Navigating Decarbonisation

An approach to evaluate shipping's risks and opportunities associated with climate change mitigation policy

Publication data

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Bibliographical details:

Raucci, C, Prakash, V, Rojon, I, Smith, T, Rehmatulla, N & Mitchell, J 2017, 'Navigating Decarbonisation: An approach to evaluate shipping's risks and opportunities associated with climate change mitigation policy', UMAS, London

Publication date:

20.02.17

Commissioned by:

Carbon War Room

Preface

This report has been written by a team of experts from UMAS for the Carbon War Room. The report outlines a possible approach to evaluating risks related to climate change mitigation policy in the shipping industry through an illustrative case study of investments in newbuild drybulk vessels in the size range of 60,000-99,999 dwt. The views expressed are those of the authors, not necessarily of the client.

Acknowledgements

This research was funded by the Carbon War Room and their stranded assets in shipping research program. The authors would also like to thank Katharine Palmer of Lloyd's Register and Thomas Bracewell of Hartland Shipping for their on-going involvement in helping us understand stranded shipping assets in a broader industry context and for reviewing this work. Whilst not a component of this project, the study builds on experience and knowledge gained during the Research Councils United Kingdom (RCUK) Energy programme and industry-funded Shipping in Changing Climates (SCC) project. The authors would like to thank MSI for co-funding the SCC project and the PhD studentship that has enabled some of this research.

About UMAS

UMAS is a sector focused commercial advisory service that draws upon the world leading shipping expertise of the UCL Energy Institute, combined with the advisory and management system expertise of MATRANS. In combination, UCLC, UCL Energy Institute and MATRANS operate under the branding of the entity UMAS. For more details visit www.u-mas.co.uk

UMAS undertakes research using models of the shipping system, shipping big data (including satellite Automatic Identification System data) and qualitative and social science analysis of the policy and commercial structure of the shipping system. Research and consultancy is centred on understanding patterns of energy demand in shipping and how this knowledge can be applied to help shipping transition to a low carbon future. UMAS is world leading on two key areas; using big data to understand trends and drivers of shipping energy demand or emissions and using models to explore what-ifs for future markets and policies.

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Contents

List of figures:

List of tables:

Foreword

James Mitchell, Carbon War Room

With global implementation of the Paris Agreement underway and climate policies at the doorstep of the international shipping industry, there is a need to ensure that financing and investment decisions made today account for and manage climate transition risks. We don't have much evidence this is the case today, but, by acting now, there are opportunities for long-term value creation and supporting the profitable decarbonisation of the international shipping industry.

The urgency of making such considerations should not be understated. A newbuild financing decision made today could result in a vessel delivered in 2020, and, based on the current state of political discussions, that vessel will very probably have to compete under either new IMO or new EU policy actions before its first drydock.

Navigating Decarbonisation is part three of our work on climate risk and stranded assets in shipping. It has been undertaken after part two of this work, *Revealed Preferences*, which showed that markets fail to reward owners of efficient vessels because fuel savings are not shared effectively through time charter day rates and efficient vessels don't do more work than their less efficient peers. Part one of this work, *Dead in the Water*, identified general awareness amongst most financiers of climate-related stranded asset risks but found few with plans to manage risks proactively. Altogether, the findings of these three reports suggest that climate transition risk is not well understood, and that actions need to be taken to both understand and manage these risks.

This report takes the first step by laying the groundwork for asset-level assessment of climate transition risk. In doing so, findings suggest that the financial implications of policies designed to mitigate international shipping's GHG emissions could be material and should thus be understood and managed. *Navigating Decarbonisation* also suggests that because of the nature of shipping markets and the ability of owners to modify vessels to keep them competitive in carbon-constrained markets, catastrophic asset stranding of entire fleets will probably not occur solely due to climate policies.

Instead, we should expect GHG mitigation policies to accelerate the differentiation between companies that are innovative, well-managed, and well-capitalised and those companies that are not. Furthermore, we should expect to see a similar differentiation between vessels. Vessels must be designed for flexibility and ease of modification so they can deliver acceptable cash flow, maintain value, and maintain liquidity both before and after the implementation of GHG policies.

At the Carbon War Room, a market-minded and business-focused non-profit organisation, we recognise the challenges faced today. Many markets are weak, capital requirements are increasing, and compliance with upcoming regulations will require significant capital investment. To be abundantly clear, we are not necessarily advocating the immediate increase of CAPEX on more highly-specified newbuilds and retrofits of existing ships. These decisions need to be made on a company and asset-specific basis.

We are advocating for enhancing due diligence to ensure that decarbonisation is both successful and profitable. This report identifies the first steps that can be taken by financiers, shipowners, and shareholders to help ensure investments deliver long-term value and contribute to successful decarbonisation. We look forward to working with leaders across each of these groups to better identify and manage shipping's climate risk. Please feel free to reach out to us about this work or to become involved.

Executive summary

In the face of impending climate change mitigation regulations both inside and outside of the shipping industry, there is a need to better understand which assets will remain competitive, which will not, and what this will mean for the owners and financiers of billions worth of assets.

This report outlines a possible approach to evaluating shipping's risks associated with climate change mitigation policy through an illustrative case study of investments in the newbuild drybulk fleet in the size range 60,000-99,999 dwt.

This approach forecasts the evolution of the global fleet using techno-economic modelling and estimates the ability of an individual vessel to remain competitive in multiple possible futures, which include evolving fleet energy efficiency, regulatory requirements, and macro-economic factors.

Two investment perspectives (short-term and long-term) are taken in a number of scenarios to anticipate how vessels will compete in a range of potential futures. This enables us to incorporate uncertainty into decision-making. Variables defining the scenarios include build year, carbon price, freight rate growth, and market barriers. In the short-term perspective scenario, the shipowner or investor evaluates the investment within a short time horizon. Market barriers to the adoption of energy efficiency technologies in this scenario are high. In the long-term perspective scenario, the shipowner or investor evaluates the investment within a long time horizon and market barriers are low.

Key findings

This report's key findings can be encapsulated as answers to five key research questions.

1. *How might the fuel, machinery, and energy efficiency technology used by ships within the specified fleet change over time, both for newbuilds and existing ships?*

This study finds that, for both types of investment perspective considered, an incremental deployment of energy efficiency technology was a likely response to the onset of climate change mitigation policy. For the size range of bulk carrier considered as the case study, this included the introduction at certain points in the future of hull and propulsion improvements, machinery efficiency improvements and energy recovery devices, and renewable propulsion (Flettner rotors).

Fuel and machinery choices remained relatively conventional (fuel oil and 2-stroke), with a scrubber or a 0.5% compliant fuel being selected as a response to the 2020 fuel sulphur limit, depending on the investment perspective and scenario considered.

Whilst low carbon fuels (bio or synthetic fuels such as hydrogen or ammonia) may be necessary in the timescales modelled in this report to enable international shipping's low carbon transition, under current technology costs these were not economically viable under the carbon price scenarios considered.

It is worth noting that the short-term perspective scenarios typically produce ships with lower technical specifications that operate at a relatively constant speed over time (from 9 to 11 knots), whereas the long-term perspective scenarios result in ships with higher technical specifications that operate at a higher speed that increases over time (from 10 to 14 knots). Both perspectives lead to an improvement of operational fuel oil consumption rates (SFC) of about 7 to 8% in 2050 compared to 2020, however the gap between SFCs is significant between 2025 and 2040.

These differences observed for the technical specifications can be associated with the fact that there are differences in the time periods over which investments in energy efficiency technology improvements must be recouped. The time horizon used to recoup energy efficiency technology investment is 7 years in the long-term perspective, but only 3 years in the short-term perspective. Hence, for a ship specified in 2020, the shipowner has a longer view of how the market would evolve and factors in the introduction of a carbon price in 2025. This is not the case in the short-term perspective scenarios, where the time horizon for recouping energy efficiency investments is 3 years.

2. *What does this evolving landscape mean for ships built at different points in time? For example, how might a 2020-built vessel operate and compete with more modern ships entering the fleet in 2030?*

This report assumes that further regulation on CO_2 emissions will occur at some point between 2020 and 2030. The results show that a ship built in 2020 that does not anticipate to operate under carbon pricing will either need to be operated at lower speed (and therefore lower revenue), or undertake retrofitting to be competitive. Hence, when adding the operational performance to the comparison, an even greater divergence in productivity and earnings can be observed between ships specified in different years and under different investment perspectives. For example, a ship built in 2030 under a long-term perspective is generally able to operate at consistently higher speeds and at lower operational SFC rates than a ship built in 2020 (or even 2030) under the short-term perspective. If such ships were competing against each other, the less-efficient ship may become illiquid and its value may depreciate at a rate faster than anticipated.

3. *How might different investment horizons influence the composition of the fleet and its ability to manage a low carbon transition?*

In general, the short-term perspective scenario leads to a ship with a lower technology specification operating at a relatively constant speed over time, whereas the long-term perspective scenario leads to a ship with higher technical specification operating at a higher speed that increases over time.

The total costs of operating the ship are lower in the long-term perspective scenario than in the short-term perspective scenario. This can be explained by the lower voyage costs incurred by the ship in the long-term perspective scenario due to the better technical and operational specifications compared to the ship in the short-term perspective scenario.

The charterer revenues for the ship in the long-term perspective scenarios are generally higher than in the short-term perspective scenarios, because the ship with higher technical and operational specifications can increase its speed and therefore its productivity or transport work.

Ships built in 2030 generally match or exceed the Internal Rate of Return (IRR) performance of the 2020 built ships under both investment horizons and appear to be a marginally more resilient investment. However, the IRR difference is narrower between 2020 and 2030 built ships in short-term scenarios than in the long-term scenarios, suggesting that lower market barriers in the long-term scenarios exacerbates the disadvantage of having an older (potentially less competitive) vessel.

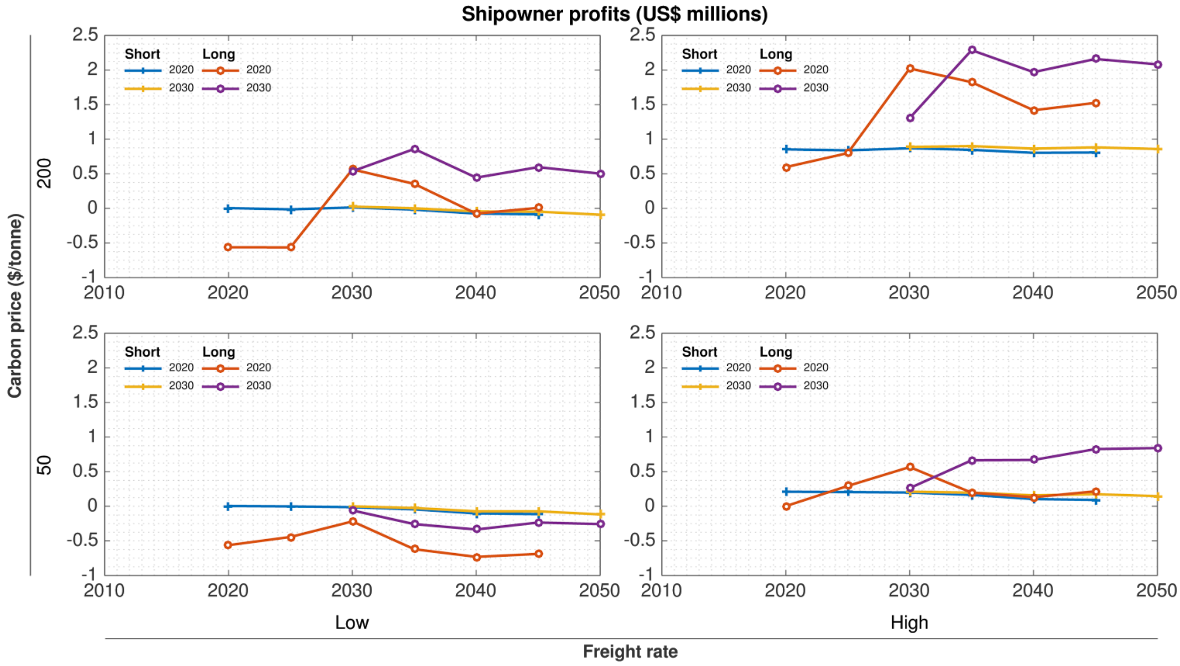
4. *How might known market barriers and failures in the shipping industry (particularly between the owner and the charterer) influence the above outcomes?*

We simulate the extent of market barriers to investment in energy efficiency technologies by altering the share of the fuel cost savings that charterers feed back to shipowners (e.g. through higher time charter rates). Thus, long-term scenarios with lower barriers imply a greater amount of fuel cost savings passed through to shipowners, whilst short-term scenarios with high barriers imply lower cost savings passed through to shipowners.

Long-term investments with low market barriers generate marginally better IRRs than short-term investments with high market barriers. This rewarding of a long-term perspective with high IRR becomes more pronounced as the carbon price increases. Today's shipping markets are estimated to have generally high market barriers, which therefore suggests that shipping markets are structurally inhibited from taking the investment decisions that may help them to navigate shipping's decarbonisation. However, in the event of application of carbon pricing to the shipping industry, the clarity of price signal feedback from the charterer to the shipowner is unknown and should be viewed as a source of uncertainty in decision-making.

5. What do these factors in combination mean for the resilience of assets to risks induced by climate change mitigation regulations and ultimately their profitability as well as the volatility of returns?

The figure below shows shipowner profits in the short-term and long-term perspective scenarios for different levels of risk related to climate change mitigation policy (carbon price) and freight rate growth out to 2050. Long-term scenarios typically generate higher profits for the shipowner over the ship's lifetime, except in the case where low freight rates coincide with a low carbon price. These ships generally have higher IRRs and may therefore be considered more resilient to climate change-related risks.



The shipowner profits in the short-term perspective scenarios are more stable and fluctuate less than in the long-term perspective scenarios, but they are also generally lower than in the long-term perspective scenarios, with the exception of the scenario with low freight rates and low carbon prices, where profits in the long-term perspective are lower and in fact negative compared to those in the short-term perspective. The improved profit performance of ships built under long-term scenarios is a result of a variety of effects, but the driving factor is generally the operational cost advantages that those ships either possess at build or gain over time through retrofits. Indeed, cost advantages, measured in this study as cost per thousand tonne kilometres, typically translate to better IRRs and offer a buffer to future cost shocks or improved competition. If, for example, vessels built with short-term horizons and high market barriers were competing with vessels built with long-term horizons and low market barriers, the difference in operating costs would render the cost-inefficient vessels susceptible to asset devaluation—or even illiquidity—relative to their more efficient peers. Energy efficiency improvements may thus be central to precluding rapid asset devaluation.

It is, however, necessary to evaluate these statements within the context of the conditions placed across our scenario space and the limitations of our modelling methodology. Other measures in conjunction with the IRR and operating cost differences may be used for this purpose and can assist in the assessment of the value or relative resilience of a ship in a more holistic way, e.g. cumulative profits over the ship's lifetime, its average profit per year, the profit volatility (through standard deviation), the ratio of volatility to the average annual profit (the coefficient of variation), and the rate of return on investing in energy efficiency technology. In particular, certain market conditions—low market barriers, high freight rates, and high carbon prices—facilitate or even encourage rapid technology uptake, and it is those conditions that need to be fostered to ensure a smooth transition towards shipping's decarbonisation whilst minimising risk to shipping assets.

Implications

The implications of our results can be separated into those attributable as the key agents or stakeholders in the investment in shipping markets: shipowners and financiers.

Shipowners

While this report only considers a limited set of scenarios for one ship type and size range, it demonstrates that different approaches to anticipating and evaluating risks related to climate change mitigation policy can have very different and important implications on a shipowner's ability to remain profitable and competitive in changing and uncertain market conditions. However, it also shows that there is no one-size-fits-all approach, but rather that different market conditions require different approaches and responses. In particular where market conditions are unpredictable and policy measures uncertain, it is key to plan in flexibility from the onset and consider how to deal with various future scenarios. This includes considering questions such as the following:

1. What would be the most profitable way to modify a ship in the future to lower operational carbon emissions (e.g. as a response to carbon pricing) per t.nm by 20, 40, 60 or even 80%?
2. What could be done to a ship now to enable it to accept these future modifications at minimal additional cost and is there a way to justify these modifications sooner?
3. How would any future retrofitting be financed?

This report demonstrates that scenario analysis that combines an integrated techno-economic assessment with a number of foreseeable policy scenarios can help navigate future uncertainties. To our knowledge, such analysis is not standard practice in the shipping industry's financial decision-making process, despite the scale of shipping's asset values and risks to those values from climate change mitigation policy and despite the fact that tools to investigate competitiveness, risks and resilience of different ship designs and specifications are increasingly available and rigorous. In light of the mounting pressure on industries, shipping included, to decarbonise, now would be a good time to re-think such practices. Practical first steps would be for shipowners to enrich existing impairment and sensitivity analyses with carbon stress tests on the assets and markets where their exposure is highest, and to engage with investors to ensure that they have robust climate strategies which will deliver long-term value to shareholders.

Financiers

This report represents a significant first step towards incorporating risks associated with climate change mitigation policies into financing decisions, building climate-resilient portfolios, and identifying the opportunities that climate change mitigation creates for financiers. The challenge created by future climate change mitigation policy is similar for ship financiers. It is a question of how to ensure that cashflow generation, value, and liquidity of assets will remain acceptable when facing risks related to future climate change regulation of unknown stringency.

There are three implications. First, while findings are illustrative of an approach to understanding risks, they also suggest that financial implications of climate change mitigation will likely be material and should be understood. Techno-economic scenario analysis represents a way to carbon stress test assets as well as sectors to enrich risk adjustment and valuation models. This could be considered for both corporate lending and project finance. The same approach could also be used to assess the magnitude of risks inherent in a current portfolio, and assist in identifying how this risk can be rebalanced.

Second, findings suggest concrete ways to improve lending due diligence to identify shipowner preparedness for climate mitigation, for example:

1. Particularly if it is a newbuild, what actions are being taken to ensure that the vessel can be modified as easily and cheaply as possible?
2. Are there plans to use innovative cost-sharing measures to make vessel modifications?
3. If vessels need to be modified, where will the capital come from?

Third, while case study findings don't suggest the immediate increase in capital expenditure to improve efficiency of newbuilds, they do suggest that carbon pricing may create a high future demand for capital for vessel modifications. This should be viewed as an opportunity, though one in which many challenges are already recognised. Loan guarantee schemes represent excellent opportunities to de-risk these investments initially and to develop expertise to prepare for this increase in demand.

1 Introduction

With the adoption of the Paris Agreement in December 2015, governments agreed to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. This provided a clear message to both nations and industry sectors that business as usual growth in emissions was no longer acceptable and that both must decarbonise to avoid dangerous climate change. The gravity of this message was underscored by the record pace at which the Paris Agreement was ratified.

The implications of the long-term temperature goals are significant and create climate risks. For example, 60%-80% of coal, oil and gas reserves of listed firms will have to be left unused in order to meet these goals (Carbon Tracker & Grantham Research Institute 2013). In the power generation sector, the International Energy Agency (IEA) estimates that it is necessary to close a quarter of subcritical coal-fired power generation worldwide by 2020 in order to put emissions in line with a 2°C future (IEA 2013). This could have severe consequences on the portfolios of both government-owned and private companies (Caldecott & Mitchell 2014). Both examples create significant challenges for companies, governments, and investors as they are faced with potential climate change-related regulation, reputation, and litigation risks.

However, as UCL and CWR have established in the August 2016 instalment of the work on stranded assets in shipping (Prakash et al. 2016), identifying climate risk in shipping is more difficult than in the energy exploration and production and power generation sectors. In shipping, assets can easily relocate to find more favorable regulatory regimes, making global regulations the likely levers for change. This is compounded because few entities are consumer-facing and incentivised by societal pressure to change, and there has been little to no consideration of litigation risks. Furthermore, the large magnitude of business risks in shipping coupled with a market failure around rewarding investments in energy efficiency makes asset-related climate risks difficult to identify. In light of the temperature goals of the Paris Agreement, shipping’s decarbonisation is inevitable, therefore material risks loom for shipowners and financiers, and these must be understood, even if specifics of the transition and its timing remain uncertain.

This report outlines a possible approach to anticipating and evaluating the risks associated with impending regulation to achieve this decarbonisation on shipping markets through an illustrative case study of investments in the newbuild drybulk fleet in the size range of 60,000-99,999 dwt. Our approach predicts the evolution of the global fleet using techno-economic modelling and estimates the ability of an individual vessel to remain competitive in multiple possible futures, including evolving fleet energy efficiency, regulatory requirements, and macro-economic factors.

1.1 Potential drivers of risks in shipping

There are multiple potential drivers of risks faced by shipping, capable of rendering vessels uncompetitive and therefore being written down or written off prematurely. Smith et al. (2015) suggest two categories of risks for shipping: supply side risks, which are related to the ship’s specification, and demand side risks, which are risks associated with the demand for a certain specification of ships. This report focuses on risks relevant to climate change mitigation policies and regulations in shipping as shown in Figure 1.

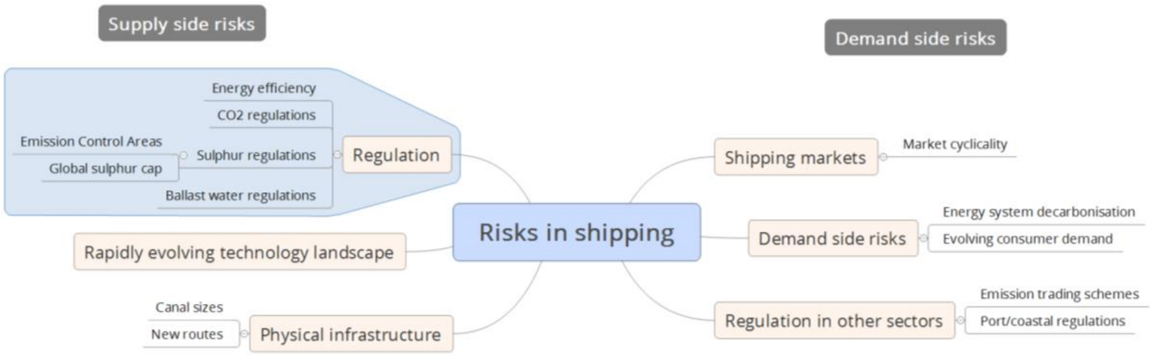


Figure 1: Potential drivers of risks faced by shipping

1.1.1 Supply-side risks

1.1.1.1 GHG and air emissions regulation risks

On the supply side risk, future regulation aiming to place shipping's GHG emissions on a 2°C pathway (as shown in Figure 2) would require a peak in emissions by 2020, followed by a 50% reduction of 2012 emissions by 2050 (Smith et al. 2016). In order to achieve absolute emissions reductions, whilst accommodating an increase in transport demand, shipping would need to reduce its average carbon intensity (the amount of CO_2 emitted per tonne of goods moved) in the range of 60-90% on 2012 levels (Smith et al. 2015). This is a significant supply side risk as the GHG reduction regulation would require a new ship's specification to use a number of energy efficiency technologies and potentially switch to alternative low carbon fuels, therefore a ship incapable of achieving the required reduction of carbon intensity could lose its economic value.

In addition to CO_2 emissions legislation, the shipping industry faces other upcoming regulations. One example is the global sulphur cap which will enter into force in 2020, requiring either the use of compliant low-sulphur fuel, or the fitting of sulphur treatment equipment (scrubbers). The choices made by shipowners may affect the competitiveness of their ships, heighten the valuation impact of any energy efficiency differentiation between ships and may ultimately result in some ships being scrapped earlier than anticipated.

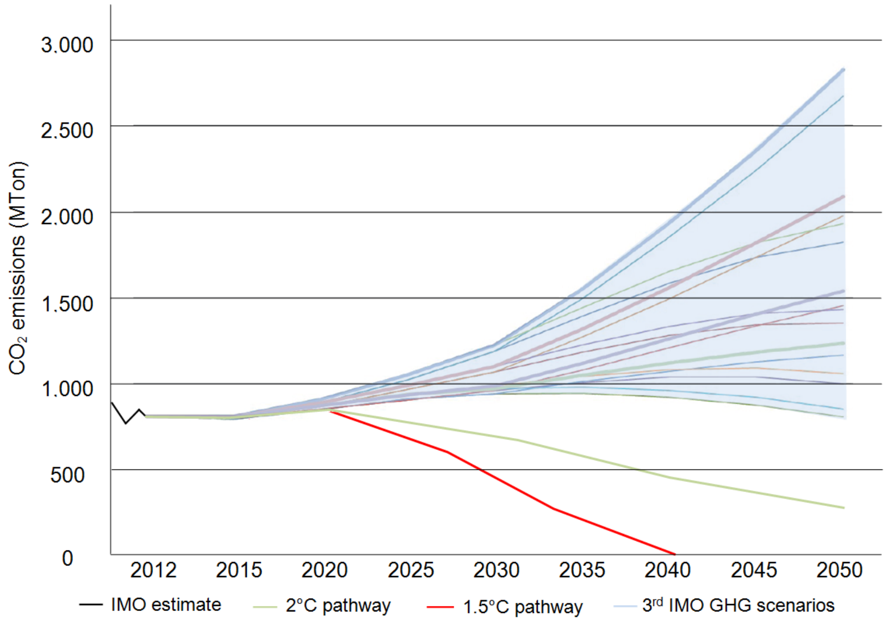


Figure 2: Shipping emissions trajectories

1.1.1.2 Energy efficiency risks

Increasing vessel energy efficiency can also be considered as a potential risk in shipping markets. For example, there is increasing pressure on existing ships to compete directly with more energy efficient newbuilds and avoid being classed at the bottom of the two-tier market of high- and low-efficiency vessels. Previous work by Prakash et al. (2016) tests whether technical vessel efficiency measures can be used to anticipate those risks by establishing some understanding of the role of vessel efficiency in competitiveness in past markets. The findings, however, suggest that there is little or no evidence of premiums for better GHG-rated ships (GHG rating used as a proxy for energy efficiency) and that no significant difference is observed in terms of productivity (time spent loaded and number of loaded voyages, for example) for ships with better GHG ratings. Mitchell & Rehmatulla (2015) also observe that only a minority of the shipping financiers take into account energy efficiency in their decision making process.

1.1.1.3 Technology and Infrastructure Risks

Other forms of supply side risks include risks from rapidly evolving technologies, e.g. the ability to bunker in an evolving fuels market or the ability to compete commercially against ships able to use cheaper fuels, as well as from evolving ship specifications, e.g. changes in size categories due to infrastructure evolution and canal constraint relaxations.

1.1.2 Demand-side risks

Regulation in other sectors can also potentially impact shipping assets. On the demand side risks, the commodities carried (e.g. crude oil, oil products, and coal) and the trade served by ships (e.g. Australia to China) can evolve as energy systems decarbonise, switching from fossil fuels to renewable forms of energy. This could impact the derived demand for oil tankers and drybulk ships.

1.2 Aims and research questions

Our aim in this work is to explore how the omission of the regulatory risk (aimed at reducing GHG emissions from shipping) in conventional asset evaluations could be rectified and what this would imply for the shipowners and financiers. Derivative of this aim, this report attempts to answer the following research questions:

1. How might the fuel, machinery, and energy efficiency technology used by ships within the specified fleet change over time, both for newbuilds and existing ships?
2. What does this evolving landscape mean for ships built at different points in time? For example, how might a 2020 built vessel operate and compete with more modern ships entering the fleet in 2030?
3. How might different investment horizons influence the composition of the fleet and its ability to manage a low carbon transition?
4. How might known market barriers and failures in the shipping industry (particularly between the shipowner and the charterer) influence the above outcomes?
5. What do these factors in combination mean for the resilience of assets to risks induced by climate change mitigation regulations and ultimately their profitability as well as the volatility of returns?

2 Approach

Our approach is to forecast the evolution of the global fleet using techno-economic modelling and estimate the ability of an individual vessel to remain competitive in multiple possible futures, taking into account evolving fleet energy efficiency, regulatory requirements, and macro-economic factors. To provide an illustrative example of this approach, the case of the drybulk fleet in the size range 60,000-99,000 dwt out to 2050 is considered, a period over which it is foreseeable, as shown in Figure 2, to expect a number of the supply and demand side risks, described in 1.1, to develop.

We use GloTraM, a multidisciplinary simulation model developed by UCL, to model the technical and operational evolution of the fleet. This allows us to illustrate the relative competitiveness of vessels against this fleet. The modelling method is detailed in Appendix A.

In order to generate results from GloTraM, we need to make a number of assumptions about some of the inputs to the modelling that describe various foreseeable scenarios of the future. These assumptions are defined in Appendix B.

Section 3 presents two base scenarios that are predicated on contrasting investment attitudes and owner/operator structure. This simulates two different attitudes to newbuild specification and so will create at each point in time two different levels of design specification and associated different economic performance. Comparing the results from these scenarios allows us to consider how competitiveness and profitability might be affected at several points in time in the future.

Section 4 then adds to the base scenarios a number of further variations to some of the input parameters and assumptions to generate further results from GloTraM. This allows us to test the robustness of some of the findings derived from the base scenarios, as well as to comment more generally on the scale of differences, in technological and commercial terms, that might arise from some of the different foreseeable future developments in regulation and macroeconomics.

Section 5 draws together results from Section 4 and 5 and connects them to qualitative observations to derive a series of key findings.

3 Base scenarios

3.1 Base scenario definitions

The key differences in input assumptions for the two base scenarios are:

- Short-term perspective scenario: A shipowner or investor evaluates the investment within a short time horizon. Market barriers in this scenario are high, implying that only a small share of fuel/carbon cost savings specific to the chosen design are passed back to the owner of the ship.
- Long-term perspective scenario: A shipowner or investor evaluates the investment within a long time horizon. Market barriers in this scenario are low, implying that the majority of fuel/carbon cost savings specific to the chosen design are passed back to the owner of the ship.

For these base scenarios (Table 1), we assume a low carbon price and a market characterised by low freight rates.

Scenario	Carbon price (fixed flat price)		Freight rate	Discount rate = interest rate	Time horizon used to recoup energy efficiency technology investment NPV_ee	Time horizon used to recoup main machinery investment NPV_mm	Market barrier (fuel cost saving pass through)
	Start year	Price ($/tonne CO_2)					
1	2025	50	Low	10%	3	15	5%
2	2025	50	Low	10%	7	30	75%

Table 1: Base scenarios

The results obtained for the drybulk fleet (size range 60,000-99,999 dwt) focus on two years: 2020 and 2030. These build years (generations) are chosen as relevant to shipowners and investors currently thinking about the specification of their future fleets and how they might compete over the next 5/10/15 years.

There are two dimensions to this comparison. On the one hand, we compare all selected ship generations in the short-term perspective scenario with those in the long-term perspective scenario. On the other hand, we compare the two generations within either the short-term or long-term perspective scenario, showing how a 2020 newbuild might operate and compete with a 2030 newbuild at different points in time. The following sections will look at technical and operational specifications, followed by the ship economics for each of the dimensions aforementioned.

3.2 Technical and operational specifications

This section aims to investigate how different investor perspectives (long-term and short-term) might influence the technical and operational specification of a ship, and its overall energy efficiency. Towards this end, it examines the changes over time in the fuel, machinery and energy efficiency technology used by ships, both for newbuilds and retrofitted ships for each of these perspectives. Ships built at different points in time are expected to adapt their operational specifications influenced by an evolving regulatory and economic landscape, which means that changes in operational speed, specific fuel consumption, and engine loads would affect the performance of the ships over time.

The results in this section do not advocate any particular measure and are used as an example to explain the method and dynamics that may occur across the limited number of scenarios. A large number of simulations and analysis of input and output variables would be required for a complete assessment.

3.2.1 Short-term versus long-term perspective scenarios

The technical specifications (main engine, fuel and energy efficiency technology) of a ship built in 2020 in the short-term and long-term perspective scenarios are shown in Table 2. The specifications in 2020 represent the newbuild specifications, whereas each row after 2020 represents any retrofits made.

The changes of the operational specification, characterised by operational speed and Specific Fuel oil Consumption (SFC) (which also includes the effect of different rates of engine load) for both the short- and long-term perspective scenarios are shown in Figure 3.

	2020 built ship in short-term perspective scenarios			2020 built ship in long-term perspective scenarios		
Year	**Main engine**	**Fuel**	**Energy efficiency technology on board**	**Main engine**	**Fuel**	**Energy efficiency technology on board**
2020	2 stroke engine	LSHFO	Trim and Draught Optimisation Engine Derating	2 stroke engine	LSHFO	Trim and Draught Optimisation Biocide Hull Coating Flettner Rotor Turbocompound Parallel Engine Derating Autopilot Upgrade
2025		LSHFO	Autopilot Upgrade		LSHFO	Solar power
2030		LSHFO	Energy Saving Lighting		LSHFO	Common Rail
2035		LSHFO	Turbocompound Parallel		HFO	Energy Saving Lighting Scrubber
2040		LSHFO	Common Rail		HFO	Engine Tuning
2045		LSHFO			HFO	Rudder Bulb

Table 2: Technical specifications of a ship built in 2020 under different investment perspectives

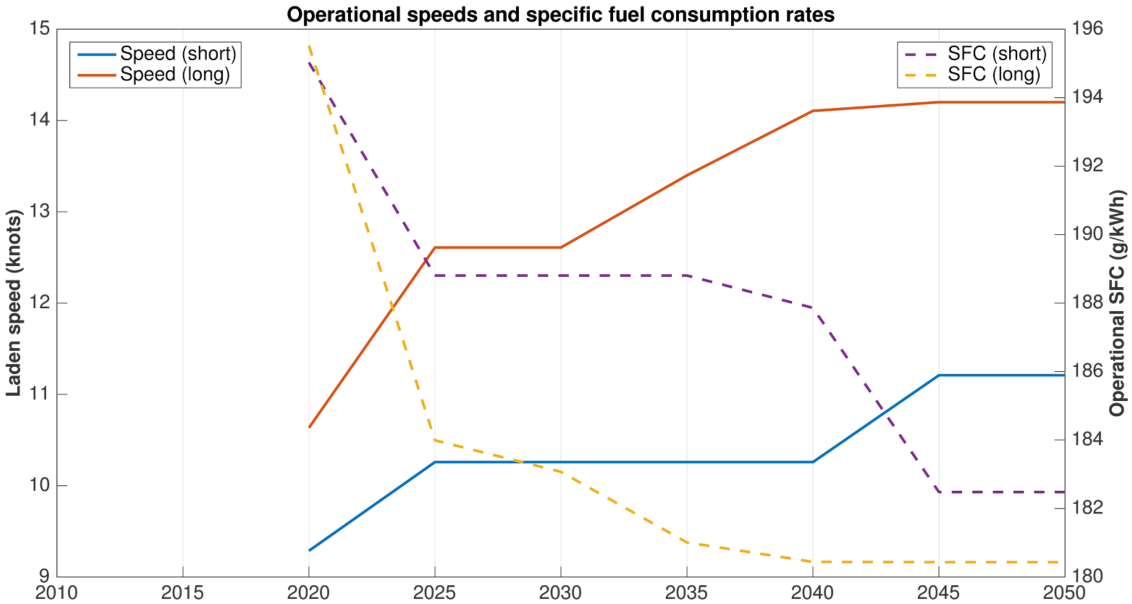


Figure 3: Operational speeds and SFC under the different investment perspective scenarios

Comparing the initial results of the short-term with the long-term perspective scenario shows that whilst both investment perspectives lead to the selection of similar engines for the newbuild ship in

2020, in general the short-term perspective scenario leads to a ship with lower technical specifications operating at a relatively constant speed over time (from 9 to 11 knots), whereas the long-term perspective scenario leads to a ship with higher technical specifications operating at a higher speed that increases over time (from 10 to 14 knots). Both perspectives lead to an improvement of the operational SFC of about 7 to 8% in 2050 compared to 2020, however the gap between the SFCs is significant during the period 2025 to 2040.

The difference observed for the technical specifications can be associated with the fact that in the long-term perspective scenario, the time horizon used to recoup energy efficiency technology investment is 7 years, which means that in the build year 2020, the investor has a longer view of how the market would evolve and factors in the introduction of a carbon price in 2025. This is not the case in the short-term perspective scenario, where the time horizon used is only 3 years.

Similarly, for the fuel selection, LSHFO is chosen in both scenarios. However, in 2035 a switch to HFO is observed in the long-term perspective scenario. The long-term perspective investor foresees the increasing price difference between LSHFO and HFO due to the longer time horizon. This price difference makes the use of HFO with a scrubber more economical than LSHFO.

3.2.2 2020 built ship versus 2030 built ship in the long-term perspective scenario

This section compares the technical and operational specifications of a 2020 built ship with that of a 2030 built ship in the long-term perspective scenario.[1] Table 3 shows the technical specifications of both ships and Figure 4 illustrates the operational speed and SFC over time.

	2020 built ship				**2030 built ship**		
Year	**Main engine**	**Fuel**	**Energy efficiency technology on board**		**Main engine**	**Fuel**	**Energy efficiency technology on board**
2020	2 stroke engine	LSHFO	Trim and Draught Optimisation Biocide Hull Coating Flettner Rotor Turbocompound Parallel Engine Derating Autopilot Upgrade Hull Cleaning		-	-	-
2025		LSHFO	Solar power		-	-	-
2030		LSHFO	Common Rail		2 stroke engine	LSHFO	Sails
2035		HFO	Energy Saving Lighting Scrubber			HFO	Trim and Draught Optimisation Solar power Engine Derating Hull Cleaning Scrubber
2040		HFO	Engine Tuning			HFO	Biocide Hull Coating
2045		HFO	Rudder Bulb			HFO	Common Rail
2050	-	-	-				Turbocompound Parallel

Table 3: Technical specifications of both ship generations in the long-term perspective scenario

[1] The focus is on the long-term perspective scenario in order to highlight the differences in the specification of the newbuilds. The short-term perspective scenario does not show significant differences between the build years.

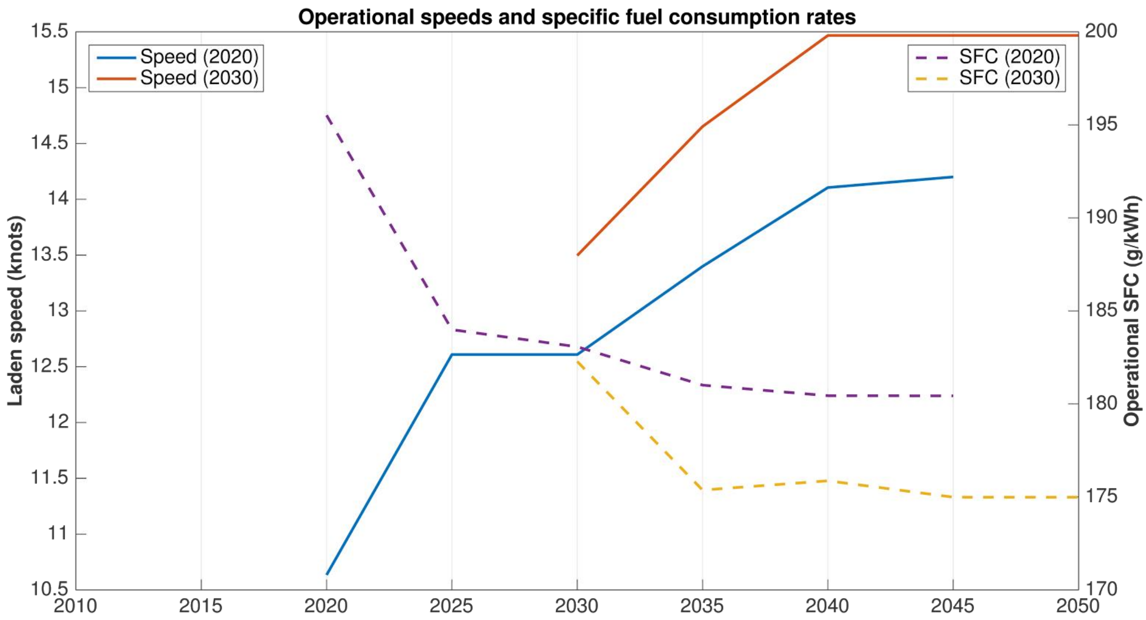


Figure 4: Operational speed and SFC for 2020 and 2030 built ship in the long-term perspective scenario

Comparing the 2020 built ship with the 2030 built ship shows that technologies are taken up at different times (both at newbuild stage and for retrofitting). This is because the technologies become profitable at different points in time depending on the prevailing market conditions, e.g. a technology that is profitable in 2020 does not necessarily have to be profitable in 2030 as freight rates, fuel prices, and other relevant market conditions might be different. For example, sails become the most profitable option in 2030 for the 2030 built ship and all the other technologies are taken up later. Apart from that, the amount and types of technologies used are relatively similar for both ships.

The fuel selection is the same in both scenarios due to the long-term perspective which takes into consideration the increasing price difference between LSHFO and HFO due to the longer time horizon of 7 years (see Figure 18 on fuel cost projections).

When adding the operational performance to the comparison, it can be observed that the 2030 built ship operates at consistently higher speeds and at lower operational SFC rates than the 2020 built ship. This is because the 2030 built ship has been specified in a way that maximises profits in the market conditions that the investor foresees prevailing in 2030 and thus has a competitive advantage compared to the 2020 built ship.

3.3 Ship economics

This section investigates how the different investor perspectives (long-term and short-term) and the build year might influence the revenue, costs, and profits streams of the charterer and the shipowner (described in further detail in appendix A and summarised in Table 4), as a result of the technical and operational specification of a ship (described in section 3.2) under the two base scenarios.

	Charterer	**Shipowner**
Revenue	Spot or voyage charter freight rate	Daily time charter rate (+ % of fuel cost saving passed)
Costs	Time charter rate + Voyage costs	Fixed operating costs + Capital expenditure
Profit	Total revenue – Total costs	Total revenue – Total costs

Table 4: Relationship between charterer's and shipowner's revenue, costs and profits.

3.3.1 Charterer revenue, costs and profits

Charterer	
Revenue	Spot or voyage charter freight rate
Costs	Time charter rate + Voyage costs (e.g. fuel, carbon price (if applicable), port charges)
Profit	Total revenue – Total costs

Table 5: Charterer revenue, costs and profits

Figure 5, 7 and 8 show the charterer's voyage costs, total revenues and profits, over time.

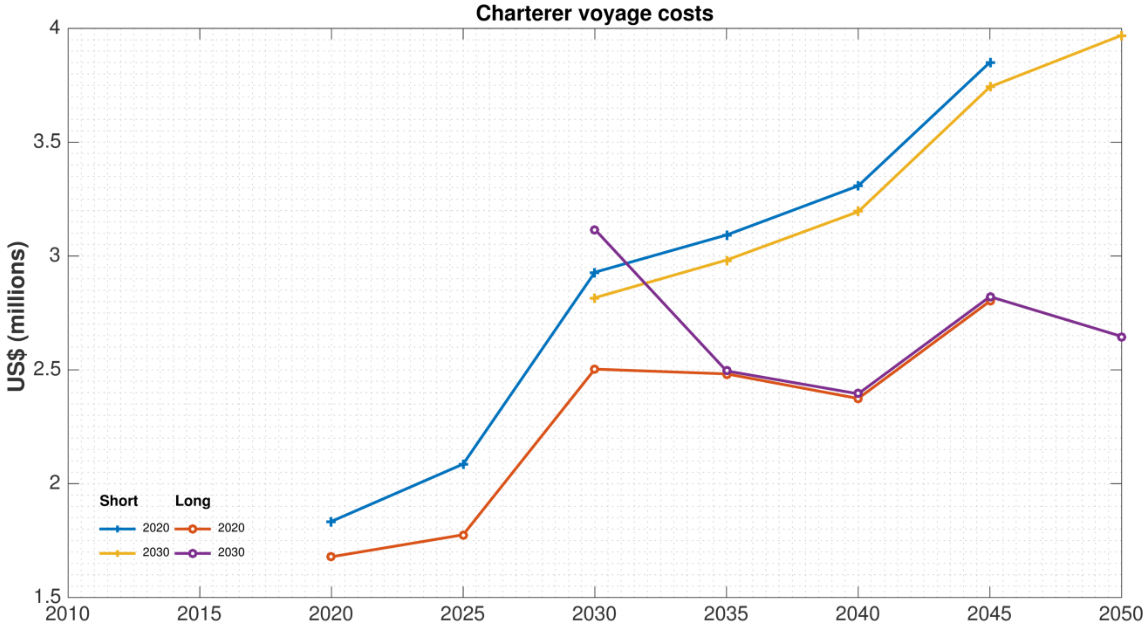


Figure 5: Charterer voyage costs under different investment perspectives and by build year

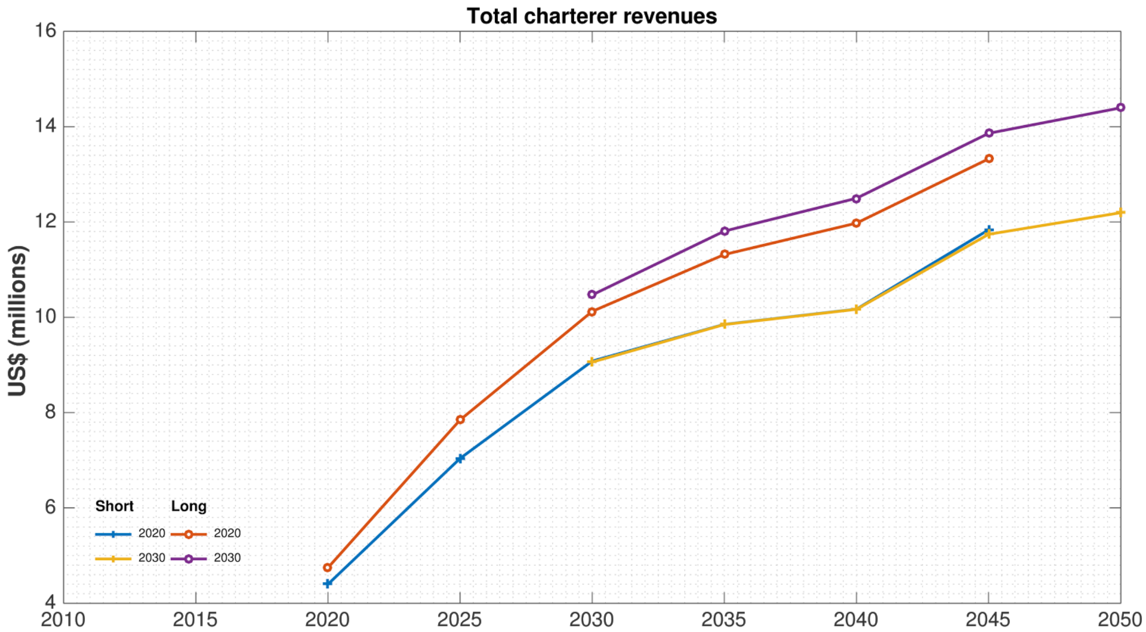


Figure 6: Total charterer revenues under different investment perspectives and by build year

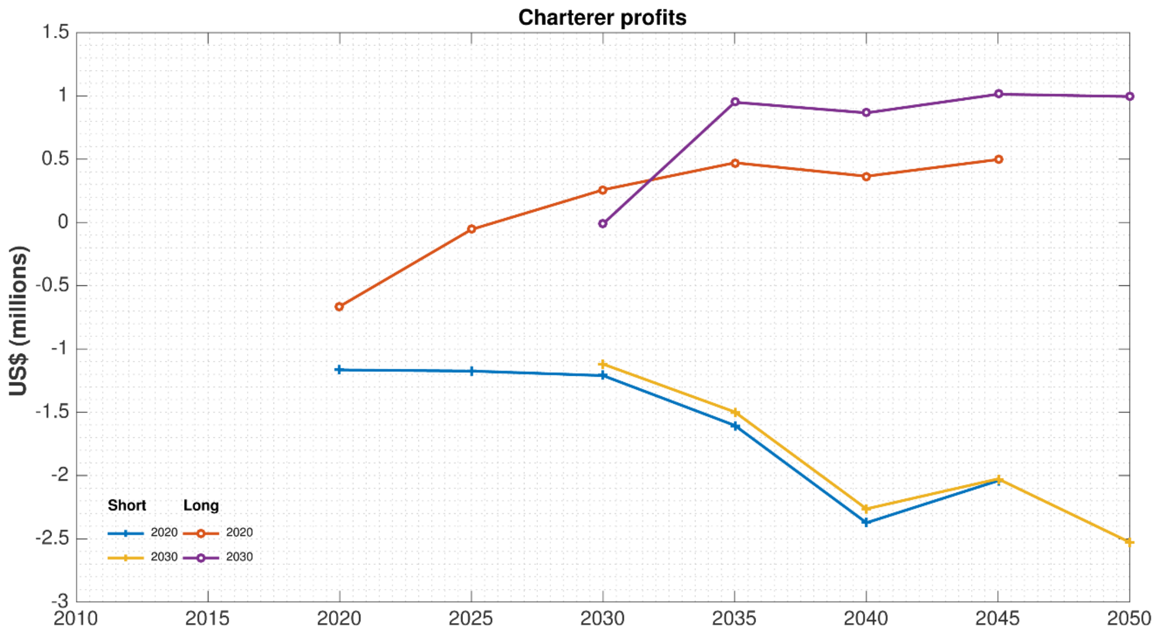


Figure 7: Total charterer profits under different investment perspectives and by build year

3.3.1.1 Short-term versus long-term perspective scenario

The costs of chartering the ship are lower in the long-term perspective scenario than in the short-term perspective scenario. This can be explained by the lower voyage costs incurred by the ship in the long-term perspective scenario as it has better technical and operational specifications compared to the ship in the short-term perspective scenario. Furthermore, the rate at which the costs increase in the long-term perspective scenario is lower than in the short-term perspective scenario, thus resulting in a widening gap between the costs in the two base scenarios over the time period.

The charterer revenue generated by the ship in the long-term perspective scenario is higher than in the short-term perspective scenario, because the ship with higher technical and operational specifications can increase its speed and therefore its productivity or transport work.

The difference between charterer revenue and costs represents the profits made by the charterer. In the short-term perspective scenario, costs are always higher than the revenue, resulting in a financial loss out to 2050, whereas in the long-term perspective, a loss is only incurred up until 2025, thereafter the charterer is making profits.

3.3.1.2 2020 built ship versus 2030 built ship

When comparing ships built in 2020 with those built in 2030 in the same scenario, the differences in charterer costs, revenues and profits are smaller than those observed during the comparison of ships specified under the short-term and long-term perspectives. In the long-term perspective scenario, the 2030 built ship generates relatively higher revenues compared to the 2020 built ship mainly due to its higher operational speed. The 2030 built ship also generates higher charterer profits.

In the short-term perspective scenario, revenue, costs and profits are similar across ship generations. The trends of a newbuild in 2030 would be similar to the one of an older retrofitted ship built in 2020. This suggests that a short-term perspective tends to generate ships that have very similar economic performance.

In general, the above results highlight that there may be significant latent risks if ships are specified under different investment perspective scenarios. A ship as specified in the short-term perspective scenario would have to compete with a ship as specified in the long-term perspective scenario. This risk appears to be higher than the risk that would stem from the competition between newbuild and retrofit ships.

3.3.2 Shipowner revenue, costs and profits

Shipowner	
Revenue	Time charter rate (+ % of fuel cost savings passed)
Costs	Fixed operating costs (incl. maintenance, wages and provisions, but excl. voyage costs) + capital expenditure (e.g. for energy efficiency technology and main machinery)
Profit	Total revenue – Total costs

Table 6: Shipowner revenue, costs and profit

The shipowner's revenue and hence profit is interlinked with the charterer's costs, as shown in Table 6 above. This is because we simulate the extent of the market barriers to the uptake of energy efficiency technology through the amount of the charterer's feedback of fuel cost savings that contributes to the shipowner's revenue and thus profits or losses. This ensures that, first, charterers are not reaping the rewards (or penalties) from operating an energy efficient vessel without rewarding (or penalising) shipowners for engendering that level of energy efficiency, and, second, there is a continuous loop where improving charterer voyage costs encourages further investments by the shipowner. High market barriers therefore imply only a moderate amount of feedback or a smaller percentage of fuel cost savings from charterers, whereas low market barriers imply a significant amount of feedback.

GloTraM further assumes that the shipowner's annual operating costs break even with the annual rate paid by the time charterer, which implies that the shipowner's profits are ultimately determined by the capital expenditure and the share of the charterer's fuel cost savings passed on to the shipowner.

In the long-term perspective, the market barrier factor is 75% and in the short-term perspective it is 5%, meaning that 75% and 5% of the charterer's fuel cost savings are passed on to the shipowner, respectively. Thus, a shipowner can be positively or negatively affected by this feedback, but this effect is more pronounced in the long-term scenarios with a pass-through rate of 75%.

The shipowner's profits are also affected by capital expenditures, e.g. for energy efficiency technology and main machinery. A ship with higher technical specifications would require higher capital expenditures – as seen, for example, in the long-term perspective scenario – and thus taken on its own have a negative impact on the shipowner's profits. The change in annual capital expenditure is shown in Figure 8 for the base scenarios.

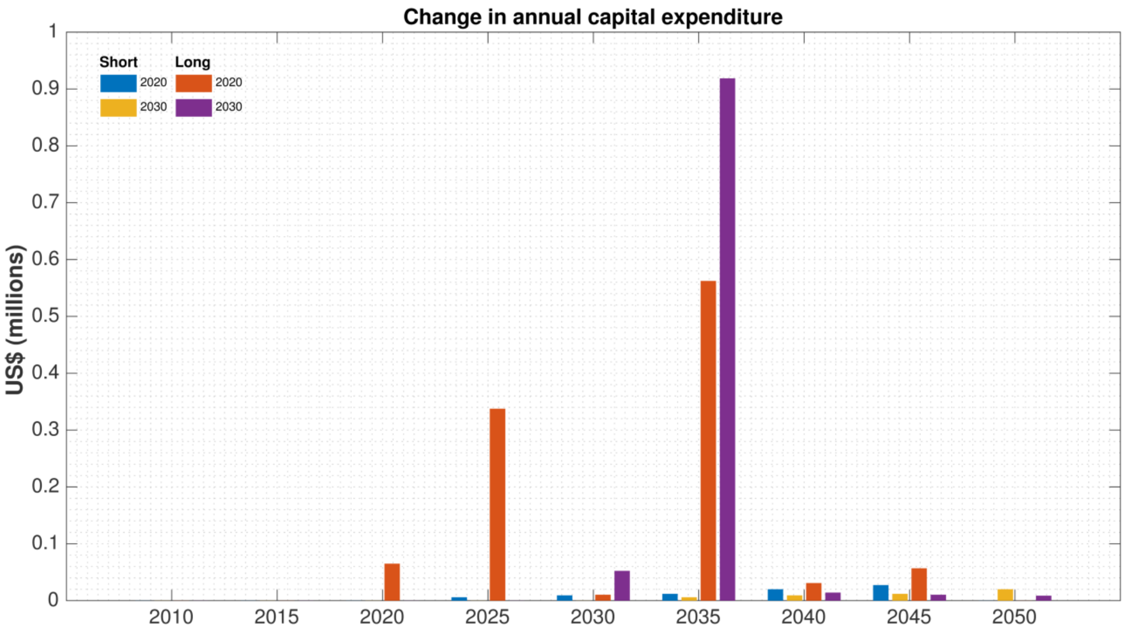


Figure 8: Annual change in capital expenditure under different investment perspectives and build year

Taking the aforementioned variables into account, it is possible to display the annual profits of the shipowner in $/year (see Figure 9). It can be observed that in almost all years, the shipowner is incurring a loss. The shipowner's loss is higher in the long-term perspective scenarios than in the short-term perspective scenarios which is somewhat counterintuitive considering that the charterer in the long-term perspective scenario makes a profit and incurs a loss in the short-term perspective. The explanation is linked to the two factors influencing the shipowner's revenues and costs as described in the sections above, i.e. the market barrier factor and the change in annual capital expenditure. In the short-term perspective scenario, the charterer only passes on a small share (5%) of fuel cost savings to the shipowner and at the same time, the change in annual capital expenditure is low, so overall the shipowner's loss is low. The situation is different in the long-term perspective scenario: here, the charterer passes on a large share of the fuel cost savings (75%) to the shipowner which, on their own, would result in moderate profits for the shipowner. However, factoring in the changes in annual capital expenditure, which are relatively high in these scenarios, considering the high technical specifications of the ships, results in the shipowner in the long-term perspective scenario incurring a loss.

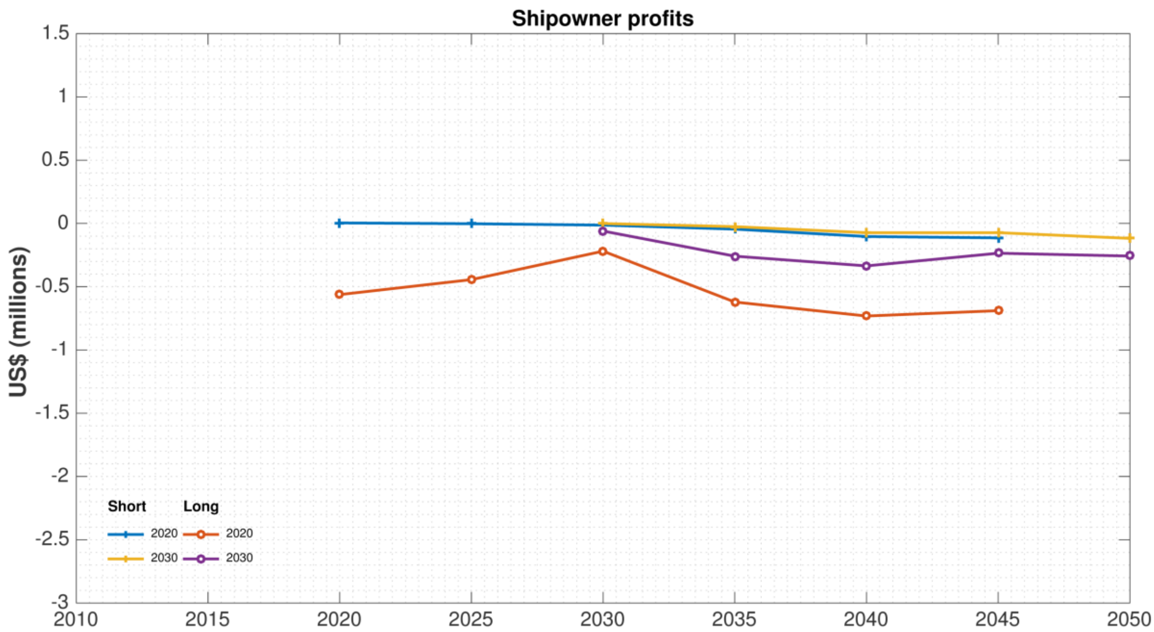


Figure 9: Shipowner profits in short-term and long-term perspective scenarios

To conclude, this section suggests that significant risks could arise as a result of the different investment perspectives and the build year of ships. Both the introduction of high specification ships specified by investors with a long time horizon and in markets characterised with low market barriers as well as the competition between the generations of ships may render certain ships riskier investments than others.

4 Results from sensitivity analysis

4.1 Introducing sensitivities to the base scenarios

To examine the robustness of the findings of section 03, a basic sensitivity analysis is undertaken in which two specific input assumptions are changed: carbon price and freight rate. These two input assumptions are believed to be both of high uncertainty and key relevance for evaluating risks from climate change mitigation policies. A number of sensitivity scenarios are defined in order to investigate the sensitivity of these key input assumptions and explore their influence on the results.

In addition to the freight rate used in the base scenarios (low case), the influence of a higher freight rate (high case) is now explored, see appendix B. Whilst an indicative low carbon price of $50/tonne was used in the base scenarios, a higher carbon price of $200/tonne is now also introduced. Table 7 provides a summary of the different scenarios.

	Carbon price (fixed flat price)		Freight rate Growth	Market barrier or fuel saving pass through	Discount rate= interest rate	Time horizon used to recoup energy efficiency technology investment NPV_ee	Time horizon used to recoup main machinery investment NPV_mm
Scenario	**Start year**	**Price ($/tonne CO_2)**					
1 (base)	2025	50	Low	5%	10	3	15
2 (base)	2025	50	Low	75%	10	7	30
3	2025	200	Low	5%	10	3	15
4	2025	200	Low	75%	10	7	30
5	2025	50	High	5%	10	3	15
6	2025	50	High	75%	10	7	30
7	2025	200	High	5%	10	3	15
8	2025	200	High	75%	10	7	30

Table 7: Carbon price and freight rate sensitivities and base case scenarios

In the following sections, the trends of the operational conditions across different scenarios are examined, followed by the voyage cost per thousand tonne kilometres and the shipowner’s profit.

4.2 Technical and operational specifications

Figure 10 and Figure 11 show the laden speed in knots and the operational SFC in g/KWh for all eight scenarios, respectively.

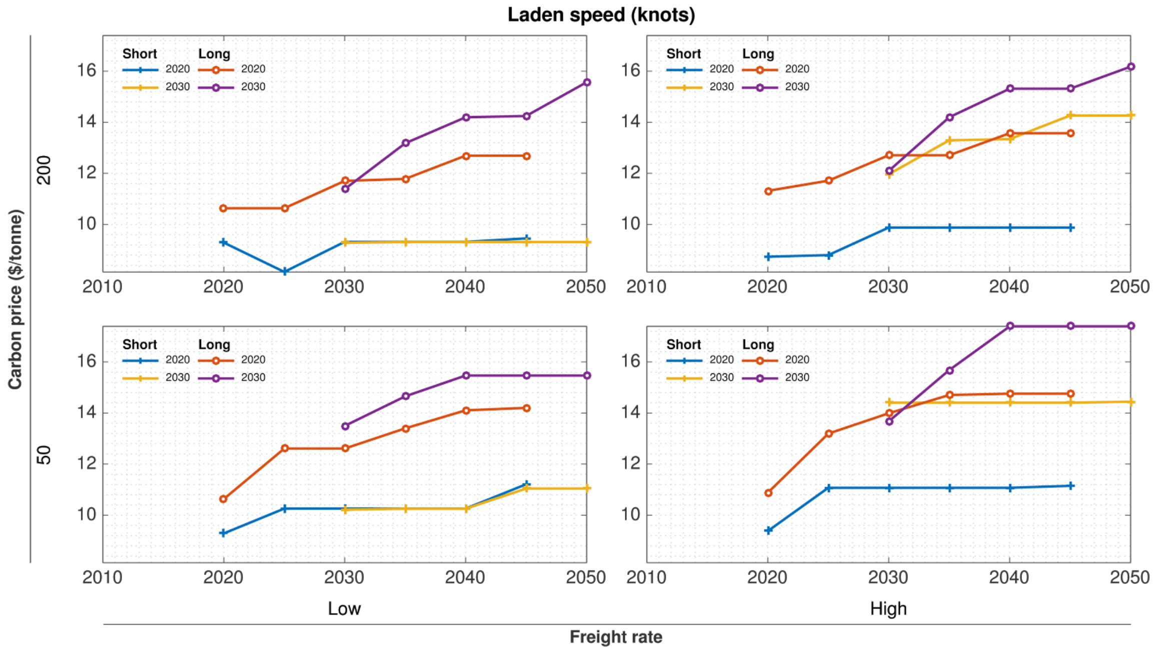


Figure 10: Laden speed in scenarios 1-8

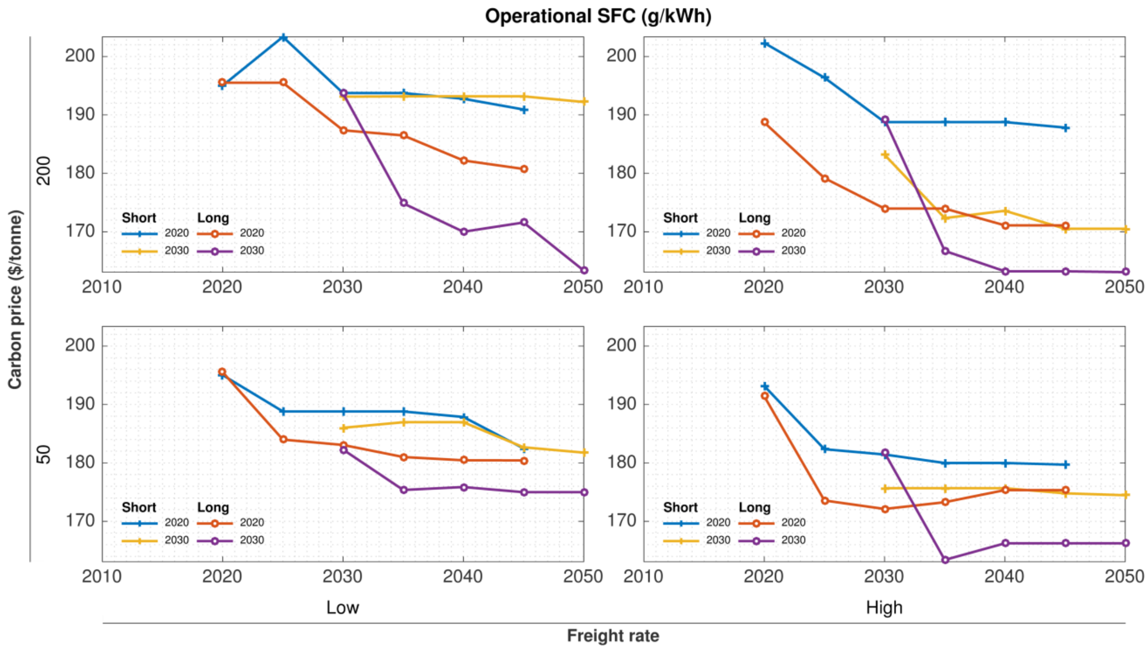


Figure 11: Operational SFC in scenarios 1-8

Based on Figure 10 and Figure 11, it can be observed that regardless of the changes in carbon price and freight rate, ships in the long-term perspective scenarios in general not only operate at higher and increasing laden speeds, but also with a lower and decreasing SFC compared to ships in the short-term perspective scenarios. This implies that ships in the long-term perspective scenarios can perform more transport work (faster ships) and with lower fuel consumption (more efficient ships) than ships in the short-term perspective scenarios.

The laden speed of ships in the short-term perspective scenarios with low freight rates is significantly lower and mostly stagnant compared to that of ships in the long-term perspective scenarios whose laden speed is not only higher but also increasing (see figure 10, plots on the left). In a low freight rate market, a carbon price of $200/tonne would reduce the average laden speed of 2020-built vessels in short-term perspective scenarios by 11% over their life time (<10 knots) compared to their respective laden speeds observed at a carbon price of $50/tonne (going over 10 knots) (see Figure 10, plots on the left, blue lines). This drop in speeds is slightly greater at 12% for 2030-built vessels in short-term perspective scenarios (see figure 10, plots on the left, yellow lines). An increase in the carbon price from $50/tonne to $200/tonne reduces laden speeds by 9.6% for 2020-built vessels and by 8% for 2030-built vessels in long-term perspective scenarios (see figure 10, plots on the left, red and purple lines). Hence, the carbon price increase has a more pronounced effect on reducing a vessel's productivity in low freight rate scenarios for those built under short-term perspectives. A similar dynamic can be observed for the scenarios with a high freight rate. For instance, the higher carbon price reduces average laden speed in short-term perspective scenarios by 7% for 2030-built vessels and by 12% for 2020-built vessels (see Figure 10).

Intuitively, the fastest ships are observed in the scenario with high freight rates and a low carbon price (see figure 10, plot on the lower right). Those ships are also the most efficient with an operational SFC significantly decreasing over time (see figure 11 plot on the lower right). The high carbon price reduces the laden speed and has a minor impact on operational SFC (see figures 10 and 11 plots on the top right) in comparison with the low carbon price scenario. This means that ships would be required to adopt lower speeds in conjunction with technical interventions in order to optimise their profit under a scenario with a high carbon price, whereas in a scenario with low carbon price and high freight rates the ships would be allowed to increase speed.

In contrast, the slowest ships are observed under the scenario with low freight rates and a high carbon price (see figure 10 plot on the top left). Although a high carbon price incentivises technical and operational (including speed reduction) interventions, a low carbon price scenario would reduce SFCs, and increase laden speed (see figures 10 and 11 plots on the bottom left).

Under the defined sensitivity scenarios, the operational and technical specifications respond to changes in freight rates and carbon prices by decreasing the operational SFC and increasing speed. The highest laden speed and lowest operational SFC (on average) can be observed in the scenario with a low carbon price and high freight rate, whereas the lowest laden speed and highest operational SFC (on average) can be observed in the scenario with a high carbon price and low freight rate.

4.3 Ship economics

Figure 12 shows voyage costs per thousand tonne kilometres incurred by charterers. This metric takes into account the transport work of the vessel and can be used to benchmark its productivity and relative costs. The cost advantage of a ship relative to its peers can thus be an indicator of an asset's performance, because cost advantages typically translate to better internal rates of return (IRR).

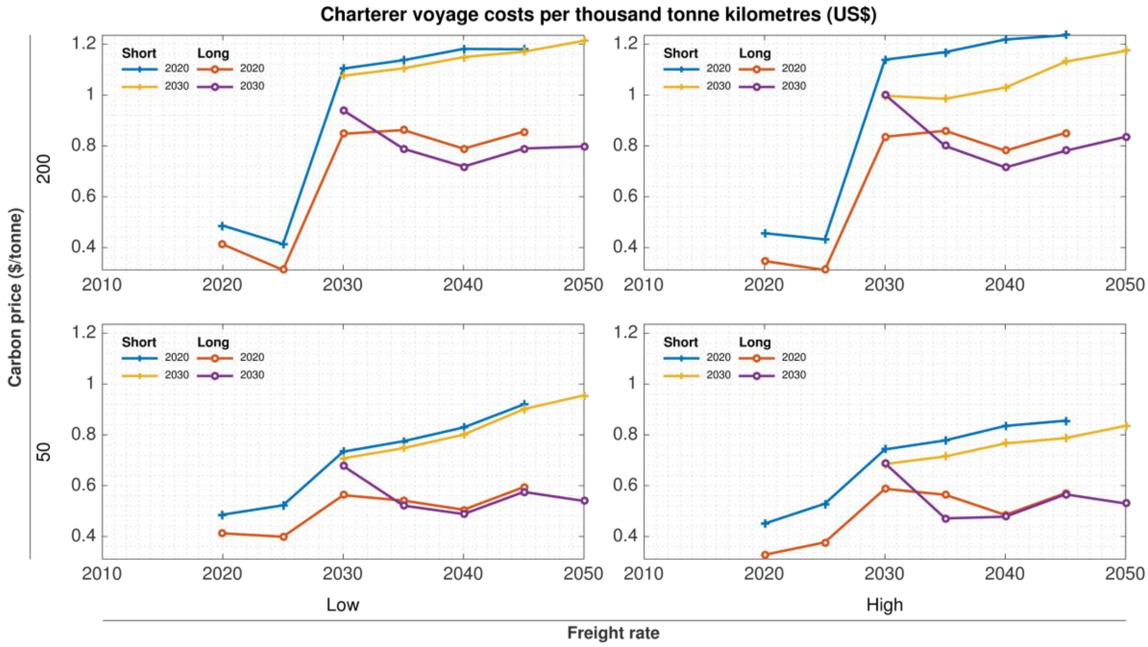


Figure 12: Voyage costs per thousand tonne kilometres in scenarios 1-8

Across all eight scenarios, the voyage costs per thousand tonne kilometres are lower in the long-term perspective scenarios than the short-term perspective scenarios. The cost gap between the long-term and short-term perspective scenarios widens and is generally most pronounced around 2040, with the widest gap being observed for scenarios 3 & 4 (low freight rate, high carbon price).

In general, if ships specified under short-term perspective scenarios were competing with ships built under long-term perspective scenarios, then the latter ship will operate with a cost disadvantage. Note that 2030 built ships do not necessarily have better cost per thousand tonne kilometre figures in 2030 compared to 2020 built ships under similar or different investment horizons, though they improve relative to their 2020 built peers in 2035 and thereafter.

In 2030, a 2020 built ship in a high freight rate, high carbon price scenario owned by an investor with a short-term investment horizon would have a cost per thousand tonne kilometre disadvantage of 22% against 2020 built ships by shipowners with long-term investment horizons and a disadvantage of 13.8% against 2030 new builds that increases to 25% by 2035. The findings suggest that in a future scenario characterised by high climate change mitigation policy risks, ships built under the long-term perspective scenario would outperform ships built in the short-term perspective scenario, in almost all cases.

The second economic parameter discussed in this section is the shipowner's profit. Figure 13 shows annual shipowner profits in US$ for all eight scenarios.

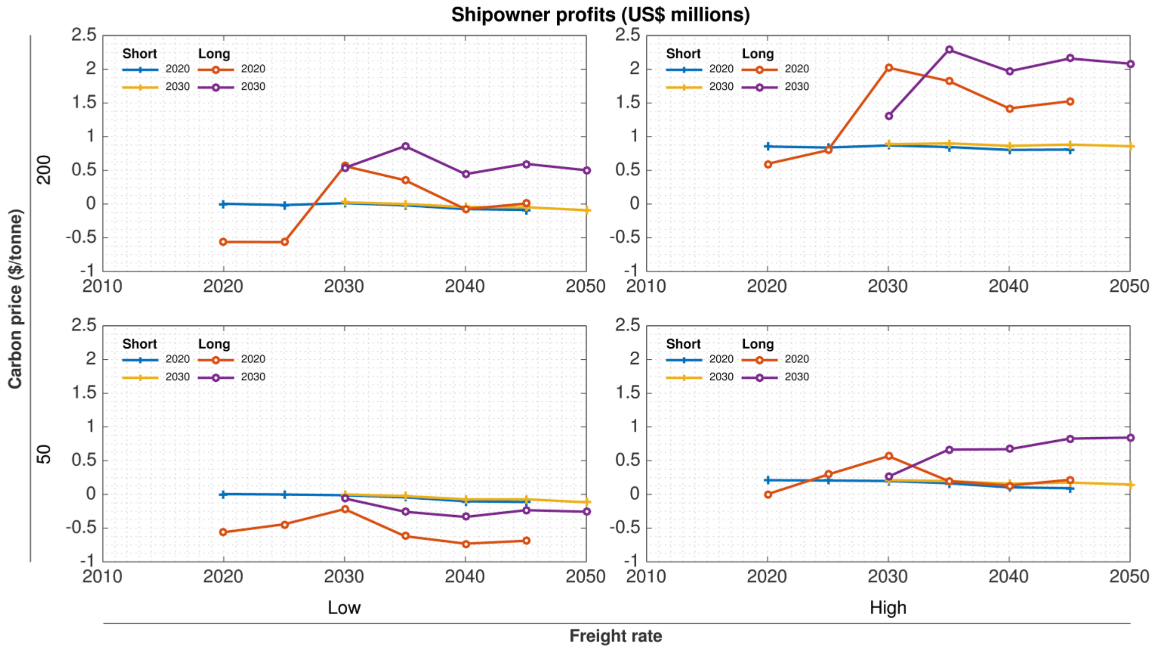


Figure 13: Shipowner profits in scenarios 1-8

While profits in the short-term perspective scenarios are more stable and fluctuate less than in the long-term perspective scenarios, they are also generally lower (US$0-1 million p.a.) than in the long-term perspective scenarios, where yearly profits of up to US$2.5 million can be observed. The exception is the scenario with low freight rates and low carbon prices (i.e. scenarios 1 and 2), where profits in the long-term perspective are lower and in fact negative compared to those in the short-term perspective (the explanation for this is provided in section 3.3.2). Due to this long-term perspective and the ability to appropriate cost savings from the charterer in the long-term perspective scenario, in a poorly performing market, a shipowner is more exposed to the feedback from charterers. In general, profits of 2030 built ships are marginally higher than those generated by 2020 built ships, with the exception of when they first start operating in 2030. The finding therefore suggests that shipowners and financiers need to better anticipate the risks to their assets which can be exacerbated in certain future scenarios, more so as a result of ships that are technically and operationally more competitive but also newbuild ships in the future.

5 Discussion

The results generated in the previous section permit us to make relative assessments about a ship's resilience and profitability in different foreseeable futures. In particular, we assess this under different assumptions about time charter rates, investment horizons, market barriers, and carbon prices.

We consider the returns from investment on vessels of differing generations within and across our scenario space, describe the fundamental differences that increase resilience (and in turn returns), and identify a few other measures that help put those differences into context. The results of this section, however, need to be understood within the limitations set by GloTraM's modelling and economic assumptions discussed in Appendix A and B.

One way to compare the relative resilience of ships within or across scenarios is using their internal rate of return (IRR), which is the discount or interest rate required to render a net present value (NPV) of zero over the investment horizon (such that the initial investment is recouped fully). The IRR at which an investment's NPV is zero depends on the cost of the initial investment, the investment horizon, the size of the cash flows, as well as their timing (see, for example, Besley & Brigham 2008).

Vessels with high rates of return are likely to be more resilient to the types of negative cost and revenue impacts that might arise from future climate change mitigation policy, and are therefore indicators of which ship specifications are more likely to remain relatively liquid in poor markets or in the presence of more competitive vessels.

When assessing returns on newbuilds ordered in 2020 and 2030 under our various scenarios, GloTraM's assumptions permit us to make the following additional simplifications.

1. Leverage is ignored and returns from investing in a ship are evaluated at its full newbuild cost, because the market for ships is effectively decoupled from the freight market in our model.
2. A ship bought in 2020 and in 2030 in scenarios with short investment horizons is sold in year 15 (2035 and 2045, respectively), where its sale value is its straight-line depreciated value given an expected useful life of 30 years. We assume an 80,000 dwt drybulk ship will have a cost of approximately US$25 million if built in 2020 and US$30 million if built in 2030, such that in 2035 the remaining value of the 2020 built ship would be US$14.6 million and in 2045 the remaining value of the 2030 built ship would be US$17.1 million.
3. Initial costs of US$25 million and US$30 million are adjusted when necessary to account for the expenditure on efficiency improving technology, main machinery changes, and fuel choices incurred at build.
4. At the point of scrapping (year 30), we assume the ships will both return US$4.2 million (given an estimated 12,000 tonnes of steel at US$350/tonne, based on Clarkson's SIN (2016) scrapping data from this year).

These are a conservative set of assumptions, in that they assume that second hand values will be unaffected by the ship's competitiveness (due, for example, to technical specifications) in a given market. If the second hand market does price in a ship's relative competitiveness, low-tech, high-fuel consuming ships may have a second hand price lower than those estimated through this method and therefore even lower effective IRRs.

IRRs in this report are therefore computed without enforced assumptions on capital structure and use GloTraM's shipowner profit outputs (Figure 13) as cash flows. Table 8 below shows the estimated IRRs for 2020 and 2030-built ships across scenarios. Note that negative IRRs occur when the sum of cash flows is less than the initial investment.

					IRR (%)		IRR Δ				
S	**FR**	**CP**	**IH**	**BTC**	*2020*	*2030*	Between generations	Increased horizon		Increased CP (short, long)	
								2020	*2030*	*2020*	*2030*
1	Low	50	15	5%	-4	-4	0				
2	Low	50	30	75%	-16	-9	+7	-12	-5		
3	Low	200	15	5%	-4	-4	0				
4	Low	200	30	75%	-6	-2	+4	-2	+2	(0, +10)	(0, +7)
5	High	50	15	5%	-3	-3	0				
6	High	50	30	75%	-3	-1	+2	0	+2		
7	High	200	15	5%	1	0	-1				
8	High	200	30	75%	4	5	+1	+3	+5	(+4, +7)	(+3, +8)

S: scenario, FR: freight rate, CP: carbon price, IH: investment horizon (years), BTC: market barrier, G: generation

Table 8: Internal rates of return across scenarios and generations

Relatively poor yields on investments across most of our scenarios could be explained by the strict assumptions in place in GloTraM. Nonetheless, several trends can be readily identified and exploring the differences in assumptions that drive those trends provides clues to the key factors that generate good returns and, in turn, foster resilience. Some of these are discussed below.

1. *Long-term investment perspectives provide marginally better returns*

Long-term investments with a high percentage of fuel savings passed back from charterers generate marginally better IRRs than short-term investments with low feedback from charterers, except in cases of low time charter rates, where holding onto ships for a long period may be detrimental - even if the return in profits from retrofitting expenditure is relatively high (see Table 8).

For example, a long-term investment horizon with a low market barrier in poor freight markets and low carbon prices (scenarios 2 compared to 1) appears to be to the detriment of shipowners (e.g. IRR of -16% in scenario 2 and an IRR of -4% in scenario 1 for a 2020 built ship), because holding onto the ship for more than 15 years is not rewarded with improved profits to merit the investment - regardless of whether the investment is made in 2020 or 2030 or the extent of retrofits implemented.

2. *Moving from a short-term to a long-term perspective is beneficial, with the positive effect on IRR boosted in markets with high carbon prices*

Increasing the investment horizon doubles the IRR for a 2030 built ship in low freight, high carbon price scenarios (4 versus 3) from -4% to -2%, but a similar change fails to materialise for 2020 built vessels (the IRR of -4% actually falls to -6%). Coupling an increased investment horizon (with the implied increased savings pass back from charterers) with a high carbon price seems to provide the greatest changes in IRRs, with a 3% increase for 2020 built ships and a 5% increase for 2030 built ships (scenario 7 and 8). This higher carbon price effect seems to hold in general across long-term perspective scenarios. As shown in Table 8, an increase in carbon price in long-term scenarios typically produces a larger gain in IRRs for both 2020 and 2030 built ships than changes to the carbon price in short-term scenarios with low profit feedback from charterers (up to a 10% increase for 2020 built ships, and up to 8% for 2030 built ships).

3. *Returns on 2030-built ships match or exceed those on their 2020-built counterparts, with the difference exacerbated by the extent of the market barrier*

2030 built ships generally match or exceed the IRR performance of 2020 built ships under both investment horizons and appears to be marginally more resilient investments. This IRR performance gap is narrower between 2020 and 2030 built ships in short-term perspective scenarios than in the long-term scenarios, suggesting that the addition of higher fuel cost saving pass through in the long-term scenarios exacerbates the disadvantage of having an older (potentially less competitive) vessel.

The improved performance of 2030 built ships compared to 2020 built ships is in part an artefact of the way that technology availability and regulatory compliance evolves in GloTraM. A vessel in 2030 has a wider range of options for technologies than those built in 2020, and the cost-effectiveness of those technologies may have improved over time. Hence, a 2030 built vessel will tend to be better equipped technologically and should be more fuel-efficient than a 2020 built vessel over its lifetime.

This advantage may be very small, as shown in section 4.2. Higher freight rates post-2030 contribute to better returns, too, as this increases feedback from charterers, which encourages further technology uptake. 2030 built ships therefore have a natural advantage that the 2020-built fleet may not be able to match in all scenarios.

4. *Maintaining competitiveness for ships built in 2020 may require persistent investment and favourable market and policy environments*

If building in 2020, having a long investment horizon, low market barriers (higher fuel savings cost pass through from charterers), and continued investment in technology is better or even necessary to reduce the negative delta on IRR relative to 2030 built ships. The cost of maintaining such resilience and preventing illiquidity will depend on the conditions in the market (through the amount of fuel savings passed back from charterers), technology availability, and operational limitations (speed, in particular). Fostering favourable conditions through policy or other interventions may be necessary to preclude the risk of premature asset devaluation.

5. *Different technology uptake pathways and rates lead to differences in operational costs, which determine competitiveness, returns, and resilience to devaluation*

Technological differences in vessels across generations or scenarios manifest themselves as differences in operational costs, which we measure through the cost per thousand tonne kilometre variable in GloTraM. Vessels built in long-term horizons with low market barriers tend to have better technology and lower operational costs. As shown in section 4.3, large differences in cost per thousand tonne kilometres can exist when comparing across generations or scenarios. The extent of the cost advantage of a ship relative to its peers is therefore an indicator of the relative resilience of the ship to asset devaluation, because cost advantages typically translate to better IRRs and offer a buffer to future cost shocks or competition.

For example, we showed in section 4.3 that, in 2030, a 2020-built vessel in scenario 7 could have a cost per thousand tonne kilometre *disadvantage* of up to 22% against vessels built in 2020 by shipowners with long investment horizons (scenario 8). Their disadvantage extends to 13.8% against 2030 new builds, but this balloons to nearly 25% by 2035. If vessels built by investors with short-term horizons and charterers who only passed on a marginal part of their profits onto the investors were competing with vessels built by investors with longer outlooks and charterers who rewarded shipowners for investing in energy efficiency, the difference in operating costs would render the cost-inefficient vessels susceptible to asset devaluation - or even illiquidity - relative to its more efficient peers. The rate of such a devaluation could be faster than its anticipated straight-line depreciation over its expected lifetime, producing even lower IRRs than calculated heretofore.

Using measures other than IRRs can generate a more complete picture of the relative resilience of ships across our scenario space, particularly to capture the influence the parameters in the scenarios themselves have on the ships in general. This is useful as, for example, IRRs provide no information about the cost of improving resilience in particular scenarios - that is, it may be easier to be resilient in some scenarios than others purely because of the way the scenarios have been set up, and identifying those scenarios can be important when designing policy or other interventions to reduce the likelihood of stranding.

Over the lifetime of the vessel, the cumulative profits to the shipowner, average profits per year, profit volatility, and the change in profits for each dollar invested in retrofitting are explored in Table 9.

S	FR	CP	IH	G	Cumulative shipowner profits (US$)	Average profit per year of lifetime (US$)	Profit volatility (US$)	Coefficient of variation	∆Profits /∆Invest ment	IRR %
1	Low	50	15	2020	-1,363,987	-34,100	51706	-1.52	-1.7	-4%
2	Low	50	30		-16,334,506	-408,363	188797	-0.46	3.7	-16%
3	Low	200	15		-883,569	-22,089	41422	-1.88	-1.2	-4%
4	Low	200	30		-1,384,595	-34,615	462701	-13.37	21.6	-6%
5	High	50	15		4,869,620	121,741	52739	0.43	-1.9	-3%
6	High	50	30		7,035,643	175,891	190118	1.08	10.3	-3%
7	High	200	15		25,099,794	627,495	25874	0.04	-2.6	1%
8	High	200	30		40,940,905	1,023,523	562804	0.55	161.2	4%
1	Low	50	15	2030	-1,444,441	-36,111	45766	-1.27	-2.9	-4%
2	Low	50	30		-5,732,104	-143,303	101961	-0.71	0.4	-9%
3	Low	200	15		-778,863	-19,472	45660	-2.34	-2.9	-4%
4	Low	200	30		14,695,290	367,382	161553	0.44	12.6	-2%
5	High	50	15		4,438,760	110,969	26780	0.24	-5.6	-3%
6	High	50	30		16,329,667	408,242	233937	0.57	28.9	-1%
7	High	200	15		21,971,300	549,282	17298	0.03	-5.9	0%
8	High	200	30		49,036,763	1,225,919	384202	0.31	34.0	5%

S: scenario, FR: freight rate, CP: carbon price, IH: investment horizon, G: generation

Table 9: Additional measures to assess resilience

These measures provide a few interesting insights.

1. *Cumulative profits and average profit per year of lifetime*

An increase in carbon price from $50/tonne to $200/tonne either reduces losses or boosts both cumulative and average profits, all else equal. For instance, losses are reduced by 35% when moving from scenario 1 to 3 for a ship built in 2020 reduces. Profits over the vessel's lifetime can increase by a factor of 3 or more when increasing carbon prices in high-freight rate, long-term scenarios (from scenario 6 to 8, for example). A change from short to long-term perspectives that coincide with lowering market barriers improves cumulative profits in low freight rate markets only if there is a high carbon price, but improves profits in high freight rate markets regardless of the level of the carbon price.

2. *Fuel savings from retrofitting or technology uptake passed onto shipowners are key to fostering resilient vessels*

The average of the ratio of the change in shipowner profits to the change in retrofit expenditure calculates the average dollar return in profits for every additional dollar spent on retrofitting a ship. This difference, however, will be due to the compounded effect of improving time charter rates, increased fuel savings, and changes in productivity that the charterer is able to exploit given both operational changes implemented, efficiency improvements made through retrofitting, as well as the amount of savings passed back from charterers pre-defined across our scenarios.

Nonetheless, as Table 9 shows, the return from retrofits is greatest in long-term scenarios - with a high percentage (75%) of feedback from charterers - relative to short-term scenarios, ranging from $0.4 to $161.2. However, strong positive returns from retrofit investments do not always coincide with strong IRRs. Consider, for example, scenario 2 where the ship only generates an IRR of -16% because freight rates are not sufficiently high over the ship's lifetime, even though the return to the shipowner from retrofitting is at $3.7 for every dollar invested. If scenario 2 is considered an exception, then the retrofit return figures confirm that the feedback mechanism between charterers and shipowners together with longer investment horizons are central to ensuring that improving resilience and reducing the risk of stranding is rewarding to those making the necessary investments.

Table 9 hence indicates that the ease of improving resilience to potential climate change mitigation policy impacts is typically higher in long-term scenarios where there are strong signals (positive or negative) from charterers for efficiency improvements, since the changes in shipowner profit per dollar invested in retrofits are higher than in short-term scenarios. Creating such an environment may be key to ensuring ships are able to adapt to changing market conditions and maintain competitiveness cost-effectively.

3. Cash flow volatility

Another issue with looking at an IRR on its own is that it does not provide any indication of the timing or stability of the cash flows over the investment time period. Assets that produce stable, positive cash flows may be considered more valuable to particular investors. Whilst this may be reflected a-priori in the cost of capital (or the amount of capital available), a particular owner's ability to withstand substantial swings may render a particular investment - even with low IRRs relative to an asset with a more volatile cash flow - more valuable. We can assess this across scenarios and generations by combining the information available from cumulative profits over the ship's lifetime, its average profit per year, the profit volatility (through standard deviation), and the ratio of volatility to the average annual profit (the coefficient of variation), as shown Table 9. For example, a ship built in 2020 in both scenarios 5 and 6 provides an equivalent IRR of -3%, but the one in scenario 5 provides a better coefficient of variation and a comparable average profit per year. The ship in scenario 5 may therefore be more valuable to particular investors than the ship in scenario 6, even once differences in specification have been accounted for.

5.1 Making investment decisions in uncertain times

The prospect of incoming climate change mitigation policy creates uncertainty. At present, with the IMO Roadmap adopted at MEPC 70, it is clear that something will change, but not when, through what mechanism and with what response.

Uncertainty is not a new topic when it comes to investment in ships and shipping. Market cycles have always created volatility in revenues and asset values, and managing the timing of entry and exit into uncertain markets has become an important component of many successful shipping businesses. In light of everyday uncertainty, what are these added climate change mitigation policy uncertainties or risks, what might the opportunities be, and how could this be handled in practice?

5.1.1 Stranded assets?

One question considered in this work is whether climate change mitigation policy can create assets that become stranded. An asset becoming 'stranded' is also a risk in everyday shipping markets where prolonged unexpected downturns can cause consistent losses and premature scrapping. However, for the particular cases considered here, there was no systematic evidence that a "low tech" ship built without foreseeing the future regulation scenarios considered, would be unable to continue to trade throughout a normal operating life. This was because:

- The nature of retrofitting means that if and when mitigation policy starts to have an impact (e.g. high carbon price starts), steps can be taken to retrofit a "low tech" ship and bring it into a more competitive specification.
- Variations in the freight rates and revenue mean that even "low tech" ships can make a profit in good markets that may be experiencing carbon prices such as those simulated here.

It should be noted that these conclusions are drawn for scenarios and timescales over which no significant change in fuel or machinery technology appeared, but where the change in technical specification is characterised by different combinations of energy efficiency technology that could mostly be fitted incrementally. Fuel and machinery switches can be much more disruptive and therefore more difficult to retrofit, making it more burdensome for an initially "low tech" conventional ship to keep up with evolving market conditions.

5.1.2 Short or long-term perspective?

Table 9 and Figure 13 in combination show that taking a longer-term perspective might produce higher profits at some point in the future and over a long-term investment period, but that this is likely to be at the detriment of profit in the near term. However, there remains uncertainty about the many parameters that would define when and to what magnitude future profits might be impacted, as well as uncertainty about the technologies that may yet become available to help reduce a ship's CO_2 emissions.

A balanced view of the likelihood of each of the different scenarios assessed here could therefore yield the conclusion that, particularly when market barriers are expected to persist, a short-term perspective may still be the more practical choice now given the better expected near-term profitability - and who knows what will happen in the long term (besides death and taxes).

5.1.3 Profits are maximised through technical and operational choices in combination

Depending on the way a ship is being operated commercially, costs and revenues can fall in different ways, and incentivise different operational decisions to maximise profits. However, a ship with higher technical efficiency normally means higher operating speeds (and therefore higher revenue) because of lower marginal increases in fuel consumption relative to a "low tech" ship. Market barriers can reduce the returns to the shipowner in such situations, but increased transparency in shipping markets could change this – as indicated by the sensitivity of the results to the market barrier factor.

5.1.4 Could options be a way forwards?

The fundamentals of the situation that shipowners and financiers face – that a "high tech" ship prepared for operation under climate change mitigation policy is likely to increase in value as time and certainty towards decarbonisation increases – makes the idea of an option interesting. An option is a contract that gives the buyer the right, but no obligation, to buy an asset at some point in the future at a given price. If the given price is the expected market value assuming "business as usual" in terms of policy, then an option could be sold on a "high tech" ship that helps reward the long-term perspective taken at the point of purchase where otherwise only a short-term perspective could be justified.

6 Concluding remarks

There are a number of concluding remarks that can be drawn by summarising this report's general content, key findings and discussions.

6.1 Understand the problem

Given the number of different environmental regulations that are already impacting shipowners and financiers, the concept of needing to apply additional technology or introducing changes to operations must not be new and suggests that there should already be a baseline understanding of climate change mitigation policy risks. A straightforward first step is therefore to keep abreast of the evolving public and private sector discussions on GHG emissions, and look out for signals that could cause changes in demand for your sector of the shipping market or affect the technology requirements and operation of your ships.

It can be tempting to assume that the timescale of any change is long (due to the decadal timescale that is often used to discuss and then implement regulatory instruments), but, given the scale of the GHG challenge and the consequent rapidly evolving policy and technology in parallel sectors, shipping needs to be alert.

6.2 Evaluate your ship's or fleet's competitiveness under potential future market conditions

To our knowledge, it is not commonplace to undertake techno-economic analysis to consider a ship's competitiveness when making financial decisions. This is because ship designs have become relatively consistent, with one or two classes of technical specification (e.g. 'eco' ships), and a rule of thumb is used to identify their differential value based on basic information available at the time of purchase. Often technical assessments are then undertaken in isolation – e.g. the decision to choose LNG, or HFO with a scrubber, or MDO/LSHFO is taken on the basis of a trade-off between the capital expenditure and operational expenditure implications of these three solutions, not an attempt at an integrated assessment that also considers how different fuel and machinery options might be compatible with different energy efficiency technologies and operating speed strategies or their relative value in the future. Scenario analysis that combines a techno-economic assessment with a number of foreseeable policy scenarios for the inevitable but uncertain future climate mitigation policy is a further tool that can help anticipate and therefore mitigate risks.

However, as demonstrated in this report, tools to investigate competitiveness, risks, and resilience of different ship designs and specifications are increasingly available and are increasing in their rigour. This makes it hard to comprehend why such an assessment is not standard practice, given the scale of shipping's asset values and risks to asset values from climate change mitigation policy.

6.3 Have an answer for these questions

1. What would be the most profitable way to modify your ship in the future to lower operational carbon emissions (e.g. as a response to carbon pricing) per t.nm by 20, 40, 60 or even 80%?
2. What could you do to your ship now to enable it to accept these future modifications at minimal additional cost?
3. Is there a way to justify any of these modifications now, perhaps through innovative solutions such as the use of options or by securing charterer investment through retrofit shared-savings clause?
4. How would any future retrofitting be financed?

Assuming choices continue to be made based on a short-term perspective - at least until there is greater certainty about future policy - then the obvious approach is to be prepared. This report illustrated conditions where progressive retrofits applied to a basic newbuild specification over the course of its life to maximise its profitability could help mitigate the risk from uncertain climate-change regulations. Planning for these retrofits in advance may make identifying and justifying funding easier, as well as potentially reducing overall implementation costs. Furthermore, having an eye out for innovative financing and identifying a method of financing future retrofits, could help ensure that if and when the time comes, finance can be raised and the retrofits can be deployed – something that has become non-trivial in today's depressed market.

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Appendix A – Overview of method

Our ship earning projections out to 2050 are based on a quantitative estimate using the shipping model called GloTraM (Global Transport Model). GloTraM combines multi-disciplinary analysis and modelling techniques to explore foreseeable futures of the shipping industry. It computationally simulates the evolution of the shipping fleet from a baseline year to the projection year.

A conceptualisation of the modelling framework can be seen in Figure 14. Each box describes a component within the shipping model. The feedbacks and interconnections are complex and only a few are displayed on this diagram for the sake of clarity. This conceptualisation allows us to break down the shipping system into manageable analysis tasks, ensure that the analysis and any algorithms used are robust, and then connect everything together to consider the dynamics at a whole-system level. A detailed model methodology documentation can be found in Smith et al. (2013) or the "Global Marine Fuel Trends" report released in 2014 (in collaboration with Lloyd's Register).

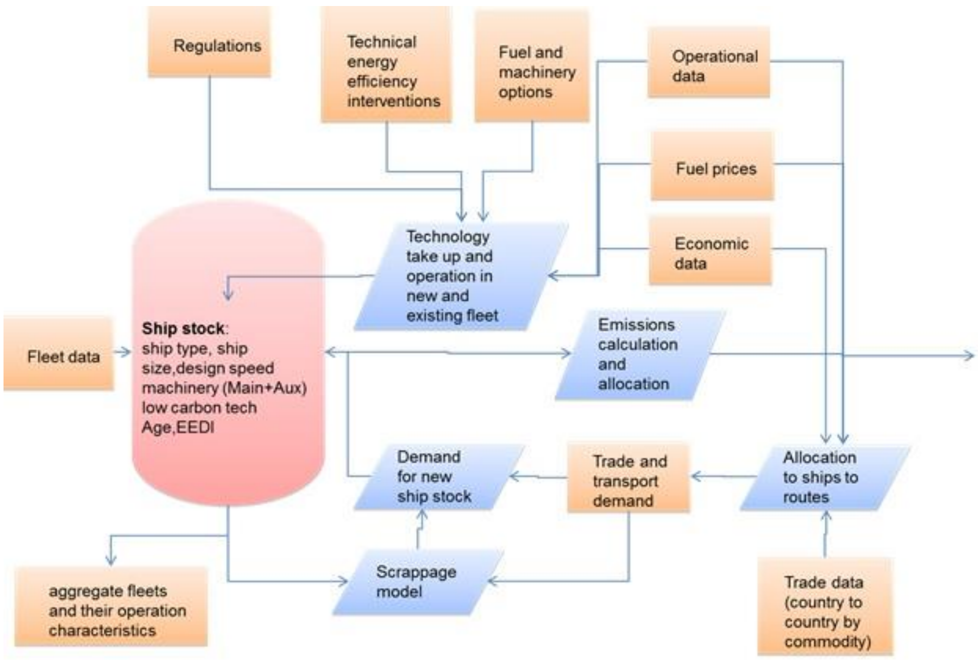

Figure 14: Schematic overview of the GloTraM model

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

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

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

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

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

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

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

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

1. Main machinery and fuel
2. Energy efficiency technologies
3. Operational speed

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

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

Calculation of profitability

The investment perspective is that of the shipowner, as the shipowner is assumed to be the agent with the responsibility for investing in newbuilds or modifications to an existing ship's specification. In order to represent the scenario where the shipowner does not also operate the ship or have responsibility for the fuel bills, the shipowner is assumed to generate revenue as a function of the ship's time charter rate and that it is in turn sub-chartered out to the spot market through voyage chartering. One consequence of this contractual simplification is that some of the fuel cost savings associated with an energy efficiency investment might not be passed back to the shipowner. To artificially facilitate this, we use a market barrier factor that represents the proportion of charterer's fuel cost savings that are returned to the shipowner. If the assumption is that there are no market barriers, or that the ship type/size category is dominated by ships which are owned and operated by the same agent, then these barrier factors can be set to 1 and they will have no effect.

In order to calculate the NPVs as measure of the profitability, the following steps are taken:

1. Calculation of the annual voyage costs, including fuel expenditure
2. Calculation of the annual voyage charter revenue, based on a US$/tonne assessment of voyage incomes
3. Calculation of shipowner's annual revenue and costs
4. Calculation of the NPV

Details on the calculation of each of these variables are given in the following sections.

Annual voyage costs

Voyage costs are calculated as the sum of the products of: fuel consumption and fuel price (for each fuel), carbon emission and carbon price (in the event there is a carbon price) and port costs and duration of time in port.

The following equation is used to calculate the ship's annual fuel consumption and the associated carbon emissions (found through the application of fuel specific carbon factors):

CV = sum(fuelcost(i)*annfuel(i)) + annCO2*carboncost

Where

- *CV are the Voyage costs,*
- fuelcost (i) is the price of fuel (i)
- annfuel (i) is the annual fuel consumption of fuel type (i) which depends on the states (loaded, ballast, and in port), *P* the power output of the main and auxiliary engines in each state, SFC their specific fuel oil consumption rate, and Ds is the number of days spent per year in that state.
- AnnCO2 is the the annual carbon emission, which depend on the carbon factor of each fuel used (i)
- Carbon costs is the carbon price

The calculation of the ship's annual supply of transport work (allowing for changes in ship speed and taking into consideration the capacity utilisation), and annual time spent in the loaded condition, ballast condition, and in port is also undertaken within the model

The inventory costs can also be calculated. These are the costs associated with the cost of financing the goods while they are in transit and are related to the value of the goods, the time they are in transit, and the cost of capital used to finance the purchase of the goods. In the event of passenger transport, this parameter can be used as an indicator of the passenger's preference with respect to journey time or speed.

Annual voyage charter revenue

The annual voyage charter revenue is calculated as the product of the total transport supply (in tonne kilometres) and the market price for the voyage charter revenue per tonne kilometres. If a ship is slow steaming, then this will reduce the total transport supply and therefore the amount of voyage charter revenue it can generate in a year.

R_{vc_pa} is the annual voyage charter revenue. This is calculated as the freight rate (*P_vc_capkm)* multiplied by the transport work (*trans_sup_capkm)*:

$$R_{vc\_pa} = \text{P\_vc\_capkm} * \text{trans\_sup\_capkm}$$

The transport work is affected by the operational (e.g. speed, utilisation) and technical (e.g. dwt) specification of a ship as well as transport demand.

The charterer's profit is, therefore, a function of the voyage charter revenue, the annual voyage cost, and the charter rate paid. It is calculated as follows:

$$Profit_{charterer\_pa} = R\_vc\_pa - C\_V\_pa - P\_tc\_pd * 365$$

Shipowner's annual costs and revenue

The shipowner's annual costs (C_{own_pa}) are calculated as the annual capital expenditure costs. The voyage costs are assumed to be paid by a charterer and are therefore included in the revenue term. This is a simplification of the contracting practices that are observed in the industry. A shipowner's fleet for example can be chartered in both the time and spot contracts and in some cases shipowners will own and operate all the ships on spot charters and therefore observe all the voyage costs. This separation, however, allows us to explore the implications of market barriers more explicitly.

$$C\_own\_pa = Cs\_base\_pa + Cs\_delta\_pa$$

Where:

- *C_own_pa* is the shipowner's annual costs
- *Cs_base_pa* is the annual baseline costs. These costs include capital costs, brokerage fees, and operating costs (excluding port/fuel/voyage costs, but including maintenance, wages, and provisions). They are assumed to be covered by the charterer paying market time-charter day rates for all year (P_tc_pd*365).
- *Cs_delta_pa* is the change in annual capital expenditure. These costs include any additional capital expenditure, beyond those of a baseline specification, associated with the chosen retrofit/newbuild specification (both capital costs for energy efficiency technology and main machinery and annualised fixed operating costs, excluding voyage costs).

The annual revenue of the shipowner is assumed to consist of the rate paid by the time charter and a share of the annual profits generated by the charterer that is passed on to the shipowner, as follows:

$$R\_own\_pa = P\_tc\_pd * 365 + B.tc * (R\_vc\_pa - C\_V\_pa - P\_tc\_pd * 365)$$

Where:

- *R_own_pa* is the shipowner's annual revenue
- Ptc_pd is the market time-charter day rate,
- Btc is the time charter and voyage charter barrier factors
- Rvc_pa is the annual voyage charter revenue,
- CI_delta and Cv_pa are the inventory cost delta (relative to the baseline inventory cost, and annual voyage cost respectively.

B_tc is the percentage of the fuel cost saving that is passed to the shipowner. It represents the time charter premium that is obtained by the shipowner as a result of the fuel savings made by the charterer following an intervention to improve energy efficiency by the shipowner as shown Figure 15. Incorporating the profit of the charterer into the revenue of the shipowner allows the model to consider the trade-off of design speed, energy efficiency and sunk costs. All of these are aligned to a single agent; the shipowner. However, a market barrier is introduced in order to reflect that not all the cost savings of the charterer may be appropriated by the shipowner due to imperfections in the market, e.g. lack of information, information asymmetry, and split incentives (Rehmatulla & Smith, 2015)

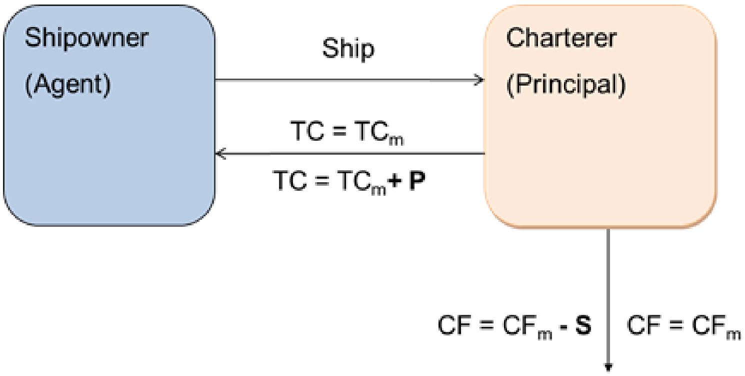

Figure 15: Illustrations of the fuel saving pass through in a time charter

CI_delta in this study is considered of second order of importance and it has been excluded from the calculation. As a consequence, Bvc does not have any influence.

The assumption that *Cs_base_pa* are covered by the charterer paying market time-charter day rates for the whole year (P_tc_pd*365) means that the model assumes a perfect market where shipowners always break even, and any excess profits or losses are those derived from the difference between the fuel cost savings passed on from charterers and the additional investment expenditure incurred, *Cs_delta_pa* (as defined above). Thus, in the absence of feedback from charterers to shipowners, shipowners would just be breaking even at all points in time unless retrofits were necessary to comply with regulation.

Calculation of the NPV

The NPV is the difference between the present value of the expected stream of revenue that an investment will generate and the present value of the expected stream of expenditures associated with the investment. The net present value is found as an assessment of the degree of profitability

$$NPV = \sum_{t}^{T} = 1\frac{R_t - C_t}{(1+r)^t} + FV_T - C_0$$

Where:

- Rt is the revenue in period t generated by the asset,
- Ct is the cost incurred each period,
- r is the cost of capital,
- FVT is the value of the asset in the final year of operation T
- C0 is the sunk cost incurred at time 0.

The interest rate (r) and the time horizon for the investment (T) are both user-specified.

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Appendix B – Input assumptions and external factors

Transport demand

Transport demand is an important driver as it affects the fleet composition and turnover, driving the number of ships that are laid up and the number of newbuilds.

The transport demand is exogenous to GloTraM, and is currently sourced from an independent transport modelling and forecasting company. For the purpose of this study, only a single transport demand projection is used for all scenarios, called 2 degree SSP3. It reflects the projections described in the Third IMO GHG Study 2014 (Smith et al. 2014) driven by the curves RCPs 2.6 and SSP3. The curve RCPs 2.6 is broadly consistent with 2°C temperature stabilisation and so projects declining demand for the transport of fossil commodities, however, the SSP3 curve is, instead, consistent with a de-globalised world. The combination of RCP 2.6 and SSP3 can be fundamentally incompatible; therefore other future transport demand could be used as input assumptions. Figure 16 shows the transport demand for the particular sector examined in this study. In this case, the phasing out of coal is more than counteracted by growth in demand for other bulk commodities and therefore it can be observed a steady growth.

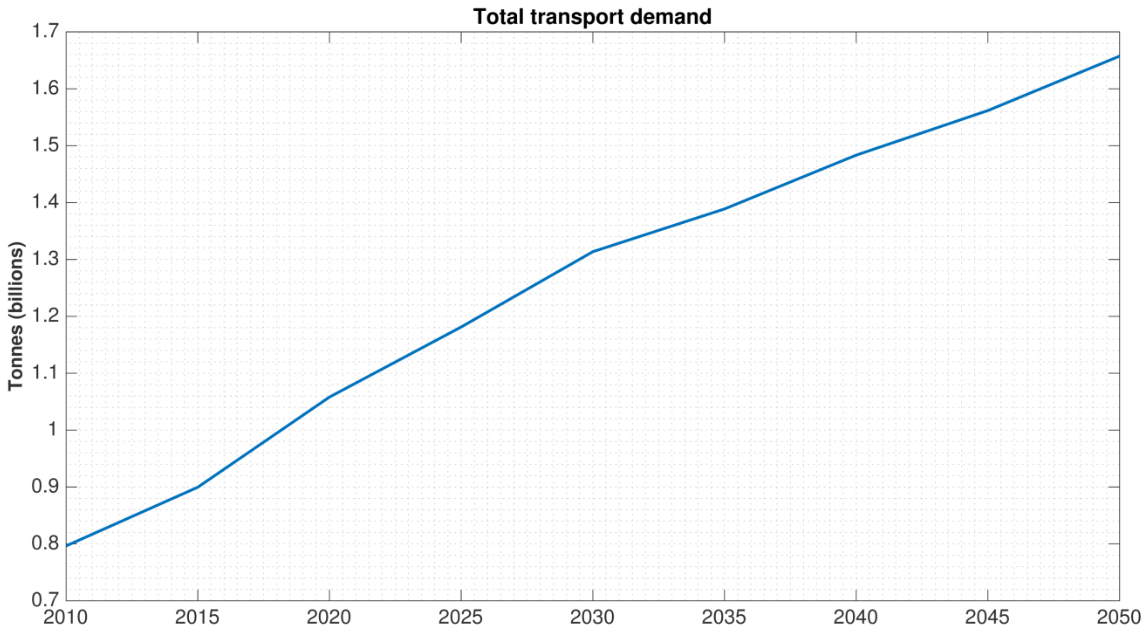

Figure 16: Transport demand for drybulk 60,000-99,999 DWT

Freight rates

Time charter rates and their long-term projections are derived from a combination of external data sources and expert judgments and are treated exogenously. Historical rates (until December 2016) are obtained from Clarkson's SIN (2016). We extrapolate projected freight rates until 2050 with a stylized curve to represent two different long-term projections: one with low projected time charter rates (low case) and another with high projected time charter rates (high case). The long-term projections exclude the cyclicality trends that are observed in historical time series. Both base scenarios explored in this section use the low projection.

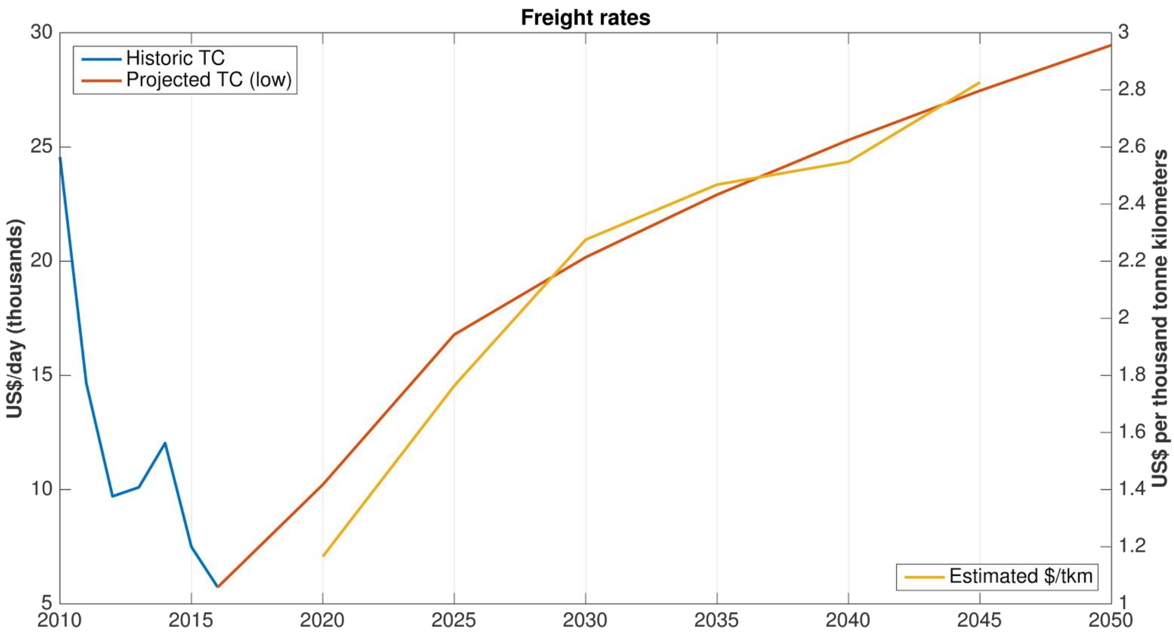

Figure 17: Freight rates

The time charter rates used are exogenous and do not take into account the differences in the rates that may be expected for ships with different technical efficiency.

Fuel price

Figure 18 shows fuel price projections for different fuels. The prices are derived from the modelling output of TIAM-UCL, which is an energy systems model that investigates decarbonisation of the global E3 (energy-environment-economy) system (Anandarajah et al. 2011).

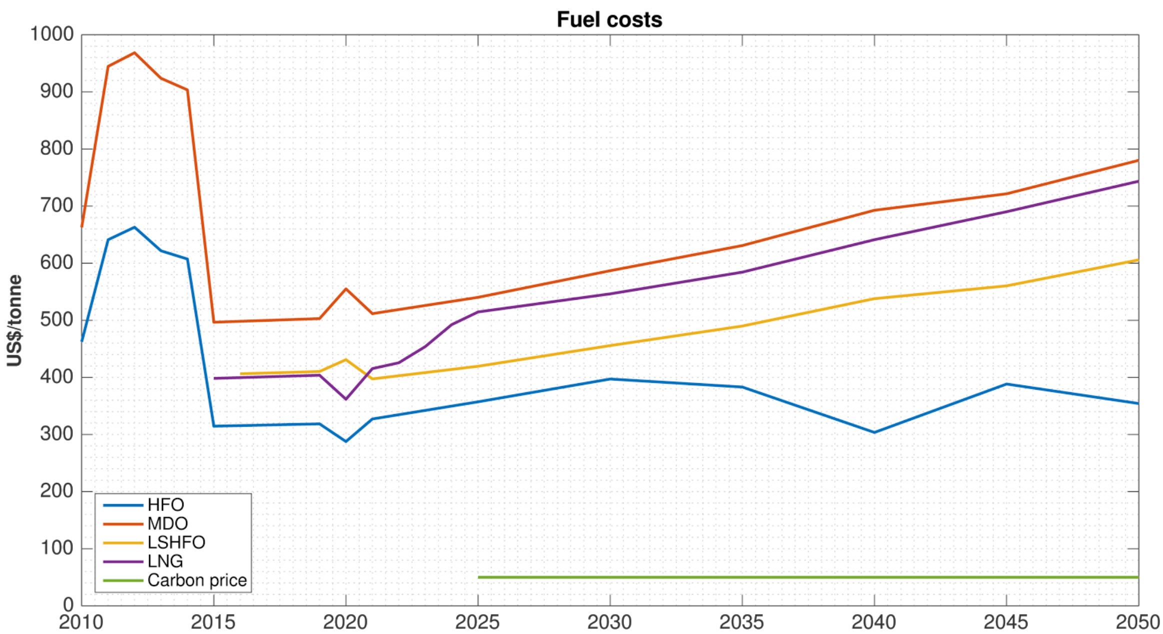

Figure 18: Fuel price projections

Carbon price

At its 70th session in October 2016, the IMO's Marine Environment Protection (MEPC) approved a roadmap (2017 through to 2023) for developing a "Comprehensive IMO strategy on reduction of GHG emissions from ships". The roadmap foresees an initial GHG emissions reduction strategy to be adopted in 2018 in time for the UNFCCC facilitative dialogue, the revised strategy is to be adopted in spring 2023.

Under the roadmap, a list of further short-, medium-, and long-term measures are to be discussed and considered for inclusion in the IMO's GHG reduction strategy. So far, no measures have been mentioned specifically, however, it is possible that such measures could include carbon pricing.

Should carbon pricing be included in the revised strategy, the earliest entry into force date would be 2025. That is because for a carbon price to enter into force, the IMO may have to adopt a new convention which requires some time. The time-scale required to establish a new convention and design the administrative infrastructure will make entry into force sooner than 2025 infeasible. For this reason, we have set the start date for carbon pricing as 2025.

Two different prices have been set to indicate a low carbon price ($50/tonne) and a high carbon price ($200/tonne). The base scenarios use the low carbon price of $50/tonne.

Discount rate and interest rate

We assume an interest rate of 10% for the capital costs (Wang et al. 2010; Smith 2013), although recognising that this value changes depending on the specific company's structure (e.g. size) and operation (Parker 2015). The discount rate is set equal to the interest rate at 10%.

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