Bridging the shipping gap: 2 degrees pathways and carbon pricing

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Abstract

This study employs the Global Transport Model (GloTraM) to analyse a plausible response from the international shipping industry when having to comply with the drawn 450ppm emission trajectory from UNEP (2011). GloTraM analyses fleet evolution, operational and technological interventions take-up responses in the shipping sector to different fuels prices and costs, regulatory constraints and revenue drivers.

1. Introduction

At the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties 15 in Copenhagen, the international community politically agreed that "deep cuts in global emissions are required according to science, and as documented by the IPCC Fourth Assessment Report with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius, and take action to meet this objective consistent with science and on the basis of equity". To achieve this, all economic sectors should identify appropriate mitigation strategies of greenhouse gas (GHG) emissions in order to meet the target of stabilizing atmospheric GHG concentration levels at 450 parts per million (ppm) by 2050. The motivation behind this study is to further our understanding on what the ambition level expressed during the Copenhagen summit, imply for the international shipping industry.

International shipping is currently estimated to have emitted 870 million tonnes of CO_2 in 2007, no more than about 2.7% of the global total of that year (Buhaug *et al*, 2009). The expected high growth in the demand for international seaborne transport implies that, by 2050, those emissions could grow by a factor of 2 to 3 if no regulations to stern them are enacted[1]. While the International Maritime Organization has already adopted the Energy Efficiency Design Index (EEDI) for ships build from 2013, this measure alone cannot guarantee absolute emission reductions, particularly if demand for international seaborne transport increases as projected

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[1] IMO second GHG study (2009)

globally. On this background, there is a need to adopt further regulation of CO_2 emissions such as a market-based measure (MBM).

The UNEP Bridging the Emission Gap report from 2011 (UNEP 2011) estimated that within a 450ppm trajectory, CO_2 emissions from international shipping should remain constant until 2020 and then reduce at the global average rate of 2.6% per year from 2020-2050, the total the emission budget deemed consistent with a 450ppm trajectory for international shipping is 28.1 $GtCO_2$ in the period 2010-2050.

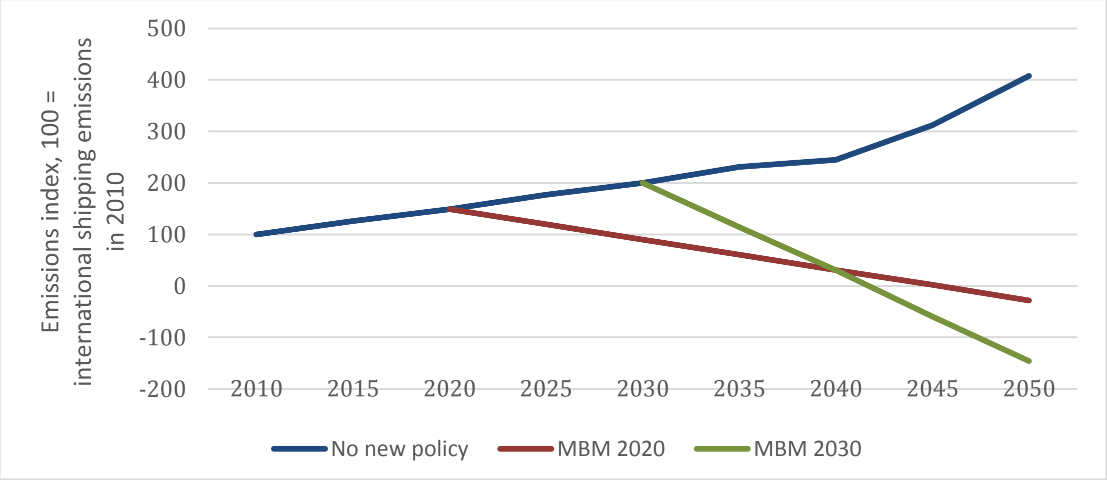

Figure 1.1 – Emission trajectories

It should be noted that the approach used in this study takes no position on the possibility of having different levels of mitigation requirements for different economic sectors in the period 2020-2050. Furthermore, following the IMOs principle of 'no more favourable treatment' (NMFT), this study does not differentiate between flag states responsibility to mitigate emissions.

2. Modeling approach

The objective of this study is to analyse a plausible response from the international shipping industry when having to comply with a global CO_2 emission limit that is deemed consistent with a 450ppm emission trajectory towards 2050. This contrasts many preceding studies which have relied mainly on a bottom-up based approach whereby reduction potential and emission trajectory has been estimated on the basis of the cost-effectiveness of mitigation measures.

This study takes instead a hybrid top-down – bottom-up approach. Based on UNEP (2011), an absolute CO_2 emission budget is provided for international shipping from 2010-2050, which forms the basis for providing fixed annual emission limits through the modelling exercise (i.e. top-down approach). The bottom-up approach implies that we will analyse, using GloTraM, how the industry will comply with the defined emission limits through a profit maximisation framework. GloTraM analyses fleet evolution, operational and technological interventions take-up responses in the shipping sector to different fuel prices and costs, regulatory constraints and revenue drivers. Dedicated scenarios for bunker fuel development; transport demand and non-CO_2 related regulation through the IMO are provided for the techno-economic analysis to provide a contextual framework of drivers that influence the shipping industry.

CO_2 emissions are modelled from the fuel combustion activities at the point of operation through the use of carbon factors based on the carbon content of the fuels following IMO guidelines[2]. Since CO_2 constitutes 99% of the greenhouse gases released during fuel combustion activities (EPA, 2008), we left out other GHG gases. Another simplification we made is to assume that all carbon from fuel is converted into CO_2, which leaves out the estimation of non-GHG related emissions, such as black carbon. Regarding the latter, it should be noted that in the current IMO discussions, only CO_2 emissions are considered to be included in an MBM, while other emissions are considered in other regulatory processes, e.g. emission of black carbon is currently being considered for inclusion in MARPOL Annex VI.

For each year of the reference period 2020-2050, we re-iterate the modelling steps in order to analyse a plausible way in which the shipping sector might comply with the emission limits towards 2050. Figure 2.1 summarizes this methodological approach[3].

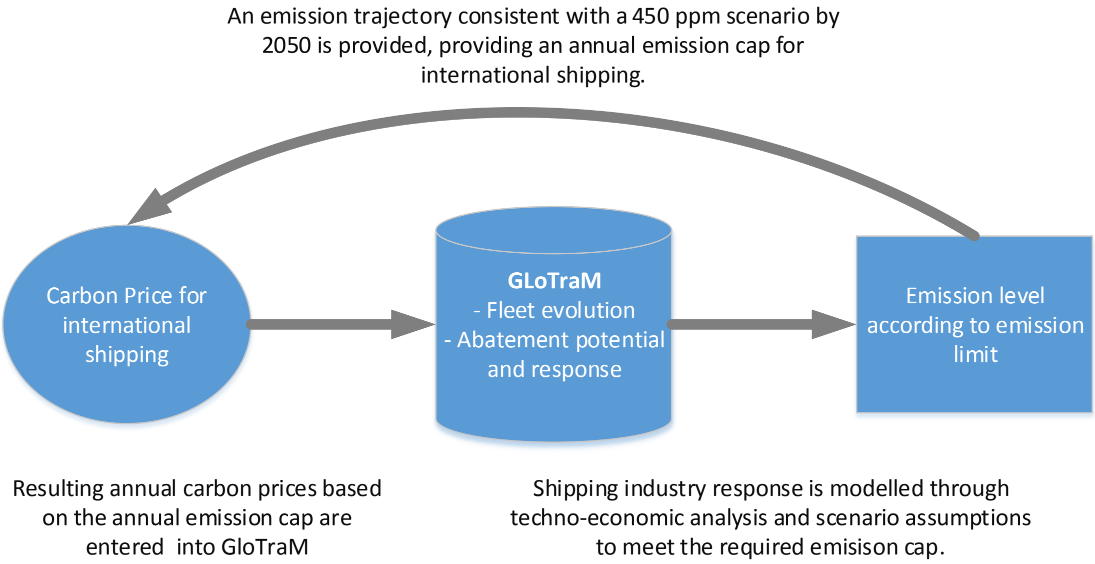

Figure 2.1 – Methodological approach

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[2] The emission factors are provided in IMO MEPC 60/WP. 6 Communication with IPCC on CO_2 conversion factors. For more details see Smith et al, 2013b.

[3] A more detailed elaboration on method and key assumption is provided in Smith et al (2013b)

2.1 Global transport demand scenario

This study follows the IMO Second GHG Report (Buhaug et al, 2009) by adopting a scenario-based approach in forecasting for global seaborne transport demand. There is a number of datasets used in this study to generate such scenarios, as outlined below.

NEA (2009), through the TRANSTOOLS V-2 approach, provides the dataset for global trade distribution used in this study. This database contains sufficiently disaggregated trade flows geographically, at a country level and by commodity[4]. The approach is an agent based financial trade model that captures country-to-country interactions.

The global distribution of trade and trade flows provided by NEA (2009) is coupled with overall projections on future transport demand provided by the Second IMO GHG report (Buhaug et al, 2009). The report uses a globally aggregated value of transport demand (expressed in tonne miles) for the international shipping fleet. These projections are based on the IPCC SRES scenarios regarding demographic and macro-economic development, which is the basis for calculating future seaborne transport demand with particular focus on A1B scenario. This scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. The B suffix indicates that the future energy use is balanced across energy sources (Nakicenovic et al, 2000). It is worth mentioning that the IPCC SRES scenarios assume no climate change mitigation measures. The IMO transport demand scenarios are based on an average of OPRF[5] (2008) and Eyring et al. (2005).

In order to adequately estimate energy use and associated CO_2 emission levels, vessels in the international fleet are allocated to international trade routes. Three commodity trades are considered in this report: wet, dry and containerized goods because these trades represent approximately 70% of the total emissions of the shipping industry Bauhaug et al. (2009) (NST/R 2 level). Disaggregated trade volumes and values between countries are specified in an origin-destination matrix for each commodity using the relative distribution of trade volumes from NEA (2009). In order to ensure that these disaggregated trade volume flows are consistent with the projected global transport demand, the total trade flows are scaled by the IMO Second GHG Report projections on transport demand growth. Following this, the scenario for global seaborne transport demand aligns the NEA scenario with the IMO A1B scenario.

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[4] Commodities are disaggregated to the NSTR level 2 (99 commodity groupings). NST/R is a standard goods classification for transport statistics (http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database)

[5] Ocean Policy Research Foundation

2.2 Future fuel mix and bunker fuel prices

Our final scenario is built on several assumptions on the evolution of the fuel mix in the shipping sector. We consider 12 different options of bunker fuels for shipping. The included conventional fuels are heavy fuel oil (HFO), low sulphur heavy fuel oil (LSHFO) and marine distillate oil and marine gas oil fuel (MDO/MGO). The three alternative fuels included are liquid natural gas (LNG), methanol (M_eOH) and hydrogen (H_2). All these six fuel types have a bioenergy-derived equivalent (Table 1). For instance, straight vegetable oil has been recently found to be fully compatible with current marine engines, being a perfect substitute for conventional HFO and current LSHFO with additional benefit of lowering CO_2 emissions (see Ecofys 2012). MDO/MGO fuels can be blended with 1st generation biodiesel from rapeseed oil and later on substituted wood waste lignocellulose based biodiesel. The bioenergy option for LNG is bio-methane. Mixtures containing 25%-100% in volume can be used without any machinery replacements provided that bio-methane is purified to LNG comparable quality standards. In the case of methanol and hydrogen, their bioenergy-derived counterparts in this study are produced using also residual wood biomass via a gasification production process.

Table 1 – Alterative fuel options

Fuel type	Name	Feedstock
Marine residual fuel oil	HFO	Crude Oil
Low Sulphur residual fuel oil	LSHFO	Crude Oil
Marine distillate oil	MDO/MGO	Crude Oil
Methanol – fossil	MeOH	Natural Gas
Hydrogen – fossil	H2	Natural Gas
Liquid natural gas – fossil	LNG	Natural Gas
Straight vegetable oil	Bio-HFO Bio-LSHFO	Rapeseed Oil
Biodiesel – 1st generation	Bio-MDO	Rapeseed Oil
Biodiesel – 2nd generation	Bio-MDO	Wood waste
Methanol – biomass	Bio-MeOH	Wood waste
Methane – biomass	Bio-LNG	Wood waste
Hydrogen – biomass	Bio-H2	Wood waste

Due to the inclusion of bioenergy as a blend in the conventional and alternatives fuels, it is necessary to derive scenarios that take into account the availability of bioenergy on a global level and specifically the share, which could be available to the international shipping sector. Three different scenarios with a low, medium and high availability of biofuels for the shipping sector have been identified. The International Energy Agency (IEA) (IEA 2011) provides the medium and high availability scenarios, while Anandarajah et al (2012) provides the low availability scenario (Table 1).

Table 2 – Bioenergy scenarios from literature

Units	Shipping biofuel 2050	Total transport biofuel 2050	Total Bioenergy Availability 2050	Scenario name	Source
Energy [EJ]	3.52	32	145	BLUE Map	IEA 2011
Share [%]	2.43%	22.07%	100%		
Energy [EJ]	11.53	105	475	High bioenergy availability	IEA 2011
Share [%]	2.43%	22.07%	100%		
Energy [EJ]	0.92	8	38	Low bioenergy availability	Anandarajah et al, 2012
Share [%]	2.43%	22.07%	100%		

This study has chosen the two extreme scenarios, namely:

- Low bioenergy availability scenario**:** 1 EJ of bioenergy is used in the shipping sector. The energy share of biofuels for the shipping sector is maintained coherent with the share presented in the BLUE Map Scenario (2.42 %) and a lower band of global bioenergy availability estimate of 38 EJ is estimated
- High bioenergy availability scenario**:** 11.5 EJ of bioenergy are used in the shipping sector. In this scenario the share of biofuels for the shipping sector is also maintained coherent with the BLUE Map Scenario, but the global bioenergy availability is estimated using the Low Risk Potential published in IEA, 2011.

Forecasts for the price of bunker fuels from 2010-2050 considered in this study were obtained through different approaches. We have assumed a relationship between the Brent oil price for oil-derived fuels (HFO, LSHFO, MDO, MGO, methanol) and a relationship with the gas price for gas-derived fuels (LNG and hydrogen).

To forecast the future bunker fuel prices we rely on low and central scenarios of oil and gas prices projections developed by the UK Department of Energy and Climate Change (DECC, 2011). A detailed description of the different approaches and assumptions used can be found in Raucci et al, 2013.

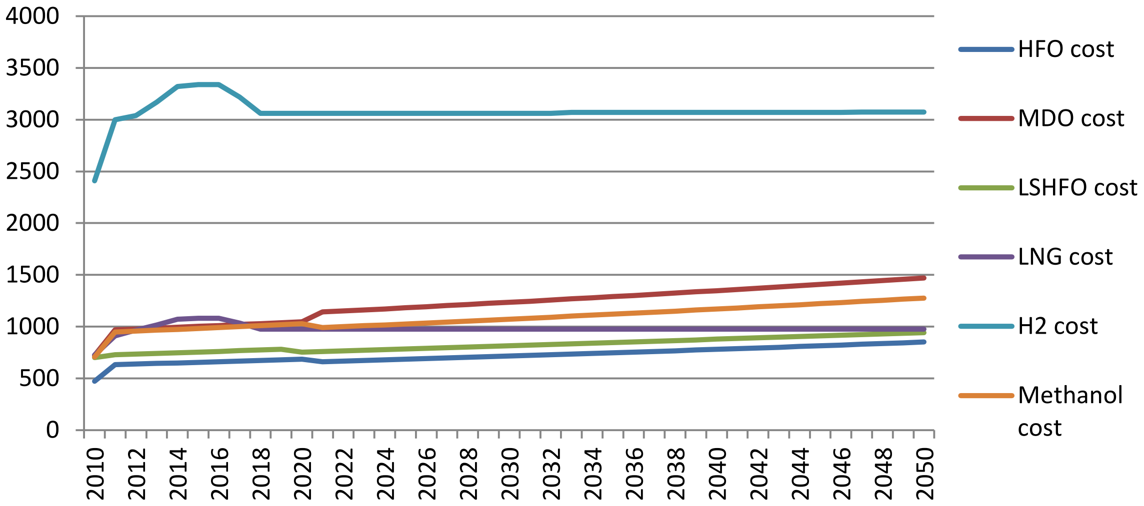

Figure 2.2 – Fuel price scenario

Figure 2.2 shows the development of cost levels for different fuels, based on DECC central scenario. Price forecasts of light fuel oil and heavy fuels oil were estimated based on historical trends and on assumptions on the response of ship operators to the policy drivers. In particular, up to 2020 prices of MGO/MDO, LSHFO and HFO were obtained by multiplying historical ratios between the fuels prices and the Brent price by the oil price forecasts from DECC (2011). After 2020 prices are largely a function of how the market is expected to deliver the emission reductions. We envisaged a hypothesis in which MGO and LSHFO would have a more significant departure from the values we have observed in the past. Forecasts for fossil fuel derived methanol were obtained with a similar approach used for MGO and HFO. A constant relationship between methanol and HFO prices has been assumed.

LNG price forecasts were obtained with a simple model of LNG infrastructure for shipping taken from Smith et al. (2012). This analysis specifies an LNG system, which goes from terminal to terminal; in the importer country, we have the receiving terminal, in the exporter the shipping terminal where LNG is liquefied. In between there is the infrastructure for storing (barges) and transporting the liquefied gas. Given the annual quantity consumed, the investment costs, the cost of gas, the annuity factor and the production level, the annualized cost and the cost per unit is calculated, which in turn gives LNG price levels for the shipping industry.

Hydrogen price forecasts for shipping were estimated using the logic from Smith et al (2012). This provides a techno-economic analysis of a basic hydrogen infrastructure with the following assumptions: hydrogen production at a centralized location from gas through steam methane reforming with CCS technology, transport through a short pipelines (20 km) to the delivery point, liquefaction for offshore and on-board storage. Details of both models and assumptions used can be found in Raucci et al (2013)

3. Future scenarios

In order to estimate carbon prices and responses to emission mitigation requirements in the shipping sector to comply with a 450ppm scenario towards 2050, it is necessary to provide assumption of key macro drivers. This study incorporate scenarios on the design and introduction of an MBM, future fuel mix and associated bunker fuel prices, global transport demand and relevant effects on non-CO_2 related regulation on fuel preferences (and carbon price developments outside the shipping sector[6]). These assumptions are outlined below. For more detail on modelling assumptions please refer to Smith et al (2013b).

Ten MBM proposals have been presented so far at the IMO and, among these, we select and incorporate two alternative MBMs in this study: (1) the emission trading scheme and (2) the fuel levy. Both these MBMs are designed to set an overall emission limit and are capable of introducing carbon pricing. The Rebate Mechanism has been included as part of the MBMs, and, following the views provided by the World Bank and the International Monetary Fund (WB and IMF 2011), a conservative measure of allocating 40% of the revenue from carbon pricing to developing countries in order to compensate them for negative costs incurred from introducing a MBM. Further 50% of the revenue is allocated to the international shipping sector; this revenue could be for (1) internal use within the shipping sector or (2) to purchase emission credits in economic sectors other than the international shipping sector, i.e. emission offsetting out-of-sector. This leaves 10% of the revenues from carbon pricing unallocated. Potentially, such revenues can be devoted to the Green Climate Fund to finance further mitigation activities, climate change adaptation or technology transfer, and/or to other purposes. This study does not take any position on the appropriate use of revenues from carbon pricing, but it provides an example of the implications of some possible ways of distributing the revenue.

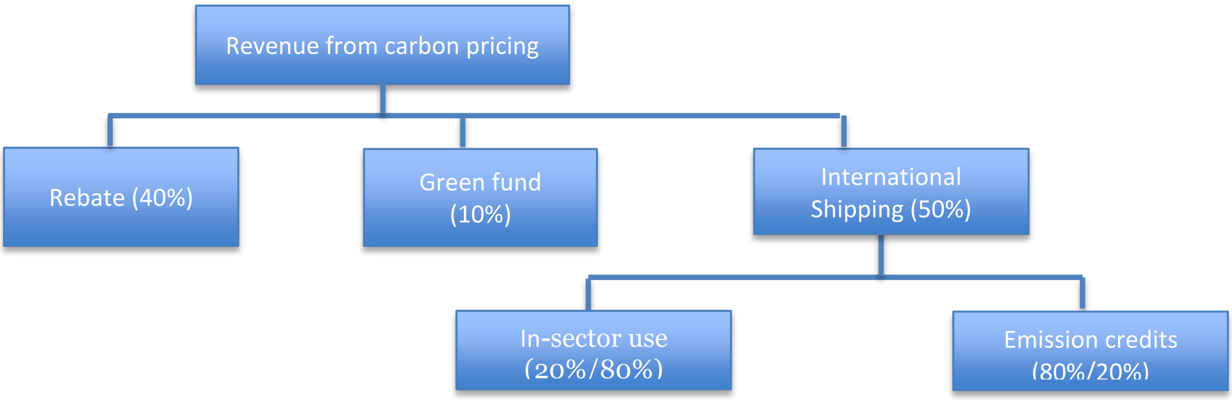

Figure 3.1 – Revenue allocation within the model

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[6] Global carbon prices are taken from DECC central scenario

The 50% of revenues targeted to in-sector use and the purchase of emission credits needs to be allocated in terms of the degree of in-sector use in the shipping sector and the degree of out-of-sector emission credit purchase. The in-sector use may include a sort of internal emission credit system and other purposes with the aim of providing financial incentives to owners and operators to be more energy efficient, switch to cleaner fuels and develop a lower carbon shipping fleet. To a certain degree, measures to reduce CO_2 emission within the fleet can become more expensive than mitigating CO_2 emission in other economic sectors', i.e. it will be economically cheaper for the shipping sector at some point to offset emissions. Because of this, the distribution of revenues from carbon pricing between in-sector use and the purchase of emission credits in and out-of-sector will influence the carbon price level within the shipping sector. In this study, the spectrum of distribution of emission purchase ranges from 20% - 80% degree of out-of-sector emission credits.

The final regulatory assumption is the date in which the MBM will enter into force. This study has modelled 2020 and 2030 as two alternative years for which this may happen. We created 8 scenarios on the basis of the following assumptions (Table 3):

- Date of entry intro force of the MBM, 2020 or 2030.
- Share of the fund allocated to in-sector CO_2 reduction or offset: 20 or 80%.
- Availability of bioenergy in the scenario: low or high.

Table 3 – List of alternative scenarios

MBM start year	2020		2030	
Fuel mix/offset	20%	80%	20%	80%
Low bio availability	Scenario 3	Scenario 1	Scenario 4	Scenario 2
High bio availability	Scenario 5	Scenario 8	Scenario 6	Scenario 7

4. Study results

This section represents the results of the model in three aspects (1) the calculated carbon price and emissions (2) emission mitigation measures and the evolution of fuel mix for the international shipping sector, and (3) the operational carbon factors.

4.1 Carbon price and CO2 emissions

Based on the combined price of reducing emission within the international shipping sector and the purchase of emission credits out-of-sector, carbon prices are calculated for each year in all scenarios. The carbon prices denote the average price for the industry to reduce one ton CO_2 for that given time period.

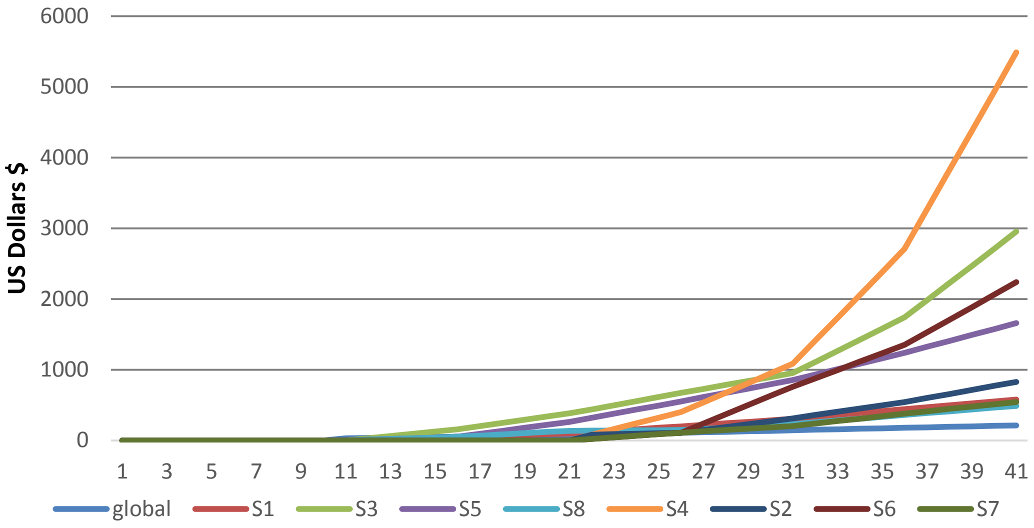

Figure 4.1 – Carbon price evolution corresponding to all scenarios

The modelled profit-maximisation approach to emission mitigation implies that the most economically attractive measures are implemented first. A general observation made in this study is that after a certain point, the increasing emission limits requirements drastically boost the marginal cost of additional emission mitigation. This cost increase is reflected in the carbon price estimates, although in varying degree depending on which scenario assumptions the carbon prices is calculated under (Figure 4.1). Scenario 4 has the highest carbon price because of a late introduction of an MBM and with 20% of revenues being allowed to be offset while scenario 8 provides the lowest carbon price due to high bioenergy availability, early introduction of MBM and the possibility of a high degree of offsetting.

4.2 Evolution of fuel mix and carbon factors

The incorporation of six fuel types with varying degree of available bioenergy blend allows GloTraM to assume future changes in both fuel mix and carbon factors in the international shipping sector. Figure 4.2 – 4.4 show the evolution of fuel mix for three representative scenarios aggregated for all ship types. Due to lack of space, three illustrative fuel mixes were selected amongst all the scenario runs, as presented in Table 3.

In scenarios with high degree of offsetting (scenarios 1, 2, 7 and 8), it can be observed that hydrogen is not introduced as a fuel since in these scenarios, the carbon price is too low to incentive such fuel switch under a profit-seeking logic. It can further be noted that LNG is introduced to a generally high extent in all scenarios. MDO share is maintained through the period.

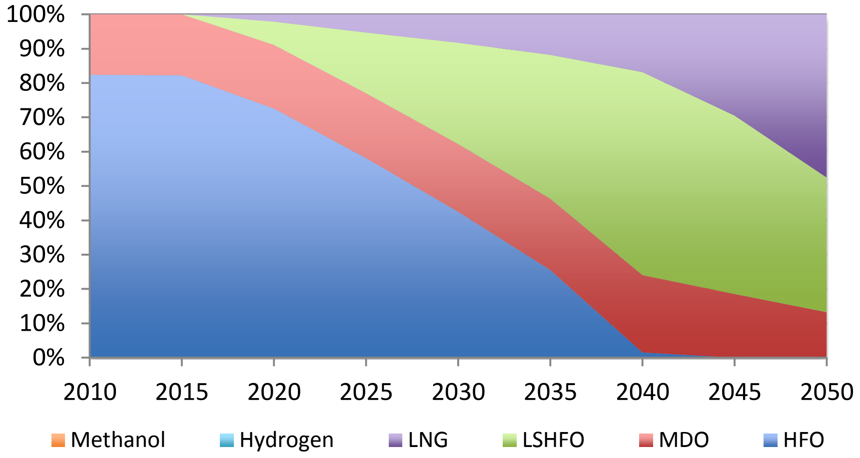

Figure 4.2 – Fuel evolution corresponding to scenario 7

The presence of hydrogen is highest under the most stringent conditions of scenario 4 shown in Figure 4.3 (i.e. low bioenergy availability, low degree of emission offsetting and late introduction of MBM). MDO is gradually replaced by LSHFO and LNG, while hydrogen dominates the shipping fuel mix in 2050.

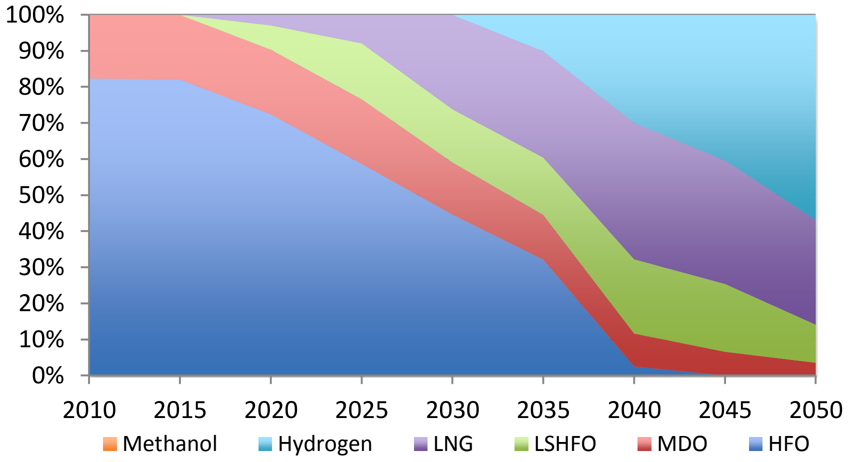

Figure 4.3 – Scenario 4 under stringent conditions

Hydrogen is also being introduced in scenarios with high bioenergy availability and early introduction of MBM, but with high focus on in-sector emission mitigation (scenario 5). Hydrogen becomes an option at a later time (in 2040) compared to scenario 4.

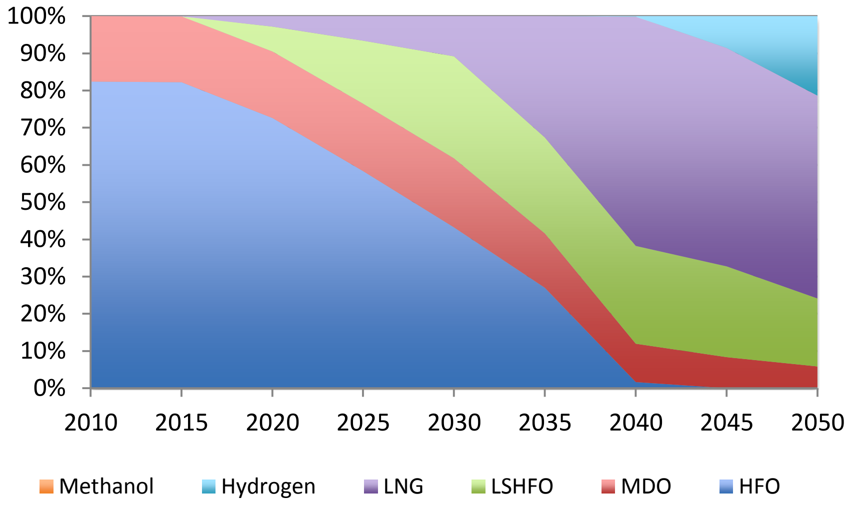

Figure 4.4 – Scenario 5 fuel evolution

While the use of MDO/MGO changes is relatively little, the use of HFO is steadily reduced over the next decades, but is partly replaced by LSHFO, at least as an intermediary solution before being substituted by LNG. Again, here MDO is substituted by LSHFO, but in this case LNG has the highest share in the marine fuel mix.

An important factor determining the CO_2 emissions from the combustion process is the carbon factors (or relative carbon content) of each fuel. The figure illustrates the carbon factor evolution for all ship types considered in this study (the plot uses average value across all ship types). The evolution of carbon factor is the same across four ship types considered since GloTraM iterates until the bioenergy availability is in equilibrium across all ship types.

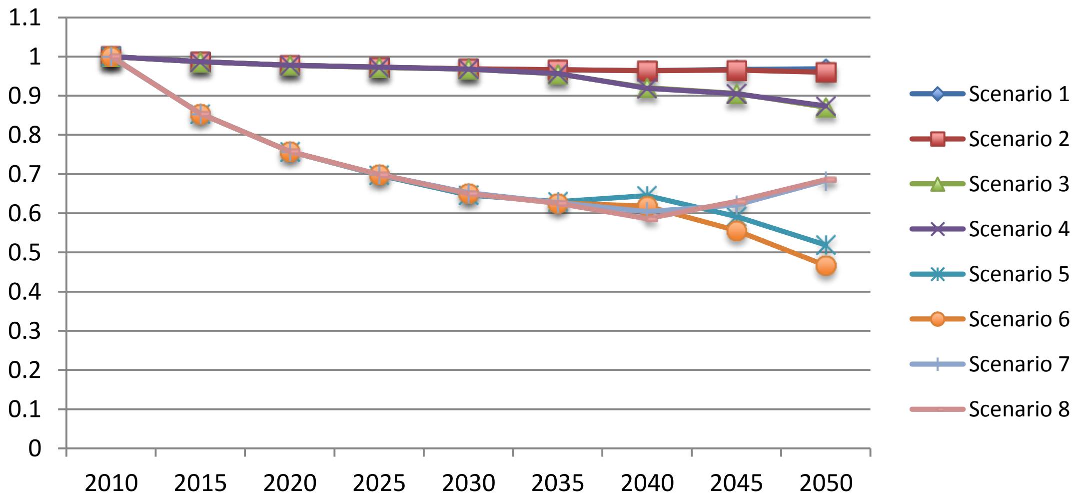

Figure 4.5 – Carbon factors averaged across all ship types

An interesting observation from Figure 4.5 is the fact that from 2040 onwards, the carbon factor goes up for some of the scenarios (e.g. 1, 2, 7 and 8). This is due to that fact that the efficiency that can be gained by all the technology options available reaches a plateau where no further carbon emission reductions can be reached. This is made clear when we look at the rate of bio-energy availability and growth rate of total fuel demand.

Figure 4.6 and Figure 4.7 show the emissions resulting from each of the 8 scenarios of the model. The dotted lines represent the in-sector emissions trajectory and the solid like shows the new emissions (when offset emissions are also included). The lowest in-sector emissions are achieved in scenario 4, which also has the highest carbon price, and the impact of the biofuel availability of scenarios 5-8 is also clearly visible.

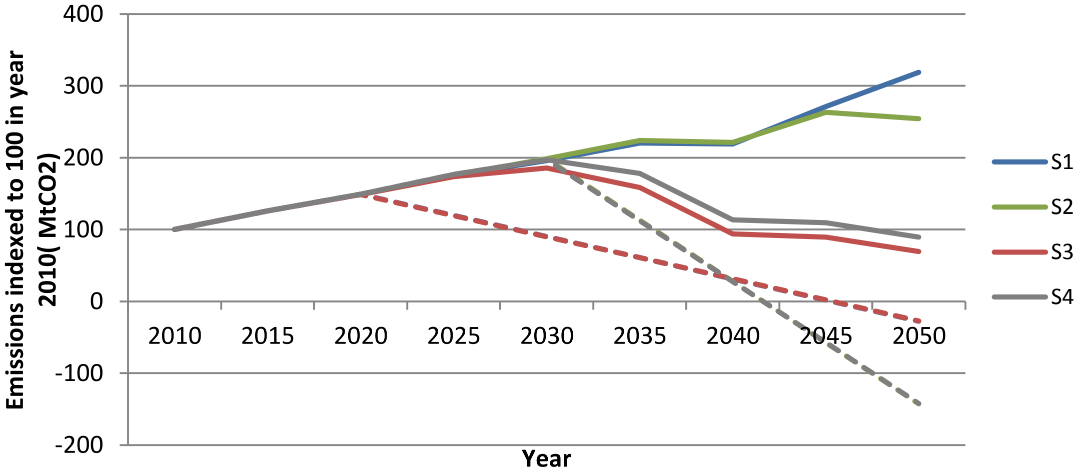

Figure 4.6 – Emissions resulting from carbon pricing for low bio-availability (S1-S4)

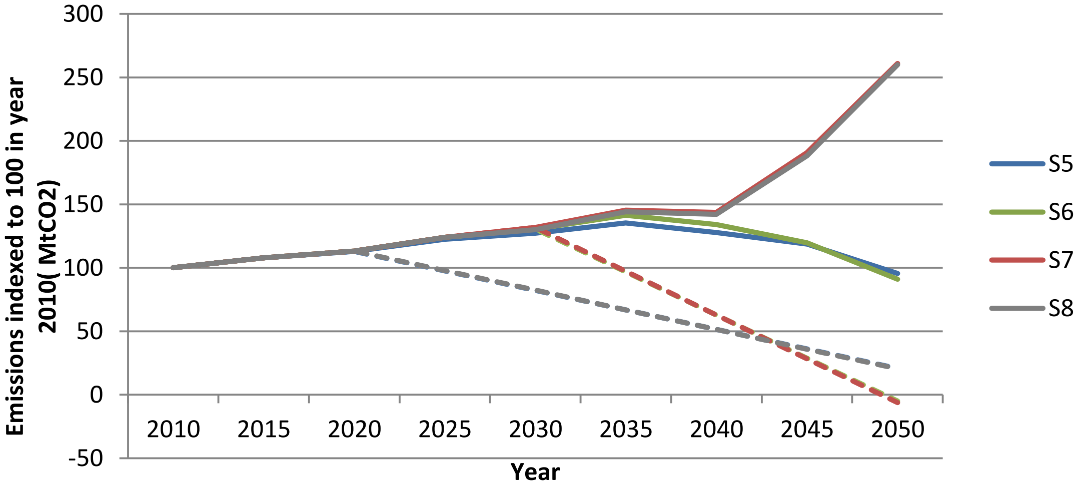

Figure 4.7 – Emission trajectories resulting from carbon pricing for high bio-availability (S5-S8)

5. Key outcomes and future actions

Since the global demand for seaborne transport will likely increase in the future, there are two ways to reduce the carbon intensity of the shipping industry: (a) reduce energy demand, or (b) reduce carbon intensity of the energy source used.

Energy efficiency technology and operational interventions (e.g. slow steaming, trim and ballast optimization) can both contribute to a reduction in energy demand and new fuel types like LNG can lower the carbon intensity and hence provide lower emission for a comparable energy use. The techno-economic logic employed in this modelling approach has however shown that these two, in combination, are not enough in any of the eight scenarios tested if we are to meet the carbon budget defined on the basis of UNEP (2011). This implies that, at some stage, new-build ships must adopt more forward-looking solutions, such as having hydrogen as a fuel. Our modelling implies that the introduction of hydrogen-based ships vary between 2030 and 2050, depending on the scenario assumptions.

If the assumptions for these alternative fuels and machinery stand the test of further scrutiny, novel fuels such as hydrogen would represent a radical departure from the current technology in the existing fleet. Therefore, this outcome demonstrates how steep the challenge is for the shipping sector to meet the ambitions to which the global community has committed. Clearly, having a very short time frame in order to meet those emission reduction objectives, it would be necessary to:

- Scale up the existing lab and demonstrator technology to the unit sizes appropriate for shipping
- Develop class society rules and other regulations for the safe storage and handling
- Develop new infrastructure for the supply of new fuels

All models are imperfect representations of the reality and GloTraM is no exception. Uncertainties exist in the assumptions and inputs used in the model (e.g. trade and fuel price scenarios, projections for changes in ship size over time, technology cost and performance estimates), and in the algorithms that represent the dynamics of the shipping system (e.g. ship-owner’s profit maximisation as applied to model technology take-up and the economics of ship speed).

One uncertainty arises from one of the key assumptions of this model is the inelasticity of transport demand to transport cost. This means that if transport costs rise (e.g. due to additional costs from carbon pricing), they do not feedback into the shipping system by creating lower transport demand. Such feedbacks are complicated to assess because they need to take into account a wide range of transport demand substitution options from local production to alternative sourcing or use of a substitute commodity.

A further complication arises when considering the possibility to shift means of transport from water to rail, road or air, in the case where the cost of sea transport rises disproportionately compared to other transport modalities. This would be highly undesirable considering that shipping is currently, and is expected to be so in the future, the least carbon intensive transport mode.

The existing fleet and its turnover (rate of renewal)

Very low carbon new-built ships (e.g. hydrogen) typically enter the fleet under a carbon price of around $600. However, the carbon prices that are required to hit the 450ppm target by 2050 can reach significantly higher values (Figure 4.1). The explanation for such high values is that at any point in time, there will be a number of existing ships built before the introduction of carbon price or before it reaches a level which stimulates technological changes.

The existing ships only have a limited number of technology and operational interventions that can be used for its de-carbonisation (e.g. retrofit to hydrogen is assumed not possible). Whilst the high carbon price incentivises extensive slow steaming and efficiency technology in the existing fleet, the minimum %MCR (Maximum Continuous Rating) on the fleet’s machinery when combined with the finite bioenergy availability sets a hard limit which means that in any year there is a basic level of emission regardless of carbon price. This basic level of emissions can only be managed through offsetting, and this implies that in those scenarios with tight constraints on the share of the carbon revenue that can be used for offsetting (e.g. in Scenarios 3-6), the carbon price is driven to extreme levels (for example reaching 5,487.64 USD/ton CO_2 in 2050 in Scenario 4).

A key assumption that is also driving high carbon price levels is how the existing fleet responds to increasingly low carbon intensities of the new-build fleet entering the market. The default assumption in GloTraM is that a ship is scrapped only at the end of its 30-year life. In practice, the arrival of new ships with greater energy and economic efficiency may force the existing ships out of the market and into premature scrappage. This would have the effect of increasing the fleet turnover and thus reduce the average age of the fleet in any given scenario. Under rising fuel and carbon prices, new-build ships would have lower carbon intensity than the ships they replace. This means that the average carbon intensity (new and existing fleet) will be lower if the turnover rate is higher. The final consequence of this is that this would reduce the upward pressure on carbon price to extreme levels as those observed in the model which operates with a lower turnover rate (everything else being equal).

The role of emission offsetting

Results from our study shows that, given that emission reduction from existing ships is bound to certain thresholds, emission offsetting appears as a necessary mechanism to ensure an economically viable pathway to achieve the 450ppm target by 2050. This raises important questions around the way a shipping carbon market is interconnected to other carbon markets and the likely price of offsetting emissions. Should the offset prices prove higher than assumed in these scenarios, this would lead to significant pressure to increase carbon prices in the shipping industry.

The issue could also raise a dichotomy between two alternatives/choices: On the one hand, it might be preferable if regulation focuses on de-carbonisation in-sector, and the shipping industry does not become a “cash cow” for the de-carbonisation of other sectors of the economy that are cheaper to decarbonise. This would make only a limited amount of revenue available for emission offsetting (e.g. Scenarios 3-6, which allocates only 20% to emission offsetting). However, the consequence of such a policy is a significantly higher carbon price within the shipping sector (see carbon prices in scenarios 3-6 relative to the other four scenarios), but with the benefit of a radical and early shift to new technologies (hydrogen-powered shipping from 2030 in Scenarios 3-6).

Assumptions around MBMs and rebate

With little existing literature and conclusions on the design and definition of either a rebate mechanism or what should be shipping’s contribution to the Green Climate Fund, only approximations can be used. The total share of revenue raised that is diverted to both of these areas in all scenarios is assumed to be 50%. Given the magnitude of the carbon prices that result from this constraint, this raises the question whether it is appropriate that the deployment of revenues should be defined as a percentage share or set at a fixed amount (or a trajectory of an amount over time). This in turn raises the question on whether the impact on developing country economies from carbon price is linear (e.g. does a doubling of carbon price result in double the economic impact and therefore double the rebate required)?

Reducing the share of revenue diverted to these directions, in any given scenario, would increase the revenue available for offsetting and in turn reduce the carbon price required to achieve the specified target. In order to identify an optimal balance between the application of the CBDR principle and the carbon price impact on the shipping sector, there is clearly a need to further our understanding of the economic impacts on none-annex 1 countries from the introduction of a MBM.

Table 4 – Revenue allocation for selected scenarios

Scenario 1	2010	2015	2020	2025	2030	2035	2040	2045	2050
CO2 rev/year	0	0	0	3.3E+10	7.2E+10	1.6E+11	2.5E+11	4.5E+11	6.8E+11
Green Fund	0	0	0	1.3E+10	2.9E+10	6.5E+10	1.0E+11	1.8E+11	2.7E+11
Rebate	0	0	0	3.3E+09	7.2E+09	1.6E+10	2.5E+10	4.5E+10	6.8E+10

Scenario 4	2010	2015	2020	2025	2030	2035	2040	2045	2050
CO2 rev/year	0	0	0	0	0	3.4E+11	4.9E+11	1.0E+12	1.5E+12
Green Fund	0	0	0	0	0	1.4E+11	2.0E+11	4.0E+11	5.9E+11
Rebate	0	0	0	0	0	3.4E+10	4.9E+10	1.0E+11	1.5E+11

Scenario 6	2010	2015	2020	2025	2030	2035	2040	2045	2050
CO2 rev/year	0	0	0	0	0	1.8E+11	2.9E+11	5.4E+11	7.8E+11
Green Fund	0	0	0	0	0	7.2E+10	1.2E+11	2.2E+11	3.1E+11
Rebate	0	0	0	0	0	1.8E+10	2.9E+10	5.4E+10	7.8E+10

Scenario 8	2010	2015	2020	2025	2030	2035	2040	2045	2050
CO2 rev/year	0	0	0	2.3E+10	3.2E+10	7.8E+10	1.2E+11	2.5E+11	4.7E+11
Green Fund	0	0	0	9.4E+09	1.3E+10	3.1E+10	4.8E+10	1.0E+11	1.9E+11
Rebate	0	0	0	2.3E+09	3.2E+09	7.8E+09	1.2E+10	2.5E+10	4.7E+10

The highest level of revenue is generated in scenario 4 (low bio availability, late start to carbon pricing and low share of out-sector allowance). On the other hand, scenario 8 is associated with the lowest revenue generated.

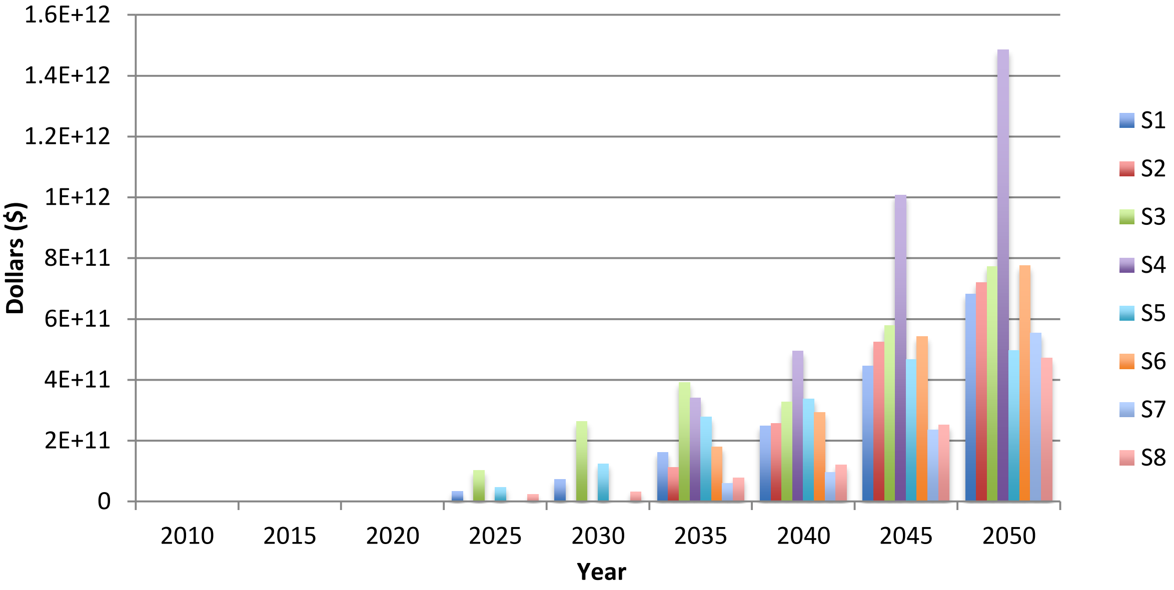

Figure 5.1 – Revenue generated through off-setting emissions

LNG as a possible short-term solution

In this study, we observe that LNG has a significant role to play in all the 8 scenarios considered. However, since hydrogen seems to replace LNG in some scenarios, it is necessary to consider if this is a short-term solution to the shipping industry, and consequently to what degree it is reasonable to invest billions of dollars in LNG-related infrastructure with the possible risks of leaving the industry with stranded assets and unnecessary cost impact?

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7. Appendix

		2020 start				2030 start			
	Global	S1	S3	S5	S8	S4	S2	S6	S7
2010	0	0.00	0.00	0.00	0	0.00	0.00	0	0
2011	0	0.00	0.00	0.00	0	0.00	0.00	0	0
2012	0	0.00	0.00	0.00	0	0.00	0.00	0	0
2013	0	0.00	0.00	0.00	0	0.00	0.00	0	0
2014	0	0.00	0.00	0.00	0	0.00	0.00	0	0
2015	0	0.00	0.00	0.00	0	0.00	0.00	0	0
2016	0	0.00	0.00	0.00	0	0.00	0.00	0	0
2017	0	0.00	0.00	0.00	0	0.00	0.00	0	0
2018	0	0.00	0.00	0.00	0	0.00	0.00	0	0
2019	0	0.00	0.00	0.00	0	0.00	0.00	0	0
2020	29	0.00	0.00	0.00	0	0.00	0.00	0	0
2021	33	10.20	31.74	10.20	10.2	0.00	0.00	0	0
2022	38	20.40	63.47	20.40	20.4	0.00	0.00	0	0
2023	42	30.60	95.21	30.60	30.6	0.00	0.00	0	0
2024	47	40.80	126.95	40.80	40.8	0.00	0.00	0	0
2025	51	51.00	158.68	51.00	51	0.00	0.00	0	0
2026	56	60.78	203.19	93.15	67.79	0.00	0.00	0	0
2027	61	70.55	247.71	135.30	84.58	0.00	0.00	0	0
2028	65	80.33	292.22	177.45	101.37	0.00	0.00	0	0
2029	70	90.11	336.73	219.60	118.17	0.00	0.00	0	0
2030	74	99.89	381.25	261.75	134.96	0.00	0.00	0	0
2031	81	119.40	439.34	319.69	137.20	80.28	80.44	21.8	21.8
2032	88	138.91	497.43	377.63	139.45	160.56	86.79	43.6	43.6
2033	95	158.42	555.52	435.57	141.69	240.84	93.64	65.4	65.4
2034	102	177.94	613.62	493.51	143.94	321.12	101.03	87.2	87.2
2035	109	197.45	671.71	551.44	146.18	401.40	109.00	109	109
2036	116	219.22	727.77	611.89	162.62	537.79	149.72	239.17	127.51
2037	122	241.00	783.83	672.33	179.06	674.17	190.45	369.35	146.02
2038	129	262.77	839.89	732.77	195.50	810.56	231.17	499.52	164.53
2039	136	284.54	895.95	793.21	211.94	946.94	271.90	629.70	183.04
2040	143	306.32	952.01	853.66	228.38	1083.33	312.62	759.87	201.56
2041	150	333.42	1109.35	930.70	254.73	1408.56	358.53	877.97	237.11
2042	157	360.52	1266.69	1007.74	281.09	1733.80	404.44	996.06	272.66
2043	164	387.62	1424.03	1084.78	307.44	2059.03	450.36	1114.16	308.21
2044	171	414.73	1581.37	1161.82	333.80	2384.26	496.27	1232.25	343.76
2045	178	441.83	1738.71	1238.86	360.15	2709.50	542.18	1350.35	379.31
2046	184	468.60	1981.36	1322.94	385.80	3265.13	599.27	1527.83	412.03
2047	191	495.36	2224.01	1407.02	411.44	3820.76	656.36	1705.30	444.75
2048	198	522.13	2466.66	1491.09	437.08	4376.39	713.46	1882.78	477.47
2049	205	548.89	2709.30	1575.17	462.73	4932.02	770.55	2060.26	510.19
2050	212.00	575.66	2951.95	1659.25	488.37	5487.64	827.64	2237.74	542.91