

# Challenges and opportunities of GHG regulations in the maritime sector

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## Abstract

The Paris Agreement temperature goals limit the increase in global temperatures to no more than 2°C, aiming for 1.5°C above pre-industrial levels and thus provide some direction as to the course of action that the maritime sector needs to take. This paper attempts to understand what the Paris Agreement means for the maritime sector emissions pathways, how this can be achieved in terms of technology and fuel mix, and how these translate to CO<sub>2</sub> intensities of the aggregate shipping fleet.

Key words: CO<sub>2</sub> emissions, Paris Agreement, shipping, scenarios, modelling

## 1 Introduction

The shipping sector carries around 80% of the volume of international trade in goods (UNCTAD 2015) and contributes to around 2% of total CO<sub>2</sub> emissions (796 million tonnes) in 2012 (Smith et al. 2014). Under business as usual scenarios, which include the existing policies, such as the EEDI (energy efficiency design index) and SEEMP (ship energy efficiency management plan) and depending on future economic and energy developments, CO<sub>2</sub> emissions from shipping are forecasted to grow between 50-250% in the period up to 2050 (Smith et al 2015).

The Paris Agreement aims to hold the increase of global temperatures to no more than 2°C and aiming for 1.5°C above pre-industrial levels. This provides a clear direction on the course of action on decarbonisation that various sectors, including the shipping sector, need to take.

Using a top down approach, Smith et al. (2015) show that under both the 2°C and 1.5°C framing of climate change (emissions budgets), taking into account the latest IPCC (Intergovernmental Panel on Climate Change) and IMO (International Maritime Organisation) studies, and shipping maintaining its current share of 2.3% of global emissions, the shipping sector would be required to halve its emissions by 2050 under the 2°C scenario and achieve carbon neutrality by 2050 under the 1.5°C scenario. Translating this at the ship level the aggregate average operational CO<sub>2</sub> intensity for all ship sizes of containerhips, tankers and drybulk (which account for 60% of emissions from shipping) requires a reduction of 80-90% on 2012 levels by 2050 in the 2°C scenario and net zero emissions in the 1.5°C scenario.

Smith & Rehmatulla (2015), using a top down model, show that even under scenarios where shipping transport demand is half of that suggested in Smith et al. (2014) and shipping is allowed to double its share of total emissions to 4.6% out to 2050, operational CO<sub>2</sub> emission intensities, in aggregate of the three ship types, would need to be reduce in the range 60-90% on 2012 levels, under a 2 degrees scenario.

IEA (2017) uses techno-economic simulation model to project scenarios of transport activity, vehicle activity, energy demand, and well-to-wheel greenhouse gas (GHG) and pollutant emissions out to 2060. IEA (2017) shows that under the 2°C scenario and existing IMO policies i.e. EEDI, which is applicable only to new ships, results in a 1% annual energy efficiency improvement per ship kilometre to 2025, whereas to meet the 2°C temperature goal the fuel efficiency per ship kilometre would require an annual rate of 2.3% between 2015 and 2025.

## 2 Method

The shipping system model, GloTraM (Global Transport Model) is used to generate future scenarios out to 2050 under current policy, a carbon price with the cap set to shipping achieving a consistent proportion of the overall 2°C and 1.5°C emission budget. The impact of these different scenarios on fuel mix, technology take up, design and operational energy efficiency and carbon price is then explored.

The model considers change of the industry by simulating its growth over time in response to changes in transport demand, macroeconomics (e.g. fuel, carbon price, newbuild price inflation), technology availability, regulation (e.g. regulations on GHG and other air emissions). The model uses the following data from various sources; fleet data, trade and transport demand data, operational data, technical energy efficiency interventions, fuel and machinery options, fuel prices, regulations, time charter and freight rate data.

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, as explained in the appendix.

Individual shipowners make decisions in the management and operation of their fleets to maximise their profit. 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 newbuilds 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 SO<sub>x</sub> and NO<sub>x</sub> 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 newbuilds for use in the next time-step.

A feature of the 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 the appendix.

## 3 Results and discussion

This paper presents the results of four scenarios under which the shipping sector is constrained to a carbon budget that is assumed to be in line with a 2°C emissions reduction trajectory. Table X outlines the four scenarios. The names of the scenarios are associated with the specific transport demand (see appendix transport demand). So, for example Green Road V1 and Green Road V2 are associated with

the transport demand scenario Green Road. The differences between V1 and V2 depend on different constraints on bio energy availability and speed limit.

	Green Road V1 (2°C)	Green Road V2 (2°C)	Mid of the road V1 (2°C)	Mid of the road V2 (2°C)
Shipping Carbon budget from 2010 to 2100	33 Gt	33 Gt	33 Gt	33 Gt
Shipping Bio-energy availability in 2050	High	Medium	Medium	Medium
Population growth	Low	Low	Medium	Medium
Economic growth/capita	High	High	Mid-range	Mid-range
Fuel and global carbon prices	TIAM - SPP1 2D	TIAM - SPP1 2D	TIAM - SPP2 2D	TIAM - SPP2 2D
Speed limit	No limit	constraint	No limit	constraint

Table 1: Modelling scenarios

In order to meet the 2°C emissions reduction trajectory (referred to as a target trajectory), the scenarios include the implementation of a Market Based Measure (MBM), which adjusts through the introduction of a carbon price, the cost-benefit to enable take-up of abatement technologies and in-sector emissions mitigation. A shipping carbon price is estimated through the reiteration of GloTraM's modelling steps. In each iteration if the gap between the target trajectory and the net shipping emissions is not bridged, the shipping carbon price increases proportionally, and the GloTraM's modelling steps are repeated until the gap is bridged.

Figure 1 shows the trends of the total CO<sub>2</sub> emissions over time for all four scenarios. On the top, there are the Green Road V1 (GR V1) and Middle of the Road (MR V1) scenarios, whereas on the bottom there are the GR V2 and MD V2. These plots also show the BAU trajectory (the CO<sub>2</sub> emission without any carbon price), and the target trajectory (the 2 degree trajectory estimated for each scenario). The grey area represents the actual CO<sub>2</sub> emissions as result of the uptake of technical and operational emissions reduction measures. The model allows a 10% discrepancy between the target trajectory and actual CO<sub>2</sub> emissions.

The associated carbon price is different because of the different settings of the scenarios, the area to be bridged (between the red line and the black dot lines) is different. Figure 2 shows on the right the carbon price indexed for GR V1 and MR V1, whereas on the left, GR V2 and MD V2. As a consequence, the way the sector meets the target is different, which means that the combinations of technical and operational emissions reduction measures used to achieve the desired reduction are different in each scenario.

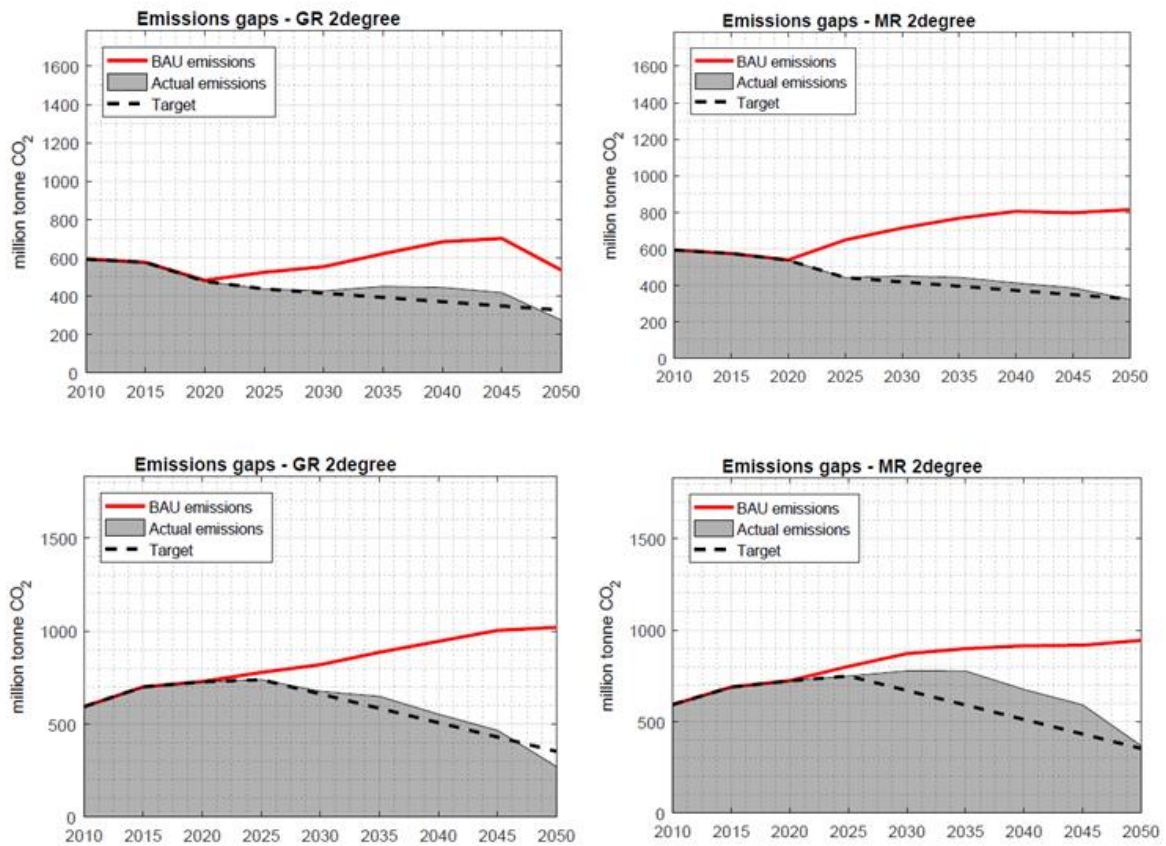


Figure 1: Trends of the total CO2 emissions over time for all four scenarios

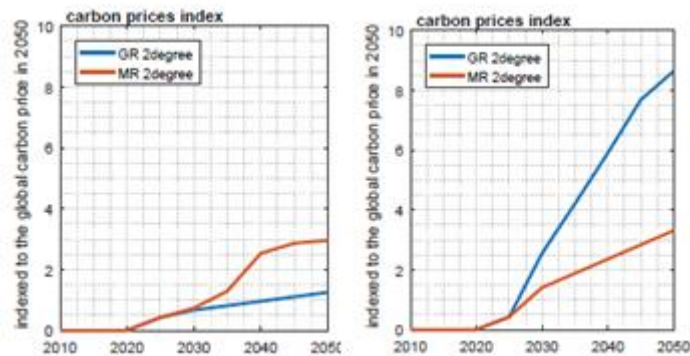


Figure 2: Carbon price index for four scenarios

Among the technical and operational emissions reduction measures, there are at least two key measures that will be discussed in this paper, these are: speed reduction and the fuel mix. With regards to the speed limit, another important aspect is the relationship between the operational speed and the number of ships required to meet a given level of transport demand. For instance, we can observe such a relationship in MR V1 and MR V2. In the first scenario, operational speed (without considering any particular limit due to safety) is allowed to be reduced significantly. The model selects very low speeds in order to reduce the emissions according with the specified carbon budget (represented by the red line in Figure 1). One can observe a reduction up to about 60% out to 2050. As a consequence, the number of ships increases significantly (see Figure 4 number of ships). In contrast, we can see the difference with the scenario MR V2, which is constrained by a speed limit

(lower bound). The speed decreases only up to 20% out to 2050. Thus, a reduction of speed is not sufficient as operational measure alone to meet the target trajectory, moreover, it may have unwanted consequence that still need to be estimated (e.g. increased traffic)

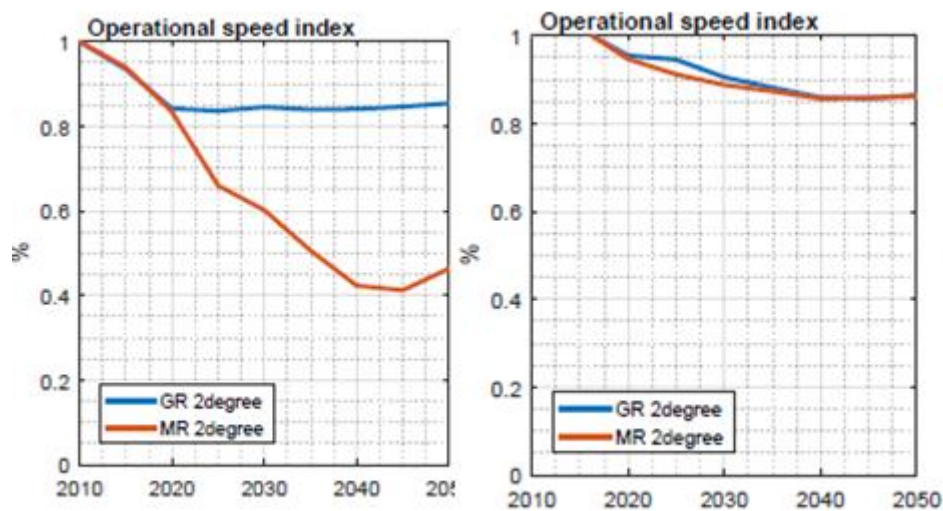


Figure 3: Operational index in four scenarios

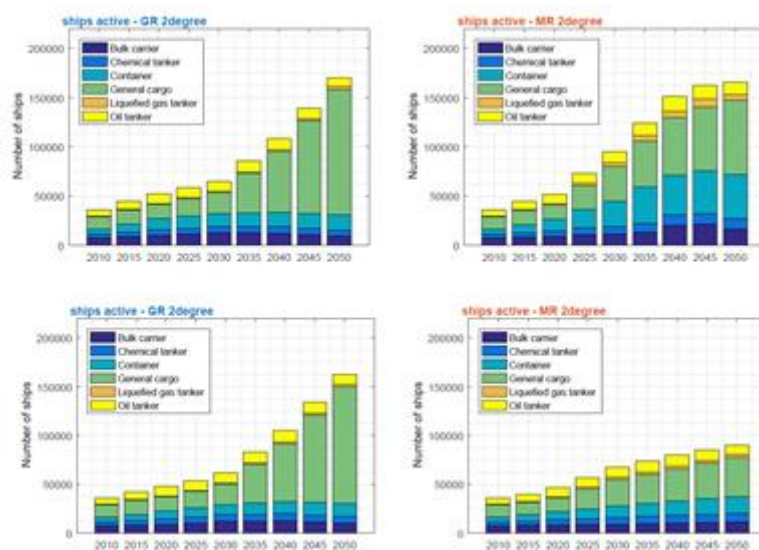


Figure 4: Number of ships in all four scenarios

Figure 5 shows the fuel mix for each scenario. There are two cases in which the decarbonisation can be achieved without the use of synthetic low carbon fuel (such as hydrogen). The first case (in scenario GR V1) where there is a significant availability and penetration of biofuels. In this case, it is possible to meet the target by switching about 80% of the fleet to biofuels along with the speed reduction and uptake of energy efficiency. The second case (scenario MR V1) is where the transport demand is low and the fleet reduces significantly the operational speed up to 60%.

In contrast to the two scenarios examined above, both GR V2 and MR V2 scenarios require a significant uptake of hydrogen with fuel cells in order to meet the carbon budget. The fuel mix in GR V2 ensures that the average carbon content of the marine fuel reduces to about 75%. In this scenario the operational carbon intensity reduces to about 80%. In contrast, the MR V2 is driven by a lower

transport demand than GR V2, this reduces the effort the industry would have to decarbonise. As a result, the take up of hydrogen is delayed till 2035 (rather than in 2025 in GR V2). The fuel mix ensures that the average carbon content of the marine fuel reduces to about 60%. The operational carbon intensity reduces to about 75% which means that other operational and technical measures contribute of about 15% of carbon intensity reduction. In this scenario LNG plays the role of a transition fuel.

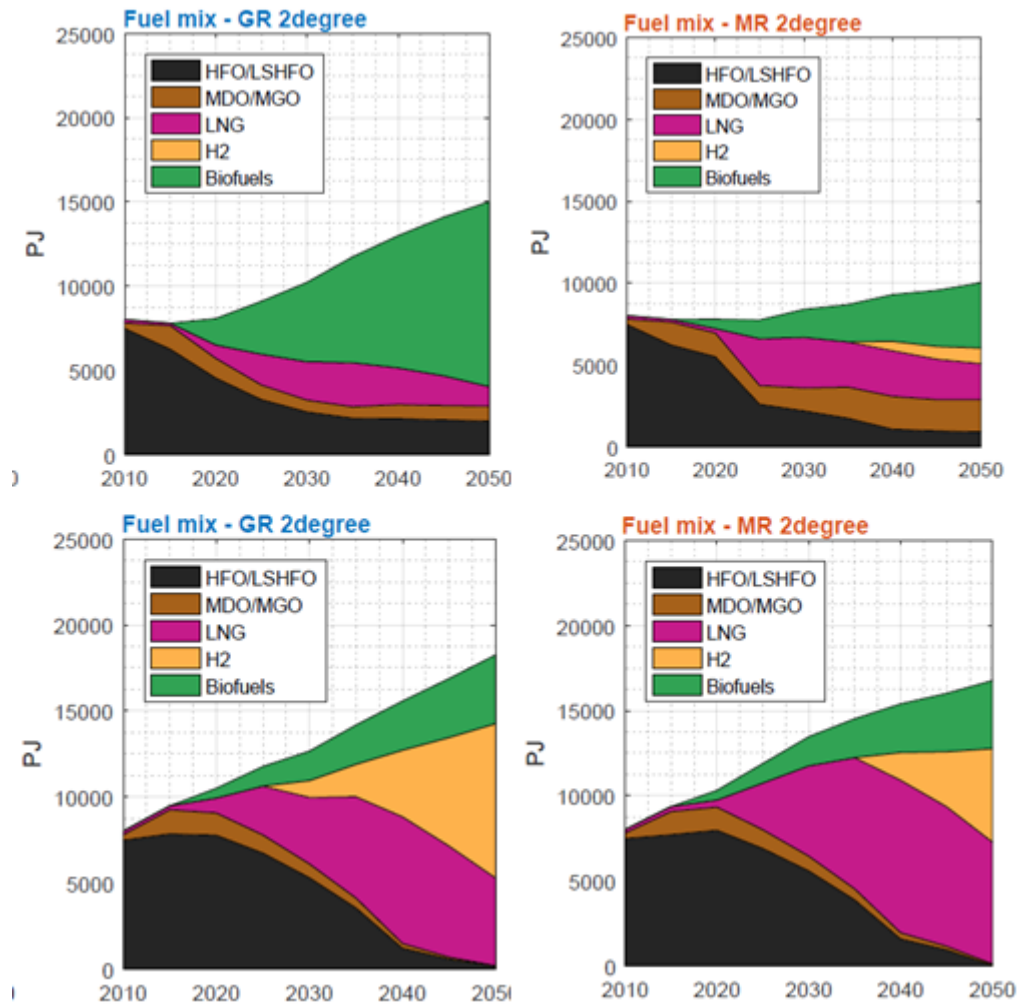


Figure 5: Fuel mix

In terms of emissions if we assume biofuels to be carbon neutral then the upstream emissions are low in GR V1. If hydrogen is part of the mix then it is very important to keep the upstream emissions down. For instance, for GR V2 and MR V2, it was assumed that hydrogen would be produced from SMR using natural gas. Since the latter has significant emissions associated, the upstream emissions increases dramatically (see Figure 6).

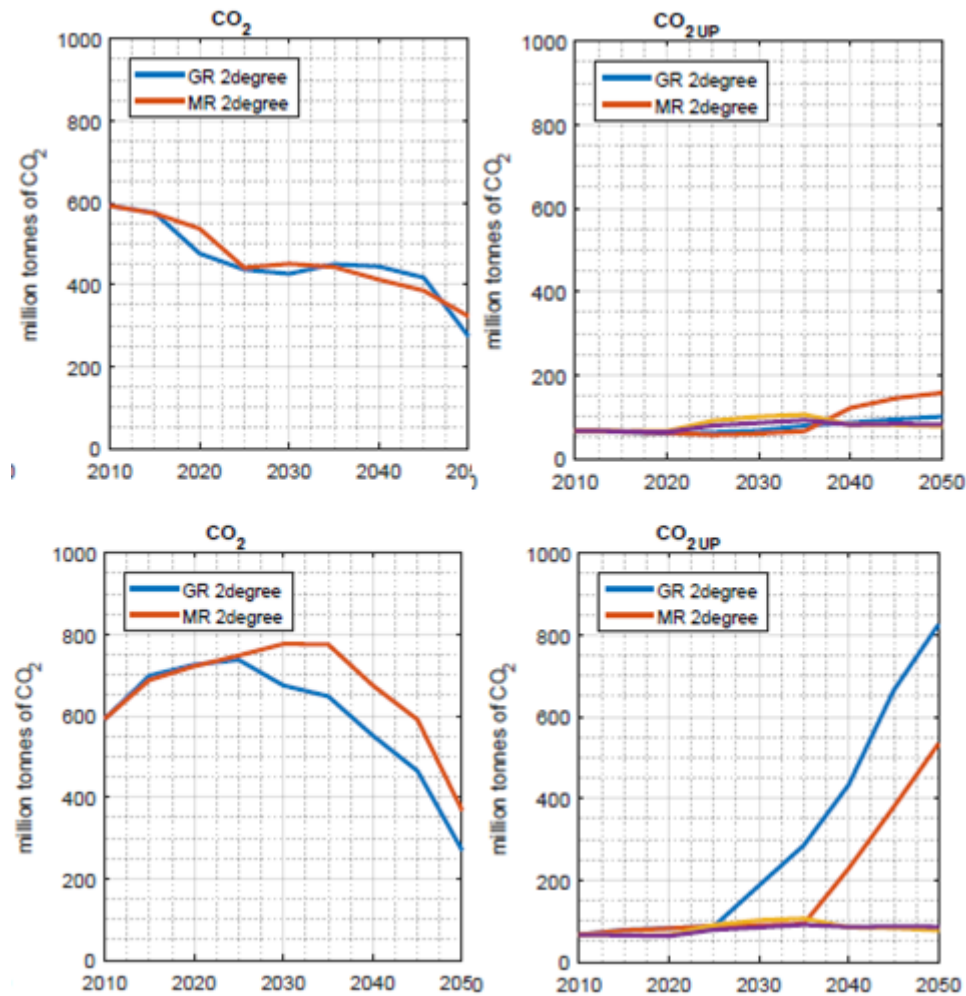


Figure 6: CO<sub>2</sub> emissions operational (left) and upstream (right)

## 4 Concluding remarks

This paper attempted to understand what the 2°C emissions reduction trajectory (compatible with the Paris Agreement) means for the maritime sector emissions pathways, how this can be achieved in terms of technology and fuel mix, and how these translate to CO<sub>2</sub> intensities of the aggregate shipping fleet. In terms of operational measures, speed reduction alone is not sufficient as operational measure to meet the target trajectory, moreover, it may have unwanted consequence such as a significant increase in traffic due to the larger number of ships active required to meet the transport demand. Thus, both operational and energy efficiency technology measures would not be sufficient to meet the target trajectory in any of the scenario. Biofuels take up is significant only when there is a high availability. A lower transport demand would reduce the effort the industry would have to expend in order to meet the decarbonisation trajectory.

## 5 References

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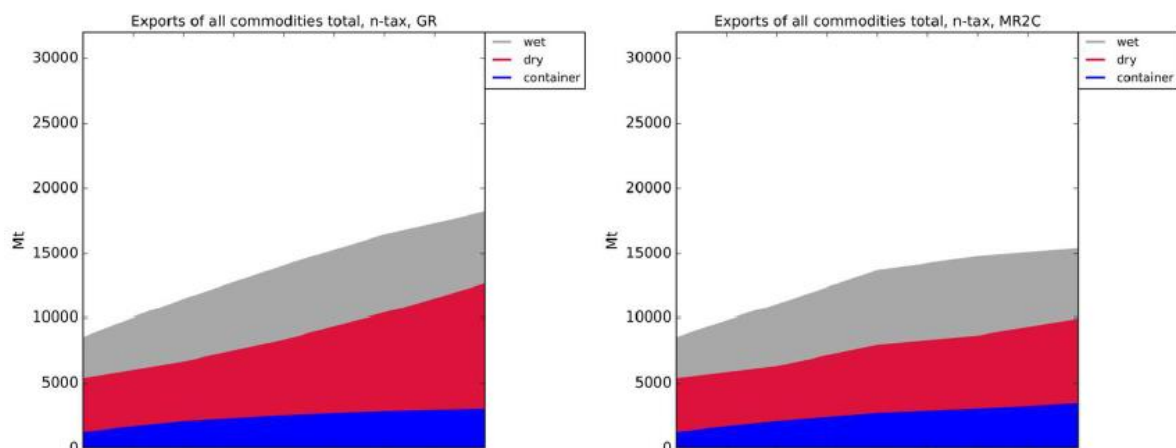
## 7 Appendix

### Model input assumptions

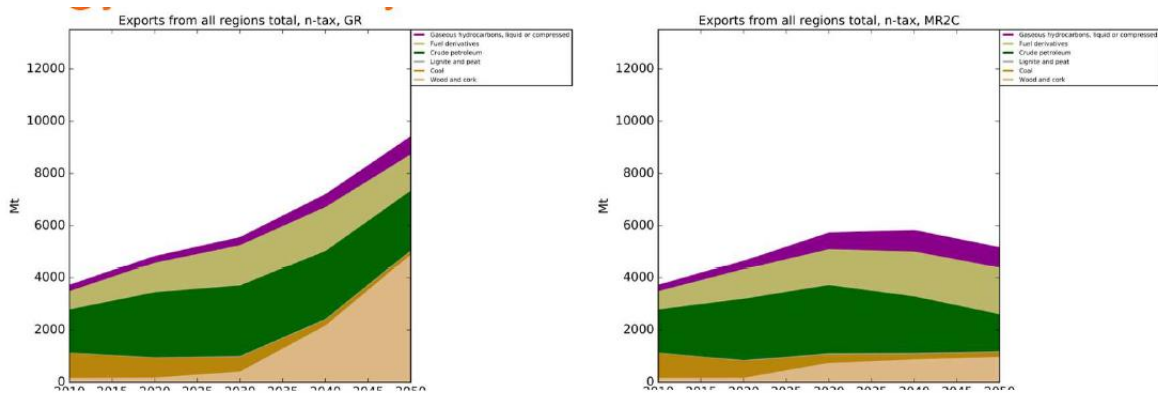
#### Transport demand

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 X shows the global transport demand by ship type.

#### Transport demand by ship types



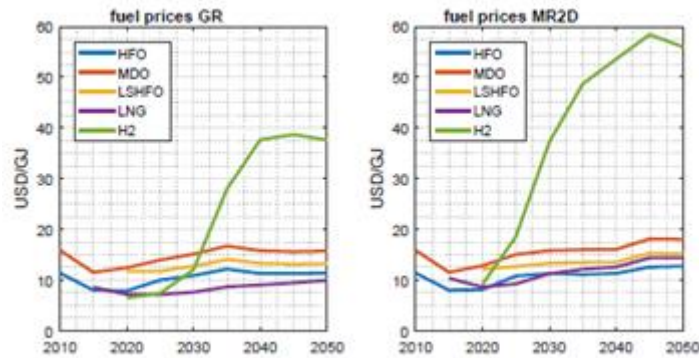




### Fuel price projections

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 40 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.

### Fuel price projections



### Ship capital expenditure

Capital costs of different engine types and sizes are taken into account in the model as well as the specific fuel consumption and 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).

### Capital costs for different engine types

Index	description	UPC \$/MW	sfc (@75% MCR) g/kWh
1	2 stroke diesel	4.00E+05	190
2	4 stroke diesel	4.44E+05	200
3	diesel electric	5.00E+05	210
4	4 stroke spark ignition (LNG)	1.40E+06	172
7	FC+LNG	2.40E+06	168

## 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 18 lists the technologies included in the model.

Table 22. 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

### Shipowner profit function

$$\text{Profit}_{\text{own\_pa}} = \text{R}_{\text{own\_pa}} - \text{C}_{\text{own\_pa}}$$

$$\text{R}_{\text{own\_pa}} = \text{R}_{\text{base\_pa}} + \text{B.tc} * (\text{R}_{\text{vc\_pa}} - \text{C}_{\text{V\_pa}} - \text{P}_{\text{tc\_pd}} * 365)$$

$$\text{C}_{\text{own\_pa}} = \text{Cs}_{\text{base\_pa}} + \text{Cs}_{\text{delta\_pa}}$$

$$\max(\text{NPV}_{\text{own}})$$

Where:

- $\text{R}_{\text{own\_pa}}$  is the shipowner's annual revenue
- $\text{C}_{\text{own\_pa}}$  is the shipowner's annual costs
- B.tc is the time charter and voyage charter barrier factors
- $\text{R}_{\text{vc\_pa}}$  is the annual voyage charter revenue
- $\text{P}_{\text{tc\_pd}}$  is the market time-charter day rate
- $\text{C}_{\text{I\_delta}}$  and  $\text{C}_{\text{V\_pa}}$  are the inventory cost delta (relative to the baseline inventory cost, and annual voyage cost respectively).
- $\text{Cs}_{\text{base\_pa}}$  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 ( $\text{P}_{\text{tc\_pd}} * 365$ ).
- $\text{Cs}_{\text{delta\_pa}}$  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).

Market barriers

Market barriers are included in the model using the barrier factors that represent the proportion of charterer's fuel cost savings that are returned to the shipowner. It 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 is passed to the shipowner. Changes to the barrier factors will influence the estimated shipowner's profit function (see Annex 4), thereby, the shipowner's decision making in the management and operation of their fleets.

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<sub>2</sub> emissions that incorporate the impact of any economic or policy stimuli.