making investments.

Non-market failures can be defined as obstacles that are not due to a failure in the market but are economic costs faced by a firm such as limited access to capital, high capital costs (Schleich & Grubber, 2008), hidden costs (Koomey & Sanstad, 1994; Golove & Eto, 1996; Hein and Blok, 1995), risk (Sorrell et al. 2004), and heterogeneity (Sweeney, 1993) that nonetheless lead to lack of uptake of energy efficiency technologies. For a complete assessment of each of the above market failures and non-market failures and their application to shipping refer to Faber, Behrends & Nelissen (2011), Acciaro, Hoffman & Eide (2013), Jafarzadeh & Utne (2014), Rehmatulla & Smith (2015) and Rehmatulla et al. (2016).

The distinction, in neo-classical economics, of market failures and non-market failures is important, since it distinguishes whether a policy intervention is justified and the order in which the interventions should be made. Policy intervention normally address market failures first and then non-market failures, though consideration of any intervention would need to carefully balance the costs of intervention with the benefits (Fisher & Rothkopf, 1989; Jaffe & Stavins, 1994; Brown, 2001).

3.2 How the EU MRV Regulation can help the market to overcome market failures

The purpose of the EU MRV is to provide a dedicated EU data set of CO_2 emissions and other relevant information from maritime transport which is made available to the public. In this respect, the EU MRV could potentially improve or address some of the above identified market failures - especially around imperfect and asymmetric information, which can be attributed to the lack of uptake of operational and energy efficiency options. The ways in which the EU MRV could improve current market failures are through both 'information feedback' and 'disclosure impact'.

3.2.1.1 Impact of information feedback on energy consumption

The EU MRV will have the effect of generating 'information feedback' to the energy user, notably ship-owners or operators, as some may well invest in advanced monitoring systems (though this is not a mandatory requirement of the Regulation). Faber et al. (2013)[6] explained that by providing real-time feed-back on fuel use or emissions, fuel flow meters and direct emissions monitoring can for instance provide ship operators with the means to train their crew to adopt fuel-efficient sailing methods and to optimise their maintenance and hull cleaning schedules. However, it is possible that for some entities, this leads to little or no savings as expected from 'information feedback'. This could be due to the method employed for monitoring fuel consumption and emissions (e.g. delayed feedback with Bunker Delivery Notes) or it could be that the entity has already invested in advanced monitoring systems due to market forces, such as high fuel prices in 2012. Rojon & Smith (2014) show that almost two thirds of shipping companies use manual tools (noon reporting) to estimate and communicate fuel consumption (with some companies using other methods in addition to manual tools). The benefits of real-time feedback in terms of energy efficiency has also been proven in other sectors; Work by Darby (2006 & 2008) on energy feedback in buildings shows savings of up to 10% have been achieved when householders were given better indirect feedback (billing or statements), and of 5–15% from direct feedback (via the meter or an associated display). Similarly, Raw & Ross (2011), Stromback et al. (2011) & Mahone & Haley (2011) show between 5-10% reduction in fuel consumption as a result of informative feedback in the building sector, while in the aviation sector Gosnell et al. (2016) show that information feedback on energy usage leads to significant improvement in energy efficiency during flight operations.

3.2.1.2 Impact of disclosure

The transparency or disclosure element of the EU MRV Regulation will allow potential users, such as charterers, to identify better performing or energy efficient ships and reward these ships either through higher utilisation or premiums. The public disclosure of energy efficiency could result in the following effects:

a) **Changes in operational practices by the shipowner,** e.g. reducing hull fouling, managing speed, virtual arrival, etc.;

b) **Take-up of energy efficiency technologies**, e.g. bulbous bow, trim optimisation, auto-pilot upgrades, etc.; and,

c) **General effects of disclosure**, e.g. competition amongst shipowners, better decisions by charterers including shared savings contracts e.g. virtual arrival (between spot charterer and shipowner), energy performance contracts (between time charterer and shipowner). The information on CO_2 and energy efficiency of ships may also be used by ports in their incentivisation programmes and potentially by financial institutions to evaluate CO_2 intensity of their portfolios and their lending decisions.

It is commonly understood in policy making that information disclosure helps to build the social and market pressure to improve a current situation (Blackman et al, 2004; Tietenberg, 1998; Foulon et al., 2002). The disclosure of information about operational energy efficiency and emissions of ships can be used by three types of users, and would lead to greater impact:

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[6] Available at: https://www.cedelft.eu/en/publications/1353/monitoring-of-bunker-fuel-consumption

a) **Charterers and Cargo owners** - to compare the energy efficiency of ships during the selection process (in addition to the existing structures e.g. data on fuel consumption and speed provided by the shipowners, Rightship GHG Rating), both in the voyage and time charter process.

b) **Shipowners** - based on the above, shipowners will be more concerned about improving their energy efficiency through the following practices (which may cause them to enter into energy performance savings contracts with charterers):

- Operational practices to improve energy efficiency, e.g. reducing hull fouling, managing speed, virtual arrival, etc.; and,
- Take-up of energy efficiency technologies, e.g. bulbous bow, trim optimisation, auto-pilot upgrades, etc.

c) **Regulators, ports, financiers, and third party organisations such as NGOs** - to evaluate performance of ships by comparing the overall energy efficiency of shipping firms (fleet) or on an individual ship basis.

It is therefore expected that the disclosure element would have the highest impact in addressing the current market failures around asymmetric information (during the chartering process) and split incentives (during operations and investments in technical energy efficiency measures). As a result, the EU MRV could be expected to lead to reductions in fuel consumption and therefore emissions, even though it does not impose direct limits on emissions or mandate emission reducing practices.

4 Overview of the modelling approach used in the study

This section provides a background to the model used to underpin the study analysis, how it functions and how it can be used to estimate the impact of different MRV approaches. It provides an explanation of the so-called rebound effect which can result from investments in energy efficiency. It also sets out the limitations of the modelling exercise.

4.1 Introduction to the Global Transport Model (GloTraM)

Estimation of the reduction potential (i.e. for CO_2 emissions, fuel savings) due to the introduction of a new regulation can be undertaken using models that simulate the future evolution of a sector. GloTraM (Global Transport Model) has been developed to explore shipping's future scenarios using a holistic analysis to assess how shipping might respond to changes in socio-economic developments and the regulatory framework.

The model simulates scrappage, retrofit of the existing fleet and newbuilds, as well as the fleet activity in response to the developments in relevant factors between the base year and the projection year (e.g. changing fuel prices, transport demand, regulation and technology availability) using a 'profit maximising' approach (explained further in Annex 1). In summary, the model assumes that individual shipowners and operators make decisions in the management and operation of their fleets to maximise their profits at every time step, by adjusting their operational behaviour and changing the technological specification of their vessels. Hence, at each time-step, the existing fleet's technical and operational specification is inspected to see whether any changes are required and specifications for new builds to meet the profit maximisation criteria.

Any changes to the technology, main machinery, design speed, and fuel choice could be driven by regulation (e.g. a new regulation for SOx and NOx emissions) or by economics (e.g. a higher fuel price incentivising the uptake of technology or a change in operating speed). The combination that returns the greatest profit within the user-specified investment parameters (time horizon for return on investment, interest rate and representation of any market barriers) is used to define a new specification for the existing fleet and the specifications for new builds for use in the next time-step.

A feature of the GloTraM model is that it includes the extent of market barriers to investment in energy efficiency technologies using a **barrier factor** that represents the proportion of charterer's fuel cost savings that are returned to the shipowner. Details of how the market barriers are embedded in the model's functions are given in section 4.2 below.

By undertaking a scenario-based analysis, the impacts of the two specific policy scenarios on market barriers can be considered. The simulations of the evolution of the shipping sector under different market barrier levels (scenarios) will allow the analysis of the uptake of energy efficiency technologies across the defined scenarios. Consequently, different fuel usage is expected, which will lead to the analysis of the resulting key emissions species emitted between the base year and the projection year. There are several inputs that are required in the model (details of the key input assumptions can be found in Annex 1). These include:

- Transport demand;
- Fuel price projections;
- Freight rate projections;
- Ship capital expenditure;
- Operating costs and revenues;
- Technology costs and performance;
- Fleet stock (types, age and technical and operational specification of the existing fleet);
- Regulations (including MARPOL Annex VI: EEDI, SOx and NOx regulations);
- Market barriers and failures; and,
- Regions aggregation and apportionment of emissions to region.

It is recognised there are different potential pathways for the future evolution of the shipping sector, reflecting future economic, technological and policy changes. The analysis presented in this study focuses on a single projection to assess the impacts of the two policy scenarios, assuming that there will be an impact only on market barriers. In other words, the input assumptions listed above are the same across the two scenarios, with the exception of the market barrier factors.

Market barriers are included in the GloTraM model by modelling the barrier factors, as measured by the proportion of the charterer's fuel cost savings that are returned to the shipowner. This reflects that not all the cost savings of the charterer may be appropriated by the shipowner due to imperfections in the market, e.g. lack of information, information asymmetry and split incentives.

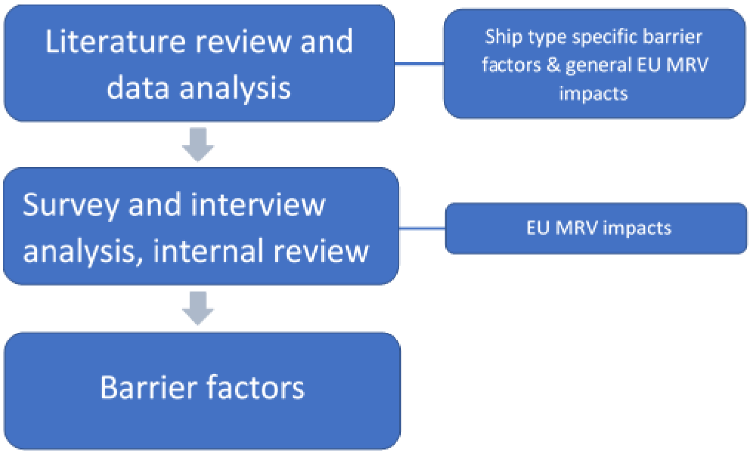
Market barriers and failures are expressed in the form of factors (vector) varying from 0 to 1 for each ship type category. A factor equal to 1 indicates that 100% of the fuel savings gained by investment in a technology are passed to the shipowner. Changes to the barrier factors will influence the estimated shipowner's profit function (see Annex 1), thereby, the shipowner's decision making in the management and operation of its fleet.

Assuming that the modelling representation of the market barriers, as described in this section, is representative of the real-world dynamics, the inclusion of the barrier factors can generate scenarios of technology and operational changes and consequently of the fuel savings and CO_2 emissions that incorporate the impact on 'information feedback' and 'disclosure impact' of the two policy scenarios under consideration.

4.2 How the two specified policy scenarios impact on barrier factors

This section provides details on how the barrier factors (used as input parameters in GloTraM) have been derived for estimating the impact of the two policy scenarios, as shown in Figure 3.

Figure 3. Process of deriving barrier factors



4.2.1 Ship type specific barrier factors

To objectively derive barrier factors for the various ship types, it is hypothesised, based on literature e.g. Murtishaw & Sathaye (2006), IEA (2007), Vernon & Meier (2012), that the barrier factors in shipping are mainly driven by:

1. Type of charter; and,
2. Duration of ownership of vessels.

4.2.2 Impact of type of charter

There are two basic forms of contracts (charterparties) for carriage of goods with which the shipowners (including operators) and charterers contract, namely the **voyage charter** and **time charter**. There are other types of contract but these are not contracts for carriage of goods, for example the **bareboat charter** is a lease of the vessel to the charterer.

Other hybrid forms of charters exist, but they can be reclassified as either voyage or time charter due to the similarities in the cost allocation. Examples of these are **trip charters**, which fall into the time charter category despite the contract being for a single voyage and **Contracts of Affreightment** (COA), which fall into the voyage charter category despite the time element (Wilson 2010). For a full breakdown of cost allocations under these contracts, refer to Rehmatulla (2014).

In effect, the reclassification of the different types of charters is to show which entity is responsible for the fuel costs. The voyage and time charters allocate or divide the responsibility for capital and running costs (including fuel costs) between a shipowner and charterer. In a voyage (or spot) charter (similar to hiring a taxi or energy included rental contracts, e.g. hotel stay), the fuel costs are borne by the shipowner, whereas in the time charter (similar to a van hire or typical residential rental contracts) the fuel costs are borne by the charterer. The result of this divided responsibility for costs is that both parties have diverging or conflicting interests to minimise their share of costs according to the charter arrangements used. There is significant empirical evidence in other sectors, such as buildings (residential and commercial) and transport, on the existence of the split incentive market failure that arises because of varying responsibility for energy costs, often called the landlord-tenant problem (see for example: Levinson & Neimann 2003; IEA 2007; Davis 2009; Maruejols & Young 2011; Vernon & Meier 2012)

Agnolucci et al. (2014), Rødde and Riise (2014), Prakash et al. (2016) and Adland et al. (2017), empirically show that energy efficient drybulk ships in the time charter market do not recoup higher charter rates and neither do they have better utilisation. It is therefore postulated that this sector, even though representative of the 'perfect competition' (Veenstra 1999; Stopford 2009), could be prone to market failures - especially those relating to imperfect and asymmetric information around energy efficiency. Rehmatulla (2014) shows that the drybulk sector has the highest time charter to voyage charter ratio (for the year 2012). This implies that in a sector where there may be more ships on the time charter, there is a high likelihood of the existence of market failures i.e. there will be lack of incentives to invest in energy efficiency due to the contracting practices.

4.2.3 Impact of ownership

The duration of ownership of an asset determines the investors' attitude towards energy efficiency investments (Berchling & Smith 1994; Scott 1997). Stott (2012) shows the different durations of ownership in three different ship types (drybulk, tanker and containerships), where the behaviour of the first shipowner differs significantly from the behaviour of subsequent shipowners. On average, fewer than 20% of shipowners keep the ship for its full working life (of around 25 years). Where there are several shipowners, on average across the three ship types the first shipowner retains the vessel for 10.5 years and subsequent shipowners retain the vessel on average for just over 3.5 years. This ownership trend in shipping could therefore have a determining effect on the investment attitude towards energy efficiency of ships. The sale and purchase in the second-hand market exacerbates the problem if the ship's resale value fails to account for energy efficiency improvements. Whilst there is evidence of the link between energy efficiency and asset values e.g. in the building sector (Fuerst et al. 2013; Kahn and Kok, 2014), there is inconclusive evidence of whether energy efficiency improvements are included in ship valuations.

Furthermore, payback period is the most common investment appraisal method used in many sectors (Pike 1996; Lefley 1996; Harris 2000). Rehmatulla (2016) and Parker (2015) show that in the shipping industry payback is the most often used as an investment appraisal method, and for energy efficiency investments appraisals could be as low as 12 to 18 months (HSH Nordbank 2014; Rehmatulla 2015). A longer duration of ownership would incentivise shipowners to invest in energy efficiency because they can recoup the investment over a longer investment horizon.

4.2.4 Estimating chartering ratio and ownership to derive barrier factors

In combination, the type of charter and ownership duration provide incentives for technology uptake (or lack of). So, for each ship type (or sector) an estimate is made for the voyage charter and time charter split and the duration of ownership. Where information is available in literature, this has been used (e.g. Pirrong 1993; Stott, 2012; Rehmatulla 2014) and where not available, some analysis is carried out using data from Clarkson Shipping Information Network (on type of charter) and World Fleet Register (on sale and purchase). The chartering ratio is defined as the time adjusted number of ships in the voyage charter in comparison to time adjusted number of ships in the time charter. The ratio is weighted by the time a ship spends in the respective charter in a given year, and not simply by number of ships, in order to account for the bias of higher number of ships in the voyage charter. A figure of 1 would represent that a ship spent a full year on voyage charter, whereas 0.5 would mean that the ship spent half the time on voyage charter and the remainder in time charter. Certain sectors have a higher number of ships (adjusted for time) on voyage charter (e.g. chemical tanker) compared to time charters and some have the opposite trend (e.g. bulk carrier). The chartering ratio is subject to change over time as it is dependent on market dynamics and the level of risks that are borne by the shipowner and the charterer in a given market (Stopford, 2009; Rehmatulla 2014). Table 2 shows the results of this analysis for the different sectors.

The ownership length is defined as the average length of ownership by the different owners over a ship's lifetime. This is used as a proxy to assess the level of incentives for investment in energy efficiency. The average life of a ship is assumed to be 25 years across all ship types. The average life of a ship varies over time due to the prevailing market conditions (e.g. over-supply) (UNCTAD, 2010). The average age of scrapped vessels stood at 21 years in 2017, down from 26 years in 2016 and down from 33 years in 2008 (UNCTAD (2018). There are also variances that occur due to the type of ship, for example, the average age of drybulk ships when scrapped ranged from 27 years to 35 years, compared to tankers which ranged from 28 to 31 years in the same period (UNCTAD 2010). Stott (2012) shows average ownership length differs over time and by ship type and size. For example, an ownership duration of 0.5 suggests that a shipowner would retain the vessel for half its lifetime. Table 3, shows the barrier factors, as a result of the chartering ratio and ownership duration. The barrier factors are derived from a simple average of the chartering ratio and ownership duration, as it is assumed that both these factors have an equal impact on market barriers. These barrier factors represent the market failures present in the current market situation i.e. prior to the implementation/effects of EU MRV regulation. Figure 4 summarises the arguments presented above in sections 4.2.2 to 4.2.4.

Figure 4. *Interaction of market barrier drivers and EU MRV policy scenarios on market failures*

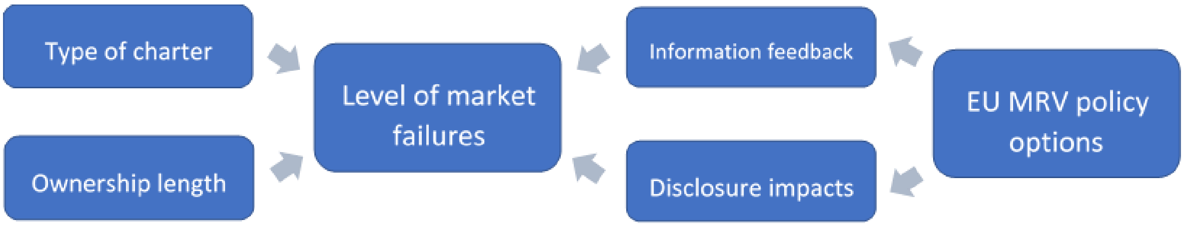


Table 2. Chartering ratio and ownership length for different ship types (current situation)

Ship type	Chartering ratio	Ownership duration
Bulk Carrier	0.35	0.28
Chemical tanker	0.80	0.32
Container	0.95	0.32
General Cargo	0.50	0.3
Liquified gas tanker	0.75	0.6
Oil tanker	0.75	0.32
Ferry pax only	0.95	0.6
Cruise	0.95	0.6
Ferry ropax	0.95	0.6

Ship type	Chartering ratio	Ownership duration
Refrigerated bulk	0.50	0.4
Ro-Ro	0.80	0.6
Vehicle	0.95	0.6

Table 3. Barrier factors for different ship types under the current market situation (prior to implementation/effects of EU MRV regulation)

Ship type	Current market barrier factors (prior to effects of EU MRV regulation)
Bulk Carrier	0.32
Chemical tanker	0.56
Container	0.64
General Cargo	0.40
Liquified gas tanker	0.68
Oil tanker	0.54

4.2.5 Scenario-specific barrier factors

The EU MRV and IMO DCS have key differences (as outlined in Section 2), which result in different levels of transparency. This will consequently affect the level of market impact created by each policy and therefore the ability to address or overcome the market failures set out above. The main differences between the two policy Scenarios relate to the data to be monitored, reporting rules, verification and disclosure.

Table 4 below describes each of the policy scenarios in relation to the monitoring, reporting, verification and disclosure elements that are aligned or retained; it also groups the policy scenarios according to the modelling scenarios. Table 4 shows how the current design of the EU MRV system (modelled in Scenario A) would differ in comparison with a MRV system that is equivalent to the IMO DCS system (Scenario B).

Table 4 shows how each policy scenario affects the core MRV requirements, which are important in addressing the market failures. For example, the transparency element would lead to impacts and the better monitoring and reporting rules would result in information feedback, as previously mentioned in section 3.2.

Scenario A - Use of the EU MRV System

This scenario applies the requirements of the current EU MRV system as designed and in force. This scenario retains all the differentiating parameters (i.e. robust monitoring and verification, as well as disclosure) and therefore it is expected to improve the current market failures around imperfect and asymmetric information.

Scenario B – Use of an MRV System Equivalent to IMO DCS

This policy scenario assumes that the EU MRV system applies all of the main technical requirements of the IMO DCS. In this scenario all or most of the key differentiating parameters for the EU MRV are given up (e.g. disclosure, less harmonized rules for verification, etc.). The IMO DCS, due to its limited transparency and less stringent monitoring and reporting, would not address any market failures, such as split incentives or asymmetric information. Therefore, the IMO DCS would not impact the current/existing ship type-specific barrier factors, which are therefore assumed to be the same as in the current situation, as set out in Table 3 above.

Table 4. EU MRV policy scenarios including impacts of elements and modelling scenarios

Alignment elements	**Scenario A – Use of EU MRV System**	**Scenario B – MRV System Equivalent to IMO DCS**
Monitoring	*retaining* all aspects & *retaining* actual cargo carried	*aligning* DWT cargo capacity & *aligning* all other aspects with IMO DCS requirements
Reporting	*retaining* all aspects	*aligning* all aspects with IMO DCS requirements
Verification	*retaining* all aspects	*aligning* all aspects with IMO DCS requirements
Disclosure	*retaining* all aspects	*aligning* all aspects with IMO DCS requirements

As mentioned in Section 3, the impacts of the EU MRV Regulation are categorised into two categories; impact of disclosure and impact of information feedback on energy consumption. The following sections further explain these impacts.

4.2.6 Using industry consultations to help to validate the barrier factors

As shown in the study method (section 1.2 and Figure 1), the study team deployed various approaches to help gain insights into current industry practice around MRV, including views on the relative importance of different elements of the EU MRV Regulation. This was in addition to reviewing insights from stakeholder responses to a Public Consultation which DG CLIMA had organised between September and December 2017 to understand better what stakeholders considered of importance in the EU MRV. An important objective of the stakeholder consultations was also to derive key information and insight that is related to barriers.

This section continues by reviewing key results on barriers from 58 responses to an online survey sent out to 157 stakeholders and summary findings from 25 stakeholder interviews. The lines of enquiry of relevance to this report[7] were principally to establish whether the hypotheses previously described in earlier sections hold, i.e. that information disclosure on energy efficiency enables more energy efficient ships to be rewarded either through:

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[7] Note that the study team used these consultations to examine a variety of aspects of the EU MRV and IMO DSC regimes as part of its overall support to DG CLIMA and which are not analysed in this particular report.

i. Better utilisation – more energy efficient ships will do more transport work ceteris paribus; and,

ii. Receiving a premium – more energy efficient ships will obtain a higher charter rate to recoup investment in energy efficiency and as a result of fuel savings to the charterer.

4.2.6.1 Results from the online survey on the impact of disclosure

Annex 2 presents a discrete set of online survey results covering views across all 58 survey respondents on the potential impacts from both greater disclosure (i.e. on decision making and engendering greater confidence) and more energy efficient ships (i.e. on price and utilisation).

Shipowners/operators generated 19 of the 58 responses (33%), representing the largest group of stakeholders and have enabled results to be disaggregated by shipowner size and sector of operation. The two other largest groups of respondents were industry trade associations (10) and independent accredited verifiers (8).

Over 60% of respondents expressed the view that the publicly disclosed information from EU MRV would be used by charterers and other parties. Almost half of these respondents were shipowners. There is no clear trend of which shipping segments support this, although almost half of those expressing this opinion were from large (50+ ships) shipowner/operators.

However, when asked about whether energy efficient ships would be able to obtain a premium (and therefore the ability of EU MRV to some extent correcting the market failure because of public disclosure), 60% of respondents suggested that premiums for energy efficient vessels will not be achieved as a result of public disclosure. However, it is important to note that 40% still believe that energy efficiency will be rewarded as a result of disclosure. Again, there is no clear trend when disaggregating shipowners by segment and size. The same type of response applies when respondents were asked about whether energy efficient ships are able to obtain better utilisation. In both questions, it seems that smaller shipowners suggest that they are able to obtain premium and higher utilisation (not statistically significant and affected by respondent weighting).

With regard to the alignment of disclosure of data, shipowners/operators were equally spread in their opinion whether disclosure will lead to greater confidence. Smaller shipowner operators and shipowners operating in the wetbulk sectors were relatively more confident that disclosure would lead to more confidence (not statistically significant due to sample size and no multiple controls). In contrast, most of the industry trade associations felt that disclosure would not lead to greater confidence. NGOs and independent verifiers thought otherwise. This further suggests that respondents may be responding strategically, hence caution is needed when interpreting the results.

4.2.6.2 Conclusions from online survey results on barrier factors

In general, the results from the online survey show that data generated as a result of the EU MRV Regulation will be used for decision making by charterers. However, many respondents felt that it would not necessarily lead to the desired outcome, i.e. more efficient ships being paid a premium and being chartered/better utilised as a result of data transparency on energy efficiency.

The results do show some heterogeneity within the sectors of operation and by size of shipowners, but this is not statistically significant. Moreover, it is felt that there is some bias amongst the survey respondents: they are generally not in favour of EU MRV and are generally in favour of the EU's adoption of the less onerous MRV requirements of the IMO DCS. This could be leading to a bias in their responses to the questions regarding premiums for energy efficiency, downplaying the potential benefits from EU MRV. Indeed, there are some interesting issues about the incentives and rewards for investing – if shipowners feel pressure to invest and to pass the savings on to users, and take on administrative burdens, they are unlikely to favour EU MRV, even if it is efficient overall. There is also evidence of collusion amongst the survey respondents, which could be further distorting the results.

Importantly, the survey was not obtained from a large (statistically significant) and representative sample from which firm conclusions can be made, so the insights must therefore be regarded as indicative only.

4.2.6.3 Results from stakeholder interviews on the impact of disclosure

Of the 25 stakeholder interviews conducted, 18 were held with shipowners, charterers and shipowner/ charterers, two leading industry trade associations, three independent verifiers, one National Accreditation Body and one major equipment supplier. Care was taken to ensure that different sized shipping companies were interviewed, with the smallest companies owning around five ships and the largest over 200 ships (other shipowners had fleet sizes of 10, 20 (several), 30, 40, 130). Those chartering ships started at a minimum of around 10 ships. In five cases, companies did not wish to disclose their fleet details, to ensure complete anonymity. A good geographical spread was also achieved, ranging from those companies limited to EU operations, to those companies operating global fleets, as well as companies with head offices registered outside the EU.

In general, the interviewees had a good understanding of EU MRV requirements (the two trade associations had a very good understanding), while some companies were less familiar with IMO DCS.

Four of the 18 shipowners/charterers felt that disclosure would result in reductions of CO_2 emissions, although in two cases the respondents noted that it was the act of generating better data that in turn would help "to make informed decisions going forward"; another stated that "disclosing data is the first step towards the long-term EU strategy of reducing in GHG emissions from the ships calling at EU ports" and that increased awareness of data may in turn reduce CO_2 emissions. A third company felt that disclosure would lead to sector benchmarking, driving performance in the sector upwards.

Of the remaining 14, seven companies were uncertain about the results of disclosure. One company felt that, while it would not produce CO_2 savings per se, it would generate "better data to make informed decisions going forward". Furthermore, it noted in particular that in order to know the environmental footprint of the industry you need to "act on hard facts and not feelings". Another company felt that disclosure could lead to innovations occurring within the industry.

Of the remaining seven companies that rejected the disclosure hypothesis, two still cited the potential to link the disclosure mechanism of the EU MRV scheme to associated mechanisms such as a future shipping emissions tax.

Both trade associations stated their members were not against transparency, but that it was more a question of the data being misleading or misinterpreted. Both stated that disclosure would not result in CO_2 reductions, with one noting that "EU MRV metrics are misleading and not appropriate for all ship types and trades".

Regarding the implications of disclosure, of the 14 shipping companies that provided a view, eight felt that disclosure of data on energy efficiency could lead to competition among shipowners to improve energy efficiency (for example, in operations and through technical interventions such as retrofits and efficient newbuilds), thereby lowering total emissions from shipping. Opinions varied widely however about the implications of disclosure and also the magnitude of the impact. One felt it "will create benchmarks"; two noted that it would create competition "to a small extent": in one of these cases the respondent felt however that "the information disclosed is not accurate in terms of energy efficiency". Another company, responding positively, believed that energy efficiency was now a "competition factor" that goes beyond simple compliance.

Of those companies providing more negative responses, one international shipowner / charterer implied that disclosure would make no difference, stating that in their markets "the demands and competition is about as fierce as it can get"; a second company believed that MRV data was "on a very high level and might be misleading", while a third believed that companies would first examine the data quality: "At the beginning it will primarily be a discussion of data accuracy. Shipowners will need to see a return for any investment, so data disclosure alone will not be enough."

Overall, while the interviews proved very informative, they are clearly not representative of the overall universe of stakeholders and insights on disclosure were almost exclusively from shipping companies and industry associations, so the results are therefore only indicative.

4.2.6.4 Summary of stakeholder consultations and impact on barrier factors

The stakeholder interview results (and survey findings) on impact of disclosure and transparency of energy efficiency suggest that the delta (difference) between the EU MRV system (Scenario A) and the requirements of the IMO DCS (Scenario B) may not be of a large magnitude. However, it could also be possible that there is bias amongst those who have been consulted in the interviews and survey. More rigorous interviews and a representative survey (especially among shipowners representing different contractual arrangements or types of charter) could potentially lead to more generalizable results and perhaps lead to a significant change in the barrier factors.

Based on the above findings, the modelling work assumed a delta of 0.30 in barrier factors between Scenario B and Scenario A, due to the combined impact of the transparency element and better information feedback (as a result of use of actual cargo carried) of the EU MRV, as explained in section 3.2.1.1. The delta is assumed to be constant across ship types for the sake of simplicity and to control for multiple variances. A more detailed and thorough analysis (e.g. through interviews of several shipping companies in each sector) would be required to estimate the delta or assess the impact of EU MRV in each sector, which would be beyond the scope of this study. Several other factors that also impact the barriers were not included such as, the time horizon, as barrier factor changes over time as well (Stopford 2009) and geographical variability as shown in other sectors.

Table 5 below provides a brief justification of why the specific deltas were chosen and section 4.2.6.5 provides further justification on the selection of the delta. In general, the delta should be interpreted as the driver for additional cost savings relative to those occurring under the IMO DCS (Scenario B) that would be recouped by the shipowner as a result of better information feedback and transparency of energy efficiency data. For example, a shipowner operating in the drybulk market would expect to recoup approximately 30% (Table 6) of their investment in energy efficiency through higher time charter rates, while, under the requirements of the EU MRV (Scenario A), they could expect this to increase to approximately 60% (a delta of 0.3) [relying on higher charter rates or the higher utilisation of their assets].

Table 5. Mapping market barriers to the two modelled scenarios

Scenario	Scenario A – EU MRV	Scenario - B – IMO DCS
Delta from Scenario B	0.3	0
Explanation	All the benefits of the EU MRV Regulation that address market barriers are retained. Key features such as cargo	Loss of all of the benefits of the EU MRV Regulation that address market failures. Alignment of cargo parameter to

	parameter and disclosure requirement are retained	DWT as a proxy, which is a key factor in data reliability and hence usability of data on energy efficiency. Loss of transparency, which is a key factor in promoting access to information on energy efficiency.

Table 6 shows the barrier factors, which take into account all the preceding analysis.

Table 6. Barrier factors for the two modelled policy scenarios

Modelling scenario	Scenario A	Scenario B
Bulk Carrier	0.62	0.32
Chemical tanker	0.86	0.56
Container	0.94	0.64
General Cargo	0.70	0.40
Liquified gas tanker	0.98	0.68
Oil tanker	0.84	0.54

4.2.6.5 Further justification on the delta between the two Scenarios

Cargo parameter

The cargo parameter is one of the key differentiating elements of the EU MRV and one that could have the highest impact in terms of providing operational efficiency information as close as possible to the "true" efficiency of the ship.

Several studies such as that conducted for INTERTANKO (Parker & Smith 2014 and O'Keeffe & Smith 2016) and for RBSA (Parker et al. 2015) confirm that there is a significant difference between the Energy Efficiency Operational Indicator (EEOI) calculated using actual cargo carried and using DWT capacity as a proxy. O'Keeffe & Smith (2016) concludes that "proxies addressed are not good approximations for the actual transport work and further distort the estimation of a ship's actual performance on the overall transportation efficiency".

The evidence on transport work and its proxies, using voluntary monitoring and reporting by RBSA and others, was presented in the European Sustainable Shipping Forum, 26th Jan 2016 and submitted at the IMO 69th MEPC session (MEPC 69 INF.26). Some of the key findings reported were:

- Energy efficiency is driven by a combination of technical and operational factors – all are important and cannot be generalized;
- Differences occur both between ships and for the same ship over time;
- Operational efficiency (including transport work) is crucial for understanding trends – especially year on year trends;
- Operational efficiency is needed for supply chain CO_2 accountancy and optimization; and,

- The four different energy efficiency metrics examined are not equivalent. Only the Energy Efficiency Operational Indicator (EEOI) represents the carbon intensity of actual transport work done.

It is estimated that 60% of the variation in operational efficiency using the EEOI, occurs due to speed and cargo (amount carried, laden and ballast journeys) (O'Keeffe & Smith 2016). Thus, removing the cargo monitoring and reporting would remove a significant explanatory variable for operational efficiency of a given ship. So, whilst there are differences in the operational efficiency values even for a single ship (as shown in IMO MEPC 68 INF.24, Smith et al. 2016, IMO MEPC 69 INF.26), it should not be seen as a justification for removing the need to monitor and report on actual transport work.

On the other hand, as highlighted in the submission ISWG-GHG/1/2/1 on "technical evaluation and further process on the indicators on energy efficiency on the three steps approach", using actual cargo data can lead to significant variation and is likely to require more administration and effort to report. Cargo load is also to a limited degree under control of the ship owner/operator and capacity utilization of the vessel is dependent on market conditions.

Bearing in mind these limitations, monitoring the actual cargo remains important to reflect the actual operational conditions. Disclosing transport efficiency indicators based on proxies could reduce the usage appeal of the EU MRV that is expected from disclosure (as mentioned in section 3.2.1.2). It will also reduce the information feedback gains (as explained in section 3.2.1.1) that are expected from understanding operational efficiency, as it can help to understand drivers and trends of operational energy efficiency, e.g. year on year. O'Keeffe & Smith (2016) show that using DWT is not a good approximation for the actual transport work. Such an approach distorts the estimation of a ship's actual operational efficiency as it considers it being fully laden all the time. Operational CO_2 intensity (gCO_2/tnm) based on DWT will in fact always be better than when based on actual cargo carried, making these two indicators not comparable. In addition, the mandatory reporting of "cargo carried" from the EU MRV allows a higher level of transparency than when compared to other voluntary schemes which disclose energy efficiency of ships. Scott et al. 2017, Prakash et al. 2016, Poulsen, Hermann, & Smink, 2018 illustrate that private standards and voluntary schemes do not cater to transparency and hamper data reliability.

Verification

The verification rules for the EU MRV are more prescriptive relative to the IMO DCS scheme (and this is generally seen as a positive across all stakeholders) as they aim to ensure alignment across the verifiers and provide a level of trust and independence. The prescriptive rules are seen to improve data quality and provide a better dataset going forward.

Transparency and disclosure

The transparency and disclosure element is one of the key differentiating elements of the EU MRV Regulation and one that could have the highest impact in terms of reducing market failures, as discussed in 3.2.1.2 and 4.2.6.3. The IMO DCS scheme would not disclose the CO_2 intensity of individual ships and will keep all the reported information from flag administrations confidential.

5 Results of the modelling

5.1 Introduction

This section presents and examines the emissions implications of the two policy scenarios, as presented in Table 4 (in Section 4). The simulations included the six ship types that are responsible for the majority of the emissions in the EU region. They are:

- Bulk carrier;
- Wet chemical;
- Container;
- General cargo;
- Liquified Gas carrier; and,
- Oil tanker.

It is estimated that the remaining ship types affected by the EU MRV Regulation would account for only 1% of the EU-associated absolute emissions. Therefore, they can be excluded from the simulations without having significant impacts on the results.

Potential changes in fuel consumption, and therefore in emissions, depend on a number of variables. This analysis focuses on three key aspects:

1. uptake of energy efficiency technologies;
2. potential changes in operational speeds; and,
3. uptake of fuels.

Each aspect is dealt with respectively in the sections below.

This section concludes by considering the key limitations of the modelling exercise, including impacts of the rebound effect.

5.2 Uptake of energy/fuel efficiency technologies

The EU MRV Regulation would encourage the uptake of fuel efficient technologies. Relative to IMO DCS (Scenario B) it will reduce market barriers and therefore increase uptake of energy/fuel efficient technologies. Table 7 shows the uptake of technologies in terms of the level of penetration (number of ships that have installed a technology over the total number of ships active in 2040) by scenarios. The scenario with the lowest market barrier (Scenario A) shows a higher level of penetration for most of the energy/fuel efficiency technologies than the scenario with higher market barriers (Scenario B). The model optimises the selection of the most profitable package of technologies in each time step, so a variation in the barrier factors means that a different package of technologies could be selected. Because of the incompatibility among some of the technologies, sometimes, the level of penetration for some technologies is lower in the scenario with low market barriers (Scenario A).

Table 7. Take up of technologies in 2040 under different MRV policy scenarios

Technology	Scenario B	Scenario A
Bulbous Bow	12%	7%
Rudder Bulb	16%	31%
Trim and Draught Optimisation	70%	68%
Vane Wheels	1%	4%
Contra-rotating Propeller	0%	2%

Stern Flaps	1%	2%
Biocide Hull Coating	73%	78%
Future Hull Coating	2%	9%
Sails	6%	6%
Superstructure Mass Reduction	2%	3%
Solar power	15%	28%
Energy Saving Lighting	59%	67%
Turbocompound Parallel	79%	86%
Hybrid Turbocharging	14%	27%
Engine Tuning	54%	68%
Engine Derating	92%	92%
Common Rail	79%	86%
Variable Speed Control of Pumps and Fans	30%	44%
Energy Storage System	3%	5%
Autopilot Upgrade	91%	92%
Hull Cleaning	95%	93%

Note that the list in Table 7 only includes the technologies that are taken up under the specific economic assumptions. For a full list of technologies included in the model, please refer to Annex 1.

On average, a higher uptake of technologies is observed under the EU MRV (Scenario A) compared to the IMO DCS (Scenario B) (about 6% average in 2040).

Along with the absolute level of penetration by scenario, it is important to analyse the relative change between scenarios. Table 8 shows such differences in take-up of technologies under the two scenarios. The major differences are observed for the following technologies: Rudder Bull, Biocide Hull Coating, Solar power, Energy Saving Lighting, Turbo compound Parallel, Engine Tuning, Common Rail, Autopilot Upgrade, and Hull Cleaning. The impacts on penetration predominantly occur on the technologies that have a lower GHG impact.

Table 8 also shows that in Scenario A there are some technologies where there is greater penetration and other technologies where there is a slight reduction in penetration over time. This can be explained by the incompatibility of similar technologies, but it also depends on the sequence the technologies are selected in the model. The sequence in which the technologies are taken up is important, since technologies are not additive in respect to the fuel consumption reduction. Once a technology is taken up, the technologies that are consequently taken up, update their saving potential (the same % fuel consumption reduction of a smaller total fuel consumption because another technology has created a reduction), which leads to longer payback. As a consequence, the level of penetration for some technologies reduces, even though the market barrier in Scenario A is lower than in Scenario B.

Table 8. Differences in level of penetration of technologies between Scenarios A and B (positive value means higher level of penetration in the Scenario A relative to Scenario B)

		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
1	Bulbous Bow	0%	1%	1%	2%	1%	1%	0%	-1%	-1%	-2%	-2%	-3%	-3%	-3%	-4%	-4%	-4%	-4%	-4%	-5%	-5%	-5%	-5%	-5%	-5%
2	Rudder Bulb	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	2%	3%	4%	7%	9%	12%	10%	8%	6%	9%	12%	15%
4	Trim & Draught Optimisation	0%	0%	1%	1%	-2%	-4%	-6%	-6%	-6%	-6%	-6%	-6%	-5%	-5%	-5%	-4%	-4%	-3%	-3%	-3%	-2%	-2%	-2%	-2%	-2%
5	Vane Wheels	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	2%	3%
6	Contra-rotating Propeller	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	2%
8	Stern Flaps	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	2%
9	Biocide Hull Coating	0%	1%	3%	4%	9%	13%	18%	15%	12%	9%	13%	17%	20%	21%	22%	23%	20%	17%	13%	12%	10%	8%	7%	6%	5%
11	Future Hull Coating	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	2%	3%	4%	4%	5%	5%	6%	6%	6%	7%
13	Sails	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	1%
17	Super-structure Mass Reduction	0%	1%	1%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
19	Solar power	0%	1%	1%	2%	3%	4%	5%	7%	9%	11%	11%	11%	11%	11%	11%	10%	10%	10%	10%	11%	12%	13%	13%	13%	14%

20	Energy Saving Lighting	0%	0%	1%	1%	4%	6%	9%	10%	10%	10%	8%	5%	2%	1%	0%	0%	2%	3%	5%	6%	7%	8%	8%	8%	8%
24	Turbo-compound Parallel	0%	2%	3%	5%	5%	5%	5%	6%	8%	10%	11%	13%	14%	16%	19%	21%	20%	19%	17%	15%	12%	10%	9%	8%	7%
25	Hybrid Turbo-charging	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	3%	4%	4%	3%	3%	6%	10%	13%	13%	13%	13%
26	Engine Tuning	0%	0%	0%	1%	4%	7%	11%	13%	15%	17%	17%	17%	17%	16%	16%	16%	19%	22%	25%	24%	23%	22%	19%	17%	14%
27	Engine Derating	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28	Common Rail	0%	10%	20%	30%	26%	21%	17%	19%	21%	24%	24%	24%	25%	20%	16%	12%	11%	10%	10%	9%	9%	8%	8%	8%	8%
29	Variable Speed Control of Pumps and Fans	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	3%	6%	9%	8%	7%	6%	9%	13%	16%	16%	15%	15%
30	Energy Storage System	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	2%
31	Autopilot Upgrade	0%	5%	10%	14%	10%	5%	0%	-1%	-1%	-1%	-1%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	1%	1%	0%
32	Hull Cleaning	0%	6%	13%	19%	16%	13%	10%	7%	4%	1%	1%	0%	0%	-1%	-1%	-1%	-2%	-2%	-3%	-3%	-3%	-3%	-2%	-2%	-2%

Another element in relation to the uptake of energy efficiency technology are the various levels of technology penetration by ship type and size category. This is important because fuel savings are applied to different absolute fuel consumptions that are estimated for each category. For example, if the level of penetration of solar power technology increases in the low market barriers scenarios only for small bulk carriers, then the overall fuel consumption reduction would have a minimal impact.

5.2.1 Changes in operational speed

The modelling framework used in this study determines ship speeds as a function of both the freight rates and the fuel price. Given these market forces, the model chooses the optimal speed in a given year. Another important feature of the model is that it allows the interaction between speed and technical energy efficiency options to be captured. The profit maximisation function (see section 4.1) evaluates the technical energy efficiency options at different operational speeds and selects the one that results in the highest Net Present Value (NPV). This means that although the EU MRV may encourage the uptake of fuel-efficient technologies, the latter will interact with the commercial ship operation driven by other market forces (e.g. fuel prices, freight rates, transport demand), which in turn may result in a change in operational speed.

Technical efficiency improvements will reduce a ship’s fuel consumption at a given speed, which in turn will reduce the cost and marginal cost of increased speed. Assuming all else being equal, a ship has a commercial incentive to operate at a higher than average speed if its technical energy efficiency is better than the average and if there is sufficient market demand. This dynamic, called the “rebound effect” (see box below for an explanation and Annex 1 for further details) is included in the model.

Understanding the rebound effect on the shipping sector from improved energy efficiency: Improvements in energy efficiency make energy services cheaper and therefore encourage increased consumption of those services and reduces the benefits of the energy savings that may otherwise have been achieved (Sorrell, Dimitropoulos, & Sommerville, 2009). It has been evidenced in the transport sector (see for example Greene, 1992) that technical efficiency improvements reduce a ship’s fuel consumption at a given speed and the gradient of the speed/fuel curve. This reduces the cost and marginal cost of increased speed. If all else is equal, a ship has a commercial incentive to operate at a higher than average speed if it has better than average technical efficiency and if there is sufficient market demand. If the technically more efficient ship operates at an increased speed, the cost savings achieved in practice are lower than those of the technical efficiency increase (a form of rebound effect) (Smith, 2012). In separate research, Bonnello & Lelliot (2017), investigated the average speeds of a cohort of ships (Suezmax) with a mewis duct retrofit. Operating speeds were increased relative to the ships which were not retrofitted, and the operational efficiency gain was significantly lower than the technical efficiency increase.

Nevertheless, the results show that over time there is no significant difference in operational speed in the two scenarios. Ships under Scenario A are on average across the fleet only marginally faster than in Scenario B. Such a difference appears to be very small (between 1 to 3% difference between the two scenarios), so there are no significant implications in terms of overall fuel consumption. Nevertheless, the results suggest that more efficient ships tend to speed up.

5.2.2 Fuel mix and savings

Another important aspect, apart from the uptake of energy efficiency technology and the potential changes in operational speed, is the uptake of different fuels. Along with the potential fuel savings due to the use of operational and technical energy efficiency measures, the switch to another fuel with lower associated emissions is another potential explanatory factor for the environmental implications.

The switch to a different fuel is driven by market forces (e.g. fuel price) and compliance with regulations. For example, the switch to a different fuel can be driven by compliance with the sulphur cap regulation. Shipowners will need to weigh up the costs of scrubber investments and the use of a more expensive compliant fuel. The model assesses the profitability of each compliant option (use of scrubber or switching to a compliant fuel) taking into account the scrubber investment costs and fuel price projections. The most profitable option will then be selected in each time step for the existing fleet and the new fleet. In addition, the profitability also takes into account the potential interaction with a given package of energy efficiency technologies. So, if the uptake of the latter are incentivised, in theory it can lead to a switch to a different fuel.

The model shows that there is not a significant uptake of alternative fuels due to the change in market barriers. For example, the share of Liquified Natural Gas (LNG) remains very similar in both scenarios.

The two scenarios should not have a significant difference in impact on the average carbon factors associated with the fuel mix. However, the model takes into account the uptake of biofuels by blending them proportionally to the fuels taken up. Because of this feature of the model, the average carbon factor of the fuel mix in scenario A results in a different average carbon factor compared to scenario B. The difference between the average carbon factors in the two scenarios accounts for approximately 0.5% of cumulative emissions, so a small difference overall but a significant quantity when using the scenarios to measure small differences in emissions. This dynamic, however, can be considered as an artifact of the model which does not reflect necessarily what may happen in the real world. The difference cannot be directly linked to the variation in barrier factors. Nevertheless, this is an important element and needs to be considered in the emission impact, as discussed in section 5.2.3

Table 9 shows time series of energy savings for each scenario and cumulative saving over the period 2016 to 2040. The results suggest that there is a potential energy saving of approximately 0.7% arising from Scenario A in comparison to Scenario B.

Table 9. Time series of energy saving per year of each MRV policy scenario [PJ per year] and cumulative saving over the period 2016 to 2040 [PJ]

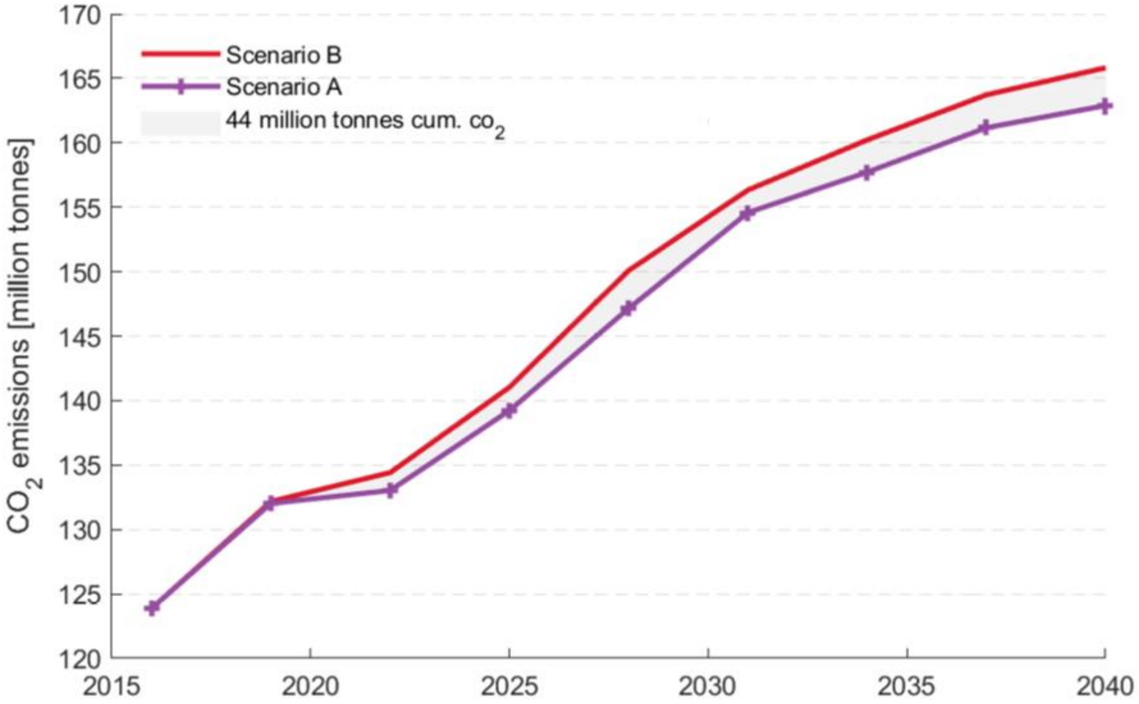
PJ/year	2016	2019	2022	2025	2028	2031	2034	2037	2040	Cumulative
Scenario B	1668	2079	2243	2431	2646	2821	2959	3093	3208	62130
Scenario A	1668	2075	2234	2417	2616	2804	2931	3065	3174	61689

5.2.3 Impact on emissions

5.2.3.1 CO_2 emissions

This section quantifies the changes in operational CO_2 emissions across the modelling scenarios. Figure 5 displays the aggregated CO_2 emissions by scenarios for the European region (refer to Annex 1 for definition).

Figure 5. EU CO_2 shipping emissions curves under the two policy scenarios



The comparison between the two scenarios shows that there is some potential emissions reduction when market barriers are reduced. Over the time horizon of 24 years, the potential cumulative emissions reduction is of about 44 million tonnes of CO_2 in Scenario A, representing approximately 1.3% of the total CO_2 emissions in Scenario B. The emissions reduction of 1.3% includes the change in global carbon factors as identified in the fuel mix section (5.2.2), therefore, the corresponding CO_2 savings need to be corrected by excluding the effect of biofuels blending. As a consequence, the resulting emission reductions are aligned with the 0.7% originating from energy savings.

5.2.3.2 SOx, NOx and PM emissions

The CO_2 emissions reduction is not the only concern as other emissions species are also part of the environmental impacts such as the emissions of SOx, NOx and PM. The fuel mix and fuel saving under the different MRV policy scenarios and the assumed emissions factors of the fuels being taken up are the main drivers for those emissions. The fuel mix and savings are presented in section 5.2.2, while the emissions factors used in this study are presented in Table 10. It is assumed that HFO with scrubbers has the same emissions factors of LSHFO, which means that switching from HFO to LSHFO or to HFO with scrubbers would have the same effect with regard to the air pollutant emissions reduction.

Table 10. SOx, NOx, and PM emissions factors [tonnes of emissions per tonne of fuel used]

	SOx	NOx	PM
Heavy fuel oil (HFO)	0.06650	0.093	0.0073
Heavy fuel oil (HFO) + scrubbers	0.01900	0.093	0.0043
Marine diesel oil (MDO)	0.00190	0.087	0.0010
Low Sulphur heavy fuel oil (LSHFO)	0.01900	0.093	0.0043
Liquid natural gas (LNG)	0.00002	0.008	0.0002

Overall, the emissions of SOx, NOx and PM appear to change slightly between the two MRV policy scenarios. Table 11, Table 12 and Table 13 below show the time series of the air pollutants per year for each policy scenario, as well as the cumulative emissions, over the period 2016 to 2040.

Table 11. Time series of SOx emissions [million tonnes per year] of each MRV policy scenario and cumulative emissions over the period 2016 to 2040 [million tonnes]

SO_X (million tonnes)	2016	2019	2022	2025	2028	2031	2034	2037	2040	Cumulative
Scenario B	2.45	2.64	0.89	0.93	0.98	1.02	1.05	1.07	1.08	31.0
Scenario A	2.45	2.64	0.87	0.91	0.96	1.01	1.04	1.06	1.08	30.8

Table 12. Time series of NOx emissions [million tonnes per year] of each MRV policy scenario and cumulative emissions over the period 2016 to 2040 [million tonnes]

NO_X (million tonnes)	2016	2019	2022	2025	2028	2031	2034	2037	2040	Cumulative
Scenario B	3.79	4.08	4.79	5.06	5.43	5.67	5.87	6.04	6.16	126
Scenario A	3.79	4.08	4.64	4.90	5.23	5.54	5.72	5.90	6.00	123

Table 13. Time series of PM emissions [million tonnes per year] of each MRV policy scenario and cumulative emissions over the period 2016 to 2040 [million tonnes]

PM (million tonnes)	2016	2019	2022	2025	2028	2031	2034	2037	2040	Cumulative
Scenario B	0.27	0.29	0.20	0.21	0.23	0.23	0.24	0.25	0.25	5.74
Scenario A	0.27	0.29	0.20	0.21	0.22	0.23	0.24	0.24	0.25	5.66

The cumulative SOx emissions reduction observed between Scenario B and Scenario A is about 0.2 million tonnes, which corresponds to about 0.9% of the SOx emissions under Scenario B. The cumulative NOx emissions reduction between Scenario B and Scenario A is about 3 million tonnes (2.4%), whereas the cumulative PM emissions reduction is about 80 thousand tonnes (1.4%).

5.3 Limitations of the modelling exercise

Generally, modelling results are subject to a number of uncertainties associated with the assumptions and methods used to computationally replicate real-world dynamics. Such uncertainties may limit the findings of a study. In this case, three potential sources of uncertainties are identified:

- **Uncertainty to define the market barrier factors and the relative impact of MRV policy measure.** Assuming that the modelled representation of the market barriers is representative of real-world dynamics, the inclusion of the barrier factors can generate scenarios of technology and operational changes and consequently of the fuel savings and CO_2 emissions that incorporate the impact on 'information feedback' and 'disclosure impact' of the EU MRV policy. One uncertainty could arise due to the spatial-temporal aspect of the market barriers. In this study, whilst the market barriers are disaggregated by ship type, it is assumed that market barriers remain constant both over time and in different geographic locations. It is possible however that the prevalence of barriers changes over time, e.g. the chartering ratio changes due to risk levels perceived by charterers (Stopford, 2009; Rehmatulla 2014). This would mean that the prevalence of the split incentive could vary over time in certain markets or sectors. For example, most LNG projects used to be set up using vessels owned or leased by the project, but this has changed in the last decade as the projects expired and LNG ships were beginning to enter the voyage charter market. In another example, in the early 1970s around 80% of the tanker fleet (in total DWT capacity) was on time charter to oil companies. However, by 1990 this position had reversed and only around 20% were on time charter; and currently only around 10% are on time charter.

- **Uncertainty on the various projected market forces assumptions such as freight rate and fuel prices.** Different input assumptions would change the cost-effectiveness of some energy efficiency technologies, therefore impacting their implementation rate. Therefore, changing the market barriers under different market forces may lead to different uptake of energy efficiency technologies. Nevertheless, a significant change in terms of cumulative emissions reduction between the two scenarios is not expected in this study.

- **Uncertainty on the specification of technologies.** Although, the technologies dataset (including capital expenditure and potential efficiency improvements) was reviewed and assessed through both stakeholder consultation and modelling analysis undertaken under the SCC research programme[8], different specifications may change the cost-effectiveness of technologies and therefore the selection under the model's profit maximisation approach. This should not have any significant implications for the findings of this study, as the relative difference between the two scenarios should be of the same order of magnitude.

5.4 Tailoring of GloTram to this study and explanation of modifications to the model in other related shipping studies

The GloTraM model has been used in other recent studies commissioned by DG CLIMA, including the Study on methods and considerations for the determination of greenhouse gas emission reduction for international shipping (2018).

A key justification for why the rebound effect is deemed to be more significant in the aforementioned study, compared to this study, is that the speed changes are a lot more significant in the aforementioned study (a 1-9% range) than for the current study (a 1-3% range). It is the speed change that is indicative of the extent of the rebound effect.

Some of the reasons as to why the speed difference and rebound effect are greater in the other study are due to:

- Larger range of market barriers; and,
- Inclusion of other important parameters (i.e. investment period and discount rate).

In comparison, the thresholds and changes to market barriers that have been included in this study are small and do not trigger significant differences in technology take-up; and it is without that difference there is no noticeable impact on speeds (or rebound effect).

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[8] http://www.lowcarbonshipping.co.uk/index.php?option=com_content&view=article&id=38&Itemid=176

6 Conclusions

This report presents the key conclusions derived from the study to investigate the modelling results and impacts with regards to the emissions implications and fuel savings of the current EU MRV system versus an EU MRV system equivalent to the IMO DCS system.

A techno-economic shipping model has been used in order to simulate the evolution of the fleet over the time period 2016 to 2040. Two scenarios are used: Scenario A applies the requirements of the current EU MRV system, as designed and in force; while in Scenario B, the EU would adopt an MRV System Equivalent to IMO DCS requirements on monitoring, reporting and verification. The IMO DCS, due to its limited transparency and less stringent monitoring and reporting, would not address any market failures, such as split incentives or asymmetric information. Therefore, the IMO DCS would not impact the current/existing ship type-specific barrier factors and hence the market failures present in current market conditions would persist in Scenario B. Under Scenario A, the current EU MRV system as designed would reduce market failures, through disclosure and information feedback. This effect is modelled by applying a lower market barrier factor.

The modelling results suggest that the main impact of reducing market barriers is through the uptake of energy efficiency technologies. There was no notable change in either the fuel mix or in operational speed due to changes in market barriers.

The uptake of technologies has an implication for the fuel savings and, as a consequence, the potential CO_2 emission reductions that might arise from each scenario. **The modelling results suggest that by reducing market barriers, Scenario A delivers a cumulative potential energy saving and a CO_2 emissions reduction of approximately 0.7% compared to Scenario B**.

A similar dynamic observed for CO_2 emissions is also observed for the other emissions species (SOx, NOx and PM). The results suggest that in Scenario A there would be a greater difference in emissions reduction compared to Scenario B. Table 14 summarises the environmental impacts of the two policy scenarios in terms of cumulative reduction (negative change) compared to Scenario B, for the period 2016 to 2040.

Table 14. Summary of environmental impacts of the two policy scenarios

	Impact of the EU MRV (Scenario A) compared to the IMO DCS system (Scenario B) for the period 2016-2040
CO_2	-0.7%
Sox	-0.9%
NOx	-2.4%
PM	-1.4%

** Note these are cumulative reductions (negative change) compared to Scenario B, for the period 2016 to 2040*

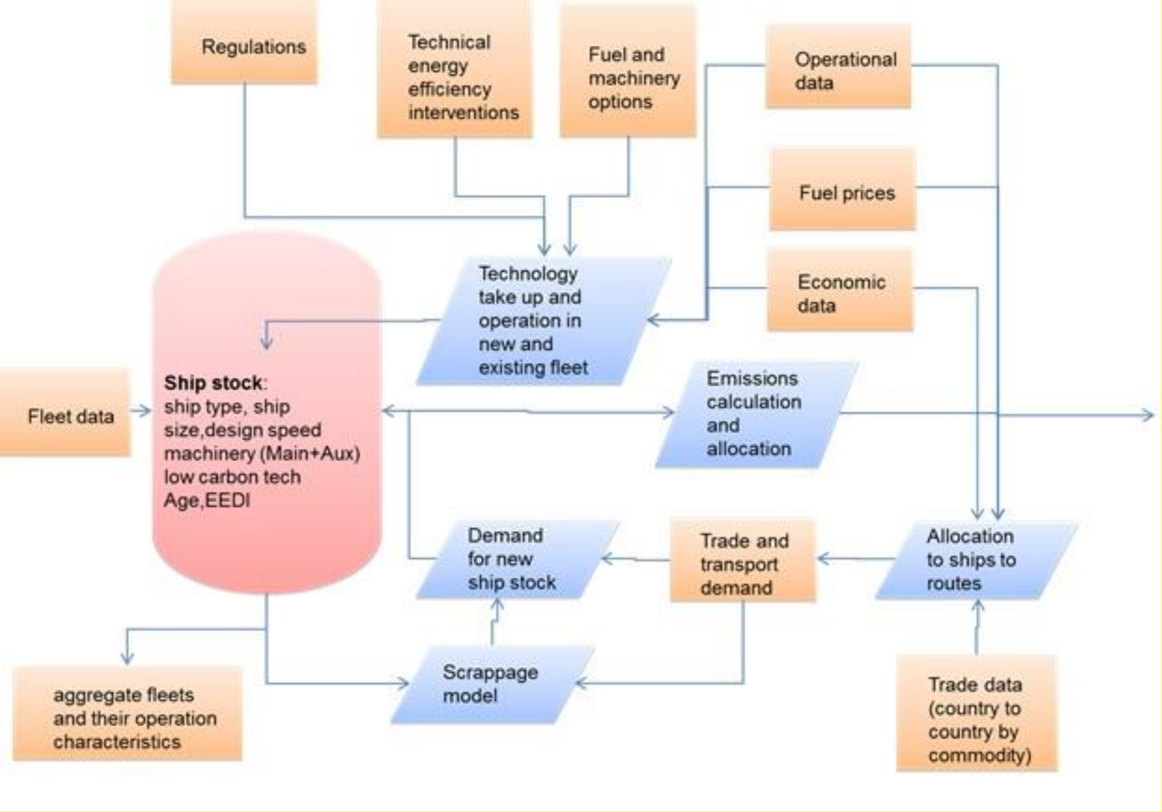
Annex 1 – Overview of GloTraM, functions and input assumptions

Overview of GloTraM

GloTraM combines multi-disciplinary analysis and modelling techniques to explore foreseeable futures of the shipping industry. It computationally simulates the evolution of the shipping fleet from a baseline year to the projection year.

A conceptualisation of the modelling framework can be seen in Figure 1. Each box describes a component within the shipping model. The feedbacks and interconnections are complex and only a few are displayed on this diagram for the sake of clarity. This conceptualisation allows us to break down the shipping system into manageable analysis tasks, ensure that the analysis and any algorithms used are robust, and then connect everything together to consider the dynamics at a whole-system level. A detailed model methodology documentation can be found in Smith, et al., (2013) or the "Global Marine Fuel Trends" report released in 2014 (in collaboration with Lloyd's Register).

Figure 1. Schematic overview of the GloTraM model



The model is initiated in a baseline year using data obtained from the Third IMO GHG Study 2014 and a number of external sources that characterises the shipping industry at that point in time, whilst a number of input parameters define the scenarios of interest for this report. The algorithms embedded in the model then time-step forwards, simulating the decisions made by shipowners and operators in the management (including the technical specification) and operation of their fleets.

The model assumes that individual owners and operators attempt to maximise their profits at every time step, by adjusting their operational behaviour and changing the technological specification of their vessels. This allows us to explore both the technical and operational evolution of the fleet.

Hence, at each time-step, the existing fleet's technical and operational specification is inspected to see whether any changes are required. Those changes could be driven by regulation (e.g. a new regulation of SOx and NOx emissions) or by economics (e.g. a higher fuel price incentivising uptake of technology or a change in operating speed). Taking the fleet's existing specification as a baseline, the profitability of a number of modifications applied both individually and in combination is considered, and the combination that returns the greatest profit within the user-specified investment parameters (time horizon for return on investment, interest rate, and representation of any market barriers) is used to define a new specification for the existing fleet for use in the next time-step.

Further, a specification for newbuilds is also generated at each time step. The starting point for this is the baseline fleet, which is taken as the average newbuild ship specification in the baseline year (2010). Changes to both the technology, main machinery, design speed, and fuel choice of the baseline ship are considered, such that the combination that meets current regulations and generates the highest profits within the constraints of the user-specified investment parameters is selected. The algorithm calculates the operational speed taking into account the short-run optimisation (for the time-step when the newbuild enters the fleet)

It is, however, assumed that there is no lag or delay from ordering to delivery, such that supply meets demand exactly at every time step. Ship values are not modelled or estimated from costs, nor are they used in the ship build decision. This means there is no explicit calculation of capital expenditures, because we make no assumptions about financing. A new ship is built if there is sufficient transport demand, whilst a ship is scrapped only when it reaches a certain age specified by the user (30 years in this case).

The key steps used to estimate the uptake of technology and the specification of operational parameters of the new build and existing fleet are listed below.

- Calculate the required energy efficiency design index (EEDI, newbuild only)
- Calculate the return on investment time period
- Calculate the profitability of the baseline ship or existing ship's specification
- For each combination of machinery specification (any alternative fuels which can use the same machinery) and operating main engine MCR %:
- Find the individual technical and operational option's profitability
- Prioritise individual options for order of take-up
- Find all compatible combinations of individual options which are more profitable over the investment time period than the baseline specification
- Check for compliance with regulation and adjust specification if required
- Select as the new specification for that ship size and age the most profitable combination of alternative fuel, operating MCR %, technical, and operational options that meets the minimum regulatory requirements
- Update the fleet database

Findings from surveying the literature and industry stakeholders show that the most prevalent methods for investment appraisal in shipping are payback period and net present value (NPV) (Parker, 2015; Rehmatulla, 2015). GloTraM forecasts the uptake of ship technology by using the NPV method to evaluate investments that could be made by the shipowner. The model values the investment over three dimensions, and the selected optima describe combinations of:

- Main machinery and fuel
- Energy efficiency technologies
- Operational speed

These three dimensions are necessary, because all three provide avenues to optimise returns and changes within one dimension typically has effects on the others. For example, a change in engine and fuel affects the specific fuel oil consumption rate (SFC), the emissions factor of the new fuel, as well as the costs (capex and opex) and the transport work that the vessel may be able to complete. A change in energy efficiency technology affects both the sunk costs and operating costs, through effects on SFC and power installed as well as the rate load of the main and auxiliary engines. A change in operational speed, on the other hand, affects transport work and fuel consumption.

GloTraM functions

The model comprises different modules which ensures that the analysis and any algorithms are robust, and connected together in order to consider the dynamics at a 'whole system' level. It is possible to identify at least 8 modules:

1. Transport demand module that estimates for a given year the total mass of freight multiplied by the distance it is transported
2. Ship stock module that maintains a database of the ships that make up fleets of ship type/size which is updated every time-step simulated
3. Transport supply module; once the transport demand for each ship type is estimated, the characteristic of the actual fleet in the stock is used to calculate the transport supply
4. Ship evaluation module that assesses the profitability of any specified ship
5. Ship fuel consumption module that calculates the annual fuel consumption and different emissions species emitted per year for each specified ship
6. Regulatory module that applies all the existing and upcoming regulations
7. Ships impact module that assesses any change due to the adoption of a technology (CO_2 abatement and new machinery technologies) for each specified ship
8. Emissions apportionment and climate module that provides national and regional statistics for CO_2 emissions according to different allocation philosophies as well as specify different level of carbon budget constraint

A key element that facilitates the above process is the calculation of the profitability of a given ship's specification which is used several times in the algorithm. Details are provided in the following section.

A key feature of the model is that investment and operational (speed) decisions are modelled for each ship type, size and age category in a way which maximises a shipowner's profits under a given regulatory and macroeconomic environment. The model is therefore based on a profit maximization approach.

The objective function is:

Profit_own_pa= R_own_pa-C_own_pa

R_own_pa = R_base_pa + B.tc * (R_vc_pa - C_V_pa - P_tc_pd * 365)

C_own_pa = Cs_base_pa + Cs_delta_pa

$$\max(NPV = \sum_{t}^{T} \frac{365P_{tc\_pd} + B_{tc}(R_{vc\_pa} + B_{vc} - C_{I_{delta}} - C_{v_{pa}} - 365P_{tc_{pd}}) - C_{s\_base} + C_{s\_delta}{}_{t}}{(1+d)^{t}}$$

Where:

R_own_pa is the shipowner's annual revenue

C_own_pa is the shipowner's annual costs

B.tc is the time charter and voyage charter barrier factors

R_vc_pa is the annual voyage charter revenue

P_tc_pd is the market time-charter day rate

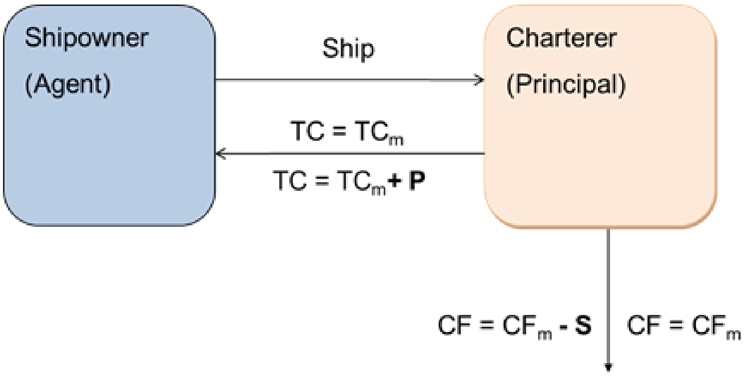
CI_delta and C_V_pa are the inventory cost delta (relative to the baseline inventory cost, and annual voyage cost respectively.

Cs_base_pa is the annual baseline costs. These costs include capital costs, brokerage fees, and operating costs (excluding port/fuel/voyage costs, but including maintenance, wages, and provisions). They are assumed to be covered by the charterer paying market time-charter day rates for all year (P_tc_pd*365).

Cs_delta_pa is the change in annual capital expenditure. These costs include any additional capital expenditure, beyond those of a baseline specification, associated with the chosen retrofit/newbuild specification (both capital costs for energy efficiency technology and main machinery and annualised fixed operating costs, excluding voyage costs).

B_tc is the percentage of the fuel cost saving that is passed to the shipowner. It represents the time charter premium that is obtained by the shipowner as a result of the fuel savings made by the charterer following an intervention to improve energy efficiency by the shipowner as shown Figure 2. Incorporating the profit of the charterer into the revenue of the shipowner allows the model to consider the trade-off of design speed, energy efficiency and sunk costs. All of these are aligned to a single agent; the shipowner. However, a market barrier is introduced in order to reflect that not all the cost savings of the charterer may be appropriated by the shipowner due to imperfections in the market, e.g. lack of information, information asymmetry, and split incentives (Rehmatulla & Smith, 2015).

Figure 2. Illustrations of the fuel saving pass through in a time charter



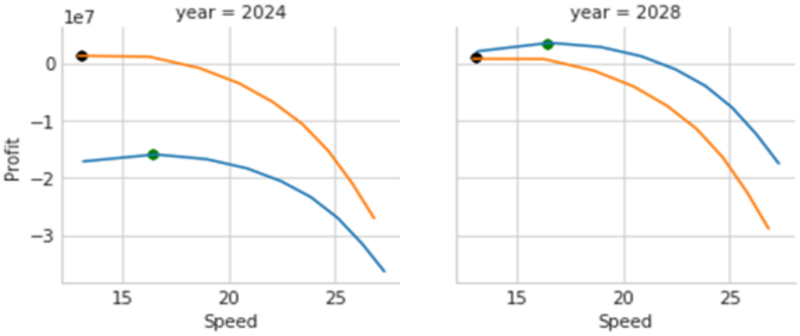
Rebound effect

Improvements in energy efficiency make energy services cheaper and therefore encourage increased consumption of those services and reduces the benefits of the energy savings that may otherwise have been achieved (Sorrell, Dimitropoulos, & Sommerville, 2009). It has been evidenced in the transport sector (see for example (Greene, 1992). Technical efficiency improvements reduce a ship’s fuel consumption at a given speed and the gradient of the speed/fuel curve. This reduces the cost and marginal cost of increased speed. If all else is equal, a ship has a commercial incentive to operate at a higher than average speed if it has better than average technical efficiency and if market demand is sufficient. If the technically more efficient ship operates at an increased speed, the cost savings achieved in practice are lower than those of the technical efficiency increase (a form of rebound effect) (Smith, Technical energy efficiency, its interaction with optimal operating speeds and the implications for the management of shipping's carbon emissions, 2012).

In separate research, Bonnello & Lelliot (2017), investigated the average speeds of a cohort of ships (Suezmax) with a mewis duct retrofit. Operating speeds were increased relative to the ships which were not retrofitted, and the operational efficiency gain was significantly lower than the technical efficiency increase.

Figure 3 shows the profit/speed curve for a selected cohort for container vessels. The effect of the technical efficiency improvements results in higher annual costs (ie. the blue curve on the left hand side is below the orange BAU curve). The additional capital costs are then paid off by 2028, resulting in the curve moving above the BAU curve. The effect of the new technology is also to change the shape of the profit/speed curve by shifting the optimal speed to the right. The change in annual costs between 2024 and 2028 has no effect on this shape, simply shifting the curve vertically, whilst maintaining the same optimal speed.

Figure 3. Profit/speed curve for a selected cohort for container vessels

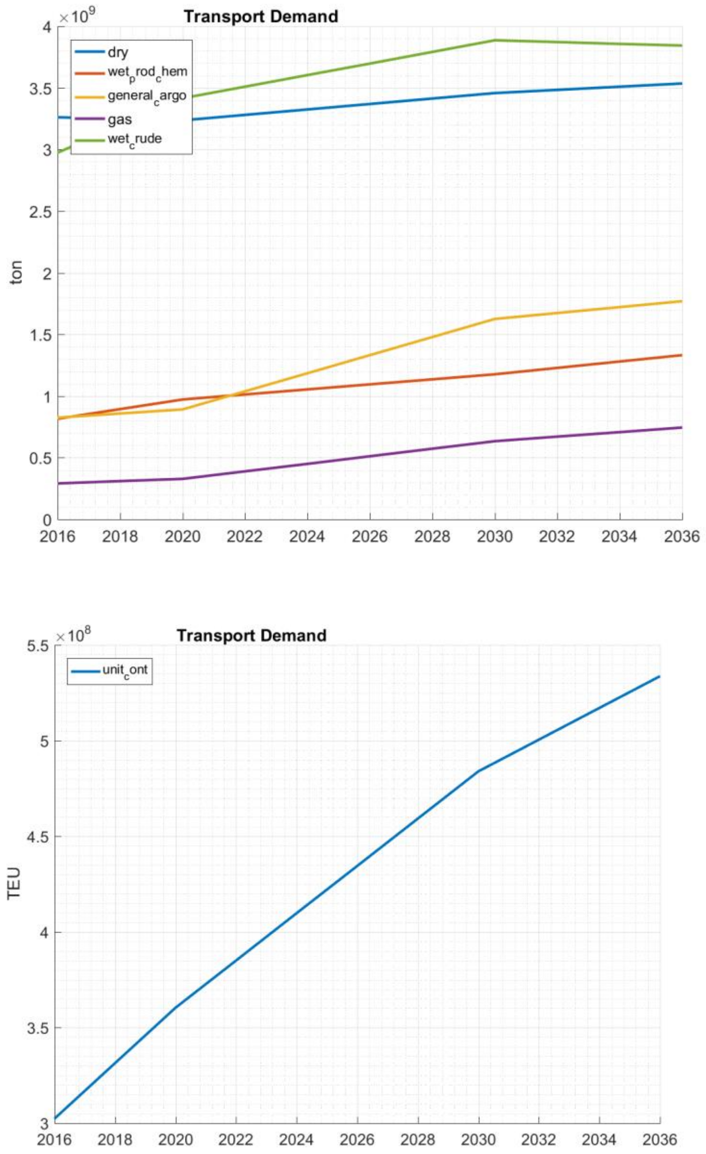


Input assumptions

Transport demand

The transport demand projection is an exogenous input parameter to the model and has been aligned to the transport demand projection used in the Shipping in Changing Climates Middle of the Road 2degrees scenario (SCC MR2D scenario, Traut et al. 2017). The evolving transport demand affects the fleet composition and turnover (the number of ships that are laid up, and the number of new builds in any given year). Figure 4 shows the global transport demand by ship type.

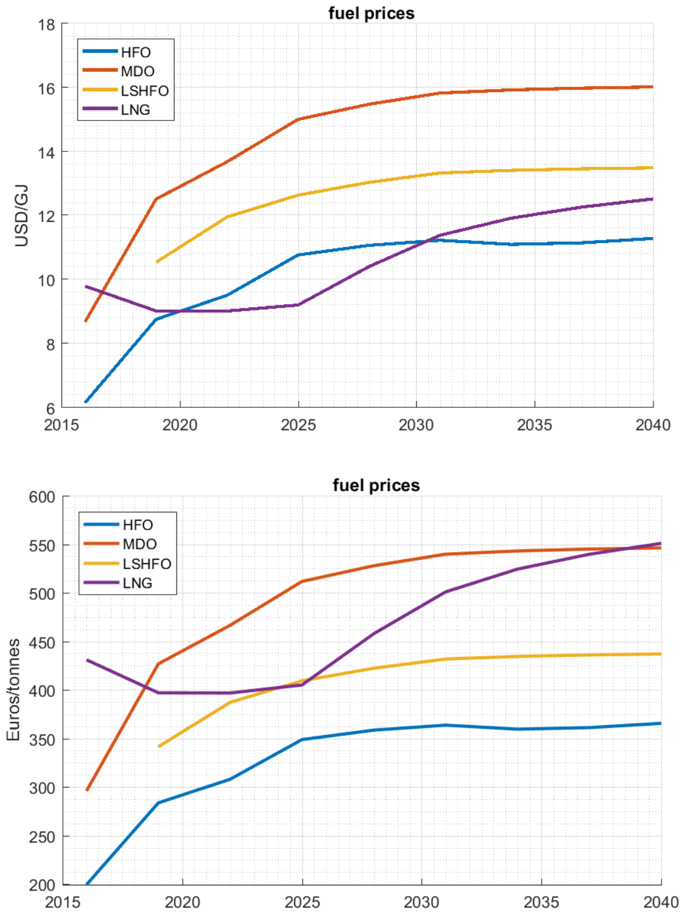
Figure 4. Transport demand by ship types



Fuel price projections

Fuel price projections are a key driver as the profitability of any combination of fuel and machinery changes over time because of the evolution over time of the fuel prices. Figure 5 shows the fuel price projections for four shipping fuels, Heavy Fuel Oil (HFO), Marine Diesel Oil (MDO), Low Sulphur Heavy Fuel Oil (LSHFO) and Liquid Natural Gas (LNG). On the left fuel prices are shown in energy basis (USD/GJ), whereas, on the right in Euros/tonnes.

Figure 5. Fuel price projections



Ship capital expenditure

Capital costs of different engine types and sizes (see Table 1) are taken into account in the model as well as the costs of alternative fuel storage system on board ships. Assumptions of scrubber investments costs are aligned with the values provided in the IMO Fuel Availability Study (CE Delft et al. 2016).

Table 1. Capital costs for different engine types

Index	description	UPC $/MW
1	2 stroke diesel	4.00E+05
2	4 stroke diesel	4.44E+05
3	diesel electric	5.00E+05
4	4 stroke spark ignition (LNG)	1.40E+06
7	FC+LNG	2.40E+06

Operating costs and revenues

The model estimates the components of operating annual costs, including the voyage costs. These depend mainly on fuel consumption, fuel price and operational conditions such as days active, days at port per nautical mile, ratio of ballast days to loaded days, time spent in ECAs, and days at sea per year. Operational conditions at base year are aligned with AIS data obtained from Prakash et al. (Forthcoming).

The model also takes into account the annual revenue expressed as price paid for unit of transport supply and the quantity of transport supply per year. Changes in average speed affect the fleet productivity. The model takes into account different speeds in order to capture the interaction between the optimal operation speed and the technical energy efficiency. The model can constrain the range in which the speed can be optimized. The constraint is applied by setting an upper and lower bound of the maximum continuous rating (MCR) of the engine.

Energy/fuel efficiency technologies

All major technical abatement and energy or fuel efficiency interventions are included. At each time step, costs and performance of each technology and combination of technologies are evaluated based on the profit maximization function of the shipowner. Table 2 lists the technologies included in the model.

The potential energy savings and associated costs for each technology can be found in Smith, T. et al., 2016. CO2 emissions from international shipping: Possible reduction targets and their associated pathways. Appendix B – Technology and Operational intervention assumptions.

Table 2. Abatement technologies included in the model

Autopilot Upgrade
Future potential for fuel cells
Steam Waste Heat Recovery exhaust gases
Organic Rankine Waste Heat Recovery scavenge air
Carbon Capture System
Sails
Rotors
Kites
Low ballast & Extreme trim
Energy storage port maneuvering
Superstructure streamlining
Lightweight Construction

Rudders
Hull aft
Hull + Propeller optimization
Air lubrication Bubbles
Air lubrication Cavity
Hull coating foul release
Hull coating hybrid
Engine derating
Pre-Swirl propeller ducts
Contra Rotating Propeller
Propeller Section Optimization
Hotel systems
Shore power
Wave harvester
Solar power
Nuclear

Regions aggregation and apportionment of emissions to region

The list of countries that form the European region is provided in Table 3. The emissions associated with the European region are distinguished as:

Domestic (sum of the voyages loaded and ballast within the European region)

International (sum of four discrete types of voyage: in-bound loaded, out-bound ballast, in-bound ballast, out-bound loaded).

Table 3. List of countries included in the European region

Andorra
Austria
Belgium
Bulgaria

Croatia
Cyprus
Czech Rep.
Denmark
Estonia
Finland
France
Germany
Gibraltar
Greece
Hungary
Ireland
Italy
Latvia
Lithuania
Luxembourg
Malta
Netherlands
Poland
Portugal
Romania
San Marino
Slovakia
Slovenia
Spain
Sweden

Switzerland
United Kingdom

Further details on the model

The baseline year is set to the year 2016 and the time horizon is 24 years i.e. from 2016 - 2040. The model is initiated in the baseline year using a number of external sources of data that characterizes the fleet stock at that point in time. The model takes into account that ships will meet the EEDI requirements, the SOx and NOx limits in place until 2020 and thereafter, and all relevant MARPOL Annex VI regulations. Ships are categorized in types and sizes as reported in Table 4. Each ship type and size category is further classified into 12 generation (age) categories.

Table 4. Ship types and size breakdown used in the model

Type name	**Size range**
Bulk carrier	0-9999
Bulk carrier	10000-34999
Bulk carrier	35000-59999
Bulk carrier	60000-99999
Bulk carrier	100000-199999
Bulk carrier	200000-+
Chemical tanker	0-4999
Chemical tanker	5000-9999
Chemical tanker	10000-19999
Chemical tanker	20000-+
Container	0-999
Container	1000-1999
Container	2000-2999
Container	3000-4999
Container	5000-7999
Container	8000-11999
Container	12000-14500

Container	14500-+
General cargo	0-4999
General cargo	5000-9999
General cargo	10000-+
Liquefied gas tanker	0-49999
Liquefied gas tanker	50000-199999
Liquefied gas tanker	200000-+
Oil tanker	0-4999
Oil tanker	5000-9999
Oil tanker	10000-19999
Oil tanker	20000-59999
Oil tanker	60000-79999
Oil tanker	80000-119999
Oil tanker	120000-199999
Oil tanker	200000-+

Annex 2 – Online survey results covering stakeholder views on the potential impacts from both greater disclosure (on decision making and engendering greater confidence) and more energy efficient ships (on price and utilisation)

Figure 1. Demographics, shipowners by size

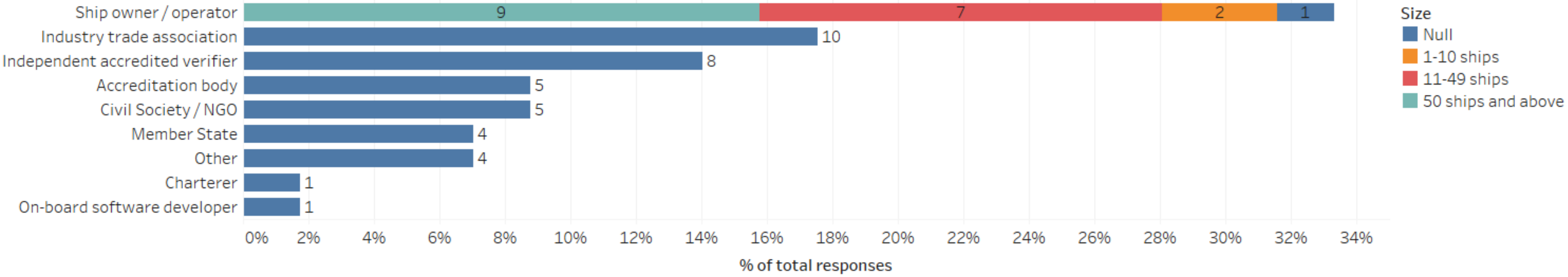


Figure 2. Demographics, shipowners by sector

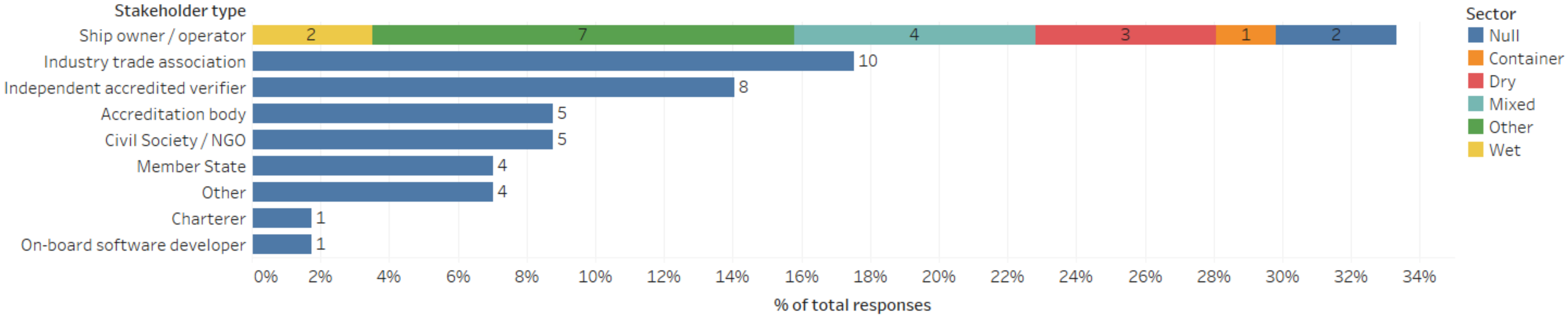


Figure 3. Disclosure aiding decision making – by stakeholder type

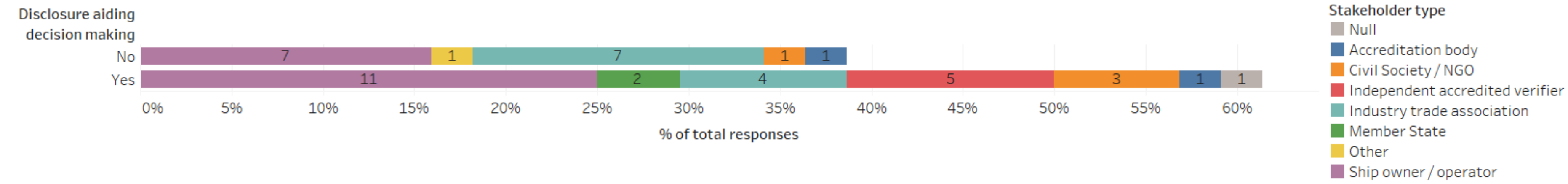


Figure 4. Disclosure aiding decision making – by number of ships in fleet

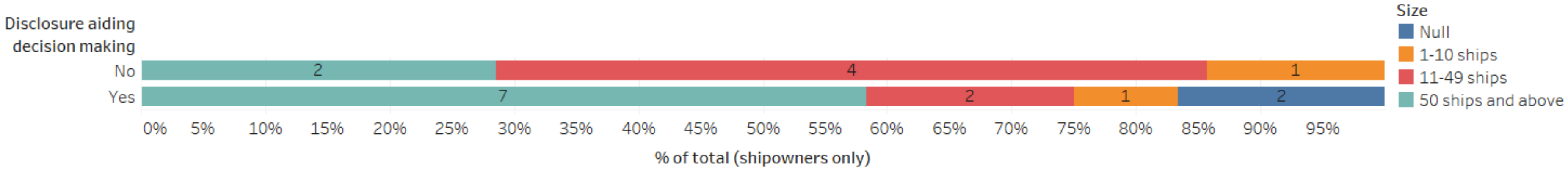


Figure 5. Disclosure aiding decision making – by sector

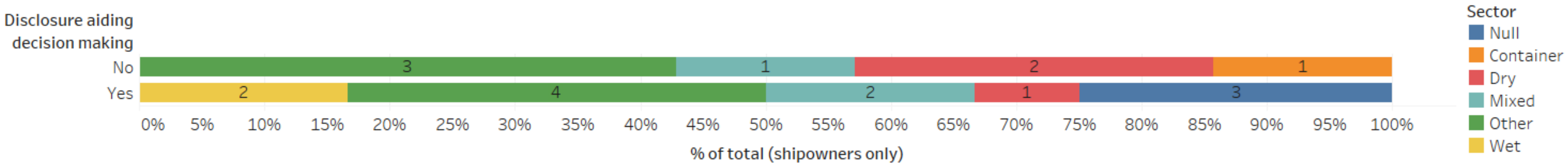


Figure 6. Disclosure leading to more confidence – by stakeholder type

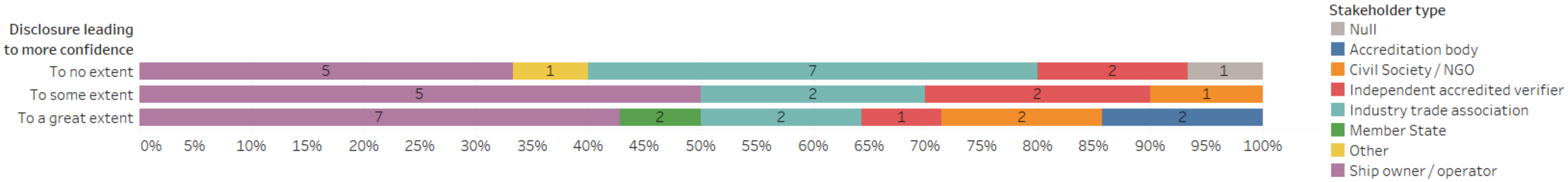


Figure 7. Disclosure leading to more confidence – by number of ships in fleet

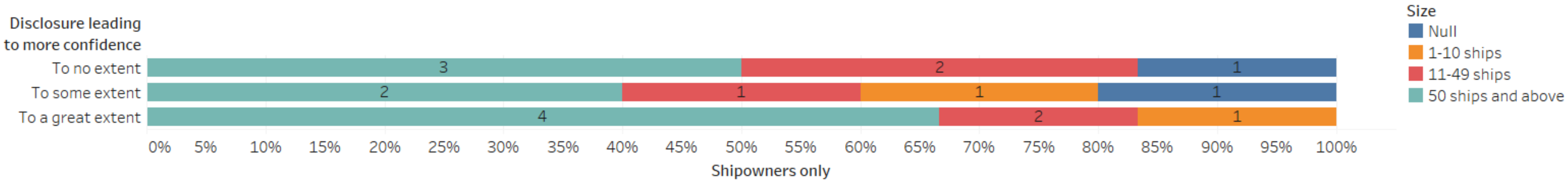


Figure 8. Disclosure leading to more confidence – by sector

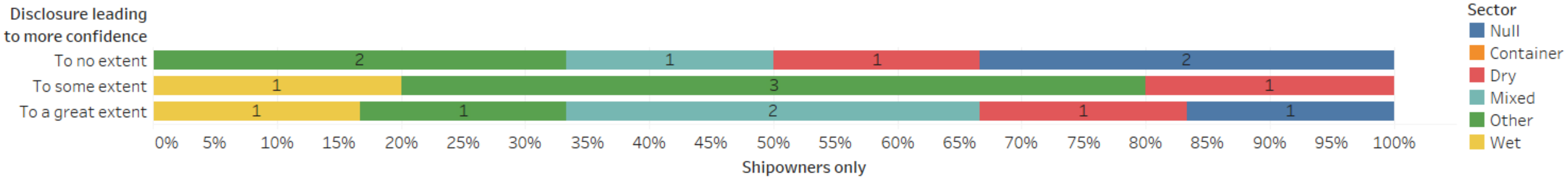


Figure 9. Energy efficient ships commanding higher premium – by stakeholder type

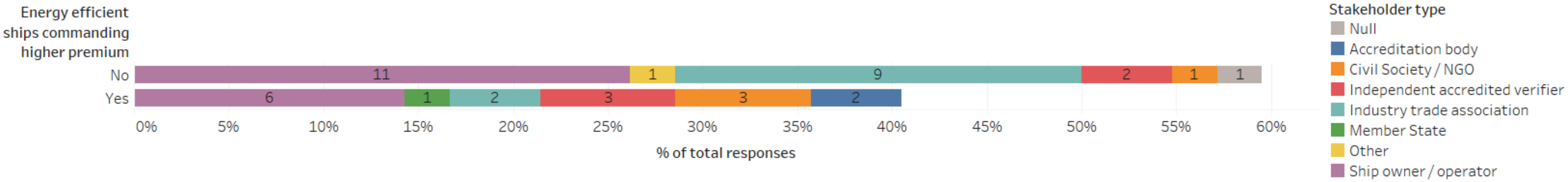


Figure 10. Energy efficient ships commanding higher premium – by number of ships in fleet

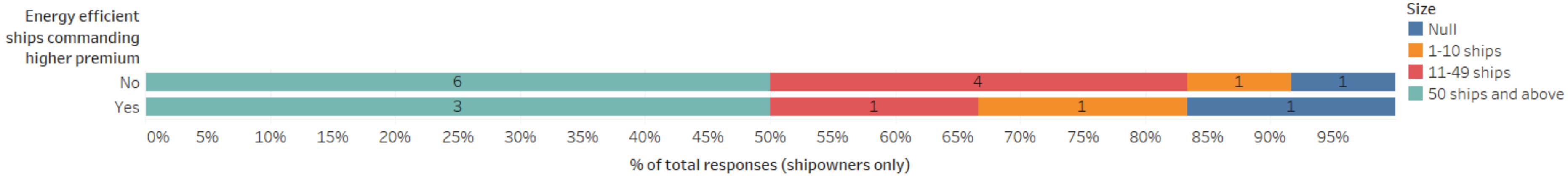


Figure 11. Energy efficient ships commanding higher premium – by sector

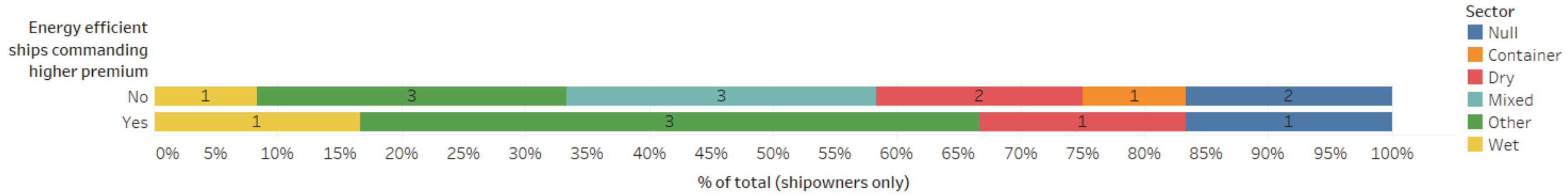


Figure 12. Energy efficient ships gaining higher utilisation – by stakeholder type

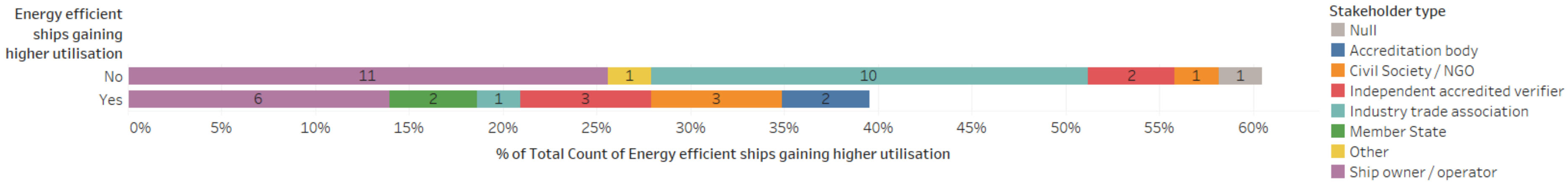


Figure 13. Energy efficient ships gaining higher utilisation – by number of ships in fleet

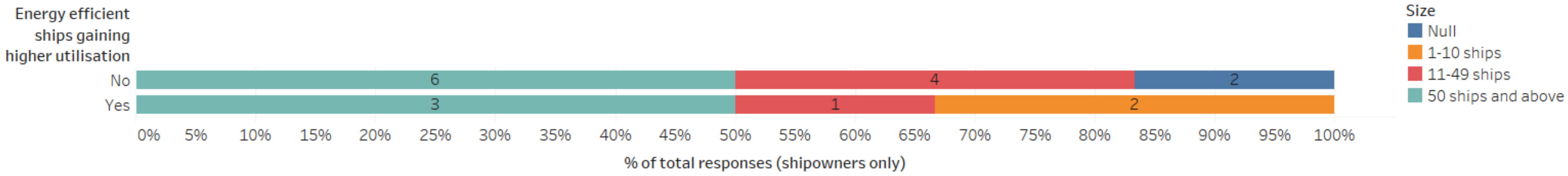
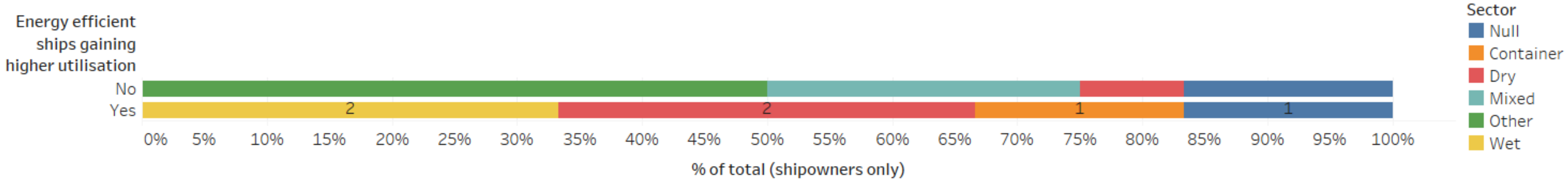


Figure 14. Energy efficient ships gaining higher utilisation – by sector



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