DNV·GL

MARITIME

LOW CARBON SHIPPING TOWARDS 2050

SAFER, SMARTER, GREENER


nuclear
hydrogen
wind
biofuel
LNG
HYBRID
HYBRID
10
CO_2
LPG
LNG
LPG
BATTERY
15
EEDI
NOx
LNG
SOx
HFO
HFO
SCRUBBER
MGO

EXECUTIVE SUMMARY

The Paris Agreement on Climate Change, adopted in 2015, is a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to below 2°C. To achieve this goal, global emissions should peak as soon as possible and then must be significantly reduced compared to todays' level. In line with this agreement, the IMO's Marine Environment Protection Committee has recently agreed on a roadmap for developing a comprehensive strategy on the reduction of Greenhouse Gas (GHG) emissions from ships. The initial strategy is expected to be adopted in 2018 and will be revised in 2023.

Reducing GHG emissions from shipping is a challenging task. Current solutions include the use of energy efficiency measures and alternative fuels. However, today's mature solutions are not sufficient for drastic reductions of GHGs due to their cost and reduction potential. Moreover, current limits on NO_x and SO_x emissions are often achieved with solutions that increase GHG emissions. On top of technical barriers, access to finance and low operating margins in many shipping segments lead to very short investment horizons, thus further complicating the uptake of technologies that could lead to decarbonisation of shipping operations.

Despite all the challenges, it is technically possible to achieve substantial reductions of GHG emissions, provided a viable strategy is adopted, and that there is strong resolve not only from the shipping industry, but from other industrial sectors as well. Shipping does not operate in a vacuum and should not be left in isolation to fulfil its obligation to reduce emissions. Collaboration with other sectors is needed to ensure availability of low carbon fuels, infrastructure for bunkering and cold ironing facilities, appropriate logistics solutions in case speed reduction becomes necessary, and development of required technical solutions. Offsetting of emissions can be a solution to avoid excessive cost and ensure reduction in other ship segments or industrial sectors where it has the lowest cost. A viable strategy for emissions reduction should also recognise the differences between shipping segments and the need to develop appropriate solutions for different ship types, sizes and types of operations.

Shipping will be expected to reduce GHG emissions and DNV GL is ready to assist the industry to negotiate the transition into a low carbon future. In this effort, we have developed a computational model that can be used to assess various scenarios for individual ship segments, for the industry as a whole and for evaluating the effectiveness of various solutions for reducing GHG emissions. This model can be used to help ship owners, policy makers and local authorities to develop an appropriate, robust strategy for further reducing the environmental footprint of shipping in a manner that will ensure that the industry stays the world's largest and most environmentally friendly transport sector.

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IMO's Marine Environment Protection Committee (MEPC) has recently agreed on a roadmap for developing a comprehensive strategy on reduction of Greenhouse Gas (GHG) emissions from ships. The initial strategy is expected to be adopted in 2018.

This report provides an evaluation of current GHG emissions from global shipping and explores the possibility for realistic reduction towards 2050, considering various levels of possible trade growth. An assessment of available technologies is performed for various ship segments and their potential impact and cost is evaluated. The results presented here are only indicative of the possible pathways that shipping can follow to reduce its impact on climate change. The model developed for performing these evaluations can be used for assessing other alternative scenarios and to provide input in the upcoming discussions, so that a realistic and robust GHG reduction strategy can be developed.

CONTENT

BACKGROUND

New challenge ahead – further GHG reductions

The Paris Agreement on Climate Change is an agreement within the United Nations Framework Convention on Climate Change (UNFCCC), dealing with greenhouse gases emissions mitigation, adaptation and finance starting in the year 2020. It was adopted in December 2015 and entered into force in November 2016. As of December 2016, 144 parties have ratified the agreement, including the USA, China, India and the European Union. The shipping industry is under increasing pressure to act upon it and reduce greenhouse gas emissions. It is considered likely that if the IMO doesn't address GHG emissions from shipping, the industry could face regional and local regulations from the European Union and maybe other nations. With such regulations, there is potential for serious market distortion and disruption to operation, as shipping is a global industry requiring global rules. IMO's MEPC has taken actions, recently agreeing on a roadmap for developing a comprehensive strategy on reduction of GHG emissions from ships. The initial GHG reduction strategy is expected to be adopted in 2018 and to be revised in 2023.

Current situation

Shipping is facing the introduction of the global 0.5% sulphur cap in 2020, one of the most important changes in its recent history. Up to 70,000 ships will be affected by this regulation. Stricter limits on sulphur (SO_x) emissions are already in place in Emission Control Areas (ECAs) in Europe and the Americas and new control areas are being established in port areas in China. As a result of the increased international attention to air pollution, a growing number of ship owners are beginning to weigh their options to ensure compliance. They face a choice of either:

- switching from heavy fuel oil (HFO) to marine gas oil (MGO) or low sulphur fuel oil with 0.5% sulphur,
- or retrofitting vessels to use alternative fuels such as LNG or installing scrubber systems which allow them to continue operating on regular HFO.

In turn, these choices must be reconciled with the availability and cost of the fuels.

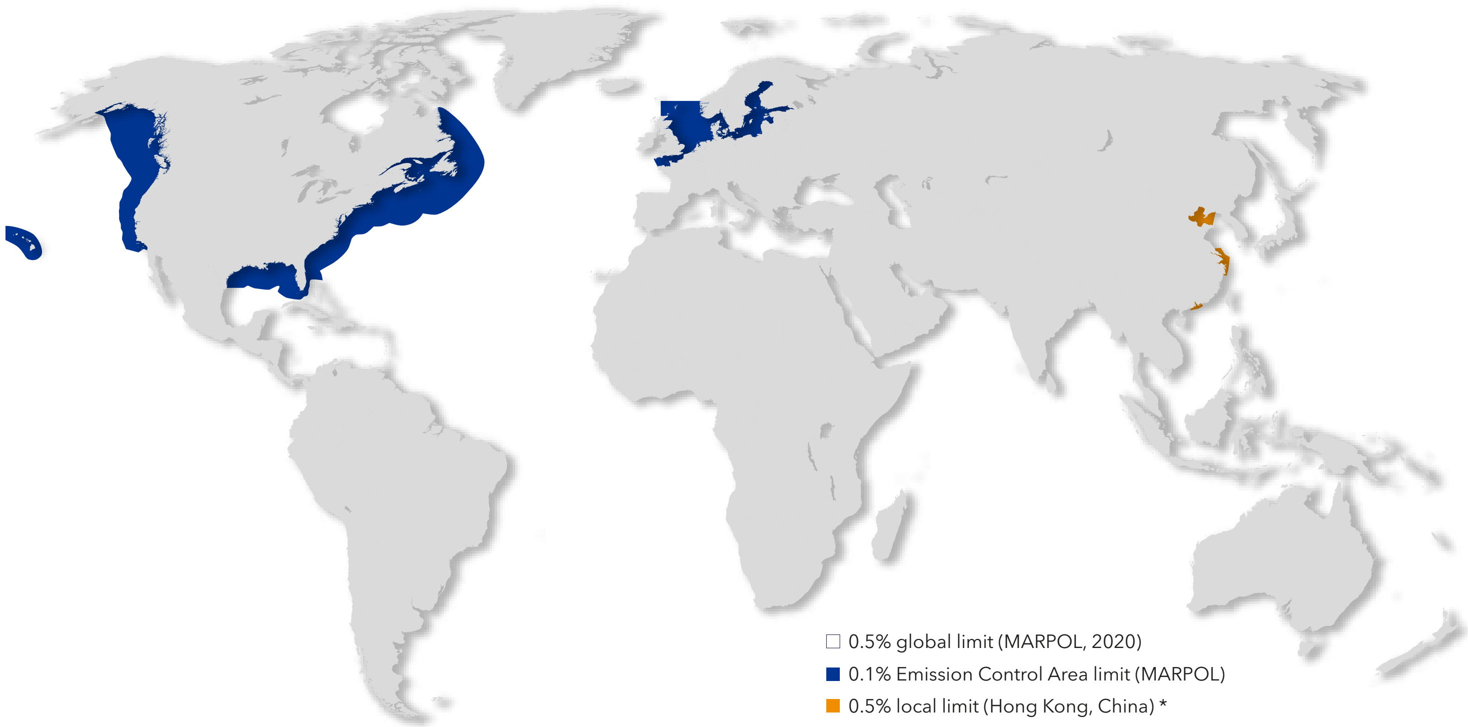
In addition, in 2016 the North American NO_x ECA came into effect and the North European NO_x ECA will be enforced for vessels built from 2021. Reducing NO_x and SO_x emissions is technically feasible, but it often comes at the expense of increased fuel consumption and hence CO_2 emissions.

These regulatory changes are taking place at a time when the industry is trying to recover from a severe market downturn, with limited access to financing and consolidation taking place in many shipping segments. This makes investments in new technology more challenging and short term solutions may be selected, particularly for old vessels. At the same time, there is high uncertainty regarding availability of various fuel types, as well as uncertainty related to the maturity of proposed technological solutions, making investment decisions even harder for ship owners.

The emissions paradox

In the effort to reduce shipping's environmental footprint and to improve air quality close to coastal areas, current regulations aim at reducing sulphur emissions globally and NO_x emissions in certain parts of the world. At the same time, the ongoing discussions on GHG reduction will result in a new set of targets for the industry.

It is important to note that some technical solutions that can be effective towards achieving one of these goals may have negative impact on the others. Vessels with scrubbers are also very unlikely to adopt a different fuel type in the future, therefore slowing down the transition to low carbon fuels. From a ship owner's point of view, it may be worth considering possible implications of technology selection for compliance with current SO_x and NO_x standards.



Area	Sulphur limit	Scrubbers
Global	0.5% (2020)	Yes
Sulphur ECA	0.1%	Yes
EU	0.1% in all ports	Open-loop restricted in some countries
China	0.5% in selected areas	Yes
California	0.1% within 24 nm	No, only through research exemption

Figure 1: Overview of existing and upcoming emissions regulations.

This can be a difficult decision given the uncertainties related to future regulations and fuel availability. On the regulatory development side, it is important that any new regulations are realistic and transparent, to avoid penalising the owners who have invested in certain solutions before the GHG strategy was decided.

Consequently, it is important that discussions on GHG reduction take into account the existing situation in the industry, so that a realistic strategy is developed, removing the uncertainty that hinders decision-making today and in the near future.

	PROS	CONS
Use of EGR	Reduces NO_x emissions for complying with Tier III standards	Fuel penalty that will increase GHG emissions
Use of scrubbers	Cost-effective way of complying with low sulphur standards	Somewhat higher fuel consumption and may slow down the introduction of energy efficiency measures due to the low fuel price
Use of LNG	Can contribute both to lower NO_x and GHG emissions	Risk of high methane slip from certain engines, has to be dealt with in an effective manner

ABOUT THIS WORK

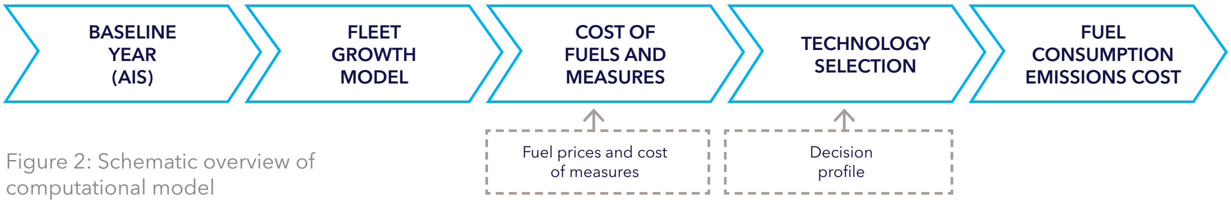


Figure 2: Schematic overview of computational model

The objective of this report is to assess the potential for realistic GHG reductions from shipping towards 2050, considering different possible trade growth scenarios for various ship segments. The reduction level will depend on availability of applicable technological solutions for each segment, their reduction potential and uptake rate. In turn, uptake will depend on the cost and expected payback of each technology, combined with the investment horizon of ship owners. All these external factors are included in a computational model developed by DNV GL.

The model is based on experience from previous work at DNV GL on GHG emissions from shipping. Its main elements are illustrated in Figure 2 and can be summarised as follows:

- Use of AIS data for creating a fuel consumption and emissions baseline. The global fleet is divided into 47 ship segments based on vessel type and size. Every ship in the fleet is treated individually by the model and an estimate of its fuel consumption is used.
- Scrap and trade growth assumptions for each segment. These assumptions can be used to generate various scenarios of trade and emissions growth. Old vessels are scrapped first, thus changing the dynamics of the fleet composition in each segment.
- Four main categories of CO_2 reduction
  - Alternative fuels
  - Energy efficiency measures
  - Speed reduction
  - Carbon pricing (by means of modified fuel prices to make low carbon fuels more attractive).
- For each vessel in the fleet (both existing and new building), there is a cost-benefit calculation for alternative fuel options and energy efficiency measures. The selection process depends on the investment horizon assumed for each vessel. Constraints apply both for existing vessels and new buildings for various fuel options and energy efficiency measures.
- Once the technology selection is completed, the new level of fuel consumption and emissions is calculated, as well as the estimated cost of implementing these options.

Baseline fuel consumption and emissions

The baseline fuel consumption for 2016 has been estimated by using global AIS data combined with information from other databases. The actual speed of each individual vessel and the installed power of its propulsion engine is used to derive the expected engine load and from this the fuel consumption is estimated. For auxiliary engines and boilers, estimates are based on the type and size of vessel, for operations during transit and in port. Using this method, the total fuel consumption for the global fleet is estimated at 233 million tonnes for the year 2016. Comparison with customer data offered for calibration shows that for the ship types contributing most to the total fuel consumption the estimates are on average 5% to 10% below measured values.

35% OF THE GLOBAL FLEET IS RESPONSIBLE FOR MORE THAN 80% OF GHG EMISSIONS FROM SHIPPING. THIS INCLUDES THE LARGEST, MOST EFFICIENT VESSELS. FIRST AND FOREMOST, THE EFFICIENCY OF THESE VESSELS NEEDS TO BE FURTHER IMPROVED IN ORDER TO ACHIEVE SIGNIFICANT GHG REDUCTIONS.

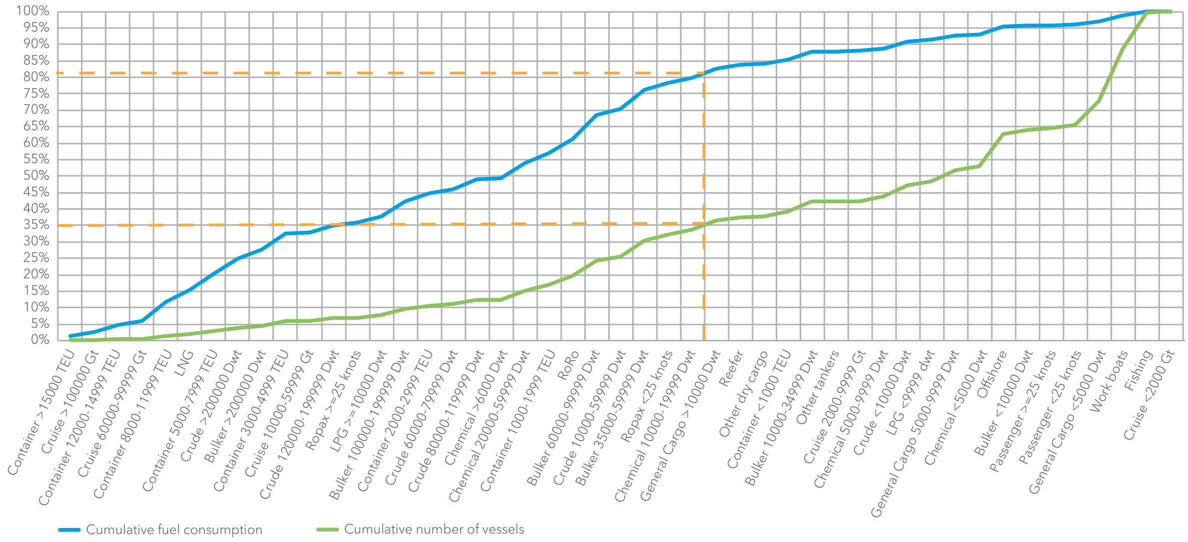


Figure 3: Cumulative fuel consumption and cumulative number of vessels. Ship types and sizes are ranked based on fuel consumption per vessel

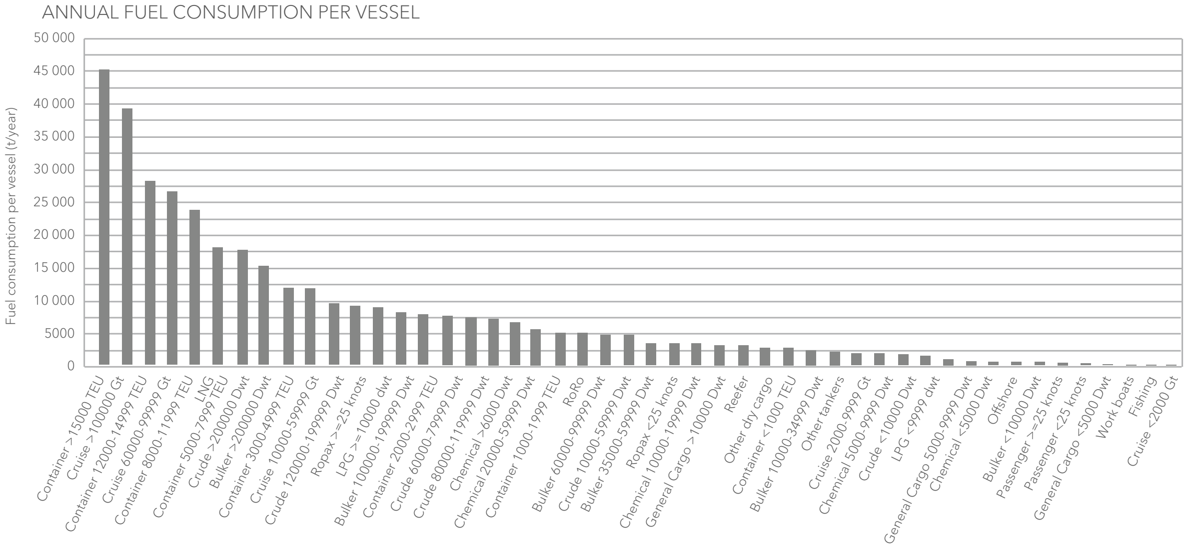
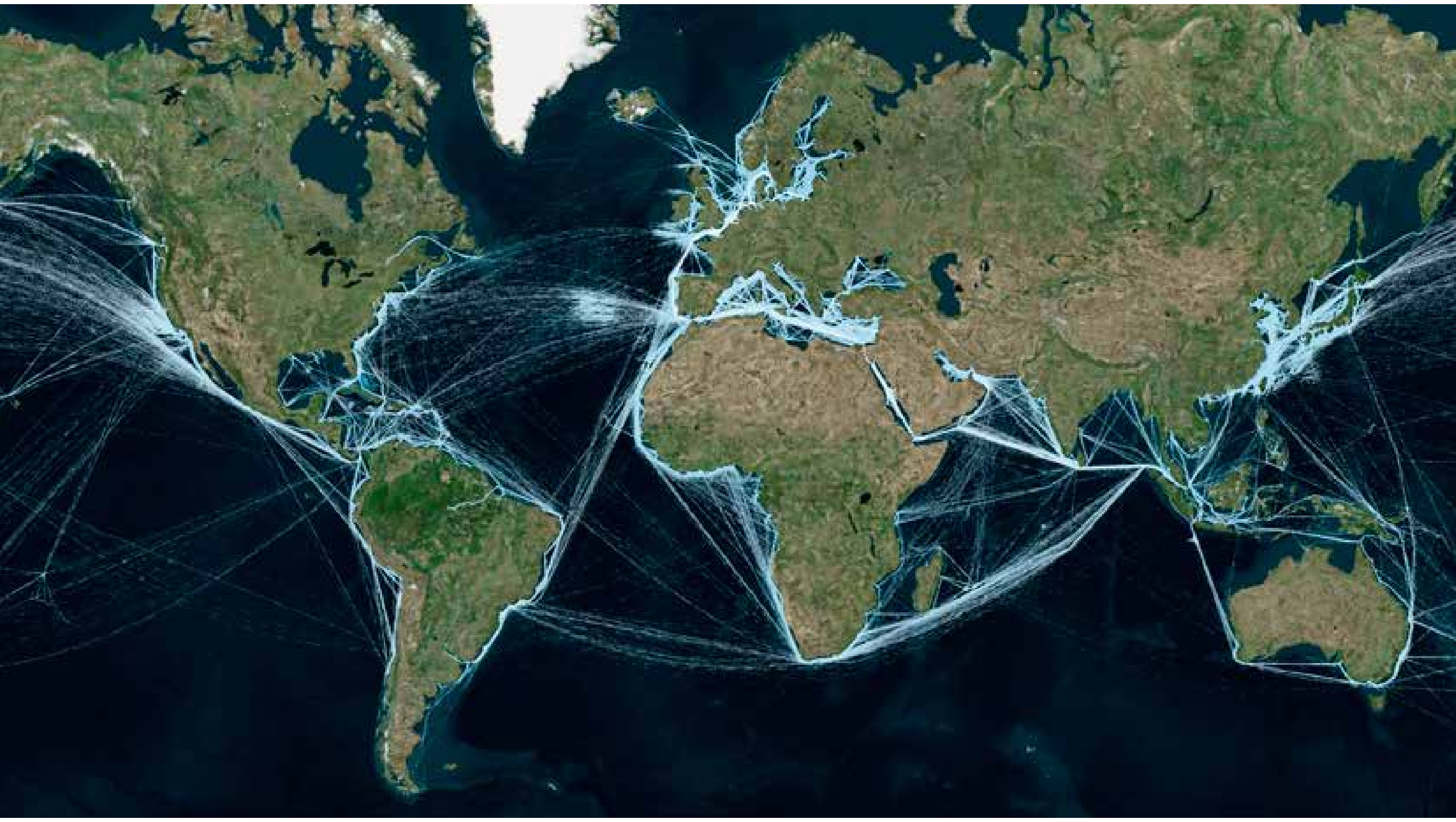


Figure 4: Annual fuel consumption per vessel.



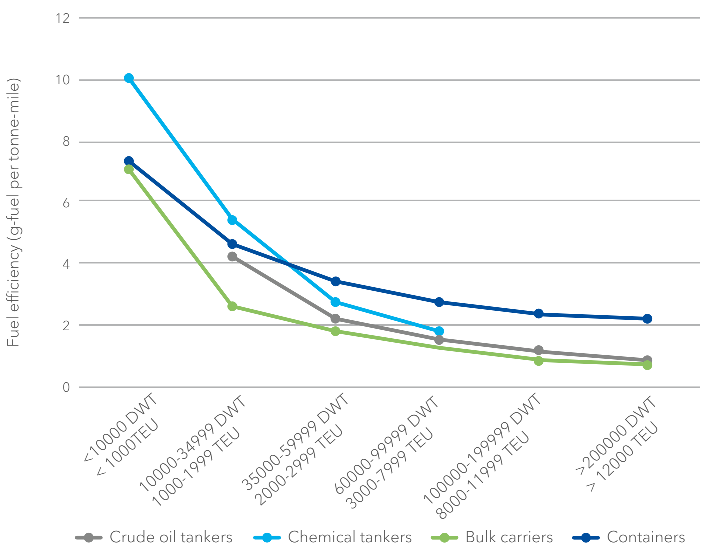


Figure 5: Fuel efficiency of main cargo carrying vessels. Nominal cargo carrying capacity is used for the calculations.

Estimates for individual vessels may vary more depending on specific equipment installed on each vessel and on specific operations that are not known to the model (for example vessel in laden or ballast condition). The calibrations revealed that estimates for the main engine fuel consumption are fairly accurate, while larger deviations are found for fuel consumption in auxiliary engines and boilers. Since the main engines are the main contributor to the total fuel consumption for most large ships, the total estimates are deemed satisfactory. Finally, an adjustment is made for vessels that have been in operation for the entire year, but where their AIS signals cover only a shorter period.

The availability of data for each individual vessel enables the use of statistics for identifying the ship types that contribute most to the total fuel consumption. In Figure 3 and Figure 4, vessels are ranked based on their fuel consumption per vessel. It can be seen that a few vessel types, corresponding to 35% of the global fleet, are responsible for more than 80% of the total fuel consumption. These segments include Container Carriers, Oil Tankers, Chemical/Product Tankers, Bulk Carriers, Gas Carriers, RoRo and large Cruise vessels. Generally, larger vessels within each segment are responsible for a higher share of the fuel consumption, due to their size and operating pattern. As illustrated in Figure 5, large vessels are also by far the most efficient ones within each segment. However, due to their large share of the global fuel consumption, they cannot be neglected in the effort to further reduce industry-wide GHG emissions.

The baseline emissions for 2020, 2025, 2030, 2040 and 2050 are derived by applying segment specific trade growth rates and then calculating the fuel consumption and emissions using the same energy efficiency and fuel as for 2016. Two main trade growth scenarios have been used for illustration of the potential of the model:

- High trade growth: based on the RCP2.6 (Representative Concentration Pathways) mitigation scenario and the SSP3 (Shared Socioeconomic Pathways) scenario for economic growth, described in the IPCC fifth assessment report, aiming to limit the increase of global mean temperature to 2°C.
- Moderate trade growth: rather low growth has been assumed, to explore the impact of a lower emissions baseline on emissions reduction towards 2050.

Table 1 presents the assumed trade growth rates for key segments for both scenarios.

SEGMENT	ANNUAL TRADE GROWTH RATE	
	HIGH GROWTH	MODERATE GROWTH
Tankers	-1.7%	-1.7%
Bulk Carriers	2.5%	1.0%
Containers & RoRo	4.0%	1.0%
Short Sea Shipping	1.6%	1.0%
Offshore	2.0%	0.5%
Passenger	2.0%	1.0%

Table 1: Assumed trade growth rates for various ship segments under high and moderate growth scenarios.

Alternative fuel options and energy efficiency measures

The cost estimation is very challenging, considering that the cost of various GHG reduction measures for each ship type and size cannot be accurately estimated, particularly with a time horizon of 35 years. Fuel price volatility is an additional factor complicating this problem. Therefore, cost is not the main focus of this work, but rather used as an indication of which solutions may be more cost effective than others. The fuel options and energy efficiency measures available in the model are listed in Table 2, accompanied by key assumptions on the emissions reduction potential for each option. Some of the energy efficiency measures have been grouped for simplicity into the following categories:

- Machinery: includes optimisation of auxiliary systems, engine performance optimisation, engine de-rating, exhaust gas boilers on auxiliary engines, variable engine speed, shaft generators (PTI/PTO), efficient lighting system and variable frequency drives
- Hydrodynamics: Hull cleaning, hull coating, hull form optimisation, hull modifications, propulsion efficiency devices, propeller efficiency and propeller retrofit
- Operational: autopilot optimisation, trim/draft optimisation, weather routing
- Renewable energy: sails, kites, solar panels

The exact effectiveness of each measure depends on details related to each individual vessel's size and type, machinery equipment installed onboard and operational profile. The GHG reduction potential for the fuel options is estimated taking into consideration the lifecycle emissions associated with each option, including production and transportation. More details on the assumptions can be found in the key references listed at the end of this document.

Speed reduction is considered separately from other operational or energy efficiency options because it includes building of more vessels to cover the expected trade demand. It is also considered as the measure with the highest potential for offering realistic fuel savings and it would be desirable to investigate its impact in more detail.

Some of the fuel options listed in Table 1 are considered fully mature, while others are under development or have limitations that mean that they can only be applied to certain ship segments. As an example, pure electric propulsion is applicable only for small coastal vessels with existing technol-

FUEL OPTION	GHG EMISSIONS CHANGE (RELATIVE TO BASELINE)	ENERGY EFFICIENCY	FUEL SAVINGS (DEPENDING ON SHIP TYPE AND SIZE)	
			MAIN ENGINE	AUXILIARIES
Baseline: Switch to Low S Fuels	-	Hull Form – New buildings	12-17%	-
HFO with scrubbers	+5%	Hydrodynamics – Retrofit	13-20%	-
LNG	-20%	Machinery improvements	4-8%	12-23%
LPG	-17%	Waste Heat Recovery	0-8%	-
Methanol (from Natural Gas)	+5%	Hybridization	3-15%	
Biodiesel	-50%	Operational measures	3-11%	-
Biomethanol	-50%	Cold Ironing	-	30-70%
LBG (Liquefied Biogas)	-90%	Renewable Energy (Solar, Wind)	0-10%	0-2%
Electricity from renewables	-50% to -20%	Air Lubrication	3-5%	-
Hydrogen	Depending on H_2 production	CUMULATIVE PER VESSEL	21-37%	
Nuclear	-99%	Speed reduction	Fuel savings depend on % of speed reduction. New vessels may have to be used to cover transport demand, therefore reducing the overall savings.	

Table 2: List of Alternative Fuels and Energy Efficiency Measures and their expected impact.

ogy. Nuclear propulsion could in principle be used for large vessels, but there are significant political and societal barriers for its adoption; however, it is included in the model to explore the theoretical potential for emissions reduction. The use of scrubbers is not an option for reducing GHG emissions, but it is considered because vessels that will adopt scrubbers in the next few years are not expected to switch to other fuel types in the future, thus making the transition to lower carbon fuels slower. It is generally possible to retrofit a vessel to use a different fuel type. However, with the exception of biodiesel, any such retrofit can be very costly and it is not expected that a large number of vessels will be retrofitted. Retrofitting vessels for using scrubbers may be attractive, particularly for large vessels despite their cost. It is also assumed that any vessels older than 15 years will not do any major retrofits.

Similarly, some energy efficiency measures apply to most ship types and are well known (for example machinery measures), while others, such as waste heat recovery are handled separately due to their complexity and high cost. Some advanced measures are included, such as renewable energy and air lubrication, to explore how much they could contribute to GHG reductions if they are used in large scale.

All measures listed above are used with assumptions on their potential impact for each ship type and size and estimated cost. Therefore, the solutions with shortest payback time for each vessel are selected in an effort to make the model results as realistic as possible. Obviously, only one fuel option can be used for each vessel, and the intention is to use the model for scenario analysis to identify the impact of different solutions.

UNCERTAINTIES – AND THEIR POTENTIAL IMPACT

Modelling a complex problem, such as the expected shipping activity over a period of 35 years and potential solutions for reducing fuel consumption and emissions, naturally involves significant uncertainties. There are two major types of uncertainties:

a) technological;
b) market and regulatory uncertainties.

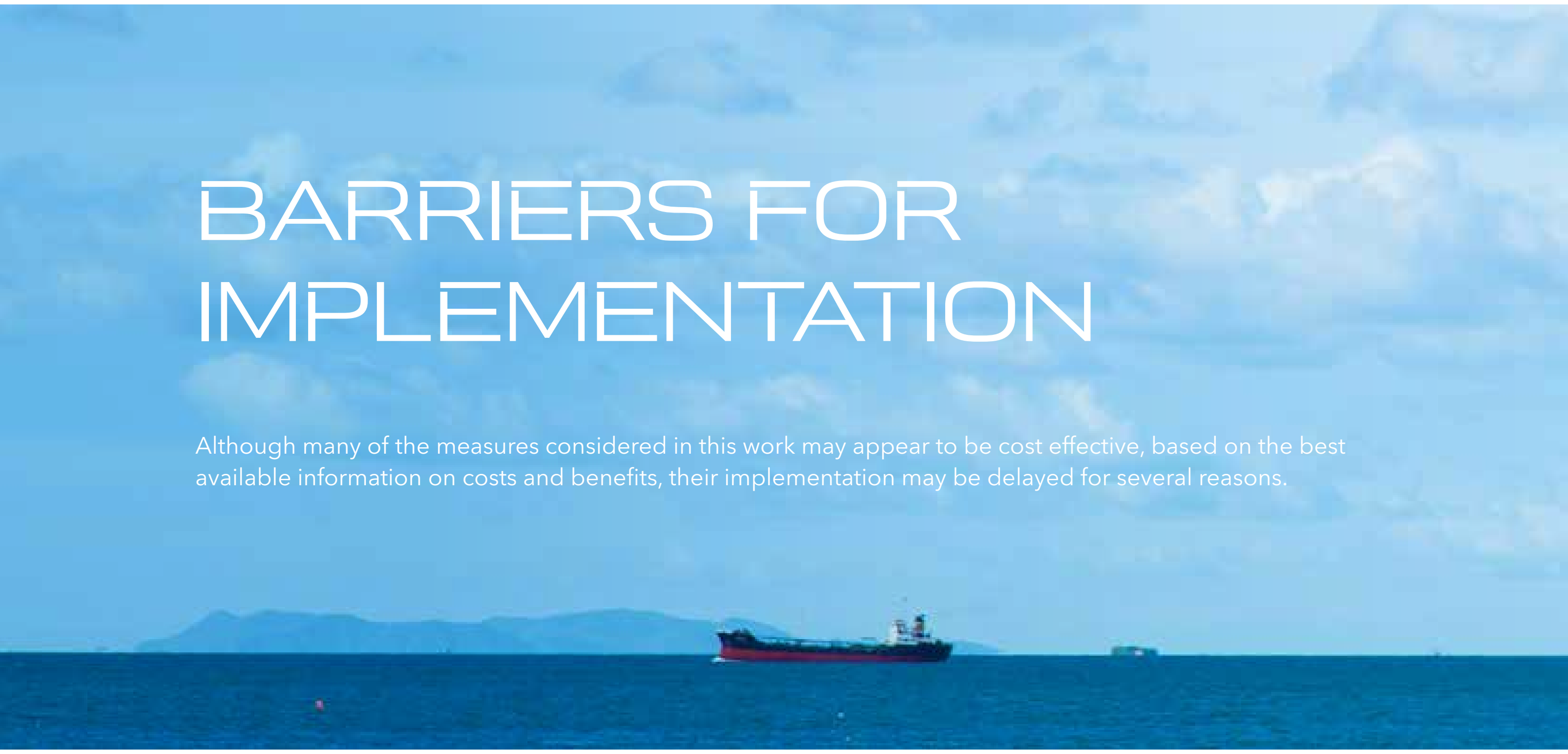
Technological uncertainties include potential technological game-changers that could act as a catalyst for drastic emissions reduction. One example is the development of reliable and affordable Carbon Capture Systems (CCS) that could filter out CO_2 emissions. Such systems exist for land-based power plants, but they are associated with high costs and significant increase in fuel consumption. Based on current knowledge, it is very unlikely that CCS systems will be deployed on ships in a significant scale in the next few decades. Therefore, such solutions are not considered in this study. If they become available in the future they will accelerate decarbonisation of the industry, but a robust strategy cannot be based on the hope that such solutions will emerge.

There are also technologies known today, but not mature enough for large scale deployment. Examples include the use of batteries, which can today only be used for small vessels, or the use of hydrogen, which suffers from high costs, very large space requirements for fuel tanks and low maturity of fuel cells for marine applications. The use of biofuels can also be added, with the main uncertainties being associated with production capacity in a sustainable manner and availability for shipping, as well as their price level. All these options are also related to developments in other industries, as well as to local conditions in different parts of the world. Their price level depends on such factors as local electricity prices associated with the charging of batteries or production of hydrogen from electrolysis, or on the cost of collecting and processing biomass for producing biofuels. Their sustainability, or potential for reducing GHG emissions, also depends on local conditions, such as the local energy mix in the electricity used for batteries and hydrogen and available feedstock for producing biofuels. Therefore, for these technologies it is assumed that they will only be adopted if they can reduce GHG emissions by a significant amount. It is very difficult to provide good estimates for their costs, but it is possible to estimate at what price level they will become competitive with conventional technologies. This information could be used in case a carbon pricing system is introduced in the future.

Market and regulatory parameters include:

- Trade growth per ship segment: This will define the baseline for expected emissions growth. Depending on how strong or moderate growth is, different solutions may have to be employed if there is a requirement for a fixed amount of emissions in 2050. A strong growth will be accompanied by more radical solutions, while in a moderate growth scenario conventional and easy to introduce technologies may suffice. In a strong growth scenario, new building activity may help accelerate the introduction of new technologies.

- Fuel prices: The price differential between various fuel types will determine which solutions will be favoured. However, the model has the possibility to force uptake of certain fuels for various ship segments to explore their potential impact on GHG emissions. Moreover, the fuel price level may affect decisions on energy efficiency technologies uptake, since it will affect their expected payback period.
- Regulatory pressure: While it seems likely that a certain level of political pressure will be asserted for reducing GHG emissions, it is not known if certain measures will be taken. The EU MRV (Monitoring, Reporting and Verification) scheme is one example that paves the way for such regulations. Some quantifiable examples include carbon pricing and speed limit enforcement.
- Uptake rate of new technologies: There are several barriers to the uptake of new technologies, even when they seem to be cost-effective. Therefore, maximum uptake rates in the model can be adjusted to account for some of these uncertainties and model more realistic scenarios, or they can be used to force new technologies to be adopted at a fast pace to examine their potential impact on GHG reduction.
- Investment Horizons: As discussed, investment horizons can vary depending on global economic conditions, company size, access to financing and degree of risk aversion. In the computational model, investment horizons are defined as probability distributions and they can be modified or skewed to show the potential for accelerating uptake of technology if longer investment horizons can be attained, e.g. by solutions such as "green" financing schemes.



The main barriers for implementation include:

Maturity of technology
New technologies are adopted by a few pioneers first and it may take more than a decade until large scale deployment, provided that the technology will prove reliable and fulfilling its promises. This is due to reluctance to use new, unproven technologies and due to the lack of adequate infrastructure or support personnel for installing, maintaining and operating the new solution. This is a natural behaviour, very unlikely to change, unless the use of certain technologies is enforced through regulations or if a sudden breakthrough is achieved.

Access to finance and investment horizon
This may be the single most important barrier for implementation of any new technology. The required payback time varies depending on ship segment and general economic conditions, but is typically quite short, often less than 2 years for many companies. The problem is more pronounced in cases where owners do not pay the fuel cost. Large companies can usually afford having longer investment horizons than smaller ones, while they also have the advantage of economies of scale, which offer leveraging when negotiating prices. In recent years "green" financing schemes have been initiated to enable longer term investments in technology by sharing costs and benefits between owners and investors. Similar initiatives may be needed in the future to enable investments to accelerate reduction of GHG.

Technical complexity and crew competence
When introducing a new technology, there is increased complexity that must be handled by the crew, adding to their existing workload. There are large variations between segments: Offshore Supply Vessels and large Cruise vessels are known for being early adopters of new technologies and typically have highly qualified crew. In other segments, there is concern that a lack of qualified crew will be a significant barrier for adopting new technical solutions. This problem can be solved if equipment manufacturers and ship owners cooperate to provide appropriate training. This is a non-technical barrier that has to be dealt with in order to accelerate the uptake of new solutions.

Yard capacity

This applies mainly for retrofits of existing vessels and can only delay a transition for a limited period of time, typically a few years. Currently, this may be one of the limiting factors for installing scrubbers to existing vessels. While this can be a problem for owners who are eager to invest in scrubbers, it may give the industry time to keep its options open to other potential solutions, such as the use of new fuels or more targeted investment in energy efficiency measures.

Political and regulatory barriers

Some technologies or energy efficiency measures can only be adopted when backed by regulations due to their high cost. Enforcement of regulations and ensuring that there is a level playing field with the same rules for everyone is also very important. One example is radical speed reduction: speed reductions of up to 10–20% may be possible voluntarily, but for larger reductions, of 30–50%, policy actions most likely have to be taken to ensure that this is a viable solution for ship owners and enforcement will be necessary to make sure that those not complying are not having a competitive advantage.

Commercial factors

Very often, non-technical factors can delay or avert the introduction of a technical solution that is beneficial and cost-effective. One common example is related to whether the owner or the charterer is paying for fuel. In long-term charters, it is easier to make an agreement to share the cost of an investment, while in short term contracts or spot trade this becomes much harder. Rethinking the way that charter contracts are made could solve this problem. Another barrier is lack of flexibility from the yards, particularly in times of strong growth, to optimise vessel design or to implement tailor-made solutions to optimise energy efficiency management on board. The price tag for deviations from off-the-shelf designed vessels often makes new buildings less efficient than what they could have been.

POTENTIAL LOW CARBON PATHWAYS

This work is not intended to predict the future or propose a definitive solution to the very complex problem of reducing GHG emissions from shipping. The main intention is to provide a tool that can be used to evaluate alternative scenarios and potential solutions, that can support the public discussion and help develop a robust and realistic GHG reduction strategy for shipping.

In the following, example scenarios are used to illustrate some of the barriers and uncertainties of the problem, such as the impact of trade growth, investment horizons and uptake of different measures for reducing GHG emissions. In order to make alternative fuels more attractive and show their potential impact, it is assumed that the spread between HFO and low sulphur alternatives will grow after 2020. It is assumed that HFO costs 270 USD/ton and MGO 600 USD/ton, which is higher than the current price in most locations.

High versus moderate trade growth

The rate of global economic growth and sea trade will determine to a large extent the fleet growth, fuel consumption and emissions in the next few decades. A strong trade growth will result in substantial increase of fuel consumption and will require drastic measures for reducing the corresponding GHG emissions. A more moderate growth in trade demand will allow reaching GHG reduction targets with more conventional measures or at a lower cost. This is illustrated in Figure 6, where the following cases are shown, both for strong and moderate trade growth:

- Baseline or business as usual: It is assumed that new vessels are built to cover trade demand without any improvements in energy efficiency or adoption of alternative fuels.
- Energy efficiency: Uptake of energy efficiency measures, when they are cost effective, with expected return on investment varying between 2 and 10 years.
- Alternative fuels: Strong adoption of fossil-based alternative fuels is assumed, such as LNG and LPG after 2025. There is also strong penetration of renewable electricity for small vessels.
- Speed reduction: Moderate speed reduction is gradually introduced after 2020, reaching 20% by 2050.

It is clearly seen in Figure 6 that under the moderate growth scenario, the emissions' level in 2050 will be significantly lower than in the high growth scenario when the same measures are applied. In both scenarios, further reductions are possible by introducing low carbon fuels (biodiesel or other biofuels), more aggressive speed reduction and more aggressive uptake of energy efficiency measures.

Short versus long investment horizons

Two separate investment horizon distributions are used to illustrate the impact of payback time expectations on investment decisions and uptake of new technologies. In this example, the investment horizons assumed are summarised in Table 3. Investment horizons for individual ship segments can vary in the model, but here a uniform assumption has been made.

In the results presented in Figure 7, it is assumed that scrubbers will be installed until 2030, while batteries will have a strong penetration thereafter. This is achieved by assuming very low installation and operational expenses to make them financially attractive. LNG and LPG are always available as fuel options, but have low penetration until 2030 because scrubbers have shorter payback times for most ship types. After 2030, LNG and LPG are selected for

IN A MODERATE GROWTH SCENARIO, EMISSIONS CAN BE REDUCED BELOW CURRENT LEVELS WITH CONVENTIONAL MEASURES. IF GROWTH IS STRONG, MORE RADICAL SOLUTIONS WILL BE NECESSARY.

Figure 6: Comparison of GHG emissions under high and moderate trade growth scenarios, and varying uptake of alternative fuels and energy efficiency measures.

more vessels, but their penetration is limited in the short investment horizon case. When the investment horizon is extended to 10 years, the uptake is significantly increased, leading to emission stabilisation.

A combination of LNG and LPG is selected for approximately 40%-70% of the vessels in 2050, depending on the scenario. These fuels can realistically be available in that timeframe, even though their penetration may be quite slow in the next decade. However, they can only contribute with a modest reduction of GHG of maximum 20%. Additional reductions can be achieved by gradu-

EXPECTED PAYBACK TIME	% OF VESSELS	
	SHORT HORIZON	LONG HORIZON
Less than 2 years	30%	5%
Less than 5 years	50%	5%
Less than 10 years	20%	90%

Table 3: Assumed investment horizons for illustrating impact on technology uptake

ally introducing energy efficiency measures. Further emissions reductions are also possible, if necessary, by introducing low carbon fuels such as sustainable biofuels. Naturally, speed reduction can also be used in combination with any of the above measures to adjust emissions levels.

Scrubbers versus low carbon fuels

Using scrubbers to comply with low sulphur standards may be a financially attractive option, but it can also lock the industry into a fuel that does not allow for significant GHG emissions reductions. Using LNG or LPG as fuel can contribute to small GHG reductions, but if

> EXTENDING INVESTMENT HORIZONS FROM 5 TO 10 YEARS LEADS TO MUCH STRONGER UPTAKE OF NEW TECHNOLOGIES, AND THEREBY REDUCING GHG EMISSIONS. FINANCING MECHANISMS ARE A PREREQUISITE FOR ENCOURAGING INVESTMENTS.

> INSTALLING SCRUBBERS LOCKS VESSELS INTO USING HFO AS FUEL. OTHER SOLUTIONS MUST THEN BE USED TO REDUCE GHG EMISSIONS.

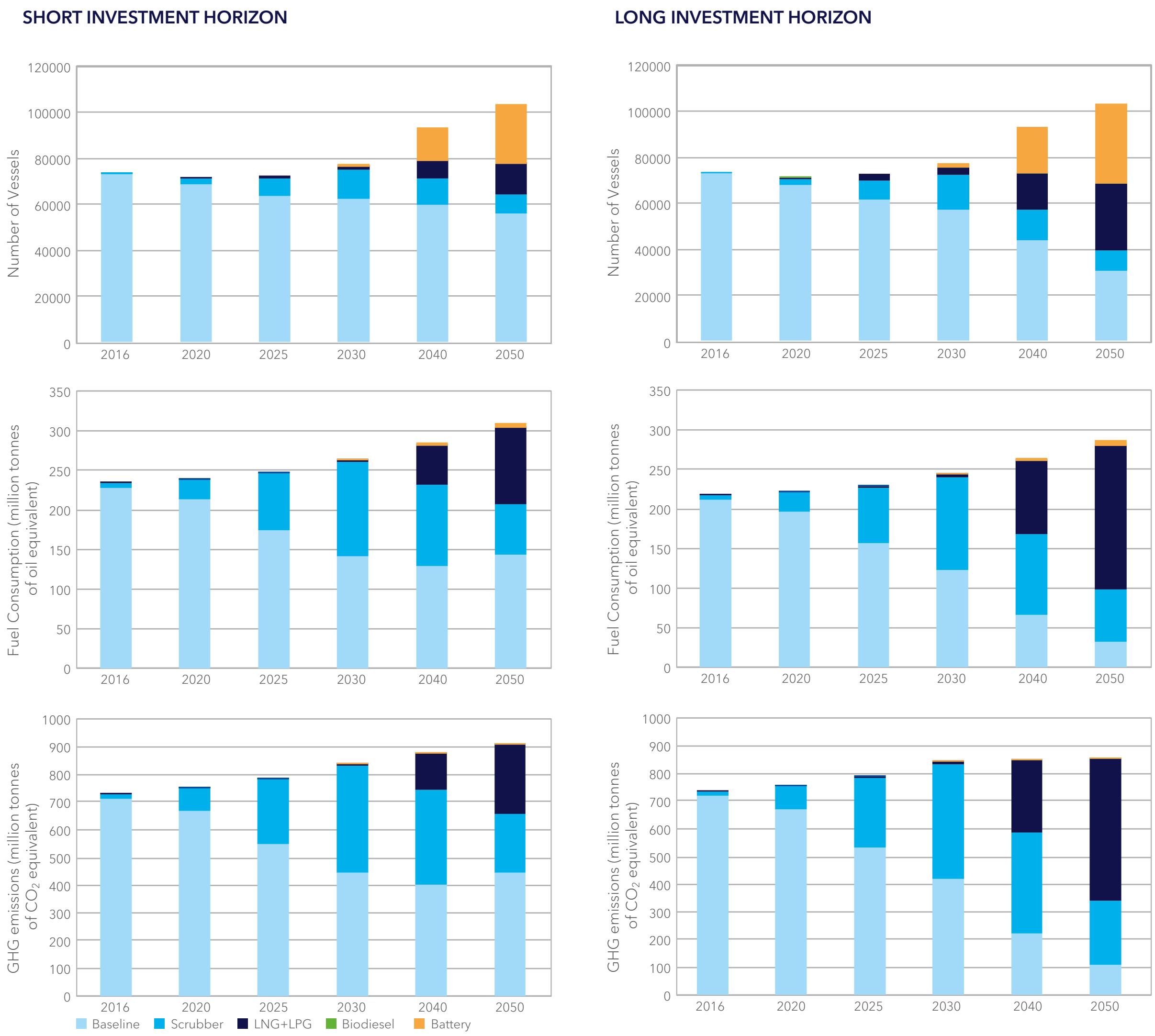


Figure 7: Comparison of short and long investment horizon and impact on technology uptake.

more substantial reduction is desired, other alternatives may have to be used. In the following example the impact of introducing a low carbon alternative fuel is shown, using biodiesel with potential to reduce GHG by 50% after 2030 and at a price that makes it an attractive alternative to distillate fuels. The moderate trade growth scenario is used. It is assumed that scrubbers will only be installed until 2025. One scenario considers only LNG, LPG and batteries as alternatives, while the second scenario introduces biodiesel in 2030 by reducing its price to make it competitive with low sulphur fuel. In both cases, long

SUPPORTING THE USE OF LOW CARBON FUEL OPTIONS, FOR EXAMPLE BIOFUELS, CAN MAKE A DIFFERENCE IN REDUCING GHG. TO MAKE IT HAPPEN, THE PRICE DIFFERENTIAL BETWEEN BIOFUELS AND FOSSIL FUELS MUST BE ELIMINATED. THIS CAN BE DONE BY INTRODUCING CARBON PRICING.

ELECTRICITY CAN BE USED TO POWER SMALL VESSELS, IF BATTERIES AND CHARGING COST BECOME FINANCIALLY ATTRACTIVE. THIS WILL ONLY COVER A VERY SMALL SHARE OF TOTAL FUEL CONSUMPTION, BUT HAS ADDITIONAL BENEFITS IN TERMS OF LOCAL POLLUTION REDUCTION.

SCRUBBERS INSTALLED UNTIL 2025 | **SCRUBBERS INSTALLED UNTIL 2025 – BIODIESEL FROM 2030**

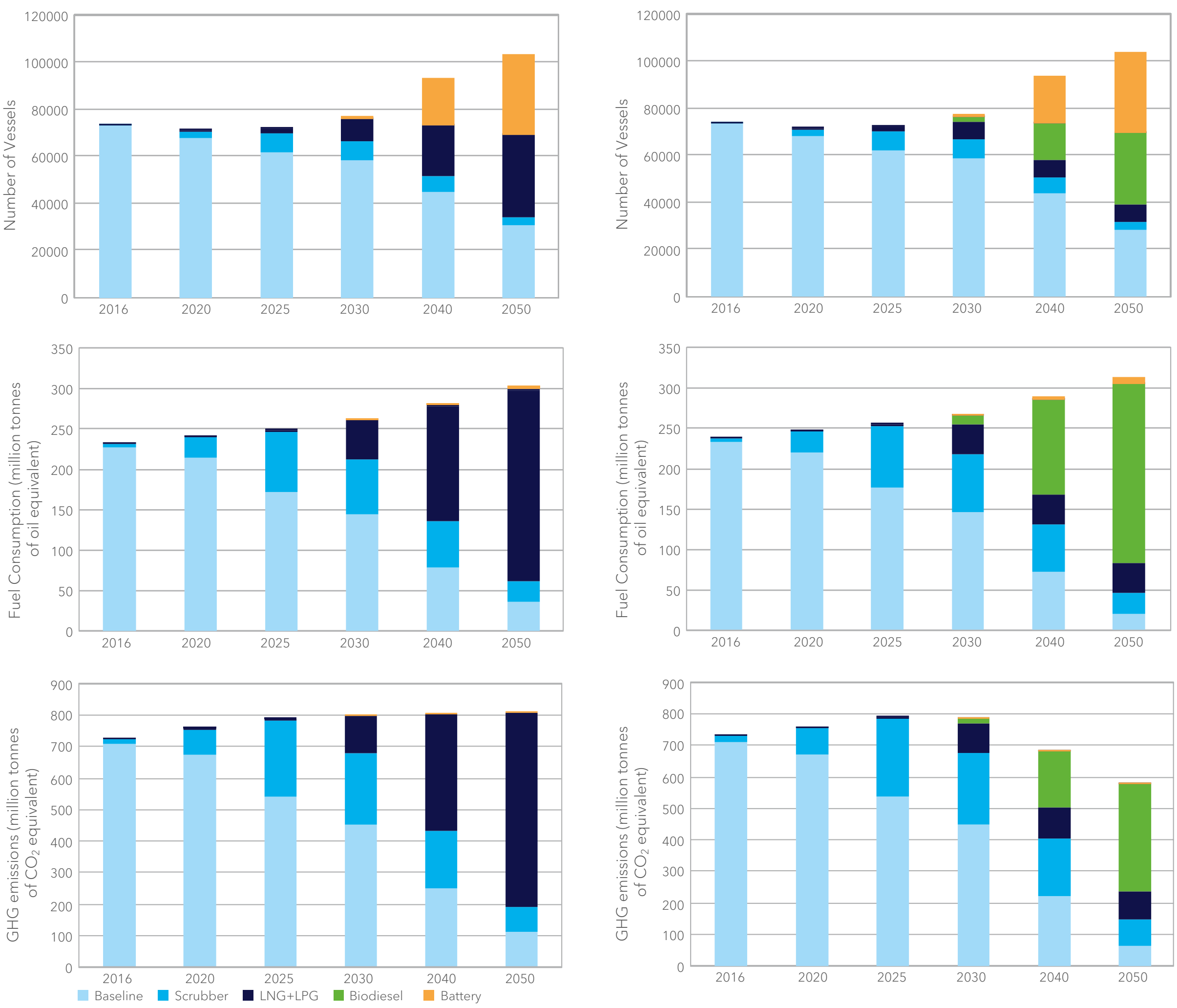


Figure 8: Moderate growth scenario, long investment horizon: impact of scrubbers and biofuel on GHG emissions.

DELAYING CHANGE WILL MAKE THE TASK OF REDUCING GHG EMISSIONS EVEN MORE CHALLENGING, SINCE IT TAKES SEVERAL YEARS TO ADOPT NEW TECHNOLOGY AND REPLACE OLD VESSELS. DECARBONISATION NEEDS TO START AS SOON AS POSSIBLE IF REDUCTIONS ARE TO BE ACHIEVED.

investment horizons are assumed. The results are presented in Figure 8, showing that when fossil-based alternatives are used (LNG, LPG) emissions can be stabilised but not reduced. When sustainable biodiesel is introduced, at a price that makes it attractive for operators to use it, they can contribute to significant emissions reduction.

Extensive introduction of alternative fuels in a short period of time can be complicated by competition with other sectors as well as availability and pricing. Building the infrastructure for bunkering can also take time. Energy efficiency measures can be introduced faster, especially in newbuildings, but some of them may have a considerable cost that can delay their adoption.

Three important questions related to the introduction of biofuels in general are related to their availability, GHG reduction potential and pricing. In order for such fuels to become available for shipping, developments on all fronts are necessary to ensure that the fuels meet certain sustainability criteria, are produced in the volumes necessary, at a quality that ensures compatibility between fuel batches and at a price that makes them competitive for the shipping market. These questions must be resolved, if a decision to adopt low carbon fuels is taken.

In the example illustrated in Figure 8, renewable electricity is selected for small vessels and a combination of LNG and LPG for larger ones. By 2050 roughly one in three vessels will be electric (assuming that the cost of batteries will be competitive and renewable electricity will be available all over the world); however, this corresponds only to about 2-3% of the total fuel (or energy) consumption. This is because batteries are assumed to be capable for powering small vessels only, with relatively low fuel consumption per vessel.

Other options that could be considered are nuclear propulsion and hydrogen as a fuel. Nuclear propulsion offers a nearly zero-emission alternative, but must overcome political and societal barriers, while its cost may be an obstacle as well. Hydrogen may also be considered a zero-emission alternative, if it is produced with electrolysis from excess of renewable electricity. Currently, main barriers include very costly systems and large fuel tanks (up to 25 times larger than comparable oil tanks).

Energy efficiency and speed reduction

Introduction of energy efficiency measures and speed reduction are practically the only means of reducing GHG emissions for most existing vessels. Retrofitting for using other, less carbon intensive fuels is possible, but usually very costly. Very few vessels are therefore expected to undertake such conversion projects. Using biodiesel instead of fuel oil is also possible and may be an option in the future, but it is currently not done due to availability and pricing of biofuels.

The potential for fuel savings from energy efficiency measures alone can range from 21-37% for individual vessels, depending on the vessel design and operations, equipment already installed onboard and possibilities for modifications. In practice, the realistic savings potential is determined by the cost of different technologies, their expected payback time and willingness of the ship owner to invest in new and not always well-proven technologies. The energy efficiency measure selection will vary for each ship type and size, as illustrated in Figure 9, where the relative contribution of each measure to fuel savings is presented for a few selected ship types. In small vessels, spending a large share of their time in port, cold ironing has the strongest potential for reducing fuel consumption. However, the degree of GHG emissions reduction will depend on the shore-based electricity mix. Waste heat recovery has an impact only for large vessels and hybridisation has varying potential depending on the ship type and operations. Renewable energy (solar and wind) generally has a small and varying impact.

Another decisive factor in selecting energy efficiency measures is the expected payback time. This varies a lot, not only with the vessel type, but also with the operational profile of each vessel. An example is provided in Figure 10, where the payback time for a few selected ship types is shown. Typically, small ships require longer payback periods than larger ones, due to their relatively low fuel consumption. One exception to this rule are hybrid systems, which in many cases have more advantages for smaller

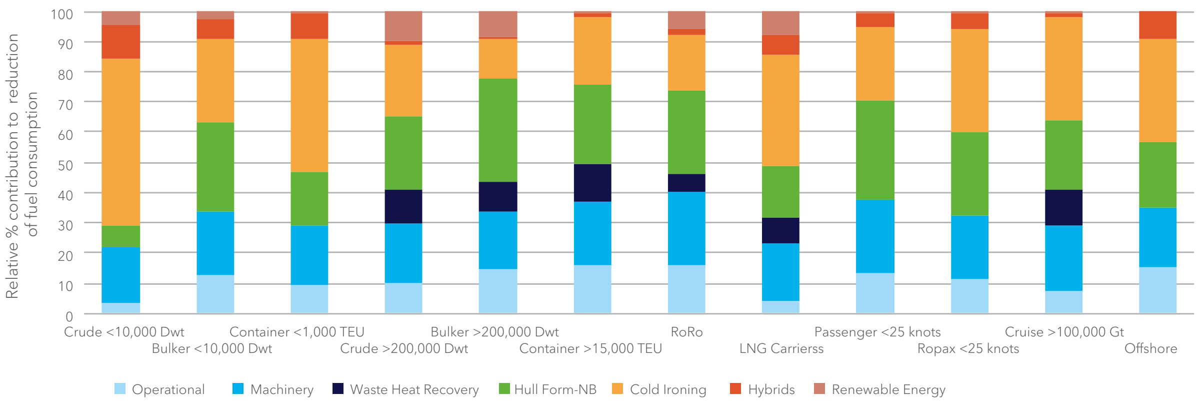


Figure 9: Relative contribution of energy efficiency measures to fuel savings for selected ship types, including both propulsion and auxiliary systems.

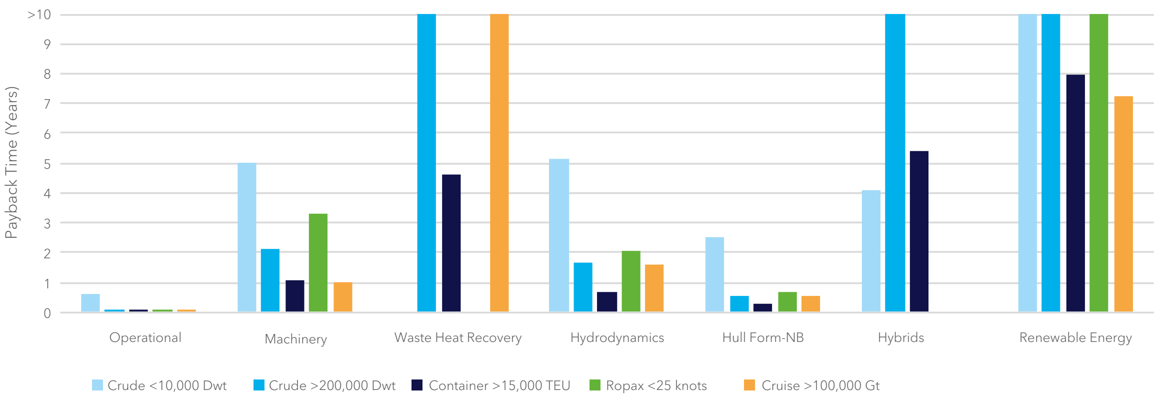


Figure 10: Payback time for energy efficiency measures and selected ship types.

vessels due to their operational profile. Renewable energy sources generally have long payback periods. In the model, the payback time is calculated for individual vessels, based on their actual operational profile and a decision on measure selection is taken based on the investment horizon for the vessel.
In the example presented in Figure 11, the impact of energy efficiency measures in reducing global fuel consumption is shown. The overall reduction in 2050 is approximately 17%, compared with the baseline case. A somewhat stronger reduction, up to 30%, may be possible with stronger uptake of existing technologies; however, this will depend on their expected payback time and/or on regulations pushing in this direction. It is interesting to note that some measures, such as waste heat recovery, which have high potential for certain ship types have rather low overall impact, due to their applicability to a few ship types and sizes and due to their relatively high cost, which makes uptake rather slow. In Figure 12, the relative contribution of each measure to the GHG reductions in 2050 is given in more detail. Overall, cold ironing is the measure with the highest potential for fuel savings, assuming that it can be used in all ports and by all vessels. If it can be used globally and combined with renewable electricity, then the potential for emissions reductions is significant.

Stabilising emissions at current levels entails significant effort even under the moderate growth scenario, while reducing them will require industry coordination and resolve, as well as cooperation with land-based industries.

A relatively simple way to further reduce fuel consumption and emissions is speed reduction. The industry has already introduced slow steaming in many segments and a further 10-20% reduction could be possible without major change in equipment or logistics. This would correspond to a reduction in fuel consumption in the order of 30%, also accounting for the fact that more vessels will be needed to cover the transport demand. In case speed is reduced by more than 20%, established logistics practices and charter contracts may have to be modified, while vessels will also have to be specifically designed for this type of

UPTAKE OF ENERGY EFFICIENCY MEASURES CAN BE SLOW IF THE PAYBACK TIME IS LONG. APPROPRIATE FINANCING SCHEMES ARE NEEDED TO ACCELERATE CHANGE.

THERE IS SIGNIFICANT POTENTIAL FOR EMISSIONS REDUCTION FROM COLD IRONING, PROVIDED THAT INFRASTRUCTURE WILL BECOME AVAILABLE AND SHORE-BASED ELECTRICITY WILL BE PRODUCED FROM RENEWABLE SOURCES.

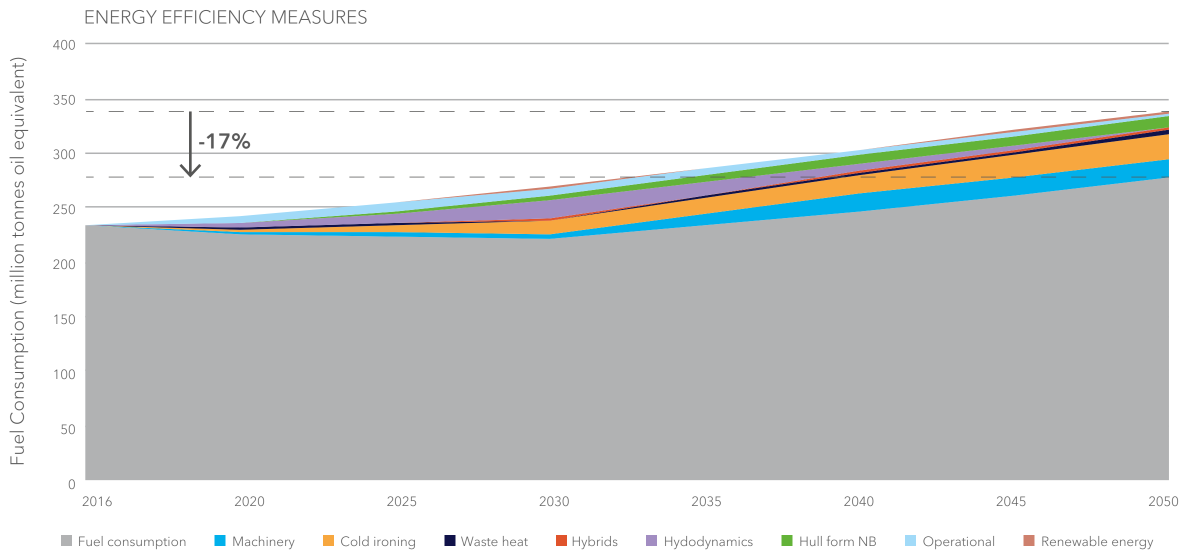


Figure 11: Impact of energy efficiency measures on global fuel consumption

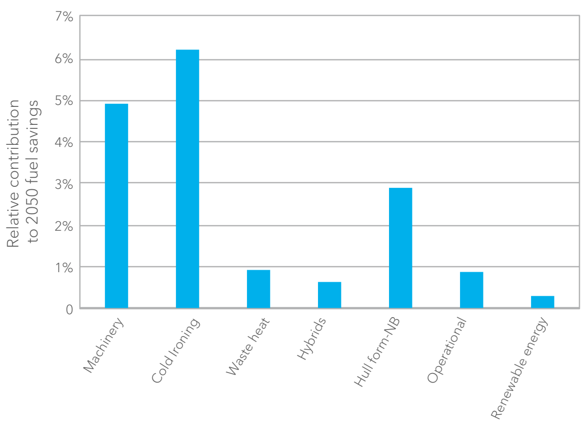


Figure 12: Contribution of energy efficiency measures to fuel savings in 2050. Hydrodynamics appear very low because they apply only to ships existing in 2016 that have mostly been scrapped by 2050.

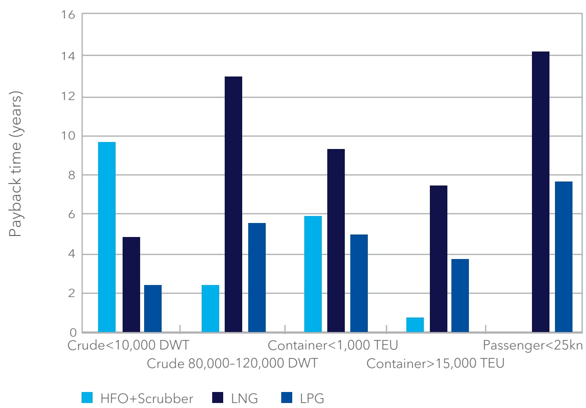


Figure 13: Estimated payback time for scrubbers, LNG and LPG, for selected ship types and sizes

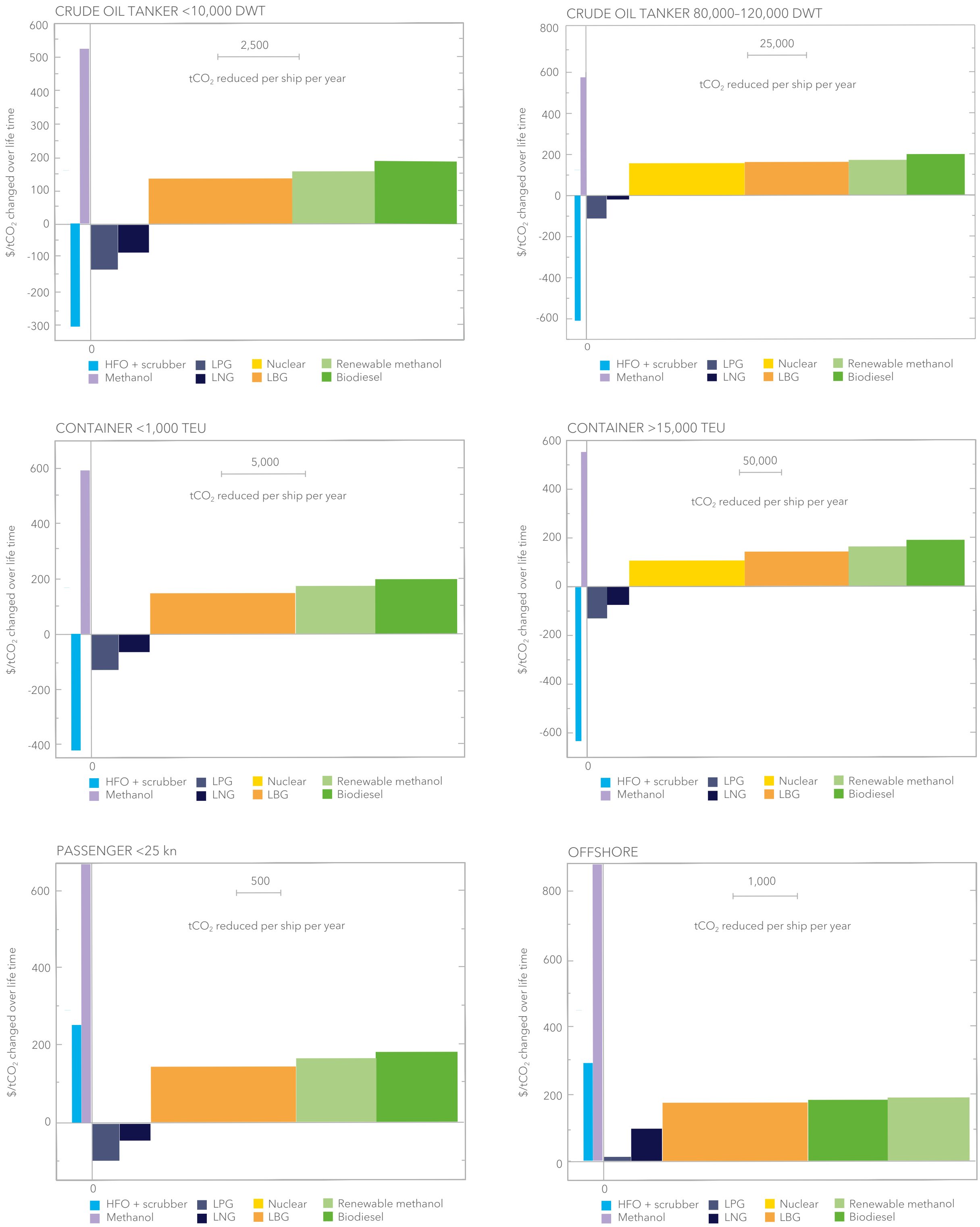


Figure 14: Marginal Abatement Cost Curves (MACC) for selected ship types and fuel options. Positive cost values indicate non cost-effective solutions at current prices. Negative cost indicates cost-effective solutions within the lifetime of the vessel. Scrubbers and methanol from natural gas increase emissions by a small amount in all cases.

operation. Speed monitoring may be necessary to ensure all vessels are complying with agreed speed limits. Introducing drastic speed reduction can also increase the risk of not having adequate power available in case of adverse weather conditions or to avoid dangers from piracy. Therefore, vessels must be adequately designed to minimise these risks.

What Does It Cost?

The main barrier for introducing any new technology in shipping is related to financial feasibility. Many ship owners have rather short investment horizons, often between two and five years. This makes the adoption of any new technology difficult, particularly when combined with uncertainty over future regulations and availability of fuel. Moreover, in the current industry situation access to finance becomes even harder, further reducing the options available to owners.

In Figure 13 the estimated payback times for a few selected ship types and sizes is given for scrubbers, LNG and LPG. All prices are for newbuildings and the costs are expected to be significantly higher for retrofits. Scrubbers appear to be very expensive for small vessels, but become a very attractive option for larger ones. LNG is more expensive than LPG due to cryogenic materials required and the cost of fuel tanks. The high cost of fuel tanks is the reason that LNG (and to some extent LPG) require long payback periods for large vessels. Both fuels are quite attractive for small vessels, but cannot compete with scrubbers for large vessels. This is an additional challenge, as many owners may opt for scrubbers for complying with the upcoming 2020 low sulphur standards, thus delaying the transition to low carbon fuels.

It is obvious from the example in Figure 13 that different solutions will be appropriate for different ship types and sizes. In Figure 14 a number of Marginal Abatement Cost Curve (MACC) diagrams are presented for selected ship types, to illustrate which fuel options can be cost effective and what are the potential savings per ship. The vertical axis shows the cost per tonne of CO_2 changed (reduced or increased) during the lifetime of the vessel. The reason for introducing the term "CO_2 changed" is the fact that some fuel options, such as scrubbers or methanol produced from natural gas will result in higher total emissions. A negative cost indicates savings over the lifetime (typically 25 years), while a positive cost indicates solutions that are not cost-effective. The horizontal axis shows the potential CO_2 savings for each fuel option per vessel per year. The conventional alternatives (LNG, LPG) yield small reductions, while biofuels and nuclear have the potential to drastically reduce emissions. However, this reduction comes at a significant cost per tonne of CO_2 averted.

A Global or a Local Challenge?

While the reduction of GHG emissions is a global challenge, it is important to point out that there is no one solutions that fits all ship types, trades and geographies. To illustrate this, in Figure 15 the share of ship types contributing to GHG emissions are shown for Norway, compared to the global average. Due to activities related to the local economy and geography of Norway (fishing, oil extraction, passenger ferries), the profile of operating vessels is very different from the global average. The same is expected for many other coastal countries. Therefore, the solutions required for the ship types operating in coastal waters and in short-sea traffic may be different than those needed for the global fleet of cargo vessels. A reliable strategy should address these differences to ensure all ship types will contribute to the effort of reducing GHG emissions.

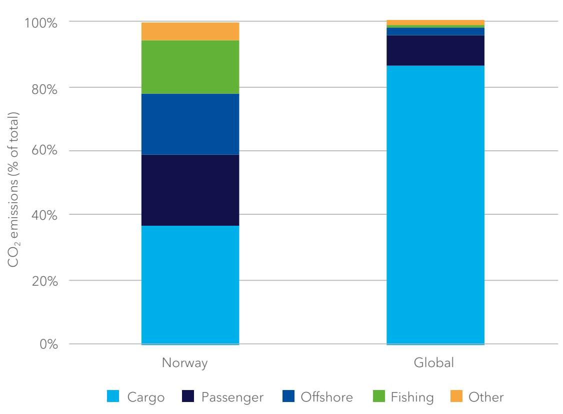


Figure 15: Share of ship types contributing to CO_2 emissions in Norway and globally.

MOVING FORWARD

Developing a realistic and robust strategy for reducing GHG emissions from global shipping is not going to be an easy task. Decarbonising the shipping industry will be disruptive in terms of financial cost, introduction of new technology, crew competence requirements and operational patterns. Addressing the particularities of individual shipping segments will help minimise disruptions and requires good understanding of these sectors and their needs. For this purpose, DNV GL has developed an activity-based, bottom-up model that handles each vessel in the global fleet individually and can identify the most appropriate solutions for reducing their carbon footprint, taking into account also typical investment profiles for each segment. The model can evaluate the potential reduction of GHG emissions and estimate the cost of selected solutions for the global fleet or for groups of vessels, such as vessels operating in certain geographical areas, vessels of specific types, or vessels of individual owners. The model can be used by:

- Ship owners trying to identify the optimum solutions for their vessels
- Local authorities developing strategies and supporting mechanisms for reducing emissions from vessels in their geographical areas
- Policy makers developing a global strategy for reducing GHG emissions, taking into account the differences between individual ship types and operations.

There is a long list of options for reducing emissions considered in the model, including conventional and low carbon fuels as well as technical and operational energy efficiency measures. A combination of switching to alternative fuels, introducing energy efficiency measures and speed reduction can yield significant reduction of GHG emissions. The level of emissions in 2050 will depend on trade growth, the start date of the decarbonisation effort and the uptake rate of available solutions, as well as the mix of solutions selected. It is estimated that in a high trade growth scenario emissions can be maintained at levels approximately 20% higher than today using cost-effective measures. Under a moderate growth scenario, use of cost-effective measures can reduce emissions considerably, by approximately 30% compared to today. In both scenarios, further emissions reductions are possible with higher uptake of known technologies and introduction of more radical solutions, such as biofuels, batteries and speed reduction in the order of 30-50%. Introduction of biofuels, batteries and other low carbon fuels will be possible only if their price is competitive with fossil-based fuels. One of the main barriers to overcome is related to relatively short investment horizons of ship owners. Financial mechanisms that extend horizons to 10 years or beyond will contribute significantly in adoption of new technology and consequently emissions reduction. While all shipping segments will need to contribute to the effort of reducing GHG emissions, it should be recognised that certain ship types are responsible for the largest share of emissions: 35% of the fleet consumes more than 80% of the fuel and a proportional amount of emissions. These are the largest cargo vessels, which are also the most efficient ones. Particular efforts have to be made to address the challenge of further reducing the carbon footprint of the best performers. If these vessels are neglected, it is impossible to achieve any significant emissions reduction.

It is essential that the effort to reduce GHG emissions starts as soon as possible to ensure a smooth and viable transition for the industry. For this to happen, regulatory uncertainty should be removed and appropriate policies for supporting and managing change have to be developed. It is in the interest of all stakeholders in the industry, including owners, equipment manufacturers, and regulators, to start this process now and use it as an opportunity to further improve the operational efficiency of shipping, as well as its environmental performance.

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