A CLIMATE SCENARIO BASED RISK
ASSESSMENT OF INTERNATIONAL SHIPPING

Paris aligned shipping and financial uncertainty

KLP DNB DNV

This report was developed by KLP and DNB as part of the «Financing Paris-aligned shipping» pilot in the Green Shipping Programme, with input from the DNV, the Norwegian Shipowner Association, Norsk Hydro, Equinor, Teekay, Wärtsilä, Massterly and the Ministry of Climate and Environment. The Green Shipping Programme is a collaborative project between the authorities and the private business community and aims to support increased uptake of environmentally friendly solutions for ships. The goal of the programme is for Norway to become a world leader in environmentally friendly and efficient shipping.

Authors:
Simon Røksund Johannessen, KLP
Jørgen Lian, DNB Markets
Lars Erik Mangset, KLP
Øyvind Endresen, DNV

Design:
Circus Reklame og Design

Thank you to all the participating partners in this project for your valuable contribution, views and data.

For more information please contact:
Simon Røksund Johannessen: Simon.Roksund.Johannessen@klp.no
Jørgen Lian: Jorgen.Lian@dnb.no
Lars Erik Mangset: lmt@klp.no

Participants partners:

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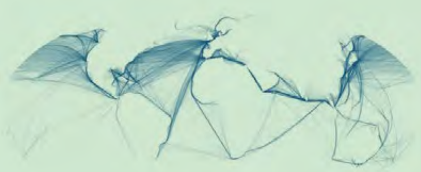
Key Results

The objective of this pilot study is to aid in developing practical criteria for investing in ships for equity investors, credit owners, and ship-owners alike which is consistent with the 2-degree target of the Paris agreement. The study assesses the financial risk of ship investments with various ship engine technologies given the prospect of regulation of the industry to reach future emission targets.



The risk is measured on the basis of drawing a climate policy scenario and in two energy price scenarios, base case (lower energy and carbon prices) and high case (higher energy and carbon prices). These represent a future with two different ambition levels on CO_2 mitigation.

CO_2

Financial impacts are measured for Capesize (bulk), VLCC (tankers), and 10 000 TEU (Container). The study includes modelling the financial impact of traditional internal combustion engines running on MGO/HFO/VLSFO as well as dual fuel LNG and ammonia engine technologies. Financial impacts on sailing in the different climate policy scenarios are also modelled. EEDI/EEXI/CII is included in the risk assessment as well as carbon pricing and fuel blending requirement.

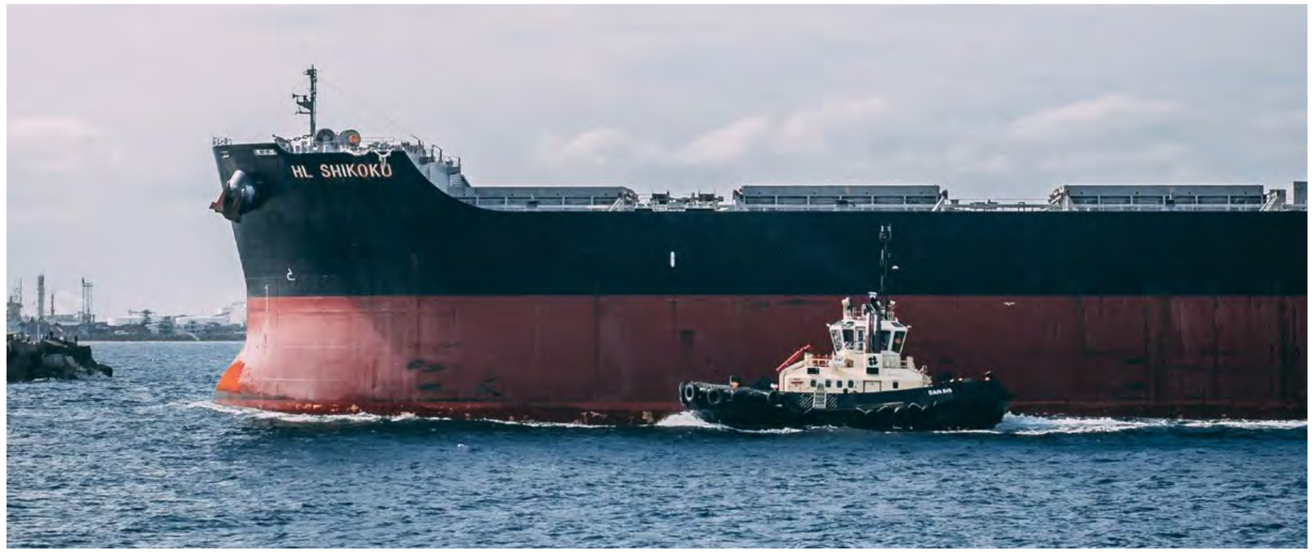
The financial impact of known future regulations such as EEDI/EEXI/CII is included in the risk assessment as well as carbon pricing and fuel blending requirement being included in the regulation anticipated from 2030 in both the base case and high case scenario.

In our base case scenario, and with our expected policy scenario, we are broadly aligned with the initial ambitions in IMO's GHG reduction strategy of cutting carbon emissions by 50% within 2050 and achieving 40% carbon intensity improvements by 2030 and 70% by 2050.

In our high case scenario, we manage to reach carbon neutrality by 2050, which would be aligned with the ambitions of the Paris agreement to keep global warming below 1.5°C.

Findings from the study

- Our findings show a very negative financial impact on traditional engine technology running on MGO/HFO/VLSFO in the high case scenario, with near-zero or negative IRR on the capital being invested on all such ship types under this scenario.
- IRRs are lower for ammonia engine technologies compared to MGO/HFO engine technology under the base case scenario, however, generate acceptable IRR in a tougher high case regulatory environment where traditional engines have negative IRRs.
- The IMO target for emissions reduction is within reach with existing engine technology for VLCCs and Capesize based on MGO/VLSFO/HFO and LNG as fuel, albeit 50% blending of zero-emission fuel and further speed reduction is needed.



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2. SUMMARY OF REPORT

A study of climate risk in international shipping

International shipping is set to undergo a significant transformation as the sector needs to decarbonize to contribute to the emission mitigation goals in the Paris agreement. For financial stakeholders in shipping, this represents a risk and opportunity, since it is uncertain how this transition will play out, considering future climate-related regulation and energy prices.

While the IMO has already adopted an ambition to reduce absolute emission by 50% in 2050, relative to 2008 levels, there is uncertainty regarding what regulatory measures will be put in place to achieve this target. Moreover, it can be argued that the IMO target for 2050 appears incompatible with the Paris agreement, which calls for net zero emission in 2050 to meet the 1,5-degree goal, or 2070 to meet the 2-degree goal[1].

On this background, this study has analyzed climate risk by constructing a policy scenario and two sets of energy and carbon price scenarios. The policy scenario is derived based on expectations on what type of policy that the IMO will introduce towards 2050. Then two price scenarios are derived with different levels of carbon prices and energy prices.

The base case scenario incorporates plausible energy and CO_2 prices based on today's forward market and outlook. The high case scenario assumes higher political support for rapid decarbonization driving up both energy and CO_2 pricing. Hence, it is the assumed price of carbon emissions and fuels that separates the two scenarios in our modeling.

The climate risk analysis is focused on drawing two scenarios regarding energy price and carbon price, and analyzing how this affects the profitability of ship investments as well as analysing fleet-wide effects of changing fleet composition over time, given the restraints in the policy. The assumed regulatory global policy has been formulated based on the current outlook and contributions from various relevant industry sources and is schematically depicted below. (Table 01)

Table 01

Regulatory assumed timeline with existing or imminent regulations in green, future likely regulations in light green.

		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Energy Efficiency Design Index (EEDI)	VLCC Capesize 10k TEU	20 %				30 %					40 %																				
		20 %				30 %					40 %																				
				40 %																											
Energy Efficiency Existing Ship Index (EEXI)	VLCC Capesize 10k TEU			20 %							40 %																				
				20 %							40 %																				
				40 %																											
Carbon Intensity Indicator (CII) & Super SEEMP				Grading system to reference line																											
Emissions Trading System (ETS) or other market-based mechanisms											Carbon pricing																				
Blending requirements for carbon neutral fuels											20 %					25 %					50 %										

1. IPCC 2018. Global warming of 1.5°C An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

This model is constructed by two components:

1. A per-vessel freight rate optimization model: Within each ship segment, several generic vessel types are defined, considering today's investment alternatives and greener vessel alternatives in the future. The generic vessels are assumed representative for their sub-segment and allow us to conduct a fleet-wide analysis of key components such as optimal speed, emissions, carrying capacity, vessel type technologies, etc. This allows us to investigate the impacts of changing fleet composition at the time and to estimate generic earnings for shipowner with different vessel technologies. This allows us to forecast what vessel technology should be the preferred investment.

2. A market equilibrium model minimizing freight costs for the charterer: As fuel and carbon prices change in the high case and base case scenario, the profitability of the generic vessel will vary relative to one another from year to year. To capture this dynamic, the model determines an equilibrium freight market for any given year based on the underlying modeling assumptions (e.g. fuel price, regulations, etc) that results in a time charter equivalent (TCE) rate per vessel type. The underlying assumption is that shipowners will fiercely underbid each other for cargo until there is only one vessel (type) that can make the required TCE freight rate in USD/day to defend the investment in the vessel. Meanwhile, the charterer minimizes his freight cost in USD/tonne and is indiscriminate between vessel types as long as the cargo gets from A to B. This reflects the reality of the highly competitive and global shipping business.

Based on various inputs and assumptions, the model allows for a quantitative and relative assessment of the attractiveness of all vessel technologies assessed.

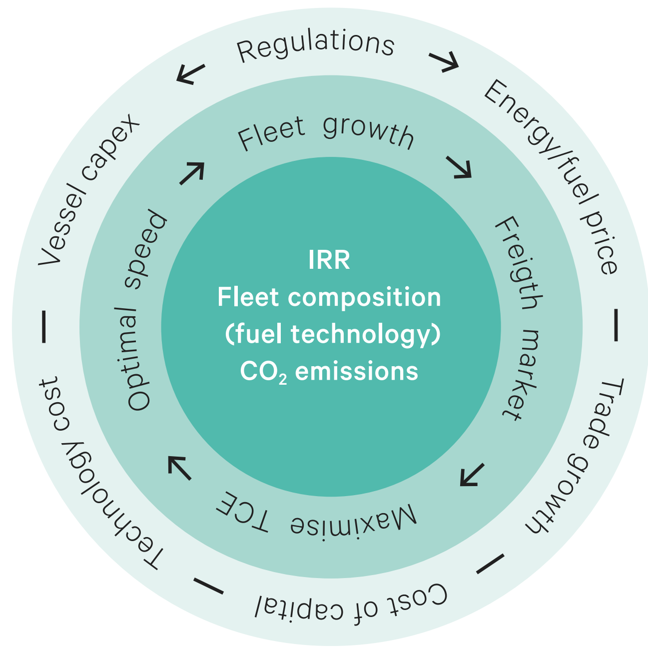
MODELLING APPROACH

The financial model developed in this study determines what vessel engine technology that will be the preferred investment choice at any given time. The output from the model forecasts the development in engine-technology mix in the fleet. The development of engine technology is only motivated by rational economic incentives (i.e. investors seeking to maximize financial returns on their investment). The external inputs that dictate the investment cost are engine and vessel Capex, development in alternative fuel prices. The fleet composition then changes over time as older vessels being scrapped and newbuilds of the preferred technology are being ordered and we can estimate the emissions from the fleet and how these develop. (Graph 01)

Finally, we are able to use the model output to determine the financial returns on each asset for an investment made and illustrate the financial sensitivity of varying regulations and price scenarios on tank, bulk and containers. The financial impact is measured as internal rate of return (IRR), which is analysed based on a model that estimates expected returns on different assets for the duration of their lifetime on a yearly basis.

Graph 01

Conceptual model overview



VESSEL TYPES AND ENGINE TECHNOLOGIES

The financial risk is measured by comparing the expected internal rate of return (IRR) between different ship engine technologies in the two modeled scenarios towards 2050: (1) traditional engine on HFO/VLSFO (mono fuel) (2) dual fuel LNG engine, and (3) dual fuel ammonia engine. It should be noted that there are other alternative engine technologies and drop-in fuels that are not covered in this study, e.g. LPG and methanol. The study also encompasses more expensive carbon-neutral or zero-carbon drop-in fuels such as biofuel or e-fuels in these technologies' fuel mix. It should be highlighted that the ammonia engine is still under development, as well as potential infrastructure development. Ongoing industry developments on ammonia engine systems will be viable in the near future and well within the timelines used in this study. The study does not evaluate pure hydrogen (although green ammonia is a hydrogen derivative) or battery technologies as these alternatives incur challenges for application in deep sea and long-haul freight which makes up the majority of shipping transportation work. Three different shipping segments are included in the study: Capesize (Bulk), VLCC (tanker), and 10 000 TEU (Container). The findings and conclusions from this study cannot directly be transferred to coastal and short sea shipping. (Table 02)

Table 02

Vessel specific engines system.

	Fuel Type			
Engine System	**Bio-HFO HFO**	**Bio-VLSFO/MGO VLSFO/MGO**	**Bio-LNG LNG**	**Blue/Green NH3 Ammonia**
Internal Combustion Engine		✓		
Internal Combustion Engine/ with scrubber	✓			
Dual fuel LNG ICE		✓	✓	
Dual fuel Ammonia ICE		✓		✓
Dual fuel NH3 ICE w/scrubber	✓			✓

High level results/findings

VLCC CASE STUDY

Our findings suggest that older secondhand vessels provide a better return on invested capital than modern vessels (resales or newbuilds). The asset's shorter remaining economical lifetime considerably outweighs the benefits of modern and efficient vessels near-term as stringent environmental measures are expected to severely impact freight markets beyond 2030.

With regards to future newbuild, our base case assumption indicates a preference for LNG shipping engines. However, if fuel prices are headed higher, and similarly for the price of CO_2, the conclusion is radically different. In such a scenario, incurring the additional Capex of an ammonia-fuelled vessel today becomes the preferred option, ahead of LNG and traditional technology, respectively. Still, the scrubber-fitted option remains the most attractive alternative allowing for use of cheap fuels near term. Also, note that the 2020-built traditional diesel engine has a negative financial return under a high energy and carbon price scenario. The results are perhaps unsurprising as they relate to added investment Capex for future cost savings on fuel in return, but nonetheless highly relevant in the context of today's investment decisions for the shipowner and related stakeholders. (Graph 02)

Aggregating the fleet and accounting for fleet growth we find that our base case scenario broadly aligns emissions with IMO's current stated ambitions of 50% cuts by 2050. However, our high case scenario prompts a different fleet composition incentivized purely by economically rationalizing investments in the most beneficial vessel technology, which is ammonia-fuelled vessels from 2030. (Graph 03)

DRY BULK, CAPSIZE CASE STUDY

Similar to the results for the VLCC case study, our analysis of the Capesize segment reveals a preference for the 10-year old Capesize with a scrubber among potential vessel types in the segment for the same reason. However, the relative advantage of these assets is more sensitive to the high price scenario due to already low speeds and thus less flexibility to offset fuel costs with lower speeds than seems to be the case for VLCCs.

Among the newbuild alternatives, we again find significant differences in the two scenarios. Our base case scenario marginally prefers the scrubber-fitted newbuild to the LNG alternative for 2022-2030 delivery, however drawing closer to CO_2 pricing in 2030, LNG-engine for newbuilds takes over from 2030 and onwards. The high price scenario would put the ammonia-fuelled vessel with scrubber at an advantage to these alternatives. These results are broadly similar to that in the VLCC case study. (Graph 04)

As the expected life span of a Capesize vessel extends beyond that of the VLCCs, carbon-neutrality is reached first by 2050 in the high case scenario. Under the base case scenario, we see the fleet struggling to meet the current ambition for 50% reduction has increased demand for freight will exert upward pressure on aggregate emissions despite considerable efficiency improvements. (Graph 05)

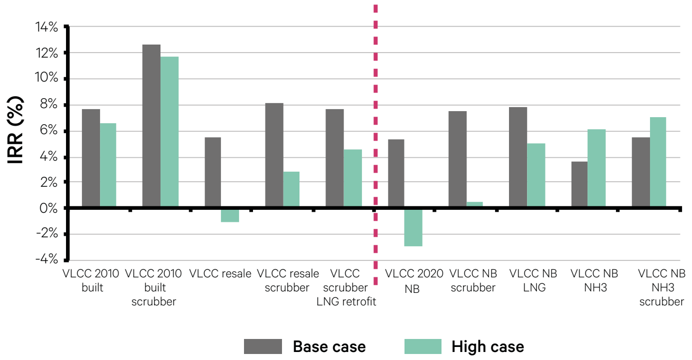
CONTAINER, 10K TEU CASE STUDY

Using our model for a 10k TEU container vessel in our base case scenario, we arrive at a different result from the previous segments. The preferred vessel in our base case is now the modern resale with either a scrubber installed or a future retrofit to LNG propulsion. This defers from the preference for older vessels with shorter remaining economic life in the case of VLCCs and Capesizes. This is explained by the stringent requirements in the planned regulations and early implementation for this segment (EEXI with a 40% reduction already from 2023). The forced reduction in sailing speed severely impacts the economics of the vessel, and the fuel economics of modern container vessels becomes an immediate advantage. Looking at the newbuild alternatives we discover that LNG propulsion would be the vessel of choice, ahead of the scrubber-fitted alternative.

If we apply our high price scenario, the impacts are detrimental for all assets but the dual fuel designs running on carbon free ammonia. This is a direct result of the high consumption figures on these assets and the massive cost burden associated with expensive blending fuels and the cost of emissions. From the results, we can infer that relatively recent containership technology looks exposed to rapidly shifting regulatory requirements. (Graph 06)

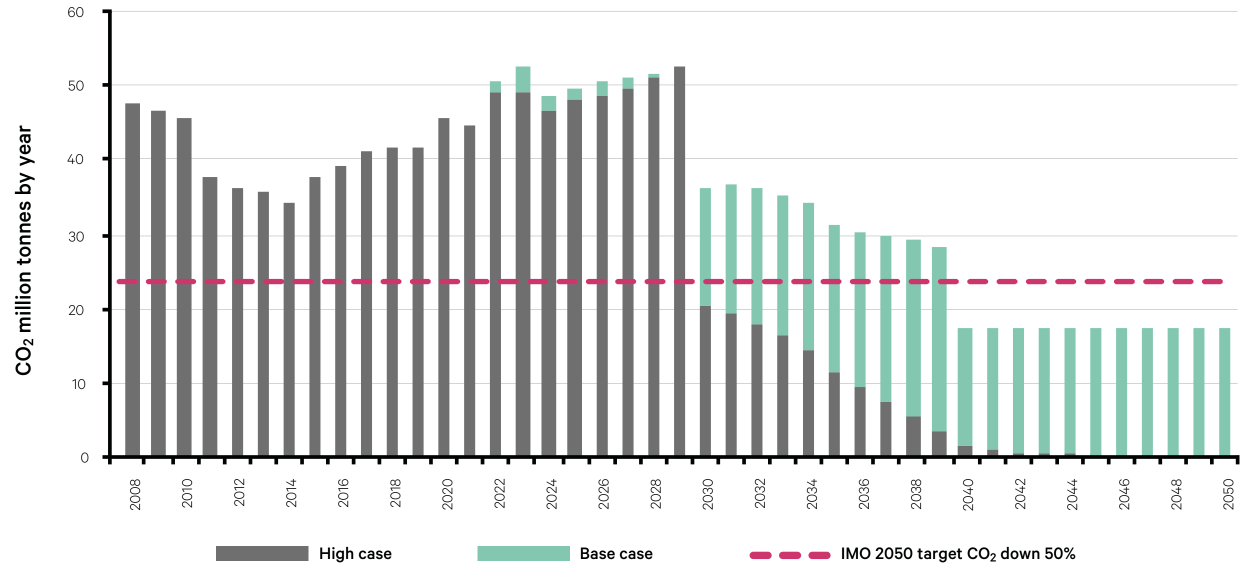
Graph 02

IRRs among different investments in VLCC technology today in both scenarios. (Source: DNB Markets)



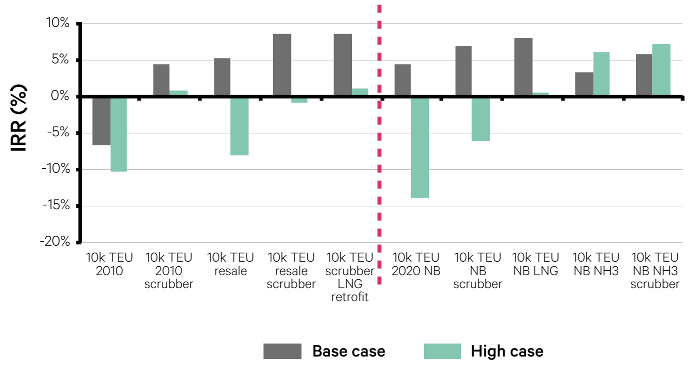
Graph 03

Aggregate CO_2 emissions from the VLCC fleet under both scenarios compared to IMO's current ambitions of 50% reduction by 2050. (Source: DNB Markets)



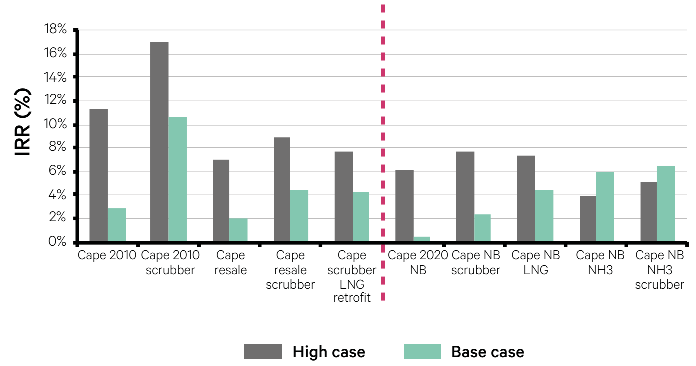
Graph 04

IRRs among different investments in 10k TEU containership technology today in both scenarios. (Source: DNB Markets)



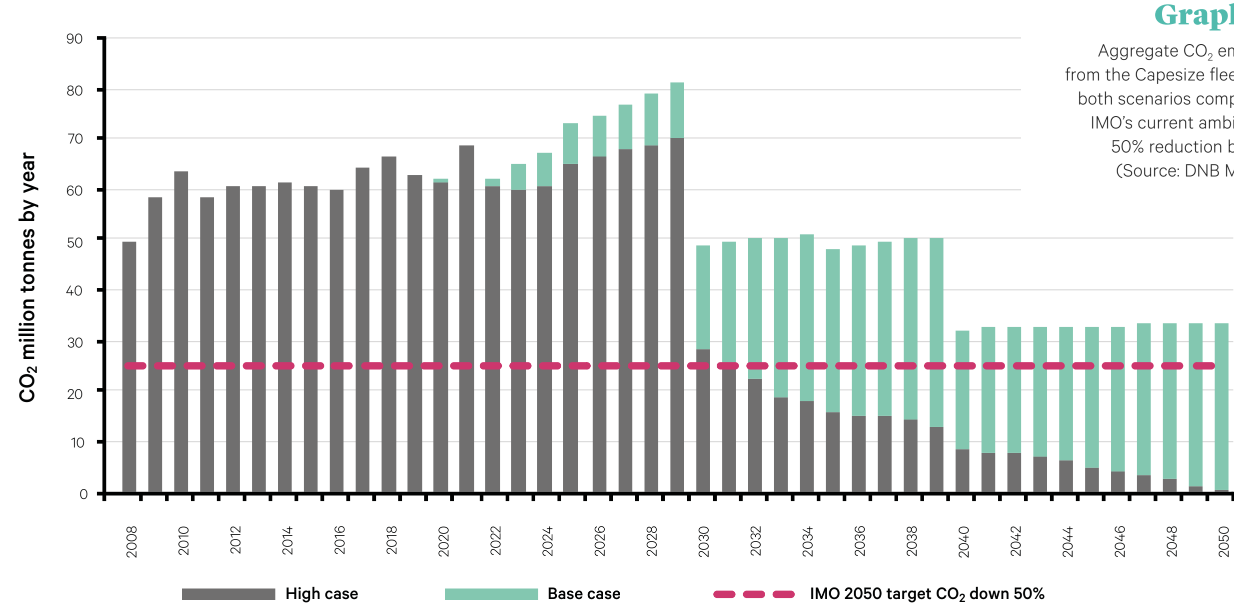
Graph 05

IRRs among different investments in Capesize technology today in both scenarios. (Source: DNB Markets)



Graph 06

Aggregate CO_2 emissions from the Capesize fleet under both scenarios compared to IMO's current ambitions of 50% reduction by 2050. (Source: DNB Markets)



«Climate-related development is an uncertainty that ship owners and other stakeholders in the maritime industry need to consider already today.»

3. INTRODUCTION

A study of climate risk in international shipping

International shipping is set to undergo a significant transformation in the next three decades and towards the end of the century in order to contribute to the goals in the Paris agreement on limiting global warming to well below 2-degrees and preferably not exceeding 1,5-degrees.

To succeed, a major transition from today's fleet dominated by traditional internal combustion engines and the use of heavy fuel oil and distillates fuels will be necessary. How this transition will take place considering the introduction and cost of new technology, fuel price, and the introduction of stringent climate regulation is uncertain, particularly related to the pace of these changes. Also, cargo owners, port state, banks, charterers, and other stakeholders can increase pressure for decarbonization on deep sea transportation. This uncertainty represents both a financial risk and an opportunity that ship owners and other stakeholders in the maritime industry need to consider already today.

This report presents a climate risk assessment undertaken for international shipping, considering three vessel segments: tankers, dry bulk and container. Our ambition is to build a modeling framework in which we can determine what vessel technology will be the preferred investment at any given time. In total we assess four different engine technologies in life cycle perceptive, considering both new buildings and ships in operation. The different technologies selected are tested and evaluated under two different future scenarios, with a 2050 horizon.

We wish to highlight financial risk in asset investments in shipping resulting from the rapidly evolving regulatory backdrop. We believe this could assist industry stakeholders' investment decisions and elevate awareness in driving factors for shipping's supply side fundamentals.

This report is structured as follows:

Chapter 4:
General introduction to the topic and establish why climate risk assessment is necessary for international shipping

Chapter 5:
Present the modelling approach that has been developed to perform a climate risk assessment

Chapter 6:
Outline the main findings and results from the study

Chapter 7:
Different maritime stakeholders' perspective on what it will take to reach the climate goals and the implications on their business

4. MOTIVATION OF STUDY

Why analyse climate risk in international shipping?

It is the International Maritime Organization (IMO) which is tasked to develop and adopt regulation of GHG emission from the international shipping fleet. However, even if international shipping formally is not part of the Paris-agreement, there are still expectations that the IMO should put in place regulation that sufficiently contributes to the emission targets the global community agreed upon in Paris 2015.

One challenge in meeting future emission targets will be to strongly decouple growth in transported goods with resulting emissions. International shipping accounts for 80 percent of global trade volume and over 70 percent of trade value[1], and studies suggest that it may grow between 25%-50% by 2050[2], or even as much as 115%[3]. The expectation of strong growth in transport volumes together with pressure to reduce emissions at a faster pace, implies uncertainty as to how long incremental changes to energy efficiency will be a viable strategy, and when there will be a stronger push towards zero-emission solutions.

Shipping is recognized for being a low-carbon transport solution compared to other transport modes, as it constitutes little less than 3% of the man-made greenhouse gas emissions[4]. But, its relative share in emission will rise if land-based industries undergo a steeper decarbonization path, hence there has been a great interest in studying ship emission and decarbonization pathways[5] and scenarios on transitioning from conventional to zero emission fuels[6] . The studies show that while emissions can be reduced by increasing the energy efficiency of ships, carbon neutral and zero-emission fuels are essential to succeed with the decarbonization that is needed.

While new technology and infrastructure is required to enable further decarbonization of shipping, the key driver of ensuring that emissions are reduced at the required pace appears to be changes in the regulatory frameworks, most prominently those pushed by the IMO, but also other regulatory initiatives on a national and regional level. In addition, there will be a variety of other drivers of the transition to a zero emission shipping in the long term, such as supply and demand change in the market, changing customer preferences, technological development not foreseen today as well as changes in stakeholder requirements to shipping (e.g. shipowners, creditors and society at large). These other climate-related risk factors are not directly addressed in this study.

Failing to consider future climate regulation in today's investment decisions may result in severe financial consequences. For instance, unforeseen carbon tax exposure, geographic trade restrictions (such as the existing SECA-areas today), and new progressive policies introduced in the future could adversely impact expected financial returns, or could even result in stranded assets. Hence, the financiers of new vessels should undertake a climate risk assessment to stress-test how future requirements may impact the profitability of vessels under different scenarios.

The purpose of this analysis is to explore how future climate-related development can impact the profitability of shipping, developing case studies in specific shipping segments. We hope to contribute in better understanding on how climate risk factors impact profitability and which risk factors are the most important drivers of future profitability.

1. UNCTAD2018. Review of Maritime Transport 2018.
2. I.a. Smith T., et al (2014), Third IMO GHG Study 2014; International Maritime Organization (IMO) London, UK, June 2014.
3. Faber et al., 2020. Fourth IMO Greenhouse Gas study 2020. International Maritime Organization (IMO) London, UK
4. Faber et al., 2020. Fourth IMO Greenhouse Gas study 2020. International Maritime Organization (IMO) London, UK
5. I.a.Eide et al (2017), Navigating a low-carbon future, Consequences for NSA (Norwegian Ship owner Association) members from CO_2 regulations, Report No. 2017-0205.https://www.rederi.no/en/DownloadFile/?file=176270; DNV GL (2019), Maritime Forecast to 2050.
6. I.a. DNV GL (2019) Maritime Forecast to 2050.; Eide, M.S., Chryssakis, C., and Endresen, Ø., CO_2 abatement potential towards 2050 for shipping including alternative fuels (2013), Carbon Management, June, Vol. 4, No. 3, Pages 275-289, 2013.

IMO target:

Even if the IMO target can be considered ambitious, it is noteworthy to observe that the IMO target for 2050 appears incompatible with the Paris agreement, which calls for net zero emission in 2050 to meet the 1,5-degree goal, or 2070 to meet the 2-degree goal . Hence, regarding the IMOs GHG strategy, there are at least two material uncertainties facing shipowners that need to assess if newbuild vessels ordered today will be robust in meeting future regulatory requirements:

1. Whether IMO's 2050 target will become more ambitious. The IMO will revise its long-term ambition every five years, with the next deliberations to be held in 2023. Recently, the Biden administration in the US called the IMO to guide the industry towards zero emissions by 2050 , and the EU Green Deal sets put more emphasis on the shipping sector for the EU to reach its net zero target by 2050.

2. What measures the IMO will put in place to meet its ambitions and how that will impact individual vessels.

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5. METHODOLOGY

Modelling approach

Our model is based on financial and economic theory, which simply assumes rational allocation of capital to the most financially attractive shipping investment. Hence, we aim to capture the implications for shipping's environmental transition solely based on economic rationale and optimising financial returns. In order to construct realistic scenarios, we have scaled on valuable competence and contributions from GSP to form our assumptions to be covered in the following, before we delve into the mechanics of the financial modelling.

5.1. CONSTRUCTING CLIMATE RISK SCENARIO

A key component in climate risk assessment is the construction of future scenarios, which is a set of assumptions that seek to describe a plausible future development. The scenarios are constructed using a future-forwards approach, where present days IMO regulation and energy prices is the starting point for considering how they may develop in the future. In other words, the scenarios build on what is plausible future development, given where we stand today.

The assumption in the scenarios incorporates future energy prices, different fuel and technology types, future amendments of existing IMO regulation, and the introduction of new IMO regulation. Based on these scenarios, our model estimates future CO_2 emission levels and financial impact on investment decisions ship-owners make on newbuilds. Two scenarios are constructed:

BASE CASE SCENARIO:
Energy price levels and regulatory stringency which we see as most plausible given the current IMO GHG strategy.

HIGH CASE SCENARIO:
Energy price levels and regulatory stringency we believe surpass the current ambition level of 50% reduction by 2050 at the IMO.

The different assumptions of the scenarios, input factors, and how they have been constructed, are explained in the following sub-chapters.

The purpose of the scenarios is to provide insight in terms of assisting shipping stake-holders to:

- Identify possible threats and opportunities that impact the profitability of ship investments
- Assess the profitability of different ship engine technologies in the scenarios
- Identify possible trigger points, which will enable judgment in real world situation on whether parts of the scenario may become true
- Serve as a basis for further knowledge development and monitoring regarding emerging climate risks. The scenarios have been constructed based on a set of different sources, such as data from recognized databases and published literature as the DNV Energy Transition Outlook, as well as the application of expert judgement where secondary data is not available

5.1.1. FUEL PRICE TRAJECTORIES

Marine engine technology economics is highly dependent on energy price variables. The future predicted price for MGO, HFO, LNG, and ammonia will together with investment cost determine the economic competitiveness between the marine engine technologies. Table 03 shows the forecasted trajectories/developments of fuels included in our forecast modelling. The price trajectories are based on relevant literature and input from project partners. The most important price variable is the future development in oil price, and changes in LNG, MGO, and HFO pricing is linked to the development in oil price. Prices are shown in real prices. (Table 03)

The base case simulates an oil price close to the market future curve on oil price, while the high case uses a higher oil price due to cost increases in cost for production and exploration that will follow from tighter environmental regulation to reach goals in the Paris agreement. A sharp increase in marine fossil fuel price is forecasted from 2030 as this study assumes global CO_2 pricing on marine fuels in both scenarios.

Ammonia is today mainly produced from natural gas (brown ammonia) and is thus not a zero-emission fuel. In this study cost of ammonia is linked to the cost of natural gas and CO_2. Historically ammonia pricing has varied between 200 and 700 USD per ton, depending on natural gas cost. US producers have the recent years managed to deliver brown ammonia to the market at 220 USD per ton due to the low US gas price.

Green and blue ammonia are zero emission fuels in an operational phase. Green ammonia is produced through the use of zero emission electricity, while blue ammonia is produced from natural gas, where CO_2 is captured and safely stored. Today the cost of green ammonia is around 600-700 USD per ton, but there are projects for green and blue ammonia being developed that expect that this cost can be reduced to 400 USD per ton. Green and blue ammonia will thus be competitive with brown ammonia at a CO_2 pricing of around 100 USD per ton.

Regardless of the decarbonization pathway, we find it very likely that biofuels will be an important component to reach regulation requirements. Bio-MGO and bio-methanol are assumed to be used as drop-in fuels. Biofuels are today trading to a high premium to fossil alternatives due to production cost and availability. As the marine industry will need to compete for these fuels with other industries where blending requirements are being introduced, this study assumes that biofuels will continue to trade at a premium to fossil alternatives. The introduction of global CO_2 pricing in the future is assumed to put an according to premium on bio alternatives, benefiting the producers.

Table 03

Developed price trajectories of fuels and CO_2 in our forecast modelling.

Primary source	Scenario	2021	2030	2040	Unit
Crude oil	High	59	80	80	USD/Barrel
	Base		60	60	
Natural Gas	High	6,5	8,8	8,8	USD/MMBtu
	Base		6,6	6,6	
HFO	High	325	440	440	USD/Ton
	Base		330	330	
VLSFO	High	421	540	540	
VLSFO	Base		430	430	
Spread HFO/VLSFO		96	100	100	Eur/MWh
Clean Electricty energy for Green Amonia			30	30	
CO_2 Price	High	30	300	300	USD/Ton
	Base		100	100	
Brown NH3	High	250	910	910	USD/Ton
	Base		450	450	
Green NH3/Blue NH3			400	400	USD/Ton
Bio Diesel	High	900	2 010	2 010	USD/Ton
	Base		1 220	1 220	

5.1.2. REGULATIONS

While certain IMO regulations are already adopted or have been approved by the committee, it is our view that there will need to be additional political intervention in order to steer emission from the international fleet towards either a 50% reduction (base case) or higher reduction in CO_2 levels (high case) by 2050. Even more so should the ambitions for the IMO's GHG strategy be heightened at the scheduled revision in 2023. Since future policy changes are inherently uncertain, this study has interviewed key experts in the field, ranging from industry experts to people central in the IMO negotiations. Based on their input, a set policy assumption has been derived for both mitigation scenarios.

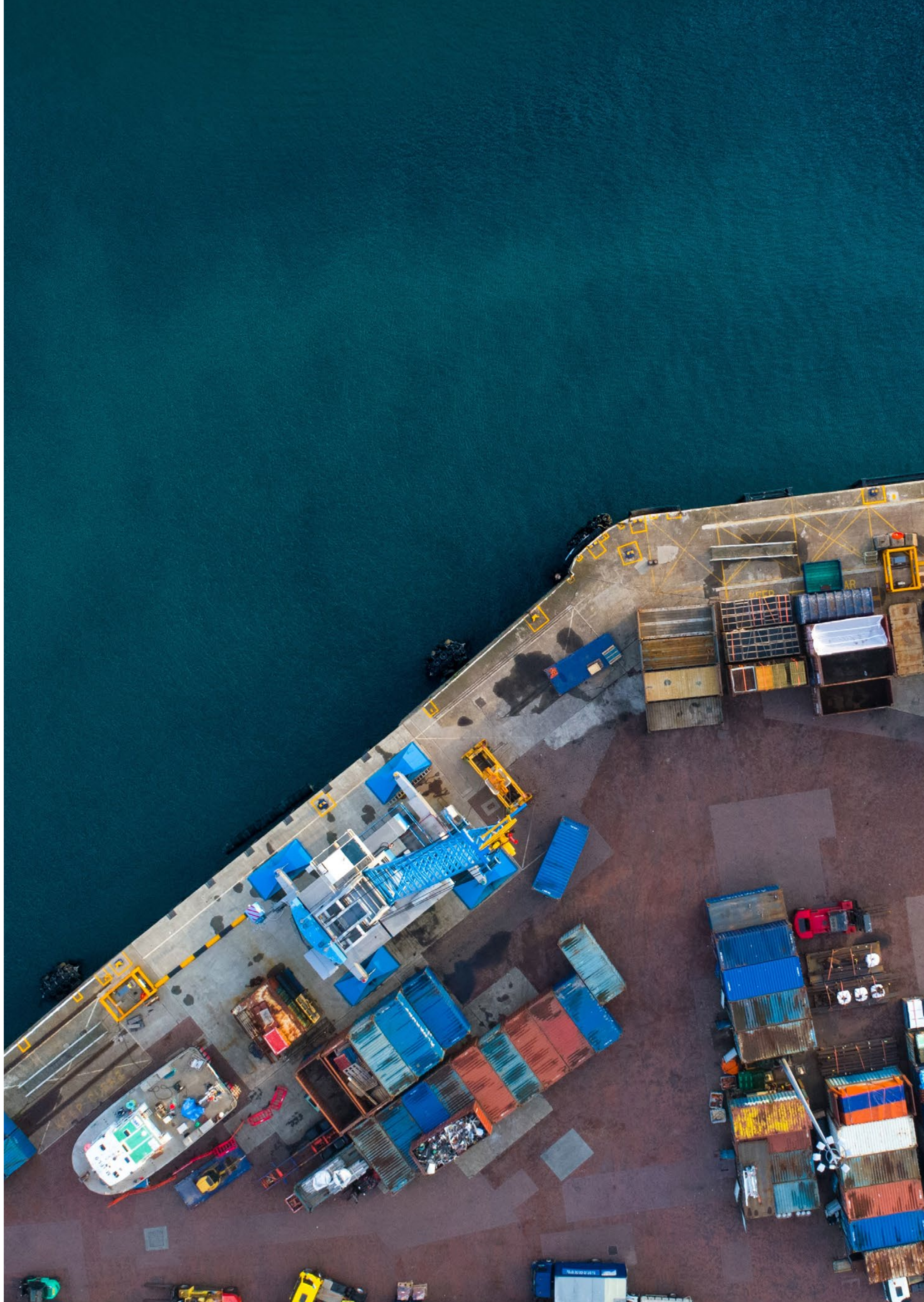
In the development of the policy scenarios, we have assumed a certain timeline for the introduction and amendments of the different policy instruments from the IMO. This timeline has been determined based on valuable input from industry sources and assumes an interplay between the EU and the IMO, where the EU is a first mover in implementing key regulation that has not yet progressed much in the IMO negotiations, notably carbon price and zero-emission fuel blending requirement. The logic of this assumption is the observed introduction of green policies in the EU, coupled with the observation that the EU has considerably fewer member countries than the IMO, which enables them to have a faster policy development and possibly also faster implementation pathway. There is also precedence that the EU has pushed the IMO on climate regulation before, such as the introduction of the MRV requirement on CO_2 in the EU.

Three main components have been used for constructing future policy for regulation in shipping:

1. Design and operational requirements: It is expected that the current and more recent IMO regulation will be continued with increasingly stringent requirements. This implies that energy efficiency requirements for newbuilds will become more progressive, as will requirements on existing ships in operations. Relevant regulations include the existing Energy Efficiency Design Index (EEDI), the proposed Energy Efficiency Existing Ship Index (EEXI), and the implementation of an operational Carbon Intensity Indicator (CII) & Super-SEEMP.

2. Carbon price: The IMO will seek market-based mechanisms for carbon pricing, and a similar system to the European Emission Trading System (ETS) is likely. The scenario incorporates a carbon price that enters into force in 2030. For matters of simplicity, the carbon price is kept unchanged up until 2050.

3. Carbon-neutral fuel requirements: With technological advancements and increased availability in zero-emission and carbon-neutral fuel technologies, we find it likely that blending requirements will be introduced for shipping as it has for road diesel and gasoline today. The scenario incorporates such blending requirements from 2030, with the blending requirement increasing over time.



Scenario of future climate regulation of international shipping

Regulation aimed to curb emission is a key uncertainty regarding financial climate risk. To analyze this effect, we have assumed the development of existing regulation, as well as the introduction of new regulation.

Table 04

Policy scenario assumed in this study, London, UK, 2016.

<table>
<tr><th></th><th></th><th>2021</th><th>2022</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th><th>2032</th><th>2033</th><th>2034</th><th>2035</th><th>2036</th><th>2037</th><th>2038</th><th>2039</th><th>2040</th><th>2041</th><th>2042</th><th>2043</th><th>2044</th><th>2045</th><th>2046</th><th>2047</th><th>2048</th><th>2049</th><th>2050</th></tr>
<tr><td rowspan="3">Energy Efficiency Design Index (EEDI)</td><td rowspan="3">VLCC
Capesize
10k TEU</td><td colspan="4">20 %</td><td colspan="5">30 %</td><td colspan="21">40 %</td></tr>
<tr><td colspan="4">20 %</td><td colspan="5">30 %</td><td colspan="21">40 %</td></tr>
<tr><td></td><td colspan="29">40 %</td></tr>
<tr><td rowspan="3">Energy Efficiency Existing Ship Index (EEXI)</td><td rowspan="3">VLCC
Capesize
10k TEU</td><td colspan="2"></td><td colspan="7">20 %</td><td colspan="21">40 %</td></tr>
<tr><td colspan="2"></td><td colspan="7">20 %</td><td colspan="21">40 %</td></tr>
<tr><td colspan="2"></td><td colspan="28">40 %</td></tr>
<tr><td colspan="2">Carbon Intensity Indicator (CII) & Super SEEMP</td><td colspan="2"></td><td colspan="28">Grading system to reference line</td></tr>
<tr><td colspan="2">Emissions Trading System (ETS) or other market-based mechanisms</td><td colspan="9"></td><td colspan="21">Carbon pricing</td></tr>
<tr><td colspan="2">Blending requirements for carbon neutral fuels</td><td colspan="9"></td><td colspan="5">20 %</td><td colspan="5">25 %</td><td colspan="11">50 %</td></tr>
</table>

ENERGY EFFICIENCY DESIGN INDEX (EEDI)

In 2011 MARPOL Annex VI was amended to include energy efficiency requirements, including the Energy Efficiency Design Index (EEDI) for all new ships and a mandatory Ship Energy Efficiency Management Plan (SEEMP) to be kept on board all vessels. These requirements entered into force in 2013. The EEDI is sequentially implemented in phases generally running for 5-year periods with tightened requirements to the energy efficiency of newbuilds. Currently, we are in phase 2 (since 1 January 2020) prescribing a 20% reduction from the «reference line». (Table 04)

Recently at the MEPC 75 committee at the IMO, the EEDI phase 3 requirements were significantly strengthened and set to be introduced earlier from 2025 to April 2022 for several vessels, including gas carriers, general cargo ships, and LNG carriers. For a typical 10k TEU container vessel, the requirements from 2022 will be a 40% reduction (compared to the current 20% for bulkers and tankers until 2025, and 30% thereafter). The current regulations are limited to phase 3 from 2025, but an investigation into a potential phase 4 of EEDI requirements is already being made. See the above regulation timeline in Figure 3 for planned and assumed EEDI requirements for the segments covered in this report. While these regulations affect newbuilds in isolation, the changes to EEDI have implications for the proposed EEXI regulations. (Graph 07)

ENERGY EFFICIENCY EXISTING SHIP INDEX (EEXI)

The EEXI regulations were proposed to the MEPC 75 in late 2020 and will be put forward for adoption at MEPC 76 in June 2021 with likely entry into force on 1 January 2023. The regulation is a technical 'license to operate for existing ships relating to the mandatory vessel surveys where each vessel would need to get an approved EEXI document to ensure the vessel's energy efficiency is within the set limits. The current structure of the EEXI would align existing ships with the prevailing EEDI standards for newbuilds but is set to be reviewed by the IMO within 1 January 2026 whereby the requirements could be strengthened and, in our view, likely realigned with the prevailing updated EEDI requirements. For the select segments in our study, this would entail a 20% reduction for existing VLCCs and Capsizes, while 40% for the 10k TEUs compared to the reference line, and an expected tightening to bring VLCCs and Capesizes to 40% from 2030 in our modeling/scenario. All vessels would be required to verify their compliance at the first annual survey following entry into force, which would ensure all vessels comply with the regulation within a year. While there exist several potential solutions and installations to improve the efficiency of existing vessels, the dominant approach is likely to be limiting engine power (i.e. lowering operational speeds).

CARBON INTENSITY INDICATOR (CII) AND ENHANCED SEEMP (SUPER-SEEMP)

The CII would be the corresponding operational requirement to the EEXI as a technical requirement. The timeline for the CII regulations mimic EEXI and would be applicable from 2023. It would require all vessels to calculate an annual operational CII (i.e. target carbon emissions per transport work), which determines the annual reduction factor needed to ensure continuous improvement of the ship's operational carbon intensity within a specific rating level (see illustration below) in order to achieve the IMO's GHG strategy targets, e.g. 40% reduction in carbon intensity by 2030. The actual annual operational achieved CII (i.e. the vessel's actual carbon emissions per transport work) would be required to be documented and verified against the required CII. This would enable the operational carbon intensity rating to be determined with the intention to drive fleet-wide energy efficiency improvements on an operational level, as opposed to the EEXI technical documentation.
Hence, there are two new measures: The technical requirement to reduce carbon intensity, based on a new Energy Efficiency Existing Ship Index (EEXI); and the operational carbon intensity reduction requirements, based on a new operational carbon intensity indicator (CII). The dual approach aims to address both technical (how the ship is retrofitted and equipped) and operational measures (how the ship operates with varying speeds, weather, loads, etc).

The rating would be given on a scale - operational carbon intensity rating A, B, C, D, or E - indicating a major superior, minor superior, moderate, minor inferior, or inferior performance level. The performance level would be recorded in the ship's Ship Energy Efficiency Management Plan (SEEMP).

A ship rated D for three consecutive years, or E, would have to submit a corrective action plan, to show how the required index (C or above) would be achieved. Administrations, port authorities and other stakeholders as appropriate, are encouraged to provide incentives to ships rated as A or B. (Graph 08)

CARBON PRICING – TIME OF IMPLEMENTATION

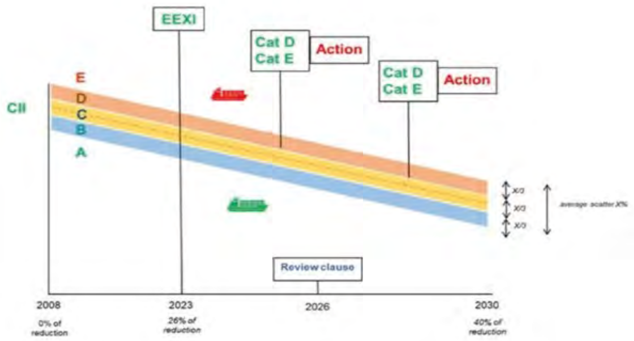
The IMO is looking at market-based mechanisms to incorporate the cost of emissions in its regulations for shipping. While certain stakeholders in the industry have proposed a carbon levy as a potential solution, we believe the IMO views introducing a framework similar to the EU's emissions trading system (ETS) and link the carbon price to the ETS. As such, the market would price carbon emissions according to demand and shipping would have to integrate such costs in its business. This solution potentially secures a level playing field for the industry at a fair cost in comparison to other polluting industries. As emissions quotas are tightened over time, the resulting cost increase should spur investments and abatements in the most rational manner. Implementing such mechanisms is further out in time, and we have modelled for this to be included from 2030 in our scenarios.

FUEL BLENDING REQUIREMENTS

Another policy that has direct implications on emissions from fuel, is carbon-neutral or zero-carbon fuel blending requirements. Such regulations exist today for road fuel where diesel and gasoline are blended with various biofuels. This lowers the carbon intensity of existing fuels against an anticipated price increase due to the scarcity and cost of biofuel alternatives. It will require at least 150 million tons of biofuel in 2040 to reach the blending targets for the shipping industry. Electro fuels as drop-in fuels will therefore likely be part of the solution. Electro fuels for diesel and LNG are not explicitly assessed in this study but are assumed to trade at par with their bio-fuels alternatives for diesel and LNG as drop-in alternatives. Concerns have been raised about the true impact of certain biofuels on carbon emissions in full life-cycle analysis (LCA). However, assessing the effect of biofuels in climate change mitigation is beyond the scope of this report and we have implemented blending requirements from 2030 of a general biofuel component. This considerably impacts carbon emissions as we implement a requirement reaching 50% from 2040 and we do not account for potential sourcing issues for such fuel. Besides lowering the aggregate carbon factor of fossil fuels, the added biofuel component also lifts fuel costs and contributes to slowing the fleet which again runs through to lower consumption and emissions.

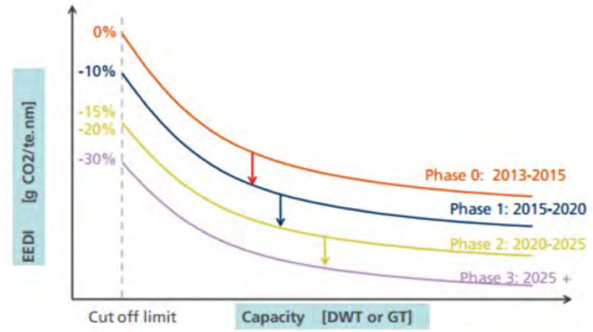
Graph 07

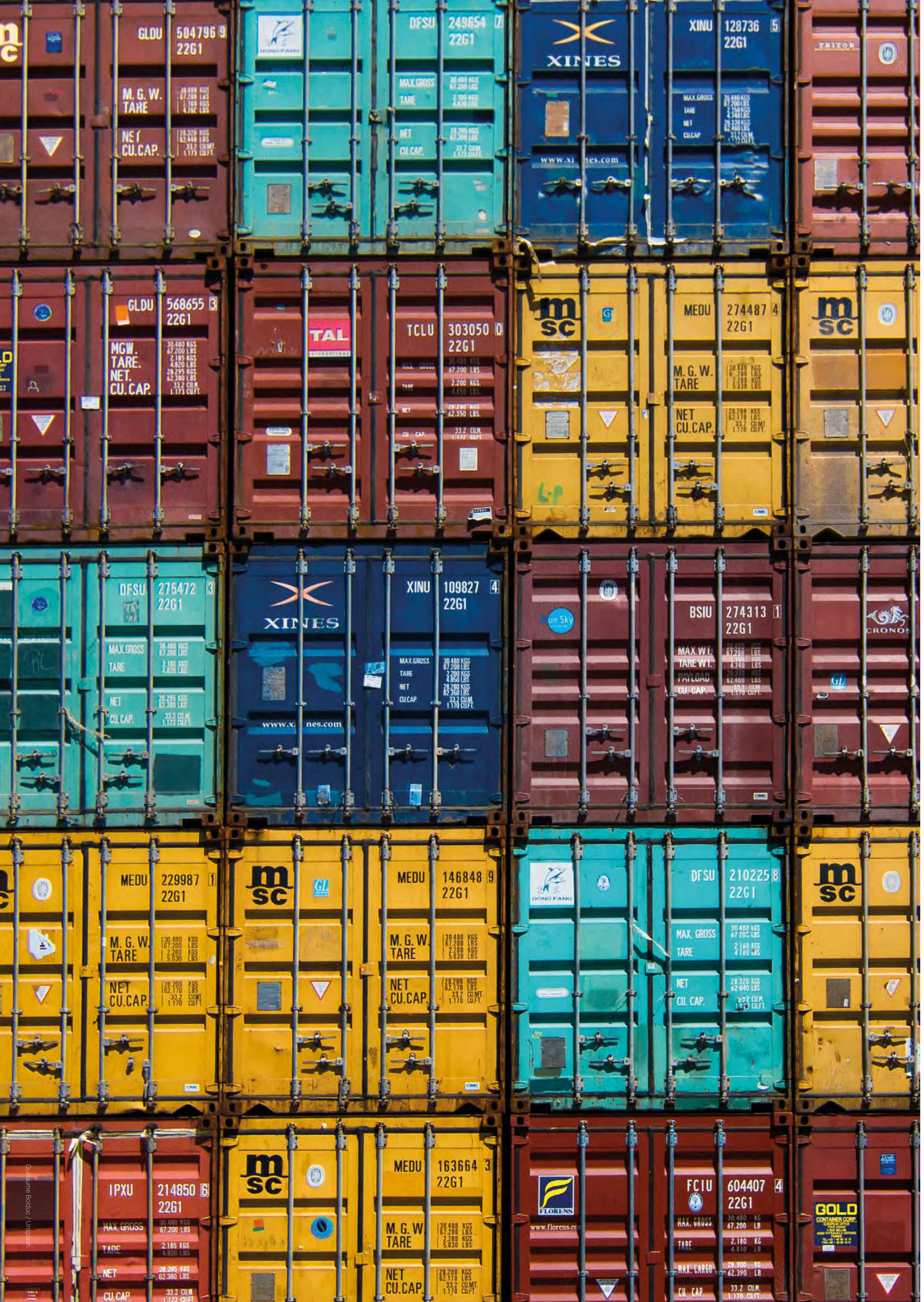
Concept of Required EEDI, reduction factor, cut off limits and EEDI phases.
Source: IMO. "IMO Train the Trainer (TTT) Coure on Energy Efficient Ship Operation. IMO, London, UK, 2016.



Graph 08

Illustration of the CII rating system and enhanced SEEMP
Source: IMO document, GHG-INF.2/1/1





Guillaume Bolduc / Unsplash

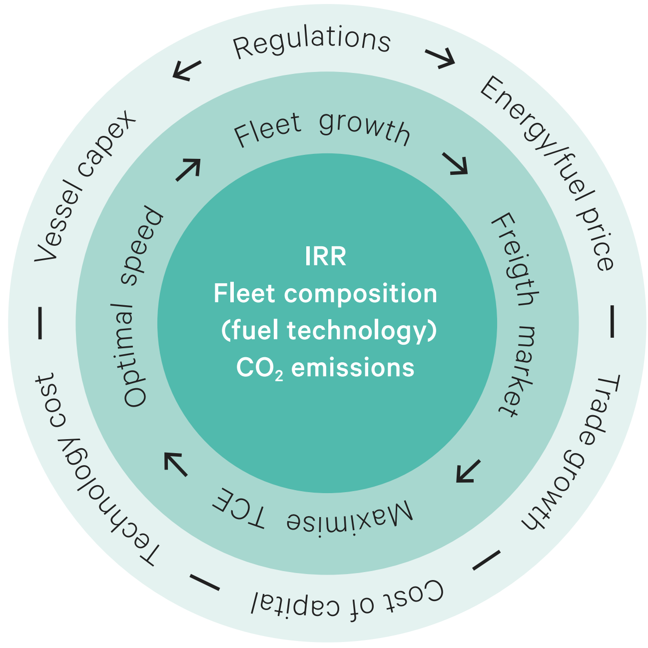
Graph 09

Conceptual model overview.

Assumption

Model

Results



5.2. OVERALL MODEL DESCRIPTION

Our ambition is to build a modelling framework in which we can determine what vessel technology will be the preferred investment at any given time. By doing so, we will be able to construct a feasible fleet composition motivated by purely rational economic incentives (i.e. investors seeking to maximize financial returns on their investment). As the fleet composition changes over time (due to older vessels being scrapped and newbuilds of the preferred technology being ordered), we can estimate the emissions from the fleet and how these develop.

The following figure illustrates the various assumptions which affect the model and its results. Regulations concerned with decarbonization are the main backdrop for the study. Firstly this impacts energy markets and fuel prices both directly (e.g. CO_2 surcharges) and indirectly (e.g. higher cost of capital limiting fuel production and supply). Secondly, technical requirements add to vessel capital expenses in order to comply and incorporates the cost of various clean technologies. We also factor in expectations of transport demand growth and a reasonable cost of capital for calculating financial returns. (Graph 09)

These assumptions drive our model that sets an equilibrium freight market on a USD/tonne basis, which translates into USD/day (time charter equivalent– TCE) earnings for the shipowner net of expenses including fuel etc. In order to maximize TCE, vessels optimize speeds to limit fuel expenses which again provides the basis for fleet growth and the number of vessels needed to handle the expected transport demand for any given year. By running the model on a yearly resolution we can determine the most attractive vessel at any given time as the preferred newbuild vessel, and accordingly over the lifetime of the assets determine earnings per vessel type and derive absolute financial returns on various vessels while forecasting aggregate CO_2 emissions and fleet carbon efficiency.

In order to achieve this, certain simplifications need to be made. Firstly, we will limit the study to a single shipping sector (e.g. tankers, dry bulk, containers) and subsegment by vessel size (e.g. VLCC, Capesize, 10k TEU). Within each study, we simplify the number of vessel types by vintage (assumed 10-year intervals between each design shift) coupled with relevant propulsion technology for each vessel type. By doing so, we lose some of the actual distinctions in vessel designs, but in aggregate our simplified results are closely aligned with actual estimates for CO_2 emissions. Finally, we are able to use the model output to determine the financial returns on each asset with a given technology for an investment made today and illustrate the sensitivity of varying regulations and price scenarios on the various vessel types.

The model is run reiteratively on a yearly resolution and the resulting output estimates expected returns on the different assets for the duration of their lifetime. Based on various input assumptions, the model allows for a quantitative and relative assessment of the attractiveness to invest in different vessel types and technologies. The model is run on our base case scenario, and stress tested for a high energy and carbon price environment in the high case scenario to assess the impact of changes to our underlying assumptions.

In short, our modelling approach relies on a two-step framework that will be elaborated further below:

1. **a per-vessel freight rate optimization model**
2. **a market equilibrium model minimizing freight costs for the charterer**

We wish to highlight financial risk in asset investments in shipping resulting from the rapidly evolving regulatory backdrop. We believe this could assist industry stakeholders' investment decisions and elevate awareness in driving factors for shipping's supply side fundamentals.

5.2.1. VESSEL-BASED FREIGHT RATE OPTIMISATION MODEL

The first component of the two-step framework includes a pre-defined number of generic vessel types and their varying vessel specifications in terms of propulsion technology (i.e. fuel type) and fuel efficiency (i.e. speed/consumption curves). By defining such generic vessels, we can approximate the aggregate fleet composition on factors such as optimal speed, emissions, carrying capacity, propulsion technology, etc. This allows us in a simplified manner to investigate the impacts of changing fleet composition over time. Likewise, we are at any given time and freight market able to estimate generic earnings for the shipowner for ships with different propulsion technologies, which allows us to forecast what vessel types should be preferred investments (future newbuild deliveries) and divestments (scrapping). This again impacts the future fleet composition as we dimension the fleet to expected shipping demand growth in the various segments.

Based on endogenous equilibrium freight markets (as explained below under step two of the model) and exogenous price assumptions for fuels and blending fuels, the model optimizes the individual vessels' speed and consumption to maximize revenue for the shipowner. This is done using a relevant voyage calculation for the segment in question, preferably a dominant trade route reflecting the representative sailing route for a given ship segment. Furthermore, we constrain the optimization model to comply with anticipated regulatory limitations on carbon intensity indicators – essentially limiting vessel speed where applicable. Finally, the model generates vessel-specific timecharter equivalent (TCE) freight rates for each of the assets which are used in the final assessment of potential investment returns. (Table 05)

Table 05

Vessel specific rate model to maximise shipowner earnings, given a set freight market and fuel cost. (Source: DNB Markets)

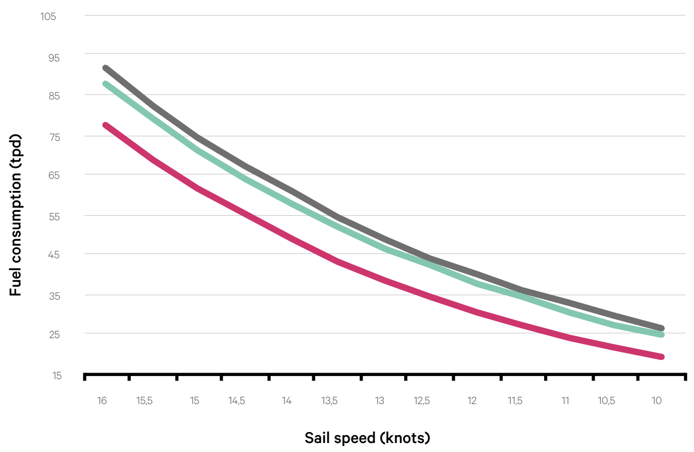
Freight market at gross (USD/tonne)					
Vessel 1 2010 built	Vessel 2 2010 w/ scrubber	Vessel 3 2020 built	Vessel 4 2020 w/ scrubber	Vessel 5 2020 LNG fueled	Vessel 6 2020 NH3 fueled
Consuption curve Regulatory limits	Consuption curve Regulatory limits	Consuption curve Regulatory limits	Consuption curve Regulatory limits	Consuption curve Regulatory limits	Consuption curve Regulatory limits
+	+	+	+	+	+
Fuel prices (USD/tonne)					
Vessel 1	Vessel 2	Vessel 3	Vessel 4	Vessel 5	Vessel 6
Optimal speed Daily fuel cons TCE rate (USD/day)	Optimal speed Daily fuel cons TCE rate (USD/day)	Optimal speed Daily fuel cons TCE rate (USD/day)	Optimal speed Daily fuel cons TCE rate (USD/day)	Optimal speed Daily fuel cons TCE rate (USD/day)	Optimal speed Daily fuel cons TCE rate (USD/day)

As highlighted in the vessel types and technology section below, we have differentiated the generic vessels on vintage, relating to prevailing vessel technology and hydrodynamics, and engine fuel compatibility to approximate the fuel efficiency dimension. From observed fleet data, we have pinpointed larger technological shifts at certain periods with the most prominent being the shift to eco-vessel designs between 2010-2020. Hence, our main differentiated vintages are a generic 2010 vessel design (ordered during peak shipping activity levels before the financial crisis) and a generic eco-vessel built in 2020. The two vintages represent the typical second-hand and resale/newbuilding alternatives to vessels in the fleet, which in our view represent the bulk of shipowners' investment alternatives in today's market. (Graph 10)

The second dimension is fuel type, and we have included VLSFO (standard ship), HFO (scrubber-fitted vessel), LNG, and ammonia dual fuel engines in our analysis, which is further discussed in the vessel types and technology section. The 2010 vintage is limited to VLSFO and HFO, while resale 2020 vessels expand to include LNG retrofitting (assumed in 2030) and a 2020-design newbuild (assumed 2-year lead time) can also include dual fuel ammonia propulsion, with or without a scrubber, in addition to the previously mentioned alternatives. The fuel type naturally dictates the resulting fuel cost in the optimization model, but also modeled emissions that potentially impact the regulatory limitations on a vessel-by-vessel basis (e.g. CII and EEXI regulations). (Graph 11)

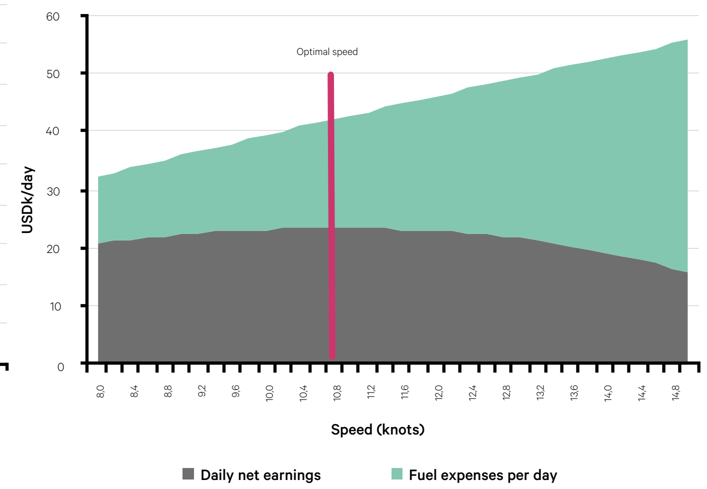
Graph 10

Illustrative speed/consumption curves for Capesize vessels. (Source: DNB Markets)



Graph 11

Capesize speed optimisation visualisation. (Source: DNB Markets)



5.2.2. FREIGHT MARKET EQUILIBRIUM MODEL

The second component of the two-step approach encompasses the wider freight market and formation of an equilibrium freight market based on the underlying modelling assumptions (e.g. fuel price, regulations, etc). Assuming a highly competitive market, for which shipping markets are notorious, we expect the marginal freight provider to be making target returns on the most cost-efficient vessel investment, resulting in inferior rates and levels of return for alternative vessel types. The target returns are depicted as parity time charter equivalent (TCE) rates per vessel type based on a set of vessel-specific assumptions highlighted in the vessel types and technology section.

In layman's terms, this means we assume shipowners will fiercely underbid each other for cargo until there is only one vessel (type) that can make the required TCE freight rate in USD/day to defend the investment in the vessel (dictated by an 8% return on investment over the lifetime of the vessel). For the charterer, this translates to a freight cost in USD/tonne that he indiscriminately would be willing to pay any shipowner to ship his goods. However, for inferior vessel types with higher costs (e.g. for fuel due to consumption), this would translate to a TCE below the required rate to make the 8% return. (Table 06)

5.2.3. MODEL OUTPUT AND RATIONALE

As input factors such as fuel and carbon prices change, the superior technology (i.e. the generic vessel type able to make sufficient returns) will vary from year to year, and drive investment appetite for the leading vessel alternative to meet future expected transport demand needs. This would imply that prospective shipowners would opt for ordering a certain vessel type, such as a scrubber-fitted VLCC, versus another, such as the more expensive LNG-fuelled VLCC, purely based on anticipated financial returns. In order to shift the preference to LNG, the earnings potential of the vessel would need to improve on a relative basis to at least offset the increased cost of such a vessel, for instance by regulations raising the CO_2 price sufficiently. We extend our model to cover the expected vessel lifespan of a newbuild vessel ordered today, which results in an outlook towards 2050. Hence, the leading technology at any point in time should in our view be the preferred vessel for contracting at the yards. (Table 07)

As older vessels are scrapped and new ones are ordered, this rational channelling of investment capital leads to an evolving fleet composition over time that varies in the different scenarios. Based on the individual vessel metrics and fleet composition we are able to forecast several fleet metrics, including CO_2 emissions both per transport work and in aggregate allowing us to compare our outlook to the comparative metrics and ambitions proposed by the IMO and related to the Paris agreement. (Graph 12)

In aggregate, the resulting output should be closely aligned to realistic expectations for fleet development provided the underlying assumptions hold water and rational investment decisions are made. However, as the regulatory outlook remains highly uncertain and other soft factors can affect near-term decision making, one might expect a greater diversity in contracting behaviour compared to our stylized forecasts. Simplifications made in the model, including the limited number of generic asset types and technology combinations, uncertainty surrounding fuelling infrastructure and availability, and a vast variety of different trade routes, all limit the practical applications of the results. Still, we believe the results are highly relevant as a guiding light in these uncharted waters and illustrate quantitatively the current qualms with investing in shipping assets with an unprecedented level of regulatory and operational uncertainty.

Table 06

Market rate model: Freight minimised to comply with low-cost freight provider and incentivise rational capital allocation. (Source: DNB Markets)

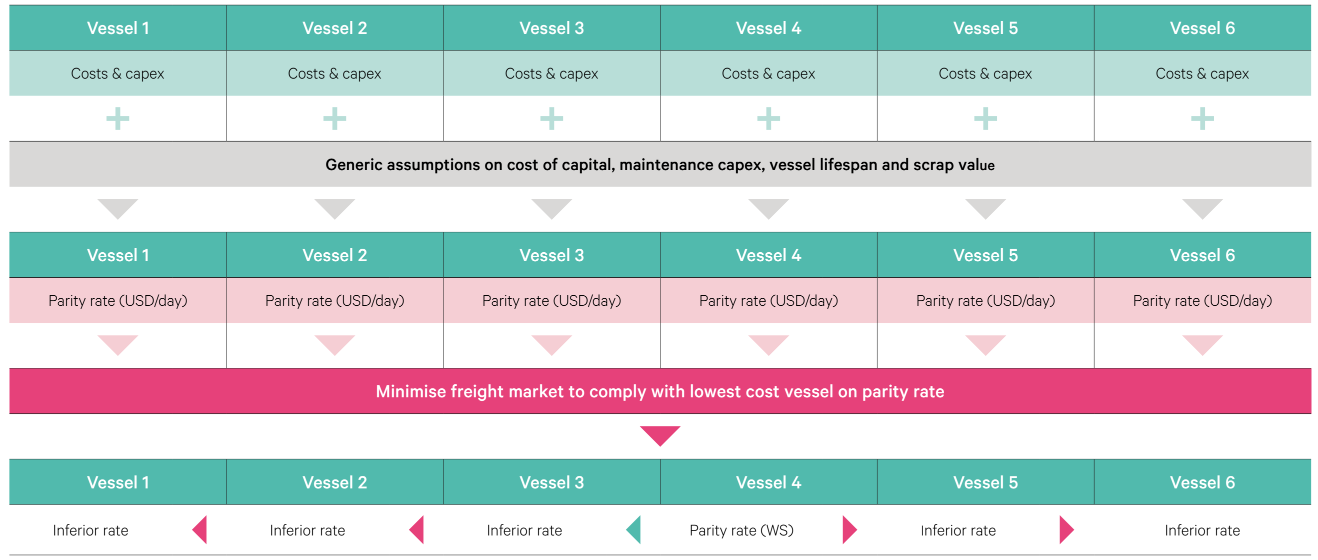


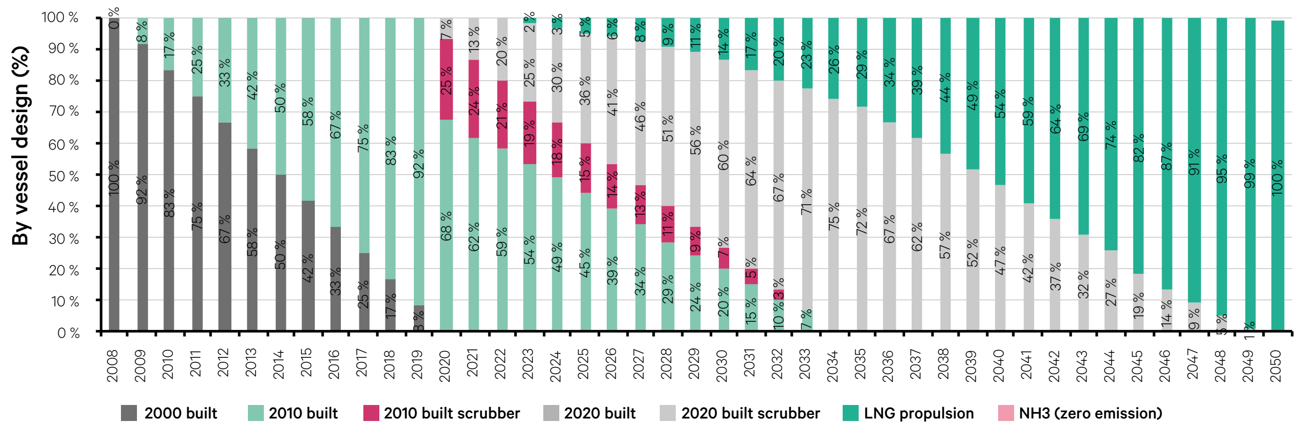
Table 07

Illustrative overview of market setting Capesize vessel (green) in forecast years 1-10 (i.e. 2021-2030), base case. (Source: DNB Markets)

TCE rate (000 USD/day)	1	2	3	4	5	6	7	8	9	10
Cape 2010	17	14	13	14	14	14	14	14	14	13
Cape 2010 scrubber	21	17	17	17	17	17	17	17	17	15
Cape resale	20	16	16	16	16	16	16	16	16	17
Cape resale scrubber	23	19	19	19	19	19	19	19	19	18
Cape scrubber LNG retrofit	23	19	19	19	19	19	19	19	19	22
Cape 2020 NB			16	16	16	16	16	16	16	17
Cape NB scrubber			19	19	19	19	19	19	19	18
Cape NB LNG			20	20	20	20	20	20	20	22
Cape NB NH3			16	16	16	16	16	16	16	17
Cape NB NH3 scrubber			19	19	19	19	19	19	19	18

Graph 12

Illustrative fleet composition for Capesize vessels in base case scenario by vessel technology. (Source: DNB Markets)



5.2. VESSEL TYPES AND ENGINE TECHNOLOGY

5.2.1 ENGINE TECHNOLOGY

The global fleet is today mainly powered by diesel combustion engines running on VLSFO/HFO. About 200 vessels are powered by LNG, while LPG is emerging for LPG carriers.

Long distance freight puts a limitation on engine technologies that are economically viable to serve an engine for 30 days or longer at open sea. Hydrogen engines have been excluded from this study due to the complexity and large part of the cargo space the bunker fuel would occupy. Batteries are not a viable option for long distance freight due to investment cost, weight, and power storage limitations. Other than traditional internal combustion engines powered by diesel/HFO/VLSFO this study, therefore, has focused on LNG and ammonia as probable fuel alternatives, both for use in ICE technology. It should be highlighted that the ammonia engine is still under development, as well as potential infrastructure development. Ongoing industry developments on ammonia engine systems will be viable soon and well within the timelines used in this study.

LNG and ammonia engine technology have been assumed to have the option to be dual fuel, i.e. able to interchangeably use VLSFO/HFO. Biofuels have been used as a drop in fuel to comply with the regulation on blending requirements as it can be used in traditional internal combustion engines as an alternative to fossil diesel/HFO/VLSFO. It is assumed that technology and fuel are readily available when being adopted. (Table 08)

5.2.2 VESSEL TYPES AND CAPEX ASSUMPTIONS

To assess IRRs for ships with different engine technology, the cost of ordering or retrofitting a ship is required. The cost of newbuildings within tank, container, and bulk is transparent when it comes to MGO/HFO engine technology, however, cost estimates for LNG, dual fuel, and especially ammonia engines can deviate from the assumptions done in this study. Also cost estimates for retrofitting MGO/HFO vessels to new engine technologies will vary between ships within the same asset class, depending on the origin of yard, tanks, age, and general state.

Table 09 shows the Capex assumptions used for newbuildings and the cost of retrofits. The cost estimates are done to the best of our knowledge, but if one of the new engine technologies becomes dominant we think there can be room for reducing the cost gap against traditional MGO/HFO engines. (Table 09)

Table 08

Vessel specific engines system .

	Fuel Type			
Engine System	Bio-HFO HFO	Bio-VLSFO/MGO VLSFO/MGO	Bio-LNG LNG	Blue/Green NH3 Ammonia
Internal Combustion Engine		✓		
Internal Combustion Engine/ with scrubber	✓			
Dual fuel LNG ICE		✓	✓	
Dual fuel Ammonia ICE		✓		✓
Dual fuel NH3 ICE w/scrubber	✓			✓

Table 09

Capital expenditure assumptions.

Vintage	Fuel	VLCC	Cape	10kTEU
2010	VLSFO	46	23	48
2010	scrubber	49	25	52
2020	VLSFO	90	49	96
2020	scrubber	92	51	100
2020	LNG retro	92+25	51+20	100+20
2020 NB	VLSFO	90	49	96
2020 NB	scrubber	92	51	99
2020 NB	LNG	105	62	109
2020 NB	NH3	105	62	109
2020 NB	NH3+scrub	107	64	112

6. RESULTS

Findings from study

Main findings and result

In this section, financial performance under a base case scenario and high case scenario is measured for different engine technologies. This section also shows emission development and fleet composition for VLCC and Capesize under the forecasted scenarios towards 2050. Internal rate of return (IRR) of different engine technologies and ship types are measured under the different scenarios. Both IRR on secondhand tonnage and newbuild are included in the study. The study points to the main financial risk factors related to decarbonization regulation and CO_2 pricing that should be taken into consideration when making investment decisions in new or old tonnage.

«Old secondhand vessels provide a better return on invested capital than modern vessels.»

Key findings from the study are:

- Very negative financial impact on traditional engine technology running on MGO/HFO/VLSFO in the high case scenario. Near-zero or negative IRR on the capital being invested is found on all ship types under this scenario.
- IRRs are lower for ammonia engine technologies compared to MGO/HFO engine technology under the base case scenario, however, ammonia generates acceptable IRR in a tougher high case regulatory environment where traditional engines have negative IRRs. As such, our study finds that ammonia is more financially robust considering the uncertainty regarding future policy development in the sense that it can move towards base case or high case.
- The IMO target for emission reduction is within reach with traditional engine technology for VLCC and Capesize, albeit 50% blending of zero-emission fuel and further speed reduction is needed.
- The study shows that older vessels have better risk/return characteristics, given that they will leave the global fleet before the modelled introduction of a more stringent regulatory regime.
- LNG engine technology becomes the preferred engine technology in our base case for Capesize, VLCC, and the 10k TEU container vessel. However, in our high case, it carries much of the inherent financial risk as traditional diesel combustion engines since their CO_2 footprint is only 17-23% lower. As such, we believe LNG serves as a bridging technology on the path to tighter regulations and decarbonization ambitions, such as aligning shipping with the Paris agreement.

«Findings reflect a technology shift from HFO to LNG around USD50/tonne, while the shift to ammonia would need a carbon pricing between USD 250/tonne and 300/tonne.»

Findings VLCC

6.1. CRUDE TANKERS – VLCC CASE STUDY

Graph 12 show IRR for the base case scenario and high case scenario for VLCCs on different engine technologies. In the resulting IRR for the case study of VLCCs, we find the current uncertainty and expectations of increasing future regulatory pressure to prefer older vessels on the water as exemplified in the study by a 2010-built vessel. Among engine technologies for newbuilds, ammonia is the preferred technology in a high price scenario, while LNG marginally wins out against traditional diesel engines in a base case scenario. (Graph 13)

Old secondhand vessels provide a better return on invested capital than modern vessels (resales or newbuilds). The asset's shorter remaining economical lifetime considerably outweighs the benefits of modern and efficient vessels near-term as stringent environmental measures are expected to severely impact freight markets beyond 2030. As implementing changes to regulations is a lengthy process, this remains the case for the high case scenario as well. Note that retrofits of existing vessels show consistently lower returns compared to the newbuild alternatives in the study due to the higher Capex component associated with installing new engines and tanks. This translates to the conclusion that steeply discounted second-hand asset values should appraise on a relative basis to newbuilding prices and modern asset values (resales) to even out the difference, i.e. the economic value of an old vessel is above the investment cost, and vice versa for the resale or newbuild. For a scrubber-fitted 2010 vessel to match the IRR of a scrubber-fitted resale (i.e. the 2020-built vessel) in our base case, the asset could add USD9m to its value, or an 18% increase from the modeled USD49m, while resale values remain unchanged. Similarly, USD21m or 43% higher price for a 2010-built VLCC with a scrubber would be needed to match the IRR for a scrubber-fitted resale in the high case scenario. (Graph 01)

While the analysis reveals a preference among existing vessels for older assets on the water, the question remains what type of vessel will be the preferred vessel among the newbuilds to cater for fleet growth to meet an expected increase in transport demand in the future. In this instance, the two scenarios deviate. Our base case assumptions indicate a marginal preference for LNG propulsion (7.8% IRR) above the traditional engine with scrubber (7.5%). As we will cover below, this has certain implications for the composition and emissions of the fleet under our base case assumptions.

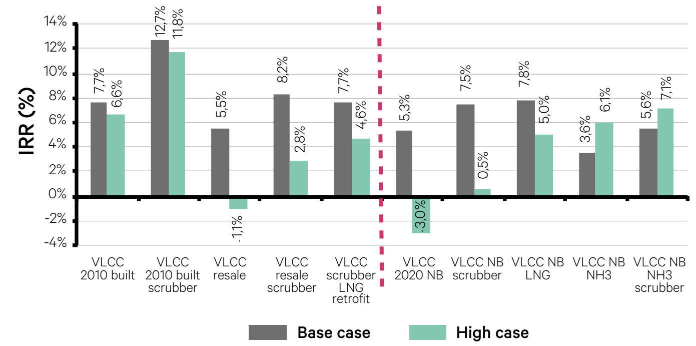
If fuel prices are headed higher, and similarly for the price of CO_2, the conclusion is radically different. In such a scenario, incurring the additional Capex of an ammonia dual fuel vessel today becomes the preferred option, ahead of LNG and traditional technology, respectively. The results are perhaps unsurprising as they relate to added investment Capex for future cost savings on fuel in return, but nonetheless highly relevant in the context of today's investment decisions for the shipowner and related stakeholders. Since LNG propulsion results in only a partial CO_2 reduction, financial returns are between traditional engine technology and ammonia in a high regulatory environment. LNG propulsion seems therefore to be a viable alternative to existing engine technologies near term, before a potential tightening of regulations and increased costs impact returns and deteriorate the investment case for this technology. (Graph 14)

Investigating the potential impact of carbon emissions pricing in the shipping industry highlights the importance of expected cost levels for the attractiveness of various propulsion technologies. In the following chart, we illustrate the impact of CO_2 prices ranging from USD100/tonne (base case) to USD300/tonne (high case) on potential vessel earnings within the VLCC space assuming the most cost efficient vessel sets the market at its parity rate. The market setting technologies are marked in red for various price scenarios, and each vessel's parity rate is disclosed in the legend.

For the VLCC's our findings reflect a technology shift from HFO to LNG around USD 50/tonne, while the shift to ammonia would need a carbon pricing between USD250/tonne and USD300/tonne. The 'LNG window' between cUSD50/tonne and cUSD275/tonne reflects the approximate 25% CO_2 savings achieved by the greener transition fuel before the cost burden increases sufficiently to favor the potential zero-carbon technology of ammonia.

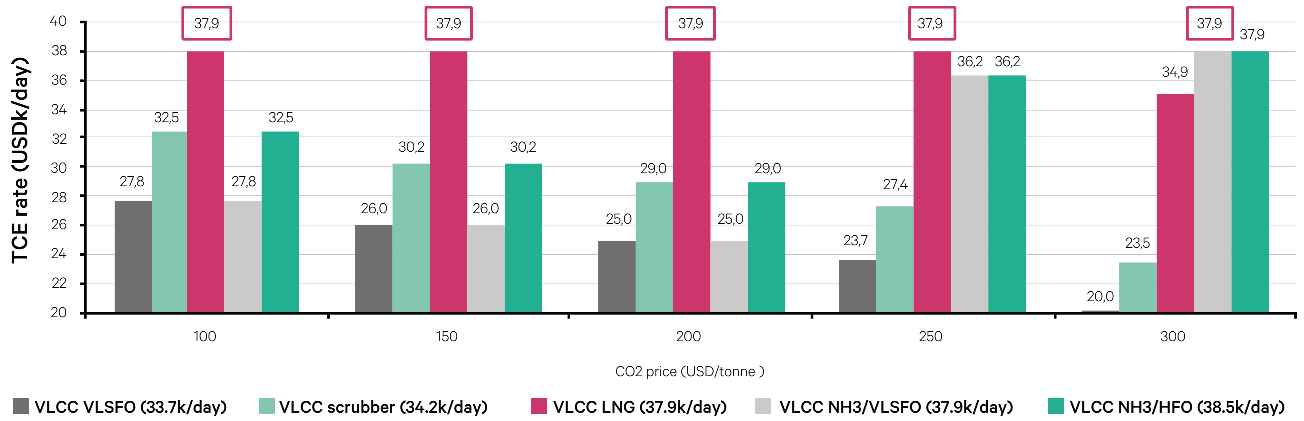
Graph 13

IRRs among different investments in VLCC technology today assuming our base case assumptions. (Source: DNB Markets)



Graph 14

Market-setting fleet technology at varying CO_2 pricing environments, triggering shift from traditional fuel (HFO) to transitional fuel (LNG) and to zero-carbon fuel (ammonia) as the cost of emissions increase. (Source: DNB Markets)



6.1.1. BASE CASE SCENARIO IMPLICATIONS

The base case scenario motivates the selection of the traditional vessel technology with scrubber among newbuilding alternatives up until 2030 when LNG propulsion becomes the most attractive option. We already have certain VLCCs in the order book with LNG propulsion against long-term contracts and find that the economics between traditional engine and LNG is marginal under our base case scenario until 2030. This underpins the recent interest in ordering LNG vessels against longer contracts and employment on certain trades to minimize operational challenges of these vessels before infrastructure is fully developed for increased optionality.

Our findings result in the VLCC fleet composition shown in the following chart. The historical characteristics of the VLCC fleet indicate an average age just shy of 10 years indicating a full shift of vessel generations over an approximate 20-year time frame. Hence, the average fleet is assumed a 2010-built vessel entering 2020 (~100% of the fleet) and as retrofit scrubbers are installed and new-build deliveries of scrubber-fitted 2020-built designs are delivered, the composition steadily changes. The 2020-built scrubber-fitted VLCC reaches 50% of the fleet in 2026 and peaks at 80% by 2030, before interest in LNG accelerates and brings the share of the fleet from 12% in 2030 to 100% by 2041. (Graph 15)

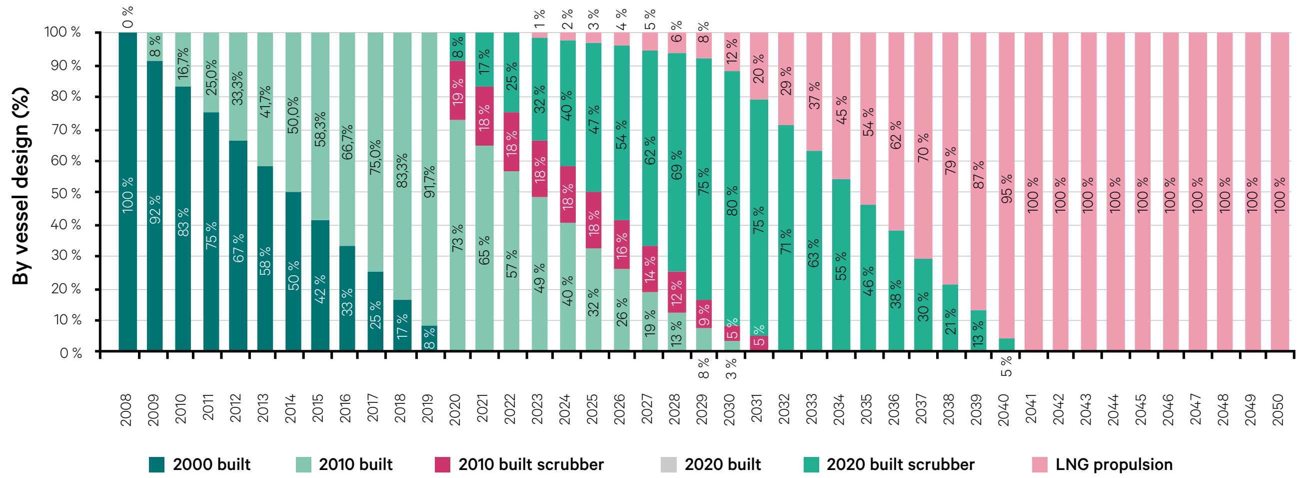
We dimension the fleet size to match anticipated shipping demand, reflecting a modest 0.3% CAGR from 2020-2050 for the tankers, to aggregate the impacts of the fleet and compare to IMO reduction targets. The size of the fleet will increase from approximately 800 VLCCs in 2020 to nearly 1,000 by 2050. Deciding on aggregate future shipping demand is beyond the scope of this report, but we have incorporated some growth from 2020 to 2030 and keep demand reasonably flat thereafter. While peak oil demand could be close according to certain forecasts, the composition of trade and average distance dictates the aggregate shipping demand which complicates the matter. Furthermore, alternative liquid fuels could also be transported on tankers in the future, making up some additional demand for fossil fuels today. As we are interested in the transport capacity of the fleet, this is dependent on the average sailing speed of the fleet which is illustrated in the chart below. (Graph 16)

Based on our model and optimal speeds, we estimate the average speed of the VLCC fleet will see step changes downwards in periods when new regulations are being enforced while transitioning to new more efficient vessels will lead to a steady increase in optimal sailing speeds. This holds until a uniform fleet composition is achieved when only changes to assumed freight markets, fuel costs or regulations would impact speeds. However, in practice it would be fair to expect tight or loose shipping markets to impact freight rates and thus speeds to effectively smooth the impact year-over-year for the modelling step changes that happen due to regulations (e.g. for 2030 when both biofuel blending requirements and CO_2 pricing is implemented overnight slowing the fleet from 12.8 knots to 11.7 knots). (Graph 17)

We have identified an estimated CII based on the annual efficiency ratio (AER) for the VLCC fleet in terms of CO_2 emissions per transport work (deadweight-tonne-miles) and the estimated ambitions of IMO to reach 40% and 70% efficiency improvements by 2030 and 2050. In our base case modelling we are essentially aligned with the existing ambitions for the IMO's initial GHG strategy on these metrics. We also reach IMO's absolute reduction target of 50% cuts from 2008 levels by 2050 as we model for very limited fleet growth coupled with increased environmental efficiency in the fleet. However, further initiatives need to be implemented in order to reach even more stringent regulations of reach carbon neutrality within the same time frame, assuming our base case price trajectories hold true. (Graph 18)

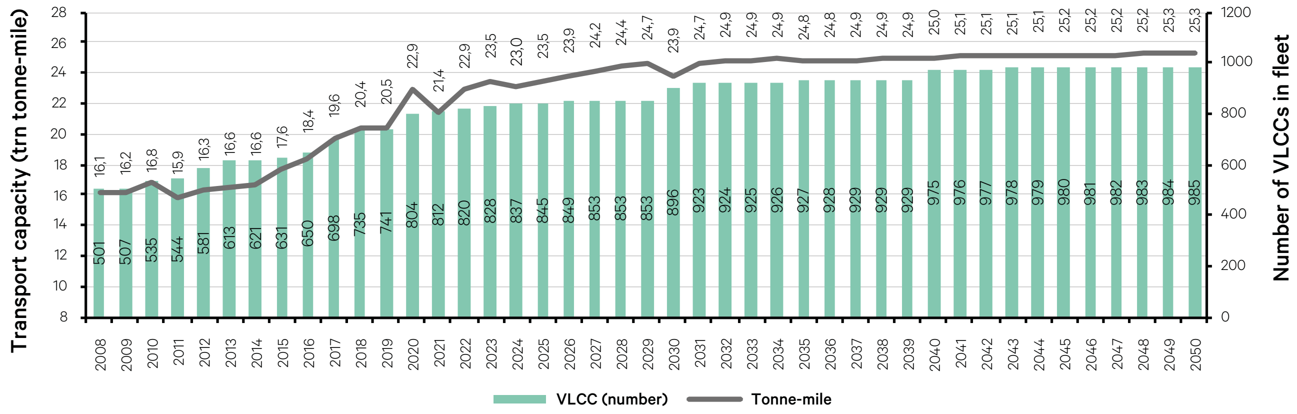
Graph 15

Composition of the VLCC fleet in our base case scenario leading to modern scrubber-fitted vessels as the preferred vessel technology until LNG takes over from 2030 and reaches full penetration by early-2040. (Source: DNB Markets)



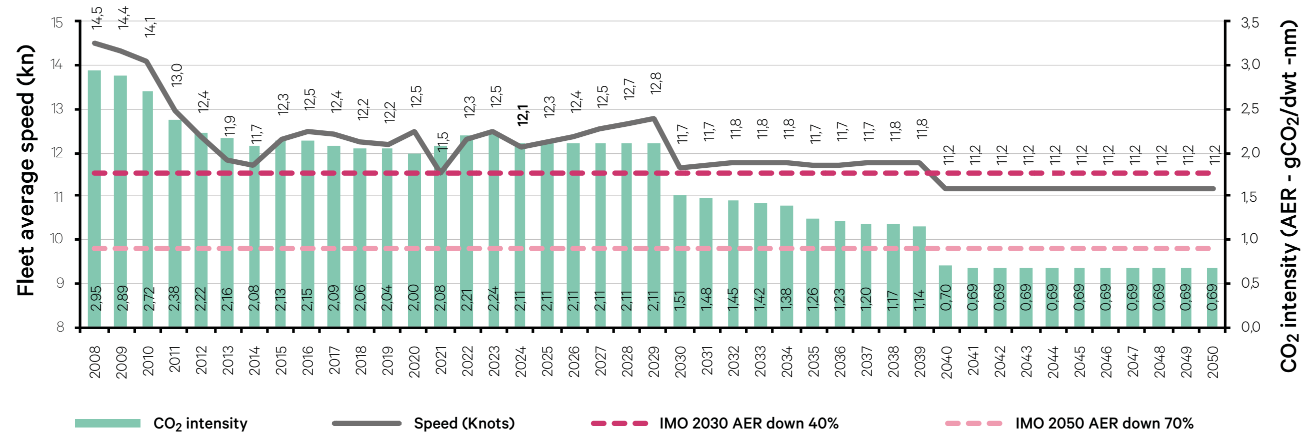
Graph 16

Aggregate fleet development to match anticipated future shipping demand growth. (Source: DNB Markets)



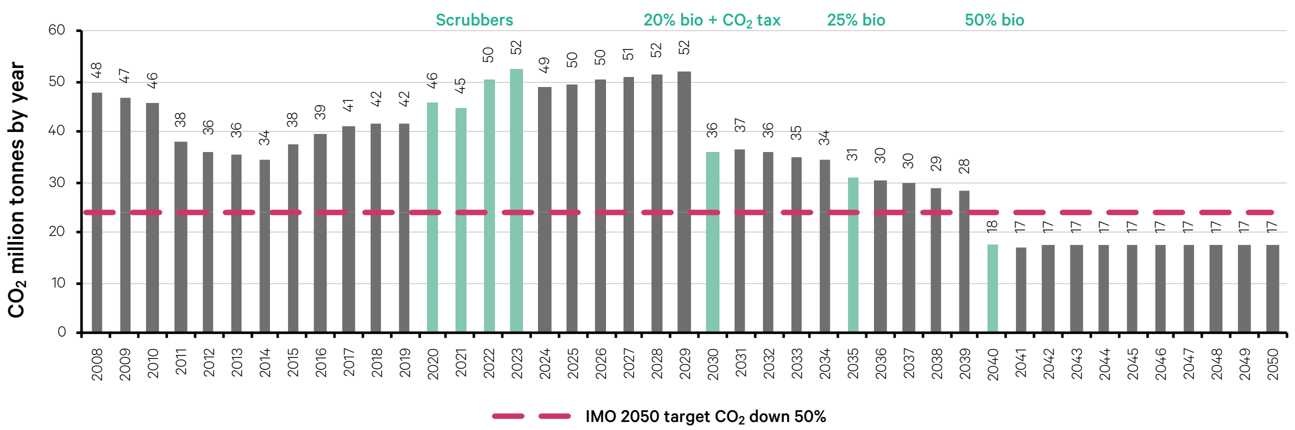
Graph 17

VLCC fleet average speed development and emissions efficiency improvements based on AER versus IMO ambitions. (Source: DNB Markets)



Graph 18

Aggregate CO_2 emissions from the VLCC fleet versus IMO ambition of 50% reduction by 2050. (Source: DNB Markets)



6.1.2. HIGH CASE SCENARIO IMPLICATIONS

In order to exemplify the impacts of increased energy prices and higher costs for CO_2 emissions, we have run our model on our high case price trajectories in a similar fashion to the above conclusions under the base case scenario. Given the higher cost of fossil fuels and the USD300/tonne CO_2 price, the preferred vessel technology shifts from the 2020-built scrubber-fitted vessel directly to the ammonia-fuelled vessel after 2030 regulations are enforced. (Graph 19)

As the current order book already has seen orders for some LNG vessels, and we believe the economic disadvantage of the LNG technology is not fully deterring of additional orders in the 2020-2030 period, we have modelled LNG vessels reaching 15% of the fleet by 2030. The ammonia-fuelled vessels reach 50% of the fleet by 2035, while a 100% shift to a potential carbon-free fleet is reached in 2046. (Graph 19)

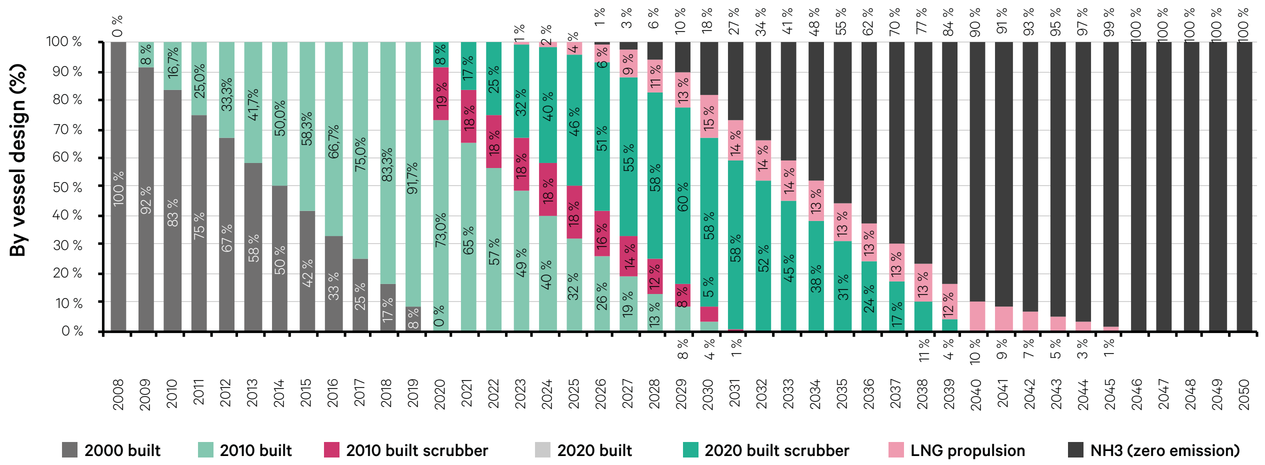
Due to the steep and stepwise change to fuel costs following the implementation of USD300/tonne CO_2 price and fuel blending requirements from 2030, the average speed in the fleet declines dramatically before recovering as older vessels are replaced to a lower level than in the base case. (Graph 21)

The implications of shifting to the carbon free ammonia-fuelled vessel become apparent in the assessment of carbon intensity and aggregate carbon emissions from the VLCC fleet. The AER declines by nearly 70% by 2030 and reaches zero in 2046 compared to stated IMO targets of 40% and 70% reductions, respectively. The aggregate emissions are halved from 2008 levels by 2030 and eventually reach zero in 2046 compared to the 50% reduction target by 2050 in IMO's initial GHG strategy.

Hence, we believe the high energy price environment coupled with our outlook for regulations being implemented in the future are more than sufficient to reach zero-carbon shipping by mid-century, while the current regulations coupled with our base case assumptions get in line with the IMO's stated ambitions.
VLCC fleet average speed development and emissions efficiency improvements based on AER versus IMO ambitions. (Graph 22)

Graph 19

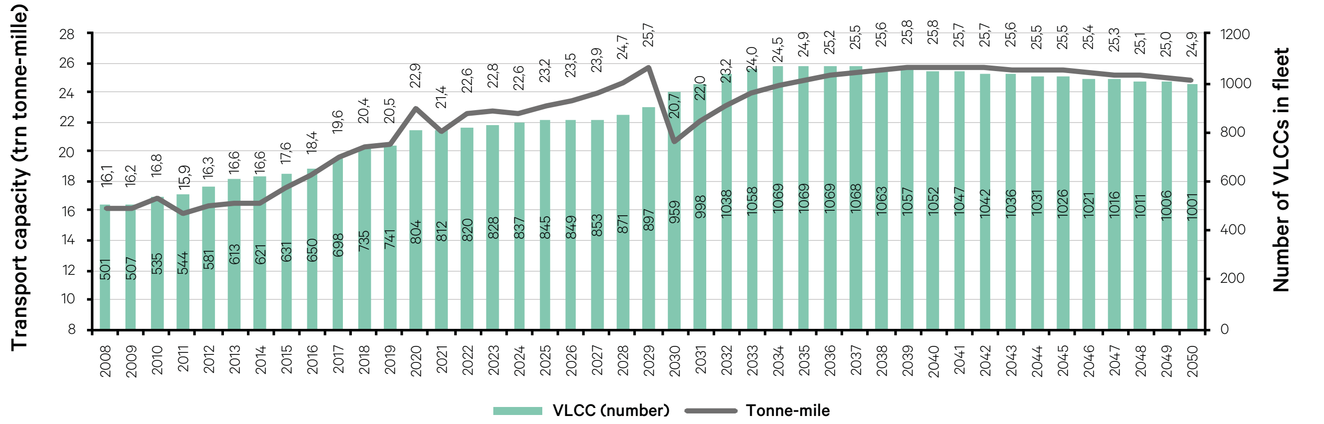
Composition of the VLCC fleet in our high case scenario shifting from modern scrubber-fitted vessels as preferred option to ammonia-fuelled vessels after 2030 regulations are enforced. (Source: DNB Markets)



«The preferred vessel technology shifts to the ammonia-fuelled vessel after 2030 regulations are enforced.»

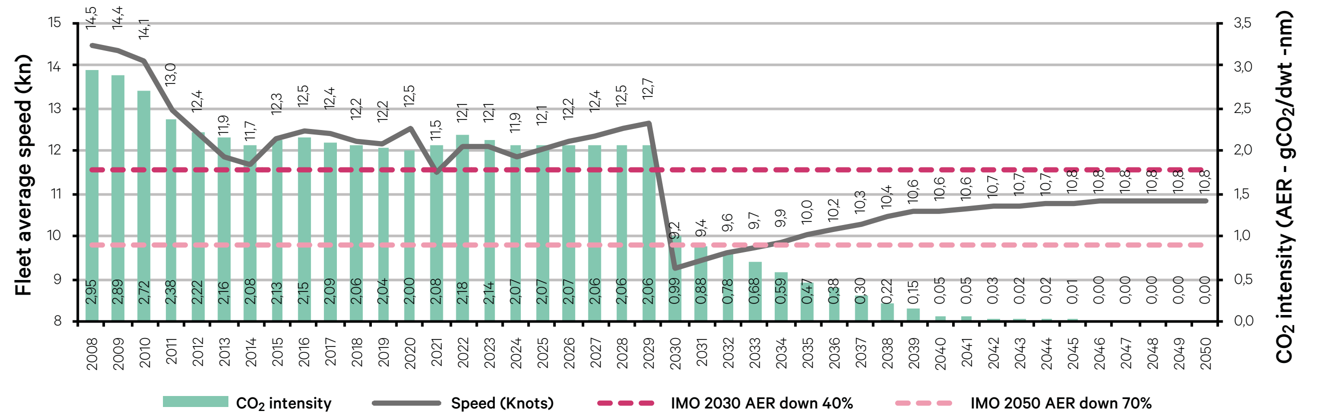
Graph 20

Aggregate fleet development to match anticipated future shipping demand growth. (Source: DNB Markets)



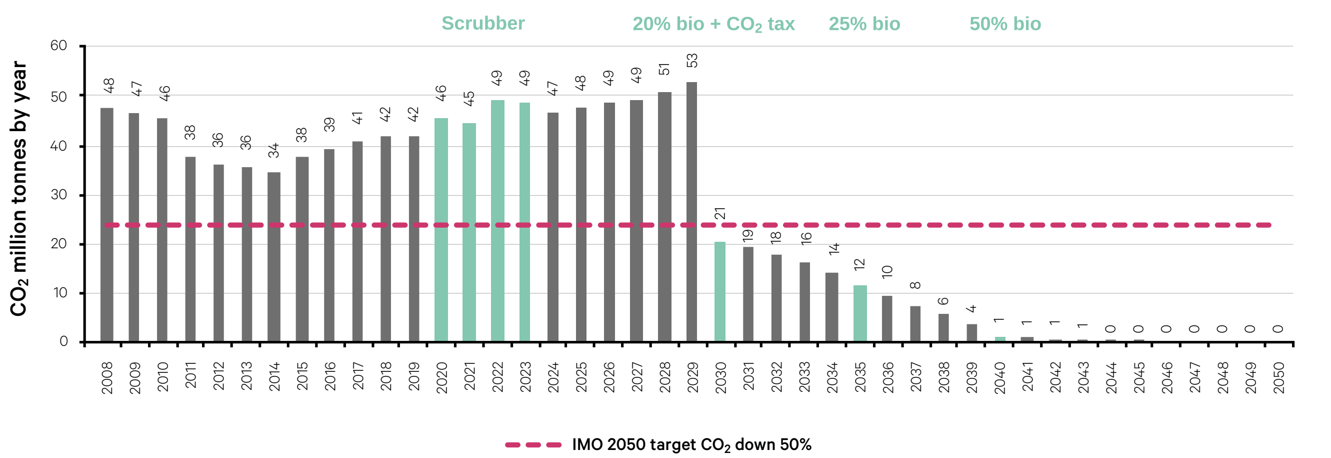
Graph 21

VLCC fleet average speed development and emissions efficiency improvements based on AER versus IMO ambitions. (Source: DNB Markets)



Graph 21

Aggregate CO_2 emissions from the VLCC fleet versus IMO ambition of 50% reduction by 2050. (Source: DNB Markets)



Findings capesize

6.2. DRY BULK – CAPESIZE CASE STUDY

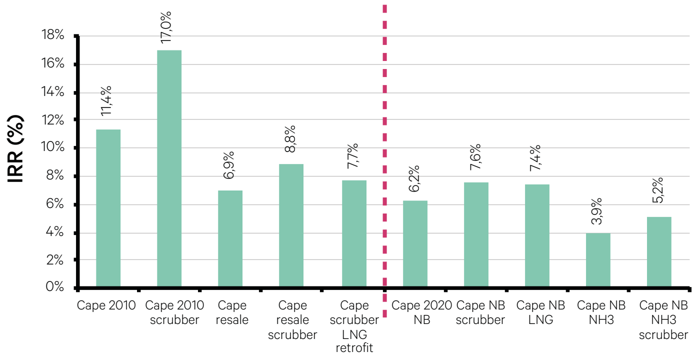
Similar to the results for the VLCC case study, our analysis of the Capesize segment reveals a preference for the 10-year old Capesize with a scrubber among potential vessel types in the segment for the same reason. However, the relative advantage of these assets is more sensitive to the high price scenario due to already low speeds and thus less flexibility to offset fuel costs with lower speeds than seems to be the case for VLCCs. In our base case, we calculate the value of a 10-year old scrubber-fitted Cape that needs to appreciate USD9.5m to USD34m in order to match the IRR of the scrubber-fitted resale at a cost of USD51m. This resembles a nearly 40% potential upside for the asset versus the modeled USD25m. In the high case scenario, the upside would be 26% or USD6.5m. (Graph 23)

Among the newbuild alternatives, we again find significant differences in the two scenarios. Our base case scenario marginally prefers the scrubber-fitted newbuild to the LNG alternative, however, LNG takes over as the preferred engine for newbuilds from 2030 and onwards as higher carbon pricing is introduced from 2030. The high price scenario would put the ammonia-fuelled vessel with scrubber at an advantage over the alternatives. These results are broadly similar to that in the VLCC case study with slight differences in the preference of LNG versus traditional with a scrubber. (Graph 24)

We investigate the sensitivity of pricing CO_2 for the Capesize case study as we did for VLCCs above and discover that USD100/tonne CO_2 price incentivizes the switch to LNG fuel in our base case, while the shift to ammonia needs a price between USD250-300/tonne. Within this range (100-275), the estimated savings from the approximate 25% emissions reduction from LNG propulsion is the preferred technology, before the zero-emissions alternative of ammonia is incentivized at levels above this. (Graph 25)

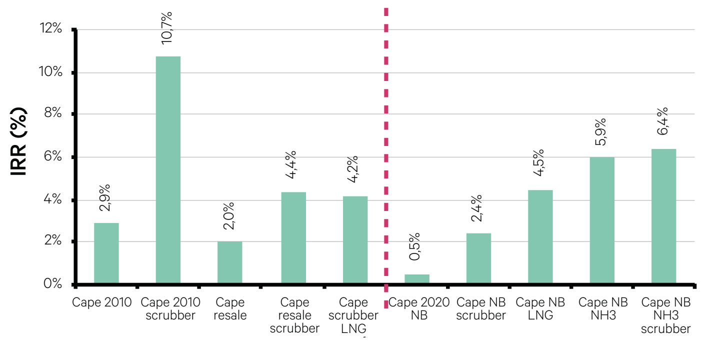
Graph 23

IRRs among different investments in Capesize technology today assuming our base case assumptions. (Source: DNB Markets)



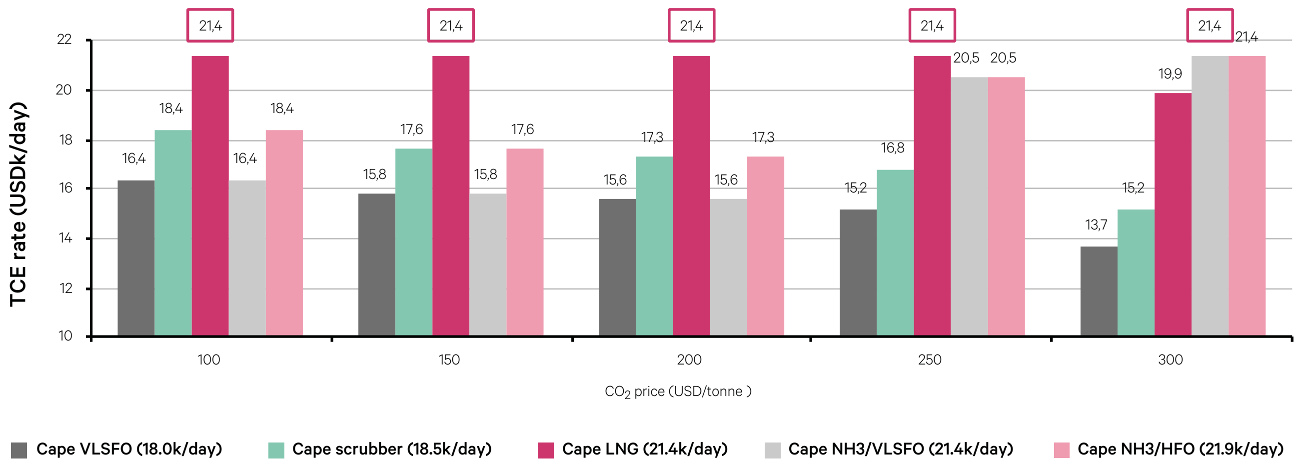
Graph 24

Our high energy price and elevated CO_2 price scenario enhances the favourability of alternative carbon neutral fuel vessels already today. (Source: DNB Markets)



Graph 25

Market-setting fleet technology at varying CO_2 pricing environments, triggering a shift from traditional fuel (HFO) to transitional fuel (LNG) and to zero-carbon fuel (ammonia) as the cost of emissions increase.



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«... LNG propulsion becomes the go-to technology in our base case scenario.»

6.2.1. BASE CASE SCENARIO IMPLICATIONS

Our base case scenario results in traditional scrubber-fitted Capesize vessels being ordered until 2030, after which LNG propulsion becomes the go-to technology at the yards. Based on recent developments in interest for LNG as a fuel in certain Capesize trades, we factor in a marginal share of such vessels already from 2023. We factor in a 25-year lifespan for the vessels, but including fleet growth, the shift in generations of technology occurs at slightly above the 20 years we assumed for VLCCs. The resulting fleet composition entails the last non-scrubber traditional vessel leaving the fleet early 2030 when scrubber-fitted vessels make up roughly 75% of the fleet and the LNG-fuelled vessels 25%. By 2050 the entire fleet will be propelled by LNG-fuelled vessels in our base case.
(Graph 25)

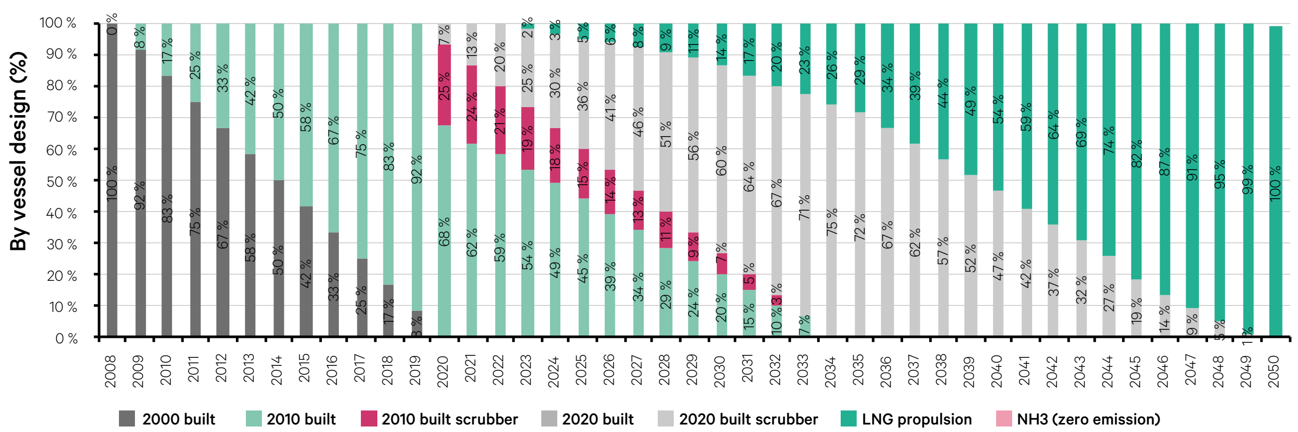
We dimension the fleet size to match anticipated shipping demand growth for dry bulk of 2.2% CAGR from 2020-2050, to aggregate the impacts of the fleet and compare them to IMO reduction targets. The demand growth has been decided based on forecasts in various scenarios as published by the IMO in its latest GHG study. The size of the fleet will increase from approximately 1,800 Capesize vessels in 2020 to above 3,700 by 2050. As we are interested in the transport capacity of the fleet, this is dependent on the average sailing speed of the fleet which is illustrated in graph 26.

Based on our model and optimal speeds, we estimate the average speed of the Capesize fleet will see step changes downward in periods of new regulations being enforced while transitioning to new more efficient vessels will lead to a steady increase in optimal sailing speeds. This holds until a uniform fleet composition is achieved when only changes to assumed freight markets, fuel costs or regulations would impact speeds. However, in practice it would be fair to expect tight or loose shipping markets to impact freight rates and thus speeds to effectively smooth the impacts YOY for the simplistically modelled step changes due to regulations (e.g. for 2030 when both biofuel blending requirements and CO_2 pricing is implemented overnight slowing the fleet from 11.8 knots to 9.9 knots). (Graph 27)

We have identified an estimated annual efficiency ratio (AER) for the Capesize fleet in terms of CO_2 emissions per transport work (deadweight-tonne-miles) and the estimated ambitions of IMO to reach 40% and 70% efficiency improvements by 2030 and 2050. In our base case modelling we end below the existing ambitions for the IMO's initial GHG strategy on these metrics. However, we fall short of the IMO's absolute reduction cuts of 50% from 2008 levels by 2050 as we model for fleet growth to meet our forecasted demand. Hence further initiatives need to be implemented in order to reach these goals, and even more stringent regulations to reach carbon neutrality within the same time frame, assuming our base case price trajectories hold true. (Graph 28)

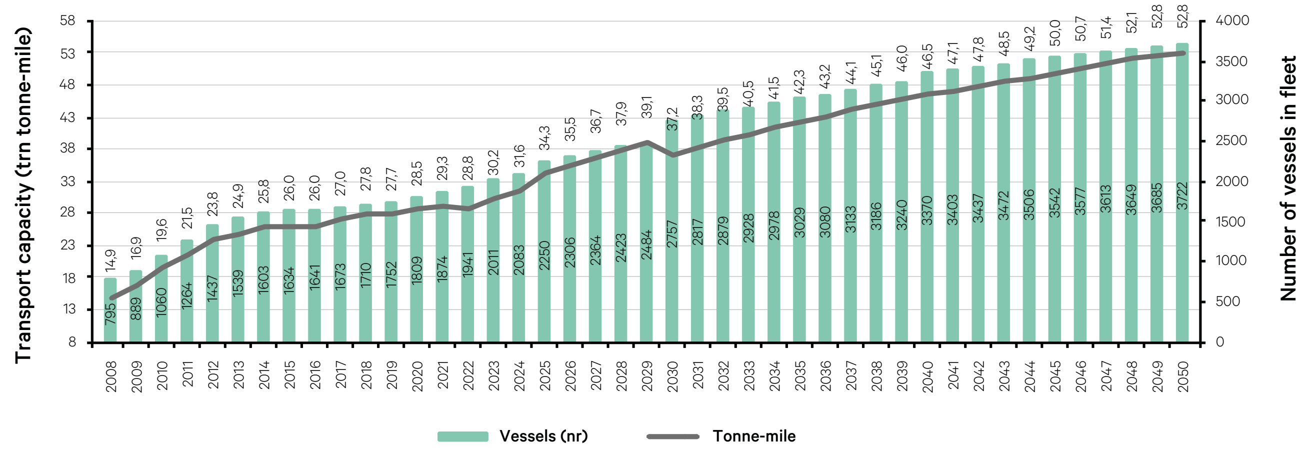
Graph 25

Composition of the Capesize fleet in our base case scenario leading to modern scrubber-fitted vessels as the preferred vessel technology until CO_2 price pushes the preference to LNG fuel from 2030. (Source: DNB Markets)



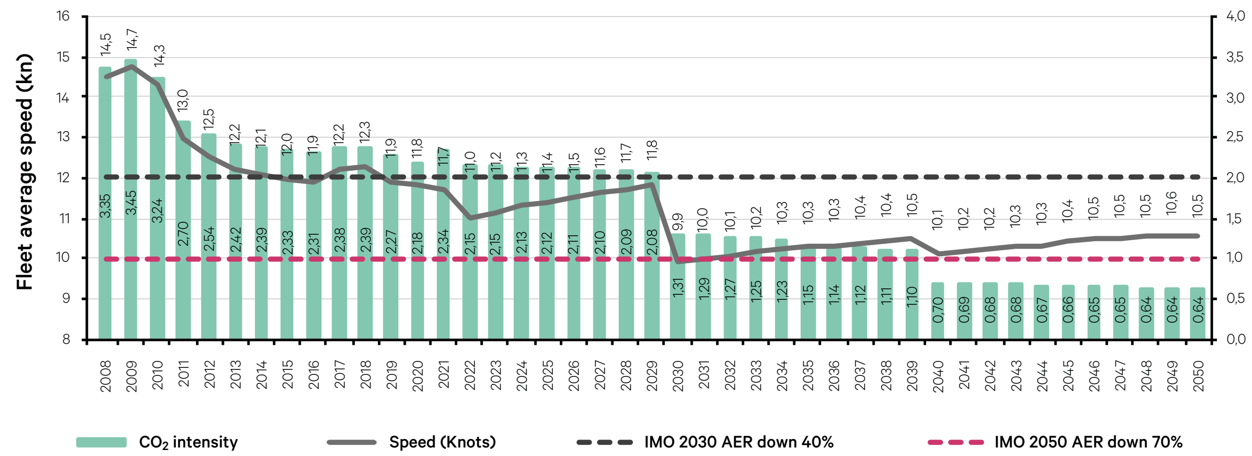
Graph 26

Aggregate fleet development to match anticipated future shipping demand growth. (Source: DNB Markets)



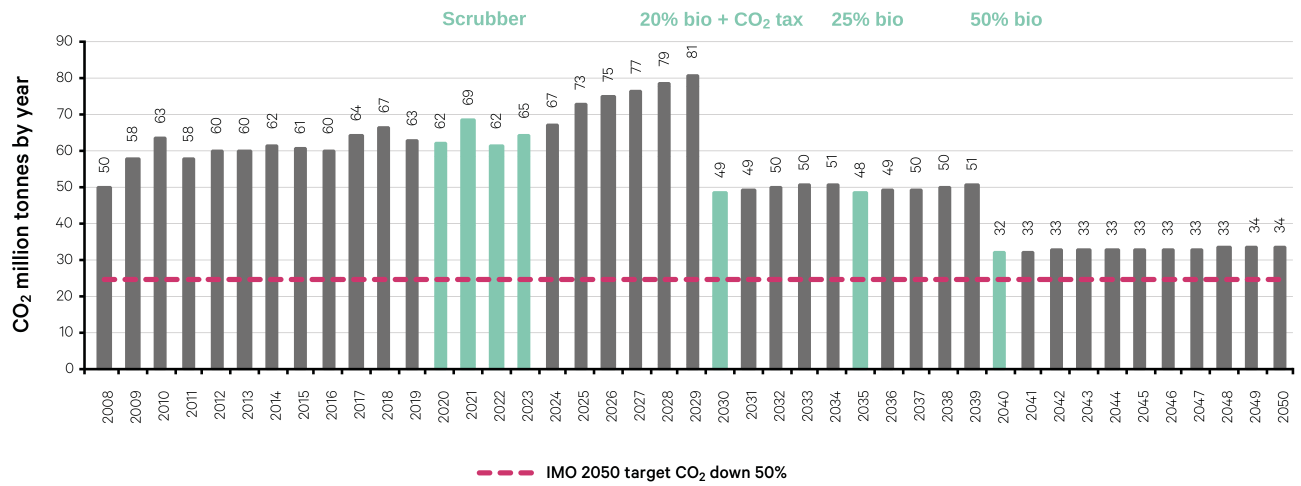
Graph 27

VLCC fleet average speed development and emissions efficiency improvements based on AER versus IMO ambitions. (Source: DNB Markets)



Graph 28

Aggregate CO_2 emissions from the Capesize fleet versus IMO ambition of 50% reduction by 2050. (Source: DNB Markets)



6.2.2. HIGH CASE SCENARIO IMPLICATIONS

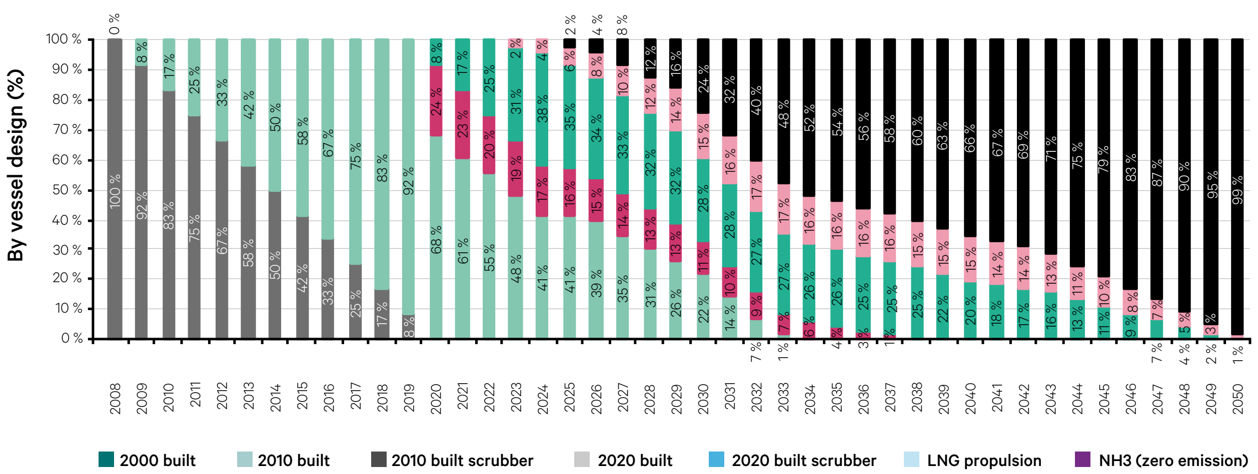
In order to exemplify the impacts of increased energy prices and higher costs for CO_2 emissions, we have run our model on our high case price trajectories in a similar fashion to the above conclusions under the base case scenario. Given the higher cost of fossil fuels and the USD300/tonne CO_2 price, the preferred vessel technology shifts from the 2020-built scrubber-fitted vessel directly to the ammonia-fuelled vessel after 2030 regulations are enforced. This matches the findings in the VLCC case study under the high case scenario. The ammonia-fuelled vessels reach 50% of the fleet by 2034, while nearly 100% shift to the potential carbon-free fleet is reached in 2050. (Graph 29 and 30)

Due to the steep and stepwise change to fuel costs following the implementation of USD300/tonne CO_2 price and fuel blending requirements from 2030, the average speed in the fleet declines dramatically before recovering as older vessels are replaced to a lower level than in the base case. (Graph 31)

The implications of shifting to the carbon free ammonia-fuelled vessel become apparent in the assessment of carbon intensity and aggregate carbon emissions from the Capesize fleet. The AER declines to below the 70% reduction target by 2030 and reaches near zero by 2050 compared to stated IMO targets of 40% and 70% reductions, respectively. The aggregate emissions are halved from 2008 levels by 2031 and eventually reach zero in 2050 compared to the 50% reduction target by 2050 in IMO's initial GHG strategy. Hence, we believe the high energy price environment coupled with our outlook for regulations being implemented in the future looks sufficient to reach zero-carbon shipping by mid-century, while the current regulations coupled with our base case assumptions get you close to reaching the IMO's stated ambitions. (Graph 32)

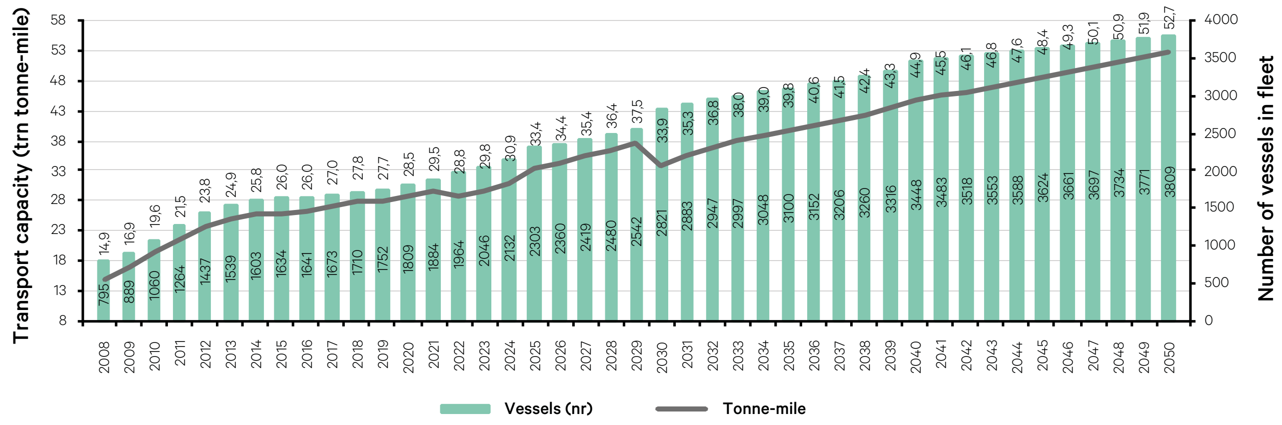
Graph 29

Composition of the Capesize fleet in our high case scenario shifting from modern scrubber-fitted vessels as preferred option to ammonia-fuelled vessels after 2030 regulations are enforced. (Source: DNB Markets)



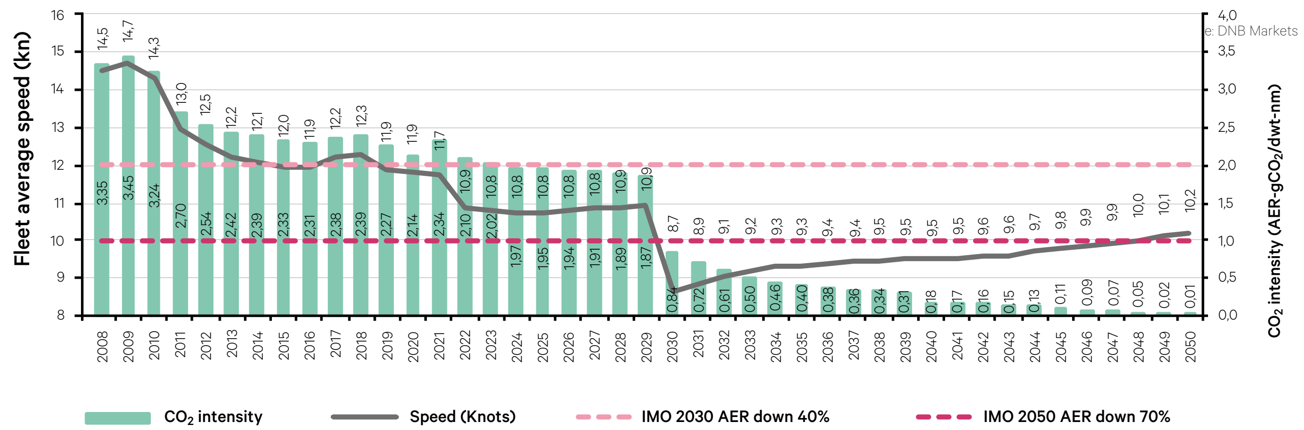
Graph 30

Aggregate fleet development to match anticipated future shipping demand growth. (Source: DNB Markets)



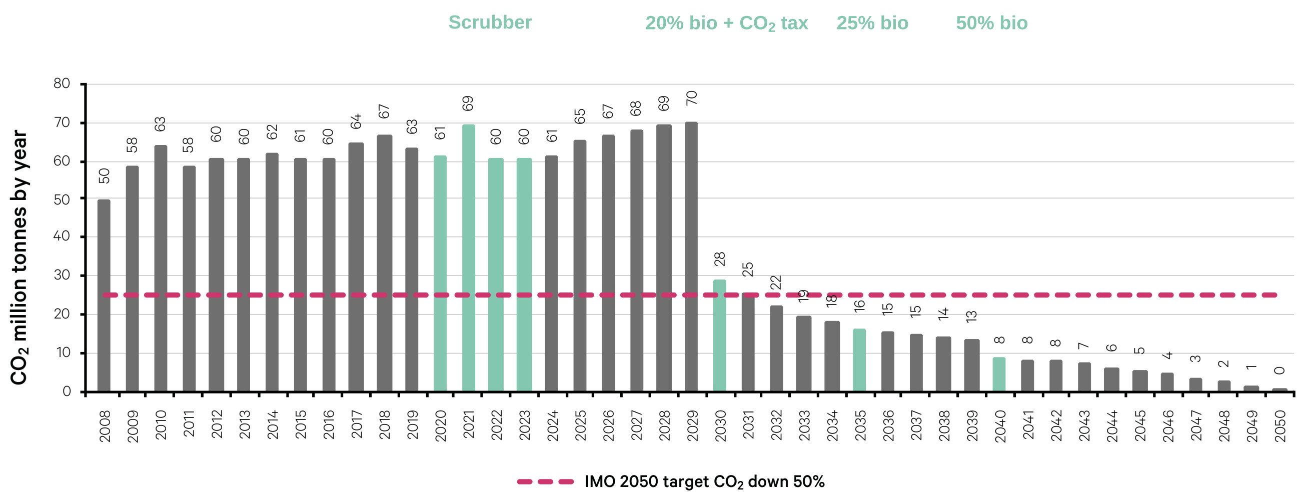
Graph 31

Capesize fleet average speed development and emissions efficiency improvements based on AER versus IMO ambitions. (Source: DNB Markets)



Graph 32

Aggregate CO_2 emissions from the Capesize fleet versus IMO ambition of 50% reduction by 2050. (Source: DNB Markets)



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Findings container

6.3. CONTAINER – 10K TEU VESSEL CASE STUDY

While the mechanics of freight market formation are, theoretically, straightforward in the fragmented crude tanker and dry bulk markets, the container market is dictated by integrated logistics networks and service offerings provided by largely consolidated liner companies and alliances across the individual companies. Hence, the model applicability to this segment is slightly constrained, but from the view of a tonnage provider still relevant to illustrate the relative attractiveness of viable vessel technologies for potential investment. (Graph 33 and 34)

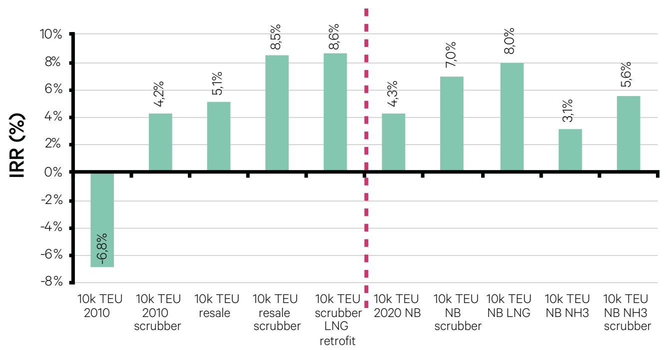
Using our model for a 10k TEU container vessel in our base case scenario, we arrive at a different result from the previous segments. The preferred vessel in our base case is now the modern resale with either a scrubber installed or a future retrofit to LNG propulsion. This clearly defers from the preference for older vessels with shorter remaining economic life in the case of VLCCs and Capsizes. This is explained by the stringent requirements in the planned regulations and early implementation for this segment (EEXI with a 40% reduction already from 2023). The forced reduction in sailing speed severely impacts the economics of the vessel, and the fuel economics of modern container vessels becomes an immediate advantage. Looking at the newbuild alternatives we discover that LNG propulsion would be the vessel of choice, ahead of the scrubber-fitted alternative.

If we apply our high price scenario, the impacts are detrimental for all assets but the ammonia-fuelled designs running on carbon free ammonia. This is a direct result of the high consumption figures on these assets and the massive cost burden associated with expensive fuel and the cost of emissions. From the results, we can infer that relatively recent containership technology looks exposed to rapidly shifting regulatory requirements.

We assess the sensitivity for carbon pricing on the 10k TEU segment and arrive at similar conclusions as in the other two segments. On our base case fuel price assumptions we need to see the price of CO_2 emissions reach beyond USD250/tonne to accelerate the shift to zero-carbon technology with ammonia-fuelled vessels. (Graph 35)

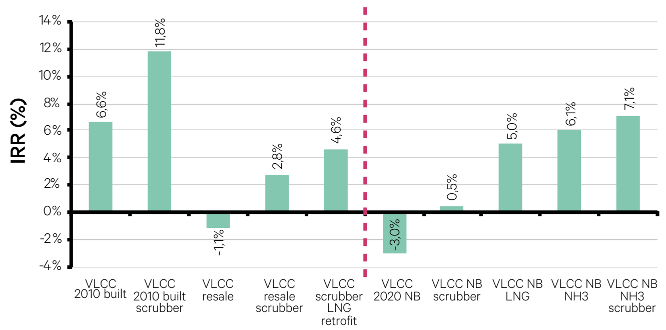
Graph 33

RRs among different investments in 10k TEU containership technology today assuming our base case assumptions. (Source: DNB Markets)



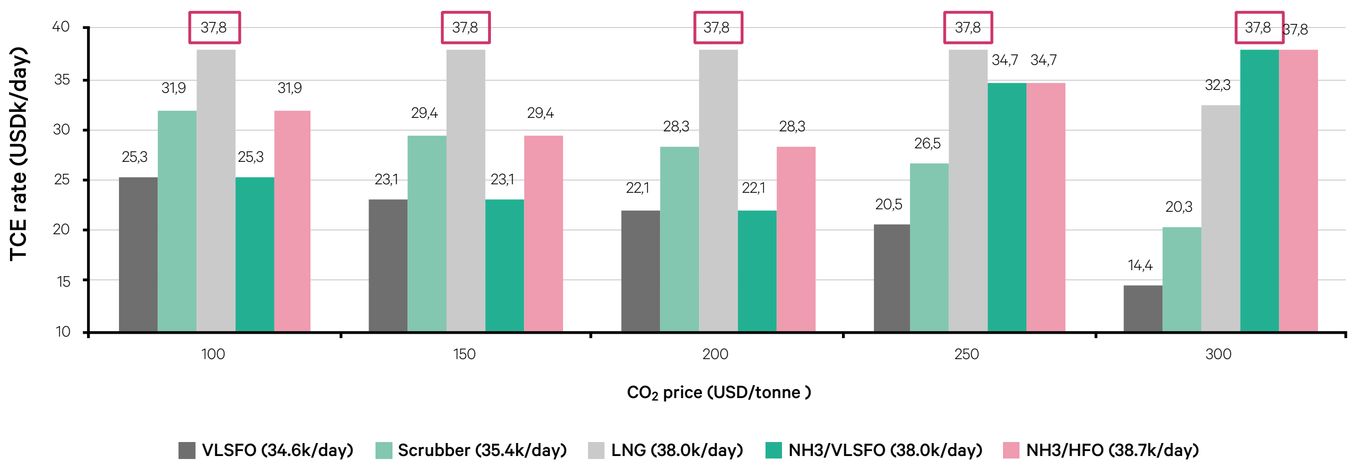
Graph 34

Our high energy price and elevated CO_2 price scenario enhances the favourability of alternative carbon neutral fuel vessels already today. (Source: DNB Markets)



Graph 35

Market-setting fleet technology at varying CO_2 pricing environments, triggering shift from LNG to zero-carbon fuel (ammonia) as the cost of emissions increase beyond USD250/tonne. (Source: DNB Markets)



Besøksadresse: Dronning Eufemias gate 10 • 0191 Oslo • tlf +47 55 54 85 00
Postadresse: KLP • Postboks 400 Sentrum • 0103 Oslo • klp.no