Policy implications of meeting the 2°C climate target

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ABSTRACT

The inherently global nature of shipping has (certainly in the past half century) dictated the regulation of the shipping sector. Both the IMO and the ICS have affirmed their position that the regulation of shipping must, first and foremost, be the responsibility of agents at the global multilateral level. One interpretation of this is that shipping should be viewed akin to a sovereign nation in its own right. This position has significant implications for the responsibility of the sector as a whole in responding to the challenges posed by climate change. In the first instance, both the IMO and the ICS have established that the shipping industry is committed to its responsibility for reducing its carbon emissions, however it is also asserted that any response must be proportionate to shipping's share of the total global emissions. Mitigating against dangerous climate change has conventionally been associated with maintaining temperature rise at least under a 2°C threshold, and that framing is also used in this paper.

Scenarios of future shipping greenhouse gas (GHG) emissions suggest that under current policy, shipping emissions are expected to rise significantly – by 50 to 250% (IMO 3rd GHG study, 2014). This paper follows from the work of Smith *et al* (2015) presented in MEPC 68 that explores alternatives to the current expectations of shipping's CO2. The shipping system model GloTraM is used to generate future scenarios up to 2050 under current policy, an imposed bunker levy, and under a cap and trade emission trading scheme with the cap set to shipping achieving a consistent proporition of the overall 2°C emission budget. The impact of these different scenarios on fuel mix, technology, EEOI and carbon price is then explored.

1. INTRODUCTION

The Copenhagen Accord laid out an ambition to manage the risk of dangerous climate change by limiting the global mean temperature rise to no greater than 2°C above pre-industrial levels (Copenhagen Accord, 2009). Even with this level of warming, over time many low-lying nations could become uninhabitable due to sea level rise (Schaeffer *et al*, 2012). As a consequence, targeting just 1.5°C of warming continues to receive serious consideration from many parts of the world (Cancun Agreements, 2010; AOSIS, 2014). Both targets require an imminent peak in GHG emissions, followed by rapid and sustained emissions reductions across all sectors (UNEP, 2010).

Scenarios of future shipping GHG emissions, presented in the Third IMO GHG Study 2014, suggest that under current policy, shipping emissions are expected to rise significantly (by 50 to 250%). However, under both the 2°C and 1.5°C framing of climate change, and taking into account the latest IPCC and IMO studies, shipping emissions must be bounded by one of two alternative sets of conditions:

1. No further policy is applied to international shipping, leaving emissions on a business-as-usual growth trajectory. Under this option, the required cuts to greenhouse gas emissions from other sectors would need to go above and beyond the already significant reductions necessary to remain in line with the Copenhagen Accord and the Cancun Agreement.
2. Emissions from International shipping are limited and reduced to contribute a "fair share" towards overall GHG mitigation (at an appropriate level of probability)

2. CO2 BUDGETS CONSISTENT WITH 2°C

To derive CO2 budgets for the shipping sector that are consistent with limiting global warming to 2°C, global emissions budgets associated with such temperature is first considered. The climate model MAGIC (Meinshausen *et al*, 2011a and 2011b) is used to calculate the climate's temperature response to emissions scenarios over the 21st century. In the 2°C reference scenario, which has a 50% chance of staying below 2°C of global warming, cumulative CO2 emissions over the period 2011 to 2100 are estimated to be 1428 GtCO2 (Smith *at al,* 2015).

As a starting assumption, it is assumed that shipping's budget should be in proportion to its current contribution to global emissions. The Third IMO GHG study 2014 estimates CO2 emissions from 2007 to 2012 be an average of 2.33% of global CO2 emissions over that period. Applying that share to a total budget of 1428 Gt results in a CO2 budget of 33Gt over the time period from 2011-2100 for international shipping. If the emissions from international shipping is known in base year 2010, a potential 2°C emission trajectory can be estimated. When setting a budget, it is assumed that CO2 emissions from international shipping follow the reference scenario from the Third IMO GHG Study (2014) until the year of implementation of a regulation on shipping GHG, and then decrease linearly over time.

3. External factors (assumptions and inputs)

In this section we look at input parameters and assumptions, which make the base of the shipping model GloTraM. We refer to them as external factors and discuss each briefly in this section. For a more comprehensive discussion refer to Shipping in Changing Climates: External factors and inputs to GloTraM and ASK (Smith *et al*, 2014).

3.1 Trade Scenario

Demand projections have been taken from the IMO 3rd GHG study. The 3rd Greenhouse Gas study contains information on the growth of transport work for a set of commodity categories under various shared socioeconomic pathways (SSP) and representative concentration pathways (RCP) until 2050. In this study the chosen shared socio-economic pathway (SSPS) is SSP2/RCP 2.6. This combination is chosen as it reflects the likely challenges to meaningful mitigation whilst accepting that under 2°C many regions will have to adapt to climate change impacts. The SSPs reflect broad socio-economic narratives, which provide a framework for scenario analysis based on whether the response to climate change emphasizes mitigation or adaptation measures In summary, SSP 2 reflects an intermediate projection between rapid and slow technological change and moderate degrees of inequality where both climate change mitigation and adaptation face modest challenges with some regions suffering from climate change with a low adaptive capability. Figures for base year 2010 are taken from NEA database. Growth rates are applied up until 2050 based on IMO 3rd GHG study (Smith *et al*, 2014).

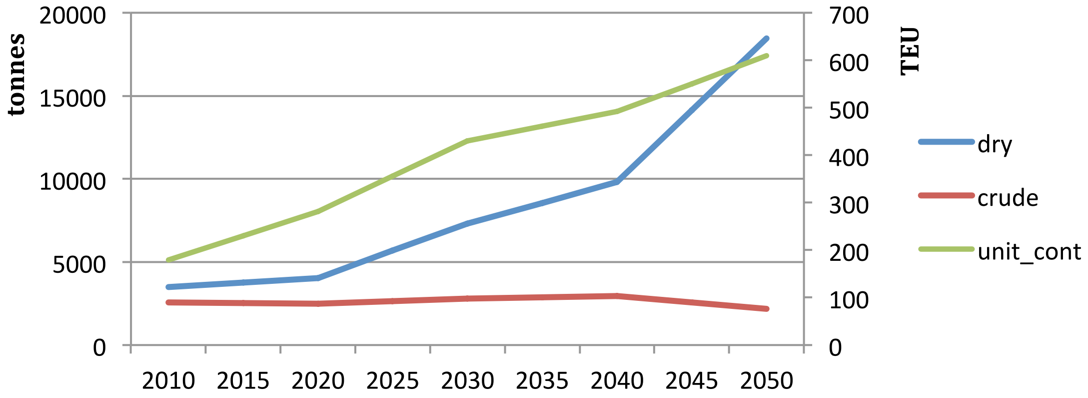


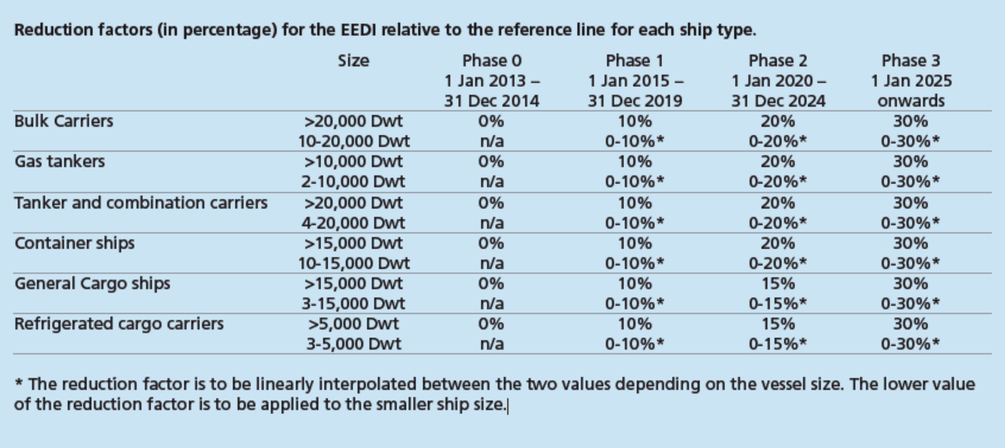
Figure 1: Demand pathways for three ship types

In the figure presented above, the demand for trade reflects the dynamics of supply and demand but also technological changes. The demand for crude oil remains relatively constant as oil is phased out in domestic and generation sectors (mostly within developed regions) whilst demand for fossil remains within the transport sector associated with increased personal mobility within developing regions. The growth in demand for dry bulk reflects increasing demand for iron ore as countries such as China remain significant producer of steel but has depleted domestic stocks. Thermal use of coal remains but is underpinned by implementation of carbon capture and storage (CCS) but large scale trade in biomass (such as wood pellets) grows significantly as many consuming regions do not have the capacity to expand domestic production. Furthermore many regions (such as the middle east) are projected to demonstrate significant increases in population but will face constraints on domestic grain demand due to both limits to suitable land but also the impacts on yield associated with an increase in temperature. The growth in container trade reflects continued demand for highly manufactured goods (reflecting availability of credit, and increases in disposable incomes) but also the extension of manufacturing supply chains with increased specialisation and trade in intermediate commodities. In particular trade amongst developing and industrializing regions propels growth in container trade. However the growth rate in container trade peaks by 2030 as the containerization rates of neo-bulk goods reaching saturation.

3.2 Regulation scenario

The regulation scenario will apply the achievement of a minimum attained EEDI for all new vessels built after 2013 according to the stringency described in the MARPOL Annex VI amendment, repeated here in Table 1. Whilst the existence of SEEMP regulation is acknowledged, it will be assumed that this does not have a measurable effect on emissions, as there is currently no enforcement of its implementation beyond the presence of a SEEMP on-board each vessel.

Table 1 EEDI reduction factors and implementation limits



Reduction factors (in percentage) for the EEDI relative to the reference line for each ship type.

	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Jan 2025 onwards
Bulk Carriers	>20,000 Dwt	0%	10%	20%	30%
	10-20,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
Gas tankers	>10,000 Dwt	0%	10%	20%	30%
	2-10,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
Tanker and combination carriers	>20,000 Dwt	0%	10%	20%	30%
	4-20,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
Container ships	>15,000 Dwt	0%	10%	20%	30%
	10-15,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
General Cargo ships	>15,000 Dwt	0%	10%	15%	30%
	3-15,000 Dwt	n/a	0-10%*	0-15%*	0-30%*
Refrigerated cargo carriers	>5,000 Dwt	0%	10%	15%	30%
	3-5,000 Dwt	n/a	0-10%*	0-15%*	0-30%*

* The reduction factor is to be linearly interpolated between the two values depending on the vessel size. The lower value of the reduction factor is to be applied to the smaller ship size.

In addition to regulation of GHG, there is existing regulation of air pollutants, which are expected to impinge significantly on the technology and economics of energy efficiency. IMO's MARPOL convention Annex VI contains regulation of both SOx and NOx, as shown in Figure 2 and Figure 3 respectively. These regulations will be included in the regulation scenario as they are specified in Annex VI documentation, the North Sea, Channel and Baltic are assumed to be both a SOx and NOx controlled ECA.

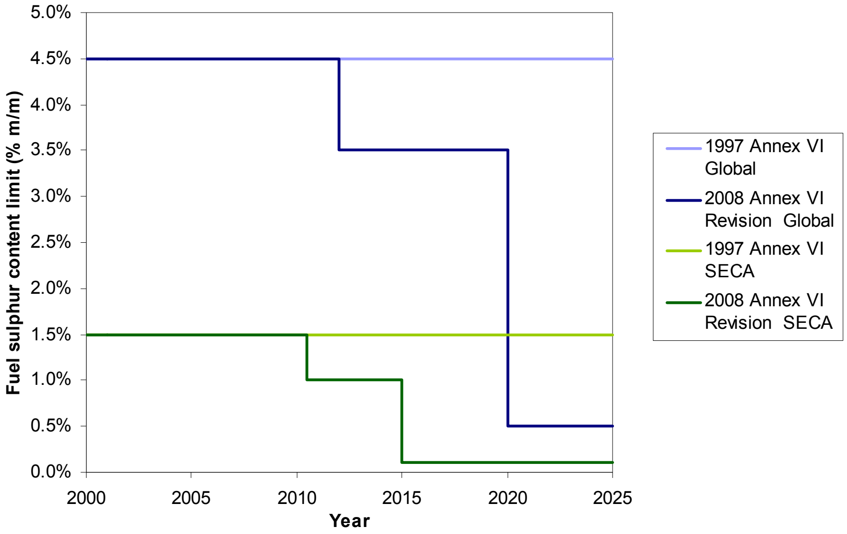


Figure 2: Default SOx limits as used in GloTraM

At MEPC 67 the IMO reviewed a progress report on the impact of the global sulphur content limits (0.5% m/m by 2020) within the context of future fuel availability based on the potential supply and anticipated demand for fuel oil, as well as wider market trends. This matter is expected to be reported in MEPC 70, and dependent on the final outcome of the review of compliant oil availability (to be finalised 2018), the more stringent sulphur limit could be deferred to 1 January 2025. In all scenarios modelled in this paper, the assumption is that the 0.5% limit is applied in 2020.

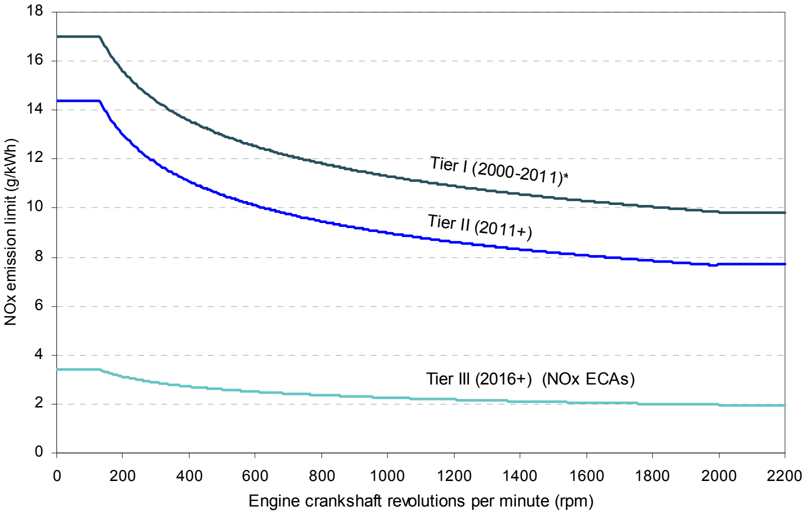


Figure 3: Default NOx limits as used in GloTraM

3.3 Fuel scenario

Fuel and carbon prices used in GloTraM are derived from commodity price information taken form TIAM-UCL, an energy systems model developed at the Energy Institute - UCL. The objective function of TIAM-UCL is to satisfy all energy-service demands[1] in a cost-optimal manner. In TIAM-UCL commodity prices are therefore generated within each year within each region[2] on the basis of matching the regional demand for that commodity with the available supply options. The demand for commodities comes from a variety of sources throughout the energy sector. For example, demand for oil would be from road transport technologies,

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[1] Examples of energy service demands are vehicle kilometers, heat required in homes, steel production etc.

[2] There are 16 regions within TIAM-UCL

aviation, shipping, the industrial sector for chemical feedstock, the agricultural sector, and the electrical sector.

A final important factor that can influence commodity prices is any CO2 shadow price (or tax) that is present in any scenario. The extraction, processing, and transport of commodities require energy, which is generally unavoidable. If this energy is carbon intensive, then the cost mark-up (CO2 price multiplied by CO2 intensity) will be reflected in the commodity price. This mark-up will increase commodity prices in carbon-constrained scenarios, and can counteract some of the reduction in price that results from reductions in demand also brought about by the carbon constraint. This can also enhance the desirability of alternative fuels such as liquid Hydrogen.

The following plot outlines the fuel scenario assumption used in GloTraM.

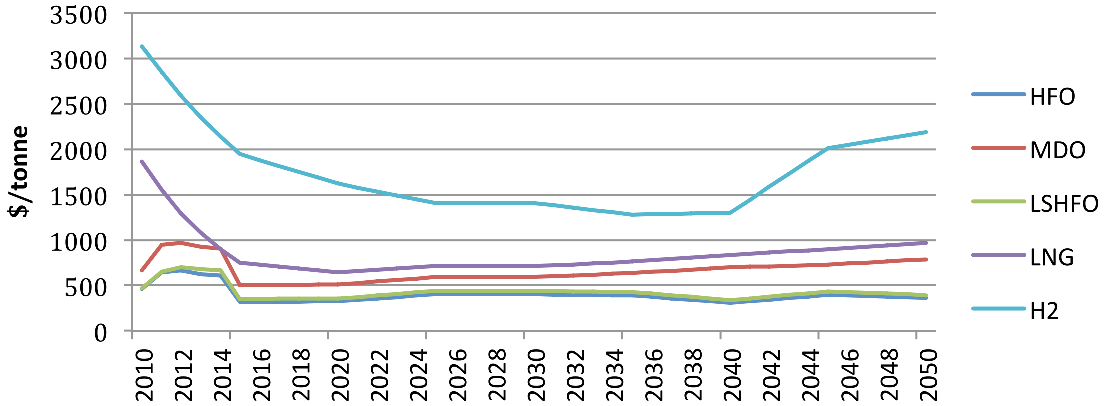

Figure 4 – Bunker prices

HFO and MDO prices during the period 2010 to 2014 are based on IEA historical data. Prices in 2015 were estimated as the oil price in 2015 multiplied by the average ratio of HFO and MDO prices to oil prices during the last 10 years. After 2015, they were assumed to be equal to the sum of the “shadow price” as calculated in TIAM-UCL and a fixed relative cost mark-up. The shadow price in TIAM-UCL as explained earlier is defined as the price paid for an increment of additional production. It incorporates the costs of production, the choices of substitutes, the constraints that are imposed (e.g. ramp-up rates on new sources of production), and any long-term energy-service demand elasticities. Real price and shadow price are not necessarily the same as the latter does not include some elements that are in the real world as extraction taxes. Because of this shadow prices of HFO and MDO in TIAM-UCL generally result to be lower than the expected real prices. So, a fixed relative cost mark-up was added representing the percentage difference between the TIAM-UCL shadow price and real world fuel prices in 2015, to the fuel price in 2015. This is the same as ‘rebasing’ the relative increase in shadow prices to the price in 2015.

LSHFO prices were obtained as the HFO prices as estimated above multiplied by the average ratio of LSHFO prices to HFO prices during the last 7 years taken from IEA historical data. This is based on the assumptions that LSHFO price will maintain a constant mark-up over the HFO price. LSHFO is assumed to satisfy the 1% sulphur limit, and then be further extended to satisfy the 0.5% limit from 2020 onwards. The assumption that satisfying the 0.5% limit adds no further cost may need to be revisited in future work.

LNG prices during the period 2015 to 2050 were obtained as the sum of the “shadow price” as calculated in TIAM-UCL and a fixed relative cost mark-up, similar to HFO and MDO prices. The real world price in 2015, however, is not available, so it was assumed to be equal to 750 $/tonnes. Conversely, before 2015 it was assumed that the LNG prices increase by 20% in each year previous to 2015. This is because LNG price is affected by the investment required for the development of a global supply infrastructure. So this factor represents the fact that early adopters will have to pay a high price, then as the global supply infrastructure develops the price decreases.

Hydrogen prices were obtained using the “shadow price” as calculated in TIAM-UCL during the period 2020 to 2050 assuming that the estimated price is representative of a global real future price. It was assumed that a global market would be formed in the future, and hydrogen price would be based on fuel production costs and supply-demand fundamentals. The period before 2020 hydrogen prices were estimated as LNG prices. The reduction in price out to 2030 reflects a similar process as evident in the LNG market as initial capital investment precedes a gradual reduction in price. The increase in price beyond 2050 reflects increased demand amongst different economic sectors following the more stringent carbon budget evident post 2040.

3.4 Investment parameters

Adoption of technology and operational energy and carbon saving interventions are assessed in GloTraM according to an investment appraisal formula. This formula calculates whether or not the intervention would increase or decrease the profitability of the vessel, according to the total impact on revenue and costs over a prescribed period. Taken into account with this assessment is the cost, to the vessel owner, of any capital needed to finance the investment and the time period over which the profitability is to be considered. The cost of capital varies depending on the firm, how it is financed etc. A discussion of representative values for the fleet can be found in IMO MEPC 61 Inf. 18 and concluded that a value of 10% was appropriate for use in models assessing the economics of energy saving investments for ships. The report did not provide a similar discussion on the investment period. Similarly this varies depending on the firm and will be a function of how the ship is financed, any time-charter periods, owner’s expectation of when the ship might be resold and the associated second hand value, internal imposition of investment hurdles to manage risk etc. A payback value that is commonly in use in equivalent analysis (e.g. LCS) is 3 years. This value will be used as a default value for the purpose of BAU appraisal, but will be treated as a sensitivity parameter in order to assess how robust the results are to the assumption of this value.

3.5 Economic parameters

The economic scenario describes the exogenous data that are used to determine the ship owner’s costs and revenue. Input data for the core costs, the fuel and carbon price per tonne and the time charter equivalent day rate are used as input into the model. These include:

- Time charter rate (tc) - this is a factor that represents the effect of market barriers in setting the time charter prices. A value of 1 is equivalent to there being a perfect market and zero barriers. For now, this is the default and only option.
- Voyage charter rate (vc) - similar to the TC factor this represent barriers in the voyage charter market and has been set at the default and only option
- Market barrier – The extent to which savings are passed on to the ship owner
- Discount rate - the interest rate used to discount future profits
- Investment horizon - the time horizon over which the profitability of an intervention (change in design speed, fuel or adoption of low carbon technology) is assessed

4. SCENARIO DETAILS (BUSINESS AS USUAL)

Following from external factors report, the following assumptions are made. We model three ship types: Dry bulk, containership and oil tankers.

- Regulation scenario
  - EEDI reduction
  - SOx and NOx (global and ECA)
- Fuel and carbon price scenario
  - Fossil fuels (2°C)
- Trade scenario
  - Base year 2010 is taken from NEA where growth rates are applied according to IMO 3rd GHG study (Smith *et* al, 2014)
- Investment parameters
  - Barrier to market

  - Discount rate
  - Return period
- Engine technology options
  - 2-stroke engine
  - 4-stroke engine
  - Diesel electric
  - Internal combustion (LNG)
  - Internal combustion (Methanol)
  - FC (Hydrogen)
  - FC (Methanol)
  - FC (LNG)
- Fuel options
  - HFO
  - MDO
  - LNG
  - Hydrogen
  - Methanol
- Technology options
  - LCS technologies

4.1 Sensitivity analysis

Systematically varying a number of possible permutations leads to the generation of a sensitivity analysis. These analyses include variations to the external factors that influence the evolution of the fleets and the take-up of technology (market penetration). Table 2 outlines these variations. We explore the influence of variables such as bio-fuel availability and investment parameters (e.g. NRP) and start year of a carbon price. In the case of S6, which is sold iteratively, we also consider the percentage of revenue allocated to buying offsets to meet the climate target. For simplicity, one representative size from each ship category is chosen and presented in the results section.

Table 2 – List of sensitivity analysis

Scenario ID	Fuel cost scenario	NRP	Barrier to market	Discount rate	Out-sector offsets	Carbon price	MBM start year	Bio availability
S0	2C	3	0.5	10%	0%	none	-	none
S1	2C	3	0.5	10%	0%	yes	2020	Central
S2	2C	10	0.5	10%	0%	yes	2020	Central
S3	2C	3	0.5	10%	0%	yes	2020	High
S4	2C	3	0.5	10%	0%	yes	2020	Low
S5	2C	3	1.0	10%	0%	yes	2020	Central
S6	2C	3	0.5	10%	20%	yes	2020	Central

Of these sensitivity runs, S0 is representative of the current policy and expected external factors. S1-S6 are variations of S0 where one parameter is altered at a time. The core variations are

1. Bio availability – A lower, upper and mid-range figure of shipping-available bioenergy is used
2. Carbon pricing – An MBM is considered in one of the sensitivity analysis (S6) where a carbon pricing is enforced in 2020. A share of 20% is assumed to be spent in buying out-sector offsets. In S1-5, carbon prices are applied but assumed to be set at a fixed price.
3. Investment parameters (e.g. NRP)

4.2 Bio-fuel availability

Scenarios 1, 3 and 4 are identical apart from the level of shipping bio-fuel availability. In scenario 1 it is assumed that the amount of bio-fuel available for shipping in 2050 is 4EJ as mid-range scenario. It is further assumed that the growth from base year 2010 out to 2050 is linear.

In scenario 3 an upper bound of 11EJ of bio-energy is assumed to be available for shipping. In scenario 4 a lower bound of 1EJ of bio-fuel is assumed to be available for the shipping sector. We test the influence of this parameter on overall emissions, fuel mix and operational efficiency of the ships.

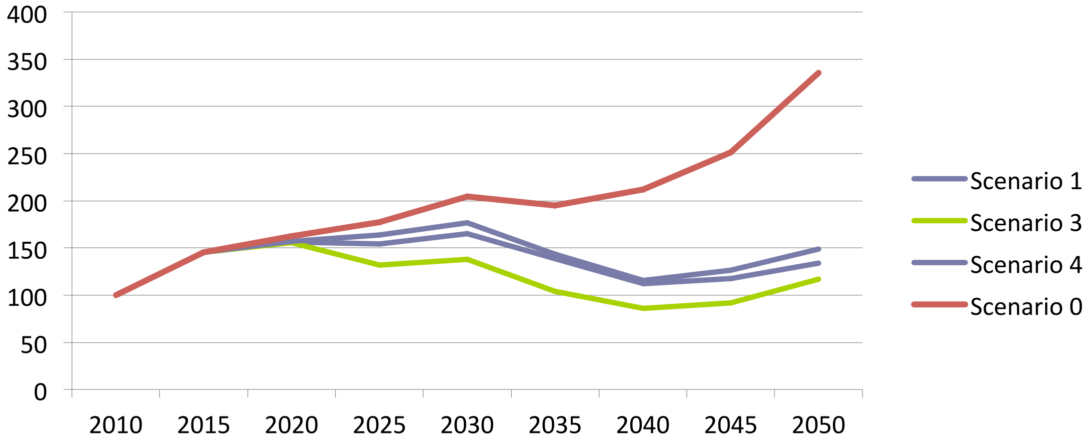

Figure 5 – CO2 emissions BAU compared to scenarios 1, 3 and 4

Figure 5 presents the baseline scenario and the three scenarios where only the availability of biofuels is varied. As expected, higher bio-fuel availability leads to lower level of emissions resulting in Scenario 3 having low emissions compared to the other two scenarios. Therefore biofuel availability is a factor in fuel choice and H2 uptake.

Table 3 – New ship parameters S1 and S3 (Container size 5)

	S1					S3				
	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
P_me	54037	20744	12005	1785	1785	54037	20744	12005	7815	2542
fi_me	HFO	LSHFO	LSHFO	H2	H2	HFO	LSHFO	LSHFO	LSHFO	LNG
V_des	24.9	18.0	15.0	8.0	8.0	24.9	18.0	15.0	13.0	9.0
V_op_load	17.5	17.5	15.2	8.1	8.1	17.5	17.5	15.2	12.6	9.1
V_op_bal	17.5	17.5	15.2	8.1	8.1	17.5	17.5	15.2	12.6	9.1

	S4				
	2010	2020	2030	2040	2050
P_me	54037	20744	12005	1785	1785
fi_me	HFO	LSHFO	LSHFO	H2	H2
V_des	24.9	18.0	15.0	8.0	8.0
V_op_load	17.5	17.5	15.2	8.1	8.1
V_op_bal	17.5	17.5	15.2	8.1	8.1

Table 3 outlines new ship parameters for containership of size 5. Fuel choice is similar in scenarios 1 and 4 (mid-range and low bio-fuel availability). There's no Hydrogen taken up in scenario 3, itself influenced by the availability of biofuel. Figure 6 shows the EEOI trend for three scenarios compared to BAU (scenario 0). The EEOI (in 2050) improves (decreases) by 76%, 67% and 81% in scenarios 1,3, 4 respectively compared to BAU where there is no bio-fuel availability.

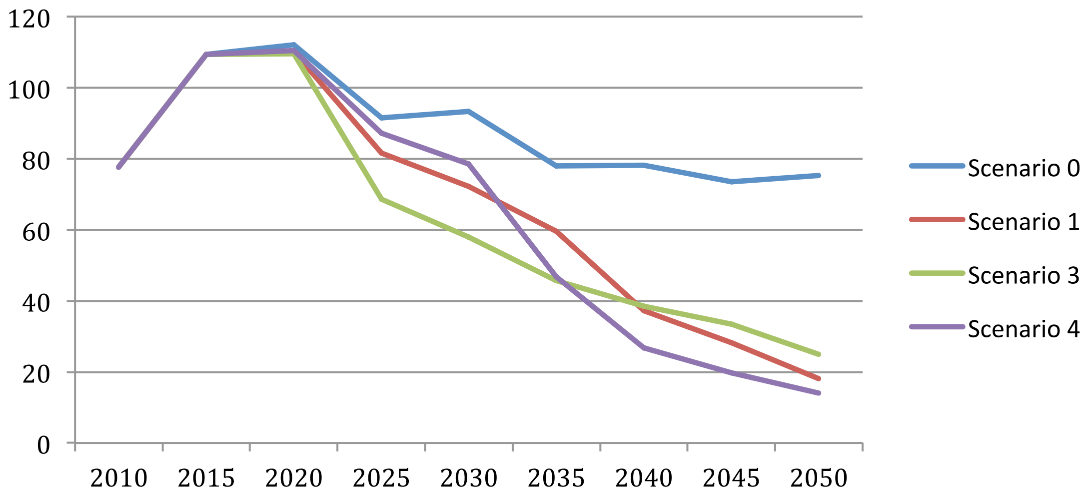

Figure 6 – EEOI trend (containership size 5)

4.3 Carbon pricing

Global carbon price is taken from TIAM-UCL as discussed in external factors section earlier. This is used as input in S1-S5. In scenario 6, a rebate mechanism is enforced and a carbon price is calculated by the model based on Figure 7 below.

The Rebate Mechanism has been included as part of the MBMs and a measure of 40% of revenues from carbon pricing has been specified in this study to compensate for negative costs incurred by developing countries. A further 50% of the funds is allocated for the purchase of emission credits, either within the shipping sector or out-sector. We have assumed the share of out-sector purchase to be 20% in this study.

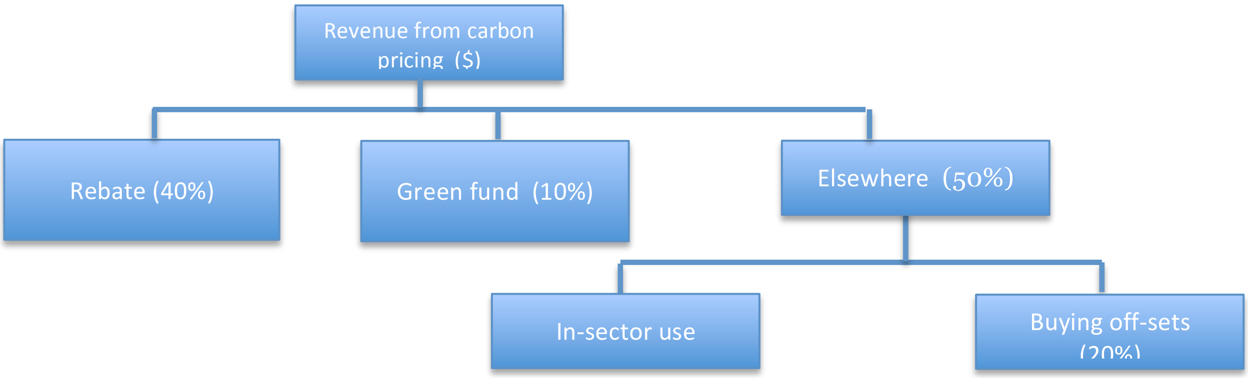

Figure 7 – Revenue allocation within the model

In order to constrain the definition of the regulation scenario, it is proposed to limit consideration of a single scenario – the adoption of a price for carbon emissions from international shipping as it is representative of both the ETS and the Fund. In order to define this scenario, a number of assumptions are required:

- Year of first implementation: 2020 - It is expected that for a carbon price to enter into force, the IMO will need to adopt a new convention. The time-scale required to establish a new convention, design the administrative infrastructure and debate the specification of the MBM will make entry into force sooner than 2020 infeasible. Mounting pressure from IMO members (particularly EU) and other agencies (UNEP) will ensure that implementation does not occur later.

- Revenue generated will be able to be used to purchase offsets from outside the shipping industry up to 20% of the revenue and these will count towards the emissions targets of the shipping industry

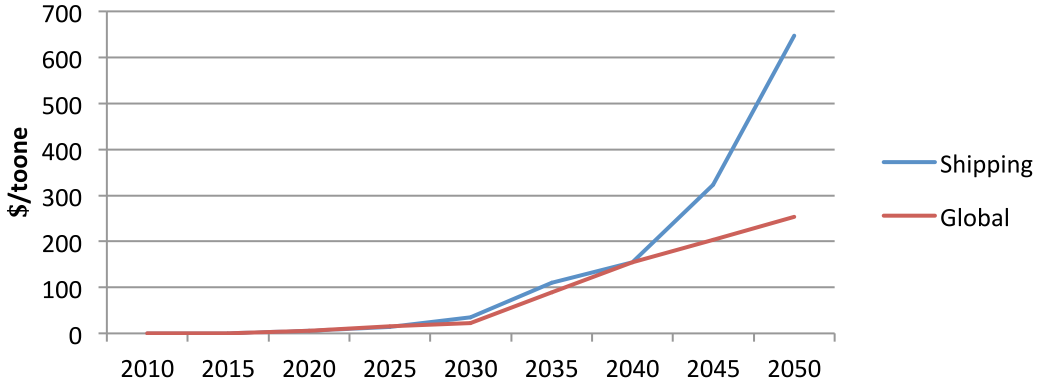

Figure 8 – Shipping carbon price compared to global levels

With the rebate mechanism in place and assuming 20% of revenue is allocated to out-sector purchase, carbon price comes to $646.9/tonne (Figure 8) in 2050.

The issue of fuel costs remains a complex one and will heavily influence the costs associated with sector decarbonisation. As seen in Figure 2 hydrogen reflects the most expensive choice of fuel. However the sensitivity analysis presented here demonstrates that conditions such as bio-fuel availability could render hydrogen uptake economically viable, in order to satisfy a stringent carbon budget.

4.4 Investment parameters

Investment parameters used in the model include the discount rate and investment time-horizon over which a return is expected (NRP). Influence of altering these investment parameters is explored. Table 4 shows the technology take-up in S1 together with number of new ships which would adopt these technologies. Scenario 2 has longer return time (i.e. 10 years). The results imply that increasing the investment time horizon is an effective way to increase the rate of technology take-up and reduce CO2 emissions.

The existence of market barriers can also have an influence on technology take-up. This might prevent any cost savings due to improved efficiency being passed to the owner of ships/assets. Scenario 5 considers total removal of market barriers, i.e. all cost savings are passed back to the ship owner.

Table 4 – Technology take-up (containership)

Technology	2010	2015	2020	2025	2030	2035	2040	2045	2050
Scenario 0									
Autopilot upgrade/adjustment	0	192	787	513	1563	1128	1298	1448	1848
Trim and ballast optimisation	0	544	902	2484	1810	1846	1407	1837	1959
Scenario 1									
Autopilot upgrade/adjustment	0	192	815	1373	1664	2647	2485	2456	2687
Trim and ballast optimisation	0	544	936	1756	2079	1686	2338	1983	2068
Scenario 2									
Autopilot upgrade/adjustment	0	723	1872	3092	3366	429	484	636	716
Trim and ballast	0	757	1872	3092	3649	4456	4286	4429	4765

optimisation									
Vane wheel	0	34	13	24	0	0	0	0	0
Propeller boss cap fin	0	398	303	1021	0	0	0	0	0
Air lubrication (air curtain with PTO)	0	2	104	168	235	0	0	0	0
Scenario 5									
Superstructure streamlining	0	20	83	0	0	0	0	0	0
Vane Wheel	0	22	93	22	21	0	0	0	0
Prop section optimisation	0	0	380	0	0	0	0	0	0
Propeller boss cap fin	0	361	915	0	0	0	0	0	0
Autopilot upgrade/adjustment	0	569	1664	3049	3693	2662	2320	1619	1698
Trim and ballast optimisation	0	700	1664	3049	3693	2143	1853	2326	2710
Air lubrication (air curtain with PTO)	0	22	93	540	627	0	0	0	0

Table 5 – Technology take-up (dry bulk)

Technology	2010	2015	2020	2025	2030	2035	2040	2045	2050
Scenario 0									
Autopilot upgrade/adjustment	0	1131	1336	2941	3287	3543	3915	8731	14257
Trim and ballast optimisation	0	1082	1486	4467	4984	5821	5627	12801	19782
Scenario 1									
Autopilot upgrade/adjustment	0	1131	1429	2985	3603	4316	4581	10105	16162
Trim and ballast optimisation	0	1082	1708	4614	5586	7435	7764	15474	26349
Scenario 2									
Autopilot upgrade/adjustment	0	1137	431	3094	1055	4268	4346	9810	27682
Trim and ballast optimisation	0	1805	2849	6952	9077	10271	10455	22656	37852
Vane wheel	0	0	0	0	0	0	0	2815	4607
Stator fins	0	0	0	0	0	0	0	2815	4607
Air lubrication (air curtain with PTO)	0	0	0	0	0	0	0	0	1113
Scenario 5									
Autopilot upgrade/adjustment	0	1095	2173	4428	5165	1109	4505	9742	4394
Trim and ballast optimisation	0	1741	2547	6611	7773	10968	7205	21738	33325
Air lubrication (air curtain with PTO)	0	0	0	0	0	246	1484	585	0

5. CONCLUSIONS

We have carried out a number of sensitivity analyses to explore the influence of a number of parameters on emissions, fuel choice, technology and operational efficiency. The consequences of all the scenario cases considered on the sector's CO2 emissions, indexed to 2010 emissions, are presented in Figure 9. Whilst the current policy scenario shows CO2 emissions steadily rising over the next 35 years, the application of a carbon price achieves a significant lowering of CO2 emissions relative to the current policy scenario. The sensitivities considering different scenarios for the availability of biofuel and investment parameters create some variability in the emissions pathway, but the cumulative emissions are similar.

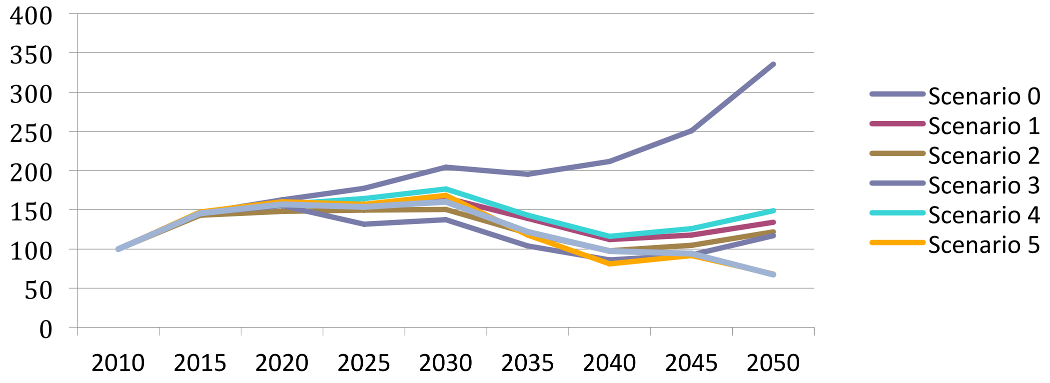

Figure 9 – Aggregate emissions (indexed to 100 in 2010)

We have tested the influence of different levels of bio-fuel availability, carbon pricing and investment parameters. The paper presents an early and hopefully indicative set of results at this stage of the research. Further refinements to the modeling and the input data will be carried out over the next 12 months, and many more scenarios will be considered and explored. Key findings so far are that:

1. With all else being equal, higher biofuel availability (11EJ in 2050) results in lower levels of emissions
2. The high biofuel scenario results in the lowest level of CO2 emissions from 2020-2040 and in this scenario emissions in 2050 are approximately similar to the emissions in 2012.
3. Increasing the investment return period from three years to 10 years results in more technology take-up and this in turn leads to lower overall emissions.
4. Reducing the effect of market barriers by increasing the fuel cost savings pass-through to the owner from 50% to 100%, results in more technology take-up only in the case of containerships. From the perspective of the impact on emissions, this effect is greater than increasing the return period from 3 to 10 years.
5. Implementing a cap and trade system that includes a rebate mechanism can achieve a trajectory of operational CO2 emissions consistent with the 2-degree pathway case. This can be seen by comparing base scenario 0 and scenario 6. Carbon pricing is enforced in 2020.

6. REFERENCES

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