Exploring methods for understanding stranded value: case study on LNG-capable ships

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About UCL Energy Institute

The shipping research group at UCL Energy Institute undertakes research using models of the shipping system, shipping big data, and qualitative and social science analysis of the policy and commercial structure of the shipping system. The research group's work is underpinned by state-of-the-art data supported by rigorous models and research practices, which makes it world-leading on three key areas; using big data to understand drivers of shipping emissions, using models to explore shipping's transition to a zero emissions future and providing interpretation to key decision makers in the policy and industry stakeholder space. The research group's mission is to accelerate the transition to an equitable, globally sustainable energy system through world-class shipping research, education and policy support.

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Contents

Executive summary 4
  Aims and objectives 4
  Key findings 4
  Implications 5
  Data and Method 6
1 Introduction 7
  1.1 Method 8
2 Context of the case study 9
  2.1 Shipowners 9
  2.2 Public funding 12
    2.2.1 Norway 12
    2.2.2 The European Union 13
    2.2.3 Japan and Korea 14
3 What is the value of the LNG-capable fleet at risk? 15
  3.1 Modelling the evolution of the fleet and the transition 15
  3.2 Valuation of the current and future fleet 17
4 How much LNG-capable ship value could be stranded? 20
  4.1 Approaches to modelling stranded value 20
  4.2 Case study results – stranded assets on LNG-capable ships in 2030 21
  4.3 Sensitivity to the choice of transition year 23
5 Conclusions 25
  5.1 Summary of results 25
  5.2 Implications 26
  5.3 Limitations 26
Appendix A: Methods 28
Appendix B: Newbuild price regression results 31
Appendix C: Scrappage price regression 33
Appendix D: Average scrappage age 35
Appendix E: Overview of GloTraM 37
Appendix F: List of references 43

List of figures:

Figure 1-1: Research questions and methods....8
Figure 2-1: Existing and ordered LNG-capable fleet, by shipping segment....9
Figure 2-2: Share of the orderbook, by delivery year, which is LNG-capable....10
Figure 2-3: Ownership of existing LNG-capable ship by country....10
Figure 2-4: Ownership of ordered LNG-capable ship by country....11
Figure 2-5: Top 20 shipowners of LNG-capable ships....11
Figure 3-1: Fleet capacity by fuel type (GloTraM data) in a 1.5-aligned scenario....15
Figure 3-2: Shipping emissions and remaining carbon budget....16
Figure 3-3: Projected newbuild capacity and fuel specification in a 1.5-aligned scenario....17
Figure 3-4: Projected retrofitted capacity and fuel specification in a 1.5-aligned scenario....17
Figure 3-5: Second-hand value of the fleet by fuel type until 2030....18
Figure 3-6: Second-hand value of the LNG-capable fleet, 2018-2030....18
Figure 4-1: Modelled stranded LNG-capable value - aggregate results....21
Figure 4-2: Average stranded value per shipping segment....22
Figure 4-3: Stranded value due to the need to retrofit to ammonia and the competition with LSHFO, by build year....23
Figure 4-4: Stranded value due to retrofitting to ammonia and competition with ammonia newbuildings, by build year....23
Figure 4-5: Sensitivity of LNG-capable stranded value to the timing of the transition....24
Figure 0-1: Schematic overview of the GloTraM model....37
Figure 0-2: Illustrations of the fuel saving pass through in a time charter....41

List of tables:

Table 1: Summary of the results....25

List of abbreviations

Acronym	Definition
CAPEX	Capital Expenditure
CII	Carbon Intensity Indicator
ECA	Export Credit Agencies
EEDI	Energy Efficiency Design Index
EIB	European Investment Bank
GHG	Greenhouse Gas
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
LNG	Liquefied Natural Gas
LSHFO	Low Sulphur Heavy Fuel Oil
SZEF	Scalable Zero Emission Fuels
WFR	World Fleet Register

Executive summary

Transitions create both risks and opportunities. For shipping's transition away from fossil fuel use, much has been published on the nature of the opportunity, including understanding the case and opportunity for first movers (Smith et al. 2021). Less has been published on understanding the flip side of the opportunity, the risks to fossil assets and those exposed to those assets. Shipping is a sector where valuation is currently based on fundamentals at the point in time of the valuation, so pricing in future developments including uncertain regulatory or technology change, is not commonplace, or at least transparent. This structural feature of current valuation processes has the potential to build up risk for individual companies, or for the sector as a whole. A precedent for this is well established in industries that are more advanced in their transition (Caldecott et al. 2017; Carbon Tracker Initiative 2018). In combination, this raises two high level guiding questions which have guided this report: what is the potential materiality of stranded asset/value risk for shipping, and how could this be assessed and incorporated into strategies now, in order to reduce and mitigate the risk?

Aims and objectives

To address these high-level questions, this paper undertakes a case study on the risks associated with a particular candidate technology/fuel for shipping: LNG (Liquefied Natural Gas). LNG's application as a marine fuel is a relevant candidate for use in a case study because it is associated with new investment today, which is widely recognised to be incompatible with the long-run movement away from use of fossil fuels. However, it has been portrayed as a transition fuel on the pathway for shipping's decarbonisation. In recent years, increasing numbers of ships have been built to be LNG-capable (e.g. with dual fuel LNG/LSHFO machinery and storage and supply equipment for LNG), and many more are on order. However, there is growing scientific evidence that shows the climate benefits are limited, if not negative, compared to LSHFO (Low Sulphur Heavy Fuel Oil), when considering a full lifecycle analysis of emissions and accounting for all greenhouse gases (GHG) emissions. Furthermore, there is growing evidence that the least-cost pathway for shipping to meet its required shift away from fossil fuels is to reach a mix of electrification, and use of hydrogen and hydrogen-derived fuels (ammonia, methanol). Under an assumption that liquid bio and synthetic methane with equivalent GHG reductions to ammonia/methanol will be less competitive than ammonia, this creates a risk that the more capital-intensive LNG-capable[1] assets will have a more limited economic life and/or higher risk of stranded value than less capital intensive conventionally fuelled (HFO/LSHFO) assets.

To undertake a case study on stranded value risk, this report simulates a hypothetical scenario in which a growing rate of ordering of LNG-capable fleet in the 2020-2030 decade is followed by a period from the late 2020's of policy stimulus to strongly incentivise a shift to zero emission shipping, in line with the 1.5 degree temperature goal. To add context to this case study, the report looks at the following research questions:

1. Who are the main owners of LNG-capable ships today?
2. What could be the value of the LNG-capable fleet by 2030 if there is rapid growth in ordering?
3. If newbuild ordering and financing does not accurately anticipate the way policy and transition affects valuations of LNG-capable fleet, what methods could estimate the magnitude of stranded value both at the asset and fleet levels?

Key findings

- In 2022, the size of the LNG-capable fleet (dwt, number of ships) is small. There is therefore still time to anticipate regulatory and technology developments and manage exposure to a class of assets that may be particularly exposed to stranded value risk.

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[1] A ship is considered LNG-capable if at least one of the fuel types for its main engine is registered as LNG on Clarksons' World Fleet Register. This includes dual-fuel ships but excludes 'LNG-ready' ships, which need a retrofit to be able to use LNG as a marine fuel.

- The risk of stranded value is greatest for assets built closest to the point in time when policy and technology change, so the existing fleet are less exposed to the risk than forthcoming newbuildings. However, there is rapid and accelerating growth in ordering of LNG-capable newbuildings. Unchecked, there is material risk of the simulated scenario arising in practice. E.g. that the magnitude of the LNG-capable fleet and "value at risk" could be around $850bn in 2030.
- As Scalable Zero Emission Fuels (SZEF, such as hydrogen, ammonia, methanol) become increasingly mainstream, owners and operators of LNG-capable and conventionally fuelled assets are likely to face a choice of how to remain competitive with zero emissions newbuilds: between higher fuel costs (using drop-in fuels) or retrofitting (to SZEF).
- The scenario assumes that retrofitting is the least-cost choice for compliance/competitiveness in the 2030's, especially for younger assets (e.g. 5-10 year old vessels). The costs of the options to remain competitive or in compliance are used to explore how the market could value LNG-capable vessels relative to other existing and newbuild vessels at a point in the future when policy and technology has clarified (in this case 2030). Two different methods are proposed and applied to a 2030 market scenario[2]. The methods produce similar findings and estimate the average aggregate stranded-value of LNG-capable vessels as approximately 15-25% of their second-hand value in 2030, in the simulated scenario.
- The total stranded value is dependent on the scale of LNG-capable fleet growth this decade. If the transition from LNG to SZEF occurs over a longer period, e.g. to 2034, and many LNG-capable ships are built, the stranded value could be a larger total value. Conversely, the earlier the transition to SZEF starts, the lower the total value of the LNG-capable fleet and the lower the total stranded value.
- While most LNG-capable ships are currently LNG carriers, the recent uptake in LNG-capable ships means that most of the orderbook now includes the largest shipping segments, namely containers, oil tankers and bulk carriers.
- Greece, Japan, Bermuda and South Korea are the largest LNG-capable ship-owning countries. Governments, such as Norway, the European Union, South Korea and Japan, and public finance institutions, such as the European Investment Bank and the Japanese and Korean Export Credit Agencies have played a major role in providing financial support to LNG-capable ships over the last decade. In all these regions, public funding and support for LNG as a marine fuel is increasing.
- The continued growth in investment is contributing to the creation of stranded value risk and by association creating technology lock-in risk that can delay the transition to SZEF and therefore shipping's decarbonisation.

Implications

- Further testing and exploration of the methods developed in this study could help to investigate and understand stranded value in a wider range of scenarios (fleet evolution prior to SZEF uptake and SZEF technology), and help to advance further discussion on materiality and avoidance of stranded value risks.
- Early clarification of policy is key for avoiding a build-up of stranded value in the shipping industry. The longer it takes for policy to signal and clarify which fuels and specifications will be in compliance or competitive, the greater the risk of fleet ordering that results in significant stranded value.
- The potential level of stranded value in this case study indicates a risk to shipping's low-carbon transition. Not only does investment in LNG-capable assets risk increasing the cost of shipping's decarbonisation, but it also could create incentives for resistance to 1.5-aligned which could act against drivers of shipping's transition to SZEF.
- To minimise these risks, investors (shipowners and financiers) should consider not ordering LNG-capable ships and investing in conventionally fuelled ships which are designed for retrofit to zero-

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[2] 2030 was chosen in the scenario analysis because the modelled fleet would reach the carbon budget for shipping in the early 2030s if methane emissions are included and modelled fleet shows a peak in retrofitting in 2034. Because the date when stranded asset risk materializes is uncertain, the sensitivity of the amount of stranded assets to this assumption is checked by using the alternative dates of 2026 and 2034.

emission fuels. For existing LNG-capable ships, investors should consider ways to manage the risk of stranded value – e.g. factoring in the cost of retrofit (or other action to remain competitive/compliant) at the point of newbuild or using a steeper than linear depreciation curve.

Data and Method

A variety of methods and data sources are used to answer thee research questions. To understand which shipowners are financing LNG-capable ships, data from Clarkson's World Fleet Register (WFR) is used to identify which shipping segments, countries and companies own the current and ordered LNG-capable ships. In addition, illustrative case studies obtained from desktop research were provided to show how public funding has also promoted the uptake of LNG-capable ships. The future value of the LNG-capable fleet is estimated using the modelled future fleet in GloTraM, which combines multi-disciplinary analysis and modelling techniques to explore foreseeable futures of the shipping industry; and a regression analysis of newbuild and scrappage prices of ships. To estimate the potential for stranded assets in the case of a transition of shipping to ammonia, a novel modelling approach of stranded assets in the shipping industry is proposed. The concept behind this approach comes from the potential reduction in second-hand value of any LNG-capable ship in 2030 to the value of the other ships it competes with on the market. For the purpose of the analysis, it is assumed that commercial and regulatory pressures incentivise the use of SZEF from 2030 (in the case of this study, the example of ammonia is applied). Since LSHFO-ships are lower cost than LNG-capable ships, it is estimated that this will lead to a direct loss of value for LNG-capable ships. An alternative estimation is obtained by assuming the second-hand value of the LNG-capable ships reduces to the point where a buyer would be indifferent between buying a new ammonia-fuelled ship for a given cost and buying the LNG-capable ship with the intention of retrofitting it.

1 Introduction

Transitions create both risks and opportunities. For shipping's transition away from fossil fuel use, much has been published on the nature of the opportunity, including understanding the case and opportunity for first movers (Smith et al. 2021). Less has been published on understanding the flip side of the opportunity, the risks to fossil assets and those exposed to those assets. Shipping is a sector where valuation is currently based on fundamentals at the point in time of the valuation, so pricing in future developments including uncertain regulatory or technology change, is not commonplace, or at least transparent. This structural feature of current valuation processes has the potential to build up risk for individual companies, or for the sector as a whole. A precedent for this is well established in industries that are more advanced in their transition (Caldecott et al. 2017; Carbon Tracker Initiative 2018). In combination, this raises two high level guiding questions which have guided this report: what is the potential materiality of stranded asset/value risk for shipping, and how could this be assessed and incorporated into strategies now, in order to reduce and mitigate the risk?

To address these high-level questions, this paper undertakes a case study on the risks associated with a particular candidate technology/fuel for shipping: LNG (Liquefied Natural Gas). LNG's application as a marine fuel is a relevant candidate for use in a case study because it is associated with new investment today, which is widely recognised to be incompatible with the long-run movement away from use of fossil fuels. With 31% of the deadweight ordered being able to run on Liquefied Natural Gas (LNG) without retrofit – "LNG-capable" – and another 4% which could easily retrofit to LNG – "LNG-ready" (Clarksons World Fleet Register)[3], a transition of the shipping industry from Low Sulphur Heavy Fuel Oil (LSHFO) to LNG seems to be underway. Although LNG as a marine fuel currently only represents a small share of the existing fleet's fuel compatibility, it has been portrayed as a transitional fuel by some institutions over the last decade (CMA CGM 2021; DNB Markets 2021; DNV GL 2020). However, there is growing evidence that the benefits on lifecycle greenhouse gases (GHG) emissions of using LNG as a fuel for ships compared to LSHFO are limited, if not negative (Balcombe, Heggo, and Harrison 2022; Pavlenko et al. 2020). This LNG uptake therefore comes at odds with the necessity for shipping to dramatically reduce its GHG emissions to contribute to avoiding the consequences of dangerous climate change.

Given that the typical lifespan of ships is a couple of decades or more, in order for the shipping industry to meet the target of the Paris Agreement to limit global temperature increase by 1.5ºC by the end of the century, recently ordered LNG-capable ships will have to evolve to use scalable zero-emission solutions or be scrapped earlier than their expected end of life. Furthermore, there is growing evidence that the least-cost pathway for shipping to meet its required shift away from fossil fuels is to reach a mix of electrification, and use of hydrogen and hydrogen-derived fuels (ammonia, methanol). Under an assumption that liquid bio and synthetic methane with equivalent GHG reductions to ammonia/methanol will be less competitive than ammonia, these ships are therefore at risk of becoming stranded if GHG mitigation policy in line with the Paris Agreement is implemented. We define stranded assets as assets "which have suffered from unanticipated or premature write-downs, devaluations or conversion to liabilities" (Caldecott and McDaniels 2014).

To undertake a case study on stranded value risk of LNG-capable assets, this report simulates a hypothetical scenario in which a growing rate of ordering of LNG-capable fleet in the 2020-2030 decade is followed by a period from the late 2020's of policy stimulus to strongly incentivise a shift to zero emission shipping, in line with the 1.5 degree temperature goal. The report looks at the following research questions (RQ):

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[3] A ship is considered LNG-capable if at least one of the fuel types for its main engine is registered as LNG on Clarksons' World Fleet Register. This includes dual-fuel ships but excludes 'LNG-ready' ships, which need a retrofit to be able to use LNG as a marine fuel.

- RQ1: Who are the main owners in LNG-capable ships?
- RQ2: What could be the value of the LNG-capable fleet by 2030 if there is rapid growth in ordering?
- RQ3: If newbuild ordering and financing does not accurately anticipate the way policy and transition affects valuations of LNG-capable fleet, what methods could estimate the magnitude of stranded value both at the asset and fleet levels?

1.1 Method

The research questions are answered using several research methods, presented in Figure 1-1. Two main research methods are used to answer RQ1. To understand which shipowners are financing LNG, data on Clarkson's World Fleet Registry (WFR) is used to identify which shipping segments, countries and companies own the current and ordered LNG-capable ships. In addition, a few illustrative case studies based on desktop research were provided to show how public funding has also promoted the uptake of LNG-capable ships.

RQ2 is answered using on the one hand the modelled future fleet in GloTraM (refer to Appendix E); and a regression analysis of newbuild and scrappage prices of ships on the other hand (Appendix B, C & D). To answer RQ3, a novel modelling approach of stranded assets in the shipping industry is proposed (Appendix A) and applied to this case study.

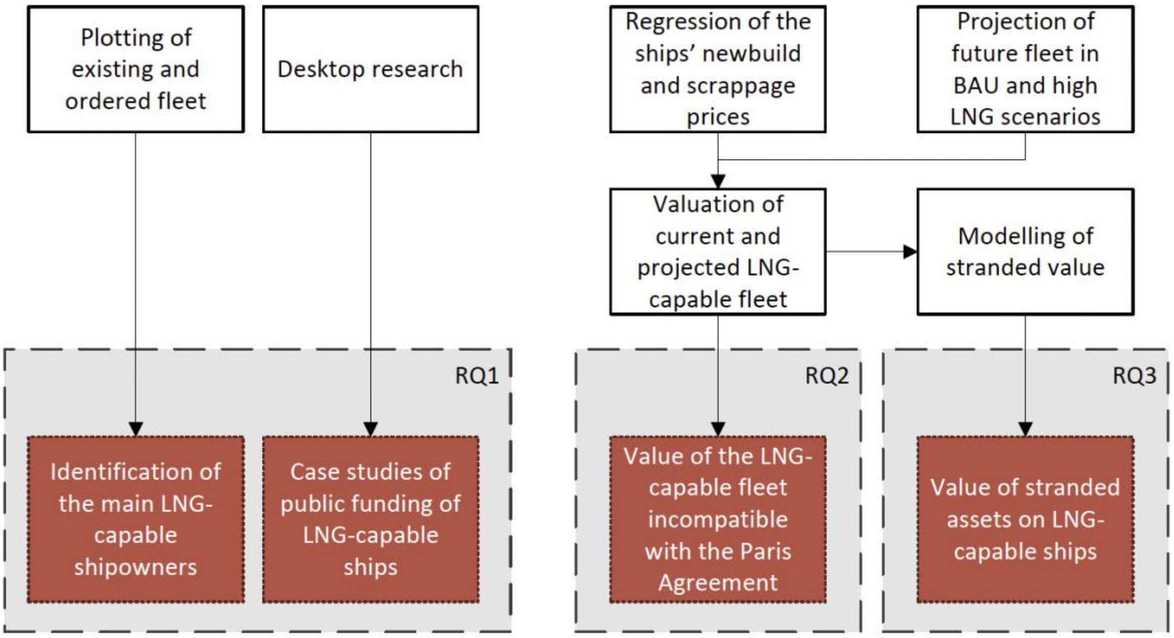

Figure 1-1: Research questions and methods

The remainder of the report is structured as follows: Section 2 provides insights on who the main investors in LNG-capable ships are (RQ1). Section 3 provides an estimate of the current and projected LNG-capable fleet and answers RQ2. Section 4 applies a new approach for modelling stranded assets if LNG-capable ships adapt to the least cost fuel/technology pathway that achieves decarbonisation in line with the Paris Agreement targets, to answer RQ3. Finally, section 5 provides some concluding remarks from the study and implications for investors.

2 Context of the case study

This section provides some context to the case study and investigates which investors are providing finance to build new LNG-capable ships (including LNG carriers). This section looks at the shipowners (section 2.1) and the sources of public funding (section 2.2).

2.1 Shipowners

This section presents the ordered and owned LNG-capable fleet from WFR dataset[4]. A ship is considered LNG-capable if at least one of the fuel types for its main engine is registered as LNG on Clarksons' WFR. This includes dual-fuel ships but excludes LNG-ready ships, which need a retrofit to be able to use LNG as a marine fuel. Figure 2-1 shows several interesting trends. First, ships ordered are going to more than double the existing LNG-capable fleet when launched on water[5]. Second, while the existing LNG-capable fleet mainly concerns liquefied gas tankers, LNG-capable ships increasingly come from other shipping segments, mainly containers, oil tankers and bulk carriers. This suggests that while LNG as a fuel was mostly relevant to the niche of LNG-carriers in the past, it is now gaining traction outside of this initial niche. Overall, at the time of writing, LNG-capable ships represent 30% of the total orderbook in deadweight, while it only represents 2% of the total existing fleet (because nearly all the existing fleet are conventionally fuelled with oil-derived fuels).

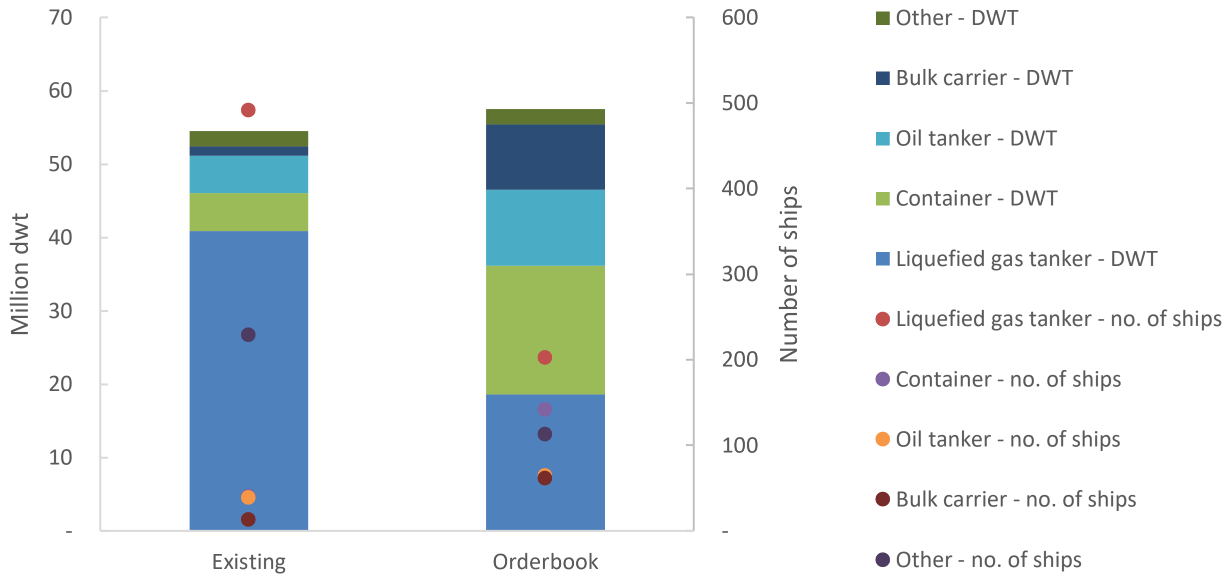

Figure 2-1: Existing and ordered LNG-capable fleet, by shipping segment

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[4] Downloaded on 10/05/2022

[5] Orderbook refers to ships whose built date is later than the date of writing, i.e. 14/06/2022

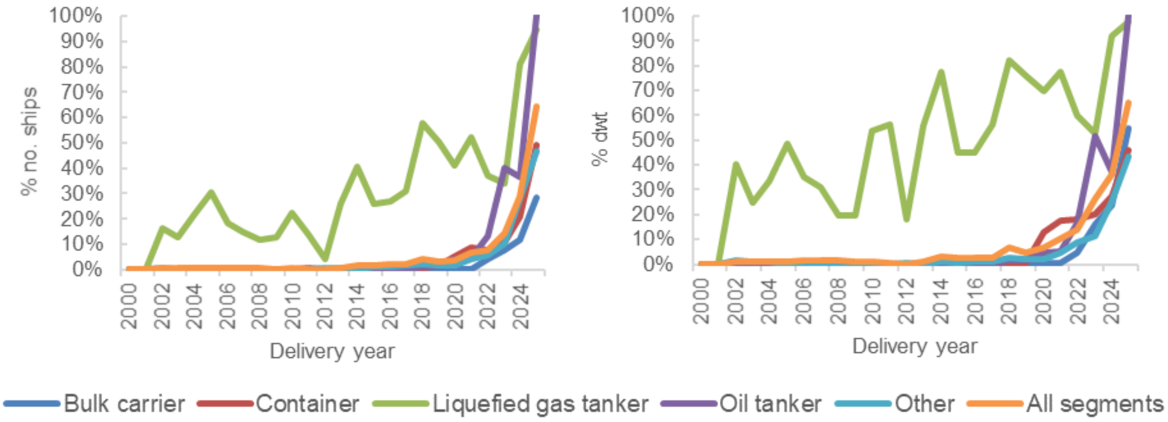

Figure 2-2: Share of the orderbook, by delivery year, which is LNG-capable
The results are presented as a share of the total number of ships (left) and deadweight (right) delivered per year – e.g. 7% of the deadweight across all segments delivered in 2020 was LNG-capable, the remainder was not. Because ships which cannot use LNG as a marine fuel are not reported, the numbers do not add up to 100%. Results after 2022 correspond to the orderbook and the years to the expected delivery year.

Figure 2-3 and Figure 2-4 show respectively the existing and ordered LNG-capable fleet, by the headquarter country of their shipowners'. They show that the geography of the orders has also changed in recent years. Historically the shipowners ordering LNG-capable ships were mostly based in Greece, Japan, Bermuda and South Korea (by deadweight). Although those countries remain in the top owning countries on the orderbook, Singapore and Switzerland have become the largest countries by deadweight of LNG-capable ships ordered. On the other hand, it is noteworthy that Norway, which has been a strong supporter of LNG-capable ships at the beginning of the transition (Baresic 2020) has fallen from the top 10 countries.

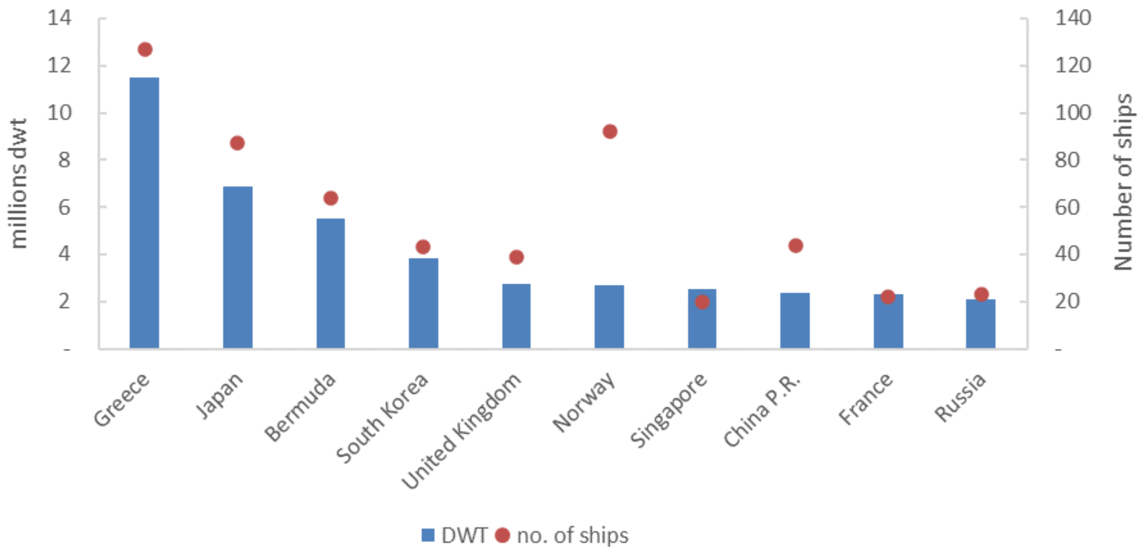

Figure 2-3: Ownership of existing LNG-capable ship by country
Countries correspond to the headquarter country of the shipowners

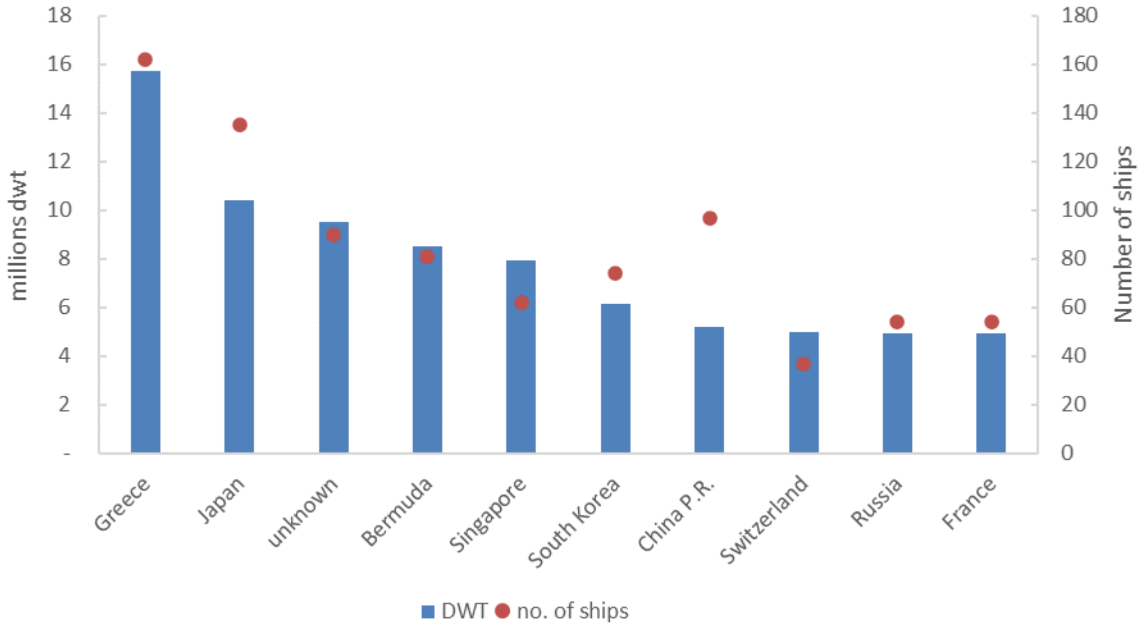

Figure 2-4: Ownership of ordered LNG-capable ship by country
Countries correspond to the headquarter country of the shipowners

Figure 2-5: Top 20 shipowners of LNG-capable ships

It is worth noting that a large amount of the ordered fleet has no identified shipowner in the WFR, which might bias the results. This is presumably because the data on orders is volunteered and partial, and many orders may be placed confidentially or without announcements. Despite this limitation, and assuming that the sample of identified shipowners of ordered ships is representative of the full orderbook, several findings are worth highlighting. The top 20 shipowners presented in Figure 2-5 (excluding the “unknown” category) represent 55% of the existing and 56% of the ordered LNG-capable fleet by deadweight, so the ownership of the LNG-capable fleet is fairly concentrated. For comparison, the top 20 shipowners of the full fleet, consisting of all conventional and alternative fuels, only own 21% of the existing fleet, and 3% of the orderbook.

Most of the largest owners of LNG-capable ships have both a strong existing fleet and a large orderbook (Eastern Pacific Shipping, Angelicoussis Group, CMA GMA, Mitsui OSK lines to cite a few). Four new entrants on the market are worth highlighting since they have ordered large amounts of LNG-capable ships: MSC, Hapag-Lloyd, Seaspan and Himalaya Shipping. Finally, a few groups with historically strong fleets of LNG-carriers have ordered smaller additional LNG-capable capacity than their counterparts, although they hold a large amount of existing LNG-capable fleet (GasLog, BW Group, Dynacom, Seapeak).

2.2 Public funding

This section introduces how public funding from governments can have a direct or indirect impact on the uptake of LNG-vessels and LNG as a marine fuel. Worldwide, a plethora of examples exist with various initiatives that have driven the uptake of LNG as a marine fuel, commonly painting LNG as a clean shipping fuel. Though this report merely focuses on three geographical areas: Norway, the European Union, and Japan & Korea, these examples provide a valuable angle to the question at hand, as such markets have proven influential in the maritime sector: Norway is seen as a leader in the battle against climate change; the European Union operates around a third of the world's registered shipping fleet; and Japan and Korea are two of the largest ship-building nations in the world.

The funding may come in different forms, i.e. as direct government funding through ministries, publicly funded banks or Export Credit Agencies (ECA) or even an emissions tax paid by ship owners themselves, but commonly, these approaches are inherently funded by the government of their respective nations or group of nations and can have a major influence on the amount of LNG assets. Subsequently, such activities have a huge influence on the reaction of the private sector and further facilitate LNG uptake, and as consequence cause an even greater risk of stranded assets.

2.2.1 Norway

In 2007 a Nitrous Oxide (NOx) tax was introduced by the Norwegian government; a measure to reduce the NOx emissions from energy generation, including those from shipping (Bektas et al. 2018). Specifically, the protocol meant that ships operating in the Norwegian waters would be subject to approximately $2.60 per kg of NOx (Bektas et al. 2018). The tax revenue that was received was then reinvested into so-called cleaner objectives. Albeit with contributions provided to electrical operation on ships and onboard exhaust treatment (NOx removing devices), LNG was predominantly funded through the fund (NOx Fondet 2018). This essentially enables Norway to create a niche-protected environment for LNG vessels and inducing surrounding markets in the Baltic Sea (Baresic 2020).

The Norwegian government provided subsidies and preferable terms for LNG uptake across the country in the last 15 years. As such, the same ship owners/operators who were paying into the fund could then apply for a subsidy that would reduce their NOx levels. Consequently, since the NOx fund was introduced, LNG-capable ships have grown in numbers in the Norwegian fleet from 4 to 61 (Laribi and Guy 2020); as of 2019, 39 of those 61 ships received financial support from the NOx fund (ReedSmith 2019). Even Danish and Swedish vessels were funded through the NOx fund and thus benefited from Norwegian LNG bunkering, but furthermore, over time, after the proof of concept of LNG fuelled ships from the NOx fund, shipowners in these respective countries were inspired and decided to transition to LNG without even receiving NOx fund support (Baresic 2020). This highlights the more global effect the NOx fund had in the maritime industry.

The government also provided a pre-emptive role in facilitating the bunkering of LNG. In 2008, a carbon tax was introduced by the Norwegian Parliament, aiming for 'carbon neutrality' by 2050; but LNG was not included. To the contrary: in order to initiate the path to net-zero carbon, the government proposed the development of LNG infrastructure to facilitate the use of the fuel in ferries (Tvedten and Bauer 2022). Subsequently, today, Norway's LNG bunkering infrastructure is well developed, consisting of 10 bunkering facilities where ships can access LNG (Miljo Direktoratet 2020), and thus has encouraged the use of LNG in other shipping sectors as well as ferries.

Despite this, with rising contention around the original exclusion of LNG from national carbon taxation (Tvedten and Bauer 2022), in 2018, the fuel was removed as an exemption. This has somewhat discouraged the uptake of LNG by making it 25% more expensive (Laribi and Guy 2020), albeit increasing the risk of stranded LNG infrastructure investment from the period before 2018. However, the NOx fund is still in full operation till 2027; as such, the fund is still granting support, totalling approximately NOK 1.2 billion, roughly $120 million for several ongoing LNG projects (NOx Fondet 2018). This will increase the risk of stranded assets compared to the risk if there was a complete halt in Norwegian subsidies of LNG infrastructure and vessel development.

2.2.2 The European Union

With greater awareness of alternative cleaner fuels such as hydrogen and ammonia, expected to play an important role in achieving the EU's objectives to reduce GHG emissions, the EU's support of LNG as a marine fuel has been dwindling in recent years. However, significant investments have been made in LNG assets over the last 10 years, and today, this issue arises once more. The conflict in Russia and Ukraine has urged European nations, who are dependent on Russian pipeline gas, to look elsewhere and, in turn, could make LNG readily available and thus a more attractive option as a marine fuel.

Since the rise of global LNG markets, the European Investment Bank (EIB) – the EU's lending arm – has financed numerous projects to increase the importation of the fuel and fuelling/bunkering of LNG for shipping under the EU Directive 2014/94/EU since 2014. This mandates an extensive LNG network to be available by 2025/2030 with the aim to encourage the use of LNG as a marine fuel (Directive 2014/94/EY of the European Parliament and of the council on the deployment of alternative fuels infrastructure 2014). As of June 2018, this totalled a quarter of a billion dollars of taxpayer's money (Transport and Environment 2018).

From a plethora of investment into LNG infrastructure from the EU, it is difficult to quantify the amount that is specific to supplying LNG as a marine fuel (as opposed to an energy commodity), but there are multiple examples of infrastructural projects that have predominantly focused on providing LNG as a marine fuel and delivered under the Directive 2014/94/EY. For example, the Iberian Peninsula has been supplied with EU funding for LNG infrastructure: firstly in 2003 for a $270 million LNG import terminal (European Investment Bank n.d.) but since the directive, the Peninsula has received additional funding from the EU in 2014 (Offshore Energy 2014) and 2020 (Offshore Energy 2020) specifically to support the uptake of LNG as a marine fuel. The latter phase of funding from the European Commission supplied €27 million under the LNGHIVE2 initiative – a Spanish led framework to drive an LNG marine fuel market in Southern Europe (European Commission n.d.).

Other examples in the EU include the lending of €49.5 million for the construction of an LNG fuelled ferry under the Green Shipping Guarantee Programme in 2017 (LNG Industry 2017) and in 2021, where a €245 million LNG import terminal is being funded in Cyprus (European Investment Bank 2021); although the terminal is predominantly for energy security, the Cyprian Government welcomes EU funding as a way of enabling LNG to become the main fuel for shipping (AllAboutShipping 2021).

In 2019, the EIB announced that after 2022 they will stop lending for any fossil fuel projects (European Investment Bank 2019). This batch of funding concludes just before an energy crisis, where due to conflict with Russia and Ukraine, Europe has focused its attention on LNG. Public funding from European nations such as Germany, France and Italy has superseded the EIB's and focused on LNG terminals, bunkering and LNG ship transportation for a greater energy security (German Federal Ministry of Economic Affairs and Climate Action 2022) (Offshore Energy 2022).

The increased public backing and investment in an LNG network over Europe since the Russian conflict could increase availability of LNG as a marine fuel. Together, with historical investment of LNG as a marine fuel in the last 10-20 years, as exemplified in this section, there is greater chance ship owners/operators are likely to take up LNG in the near future, diverting investment from fuels with genuine GHG reduction potential and increasing the risk of stranded assets. Studies from Transport and Environment suggest a quarter of Europe's shipping could be powered by LNG (Transport and Environment 2022), therefore locking in the fuel for decades with little to no climate benefit.

2.2.3 Japan and Korea

Reliance on LNG as an energy commodity has grown exponentially in recent years, specifically Japan and Korea, who are currently moving away from nuclear power after widespread concern of another nuclear disaster following the tsunami that devastated Fukushima in 2011.

The Japanese Government, in 2016, set out a strategy to develop an international LNG market with an emphasis to accelerate the uptake of LNG vessels in ports and position Japan as a LNG hub for ships (OECD/ITF 2018). Since, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLiT) funded their first bunkering vessels for ship-to-ship bunkering (NYK Line 2020) and as of January 2022, and another bunkering vessel for the supply of LNG fuel for vessels (NYK Line 2022). This follows the proposed subsidies for a Japanese cross industry plan to bunker LNG marine fuel in the heavy industrial areas of Kyushu and Setouch and supply the fuel for essential shipping routes for refineries, steel mills and car manufacturing (Argus 2022).

As part of an extensive LNG push, Japanese public funding originated from Energy Credit Agencies (ECAs) particularly the Japan Bank for International Cooperation (JBIC) and Nippon Export and Investment Insurance (NEXI). These are government-backed agencies, which have provided and continue to provide large loans for LNG infrastructure including foreign supply, importation infrastructure and LNG fuelled vessels. Roughly $7.8 billion is provided annually in Japan for fossil fuel projects, mainly LNG (Darouich, Shishlov, and Censkowsky 2021).Though it is uncertain how much of this goes specifically to LNG vessels, it highlights that the Japanese Government are trying to establish an LNG market, and with historical funding for LNG as a marine fuel, are also encouraging the uptake of LNG fuelled vessels.

Along with tax rebates for bunkering of LNG fuelled ships (S&P Global 2021), the Ministry of Trade, Industry and energy will order 40 LNG vessels by 2025, lending $620 million for small and medium sized shipbuilders (Lloyds List 2018). Similar to the situation in Japan, Korean ECAs have been heavily involved in the financing of LNG carriers including a newbuild programme funded by KEXIM and K-Sure for seven new LNG carriers (Offshore Energy 2019). Considering the size of the shipbuilding business in Korea, government support is clearly providing preferable terms for Korean shipbuilders to build LNG vessels, potentially making cheaper LNG vessels available worldwide, and thus providing incentives to an even greater market for LNG globally.

Due to the favourable conditions, private investment has followed course. Evident with the Japanese Shipping Giant, NYK line, who are reporting $900 million to order the largest order of LNG vessels yet (Maritime Executive 2021). In Korea, private investment will fund the publicly backed venture to build 100 LNG-powered vessels on-top of the 40 supplied by government funding (Lloyds List 2018). It is clear that the public funding from these nations is having an influence on amount of private funding for LNG vessels, and as such, succeeding in the development of an LNG market.

3 What is the value of the LNG-capable fleet at risk?

This section quantifies the potential maximum value of LNG-capable ships at risk of being stranded if a transition to low-carbon shipping unfolds (RQ2). Section 3.1 discusses how the fleet could evolve until the decarbonization of shipping requires shipping to stop using LNG as a marine fuel. Section 3.2 presents the projected second-hand value of the LNG-capable fleet when it happens.

3.1 Modelling the evolution of the fleet and the transition

We assume here that the transition does not happen smoothly from 2022 forward in an orderly transition to zero-carbon solutions, but here the transition away from fossil fuels is delayed to the end of the decade. We consider the case where an intermediate and partial transition to LNG unfolds in the coming decade, in line with the recent uptake of LNG as a marine fuel, before a transition to fuels with genuine GHG reductions unfolds rapidly, starting in 2030. We assume that the shipowners are blind to the risk of stranded assets until it materializes and view LNG as a transition fuel, i.e. they continue investing in LNG-capable ships until the transition unfolds and replaces the fossil-fuelled fleet. This simulated situation corresponds to a disorderly transition, i.e. a delayed policy action which only at the point where it enters into force causes the industry to realise the urgency of the situation. This takes investors by surprise and leads to a sudden shift in expectations on the future profits on fossil-fuelled ships and consequently a sudden devaluation of those assets.

The evolution of the global shipping industry from 2018 to the date when the transition unfolds is simulated in GloTraM. GloTraM is a leading global model which projects the evolution of the fleet from the 2016 baseline year on 4-year intervals, assuming that new ships are ordered to maximize the profits of the shipowners. It has been used by a variety of institutions such as the Danish Shipowners' Association (Smith et al, 2016), the DG CLIMA (Lonsdale et al, 2019) and the UK Department for Transport (Smith et al, 2019). We model a full decarbonization by 2050 of shipping operational CO2 emissions (excluding methane emissions, in particular from LNG-capable ships), and this is accompanied by a decarbonisation of the production of hydrogen (and hydrogen-derived fuels) such as ammonia. The evolution of the fleet until 2050 projected by GloTraM can be found in Figure 3-1. GloTraM projects a significant uptake of LNG-capable ships between 2022 and 2030, driven by the implementation by the International Maritime Organisation (IMO) of short-term mitigation measures (Carbon Intensity Indicator CII and Energy Efficiency Design Index EEDI) and by low carbon price in 2026 which favours LNG over LSHFO but is too low to successfully incentivize the uptake of ammonia. As a consequence, 25% of the fleet deadweight is LNG-capable in 2030. However, in 2030, the carbon price is sufficiently high that GloTraM finds a significant uptake of ammonia as a marine fuel (14% of the fleet deadweight).

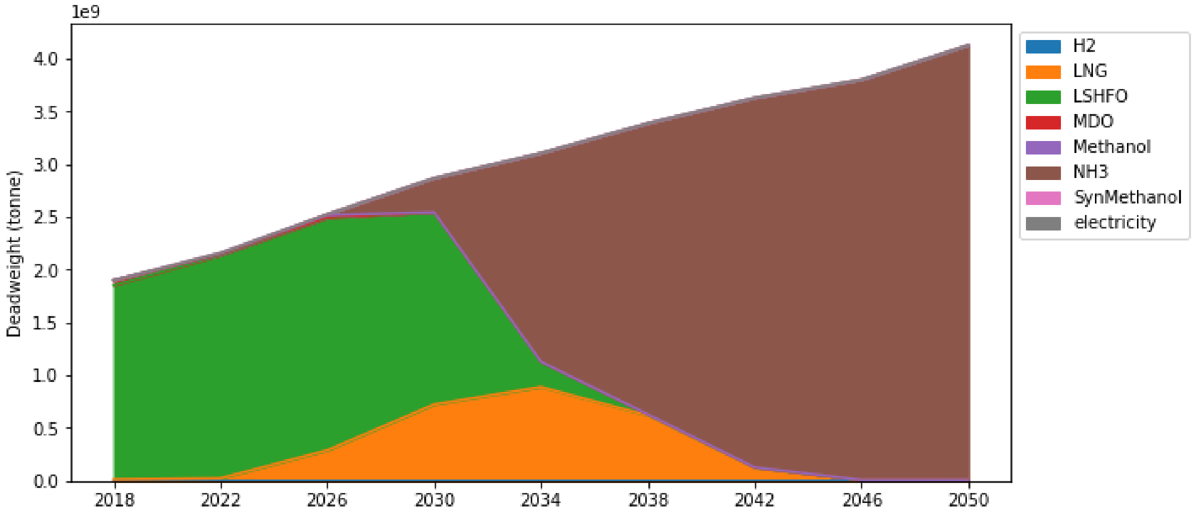

Figure 3-1: Fleet capacity by fuel type (GloTraM data) in a 1.5-aligned scenario

Decarbonization of the shipping fleet (CO2 emissions only). Note that the years after 2030 are plotted for illustrative purposes only, but this report only use modelled results up to the date at which the stranded asset risk materializes, i.e. 2030 in the standard scenario

The date at which the transition unfolds is uncertain, and therefore tested in a sensitivity analysis. We use 2030 as the standard point to evaluate the stranded assets. The choice of this date is somewhat arbitrary but follows two arguments. First, we find that the carbon budget for shipping including methane emissions is used by the beginning of 2032 (see Figure 3-2). GloTraM has a 4-year timestep and therefore presents results for 2030 and 2034, so 2030 is the last modelled year before the carbon budget is used up. Second, GloTraM finds a rapid ammonia uptake from 2030 onward (Figure 3-3), with a peak in retrofits to ammonia in 2034 (Figure 3-4), so it seems fair to assume that the transition would accelerate between 2030 and 2034 and that an initially small fleet of ammonia powered ships would be providing clear information to market actors on their options and their costs and revenues. The effect of the choice of the date at which the stranded asset risks materialize are studied in a sensitivity analysis, using 2026 and 2034 as sensitivity years.

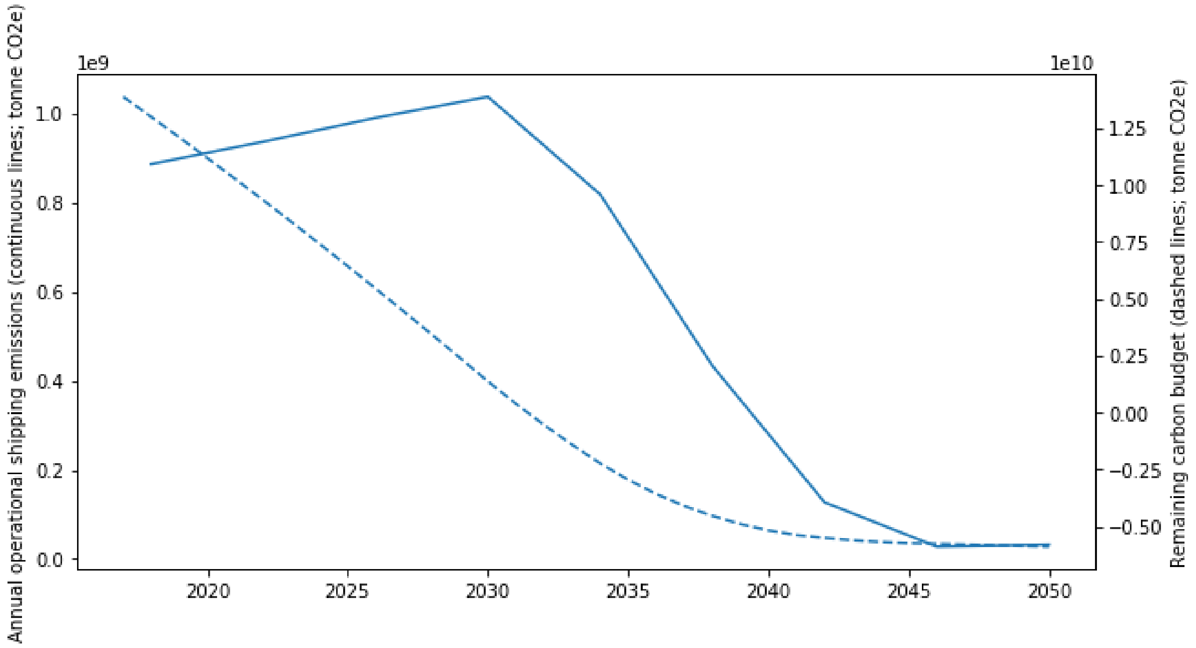

Figure 3-2: Shipping emissions and remaining carbon budget

Remaining carbon budget for shipping is calculated as the product of the global remaining carbon budget at the beginning of 2018 by the share of operational shipping emissions in world emissions in 2018 (2.89%, (IMO MEPC 2021)). The global carbon budget is taken from the Intergovernmental Panel on Climate Change (IPCC) 1.5ºC report, which estimates the remaining carbon budget from the start of 2018 consistent with a 50% chance of limiting warming to 1.5ºC to be 580 GtCO2-e (Rogelj et al. 2018). Of this estimate, 100GtCO2 should be retrieved to account for permafrost thawing and potential methane release from wetlands in the future (Rogelj et al. 2018). Annual operational GHG emissions were modelled in GloTraM.

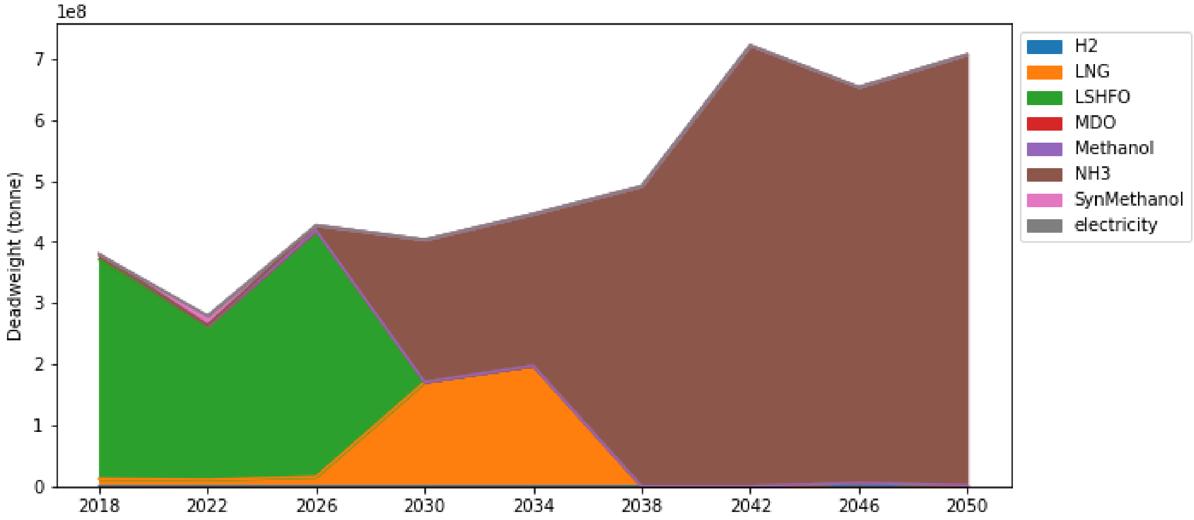

Figure 3-3: Projected newbuild capacity and fuel specification in a 1.5-aligned scenario
Modelled in GloTraM

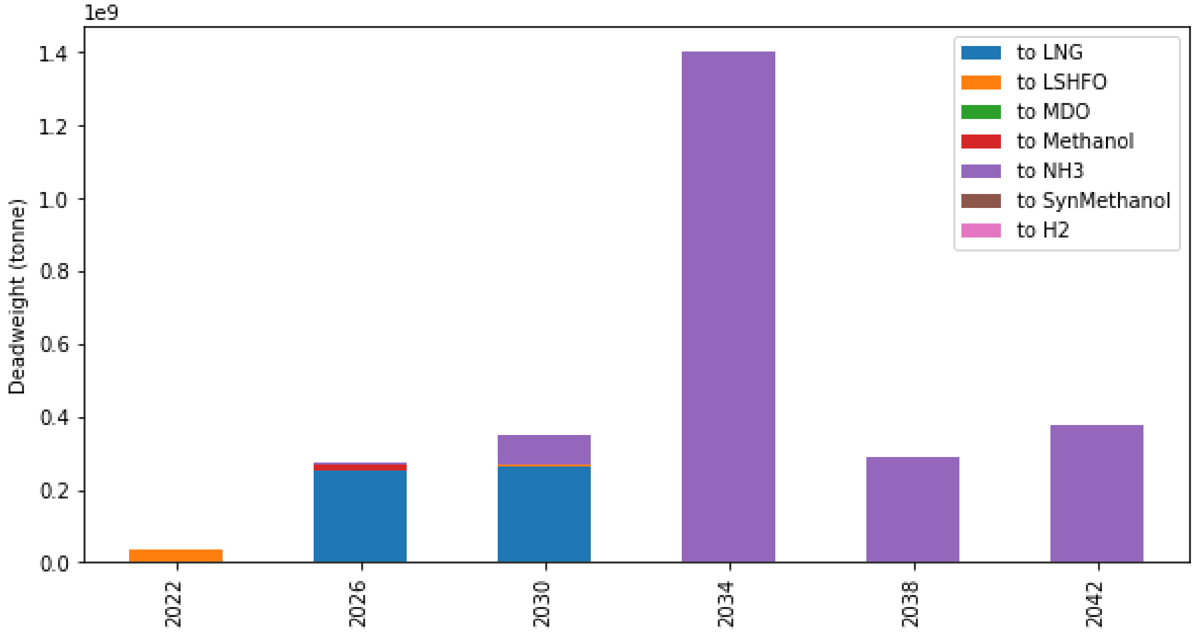

Figure 3-4: Projected retrofitted capacity and fuel specification in a 1.5-aligned scenario
Modelled in GloTraM

3.2 Valuation of the current and future fleet

The method to estimate the current and future second-hand value of the fleet is detailed in appendix A. The resulting valuation of the fleet is presented in Figure 3-5. Note that valuations were not discounted to current prices. The second-hand value of the LNG-capable fleet in 2030 reaches 44% of the total second-hand fleet value, or $890m. It is worth noting that around half of this value is represented by ships which have retrofitted to LNG since 2018 (Figure 3-6); this is because GloTraM predicts that the most profitable solution under current policy is for a large share of the LSHFO- and Marine Diesel Oil (MDO)-fuelled fleet (including LNG-ready ships) to retrofit to LNG during the coming decade.

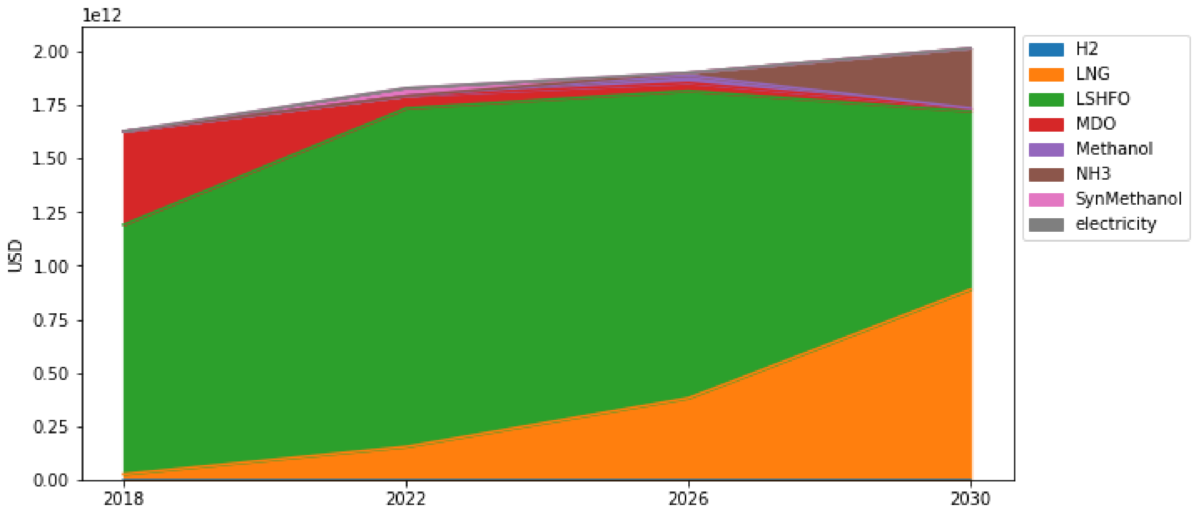

Figure 3-5: Second-hand value of the fleet by fuel type until 2030

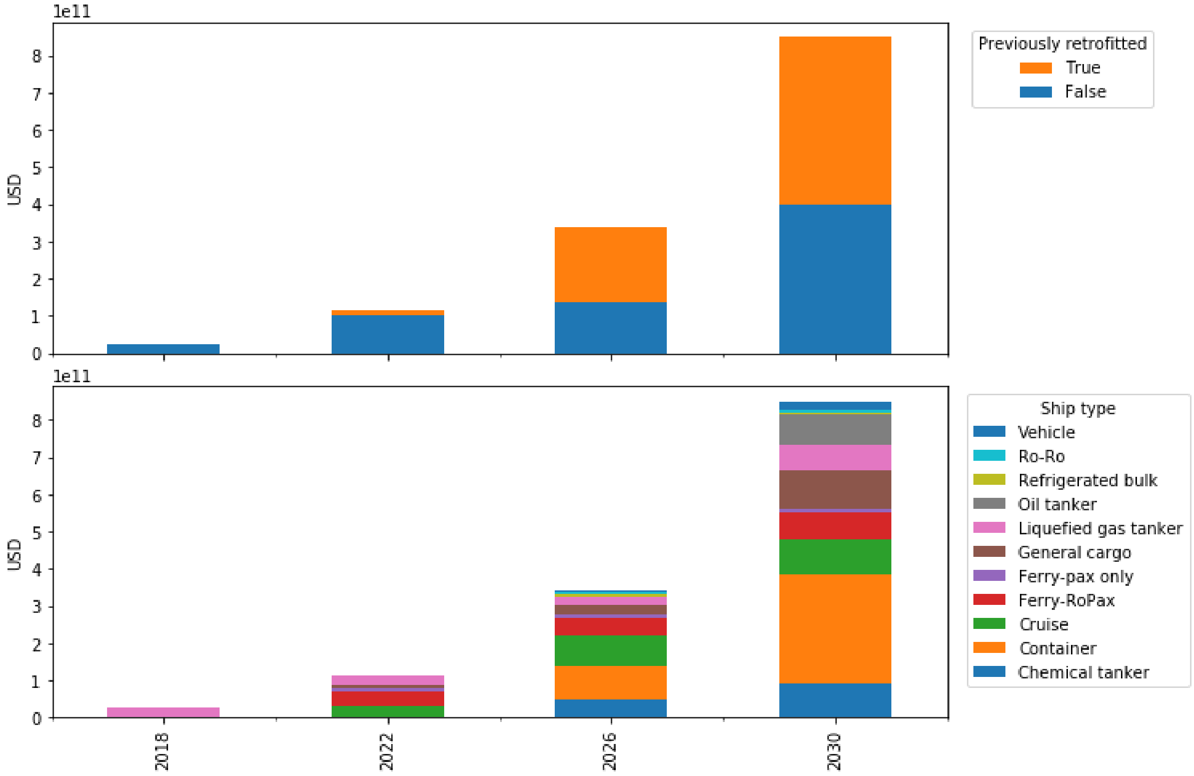

Figure 3-6: Second-hand value of the LNG-capable fleet, 2018-2030

Tugs were excluded from the analysis because there are large uncertainties on their economics and therefore uptake

By 2030, i.e. around the time of the assumed delayed transition, the large majority of the fleet is running on fossil fuels and are therefore all at risk of being stranded. Of that fossil fuelled fleet, there are $890 million of LNG-capable second-hand value at risk by 2030, if the LNG-capable ships cannot transition to the new low-carbon regime – for example, if the transition materialises through a decrease in shipping demand, or through a shift to alternative fuels to which LNG-capable ships are not easily retrofittable. If the transition unfolds through an uptake of drop-in fuels such as bio-LNG, or if the LNG-capable ships can be retrofitted to the dominant alternative fuel, then the LNG-capable fleet faces a much lower risk, although the transition would still come at a cost towards investors in the latter case. The next section investigates the impact of the latter situation, i.e. if the fuel transition's technology pathway involves an alternative fuel whereby LNG-capable ships are retrofittable. A transition to ammonia is viewed as the most cost effective low-carbon transition by several studies (DNV GL 2020; IRENA 2019, 2021; Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping 2021; Smith et al. 2019) and we therefore look at the case where all LNG-capable ships have to retrofit to ammonia.

4 How much LNG-capable ship value could be stranded?

This section is structured as follows: section 4.1 describes the approach we used to estimate the amount of stranded assets. Section 4.2 shows the results when applying this approach to our case study and if the transition unfolds in 2030, as our central scenario and section 4.3 shows the sensitivity of the results to the choice of transition year.

4.1 Approaches to modelling stranded value

As Scalable Zero Emission Fuels (SZEF, such as hydrogen, ammonia, methanol) become increasingly mainstream, owners and operators of LNG-capable and conventionally fuelled assets are likely to face a choice of how to remain competitive with zero emissions newbuilds: between higher fuel costs (using drop-in fuels) or retrofitting (to SZEF). The methods assumes that retrofitting is the least-cost choice for compliance/competitiveness in the 2030's, especially for younger assets (e.g. 5-10 year old vessels). The costs of the options to remain competitive or in compliance are used to explore how the market could value LNG-capable vessels relative to other existing and newbuild vessels at a point in the future when policy and technology has clarified (in this case 2030).

We consider two main ways by which the LNG-capable ships might lose their value when the fleet needs to retrofit to a SZEF. First, if it is as expensive to retrofit LNG-capable ships as LSHFO-fuelled ships to the most cost-competitive SZEF, and if both fleets need to retrofit, their intrinsic second-hand value in 2030 will essentially be the same. Since LSHFO-ships are cheaper than LNG-capable ships, that leads to a direct loss of value for LNG-capable ships. For illustrative purposes, let's take the example of a 120,000 deadweight oil tanker built in 2022 and with 17MW of installed power. For financing assumptions, we assume its economic lifespan is 20 years (e.g. any finance assumes second-hand value receding to zero over 20 years)[6]. We can estimate the newbuild value of this illustrative ship by using the method detailed in appendix A based on Clarkson's newbuild data: if LNG-capable, it would be worth roughly $79m while the equivalent LSHFO-fuelled would be worth $56m[7]. If we disregard the scrappage value of the vessel, in 2030, they are both 8-years old and have depreciated to $(20-8)/20 = 60\%$ of their newbuild value. The LNG-capable ship is then worth $47m and the LSHFO-fuelled equivalent $34m. If both ships have to retrofit in order to be competitive or in compliance, and if the cost of retrofitting is the same for both ships, they are worth the same, which means that the LNG-capable ships has lost its premium compared to the LSHFO-fuelled one, i.e. $47 - 34 = \$13m$ of its second-hand value.

The second way an LNG-capable ship might unexpectedly lose value is more indirect and arises from the competition between existing LNG-capable ships in 2030 with SZEF-newbuild ships – in our case study, ammonia. Let's take the case of an investor who wishes in 2030 to acquire an oil tanker with the same dimensions as described above. She has the choice between buying a second-hand 8 year-old LNG-capable ship and retrofit it to ammonia, or order a newbuild ammonia-fuelled ship. She can then run the former for its remaining 12 years or the latter for 20 years. Given a known ammonia-fuelled newbuild price, what should she be ready to pay for the 8-years old LNG-capable ship? There are several ways to quantify the answer to this question, but we simply propose here to take the value of the new ammonia-fuelled ship depreciated to 8 years old, against which we need to compare the depreciated cost of an LNG-capable newbuild including the cost of its retrofit to ammonia. Using our example, a newbuild ammonia-fuelled ship with the same dimensions would be worth around $59m, so 8-years old equivalent should be worth $60\% \times 59 = \$35m$. To compare against this, the LNG-capable ship investor would still need to pay $5m to retrofit her ship from LNG to ammonia, so she should only pay $35 - 5 = \$30m$ for the LNG-capable 8-years old ship. As a result, the LNG-capable ship has lost

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[6] We use 20 for illustrative purpose here, but when modelling the full fleet, we used the average scrap age calculated from Clarkson's WFR for the expected lifespan. See appendix A for the detailed methods and appendix D for the data used.

[7] All numbers have been rounded and the scrappage value of the ship is assumed to be 0 in this specific example for illustrative purposes; this was not the case when full results were computed.

$47 - 30 = \$17m$ of its second-hand value. The choice to use the value of the new ammonia-fuelled ship depreciated to 8 years old rests on the following underlying assumptions:

- The long-term average value of a second-hand ship is a function of its newbuild value; in other words, the newbuild and second-hand markets are linked through a linear relationship over the long run since new and second-hand ships are interchangeable;
- The long-term average second-hand value eventually outweighs the short-term variations in the market prices of second-hand ships which are ignored in this approach;
- A retrofitted and a newbuild ammonia-fuelled ship are substitutes on the market.

The methods to model stranded assets for the full fleet are detailed in Appendix A.

4.2 Case study results – stranded assets on LNG-capable ships in 2030

The stranded value was modelled for all LNG-capable ships in 2030 in the simulated scenario described in section 3. Aggregated results are shown in Figure 4-1. Several findings are worth highlighting. First, most of the LNG-capable fleet second-hand value is saved if the ships are able to retrofit to ammonia. This highlights the importance of ensuring that ships are retrofittable to limit the risk of stranded assets. Second, even though around 15% of the second-hand value of LNG-capable fleet is at risk if it loses its premium compared to LSHFO-fuelled ships, the biggest threat to LNG-capable ships is posed by newbuild ammonia-fuelled ships. Stranded value due to competition with newbuild ammonia-fuelled ships could cost the LNG-capable fleet around 25% of its second-hand value in 2030. Finally, because GloTram finds a large uptake of LNG in the 2020-2030 decade in our simulated scenario, the total amount of stranded value is large: $209bn in the case of the competition with ammonia-newbuilds.

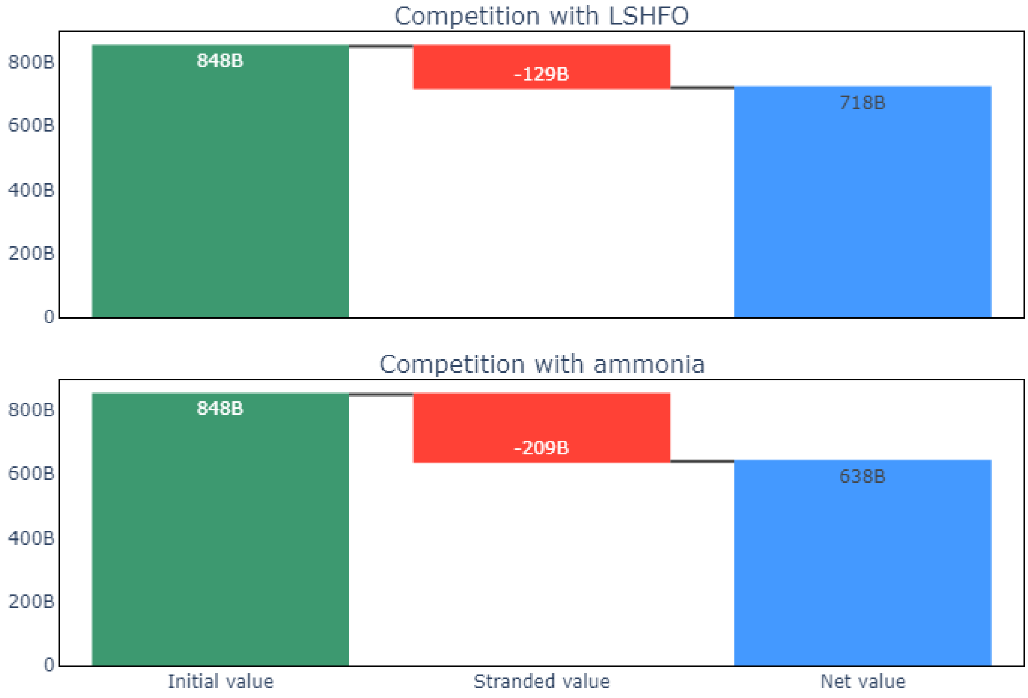

Figure 4-1: Modelled stranded LNG-capable value - aggregate results
All figures are expressed in undiscounted USD

Not all shipping segments are equally at risk of stranded assets. Shipping segments have different shares of stranded value compared to their total second-hand value, as shown in Figure 4-2. On high-value segments (for example cruise, ferries, service ships), the value of the tank and engines represents a lower share of the total value of the ship and therefore the stranded asset risk expressed as a share of total ships' second-hand value is lower than on low-value segments. Similarly, ships with large power outputs and longer ranges will require a higher capital expenditure (CAPEX) to retrofit their engines and tanks to ammonia proportionately to their total value. As a result, for each dollar invested into LNG-capable ships, the risk of stranded assets disproportionately affects containerships and bulk cargo carriers (dry bulk carriers were not modelled because no bulk carrier was projected to use LNG in GloTraM, but the same reasoning applies). In particular, containerships are the sector most at risk when using this metric; the cruise sector is the least affected. This does not mean that cruise ships will not lead to a large amount of stranded assets in absolute value, but simply that the amount of stranded assets compared to the second-hand value of the fleet is likely to be lower than for containers.

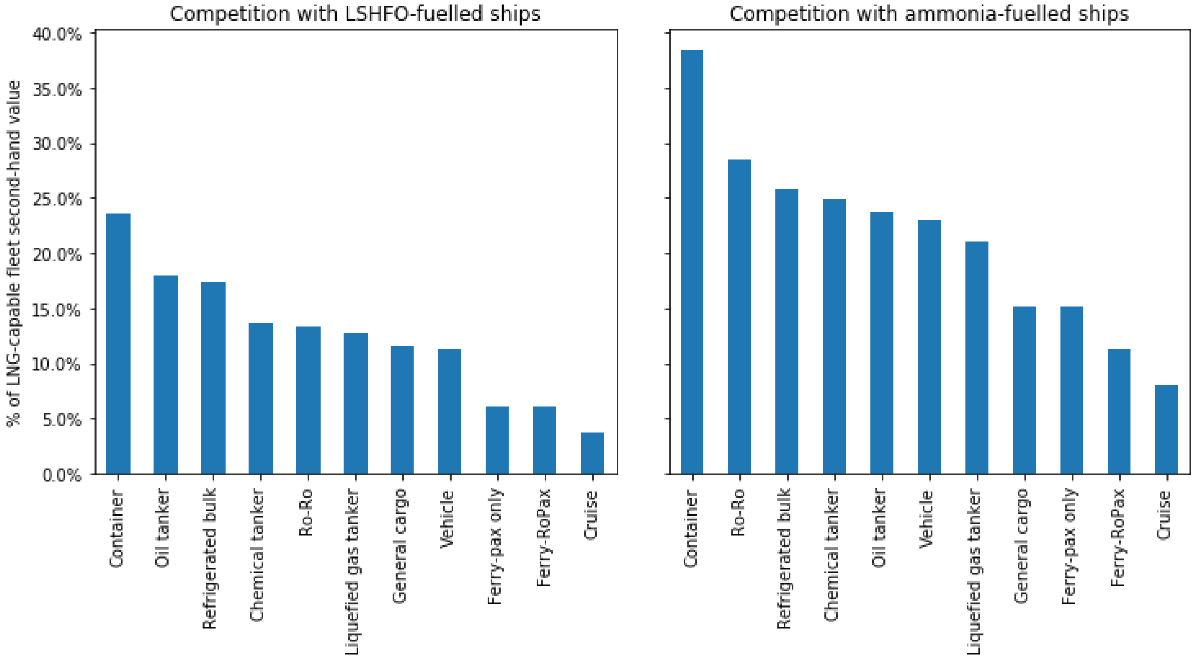

Figure 4-2: Average stranded value per shipping segment

Figure 4-3 and Figure 4-4 show the amount and share of stranded assets by build year in absolute value (left) and as share of the initial newbuild investment (right). Not surprisingly, more recent ships lose a larger share of their newbuild value, which suggests that it is riskier to invest in new LNG-capable ships as the date of the transition to ammonia comes closer.

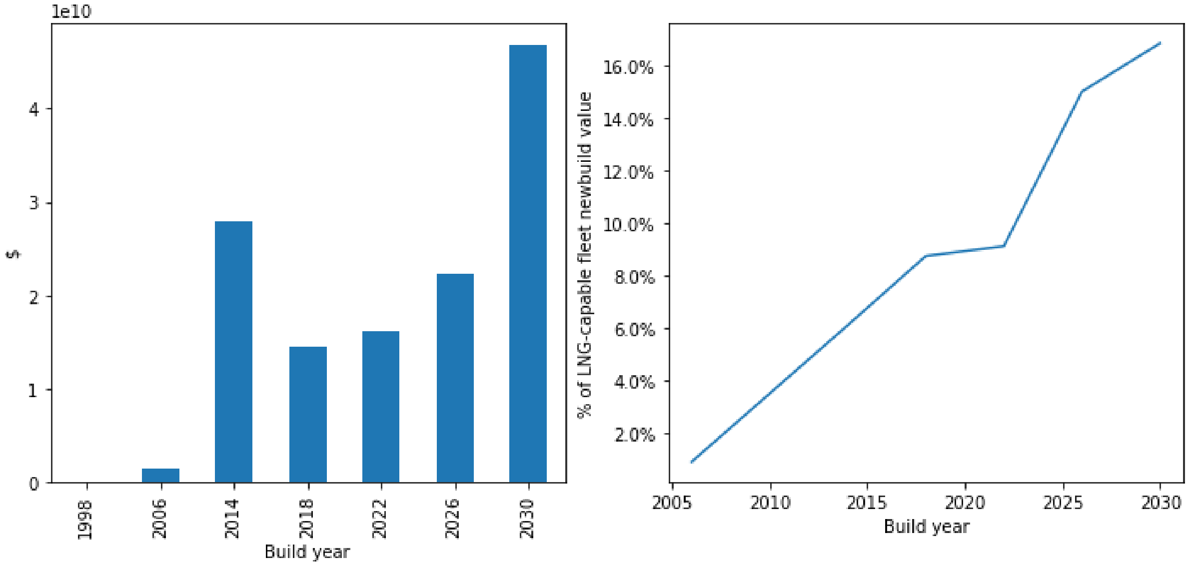

Figure 4-3: Stranded value due to the need to retrofit to ammonia and the competition with LSHFO, by build year

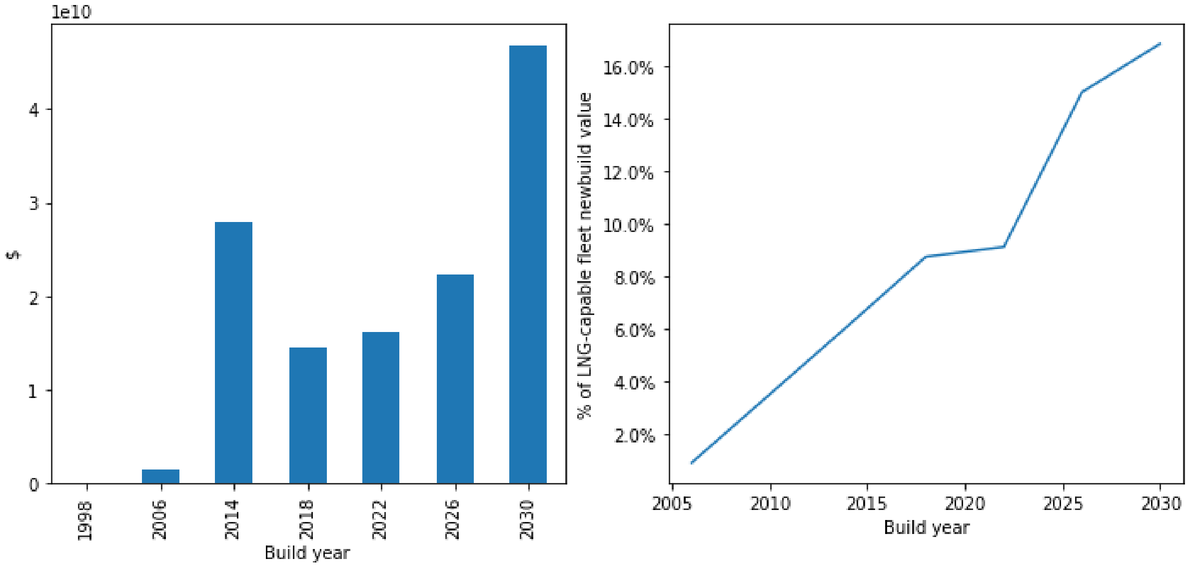

Figure 4-4: Stranded value due to retrofitting to ammonia and competition with ammonia newbuildings, by build year

4.3 Sensitivity to the choice of transition year

This section tests the sensitivity of the results to the choice of transition year. The amount of stranded value were calculated using two different years for the time at which LNG-capable ships need to retrofit to ammonia (2026 and 2034). As per the standard scenario, we assume that shipowners continue ordering LNG-capable ships until the date when climate mitigation pressure peaks up, i.e. 2026 and 2034 respectively. The absolute results, and results as share of the total second-hand value of the LNG-capable fleet at the time of stranded assets, are presented below.

Delaying the transition does not have a large effect on stranded assets, but moving the transition to ammonia 4 years earlier reduces by more than half the amount of stranded assets. This is because a large amount of the additions to the LNG-capable fleet happens between 2026 and 2030. An early transition to ammonia in this scenario would stop the transition to LNG earlier than expected and prevent investors in LNG-capable ships from losing up to $121 billion in stranded assets.

The share of stranded assets in the LNG-capable fleet's second-hand value at time of stranding is only slightly affected by the choice of year: between 13% if the risk of stranded assets arise from the competition with LSHFO-fuelled ships only, and around 24% if the risk arise from the competition with ammonia-fuelled newbuilds.

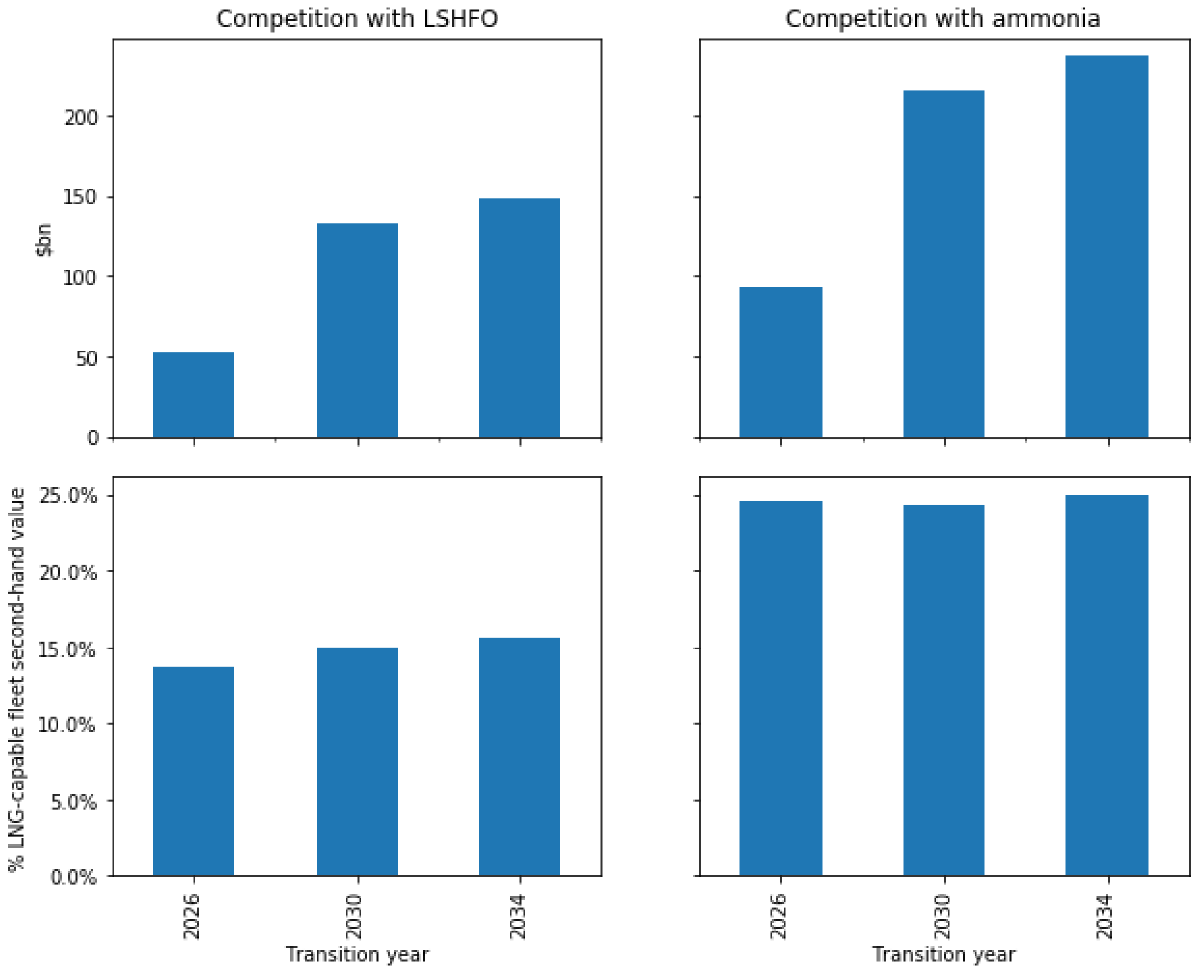

Figure 4-5: Sensitivity of LNG-capable stranded value to the timing of the transition
The lower graphs show stranded assets as a share of the LNG-capable fleet second-hand value

5 Conclusions

5.1 Summary of results

LNG has been promoted for a couple of decades as a clean alternative fuel for shipping (CMA CGM 2021; DNB Markets 2021; DNV GL 2020), and consequently, there is already an existing LNG-capable fleet, mostly on the liquefied gas tankers segment and owned by shipowners based in countries like Greece, Japan or South Korea. However, the transition of the shipping industry to LNG has accelerated over the last couple of years, so that 30% of today's orderbook is for LNG-capable ships (in deadweight). Those orders concern a much larger range of shipping segments, in particular containerships, but also bulk carriers and oil tankers.

LNG-capable ships are more expensive to build than their LSHFO-fuelled counterparts, but they show lower SOx and operational CO2 emissions. However, when accounting for methane emissions, they provide limited GHG benefits, especially if they have material methane slip during operation. Since some of current climate initiatives (Poseidon Principles) and current regulation (CII) only concern operational CO2 emissions, this can incentivise the uptake of LNG-capable vessels. However, limiting the effects of climate change and aligning shipping with the objective of the Paris Agreement requires shipping to move away from fossil fuels, including LNG. We showed that this poses a large risk of stranded assets/value to LNG-capable ships ordered recently, and to LNG-capable ships to be ordered in the future if the transition to LNG continues in the coming decade.

To undertake a case study on stranded value risk, we simulated in GloTram the evolution of the fleet in a hypothetical scenario in which there is a large uptake of LNG-capable capacity in the 2020-2030 decade. We further modelled the resulting value at risk of being stranded in 2030 due to the need to decarbonize the shipping industry in line with the 1.5 degree temperature goal. A summary of the results is provided in Table 1. The amount of stranded assets depends largely on the way transition unfolds, shown in the columns.

Uptake of bio-LNG and e-LNG and availability at prices competitive to ammonia	**Retrofitting to ammonia and competition with LSHFO**	**Retrofitting to ammonia and competition with ammonia newbuildings**	**Retrofit impossible**
$0bn	$129bn	$210bn	$848bn

Table 1: Summary of the results

These results exclude stranded assets on the tugs segment

If LNG-capable ships can move to low-carbon drop-in fuels such as bio-LNG or e-LNG and these fuels are widely available at prices competitive to ammonia, these assets are unlikely to face significant stranded value. Both of those fuels are however unlikely to be competitive with other fuels such as ammonia, which is currently one of the most promising alternative fuels (DNV GL 2020; IRENA 2019, 2021; Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping 2021; Smith et al. 2019).

We propose two methods to estimate the stranded value of an asset and of the fleet if existing ships have to retrofit to SZEF during their lifetime. If the transition unfolds by retrofitting existing ships (LSHFO- and LNG-capable) to ammonia, LNG-capable ships might lose their premium compared to LSHFO-fuelled ones, since it is as expensive to retrofit both ships to ammonia. In our case study, we modelled that this would lead to $129bn of stranded value in the simulated scenario, which might represent around 15% of the second-hand value of the LNG-capable fleet in 2030. If the transition takes the form of a transition to ammonia-fuelled ships, and if the ammonia-newbuilds create a strong downward pressure on the second-hand LNG-capable market, we showed that stranded assets might be nearly double this amount and reach 25% of the LNG-capable fleet second-hand value in 2030.

Finally, if LNG-capable ships are incapable of moving to alternative fuels – either because it is too costly or impossible to retrofit, or because the transition does not unfold as a technological transition but through a change in the consumer behaviour and shipping demand – then LNG-capable ships could lose up to all their remaining value in 2030, i.e. $890bn in our simulated scenario.

The value of stranded assets could be very large. To put the estimates of Table 1 in perspective, using the valuation method described in Appendix A, it is estimated that every year an average of $93bn of newbuild vessels were added on the water between 2014 and 2018; and the shipping portfolio of the top 62 shipping banks at the end of 2021 is $309bn (Petropoulos 2022).

5.2 Implications

This report proposes a set of methods to understand the materiality of stranded value risks. Further testing and exploration of those methods could help to investigate and understand stranded value, and help to advance further discussion on materiality and avoidance of stranded value risks.

This report stresses the importance of the clarity and credibility of future policies to investors, as new ships ordered today will hope to keep operating during the transition period over the next two decades. The longer it takes for policy to signal and clarify which fuels and specifications will be in compliance or competitive, the greater the risk of fleet ordering that results in significant stranded value. Investors today are not seeing clear signals from policy, in particular when and how methane emissions will be considered. Strong policy signals are needed to help investors in both, existing ships and newbuilds, consider and anticipate the potential impact of regulation on values as without adoption of much more stringent policy, they are unlikely to deviate from their current investment trends.

Using the case study of LNG-capable ships, and a hypothetical scenario of a high uptake of LNG in the 2020-2030 decade, this study has shown that there is a material risk that LNG-capable ships could lose part or all of their value unexpectedly around 2030s if the transition is delayed. The potential level of stranded value is a threat to shipping's low-carbon transition. Not only does investment in LNG-capable assets risk increasing the cost of shipping's decarbonisation, but it also could create incentives for resistance to 1.5-aligned which could act against drivers of shipping's transition to SZEF.

Finally, the earlier the transition starts, the smaller the amount of stranded assets/value likely to materialize on the LNG-capable fleet. Considering these findings, investors (shipowners and financiers) should consider not ordering LNG-capable ships and investing in conventionally fuelled ships which are designed for retrofit to zero-emission fuels. For existing LNG-capable ships, investors should consider ways to manage the risk of stranded value – e.g. factoring in the cost of retrofit (or other action to remain competitive/compliant) at the point of newbuild or using a steeper than linear depreciation curve.

5.3 Limitations

Key limitations include:

The valuation method for newbuilds suffers several limitations. First, the regression analysis on newbuild prices is conducted across all shipping segments, which allows us to value the whole fleet and to provide macro estimates of stranded assets. However, this analysis might overlook segment-specific price dynamics on the LNG-newbuild market. In addition, because LNG-capable ship prices could be observed on a few but not all shipping segments, this valuation method extrapolates the estimation parameters to value LNG-newbuilds to segments which have not seen any LNG-newbuild yet, while they might price LNG-capable ships in a different manner than those observed.

Second, the regression analysis could only provide an estimate of newbuild prices for the marine fuels which have been ordered (i.e. LSHFO, LNG and methanol) but not for the other alternative fuels, in particular ammonia. As a result, ammonia-newbuild prices are estimated as a component between newbuild market prices on LSHFO and a premium on machinery costs but do not reflect market price dynamics on the ammonia segment. In particular, if there is suddenly a large demand for ammonia-fuelled newbuild ships in 2030, because the shipbuilding supply is constrained in the short term, this might result in a market premium on ammonia-newbuilds above the cost differential. Our valuation function might therefore give optimistic estimates for ammonia newbuild prices, especially compared to their LNG counterparts, and should be refined once data on ammonia newbuilds become available.

On the other hand, the estimations of LNG-newbuild prices are not based on cost differential but on transactions which have already taken place. Those transactions include market dynamics: in particular, because they concern mostly first/early ships built with LNG as a marine fuel, they might carry a cost-risk which might reduce over time. If the premium on LNG newbuilds does reduce as a result of learning effects, the risk for stranded assets will naturally reduce compared to our estimate.

The valuation method for second-hand ships is naturally reductive, as it is beyond the scope of this study to replicate in details the way second-hand markets for ships work. This method describes what should be the second-hand value of the ships if it was only determined by its newbuild price, its age and the competition with equivalent ships running on alternative fuels. It does not account for short-term variations due to market dynamics, which might largely affect the second-hand value of the ships in the short term. In addition, it does not account for the fact that two ships fuelled by different fuels might not be a perfect substitute on the second-hand market, if investors have a preference for one over the other. This valuation method also assumes that ships depreciate linearly until their average scrappage price, which may not hold true in practice. In particular, it might be the case that some ships depreciate faster in their early years, since they often have lower utilisation in their later years. This method should therefore be seen as an approximation of the long-term average value of the fleet in an aggregate approach, rather than a predictive instrument of the value of a specific ship.

Finally, this report uses the results of the projection modelling by GloTraM which is subject to large uncertainty like any projection exercise. This uncertainty is mitigated by the relatively short period of projection (12 years).

This study only explores the materiality of stranded value risks in one specific scenario, i.e. a large uptake of LNG in the 2020-2030 decade followed by a large uptake of ammonia as a marine fuel. Further testing of the methods developed in this study could help to investigate stranded value in other scenarios of fleet evolution and of transition technology.

Appendix A: Methods

Valuation method of the fleet

To estimate the second-hand value of the current and future fleet, we conducted a regression of Clarkson's WFR newbuild prices by various ships' parameters, as follows:

$$\begin{aligned} P_{new}(mcr, dwt, f, s) \\ &= a1 \times dwt + a2 \times mcr + a4 \times dwt \times fueldummies + a5 \times mcr \times fueldummies \\ &+ a6 \times dwt \times typedummies + a7 \end{aligned} \tag{1}$$

With P_{new} the newbuild price of the vessel, mcr the total maximum continuous rating of the vessel (including both main and auxiliary engines), dwt the deadweight (in tonnes) of the vessel, f the main fuel of the ship and s its IMO ship type. $fueldummies$ is a series of dummy variables corresponding to the fuel (LSHFO/MDO, LNG and methanol) and $typedummies$ a series of dummy variables corresponding to the IMO types of vessel.

The vectors a_i were estimated using an ordinary least square regression analysis over 4433 data points, corresponding to the recorded newbuild prices in WFR since 2009. The results can be found in appendix B. We excluded a series of fuels from the analysis as they were outsiders and thus biasing the results[8]. The R-square of the model is 89%, which shows that it adequately predicts the newbuild prices (model 1 in appendix B). To study the sensitivity of the fuel price to short-term variations, which are not captured in the valuation method, we re-estimate the model adding interaction dummies for each ship type and each year ($years \times type$). Adding time dummies slightly increases the R-square of the model to 94% (model 2), which suggests that short-term market variations have a statistically significant impact on the newbuild prices of the ships, but this effect is relatively weak compared to the effects of the ship's design parameters. This suggest that ignoring short-term variations in newbuild prices as in equation (1) is acceptable to estimate the long-term value of the fleet.

We used the estimated parameters (a_i) to interpolate the newbuild value of the current and future fleet using conventional fuels, based on the modelled characteristics of each vessel of the current and future fleet modelled in GloTraM: power output, dwt, fuel type and ship type [9].

For most of alternative fuels, we do not have a record of their newbuild prices in the WFR. Therefore, for those fuels, we computed the newbuild value of each vessel by adding a CAPEX premium on top of the value of an equivalent ship running of LSHFO, as follows:

$$\begin{aligned} P_{new}(mcr, dwt, f, s) \\ &= P_{new}(mcr, dwt, LSHFO, s\,) + \left(Cmain_f - Cmain_{LSHFO}\right) \times MCRmain \\ &+ \left(Caux_f - Caux_{LSHFO}\right) \times MCR_{aux} + Cstorage \end{aligned} \tag{2}$$

---

[8] MDO, MGO, ethane and nuclear. We included methanol although there are few data points, for the completeness of the exercise, but the results might not be very good for this fuel. This was not considered to be an issue because the valuation of the LNG-capable fleet and the modelling of stranded assets does not use the parameters for methanol.

[9] Note that two segments were not observed in the WFR dataset of newbuild prices and could therefore not be estimated (refrigerated bulk and Ferry pax only). The newbuild value of refrigerated bulk carriers was therefore estimated using the parameters from general cargo, and Ferry pax he parameters of the Ferry RoPax.

With $MCRmain$ and $MCRaux$ the power outputs of the main and auxiliary engines respectively, $Cmain$ and $Caux$ the costs per kW of the main and auxiliary engines respectively (from GloTraM input), and $Cstorage$ the additional investment in storage required (from GloTraM data).

Finally, for each ship of the fleet at each time step, the newbuild value is linearly depreciated to its scrappage value based on the expected lifetime of the ship. The expected lifetime is proxied for each ship type and ship size by the average scrapping age of each ship type and size, calculated using the WFR (found in appendix D). The resulting depreciated second-hand value is computed as follows:

$$V_{depreciated} = V_{scrap} + (V_{new} - V_{scrap}) \times (ES - age)/ES \quad (3)$$

With ES the expected scrapping age, V_{scrap} the scrappage value and age the age of the ship. The scrappage value is estimated as a linear relation to the ship's deadweight:

$$V_{scrap} = b_1 \times dwt + b_2 \quad (4)$$

The parameters b_1 and b_2 were estimated using an OLS regression of WFR's demolition prices. Results are presented in appendix C (model 1). The validity of using the model presented in equation (4) is tested in models 2 and 3 by including additional independent variables, namely the ship type and the demolition year to account for short-term variations. Those are found to have a statistical impact on the scrappage price, but only slightly increases the predictive power of the basic regression, which only considers the deadweight (model 1) and already has a strong R-square (82%). This suggests that the regression model (4) is doing a satisfactory job in predicting the scrappage value.

The WFR data is only used to estimate the relationship between a ship's characteristics and its newbuild price (equation 1) and scrappage price (equation 4). However, it was not used to obtain the characteristics of each ship, which are necessary to interpolate their prices (ship type, power output, dwt, fuel type) but not to estimate the value of the current and future fleet. These characteristics were taken from the modelled results in GloTraM.

Modelling stranded value

The two intuitions developed in section 4.1 can be formalised mathematically for any ship as follows:

$$V_{intrinsic,competition\ with\ LSHFO}(f, dwt, s, age) = \max\left(V_{depreciated}(LSHFO, dwt, s, age), V_{scrap}\right) \quad (5)$$

With $V_{intrinsic,competition\ with\ LSHFO}$ the long-term average value of a second-hand ship of deadweight dwt, type s, running on fuel f (in our case, LNG) and age age. Note that $V_{depreciated}$ is calculated along equation (3). If the second-hand value of the ship falls below the scrappage value, the ship is scrapped and its second-hand value equals its scrappage value. The stranded value is simply the difference between the linearly depreciated value of the ship – which is a proxy of its expected value – and its intrinsic value when it is forced to retrofit to the most cost-competitive SZEF due to competition with LSHFO ships, i.e.:

$$SA_{competition\ with\ LSHFO} = V_{depreciated}(f, dwt, s, age) - V_{intrinsic,competition\ with\ LSHFO}(f, dwt, s, age) \quad (6)$$

The second intuition – stranded assets due to competition with newbuild SZEF-fuelled ships – is formalized in a similar manner:

$$V_{intrinsic,competition\ with\ SZEV}(f, dwt, s, age) = \max\left(V_{depreciated}(SZEV, dwt, s, age) - C_{retrofit}, V_{scrap}\right) \quad (6)$$

$C_{retrofit}$ is the cost of retrofitting the ship from fuel f (LNG) to the alternative fuel $SZEV$. The cost of retrofit is a function of the power output of the ship and storage capacity, and is provided by GloTraM data. The stranded value is again the difference between the depreciated and the intrinsic value of the ship:

$$SA_{intrinsic,competition\ with\ SZEV} = V_{depreciated}(f, dwt, s, age) - V_{intrinsic,competition\ with\ SZEV}(f, dwt, s, age) \quad (6)$$

To obtain the results reported in 4.2 and 4.3, the stranded value is calculated for each ship and each year modelled in GloTraM and results aggregated across the whole LNG-capable fleet.

Appendix B: Newbuild price regression results

	(1) No year FE	(2) Year FE
Deadweight	162.4***	199.2***
	(0.000)	(0.000)
Total MCR	967.3***	723.5***
	(0.000)	(0.000)
LSHFO # Deadweight	0	0
	(.)	(.)
LNG # Deadweight	128.7**	119.5**
	(0.027)	(0.017)
Methanol # Deadweight	400.6***	264.4***
	(0.000)	(0.000)
LSHFO # Total MCR	0	0
	(.)	(.)
LNG # Total MCR	441.7***	340.6**
	(0.007)	(0.015)
Methanol # Total MCR	0	0
	(.)	(.)
Bulk carrier # Deadweight	0	0
	(.)	(.)
Chemical tanker # Deadweight	129.6***	74.74
	(0.001)	(0.402)
Container # Deadweight	109.5***	250.0***
	(0.000)	(0.000)
Cruise # Deadweight	61247.0***	58615.8***
	(0.000)	(0.000)
Ferry-RoPax # Deadweight	17920.2***	-22312.6***
	(0.000)	(0.000)
General Cargo # Deadweight	132.9	673.2*
	(0.664)	(0.085)
Liquefied gas tanker # Deadweight	1069.1***	1484.5***
	(0.000)	(0.000)
Miscellaneous - other # Deadweight	141.9	190.9
	(0.176)	(0.233)
Offshore # Deadweight	7013.4***	5906.8***
	(0.000)	(0.000)
Oil tanker # Deadweight	53.10***	-4.758
	(0.000)	(0.707)
Other liquids tanker # Deadweight	31.48	-1024.3
	(0.959)	(0.573)

Ro-Ro # Deadweight	859.3*** (0.000)	310.1 (0.247)
Service - other # Deadweight	1767.4* (0.076)	3836.9 (0.113)
Vehicle # Deadweight	1816.4*** (0.000)	-2257.8*** (0.000)
Constant	14237399.1*** (0.000)	20643980.5*** (0.000)
Ship type FE	Yes	Yes
Ship type x Year FE	No	Yes
R-squared	0.892	0.939
Observations	4433	4433

Appendix C: Scrappage price regression

	(1) Demolition price	(2) Demolition price	(3) Demolition price
Deadweight	50.79*** (0.000)	54.70*** (0.000)	55.18*** (0.000)
Bulk carrier		0 (.)	0 (.)
Chemical tanker		1509474.2*** (0.000)	925736.4*** (0.009)
Container		2154055.1*** (0.000)	2129462.8*** (0.000)
Cruise		6148100.1*** (0.000)	6623368.6*** (0.000)
Ferry-RoPax		2155826.8*** (0.010)	2031123.5** (0.012)
General Cargo		646724.8 (0.241)	218632.8 (0.682)
Liquified gas tanker		3237371.1*** (0.000)	2979259.4*** (0.000)
Miscellaneous - other		1156463.3*** (0.001)	1258338.9*** (0.000)
Offshore		1197536.7*** (0.000)	1176354.7*** (0.000)
Oil tanker		1279645.1*** (0.000)	784279.6*** (0.000)
Other liquids tanker		2142468.5 (0.241)	2112121.2 (0.230)
Refrigerated bulk		1251318.1*** (0.002)	818199.1** (0.037)
Ro-Ro		1245093.4** (0.038)	1416073.9** (0.014)
Service - other		340712.2 (0.749)	223464.9 (0.828)
Service - tug		-390962.6 (0.831)	87076.6 (0.960)
Vehicle		3517659.4*** (0.000)	3756360.0*** (0.000)
Demolition year=2017			0 (.)
Demolition year=2018			326229.4 (0.195)

Demolition year=2019			44076.3 (0.865)
Demolition year=2020			-452668.6* (0.070)
Demolition year=2021			1323140.8*** (0.000)
Constant	1988116.6*** (0.000)	444848.9*** (0.010)	419185.0 (0.116)
Ship type FE	No	No	Yes
Year FE	0.825	0.861	0.873
Ship type x Year FE	735	735	735

Appendix D: Average scrappage age

Segment type	Size bin	min dwt	max dwt	Average age at scrap time
Bulk carrier	1	0	9999	41.2
	2	10000	34999	34.3
	3	35000	59999	27.7
	4	60000	99999	28.7
	5	100000	199999	21.6
	6	200000	inf	26.4
Chemical Tanker	1	0	4999	32.9
	2	5000	9999	29.9
	3	10000	19999	26.2
	4	20000	39999	25.5
	5	40000	inf	23.3
Container	1	0	999	26.9
	2	1000	1999	24.1
	3	2000	2999	25.8
	4	3000	4999	20.0
	5	5000	7999	18.9
	6	8000	11999	22.1
	7	12000	14499	23.0
	8	14500	19999	23.0
	9	20000	inf	23.0
Cruise	1	0	1999	17.4
	2	2000	9999	47.6
	3	10000	59999	39.2
	4	60000	99999	28.4
	5	100000	149999	33.1
	6	150000	inf	33.1
Ferry-RoPax	1	0	1999	40.3
	2	2000	4999	34.3
	3	5000	9999	46.8
	4	10000	19999	37.3
	5	20000	inf	30.3
General Cargo	1	0	4999	40.5
	2	5000	9999	32.9
	3	10000	19999	27.5
	4	20000	inf	28.9
Liquefied gas tanker	1	0	49999	32.3
	2	50000	99999	32.3
	3	100000	199999	38.3
	4	200000	inf	34.3
Miscellaneous - other	1	0	inf	32.9
Oil tanker	1	0	4999	37.1
	2	5000	9999	31.9
	3	10000	19999	33.4
	4	20000	59999	26.3

Segment type	Size bin	min dwt	max dwt	Average age at scrap time
	5	60000	79999	20.2
	6	80000	119999	21.2
	7	120000	199999	22.4
	8	200000	inf	20.8
Other liquids tanker	1	0	999	47.3
	2	1000	inf	47.3
Refrigerated bulk	1	0	1999	46.9
	2	2000	5999	38.0
	3	6000	9999	33.0
	4	10000	inf	29.7
Ro-Ro	1	0	4999	39.0
	2	5000	9999	27.7
	3	10000	14999	25.8
	4	15000	inf	31.0

Appendix E: Overview of GloTraM

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

A conceptualisation of the modelling framework can be seen in Figure 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).

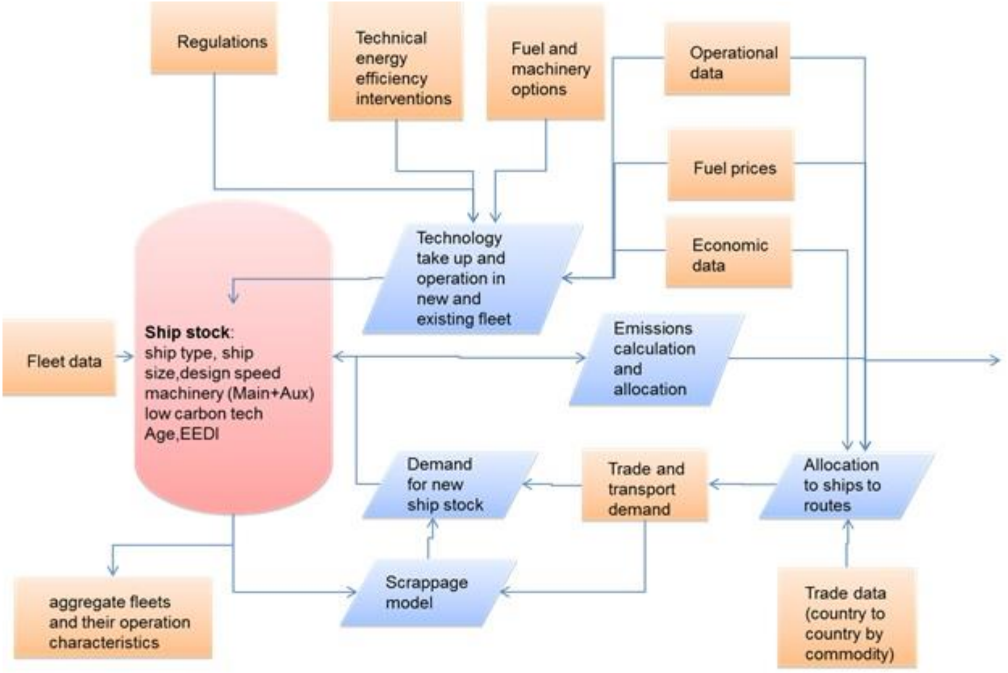

Figure 0-1: Schematic overview of the GloTraM model

The model is initiated in a baseline year using data obtained from the Third IMO GHG Study 2014 and a number of external sources that characterises the shipping industry at that point in time, whilst a number of input parameters define the scenarios of interest for this report. The algorithms embedded in the model then time-step forwards, simulating the decisions made by shipowners and operators in the management (including the technical specification) and operation of their fleets. The model assumes that individual owners and operators attempt to maximise their profits at every time step, by adjusting their operational behaviour and changing the technological specification of their vessels. This allows us to explore both the technical and operational evolution of the fleet. Hence, at each time-step, the existing fleet’s technical and operational specification is inspected to see whether any changes are required. Those changes could be driven by regulation (e.g. a new regulation of SOx and NOx emissions) or by economics (e.g. a higher fuel price incentivising uptake of technology or a change in operating speed). Taking the fleet’s existing specification as a baseline, the profitability of a number of modifications applied both individually and in combination is considered, and the combination that returns the greatest profit within the user-specified investment parameters (time horizon for return on investment, interest rate, and representation of any market barriers) is used to define a new specification for the existing fleet for use in the next time-step. Further, a specification for newbuilds is also generated at each time step. The starting point for this is the baseline fleet, which is taken as the average newbuild ship specification in the baseline year (2010). Changes to both the technology, main machinery, design speed, and fuel choice of the baseline ship are considered, such that the combination that meets current regulations and generates the highest profits within the constraints of the user-specified investment parameters is selected. The algorithm calculates the operational speed taking into account the short-run optimisation (for the time-step when the newbuild enters the fleet)

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

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.

Rvc_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)*:

Rvc_pa = P_vc_capkm * 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:

*Profitcharterer_pa = R_vc_pa - C_V_pa - P_tc_pd * 365*

Shipowner's annual costs and revenue

The shipowner's annual costs (*Cown_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).

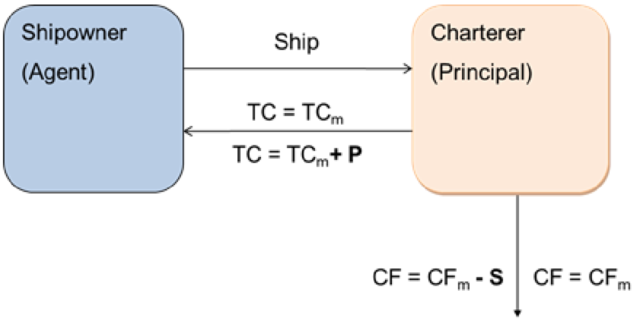

Figure 0-2: Illustrations of the fuel saving pass through in a time charter

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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