Fit for 55 and 2030 milestones for maritime shipping

A pathway towards 2050

CE Delft

Committed to the Environment

Fit for 55 and 2030 milestones for maritime shipping

A pathway towards 2050

Authors: Jasper Faber, Christiaan Meijer, Dagmar Nelissen, Emiel van den Toorn

Delft, CE Delft, November 2022

Publication code: 22.220125.144

Client: Ministry of Infrastructure and Water Management
Your reference: 31178865

Publications of CE Delft are available from www.cedelft.eu

Further information on this study can be obtained from the contact person Jasper Faber (CE Delft)

CE Delft
Committed to the Environment

Through its independent research and consultancy work CE Delft is helping build a sustainable world. In the fields of energy, transport and resources our expertise is leading-edge. With our wealth of know-how on technologies, policies and economic issues we support government agencies, NGOs and industries in pursuit of structural change. For over 40 years now, the skills and enthusiasm of CE Delft's staff have been devoted to achieving this mission.

Content

Summary

The European Commission has presented its 'Fit for 55' package (FF55) in July 2021, which contains legislative proposals aiming to reduce the emissions of maritime transport with a view to reaching a net-zero economy by 2050. This report analyses how and in what way the proposals would set shipping on a pathway towards decarbonisation by 2050 and what might eventually be necessary on top of that to reach this goal.

In order to establish which pathways exist towards decarbonisation, the report has analysed five scenario studies from different organisations and research institutes. These studies have in common that they contain roadmaps for decarbonisation of the shipping sector by 2050. Although the roadmaps use different assumptions for the availability and costs of renewable fuels, and expect that different fuels will be used in the maritime sector in the coming decades, they have several commonalities for 2030.
We consider these commonalities as milestones for decarbonisation of the maritime sector by 2050. Table 1 shows in its first two columns the 2030 milestones which are needed to decarbonise the shipping sector by 2050.

Overall, the *architecture* of the Fit for 55 package is in itself considered to be able to set shipping on the pathway towards decarbonisation by 2050:
- The package addresses both the supply and demand of marine fuels. The EU ETS and FuelEU Maritime proposals target the GHG emissions of vessels, while the ETD and RED target the fuel suppliers. In this way there are incentives for the demand of renewable and low-carbon fuels, and for investments in the supply side of these fuels. However, the requirements and incentives for fuel suppliers are at risk to be undermined by the ease with which ships can bunker outside the EU.
- The long-term goals of FuelEU Maritime and the EU ETS set, provide certainty to the market. In particular the GHG intensity limit of the FuelEU Maritime proposal which becomes more stringent over time until 2050 provides certainty and information to the market regarding the speed of the process and types of renewable and low-carbon fuels that will be demanded up to 2050.

However, the *stringency* of the Fit for 55 package falls short in creating sufficient incentives to initiate the development of fuels and technologies before 2030 which are considered to be essential for the decarbonisation of the shipping sector (especially renewable e-fuels, also denoted as RFNBOs in RED/FuelEU Maritime terminology):
- Because LNG can be used to comply with FuelEU Maritime for the 2025 and 2030 goals and is treated favourably in the EU ETS and the ETD, the demand for renewable marine fuels is lower than what would be required to increase demand for them.
- The demand for scalable renewable fuels such as RFNBOs is not increased by FuelEU Maritime because they are a more expensive way to reduce the GHG intensity than biofuels; the requirement to increase their supply, provided by the RED, is weakened because of expected evasion: when fuels become more expensive in EU ports, ships will increasingly bunker outside the EU.
- There is no attention to ship technology, especially with regards to dedicated ships that can sail on RFNBOs, like green ammonia or green hydrogen, or to the supply infrastructure for those fuels.
- With shipping becoming part of the existing ETS, at the present and foreseeable ETS price, the shipping industry will for the most part buy allowances, because reducing shipping emissions is often more expensive.

More is needed to increase the likelihood that the Fit for 55 package leads to a timely start of the decarbonisation process, which the shipping sector needs to follow towards zero emissions by 2050. The measures could be improved in the following aspects:

- Increase the uptake of renewable and low-carbon fuels, especially of e-fuels (based on 100% renewable electricity, RFNBOs) which are scalable, by either:
  - increasing the targets; and/or
  - expanding the scope of the package; and/or
  - closing the cost-gap between scalable e-fuels and advanced biofuels on the one hand and waste-based biofuels on the other.
- Require the development of production and bunkering infrastructure for fuels that require a dedicated infrastructure, such as ammonia, methanol and hydrogen.
- Support the development and construction of ships that can sail on a range of fuels, including renewable fuels (biofuels and e-fuels based on 100% renewable electricity).
- Support the supply of renewable and low-carbon fuels without raising the bunkering costs more than in other parts of the world. And
- Prevent the risk of lock-in of low-carbon fossil fuels; because of their low lifecycle GHG emission reduction potential low-carbon fossil fuels have no role in a decarbonised shipping sector.
- Prevent the risk of lock-in of low-carbon fossil fuels with little potential to increase production, because their uptake would delay investments in renewable fuels that have a role in a decarbonised shipping sector.

Table 1 summarises the milestones identified in the decarbonisation scenarios, the effect of the proposed measures by 2030, an assessment of the sufficiency of the measures, as well as suggestions for improving the proposals.

Table 1 - Assessment of contribution of Fit for 55 proposals to decarbonisation of shipping

	2030 milestones Based on scenario studies	**Relevant EU legislation that touches upon the subject, without necessarily providing for the milestone**	**Effect by 2030**	**Assessment of proposals in reaching milestones**	**Suggestions for improvement**
Share of renewable and low-carbon fuels and energy sources	10-20% renewable and low-carbon fuels and energy sources	FuelEU Maritime, RED III, EU ETS, ETD	1%	Insufficient	– Possibly specific incentive for RFNBO in FuelEU Maritime – Overall increase of targets – Possibly increase supply without causing evasion
	Clarity on ammonia and hydrogen (technical feasibility and (safety) regulations)	No legislation addresses this subject clearly	Not sufficiently addressed	Insufficient	– Dedicated financial support for addressing technological challenges (Innovation fund), e.g. in conversion- and propulsion technology onboard ships – Addressing regulatory barriers

	2030 milestones Based on scenario studies	Relevant EU legislation that touches upon the subject, without necessarily providing for the milestone	Effect by 2030	Assessment of proposals in reaching milestones	Suggestions for improvement
Types of renewable and low-carbon fuels and energy sources	Wide range of fuels to be considered and tested: Refined pyrolysis oil, blue ammonia, LPG, LNG, biomethane, methanol-DAC	FuelEU Maritime, RED III, EU ETS	LNG becomes more attractive. And to a lesser extent biofuels. Hardly any uptake of the use of RFNBOs	Partly sufficient	– Restrict attractiveness of LNG to reach the FuelEU Maritime targets so that demand for other fuels increases – Consider specific incentive for RFNBO in FuelEU Maritime or support to close the cost-gap between RFNBOs and advanced biofuels on the one hand and unscalable biofuels on the other.
	Decision on sustainability criteria for biomass and whether there is a role for energy crops	RED III, FuelEU Maritime	No dedicated cultivation foreseen	Partly sufficient	Impact of dedicated cultivation needs to be assessed.
Entry in the fleet of ships that can run on non-conventional fuels	First ships in the fleet that are powered by hydrogen or ammonia	Not addressed	Not addressed	Insufficient	Dedicated financial support for innovative ships, e.g. in the Innovation fund.
Requirements for bunkering infrastructure of renewable and low-carbon fuels and energy sources	Safety, international standards and rules	AFIR	No concrete targets for renewable fuels, mainly LNG	Partly sufficient	Specific, EU-wide bunkering infra targets for renewable maritime fuels.

List of abbreviations

AFID	Directive on Alternative Fuels Infrastructure
AFIR	Regulation on Alternative Fuels Infrastructure
CAPEX	Capital expenditure
CCS	Carbon capture and storage
DAC	Direct Air capture
DWT	Dead Weight Tonnage
EC	European Commission
EF	Emission factor
EJ	Exajoule (10^{18} Joule)
ETD	Energy Taxation Directive
ETS	Emissions Trading System
EU	European Union
FAME	Fatty acid methyl esters
FF55	Fit for 55 package of the European Commission
FQD	Fuel Quality Directive
GHG	Greenhouse Gas
H_2	Hydrogen
HFO	Heavy Fuel Oil
IA	Impact assessment
ICE	Internal combustion engine
ILUC	Indirect land use change
IMO	International Maritime Organization
IRENA	International Renewable Energy Agency
LH_2	Liquid hydrogen
LOHC	Liquid organic hydrogen carrier
LNG	Liquid Natural Gas
LPG	Liquid petroleum gas
LSMGO	Low Sulphur Marine Gas Oil
MMMCZCS	Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
MDO	Marine Diesel Oil
MEoH	Methanol
MFO	Medium Fuel Oil
MGO	Marine Gas Oil
MRV	Monitoring, Reporting, Verification
NH_3	Ammonia
OPEX	Operational expenditure
OPS	Onshore power supply
R&D	Research and development
RED	Renewable Energy Directive
RED II	Renewable Energy Directive - recast to 2030 (Directive 2018/2001/EU)
RED III	Renewable Energy Directive - FF55 proposal
RES	Renewable Energy Sources
RFNBO	Renewable fuels of non-biological origin
RLF	Renewable and low-carbon fuels
TCO	Total cost of ownership
TTW	Tank-to-wake
UCO	Used cooking oil

ULSFO	Ultra-Low-Sulphur Fuel Oil
UMAS	University Maritime Advisory Services
USD	US Dollar
VLSFO	Very-Low-Sulphur Fuel Oil
WTT	Well-to-tank
WTW	Well-to-wake

1 Introduction

The European Commission has presented its so-called 'Fit for 55' package in July 2021, which contains legislative proposals aiming to reduce the emissions of greenhouse gases by 55% by 2030 relative to 1990. The Fit for 55 package encompasses all sectors of the economy, including maritime transport.

Five elements of the package directly affect maritime transport emissions or fuels:
1. The revision of the EU emissions trading scheme (EU ETS), especially the proposal to include maritime transport emissions in the EU ETS.
2. FuelEU Maritime, a new regulation requiring ships to reduce the GHG intensity of fuels used and to use onshore power at berth.
3. The revision of the energy taxation directive (ETD) proposing to tax marine fuels.
4. The Alternative Fuels Infrastructure Regulation (AFIR), replacing the eponymous Directive.
5. The revision of the Renewable Energy Directive (RED), extending the scope of the requirements for transport fuels to marine fuels sold in the EU.

When implemented, the proposals would result in cost increases for ships and ports (CE Delft, 2021). From 2025 these are:
- the need to acquire allowances for emissions of CO_2 by ships sailing between, to and from EU ports (EU ETS);
- the obligation to reduce the GHG intensity of fuels and energy sources used on voyages between, to and from EU ports (FuelEU Maritime);
- taxation of marine fuels sold in EU ports for intra-European voyages (ETD).

From 2030, the following requirements result in additional cost increases:
- container and passenger ships are required to use onshore power when at berth (FuelEU Maritime);
- the GHG intensity of fuels sold to the transport sector has to be reduced by 13% (RED);
- ports have to offer OPS connections (AFIR).

In a previous report, CE Delft quantified the direct cost impacts of the Fit for 55 package (CE Delft, 2021). In that report we did not analyse how ships and ports would react to the new requirements, which is not straightforward, because ships have several options to evade regulation, e.g. by adjusting shipping routes or by changing their bunkering location (CE Delft, 2022). Evasion in general harms the environmental effectiveness of regulation. In addition, the incentives provided by different regulations do not always reward the same type of reactions (see e.g. (CE Delft, 2022)).

Therefore, the Dutch Ministry of Infrastructure and Water Management has requested CE Delft to analyse whether the proposals set the shipping sector on a pathway towards decarbonisation by 2050, which synergies exist between the proposals and where incentives are misaligned, missing or not strong enough, and which GHG emissions are not addressed by the current proposals.

1.1 Aim and scope of the study

The aim of the project is to analyse whether the proposals set the shipping sector on a pathway towards decarbonisation by 2050, and how the proposals could be amended to better contribute to GHG emission reductions of the maritime sector.

Specifically, the project will analyse:
- which positive incentives the Fit for 55 proposals provide for decarbonisation of shipping;
- which negative incentives the Fit for 55 proposals provide, either because incentives are misaligned, can be evaded or otherwise;
- which aspects of decarbonisation are not or insufficiently addressed by the Fit for 55 proposals;
- how the Fit for 55 proposals can be amended in order to contribute more effectively to the decarbonisation of the maritime sector;
- how the Fit for 55 proposals impact the chances of reaching global agreements on measures to address GHG emissions of shipping.

In order to do this analysis, the study will first map out how decarbonisation of shipping is expected to evolve and which milestones will need to be met by 2030. This will be done on the basis of existing literature. The milestones can then be compared with the impacts of the Fit for 55 package.

1.2 Terminology

The report uses the following labels for fuels:
- 'blue' denotes fuels that are derived from fossil fuels where GHG emissions are permanently stored underground;
- 'green' denotes fuels that are produced with renewable electricity;
- 'e-' denotes fuels that are produced from electricity;
- 'grey' denotes fossil fuels; and
- 'bio' denotes that the fuels contain carbon of biological origin.

1.3 Outline of the report

Chapter 2 presents an overview of scenario studies for the decarbonisation of the global shipping sector. We used these studies to identify the milestones which should be met by 2030 to reach carbon neutrality by 2050. The next chapter analyses the proposals under the Fit for 55 package which are relevant for shipping and it identifies which incentives are provided for which entities or actors. Chapter 4 compares the incentives with the milestones identified in Chapter 2. Where policy proposals fall short, Chapter 5 offers ideas for amending and improving them. Chapter 6 discusses the impacts of the Fit for 55 proposals on the negotiations about mid-term measures at the IMO. Conclusions are given in Chapter 7.

2 2030 milestones for decarbonisation by 2050

2.1 Introduction

In this chapter we analyse several recent publications that contain scenarios for a (near) zero-carbon, global maritime sector in 2050. On the basis of these scenario studies, we will identify milestones that need to be met in 2030, in order to accommodate the sketched scenarios. The 2030 milestones are not strictly defined in the scenarios, but originate in a synthesis and comparative analysis of the different studies.

The chapter starts with a brief overview of the efforts required to decarbonise the shipping sector, both in terms of emission reductions (Section 2.2) and in terms of costs (Section 2.3).

In Section 2.4 we will give an overview of five scenario studies that have modelled fuel mix scenarios towards 2050 (MMMCZS, Lloyd's Register & UMAS, University of Denmark, IRENA and UMAS). A comparative analysis of the studies is presented in Section 2.5. The analysis focusses on fuels, energy sources, ships and infrastructure needed, and the shape of the transition pathway.

This chapter will conclude with the 2030 milestones, as can be derived from the different studies. These milestones will be used for the assessment of the measures set out in the Fit for 55 package.

2.2 Maritime shipping scenario for 2030 and 2050

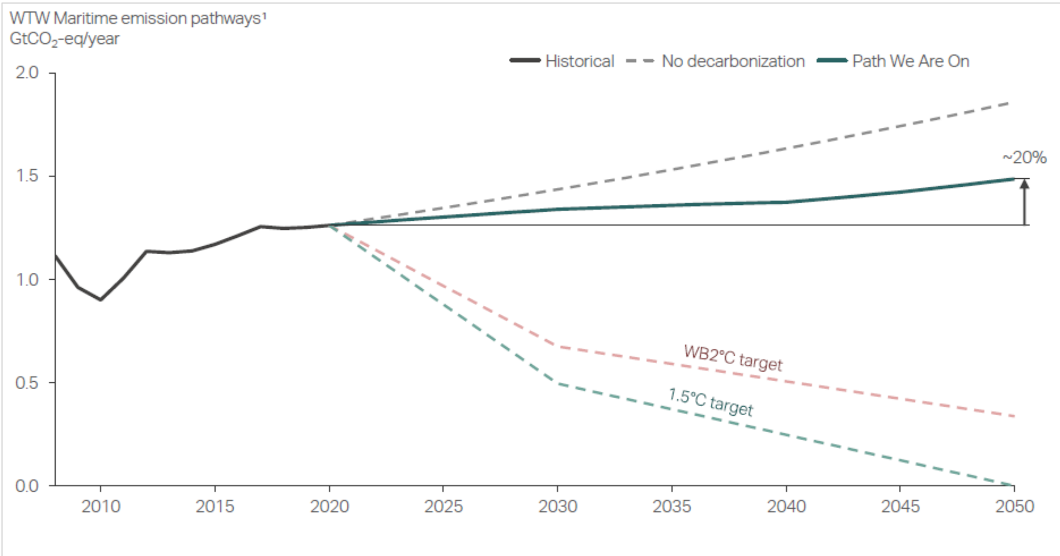
The maritime sector is responsible for approximately 3% of global GHG emissions (Faber, et al., 2020) and the effort to reduce emissions in this global and commercially diverse sector is a challenge. In a business as usual situation emissions can be expected to increase towards 2050, despite developments like an evolving modernisation of the fleet, declining renewable electricity prices and tightened energy efficiency regulation by the IMO.

The expected increase of emissions is mainly due to the growth of world trade.
Part of the dynamics is that higher efficiency of shipping leads to higher demand for shipping. The maritime sector can be expected to have an energy demand of approximately 12 EJ[1] by 2050, although this might be as low as 8 EJ, depending on the success of energy efficiency measures (IRENA, 2021). UMAS estimates however that energy demand from shipping might rise to almost 19 EJ in 2050 (UMAS, 2021).

The discrepancy between the Paris Agreement ambitions and the path we are currently on is shown in Figure 1. According to this projection (the line of "the path we are on," i.e. without implementation of measures), only 1% of energy demand in shipping is going to be met by renewable and low-carbon fuels in 2050 (Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021). WTW GHG emissions of shipping will steadily grow to 1.5 $GtCO_2$-eq./year in 2050.

[1] An exajoule (EJ) is 10^{18} Joule.

Figure 1 - Projection of maritime emissions and climate ambitions based on IMO, IEA, Clarksons and Techno-economic model MMM Center for Zero Carbon Shipping



Source: (Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021).

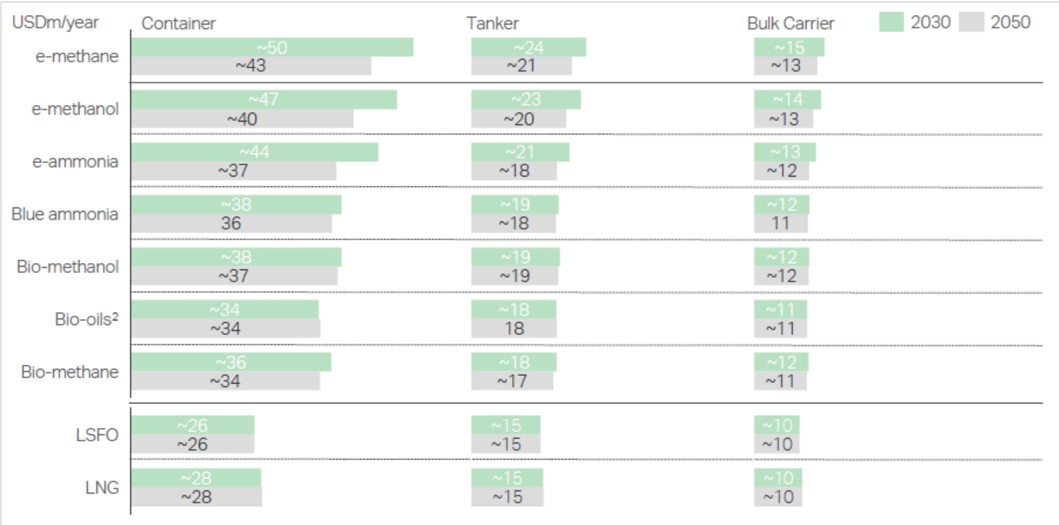
Switching to fuels with low- or zero-greenhouse gas emissions on a tank-to-wake (TTW) basis does not reduce the global GHG emissions when these fuels are produced from fossil fuels, as for example hydrogen and ammonia currently are. It is therefore necessary to switch to alternative production routes or feedstocks and to reduce emissions on a well-to-wake (WTW) basis. The WTW emissions of bio routes are very dependent on the feedstock used, with residual feedstocks leading to the highest WTW GHG emission reductions. Additionally, e-fuel routes are also very dependent on the emissions of the electricity used for the production; reduction of emissions is not as significant when e-fuels are based on the current Dutch or European grid emission intensity (TNO, 2021), but they can reach almost 100% GHG emission reduction when 100% renewable electricity is used.

While reduction of WTW maritime emissions to zero by 2050 would be in line with the 1.5°C target, few concrete policy targets with this aim have been formulated. Since the maritime sector falls outside the Paris agreement and due to the global character of the sector, national governments rarely consider it their responsibility to reduce maritime emissions to zero in 2050. The International Maritime Organization (IMO) has currently set the goal of reducing GHG in 2050 by at least 50% compared to 2008.

2.3 Cost projection of renewable and low-carbon fuels

Fuel costs represent between 20 and 34% of total annual shipping costs per vessel (Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021). Consequently, a major barrier to the introduction of renewable and low-carbon fuels is the persisting uncompetitive position of RLF compared to fossil fuels. It is estimated that in 2025 any alternative fuel will be 2 to 8 times more expensive than fossil fuels (on TCO (Total Cost of Ownership) level). Maersk has made a projection for TCOs of different renewable and low-carbon fuels for 2030 and 2050, for containers, tankers and bulk carriers, see Figure 2. It becomes clear that given the current regulations (mainly directed towards efficiency) no alternative fuel will be cost competitive in either 2030 or 2050; only a relatively modest improvement of the cost-competitiveness of RLF is achieved between 2030 and 2050.

Figure 2 - Future TCO projections of renewable and low-carbon fuels compared with fossil fuels in million USD/year



Source: (Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021).

The difference between vessels is due to different levels of fuel consumption (which in turn is related to size and distance). For container ships, which have the highest emission intensity per ton-km, the gap is the biggest, whereas for bulk carriers the cost difference is relatively small. E-fuels remain least cost competitive across all segments.

The Maersk Mc-Kinney study has already taken into account (for The Path That We Are On-scenario) that consumers are prepared to pay a premium for green transport (35% of the customers pay a premium of 8% in 2050). The study has based this on market information, but underlines that although indications show that customers are willing to pay a green premium, very few people are in practice prepared to 'walk-the-talk.' Additionally, McKinsey has interviewed around 10 major logistics companies (including in maritime shipping) and they concluded that "a group of front-running shippers indicated that they are willing to pay a premium of 5 to 10 percent for sustainable logistics services (McKinsey, 2022)."

2.4 Overview of scenario studies

In this section we will give an overview of five scenario studies for a global zero-emission shipping sector in 2050. The studies contain often internal varieties, with different assumptions.

The scenarios all have a backcasting approach from 2050 and do not have the 2022 status quo with all its restrictive circumstances as a starting point. This means that they quickly project a relatively large share of RLF in the fuel mix. This would be crucial for reaching the set target in 2050, but does not necessarily take into account the current state of play.

2.4.1 Scenario study 1: Lloyd's & UMAS (2019)

Considering the uncertainty of a specific renewable fuel mix, Lloyd's Register has defined three transition scenarios (domination of e-fuels, bio-energy and a combination of those two) towards 2050, with the aim of determining the implications for the electricity price and biomass availability. The scenarios for shipping are based on global energy production scenarios, involving all sectors and based on an energy mix that meets the 1.5°C Paris target. The three scenarios assume availability of ships required for the specific fuel and an energy production capacity that can meet demand.

Figure 3 - Three scenarios (from left to right: Renewable electricity, Biofuels and combination)

Source: (Lloyd's Register & UMAS, 2019).

The main factor to realise the **first scenario** (on the left in Figure 3) is the availability of renewable electricity at very competitive prices, since the cost of electricity represents around 80% of the cost of hydrogen production. It is expected that shipping will be served last with regards to renewable electricity, but by 2030, renewable electricity will need to be available at a price of approximately 19 $/MWh (currently around 60 $/MWh in Europe) in low cost locations like the Middle East and Latin America, although the availability of water might be an issue in those regions.

The **second scenario** will need a significant growth of bio-energy capacity in the global energy mix, with 60 EJ of biomass feedstock in 2030 and more than 300 EJ available in 2050 (for all energy purposes (Lloyd's Register & UMAS, 2019)). For maritime shipping, this would involve around 5 to 12 EJ. For comparison, current biomass production in the EU is 10 EJ, and could increase to 15 EJ, or 41 EJ under highly favourable conditions in 2030 (CE Delft, 2020). Blend standards will need to be developed and environmental concerns (air pollutants and sustainability) need to be addressed. Furthermore, a very large role in shipping for biomass with its large dedicated land areas, might in the future be considered as a lock-in.

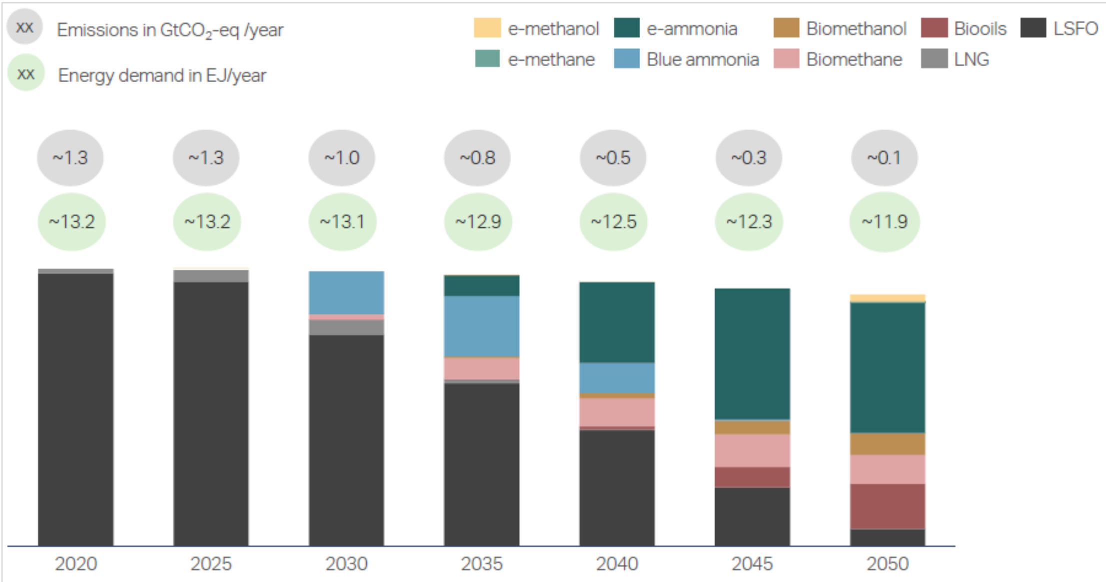
The **third scenario** needs a continuous and significant growth of renewable electricity, bio-energy and natural gas with carbon capture and storage (CCS), also involving price reductions for all three energy pathways. For the third scenario, the study asserts that CCS needs to be perceived as crucial to address climate change and it should be a widely available technology. Also, a large role for CCS would still imply a large input from fossil fuels.

2.4.2 Scenario study 2: MMMCZCS (2021)

Research by the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) shows that introducing a carbon pricing scheme from 2025 onwards with price levels similar to the EU ETS (around 50 $/t, although in the EU it's now around € 70), together with efficiency gains through currently available measures, a significant decline of electricity costs, customer willingness to pay a green premium of 12% and the mobilisation of major financial institutions that would stimulate green investments will lead to a final reduction of GHG emissions of 20% by 2050 (compared to 2020). This is – even with a significant contribution from negative emissions - evidently not enough to meet the targets of the Paris Agreement.

With all the measures of the first paragraph in place and the (global) flat levy carbon price lifted to 230$/t$CO_2$-eq. from 2025 onwards, will result in GHG emissions reduction associated with the 2 degrees target by 2050. It leads to a fuel mix scenario as given in Figure 4. With an initial growth of blue ammonia, the majority of energy demand will eventually be filled in by the cheapest e-fuel on TCO level: e-ammonia. Smaller shares of biomethane, biomethanol and bio-oils will also be used. Fuels might have different levels of attractiveness for different shipping segments.

Figure 4 - A carbon-neutral scenario for 2050 as calculated by MMMCZCS



Source: (Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021).

In case that renewable energy costs will be less competitive or when there is a limited scale-up of renewable energy capacity, the share of e-ammonia in the scenario will be replaced with blue ammonia. In turn, blue ammonia also has challenges regarding CCS standards and upstream methane emissions. Furthermore, ammonia (blue and green) is still dependent on meeting safety standards, which, if not met, will seriously restrict a zero-carbon future. Biomethane, bio-oils and bioethanol might take up larger shares if the currently projected availability of biomass would double.

A carbon price of 230 $/t will make bio-oils, biomethanol, biomethane and blue ammonia cost competitive in 2030. It will make all renewable and low-carbon fuels cost-competitive in 2050 because zero-emission pathways will also become more cost-competitive.

Application is only restrained by availability of ships and infrastructure (and possibly safety issues).

Introducing a constant levy of 230 $/tCO_2$-eq. from 2025 would be sufficient to reach the goals associated with the 2 degrees target by 2050. It would generate a cumulative income by 2050, exceeding by 1.8 $ trillion the extra fuel costs for converting maritime shipping to renewable and low-carbon fuels. If instead of a constant levy, a levy is introduced of which all revenues would be used to subsidise low- and zero-GHG fuels, a carbon price of 50 $ growing to 150-200 $ in 2040 might be sufficient, without creating large revenues.
As compared with MMMCZCS, UMAS mentions a carbon price of around $ 191/tCO_2 to be in force during the 2020s for full decarbonisation in 2050 (UMAS, 2021).

E-methanol, which costs slightly more than e-ammonia, plays only a very minor role in the scenario of MMMCZCS, and only from 2050, with the price as the key driver for giving preference to e-ammonia. However, e-methanol is suitable for blending with fossil methanol, allowing a gradual introduction. It can also be blended at low levels with diesel fuels, although the level can be increased when emulsifiers are added, but that would increase overall costs (Öko-Institut, CE Delft & DLR, 2021). It is also easy to handle, store and safer to use onboard, contrary to ammonia. Ships that operate on fossil methanol already exist and the fuel is technically identical to the bio or e-variety, but the required build-up of the e-methanol pathway results in the expectation that ships operating on 100% e-methanol can be demonstrated by 2030 (Öko-Institut, CE Delft & DLR, 2021).

2.4.3 Scenario study 3: Technical University of Denmark (2021)

The Technical University of Denmark has developed a model to calculate several decarbonisation scenarios for the maritime sector towards 2050 (Technical University of Denmark, 2021). The model takes into account a comprehensive list of variables, parameters and constraints. It optimises the fuels based on total cost minimisation (of both fuel and ship) and emission performance, but it does not take into account the possibility of retrofitting. The shipping demand scenario is based on IMO's Fourth Greenhouse Gas Study (2020), with a steady increase of demand for shipping towards 2050, coming especially from bulk shipping.

For every scenario, assumptions are made on three levels: 1) availability of the electricity grid to produce electro-fuels and inclusion of infrastructure emissions; 2) biomass availability (low, medium, high) and 3) WTW GHG emission reduction targets for 2050 (50%, 70%, 99%). It is assumed that the grid mix will reach practically zero-emission by 2040.
In addition to the varying scenarios, several sensitivity analyses are being performed.

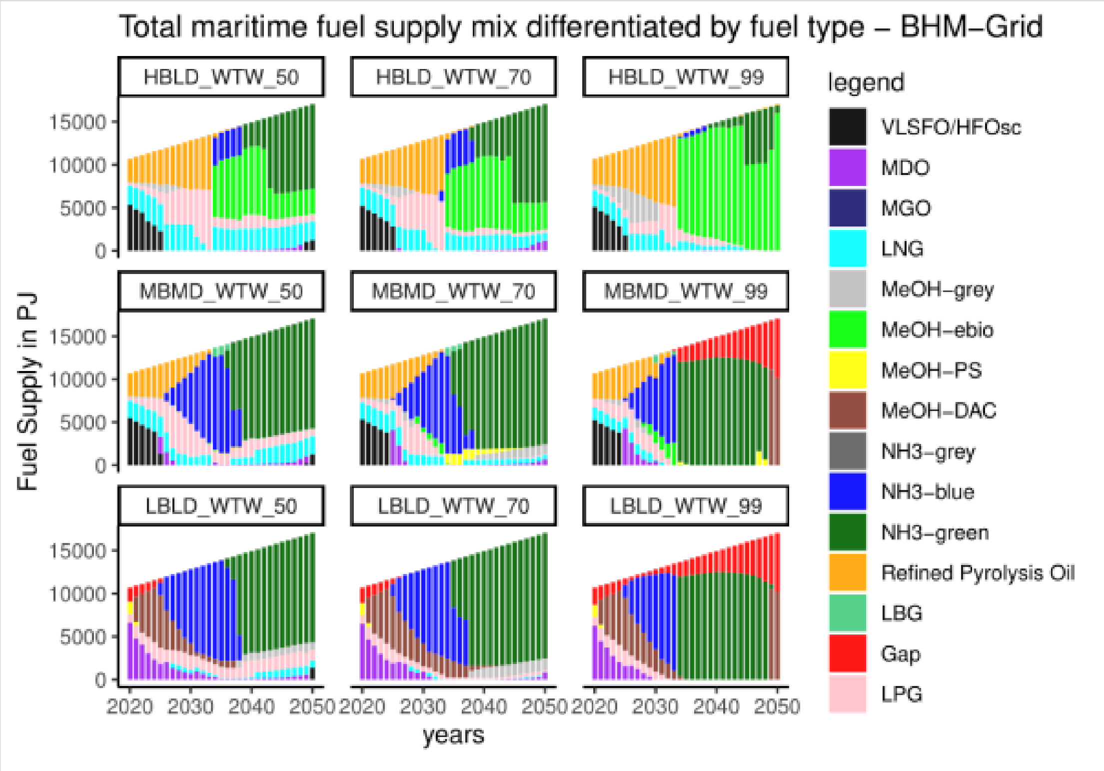
Baseline scenario

The study has a baseline scenario based on current (global) fuel production plants and with the assumption that renewables and the grid around those plants are available.
In all scenarios the maritime industry is last in line for the available biomass, after the aviation and petrochemical industry, because those sectors are considered to have a higher willingness to pay. This results in a final baseline scenario with nine sub-scenarios (biomass availability and reduction scenario differentiated), see Figure 5.

All sub-scenarios move away from VLSFO and HFO during this decade. In the scenario with high biomass availability (upper three graphs), the first decade will see an increase of the use of refined pyrolysis oil and LNG, followed by LPG and blue ammonia by the shipping sector (LNG and LPG have lower specific emissions, even though they are fossil fuels.

Their use increases because they are cheaper than biofuels, even in these scenarios with high biomass availability). During the 2030's methanol from biomass and hydrogen and green ammonia take a large share of the energy demand. The former almost being dominant in the 99% reduction option, the latter covering more than half in the 50 and 70% reduction scenarios.

Figure 5 - Baseline scenarios (50%, 70%, 90% GHG reduction & low (LB), medium (MB), high availability of biomass (HB))



Source: (Technical University of Denmark, 2021).

In the medium biomass availability scenarios, refined pyrolysis oil and small shares of LNG and LPG play a role until around 2030, after which blue - and later - green ammonia take over. In the low available biomass scenarios, the first alternative fuel appearing is e-methanol utilising direct air capture. According to TNO however, the financial feasibility of this fuel via Direct Air Capture (DAC) is very uncertain (TNO, 2021). From around 2025, the share of blue ammonia increases, which in the thirties will be taken over by green ammonia. In both the medium and low available biomass scenarios, a gap will remain in the 99% reduction ambition. This is mainly because of the high demand for electricity from the grid. Gaps are not only the result of a lack of available renewable and low-carbon fuels, but also related to the availability of new or retrofitted ships. Ships sailing on VLSFO or MGO can use pyrolysis oil and methanol with minor modifications to the engine and the fuel system. Ammonia requires dedicated tanks, fuel systems and engines. Engine builders are currently offering engines that can run both on ammonia and on MGO, which can be built into new ships with the appropriate tanks.

The baseline scenarios make clear that biomass availability has a greater effect on the projected fuel mix than the targeted emission reduction rate.

Sensitivity analyses

The study has also looked at sensitivities of several assumptions, because many factors contain a significant level of uncertainty, which in the end might change the calculated scenarios.
In a scenario without connection to the electricity grid (and therefore exclusively green electricity), green ammonia (NH_3) will be dominant in all alternatives. E-bio methanol (i.e. methanol produced from green hydrogen and carbon of biological origin) will also be important when there is a high availability of biomass. Small and declining shares of LNG and LPG exist until 2050. E-methanol with direct air capture loses its significance because its cost price is higher than ammonia.

The role of blue ammonia is largely dependent on the development of its costs and WTW emissions, as the fuel is not yet commercially available and uncertainty exists about its emission factor. When expected cost or emissions turn out to be higher than assumed, blue ammonia needs to be replaced by green ammonia.

The role of e-fuels is very sensitive due to their actual lifecycle emission intensity (with grid mix) and costs. In the sensitivity analysis, it became clear that in case e-methanol with CO_2 from DAC (MeOH-DAC) – which has strong uncertainty related to lifecycle emissions and costs – has 10% lower emissions than assumed, it becomes the dominant fuel after 2040 in the medium and low biomass available scenarios, replacing all green NH_3.

When other industries do not also compete for carbon from point sources (where carbon is released in large volumes), e-methanol produced from point source becomes dominant in the low- and medium biomass availability alternatives and the 99% reduction scenarios.

Especially in the scenarios with high biomass availability, refined pyrolysis oil may play an even greater role than now displayed up to 2040 when the costs decline of other fuels.

CO_2 price

The study has also looked at the CO_2 price needed to meet the different scenarios.
For scenarios with low biomass availability until 2025 and for any 99% emission reduction scenario at 2050, the model couldn't calculate a solution; no CO_2 price could be used to realise the scenario (meaning a CO_2 price offers no solution, regardless of its value). In the 50% GHG reduction scenario with high biomass availability, a CO_2 price of 350 €/tonne was calculated, with a slow decline after 2030. Low biomass availability scenarios have CO_2 prices of more than 400 €/tonne in 2026, and 300 €/tonne in 2040. In short, no carbon price is high enough to realise any of the 99% GHG reduction scenarios of this study. For the other scenarios, carbon prices would range between 300 and 400 €/tonne, dependent on biomass availability.

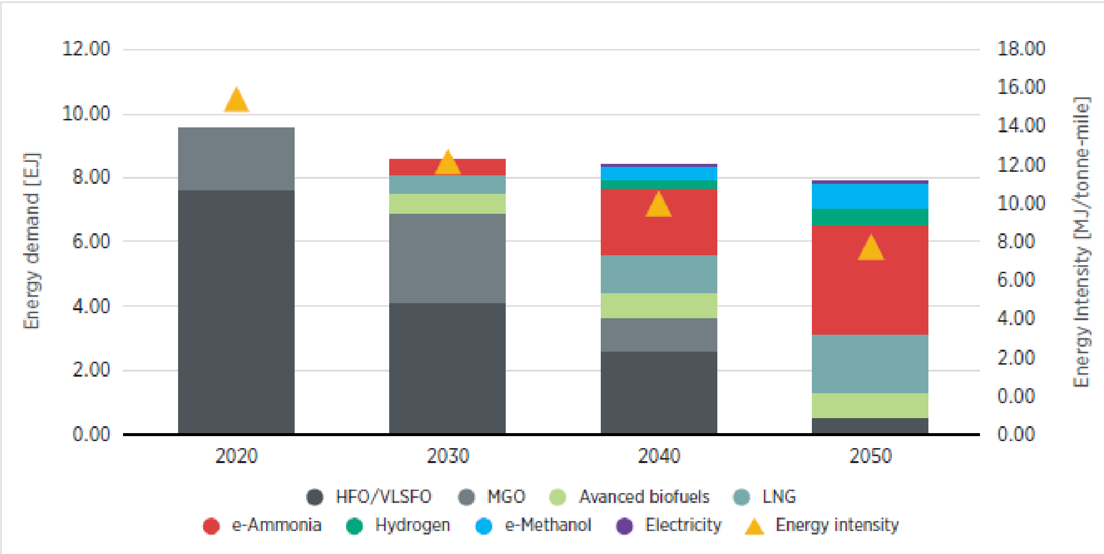
2.4.4 Scenario study 4: IRENA (2021)

The future fuel mix is highly dependent on factors like cost and availability of renewable electricity, availability of biomass, the carbon price and availability of CCS. This entails a high degree of uncertainty. As in all previous scenarios, IRENA also projects that different renewable fuels will be needed on the way towards 2050.

IRENA mapped out a scenario for a diverse fuel mix in 2050, taking into account that the shipping sector sticks to a 1.5 degrees temperature increase scenario, see Figure 6.

For this scenario, a 80% reduction of GHG emissions in the shipping sector is foreseen in 2050 compared with 2018. While the study underlines the need for a carbon levy, it is not included in the scenario, neither is the required CO_2 price specified. Eventually, e-ammonia will serve the bulk of energy demand (43% of demand i.e. 183 Mt of renewable ammonia, comparable to the total current global production of (fossil) ammonia (IRENA, 2021).
The IRENA scenario implies a demand for 46 Mt green hydrogen annually by 2050. This would be around 5,520 PJ/year (and for example 620 GW offshore wind capacity and at minimum more than 250 GW electrolysis capacity).

Figure 6 - 1.5°C energy pathway scenario



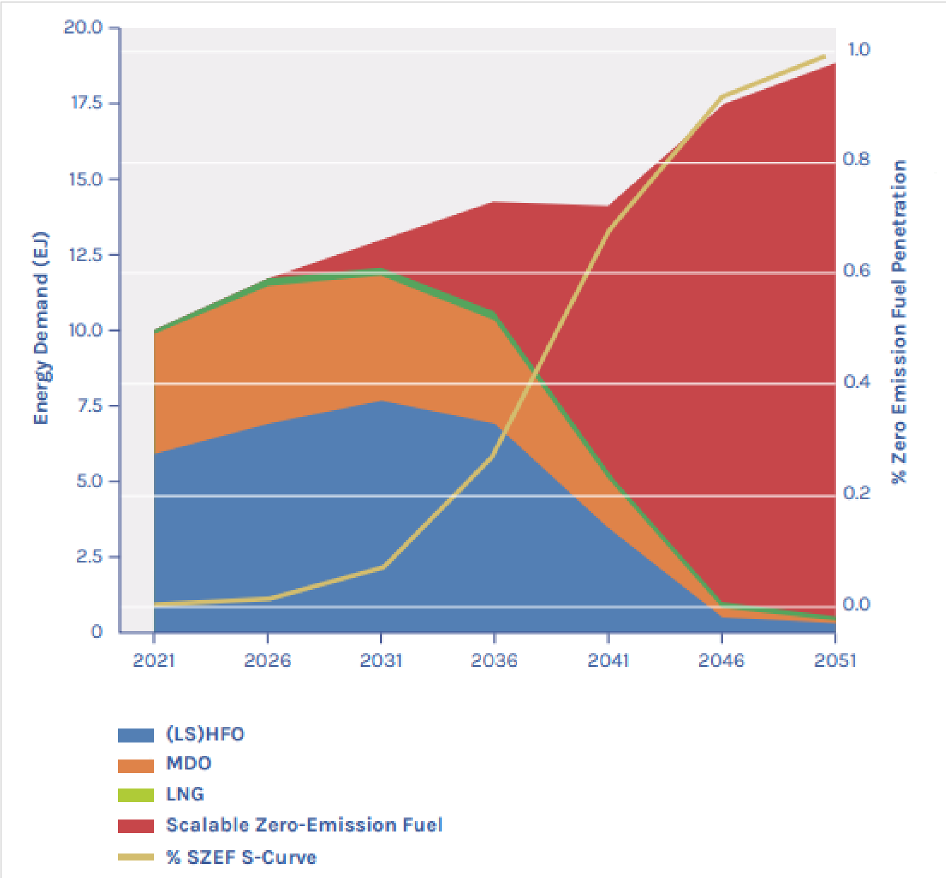
Source: (IRENA, 2021).

2.4.5 Scenario study 5: UMAS (2021)

The four previous scenario studies show a more or less linear decline of fossil fuel use (although no linear increase of zero-emission fuels). But the path towards decarbonisation might also follow a so-called non-linear S-curve for the application of renewable and low-carbon fuels, going from slow growth in the beginning to strong expansion when technologies are more mature. An S-curve would imply a lower share of zero-emission fuels in 2030.

This has for example been applied in a study by UMAS, see Figure 7. UMAS sets the target of “scalable zero-emission fuels” at 5% in 2030 (UMAS, 2021). Zero-emission fuels are here defined as fuels that have the potential to achieve (near-)zero-GHG emissions on a lifecycle basis. The assumption is that LNG will not expand any further and that LNG dual fuel engines will be retrofitted to ammonia. The S-curve assumes that GHG emission reductions are evenly achieved across all ship types. UMAS estimates that affordable and sustainable biofuels are not available on a sufficiently large scale to account for the necessary application of zero-carbon fuels. Therefore, scalable zero-emission fuels basically mean in this study hydrogen-derived fuels.

Figure 7 - Energy demand and fuel mix towards 2050



Source: (UMAS, 2021).

2.5 Comparative analysis with the aim of defining 2030 milestones

This section presents a comparative analysis of the five scenario studies presented in Section 2.4, also taking into account other studies on decarbonisation of shipping. The analysis focuses on the fuel mix, ships and infrastructure, and the shape of the transition, as these three aspects are addressed in the proposals of the Fit for 55 package.

A first general consideration is that all these five scenario studies are backcasting studies, with the clear objective of reaching (near) zero-GHG emissions in 2050. This implies that the described scenarios do not necessarily reflect an organic evolution from the status quo. In fact, it usually requires a remarkable subversion of the prevalent state of affairs.

A second important remark that applies to all the scenario studies is the high level of uncertainty. The studies model total costs of ownership of ships that have not been built yet, sailing on fuels that are not yet produced on an industrial scale. Different assumptions about how cost prices will develop may have a large impact on the results of the analyses. In the comparative analysis we try to identify a few aspects that – in our view – have reached a relatively adequate level of probability across the scenarios.

Thirdly, all the scenarios consider the global maritime sector and measures integrated in the scenarios (e.g. carbon price) are therefore applicable to the global fleet. At the moment this does not exactly coincide with a realistic perspective.

2.5.1 A diversified fuel mix

All scenario studies project that different fuels will be needed up to 2050 and thereafter. Moreover, most of the scenario studies analysed foresee that in 2050 different renewable and low-carbon fuels will be used simultaneously in maritime shipping. The fuel choice may increasingly become a function of vessel type, cargo type and sailing profiles.

It is furthermore not unlikely that the fuel mix foreseen for 2050 might not be available by 2030, or that ships may not be equipped to sail on these fuels. Notwithstanding this uncertainty, most scenario studies see a large role for e-ammonia, sometimes preceded by blue ammonia. They implicitly or explicitly assume that safety concerns will be solved, which are applicable to use and storage, especially onboard.

The scenario studies have a fuel mix comprising refined pyrolysis oil, biomethane, blue ammonia and LNG for 2030, and a growing importance for hydrogen-derived fuels in the period up to 2050. Only IRENA doesn't consider blue ammonia to be a prominent fuel on the way to or in 2050. The main deciding factor in all the scenario studies is the price of renewable and low-carbon fuels related to their GHG emission reduction potential.

TNO (TNO, 2021) has analysed the feasibility of maritime fuels and the different transition options. They conclude that e-fuels will only become technically and commercially available at a large scale after 2035 in the current policy framework. Up to 2035, the feasible fuels are mostly blue hydrogen, blue LNG, blue ammonia and biofuels, see Table 2.

Table 2 - Transition options

Fuel	Until 2025	2026-2035	After 2036
Drop-in biofuels/e-diesel	Biodiesel	Scaling advanced e-diesel	Advanced e-diesel
Methanol	Demos	Biomethanol	Biomethanol, E-methanol
Ammonia	Demos	Demo's (blue NH_3)	E-NH_3 hybrid with biodiesel
Liquid LNG (cryo)	Upscaling	Bio-LNG, blue LNG	E-LNG, blue LNG
LH_2 (cryo)	Demos	Blue H_2	E-H_2
LOHC as H_2 carrier	R&D	Demos	Upscaling

Source: (TNO, 2021).

Öko-Institut, CE Delft and DLR have also looked at a technology-open roadmap, in which market forces are trusted to take the right long-term decisions in order to meet the targets set by governments. The study states that e-fuels will be essential in reducing GHG emissions in shipping. Realising this would involve a process to facilitate further technological development of the most promising e-fuel. However, it would probably also lead to a variety of e-fuels before a potential dominance of one e-fuel becomes apparent. It is not unlikely that the more e-fuels are entering the competition for economies of scale, the more options will eventually remain competitive (Öko-Institut, CE Delft & DLR, 2021).

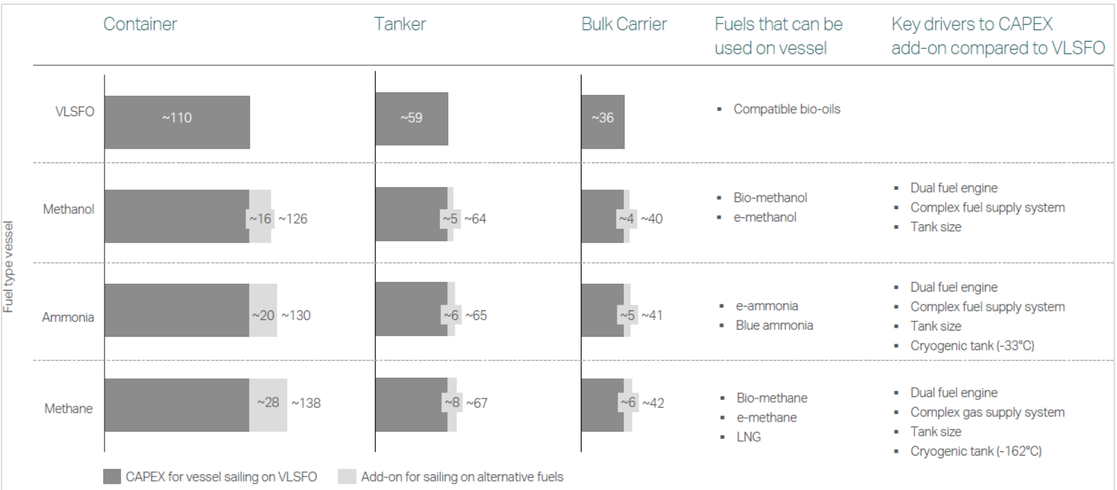
In short, based on the assumptions made, all studies see a diverse and evolving fuel mix as the most realistic outcome and agree that zero-GHG fuels will only be used after 2030, and be developed further to play a large role in 2050.

The constraint for the zero-GHG fuels is caused by a high TCO price for renewable fuels, insufficient availability of renewable electricity, insufficient availability of biomass and technical and practical issues for vessels and infrastructure (like safety issues) that need to be resolved.

2.5.2 Ships and infrastructure

The maritime sector is globalised and very diverse. Due to the large number and the long distances covered, bulk carriers, tankers and container ships account for 65% of all shipping GHG emissions per year. Cruise ships and ferries have much larger GHG emission intensities per mile. Ships are also highly capital intensive assets with operating lives of 20-30 years. Ship replacement is therefore an important moment in the process of adopting another fuel, but at the same time an additional complication in defining a pathway towards 2050. Most of the ships built in the 2020's will still be in operation in 2050. More than 60% of all bulk carriers is less than ten years old, whereas 33% of oil tankers and 36% of container ships worldwide is less than ten years old (Statista, 2020).

Figure 8 - Fuel type vessels and compatible fuels and additional CAPEX to VLSFO fuelled in 2030



Source: (Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021).

The difference in CAPEX between vessels with different fuel types which can be used in internal combustion engines is shown in Figure 8 (ships with fuel cells would be require higher investments, and fuel cells may not generate enough power for the largest ships). Ships which can sail on e-fuels are 15-115% more expensive to build than VLSFO ships. The range reflects the uncertainty about the technological development.

Retrofitting

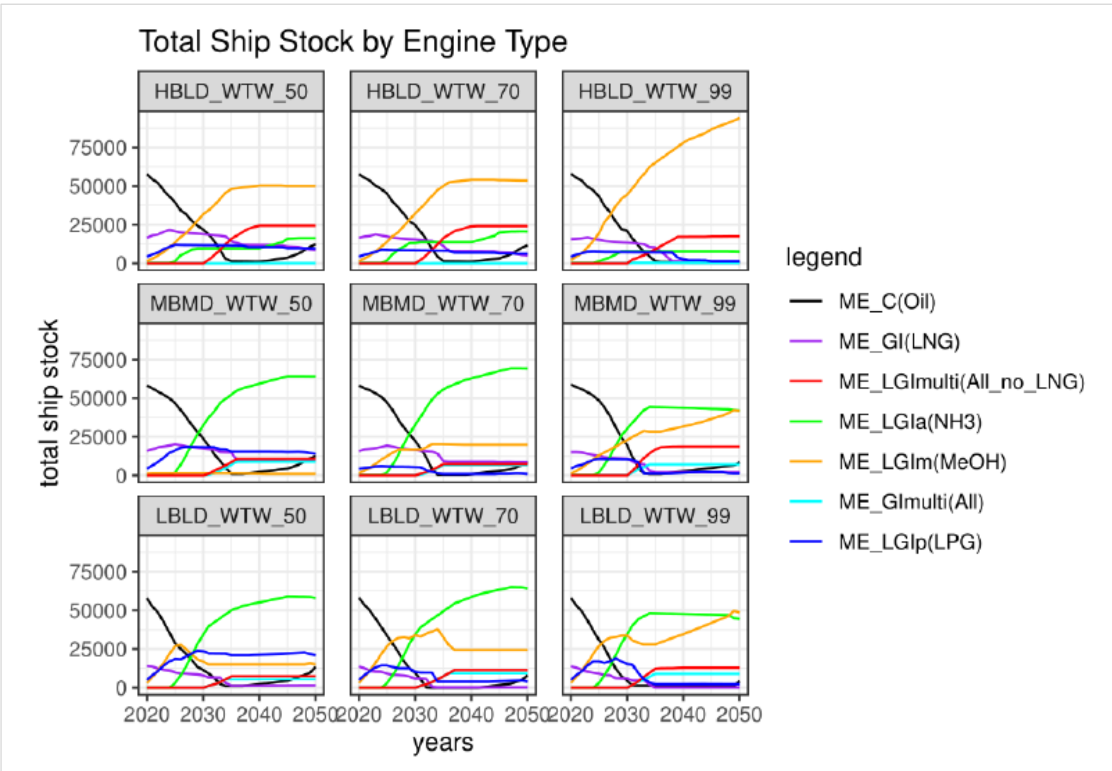
Figure 8 (fourth column) indicates the fuels which can be used in the different fuel type vessels. The existing LNG vessels can for example also sail on biomethane (bio-LNG). For the large majority of present vessels (using VLSFO) however the only alternative is compatible/drop-in bio-oils/biofuels. This implies that accommodating renewable and low-carbon fuels (except for drop-in biofuels) needs to be synchronised with fleet replacement or retrofitting.

Vessels are more or less bound by the fuel their engines can operate on. Ships can be retrofitted to use other fuel types against relatively high costs (a container vessel retrofit could cost more than $ 30 million, being half to a third of the costs of a new ship). Due to these high costs retrofitting ships older than ten years is not financially reasonable. Nonetheless, if the global shipping sector needs to be fully decarbonised by 2050, it is estimated that almost half of the global fleet will need to undergo retrofitting (Getting to zero coalition, 2021).

Engine type scenario

The model used by the Technical University of Denmark to calculate fuel mix scenarios also gives information on the ship types which are needed in those scenarios. The diversity of renewable and low-carbon fuels mapped out in the baseline scenarios entails a diversified fleet, as given in Figure 9. In none of the scenarios there is one dominant engine type used to fulfil the GHG reduction target. The engines that run on fuel oil show a steady decline in all scenarios as they are replaced by either engines running on methanol or ammonia.

Figure 9 - Total ship stock by Maritime Engine type for the baseline scenarios of Paragraph 2.4.3



Source: Technical University of Denmark.

Technical challenges

Energy density related to volume is an important aspect and results in not all ships being suitable for alternative fuel systems. For example, small ships like tugboats do not have enough space for an hydrogen system and storage. These ship types will also need to reserve much more space relative to their size when ammonia will be used. Although efficiency gains can still be realised, ships could be redesigned to store less energy on board and – if possible - refuel more often (TNO, 2021).

Advanced biofuels that have a higher energy density will become relevant for ships with small storage space or for those that are at sea for long period of time. For small ships CAPEX could be more important in deciding the feasibility of an alternative fuel, and OPEX for short sea (like ro-pax) and deep sea ships.

Major technological challenges remain onboard in solving safety issues for (e)- hydrogen and ammonia. The shipping industry is based on infrastructure for liquid fuels, making liquid biofuels and liquid e-fuels therefore more easy to be integrated. The Netherlands has facilities for bunkering fuel oils, methanol and LNG (CE Delft, 2021). These facilities can also be used for biofuels, e-diesel, and bio-/e-methanol and liquefied bio-/e-methane. For ammonia and hydrogen, new facilities need to be developed. Next to the need for new infrastructure, (e)- hydrogen and ammonia represent still major safety challenges for fuel storage, logistics and bunkering facilities. Ammonia is being transported in LPG carriers, which are already worldwide available. Moreover, a regulatory framework for (e)-hydrogen and ammonia as fuels is still absent.

For e- and biomethanol and e- and biomethane onboard fuel combustion can rely on mature and proven technology, while some small challenges remain regarding onboard safety and fuel management. Methanol can be used in internal combustion engines, and therefore many existing ships can potentially be retrofitted with dual fuel engines (Öko-Institut, CE Delft & DLR, 2021).

Onshore power

Even if batteries evolve significantly, they are not expected to play a role as primary energy source on board, due to low-energy density and high costs. Batteries might be used onshore, allowing power connections for vessels in port. Onshore power however cannot represent a solution to decarbonise maritime shipping (Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021); it merely entails efficiency gains, which are from an environmental perspective most attractive when the prime energy source of a vessel is a fossil fuel. Moreover, onshore power would eliminate air pollutant emissions (SO_x, NO_x, PM) of a vessel at berth but the CO_2 emissions are dependent on the grid mix (IRENA, 2021).

2.6 Conclusion

The development of renewable and low-carbon fuels in maritime shipping is expected to be a dynamic process, in which multiple factors will decide the eventual playing field. This premise has been demonstrated in this chapter by several scenario studies. Considering the fact that the analysed scenarios differ in outcomes, without clear preference for one alternative fuel option, defining milestones for 2030 will need to reflect flexibility. A too strong focus on one dominant fuel path might create an undesirable path dependency after 2030. Moreover, many scenarios emphasise the possibility of several renewable and low-carbon fuels co-existing in 2050. In Table 3 an overview of the outcomes of the different studies is shown for the year 2030. While the studies are based on different assumptions (that are not always made explicit) a general conclusion is that the share of renewable low-carbon fuels needs to be between 5 and 30% by 2030 for a reduction pathway towards full decarbonisation by 2050. The difference lies mainly in the shape of the pathway (concave, inverted-S or linear). In most scenarios, overall GHG emission are reduced by 15–20% relative to 2020. However, one scenario assumes that the take-up of renewable fuels will follow an inverted-S-curve, which this scenario combines with a relatively rapid growth of energy demand, resulting in an increase of emissions in the decade towards 2030.

Table 3 - Overview of 2030 milestones according to the different studies

Study	Year	Share of renewable and low-carbon fuels *in 2030 (approx.*)*	GHG emission reduction *in 2030 vs. 2020 (approx.*)*	Type of fuels in 2030
Lloyd's & UMAS	2019	30%	20%	e-fuels, biofuels, blue NH_3/H_2
MMMCZSZ	2021	20%	16%	Blue NH_3, biomethane, LNG
Technical University DK	2021	50%**	20%	LPG, LNG, bio-oils, MEoH-DAC, blue NH_3
IRENA	2021	20%	15%	e-NH_3, LNG, advanced biofuels
UMAS	2021	5%	-20%	Hydrogen based fuels

* Approximately because read from charts.

** Note that in this study, low-carbon fossil fuels are part of the fuel mix in 2030.

The **consequences** of these analyses for the definition of 2030 milestones are shown in Table 4. As described in this chapter, the situation in 2030 differs significantly from scenario to scenario. The Technical University of Denmark sets the share of renewable and low-carbon fuels at around 50%, but in an S-curve scenario, this is around 5%. The other studies have the share of renewable and low-carbon fuels above 10%. Considering the immanence of 2030 and the major challenges for zero-emission fuels, we put the milestone for 2030 at 10-20%. It also needs to be noted that in 2030, the scenarios in general see a role for fossil fuels with CCS, such as blue ammonia, not included in this share.

In the comparative analysis it became clear that a diversified strategy for different renewable and low-carbon fuels is an important element, just as the technical feasibility, especially for e-NH_3. Another prominent aspect was the availability of large amounts of biomass, especially lignocellulosic and algae, for marine fuels. By 2030, there should be clarity on these issues in order to make better estimates for decarbonisation scenarios. Because most scenarios project that the 2050 fuel mix will comprise of green e-hydrogen, green e-ammonia, and advanced biofuels based on lignocellulosic biomass or algae, it is important that these fuels are part of the 2030 fuel mix, even in small amounts.

In any scenario, renewable electricity plays an important role, which would require upscaling towards 2030. The long lifetime of vessels gives rise to the need that also vessels built during the 2020's and 2030's can undergo retrofitting towards a zero-emission propulsion. The realisation of a renewable and low-carbon fuel fleet requires bunkering infrastructure for which standards and rules should be in place.

These milestones, formulated for 2030 on the basis of the comparative analysis of the scenario studies are summarised in Table 4. They can be understood as accommodating the diverse path towards decarbonisation and will be compared with the Fit for 55 proposals in Chapter 4.

Table 4 - The defined 2030 milestones per subject

Subject	2030 milestones
Share of renewable and low-carbon fuels and energy sources	– 10-20% (including blue NH_3/H_2, excluding LNG)
Types of renewable and low-carbon fuels and energy sources	– Diversified strategy for different fuel types (Refined pyrolysis oil, blue ammonia, LPG, LNG, biomethane, methanol-DAC) – Clarity on technical feasibility and (safety) standards for future marine fuels, especially e-NH_3 – Decision on sustainability criteria for biomass (e.g. large dedicated crop cultivation or merely waste and residues)
Requirements for ships and supply chain caused by renewable and low-carbon fuels and energy sources	– Upscaling of renewable energy supply and import – Increasing number of ships that can sail on e-fuels like hydrogen and ammonia
Requirements for bunkering infrastructure renewable and low-carbon fuels and energy sources	– Safety, international standards and rules on bunkering infrastructure and procedures

3 Incentives provided by the Fit for 55 proposals

3.1 Introduction

In this chapter we analyse which incentives for decarbonisation the Fit for 55 proposals provide by 2030. For each regulated entity (or ship type) we list the obligation and incentives each proposal sets. We take a look at the risk of evasion, quantify this where possible, and shortly describe the effect on the competitive market (asking ourselves if there is a level playing field). A separate list is made for the energy carriers (such as fuels), describing the incentive of each proposal per energy carrier.

3.2 Obligations, incentives and evasion options

The different ship types have been divided in four categories: cargo ships (excl. container ships)[2], container ships, passenger ships[3], other ships[4] and ships <5,000 GT. EU ETS and FuelEU Maritime apply, according to EU MRV Regulation 757/2015, to ships serving the purpose of transporting cargo and/or passengers for commercial purposes between, to and from EU ports (the OPS regulations of FuelEU Maritime only applies to container and passenger ships). The ETD applies to all fuels sold in the EU for shipping on intra-EU voyages. The RED III applies to all fuels sold in the EU to the transport sector, including the maritime sector. The found obligations, incentives and evasion options of the Fit for 55 proposals are listed in Table 5. Table 6 lists the incentives found for the different energy carriers.

[2] Including bulk carrier, oil tanker, container, chemical tanker, general cargo, ro-ro, liquified gas tanker, vehicle, refrigerated bulk and other liquids tanker.

[3] Including ro-pax, cruise, ferry and yacht.

[4] Including offshore, service – other, service – tug, miscellaneous fishing and miscellaneous other and dredging.

Table 5 – Obligations, incentives and evasion options of Fit for 55 proposals by 2030

Regulated entity	EU ETS	FuelEU Maritime	ETD	AFIR	RED
Cargo ships (excl. container ships)	OBLIGATION - Surrender allowances for voyages to and from EU ports. INCENTIVE - Fossil fuels become more expensive. Closes a part of the price gap. EVASION – Unlikely that ships will change routes. COMPETITIVE MARKET - **N**ot affected, because all ships have the same obligations. There may be a distortion around the 5,000 GT threshold especially for the general cargo ships, small chemical tankers and small bulk vessels.	OBLIGATION - Reduce GHG intensity of fuels used on voyages to and from EU ports. INCENTIVE - Reduce amount of fuel oils. Reduce LNG engines with high methane slip. Increase use of LNG, LPG, biofuels. EVASION – Unlikely. COMPETITIVE MARKET **- N**ot affected, because all ships need to meet target. There may be a distortion around the 5,000 GT threshold.	See below: Fuel suppliers. EVASION - **Very likely.** Bunkering outside Europe. Risk that up to 86% of EU MRV fleet CO_2 emissions will be outside of the EU.[5]		See below: Fuel suppliers. EVASION - **Very likely.** Bunkering outside Europe. Risk that up to 86% of CO_2 emissions will be evaded.
Container ships	OBLIGATION - Surrender allowances for voyages to and from EU ports. INCENTIVE - Fossil fuels become more expensive. Closes a part of the price gap. EVASION – **Possible.** Changing order of ports/adding a port. Risk that up to 33% of EU MRV fleet CO_2 emissions will be outside of the EU.[6] COMPETITIVE MARKET - **N**ot affected, because all ships have the same obligations. There may be a distortion around the 5,000 GT threshold.	OBLIGATION - Reduce GHG intensity of fuels used on voyages to and from EU ports. INCENTIVE - Reduce amount of fuel oils. Reduce LNG engines with high methane slip. Increase use of LNG, LPG, biofuels. EVASION – **Possible.** Changing order of ports/adding a port. COMPETITIVE MARKET **- N**ot affected, because all ships need to meet target. There may be a distortion around the 5,000 GT threshold. OBLIGATION – Connect to on-shore power supply if at berth for >2 hours. INCENTIVE – Reduce fuel use when in port. EVASION – Unlikely COMPETITIVE MARKET – Not affected, all ships have to invest in OPS systems.	See below: Fuel suppliers. EVASION - **Very likely.** Bunkering outside Europe. Risk that up to 86% of CO_2 emissions will be evaded.		See below: Fuel suppliers. EVASION - **Very likely.** Bunkering outside Europe. Risk that up to 86% of CO_2 emissions will be evaded.

[5] Analysis of 2020 EU MRV fleet data: 86% of CO_2 emissions belong to ships who partly or completely make extra-EU voyages. If all these ships would bunker all their fuel outside the EU, 86% of CO_2 emissions would be outside of the EU. Note that a certain share of these ships already bunkers outside of the EU.

[6] Analysis of 2020 EU MRV fleet data: 33% of CO_2 emissions belong to container ships. If all container ships would change their order of ports or add a port in order to evade the EU ETS, 33% of CO_2 emissions would be outside of the EU.

Regulated entity	EU ETS	FuelEU Maritime	ETD	AFIR	RED
Passenger ships[7]	OBLIGATION - Surrender allowances for voyages to and from EU ports. INCENTIVE - Fossil fuels become more expensive. Closes a part of the price gap. EVASION – Unlikely. Cruise ships could evade by starting their cruise outside of Europe. COMPETITIVE MARKET - **N**ot affected, because all ships have the same obligations.	OBLIGATION - Reduce GHG intensity of fuels used on voyages to and from EU ports. INCENTIVE - Reduce amount of fuel oils. Reduce LNG engines with high methane slip. Increase use of LNG, LPG, biofuels. EVASION – Unlikely. COMPETITIVE MARKET **- N**ot affected, because all ships need to meet target. OBLIGATION – Connect to on-shore power supply (OPS) if at berth for >2 hours. INCENTIVE – Reduce fuel use when in port. EVASION – Unlikely COMPETITIVE MARKET – Not affected, all ships have to invest in OPS systems.	See below: Fuel suppliers. EVASION - **Very likely.** Bunkering outside Europe. Risk that up to 86% of CO_2 emissions will be evaded.		See below: Fuel suppliers. EVASION - **Very likely.** Bunkering outside Europe. Risk that up to 86% of CO_2 emissions will be evaded.
Other ships	No obligations.	No obligations.	See below: Fuel suppliers. EVASION - **Possible.** Many of these ships operate regionally, making evasion during the job harder.		See below: Fuel suppliers. EVASION - **Possible.** Many of these ships operate regionally, making evasion during the job harder.
Ships <5,000 GT	No obligations.	No obligations.	See below: Fuel suppliers. EVASION – **Possible.** Many of these ships are in short sea shipping, therefore evasion is more difficult.		See below: Fuel suppliers. EVASION – **Possible.** Many of these ships are in short sea shipping, therefore evasion is more difficult.

7 Including ro-ro and ro-pax ships

Regulated entity	**EU ETS**	**FuelEU Maritime**	**ETD**	**AFIR**	**RED**
TEN-T comprehensive ports			COMPETITIVE MARKET - Possibly affected if hub function now go to ports outside of Europe.	OBLIGATION - Supply OPS to container and cruise ships.	COMPETITIVE MARKET – Possibly affected if hub function now go to ports outside of Europe.
TEN-T core ports			COMPETITIVE MARKET - Possibly affected if hub function now go to ports outside of Europe.	OBLIGATION - Supply OPS to container and cruise ships. OBLIGATION – Supply an appropriate number of LNG refuelling points. INCENTIVE – Widespread LNG availability.	COMPETITIVE MARKET – Possibly affected if hub function now go to ports outside of Europe.
Fuel suppliers			OBLIGATION - Levy energy tax. INCENTIVE - Closes price gap partially. EVASION - COMPETITIVE MARKET - Severely disturbed because bunkering in EU becomes more expensive.	OBLIGATION - Technical standards for hydrogen, methanol and ammonia bunkering. INCENTIVE – Facilitate and consolidate market entry of renewable and low-carbon fuels. EVASION – Unlikely. COMPETITIVE MARKET – Not affected.	OBLIGATION - Supply fuels with lower GHG intensity in EU. INCENTIVE – Supply more renewable energy to ships (renewable electricity, biofuels, RCFs (not renewable but do count towards RED target in Article 25) and RFNBOs including hydrogen). EVASION - Bunkering outside Europe. Risk that up to 86% of CO_2 emissions will be evaded. COMPETITIVE MARKET - Severely disturbed, because bunkering in EU becomes more expensive.

Table 6 - Incentives of Fit for 55 proposals for various energy carriers

Energy carrier	EU ETS	FuelEU Maritime	ETD[8]	AFIR	RED
Fuel oils[9]	Cost increase 3.52 €/GJ[10]		Cost increase 0.90 €/GJ		
Low-carbon fossil fuels[11]	Cost increase 2.52 €/GJ[12]	Can be used to meet target	Cost increase 0.60 €/GJ	Supply sufficient LNG refuelling points	Cannot be used to meet target
Biofuels[13]	No cost increase		Cost increase 0.45 €/GJ		
Advanced biofuels[14]	No cost increase		Cost increase 0.15 €/GJ	Technical bunker standards	
RFNBOs[15]	No cost increase		Cost increase 0.15 €/GJ	Technical bunker standards	
OPS		Obligated use for container and passenger ships in port		Obligated supply for container and passenger ships	
Batteries		Can be used to meet target			
Wind assistance		Can be used to meet target			
Energy efficiency measures		Can be used to meet target			

3.3 Use of revenues

EU ETS

The EU ETS generates revenues for the allowances that are auctioned. A share of the allowances is set aside for a Modernisation Fund (2% of the cap) and an Innovation Fund (450 million allowances from 2020 to 2030). To put these numbers in perspective, the Union-wide cap in 2021 was 1,57 billion allowances. Around 57% of the cap is auctioned to Member States. The remaining 43% is given away for free, to i.e. the Modernisation Fund

8 ETD taxes for the period of 2023-2033; cost increase with respect to now, currently there is no tax on shipping fuels

9 Fuel oils include all forms of HFO and MDO/MGO.

10 Based on EF and LCV of VLSFO from ReFuelEU Maritime proposal, EU ETS price of 45 €/tonneCO_2.

11 LNG and LPG.

12 Based on EF and LCV of LNG from ReFuelEU Maritime proposal, EU ETS price of 45 €/tonneCO_2.

13 All biofuels that are not RED Annex IX-A biofuels.

14 RED: Annex IX-A biofuels.

15 RED: Renewable Fuels of Non-Biological Origin.

(2%) and the Innovation Fund (about 2,9%)[16]. Member States can determine the specific use of the revenues generated, but revenues have to be used for climate-related purposes, including the support of low-income households' sustainable renovation.

The Modernization Fund is a dedicated funding programme to support ten lower-income EU Member States in their transition to climate neutrality by helping to modernise their energy systems.

The Innovation Fund may also support breakthrough innovative technologies and infrastructure to decarbonise the maritime sector and for the production of low- and zero-carbon fuels in aviation, rail and road transport. The Commission can determine the details of the rules on the operation of the Innovation Fund by means of delegated acts. Projects in the territory of all Member States are eligible for funding from the Innovation Fund. (CE Delft, 2021)

FuelEU Maritime

In FuelEU Maritime revenues can be generated by the payment of penalties. According to the proposal, these revenues should be used to promote the distribution and use of renewable and low-carbon fuels in the maritime sector and help maritime operators to meet their climate and environmental goals. For this purpose these revenues should be allocated to the Innovation Fund referred to in Article 10a(8) of Directive 2003/87/EC. However, if the Member States comply correctly with all the regulations there should be little penalties.

ETD

The fuel taxes generate revenues for the ETD. There is no specification for these revenues, it is up to Member States to decide on the use.

[16] If the 450 million allowances from 2020 to 2030 are contributed proportionally by 45 million allowances each year.

4 Evaluation of Fit for 55 proposals with regards to 2030 milestones

4.1 Introduction

In this chapter, the incentives of the Fit for 55 package will be evaluated against the background of the milestones defined in Chapter 2. The Fit for 55 legislative proposals to be taken into account are: FuelEU Maritime, EU ETS, RED III, AFIR and the ETD. We only consider the initial proposals that were part of the package, not the amended proposals that at the time of writing are still subject to the legislative procedures.

First, an overview of the milestones and the relevant legislation per milestone will be given. Subsequently, the milestones and relevant documents will be compared and discussed. Finally, the extent to which the Fit for 55 proposals are sufficient to meet the 2030 milestones will be examined.

4.2 Overview of milestones

The milestones identified in Chapter 2 are shown in Table 7 with the relevant legislation in the third column, without prejudice to the fact that the Fit for 55 package is an integrated legislative package. The third column lists the legislation related to the subject of the milestones. It does not mean that the listed legislation aims at achieving the objective of the milestone. The extent to which the relevant legislation meets the milestones will be the subject of this chapter.

Table 7 – Overview of 2030 milestones

Subject	2030 milestones	Relevant EU legislation that touches on the subject, without necessarily providing for the milestone
Share of renewable and low-carbon fuels and energy sources.	10-20% renewable and low-carbon fuels and energy sources (including blue NH_3/H_2, excluding LNG).	FuelEU Maritime, RED III set targets which increase the share of renewable and low-carbon fuels (FuelEU) or renewable fuels (RED III) in the fleet.
Types of renewable and low-carbon fuels and energy sources.	Clarity (technical feasibility and (safety) standards on future marine fuels, especially e-NH_3.	No legislation addresses this subject clearly.
	Diversified strategy for different segments (Refined pyrolysis oil, blue ammonia, LPG, LNG, biomethane, methanol-DAC).	FuelEU Maritime, RED III, EU ETS treat all fuels similarly.
	Decision on suitability of large-scale, dedicated biomass cultivation for renewable fuels in maritime shipping.	FuelEU Maritime and RED III set sustainability criteria for the types of biofuels that can be used.

Subject	2030 milestones	Relevant EU legislation that touches on the subject, without necessarily providing for the milestone
	Upscaling of renewable electricity supply and import.	RED III.
Requirements for ships and supply chain caused by the application of renewable and low-carbon fuels and energy sources.	A supply chain that can serve the possibly large demand for retrofitted vessels and simultaneously decrease these costs.	Not addressed.
Requirements for bunkering infrastructure of renewable and low-carbon fuels and energy sources.	International standards and rules on safety and training for bunkering infrastructure and bunker process.	Partly addressed in AFIR.

4.3 Share of renewable and low-carbon fuels and energy sources

The analysis in Chapter 2 shows that the share of renewable and low-carbon fuels and energy sources needs to increase substantially by 2030 to meet the 2050 decarbonisation goal. According to most studies, an increase to 10-20% by 2030 is on track to decarbonise the shipping sector by 2050. If the use of renewable and low-carbon fuels would follow an S-curve (as shown in Figure 7), an uptake of about 5% in 2030 could be sufficient, provided that the rate of increase accelerates after 2030. The main incentives on the use of renewable and low-carbon fuels of the Fit for 55 package stem from the EU ETS, RED III and FuelEU Maritime. Please note that these proposals are still subject to adaptation during the negotiation process and are not yet established legislation. The analysis described below is based on the first versions of the proposals from July 14th 2021.

4.3.1 Impacts from EU ETS

The Fit for 55 package proposes to include maritime shipping from and to EU ports in the existing EU ETS from 2023. The amount of allowances will therefore be increased by 79 million to take into account the absorption of maritime transport (in 2021, there were in total around 1,6 billion allowances available). Each year, a linear reduction factor of 4.2% would be applied to the EU-wide amount of allowances for a gradual reduction of the emission ceiling and thus of the total emissions covered by the system.

Unlike previously included sectors, the shipping industry would not receive free allowances, but instead would have a three-year phase-in period during which not all emissions have to be covered. According to the impact assessment, free allocation is not needed because the risk of carbon leakage is limited and there are sufficient opportunities to pass on costs. But since carbon saving measures may be cheaper in other sectors of the ETS, the initial impact of including maritime shipping might be limited. Shipping companies will need to surrender allowances for:
— 20% of verified emissions reported in 2023;
— 45% of verified emissions reported in 2024;
— 70% of reported verified emissions in 2025;
— 100% of verified emissions reported in 2026 and every year thereafter.

The impact of the ETS is that the costs of using fossil fuels will increase, because emission allowances have to be surrendered for CO_2 emissions from fossil fuels but not for biofuels and not for fuels that do not contain carbon, such as hydrogen and ammonia (it is not yet clear how synthetic carbon-containing fuels would be treated, especially when produced outside the EU). By increasing the costs of the use of fossil fuels, the ETS would lower the price gap between fossil fuels and renewable and low-carbon fuels. The impact assessment of the proposal for the revision of EU ETS notes that the EU ETS is expected to reinforce the aims of the FuelEU Maritime initiative. Both by supporting energy efficiency improvements, reducing the need to buy fuel and by bridging the price gap between conventional and sustainable fuels. However, the impact assessment notes that the EU ETS would have limited contribution to achieving the goals of the FuelEU Maritime initiative in terms of uptake of renewable and low-carbon fuels by 2030.

The ETS price in the range of 45 to 55 € per tonne of CO_2 would improve the cost competitiveness of renewable and low-carbon fuels compared to fossil fuels but it would not be sufficient to bridge the entire price gap. (CE Delft, 2021) shows that this would require an ETS price of 100–1,000 US$ (85–850 €), depending on the type of fuel and the price development of renewable and low-carbon fuels. Note that these kind of estimates depend on the price of fossil fuels as well. So while the ETS would induce the uptake of efficiency measures that have a cost-effectiveness up to the price of allowances, it would not, by itself, induce a change to renewable and low-carbon fuels.

4.3.2 Impacts from RED III

The Renewable Energy Directive (RED) aims to promote renewable energy in electricity, transport and heating and cooling. A revision of this directive is also part of the Fit for 55 package.[17] The transport targets in the RED II are specifically aimed at road and rail transport, with optional contribution from other transport sectors (like maritime).
The legislative proposal of the RED III is aimed at all transport modes in the territory of the EU, including maritime bunkering and aviation fuels.

In the proposal, Article 25 prescribes a GHG intensity reduction target of 13% by 2030, with a sub-target of 2.2% advanced biofuels (meaning biofuels produced from feedstocks that are included in Annex IX-A of the RED) and 2.6% RFNBOs (Renewable Fuels of Non-Biological Origin; e-fuels produced from renewable electricity, in accordance with the definition in the RED). These targets apply to the total amount of fuels supplied to the transport sector; advanced biofuels and RFNBOs supplied to the maritime and aviation sectors have a multiplier of 1.2. In the implementation phase, Member States can decide on how to divide these targets over transport sectors. The provisions for specific fuels will be discussed in the next section.

(CE Delft, 2021) showed that direct (sectoral) application of the 13% reduction target to marine bunker fuels would lead to an increase of the prices of bunker fuels sold in the EU by 13–80%, depending on the price development of (advanced) biofuels and RFNBOs (see also (Guidehouse, 2022)). This is a larger price increase than the one resulting from the implementation of the ETD, of which (CE Delft, 2022) concluded that it would result in more bunkering outside the EU. Therefore, it is reasonable to assume that the RED will result in a sharp decrease of the amount of bunker fuels supplied in EU ports. Member States may also choose a different application of the reduction target.

[17] In this report we only consider the initial proposals of the Fit for 55 package , not the adjusted proposals which are still in the legislative process at the time of writing.

4.3.3 Impacts from FuelEU Maritime

The FuelEU Maritime proposal introduces a limit on the GHG intensity of energy used on board by ships in navigation on a well-to-wake (WTW) basis (in CO_2-eq./MJ) which will be made more stringent over time. The proposed obligatory reduction in GHG intensity is showed in Table 8 and is related to the reference value. The exact reference value will be established at a later stage of the legislative procedure, but it will correspond to the fleet average greenhouse gas intensity of the energy used on-board by ships in 2020. In 2019 this was 90.98 gCO_2-eq./MJ (CE Delft, 2022).

Table 8 - Reduction in WTW GHG intensity following from FuelEU Maritime proposal (%)

WTW GHG Intensity	2025	2030	2035	2040	2045	2050
Reduction in %	-2%	-6%	-13%	-26%	-59%	-75%
gCO_2-eq./MJ*	89.16	85.52	79.15	67.33	37.3	22.75

* Based on 2019 fuel consumption value of 90.98 gCO_2-eq./MJ.

In this subsection we aim to calculate the share of renewable and low-carbon fuels needed to reach the 2030 GHG intensity limit set by the FuelEU Maritime proposal. Similar calculations have been made in the FuelEU Maritime impacts assessment, however since this impact assessment is based on an older version of the proposal, we want to update its calculations. On the one hand we do this by updating the reference year from 2015 to 2019 (which is closer to 2020, which will eventually be used as the reference year), on the other hand by updating the forecasts for the LNG-fuelled share of the fleet.

FuelEU Maritime impact assessment

The impact assessment of FuelEU Maritime is based on an older version of the proposal, in which the GHG intensity limit is slightly different. For 2030 the WTW GHG intensity reduction is given to be 7%. The base year used in the impact assessment is 2015 for which the reference value was given. We can then calculate the GHG intensity target for 2030, see Table 9.

Table 9 - GHG intensity reference value and 2030 target

	WTW GHG intensity (gCO_2-eq./MJ)
Reference value (2015)	87.0
From 1 January 2030	80.9

Source: (European Commission, 2021).

To achieve this 2030 GHG intensity target the impact assessment calculates that for PO_2 a fuel mix is necessary as displayed in Table 10. Table 11 displays the mix of renewable and low-carbon fuels used.

Table 10 - Fuel mix in 2030 according to the FuelEU Maritime impact assessment (PO_2)

	Share in total fuel (% of weight)
Oil	87.9%
LNG	3.5%
Renewable and low-carbon fuels	8.6%

Table 11 – Mix of renewable and low-carbon fuels in 2030 according to the FuelEU Maritime impact assessment (PO2)

	Share in total fuel (% of weight)
Biofuels	6.2%
Bio-LNG	1.2%
Electricity	1.2%

We can see that the FuelEU Maritime impact assessment estimates a share of 8.6% renewable and low-carbon fuels used in 2030, mostly consisting of biofuels and without any e-fuels. This 8.6% share of renewable and low-carbon fuels is below the 10 to 20% needed by 2030 according to the presented milestones, but is not that far off either. This share would be in line if the uptake of RLF would follow an S-curve, meaning that the uptake will accelerate after 2030. However, since an older reference value of 2015 is used and LNG forecasts project higher shares of LNG used, we think these calculations need an update.

Updating the FuelEU Maritime impact assessment calculations

The FuelEU Maritime impact assessment expects only a slight increase in the use of fossil LNG for shipping, from 3.2% of the fuel mix in 2018 to 3.5% of the fuel mix in 2030. However, DNV projects on the basis of orderbooks that the fossil LNG-fuelled fleet will double between 2020 and 2024.

Next to this, the reference value used in the impact assessment is the fleet average GHG intensity of 2015. The impact assessment notes that the calculation of the reference value will be carried out at a later stage of the legislative procedure, and says it should correspond to the fleet average greenhouse gas intensity of the energy used on-board by ships in 2020. Now we are not yet able to calculate the 2020 value, however in (CE Delft, 2022) the fleet average GHG intensity for 2019 is calculated, this is 90.98 gCO_2-eq./MJ. Using the reduction factor of 6% from the proposal for 2030 we can calculate the GHG intensity target to be 85.52 gCO_2-eq./MJ. This is higher than the target used in the impact assessment of 80.9 gCO_2-eq./MJ. If the 2020 fleet average GHG intensity is, like the 2019 value, also higher than the reference value used in the impact assessment, an even lower share of renewable and low-carbon fuels would be required for meeting the 2030 target.

Taking into account a doubling of the LNG use to 7%, as well as a reference value equal to GHG intensity of the 2019 fuel mix, the required share of renewable fuels would be 1%. In other words, the projected increased use of LNG would delay the start of the transition towards renewable fuels (except for bio-LNG and e-LNG). A delayed start is at odds with the milestones derived from the scenario studies, even when an S-curve is assumed that allows for a slow start. The reason for starting early is that it takes decades to replace the fleet by ships that are able to sail on renewable and low-carbon fuels, build up the bunkering infrastructure and increase the production capacity.

The smaller amount of renewable fuels can probably be met by using relatively low-cost waste-based biofuels. More advanced fuels like e-ammonia and biomethanol, which are part of the fuel mix of 2050 are likely to be more expensive and therefore unlikely to be used for compliance in 2030 (see Figure 2).

On-shore power supply

On-shore power supply (OPS) is regarded as an important step in decarbonising maritime shipping and FuelEU Maritime obliges container and passenger ships (except zero-emission ships) to use OPS, while the infrastructure will be stimulated by the AFIR.

The use of OPS does not only significantly reduce air pollutants, but also leads to a decrease of GHG emissions (if the grid mix emission intensity is below 218 gCO_2/MJ, with MDO as reference, (B. Stolz, 2021)). FuelEU prescribes a emission factor of 72 gCO_2-eq./MJ in 2030.

Passenger ships spend on average half a day per week at berth and container ships around one day per week. Furthermore, passenger ships consume a considerable amount of energy at berth. While the exact emission intensity depends on the ship, fuel and sailing schedule, and propulsion accounts for most of the energy consumption, the obligation of OPS makes a modest contribution to the reduction of GHG intensity set for the reporting period of one calendar year.

Wind and solar

In case wind and solar power is installed on board, a reward is given in the determination of energy intensity. As with OPS, wind and solar could contribute to a reduction of the annual GHG intensity. CE Delft calculated that different wind propulsion technologies can lead to fuel savings of 1% to 18%, depending on the type of ship and circumstances (CE Delft, 2016).

4.3.4 Conclusions

It is unlikely that FuelEU Maritime will result in a significant increase in the use of non-fossil low- and zero-GHG fuels before 2030 because its targets can be achieved through business-as-usual increases in the share of LNG in the fleet and because the costs of using non-fossil fuels are too high. Insofar as FuelEU Maritime requires the use of renewable fuels, they are most likely to be the lowest-cost options like liquid biofuels. Inclusion of maritime transport in the EU ETS will reduce the cost difference between the use of fossil fuels on the one hand and biofuels and other renewable fuels on the other. However, the price gap will not be closed unless the allowance prices are much higher than their current value, fossil fuel prices are high and prices of renewables low. Furthermore, carbon saving measures are most likely cheaper in other ETS sectors, and therefore the effect on shipping might be limited. Moreover, uncertainty about the treatment of carbon-containing RFNBOs (in GHG emission calculations and their contribution to GHG intensity reduction targets) may hold back investments in the production of these fuels. The RED is also unlikely to result in an increased supply (and use) of low- and zero-GHG fuels because it will increase the price of bunker fuels sold in the EU so much that ships will choose to bunker outside the EU, where the RED does not apply.

4.4 Types of renewable and low-carbon fuels and energy sources

As described in Chapter 2, different configurations of renewable and low-carbon fuels are possible to achieve a decarbonised shipping sector in 2050. In the realisation of these different scenarios, 2030 represents different milestones. The diversity of solutions adds to the complexity of assessing the effectiveness of the Fit for 55 proposals.

The analysis of the Fit for 55 package regarding the types of renewable and low-carbon fuels involves four points:
— technological differentiation;
— technological development;
— costs and carbon pricing;
— role of biomass.

4.4.1 Technological differentiation

The decarbonisation scenarios differ from each other and all foresee a diversified fuel mix in 2050. One could however perceive in all scenarios an important role for e-fuels (fuels derived from hydrogen produced through electrolysis). As described in Chapter 2, the potentially most cost-efficient zero-GHG fuels in the long term are e-fuels. Given the expected diversified fuel mix and the potential of e-fuels, it is crucial that legislation does not exclude an option, but also pays sufficient attention to building a hydrogen supply chain.

Technology neutrality is essentially a guiding principle of EU legislation. This principle is also reiterated in the Green Deal.

The GHG intensity reduction targets in FuelEU Maritime and the RED are also technology neutral, although the RED has sub-targets for Annex IX-A biofuels and RFNBOs (and limits for Annex IX-B biofuels and biofuels produced from feed and feed crops). Moreover, the GHG emission factor of food- and feed crop biofuels are equal to fossil fuels in FuelEU Maritime. For different reasons, neither the RED nor FuelEU will sufficiently stimulate the uptake of renewable and low-carbon fuels until 2030, as shown in Sections 4.3.2 and 4.3.3.

Article 18 of FuelEU Maritime states the possibility of pooling the compliance obligations of individual ships. It should be verified by the same verifier, but different companies may participate in the pool. The option of pooling offers the possibility to introduce small-scale or pilot zero-emission ships, which can balance the rest of the fleet in the pool that continues to sail on fossil fuels. This therefore could accommodate a first mover-principle. Although pooling by itself does not create a sufficient incentive for the use of renewable and low-carbon fuels, it might do so in combination with the EU ETS if the prices of fossil and renewable and low-carbon fuels make it attractive, as has been demonstrated in case of pooling for a similar but different type of measure (the IMO requirement on carbon intensity of ships) (CE Delft, 2021).

The calculation rules according to which the GHG intensity (CO_2, CH_4, N_2O) of a ship needs to be calculated are stipulated in FuelEU Maritime, with partial referral to the RED II. This WTW GHG intensity subsequentially needs to meet the reduction target, as described in Section 3.2. The exact reference value will be established later in the legislative procedure, but might be related to the average of most common fuels.

In Table 12 the emission factors as proposed in FuelEU Maritime are given, calculated as gCO_2-eq./MJ. The emission intensity will be based on a WTW basis.

Table 12 – Emission factors for different maritime fuels

Fuel type (engine type)	WTT EF (gCO_2-eq./MJ)	TTW EF (gCO_2-eq./MJ)	WTW EF (gCO_2-eq./MJ)
Fossil fuels			
HFO	13.5	78.1	91.6
VLSFO	13.2	79.40	92.6
MDO/MGO (ISO 8217 grades DMX to DMB)	14.4	76.23	90.63
LNG (Otto dual fuel medium speed)	18.5	73.89	92.39
LNG (Lean burn spark ignition)	18.5	69.56	88.06
LNG (Otto dual fuel slow speed)	18.5	66.13	84.63
LNG (Diesel dual fuel slow speed)	18.5	57.81	76.31
LPG	7.8	65.27	73.02
H_2 (natural gas)	132	0	132
NH_3 (natural gas)	121	0	121
Methanol (natural gas)	31.3	71.57	102.87
Biofuels			
Biomethane from biowaste (Close digestate, off-gas combustion) (Otto dual fuel medium speed)	14.0*	18.3***	32.3
Biomethane from biowaste (Close digestate, off-gas combustion) (Diesel dual fuel slow speed)	14.0*	1.7***	15.7
Biomethane from wet manure (Open digestate, off-gas combustion) (Otto dual fuel medium speed)	1.0*	18.3***	19.3
Biomethane from wet manure (Open digestate, off-gas combustion) (Diesel dual fuel slow speed)	1.0*	1.7***	2.7
FAME from waste cooking oil	14.9*	1.3***	16.2
Biomethanol from farmed wood	16.2*	2.5***	18.7
Biomethanol from black liquor	10.4*	2.5***	12.9
E-fuels			
E-methane (renewable electricity from Europe/Africa) (Otto dual fuel medium speed)	0.0**	18.3***	18.3
E-methane (renewable electricity from Europe/Africa) (Diesel dual fuel slow speed)	0.0**	1.7***	1.7
E-methanol	0.0**	2.5***	2.5
Electricity (OPS)	106.3 (EU mix 2020) - 72 (EU mix 2030	0	106-72

* Based on the Renewable Energy Directive 2018/2001.
** Assumed to be zero (fully renewable electricity).
*** For all renewable fuels, TTW CO_2 emissions are assumed to be zero.

From Table 12 it becomes clear that of the fossil fuels, three types of LNG (and LPG) will initially have a emission intensity under the reference value of 90.98 gCO_2-eq./MJ. Ammonia, hydrogen and methanol produced from natural gas have emission intensities far surpassing the reference value, and these fuels are therefore (from this perspective) not an option to be used for encouragement of the green NH_3, H_2, or MeOH supply chains and stimulate incremental growth through availability of ships.

The most significant emission reduction for a standard internal combustion engine (ICE) can be reached by FAME from waste cooking oil (UCO). According to the fuel standard ISO 8217 up to 7% v/v FAME is allowed to be blended with marine gasoil and up to 0,1 v/v% FAME is allowed in residual fuels (HFO), but this is not a legally established standard so companies can deviate from this if agreed. Higher blends are available commercially and they are used by ships with permission from the engine designer.

Biofuels and e-fuels each offer varieties to meet the reduction targets. It should be noted that in the case of fossil fuels, default values as given in FuelEU should be used.
For other fuels, the specific feedstock and fuel production pathways are relevant to determine the definitive GHG emission intensity, the methodology of which specified in the RED II. It is also noteworthy that OPS does not offer very low emission intensities even in 2030, and the obligation to use OPS in 2030 will not make a significant difference in the yearly emission intensity of a ship.

Banking of compliance credits

Article 17 of FuelEU Maritime offers the possibility for ships to bank surplus compliance credits. The length of validity of the credits is not specified but Transport & Environment states that there is no time limit to banking (Transport & Environment, 2022). This implies that a surplus can be generated during the years that the emission intensity of a ship is lower than the threshold, and that this surplus can be added during the years that the emission intensity target becomes more stringent. Banking is together with pooling an important mechanism to incentivise frontrunners and at the same time it takes into account the market conditions and operational obligations of companies. Since the first years of FuelEU the emission intensity target is above several fossil fuels, like LNG, ships on these fuels might accumulate credits for later years, see Table 13.

Table 13 - Year until which LNG/LPG fuelled ships can sail on banked credits with reference value 90,98 CO_2-eq./MJ

	Emission factor (CO_2 eq./MJ, WTW)	Credit ending year
LNG Otto dual fuel medium speed	92.4	N/A
LNG Otto dual fuel slow speed	84.6	2039
LNG Diesel dual fuel slow speed	76.3	2047
LNG lean burn spark ignition	88.0	2033
LPG	73.6	2048

RED III

It was shown in Section 4.3.2 that the RED has a transport target for the whole sector. The RED III also has sub-targets for specific fuels in transport. These sub-targets and the differences of the RED III with the RED II are shown in Table 14.

Table 14 – Differences between transport target of RED II and RED III

	2018 RED II	2021 proposed RED II revision
Renewable energy in transport	14% energy target (out of road and rail fuels)	13% GHG intensity reduction target (out of all energy supplied to transport)
Advanced biofuels (Annex IXa)	3.5% (out of road and rail fuels. with multiplier, 1% in 2025)	2.2% (out of all energy supplied to transport. no multiplier. 0.5% in 2025)
Renewable fuels of non-biological origin (RFNBOs)	No target	2.6% (out of all energy supplied to transport)
Waste oils (Annex IXb)	1.7% cap (out of all energy supplied to transport, but cap can be modified upon Commission approval)	1.7% cap (out of all energy supplied to transport)
Food- and feed-based biofuels	Cap at whichever is lower: 7% or 2020 consumption in each Member State + 1% (out of road and rail fuels)	Cap at whatever is lower: 7% or 2020 consumption in each Member State + 1% (out of all transport energy consumption)
Multipliers	– 2x for advanced biofuels and waste oils – 4x for renewable electricity in vehicles – 1.2x for aviation and maritime fuels. except food- and feed-based biofuels	– 1.2x for advanced biofuels and RFNBOs in aviation and maritime

The RFNBO sub-target of at least 2.6% of energy supplied to the transport sector by 2030 would imply a RFNBO consumption of at least 29 PJ/year in 2030 (CE Delft, 2022), assuming that the bunker fuel market is not hampered by the price increase caused by the RED. As argued in Section 4.3.2, this is an implausible assumption.

The target can be fulfilled with RFNBOs that are used as intermediate for the production of conventional fuels (in refineries) and by RFNBOs directly used in transport. Although RFNBOs supplied to the aviation and maritime modes shall be considered 1.2 times their energy content, it is the expectation that the largest share of the target in the Netherlands will be met by green hydrogen as intermediate for the production of conventional fuels (CE Delft, 2022). However, the 2.6% RFNBO target in combination with the 1.2 multiplier does represent a modest encouragement for RFNBOs in maritime shipping.

The sub-target for advanced biofuels will most likely not encourage (further) deployment of this fuel type in shipping in the Netherlands because in the Dutch system there has already been made progress in developing the consumption of this fuel (NEa, 2021).

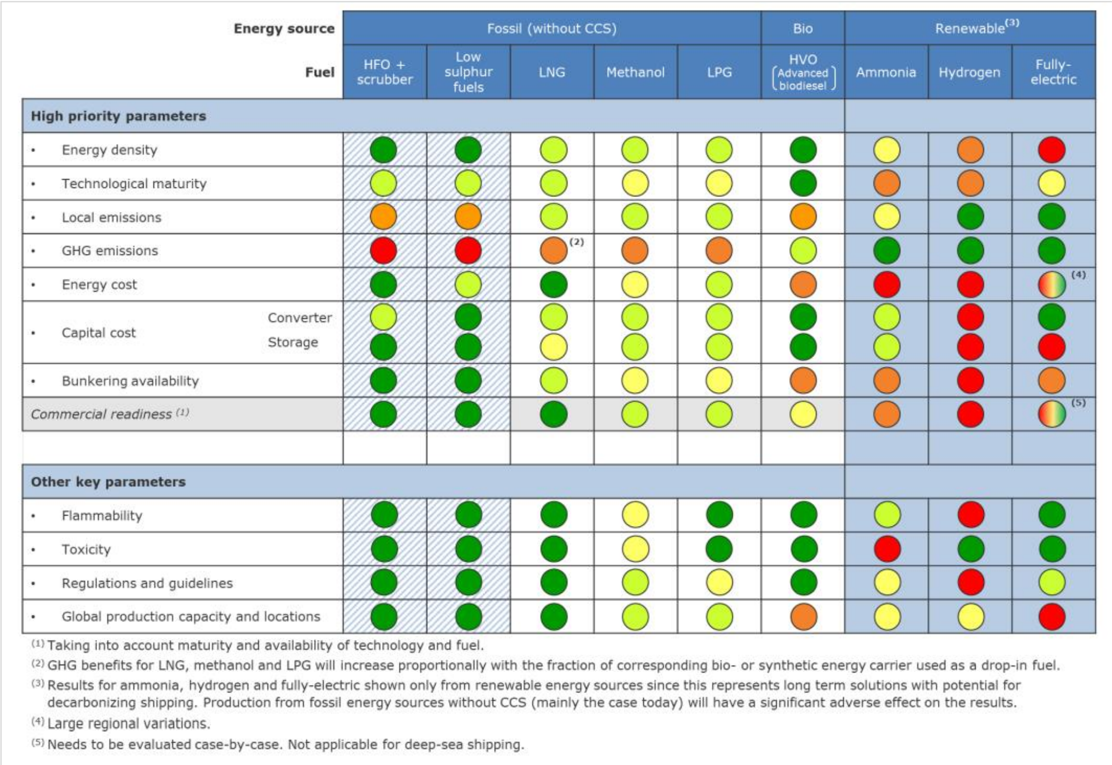
The RED III proposal also contains a 1.7% hard cap for Annex IXb biofuels (incl. UCO) in 2030. This will remarkably restrict the possibilities of UCO derived fuels (like FAME), since the Netherlands now consumes around 2.5% UCO derived biofuels (CE Delft, 2020). A VLSFO/ FAME fuel mix in proportion of 90.7 to 9.3% would be needed to meet the 2030 target of 6% reduction (CE Delft, 2022).

A downside of the RED (both II and III) from the perspective of RFNBO consumption in transport is that its targets are only for 2030, without a view on long-term consumption targets.

4.4.2 Technological development and role of e-NH_3

The main alternative options require technological development somewhere in the supply chain. A comparison for different parameters and fuels is shown in Figure 10.

Figure 10 - Development stage of different parameters for different fuels (green mature, red immature)



Source: (DNV GL, 2019).

The figure makes clear that technological development for renewable fuels is needed, addressing challenges related to flammability, toxicity and overall technological maturity. It is therefore essential that policy shapes the right conditions in which this can take place. FuelEU strives to spark demand for renewable and low-carbon fuels but also emphasises that the necessary technology development and deployment has to happen by 2030.

A main issue deciding the future of carbon-neutral shipping scenarios is the role green ammonia will play. E-ammonia is considered a good option for decarbonisation, by being projected as the cheapest e-fuel in the long term and having the option of being initially made from natural gas with CCS. However, ammonia suffers from constraints regarding its applicability onboard and in storage. In addition to crucial technological development, international standards need to be developed in order to facilitate a possible uptake and progress of the ammonia fuel chain. Also, key alliances across the technological supply chain may be needed.

Although methanol has been accepted in 2020 by the IMO as safe ship fuel, (safety) standards will still need to be developed for infrastructure facilities (TNO, 2021). This is also the case for hydrogen and ammonia. Contrary to ammonia, methanol doesn't need much engine modifications but the production of renewable methanol requires CO_2-free carbon as feedstock. If the required DAC or Bioenergy with CCS technology enhances its competitiveness in the next decade, methanol might overtake ammonia as preferred renewable option (IRENA, 2021).

The FuelEU Maritime proposal addresses the need for research and innovation. In this framework the Commission continues to co-programme the Zero Emissions Waterborne Transport partnership proposed by the Waterborne Technology Platform under Horizon Europe. The proposal also mentions that the guidelines on State aid for environmental protection and energy will be revised, in order to allow sufficient funding of the sector's green transformation (including for deployment of on-shore charging infrastructure), while avoiding distortion of competition.

Penalties shall be allocated to support common projects aimed at the rapid deployment of renewable and low-carbon fuels in the maritime sector.

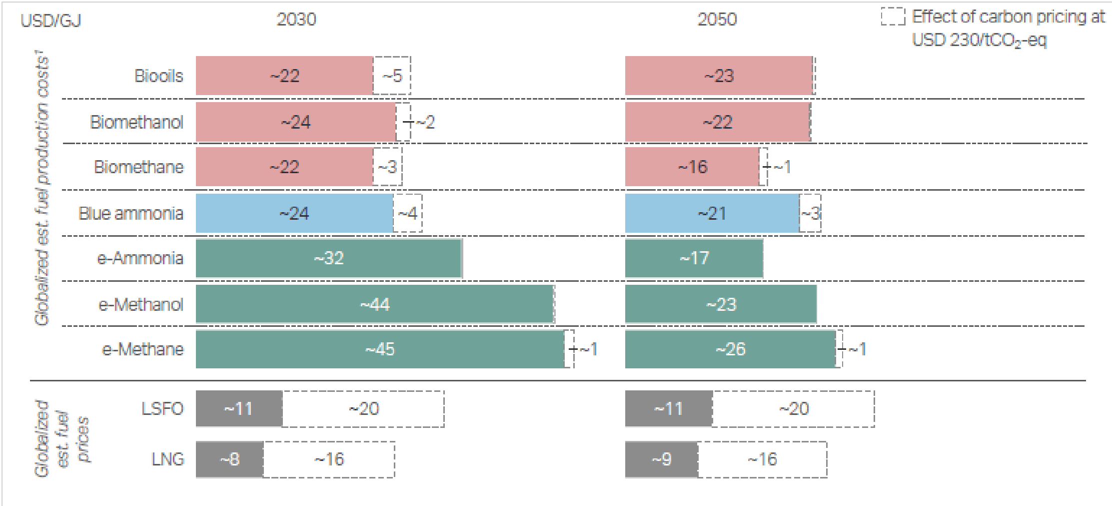
It cannot be predicted if the efforts of FuelEU Maritime will be sufficient to have the technology developed to a satisfactory level. This is because in the R&D field many more stakeholders are involved. One could however argue that specific attention dedicated to developing the e-NH_3 supply chain and vessel construction, might be a requirement.

4.4.3 Costs and carbon pricing

All scenarios foresee a durable and significant difference in cost price between fossil and carbon neutral options, well until and beyond 2050, see Figure 11. Therefore, all scenarios consider the introduction of a carbon price as an essential instrument.

Whereas FuelEU Maritime aims to spur demand, the inclusion of maritime into the EU ETS should ensure cost-effective emissions reduction and provide uniform price signals, influencing operators, investors and consumers. Although it is acknowledged in FuelEU that competitiveness of renewable and low-carbon fuels will remain a challenge on the short to medium term. Figure 11 shows that a carbon price of $ 230/tCO_2 (which is significantly higher than projected levels of the EU ETS but within the range required for decarbonisation as mentioned in Section 4.3.1) will have an insufficient effect on making e-fuels competitive in 2030. As can be seen on the right side of the figure, in 2050 cost-competitiveness of e-fuels will have improved.

Figure 11 - Effect of carbon pricing on different fuels



Source: (Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021).

Income from emissions trading will finance the Innovation Fund, which will serve to support investments in sustainable alternative maritime fuels as well as zero-emission propulsion technologies like wind technologies. The Innovation Fund supports all projects that contribute to decarbonisation of Europe. It does not dedicate an amount for maritime shipping. It has included CCU/CCS projects, but it is unlikely that the innovation fund will support further development of low-carbon maritime fuels.

The ETS puts a price on carbon and in principle not on other GHG emissions. Moreover, it considers only TTW emissions. CO_2 emissions cover currently 98% of all GHG shipping emissions, but methane emissions from ships have increased by more than 150% from 2012 to 2018, largely to the increase of LNG ships (European Commission, 2021). The ETS revision proposal acknowledges this ambiguity and hence states that progressively all GHG should be covered. The European MRV Regulation is currently limited to CO_2 emissions, therefore the monitoring approaches and emission factors for other GHG will need to be agreed upon first.

Costs of non-compliance with FuelEU Maritime

When a ship has a compliance deficit, the company shall pay a penalty, calculated by the verifier. For every non-compliant port call (without using OPS/zero emission), a company has to pay a penalty. The amount of the penalty will be multiplied by 250 € by MW of power installed on-board and by the number of completed hours spent at berth. Once the penalties have been paid, a FuelEU certificate of compliance will be issued. The penalty for not handing over enough compliance balance credits is calculated according to the formula:

Table 15 – Formula to calculate the penalty for not complying

Penalty	$\frac{\lvert(\boldsymbol{Compliancebalance})\rvert}{\boldsymbol{GHGIE_{actual}} \times \mathbf{41000}} \times \mathbf{2400}$
Compliance balance	$(GHGIE_{target}$ - $GHGIE_{actual})$ x $[\sum_{i}^{nfuel} M_i \times LCV_i + \sum_{i}^{l} E_i]$
Example: compliance balance of VLSFO in 2030, per MJ	Compliance balance = 85.52 - 92.60 = - 7.08 gCO_2-eq./MJ
Example: penalty for using VLSFO in 2030, per MJ	$\frac{7.08}{92.60 \times 41000} \times 2400 = 0.004476\ EUR/MJ$
Example: penalty for using VLSFO in 2030, per tonne of VLSFO	0.004476 EUR/MJ * 41,000 MJ/tonne = EUR 183 / tonne

ETD

The revision of the ETD – which sets minimum tax tariffs - reflects the aim to encourage decarbonisation further by taxes. All fossil fuels will be taxed (at minimum) at the highest tariff, from 2033 together with sustainable food and feed crop biofuels. Sustainable biofuels will have a lower tariff and RFNBOs, advanced sustainable biofuels and electricity will be on the lowest tariff, which is six times less than fossil fuels (Europese Commissie, 2021).

The proportion of the proposed tax tariffs is in line with the 2030 milestones. However, the contribution from tax differentiation is too limited to bridge the price gap between fossil and renewable fuels in order to realise the 2030 milestones. Moreover, it entails the risk of carbon leakage through increased bunkering outside the EU.

4.4.4 Role of biomass

The scenarios showed that the role of biomass is a defining factor in the market dynamics of moving towards zero-GHG emissions. Three aspects play a role: costs, availability and sustainability. Costs and availability are mainly decided by the possibility to have large-scale dedicated biomass feedstocks available for the production of maritime fuels, in addition to wastes and residues included in the Annex IX of the RED (food and feed biomass is discouraged in FuelEU Maritime and also limited in the RED). Whereas some varieties of zero-GHG scenarios (e.g. Technical University of Denmark and Lloyd’s & UMAS) make assumptions on the possibility, the Fit for 55 package does not seem to move into the direction of large scale, dedicated biomass cultivation for maritime shipping. Although the 2030 Climate Target Plan states in connection with the need for a growing carbon sink that ‘a shift towards growing woody biomass on cropland in a sustainable manner, including as a feedstock for advanced biogas and biofuels, could alleviate the situation (European Commission, 2020).’

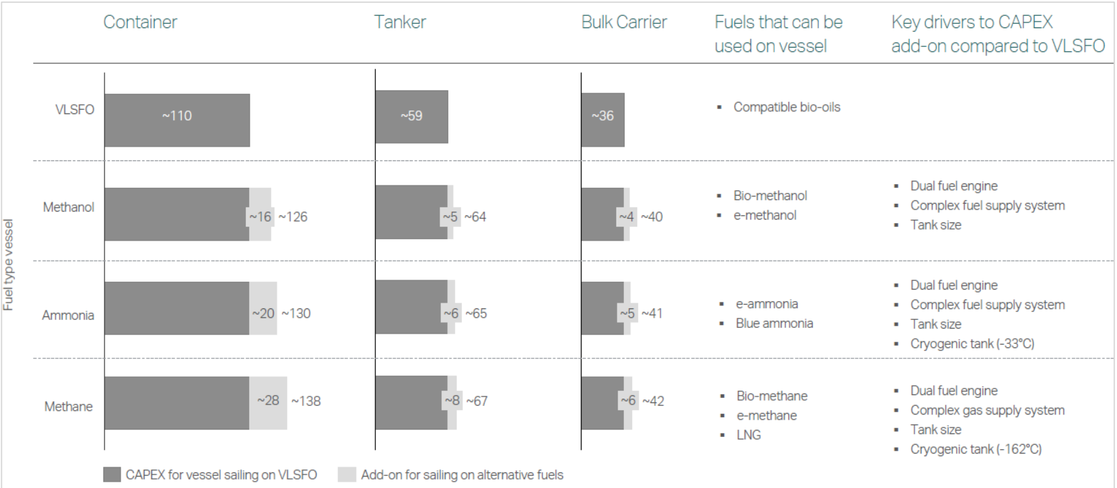
Sustainability is guarded and reinforced by LULUCF and the RED III, whereas FuelEU Maritime states that this approach needs to be stricter for the maritime sector. FuelEU Maritime therefore aims to avoid creating a large demand for food and feed crops-based biofuels, by giving it an equal emission factor to fossil fuels. The availability from Annex IX feedstock (waste and residues) is too limited for the huge quantities possibly required, and no dedicated biomass production for (maritime) fuels is foreseen.

The strict sustainability framework and the lack of a clear strategy to produce biomass feedstock for transport fuels on a large scale indicate that currently no major contribution of biomass to alternative maritime fuels should be expected. In the current situation biomass cannot account for more than single digits in share of alternative fuels in maritime shipping.

4.4.5 Upscaling of RES and import

Fuel costs are defining for TCO of vessels. It is therefore essential that cost for renewable and low-carbon fuels reduce in order to make alternative vessels more attractive for shipowners. Figure 12 shows how different fuelled vessel compare on TCO level. The right column shows the key drivers that decide the additional costs (compared to VLSFO ships). These issues will need to be addressed.

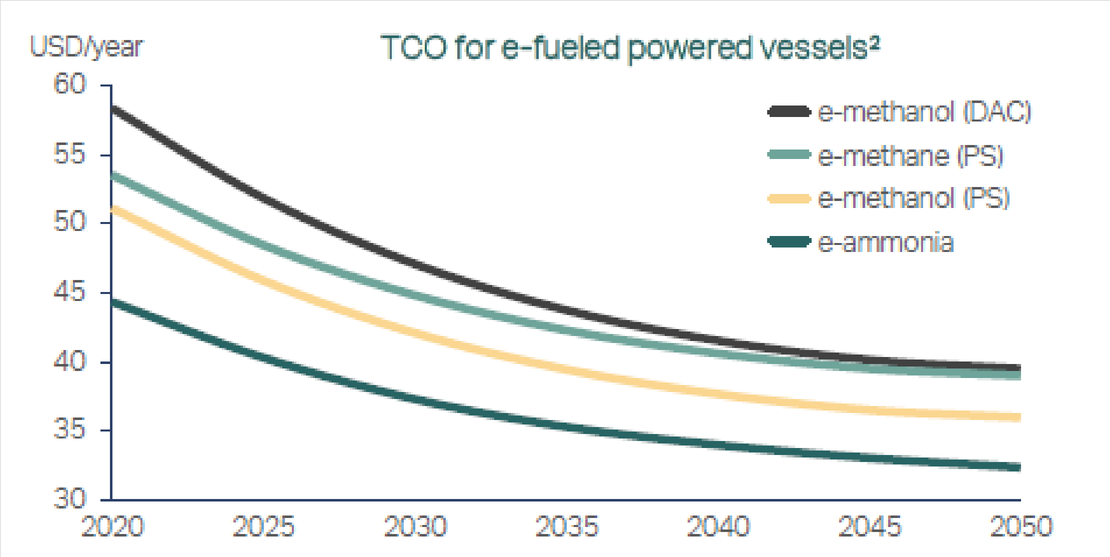
Figure 12 - CAPEX compared of different fuel type, medium-sized vessels in 2030 in M USD



Source: (Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021).

With a view towards 2050, the TCOs of different vessels on e-fuels are shown in Figure 13. While e-ammonia is currently not a cost-competitive fuel, in the future this might be the most competitive.

Figure 13 - TCO of different e-fuelled powered vessels (typical container (8,000 TEU) with 25 year lifetime



Source: (Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021).

A long-term view on vessel development should take this into account. The technical requirements of vessels for e-ammonia are not specifically addressed in FuelEU Maritime.

While the exact form of fuel consumption on board is often uncertain, all studies acknowledge the future role of e-fuels, with hydrogen as basis. Therefore, all scenarios point out that ramping up renewable electricity and reducing its costs is essential. This development would simultaneously lead to reduction of the grid mix intensity.

If the Netherlands wants to sustain its importance as bunkering location, it will also be inevitable that large scale imports of renewable energy takes place, probably in the form of ammonia and originating in windy and sunny regions. Cautiously selecting those regions with a forward-looking strategy, encompassing climatological and political considerations should be a part of this process.

The most prominent legislative proposal in advancing renewable electricity is the RED III. The RED III proposal states that member states should ensure that deployment of renewable electricity increases at adequate pace to meet demand. Member states should also establish a framework that includes market-compatible mechanisms to tackle remaining barriers within the electricity system.
Although the Offshore Renewable Energy Strategy has objectives of 300 GW in 2050, the RED III targets are limited to 2030 (European Commission, 2021). Projections foresee a renewable electricity production of around 1,950 TWh/yr. by 2030 in Europe (Agora Energiewende, 2019). If5 % of maritime energy consumption in Europe is filled in with e-NH_3, this would require a share of around 3% of all renewable electricity generated in Europe, see Table 16. If e-NH_3 would cover 30% of bunkering, it would require between 17.5-19.6% of all projected renewable electricity. It is noteworthy that almost half of maritime bunkering in Europe takes currently place in the Netherlands.

Table 16 – Example of renewable electricity requirements for 5% e-NH_3

	2030
Renewable electricity generation (TWh)	1,950
Energy consumption maritime bunkering (million TJ, 2017)	1.9
Required renewable electricity production for 5% e-NH_3 (TWh)	57-65 (2.9-3.3%)

Based on: 40-45 GJ/tNH_3; 0.0186 MJ/g (J. Allen, 2021; EEA, 2021; Europese Commissie, 2021).

Accommodating the demand for renewable electricity from the maritime shipping sector might require dedicated targets, currently not included.

Calculating renewables in the sector where they are consumed allows for imports of RFNBOs, but there is no further elaboration or European streamlining of RFNBO imports, which will be essential on the track towards 2050. The multiplier of 1.2 for Annex IXa feedstock and RFNBOs supplied to aviation and maritime modes might not be sufficient in stimulating this pathway as required by the 2030 milestones. Since the 2030 milestones may demand a much sharper increase and the multiplier might not be able to bridge the whole gap in cost price difference.

4.4.6 Conclusions

The architecture of the proposals under the Fit for 55 package provides for a technology-neutral treatment of fuels and technologies, although there remains a difference between the WTW approach of FuelEU Maritime and the RED on the one hand and the (currently) TTW, CO_2-only approach of the EU ETS. Another aspect is that a lock-in in unscalable biofuels is prevented both in the RED and in FuelEU Maritime, but at the same time a prospect for dedicated biomass cultivation is absent.

The technology neutrality is positive in principle, certainly in view of the many possible fuels for the future. However, by extending the neutrality to include fossil fuels (with a lower GHG intensity than the reference value), FuelEU incentivises the use of some fossil fuels, which delays the transition towards renewables.

The package does not create sufficient incentives for the development of fuels and technologies before 2030 which are considered to be essential for the decarbonisation of the shipping sector (especially e-fuels). The main reasons are that the TCO of e-fuels is much higher and that the proposed targets can be met by continuing to rely on fossil fuels in combination with pooling or banking. Until 2030, the least-cost option for compliance is using more LNG, not shifting to renewable fuels. On the longer term (after 2030), the Fit for 55 package can stimulate a higher use of renewable fuels.

4.5 Requirements for ships and supply chain due to renewable and low-carbon fuels and energy sources

The scenarios made clear that a diversified renewable fuel fleet is the most likely outcome in 2050 in the case zero-carbon maritime shipping is achieved.

To support this scenario, the supply chain for both fuels and ships needs to be developed. This regards the safety aspects and reaching full technological readiness as described in the previous paragraph. But one could also think of developing a retrofit supply chain, and the availability of successful pilot models.

4.5.1 Retrofit supply chain

An effective retrofit strategy might help shipowners in avoiding risks of stranded assets and simultaneously offer an important opportunity to adapt vessels to a developing renewable fuel supply chain. A strategy should address technical experience, physical capacity and the regulatory environment. Developing the retrofit supply chain also encompasses the pathway towards a fleet with diversified and dual fuel engines.

The scenarios indicated that a diversified strategy for use of renewable and low-carbon fuels in different market segments is a way to accommodate options easier to implement. Selected ship markets (ro-pax, cruise and container for example, due to consumer pressure) and geographical regions might be more suitable for initial adoption of renewable and low-carbon fuels. This strategy might be worked out and globally advanced by 2030.

FuelEU Maritime applies to ships above 5,000 gross tonnage and the OPS obligation is for passenger ships and containers. No further strategy for diversification is given, although flexibility might be applied by shipowners via pooling. That would entail decision making by shipowners based on own insight.

To avoid that the growth of LNG vessels, possibly caused by the Fit for 55 package, leads to a fleet with an unchangeable large share of LNG vessels, it is crucial that retrofitting is a cost-effective and available pathway. Retrofitting might furthermore avoid a fixed lock-in of biofuels.

4.5.2 Successful pilots before 2030

To accommodate the diversified uptake of RLF in maritime shipping, it would be useful if successful pilots of zero-emission ships have entered the fleet by 2030. This would give a signal to potential investors and policy makers about the certainty of zero-emission ships. Furthermore, it would provide a basis for further technological development of ships and incentivise the rest of the supply chain, from (bunkering) infrastructure to maintenance. While the element of pilots is not part of the Fit for 55 package in terms of policy targets, the innovation fund could play a role.

4.6 Requirements for bunkering infrastructure of renewable and low-carbon fuels and energy sources, safety, international standards and rules

It is essential that there is international agreement on bunkering infrastructure that will facilitate its smooth, safe and uniform development. The proposal for the Alternative Fuels Infrastructure (AFIR) affects the bunkering infrastructure for renewable and low-carbon fuels. It entails the following:

- A core network of refuelling points for LNG at maritime ports should be available by 2025. Refuelling points for LNG include LNG terminals, tanks, mobile containers, bunker vessels and barges:
  - Member States shall ensure that an appropriate number of refuelling points for LNG are put in place at TEN-T core maritime ports, to enable seagoing ships to circulate throughout the TEN-T core network by 1 January 2025. Member States shall cooperate with neighbouring Member States where necessary to ensure adequate coverage of the TEN-T core network. Member States shall designate in their national policy frameworks TEN-T core maritime ports that shall provide access to the refuelling points for LNG, also taking into consideration actual market needs and developments.

- By 1 January 2024 each Member State shall prepare and send to the Commission a draft national policy framework for the development of the market as regards alternative fuels in the transport sector and the deployment of relevant infrastructure. That national policy framework shall contain: a deployment plan for alternative fuels infrastructure in maritime ports, in particular for hydrogen, ammonia and electricity for seagoing vessels.

- New standards for maritime transport and inland navigation to facilitate and consolidate the entry into the market of alternative fuels, in relation to electricity supply and hydrogen, methanol and ammonia bunkering, but also standards for communication exchange between vessels and infrastructure.

Ensuring widespread availability of LNG at maritime ports incentivises the use of LNG. The collection of national policy frameworks from member states helps to create an overview of deployment plans for hydrogen and ammonia infrastructure. It does however not entail methanol, which has the potential to be an important alternative fuel for decarbonisation. The requirement of technical standards for alternative fuel bunkering incentivise the market entry of alternative fuels, especially for hydrogen, methanol and ammonia. Not having common technical standards risk that recharging and refuelling services cannot develop in a competitive manner and instead proprietary solutions will develop. Therefore standardisation removes one important barrier for the uptake of important renewable and low-carbon fuels. The AFIR however does not remove the barrier of widespread availability for these alternative fuels.

4.7 Positive aspects of the Fit for 55 package

Positive aspects of the proposals under the Fit for 55 package relate to its architecture. In principle, it is positive that the proposals in the package address both supply and demand of marine fuels, and actively discourages fossil fuels. The EU ETS and FuelEU Maritime target the GHG emissions of vessels, while the ETD and RED target the fuel suppliers. In this way there are incentives for on the one hand the demand of renewable and low-carbon fuels, and on the other hand incentives to invest in the supply side of these fuels. However, the way in which this is done is not particularly suitable for the shipping sector where ships can easily choose a bunkering location outside the EU.

What we also see as positive is the long-term goals that FuelEU Maritime and the EU ETS set. These long-term goals provide certainty to the market. Especially the GHG intensity limit of the FuelEU Maritime proposal provides certainty and insight to the market in the pace and types of renewable and low-carbon fuels that will be demanded up to 2050.

4.8 Conclusion

In this chapter, the contribution of the Fit for 55 package to the milestones as defined in Chapter 2 was assessed. An overview of this assessment is given in Table 17. Overall, it can be concluded that the package is insufficient to achieve the 2030 milestones related to the scenario studies for a zero-carbon maritime shipping sector.

Table 17 – Evaluation of the Fit for 55 package and 2030 milestones

	2030 milestones In scenario studies	Relevant EU legislation that touches on the subject, without necessarily providing for the milestone	Effect until 2030	Assessment
Share of renewable and low-carbon fuels and energy sources	10-20% renewable and low-carbon fuels and energy sources	FuelEU Maritime, RED III, EU ETS	1%	Insufficient
	Clarity on ammonia and hydrogen	No legislation addresses this subject clearly	Not sufficiently addressed, FuelEU obligations can probably be met without using e-fuels or scalable biofuels	Insufficient
Types of renewable and low-carbon fuels and energy sources	Diversified strategy for different segments (Refined pyrolysis oil, blue ammonia, LPG, LNG, biomethane, methanol-DAC)	FuelEU Maritime, RED III, EU ETS	Especially LNG	Partly sufficient
	Decision on role of biomass	RED III	No dedicated cultivation foreseen	Partly sufficient
Requirements for ships and supply chain caused by renewable and low-carbon fuels and energy sources	Upscaling of RES and import	RED III	No dedicated targets for maritime	Partly sufficient
	Retrofit supply chain	Not addressed	Not addressed	Insufficient
Requirements for bunkering infrastructure of renewable and low-carbon fuels and energy sources	Safety, international standards and rules	AFIR	No concrete targets for renewable fuels, mainly LNG	Partly sufficient

In order to increase the contribution of the package of proposals to the decarbonisation of the shipping sector, the following goals should be met:

- Increase the uptake of renewable and low-carbon fuels, especially of e-fuels which are scalable, by either:
  - increasing the targets;
  - expanding the scope of the package;
  - or closing the cost-gap between scalable e-fuels and advanced biofuels on the one hand and waste-based biofuels on the other.

- Support the development of production and bunkering infrastructure for fuels require a dedicated infrastructure, such as ammonia, methanol and hydrogen.
- Support the development and construction of ships that can sail on a range of fuels, including renewable fuels.
- Support the supply of renewable and low-carbon fuels without raising the bunkering costs more than in other parts of the world. And
- Prevent the risk of lock-in in low-carbon fossil fuels, because they have no role in a decarbonised shipping sector.
- Prevent the risk of lock-in in low-carbon fossil fuels with little potential to increase production, because their uptake would delay investments in fuels that have a role in a decarbonised shipping sector.

Some of these goals can be included in the current proposals, others would require action by individual Member States or by other actors. Chapter 5 presents proposals for improving the contribution to decarbonisation.

5 How to increase the contribution to the 2030 milestones?

This chapter develops proposals to increase the contribution to decarbonisation of the shipping sector, taking into account the conclusion of Chapter 4 that the Fit for 55 proposals fall short of meeting the milestones in 2030, derived from the communalities among the scenario studies analysed in Chapter 2.

We distinguish three types of improvements: changes in the proposals (Section 5.1); use of revenues raised from the maritime sector as a result of implementation of the Fit for 55 package (Section 5.2); and further action by Member States (Section 5.3).

5.1 Improvements of the proposals in the Fit for 55 package

The Fit for 55 package can be improved to increase the uptake of renewable and low-carbon fuels before 2030, while reducing the risk of lock-in in low-GHG fossil fuels (like LNG and LPG) and waste-based biofuels with little potential to increase supply due to intrinsic low availability.

One way to increase the uptake of renewable and low-carbon fuels would be to increase the 2030 targets in the proposals. A counterargument could be that the Commission's Impact Assessment of FuelEU Maritime shows that there is just sufficient renewable fuel available for the current targets. The IA states that the uptake of renewable fuels in maritime transport is a long and complicated process requiring cooperation of many different stakeholders. Moreover, the Commission recognises the financial and technical challenges that operators are confronted with to meet the proposed targets. However, a closer inspection of the Impact Assessment reveals three reasons why higher targets are possible:

- First, the Commission's Impact Assessment of FuelEU Maritime did not take into account that LNG will contribute to the targets in 2030. In reality, the number of LNG-fuelled ships is projected to double in the next few years, resulting in an increased use of LNG in the shipping sector, which, on average, will reduce the GHG intensity of fuels.[18] This means that the demand for biofuels and RFNBOs from the shipping sector will be lower than modelled in the Impact Assessment. The difference could be used to increase the targets.

- Second, the Commission's Impact Assessment of FuelEU Maritime assumed that almost all fuels will be bunkered in Europe and that imports of renewable and low-carbon fuels will be limited to 1.5% in 2030. This is implausible for two reasons. First, even currently, marine biofuels (B7, B20, B30, etc.) are available worldwide and it is unlikely that they

[18] DNV Alternative Fuel Insight portal listed 295 LNG-fuelled ships in operation on 1 June 2022 and 510 on order, of which 494 would be delivered by 2025 (DNV, sd). In 2020, the year for which the reference value is calculated, there were 188 LNG-fuelled ships worldwide. This means that the LNG-fuelled global fleet will more than quadruple between the year in which the reference value is calculated and the first year in which ships have to meet a target in FuelEU. Depending on the type of engine, this will reduce average GHG intensity of fuels by 0.3-6%, with a central estimate of 3%. This means that it cannot be ruled out that the 2025 target is BAU, when the increase in LNG ships in the EU follows the global pathway.

will not be used on voyages to and from the only jurisdiction which regulates the GHG intensity of marine fuels. Second, a share of fuels on voyages to and from EU ports is currently bunkered outside the EU: EU MRV emissions are 5.4% higher than emissions calculated on the basis of bunker fuel sales, even though these statistics include sales to small ships and ship types excluded from the EU MRV. For these two reasons, it is reasonable to assume that the target of FuelEU Maritime will at least partly be met with imported fuels. This means that domestically produced RLF, as modelled in the Impact Assessment could cover a larger share.

— Third, the Commission's Impact Assessment did not take into account that the ETD and RED III will result in increased bunkering outside the EU. Less bunkering means a lower target for biofuels and RFNBOs, because the target is based on consumption (incl. Bunkering). This might imply that the modelled, absolute quantities of RLF may cover a larger relative share of renewable fuels.

Scope of legislation

A second way to increase the uptake of renewable and low-carbon fuels is to expand the scope of the package. Ships smaller than 5,000 GT and non-cargo, non-passenger ships are excluded from both the EU ETS and FuelEU Maritime. In addition to reducing the environmental effect of the package, this also creates market distortions.
The environmental effects can be estimated on the basis of the global fleet, in which non-cargo, non-passenger ships accounted for 11% of maritime GHG emissions in 2018 (Faber, et al., 2020). The emissions of ships between 400 and 5,000 GT have been estimated at 7% of the total emissions in the geographical scope of the EU MRV in 2010 (European Commission, 2013). Transport and Environment states that emissions of ships under 5,000 GT were in 2019 15% of total shipping emissions in Europe (Transport & Environment, 2022).
Hence, it is likely that the inclusion of small ships and non-cargo, non-passenger ships would increase demand for RLF by 10 to 20%. The benefits of including these ships would be that it reduces the market distortion and that some ship types, like tugs and offshore support vessels, provide an exceptionally good opportunity for pilot projects with RLF, as they do not require fuels to be available globally, but just in the port which they serve.

Stranded assets and lock-in

An increase in the uptake of RLF will result in investments in fuel production, and, depending on the properties of the fuel, possibly bunkering infrastructure and ships.
When these investments are made in fuels, ships and bunkering infrastructure that have no role in a decarbonised shipping sector, the assets will be stranded which has negative economic impacts (and drains the necessary investments of resources).

More could be done to prevent the risk of lock-in in low-GHG fossil fuels like LNG and LPG, which have no role in a decarbonised shipping sector unless there are credible large-scale pathways from these fossil fuels to their renewable analogues. These are currently lacking.

Specifically, the benefits of using LNG could be reduced by requiring that compliance surpluses can only be granted for renewable fuels and that fossil LNG cannot be used to offset excess emissions of other ships in a pool. In order to encourage the uptake of sustainable alternatives of LNG, LNG-fuelled ships could be required to use a LNG-specific reference value rather than the fleet average reference value. This would require them to blend in biomethane or e-methane from 2025 onwards, of which there is limited supply combined with a high potential demand from other sectors. A criteria for a minimum supply chain reduction is also an option.

Subtarget for RFNBOs in maritime

In order to direct investments at RFNBOs, which all studies reviewed in Chapter 2 show to be necessary for decarbonisation, an RFNBO subtarget could be set in FuelEU Maritime (or the RED III, as proposed by the ITRE committee), similar to the subtarget in ReFuelEU Aviation and for the same reason as stated in the RED, namely that “Specific but realistic sub-targets for RFNBOs for the transport and industry sectors in 2030 would be a first step for their larger scale development after 2030.” (European Commission, 2021)

5.2 Use of revenues from the Fit for 55 package

The way in which revenues from the Fit for 55 package are used can support the decarbonisation of the sector. Revenues are raised from the maritime sector in two proposals. First, the EU ETS would raise revenues from the auction of allowances for the shipping sector, which could amount to several billion euros.[19] Second, FuelEU allows shipping companies to comply by paying a penalty commensurate with the excess GHG emissions (see Section 4.4.3).

ETS auction revenues are mostly fiscal income for Member States while a share of allowances is made available to a Modernisation Fund, an Innovation Fund and the Union budget. Of these, the innovation fund is the most relevant. The Innovation Fund may, amongst others, support breakthrough innovative technologies and infrastructure to decarbonise the maritime sector and for the production of RLF in aviation, rail and road transport. The Commission can determine the details of the rules on the operation of the Innovation Fund by means of delegated acts.

The FuelEU Maritime proposal specifies that penalties should be used to “support common projects aimed at the rapid deployment of renewable and low-carbon fuels in the maritime sector. Projects financed by the funds collected from the penalties shall stimulate the production of greater quantities of renewable and low-carbon fuels for the maritime sector, facilitate the construction of appropriate bunkering facilities or electric connection ports in ports, and support the development, testing and deployment of the most innovative European technologies in the fleet to achieve significant emission reductions” (European Commission, 2021).

Since the fuel mix of a decarbonised fleet is uncertain, and since many fuels may not be globally available at the time of their introduction, there is a benefit in having ships that can sail on a range of fuels. Such a ship could operate globally when RLF are available in some parts of the world only, and would have a much lower risk of becoming a stranded asset when the shipping sector has completed its transition to renewable fuels.

A ship could use a multitude of zero-emission TTW fuels, many of which would still have well-to-wake emissions. This means that the Technical Screening Criteria of the Taxonomy Regulation only capture a small subset of possible future ships. These criteria are currently aimed at ships with zero-tailpipe emissions and at improving energy efficiency by retrofits

[19] The emissions of the shipping sector amount to 144 Mt CO_2, of which about two thirds would be in the geographical scope of the EU ETS: 96 Mt (European Commission, 2021). At an allowance price of 50 or 100 €, auctioning revenues could range from 5 to 10 billion € per year.

(European Commission, 2021). In order to contribute to the decarbonisation of shipping, the innovation fund should also support the development of ships (capable to) use e-fuels like green ammonia and green hydrogen, and the production of e-analogues of currently used fuels like green e-methanol and green e-methane.
It could also be considered to subsidise RLF supplied to the shipping sector. While in principle, subsidising fuels risks distorting the market, this may be the only effective supply side policy for shipping. Because of the global nature of the shipping sector, supply policies like RED and ETD will be avoided by bunkering outside the EU, thus reducing their environmental effect.

5.3 Further action by Member States

Member States can also undertake the financial support described in Section 5.3, possibly from the revenues of ETS auctions which, according to the proposal of the Commission, should be used for “climate-related purposes” (European Commission, 2021).

Several Member States, including the Netherlands, have signed the so-called Clydebank Declaration, by which they commit to support the establishment of “green shipping corridors”, specified as “zero-emission maritime routes between two (or more) ports”.
It is within this context that States could support the development of bunkering infrastructure and fuel production for the green corridors.

6 International negotiations

Next to the developments in Europe, possible policy measures to address the climate impacts of shipping are being discussed at a global scale in IMO. In 2018, IMO has adopted its Initial Strategy on reduction of GHG Emissions from Ships, which includes, amongst others, the vision to phase out GHG emissions from international shipping as soon as possible in this century (IMO, 2018). The IMO has adopted so-called short-term measures to improve the carbon intensity of ships and its Member States are currently negotiating so-called mid-term measures. Most of the proposed mid-term measures aim to lower emissions by increasing the use of renewable and low-carbon fuels (the terminology in IMO is low- and zero-GHG fuels).

The proposals made as part of the Fit for 55 package can be expected to have both positive and negative impacts on the ongoing international negotiations.

A positive impact could be that the EU shows its willingness to address maritime GHG emissions, even when the preferred global approach does not yield sufficient results.

Another positive impact could be that the Directives and Regulations demonstrate the feasibility of certain types of policies. This is relevant because several EU proposals have similarities with policy proposals currently debated in IMO. For example, FuelEU Maritime has similarities with the so-called Greenhouse Gas Fuel Standard, advocated by the EU and Norway (Austria, et al., 2022); Norway has proposed an emissions cap and trade system in IMO, which bears similarities to the EU ETS (Norway, 2022); etc.

There are precedents for countries and regions leading by example. An oft-cited case is the phase-in of double-hulled tankers and the phase-out of single-hulled tankers. In the wake of the Exxon Valdez disaster, the US adopted legislation requiring oil tankers to have double hulls in 1990, and IMO followed two years later with global requirements. Following the Erika and Prestige accidents, the EU succeeded in getting IMO to adopt an accelerated phase-out of single hull tankers by threatening to take unilateral action (Stenman, 2005).

Such an impact would fit within a broader development where the EU exerts power by setting rules that become de facto global standards (Bradford, 2020). While the case has been made convincingly that this has occurred in areas as far apart as chemicals and data protection, and that the EU anti-trust regulations have prevented mergers of non-EU companies, it is questionable whether it would also apply to operational requirements imposed by the Fit for 55 proposals. The IMO however certainly feels pressure to develop its strategy further now the EU has presented FuelEU Maritime.

Moreover, the Fit for 55 package could also have detrimental effects on the ability that EU Member States have to participate in the negotiations. Stemming from the Fit for 55 package, EU Member States have to negotiate a common EU position in the negotiations. Although this secures 27 supporters of any position negotiated by the EU, it can also reduce the leeway that Member States have to adopt more ambitious positions than the common position. This leeway has proved to be essential in negotiating the Initial Strategy (Earsom & Delreux, 2021).

Another positive impact is that implementation of the EU proposals could provide information on the costs for and impacts on the shipping sector. It could also incentivise innovation in fuels and technologies, and help build up a critical mass of bunkering infrastructure.

At the same time, implementing the Fit for 55 package could also antagonise non-EU IMO Member States and reduce their willingness to cooperate. An example of such a reaction is provided by a submission by Bangladesh, China, India and Panama claiming that regional measures would have a detrimental effect on decarbonisation of the shipping sector globally and on international trade (Bangladesh, et al., 2021). While this submission has been discussed at IMO, it did not gain sufficient support to stop the EU from going forward. The resistance against EU measures could also stem from the fact that non-EU-flagged ships will be required to comply with the EU legislation that is implemented on a route-basis, such as EU ETS and FuelEU Maritime.

In conclusion, whether or not the adoption of the Fit for 55 package will have positive impacts on the negotiations in IMO probably depends on how they are presented to other IMO Member States and how examples derived from it will be fed into the negotiations by EU Member States.

7 Conclusion

The maritime shipping sector is capital intensive, has a global character and ships have an economic life of 25 years or more. Consequently, considerable technical and financial challenges exist for both the formation of a renewable fuel supply chain and the application of renewable fuels in the sector.

With a view to the objective to decarbonise the shipping sector in 2050, this study has compared the effects of the Fit for 55 package with milestones for 2030 of a pathway towards decarbonisation of the shipping sector by 2050. The milestones were derived from several recent studies that mapped out scenarios for a decarbonised shipping sector by 2050. The scenarios portray what is needed to achieve the objective in 2050, but often did not take into account market and non-market barriers which hold back the swift uptake of renewable and low-carbon fuels (RLF) in shipping.

In Chapter 2, the global scenario studies were analysed to identify milestones that need to be met by 2030, for the share of renewable and low-carbon fuels and other relevant indicators. All studies contain scenarios leading to full decarbonisation by 2050. However, they have different pathways towards 2050, both in timing of emission reductions and in the fuel mix considered. Consequently, they also have diverging milestones in 2030. The first important conclusion for 2030 is that there is still much uncertainty about which fuel has the best chance of becoming the most cost-effective. Secondly, judging by the different outcomes sketched by the scenarios, it is likely that in 2050 a range of different renewable fuels will exist simultaneously, accommodated by the diversity of the sector. Notwithstanding the uncertainty, a synthesis leads to milestones for 2030 as given in Table 18.

Table 18 - 2030 milestones as defined on the basis of several 2050 scenario studies

Subject	2030 milestones
Share of renewable and low-carbon fuels and energy sources	10-20% of biofuels and RFNBOs
Types of renewable and low-carbon fuels and energy sources	– Diversified strategy for different fuel types (Refined pyrolysis oil, blue ammonia, LPG, LNG, biomethane, methanol-DAC) – Clarity on technical feasibility and (safety) standards for future marine fuels, especially e-NH_3 – Decision on sustainability criteria for biomass (e.g. large dedicated crop cultivation or merely waste and residues)
Requirements for ships and supply chain caused by renewable and low-carbon fuels and energy sources	Upscaling of renewable energy supply and import increasing number of ships that can sail on e-fuels like hydrogen and ammonia
Requirements for bunkering infrastructure renewable and low-carbon fuels and energy sources	Safety, international standards and rules

In Chapter 3, the legislative initiatives of the Fit for 55 package relevant for maritime shipping were analysed. Effects come from FuelEU Maritime, the EU ETS, the RED III, the ETD and the AFIR. The proposals provide for a (mainly) technology-neutral treatment of fuels and technologies, although there remains a difference between the WTW approach of FuelEU Maritime and the RED on the one hand and the TTW, CO_2-only approach of the EU ETS on the other (the ETD has yet a different classification of fuels which bears some resemblance to a WTW approach).

In Chapter 4, the milestones as defined in Chapter 2 were compared with the effects of the Fit for 55 package, as described in Chapter 3. Until 2030, the Fit for 55 package does not create sufficient incentives for the development of fuels and technologies which are considered to be essential for the decarbonisation of the shipping sector in 2050 (especially for the e-fuel supply chain). It therefore provides insufficient incentives to meet the 2030 milestones that were derived from the scenarios in Chapter 2.

The main reasons are that the costs of using e-fuels are much higher than conventional fuels and that the proposed targets can be met by continuing to use fossil fuels in combination with pooling or banking and using about 1% of biofuels. Until 2030, the least-cost option for compliance with FuelEU Maritime is using more LNG, not shifting to renewable fuels, while LNG is also treated favourably in the EU ETS. The ETS also offers many emission reduction options in other sectors that are less costly than reducing emissions in the shipping sector, especially by using renewable fuels. Although the Impact Assessment of FuelEU Maritime estimates that by 2030, international maritime might sail on 6-9% RLF (with also the ETS contributing to this development), in Chapter 4 it was calculated that this estimate is based on two outdated assumptions: a GHG intensity reference of 2015 and a too conservative estimate of LNG growth. When these estimates are corrected, the share of RLF decreases to 1%. In the longer term (after 2030), the Fit for 55 package can stimulate a higher use of renewable fuels. A summary of the results of the comparison is shown in Table 19.

Table 19 – Comparison of 2030 milestones and effects of the Fit for 55 package

	2030 milestones Based on scenario studies	Relevant EU legislation that touches on the subject, without necessarily providing for the milestone	Effect until 2030	Assessment of proposals in reaching milestones	Suggestions for improvement
Share of renewable and low-carbon fuels and energy sources.	10-20% renewable and low-carbon fuels and energy sources.	FuelEU Maritime, RED III, EU ETS	1%	Insufficient	Possibly RFNBO maritime target in FuelEU Maritime. Overall increase of targets.
	Clarity on ammonia and hydrogen (technical feasibility and (safety) regulations).	No legislation addresses this subject clearly.	Not sufficiently addressed.	Insufficient	Dedicated financial support for addressing technological challenges (Innovation fund), e.g. in conversion- and propulsion technology onboard ships

	2030 milestones Based on scenario studies	Relevant EU legislation that touches on the subject, without necessarily providing for the milestone	Effect until 2030	Assessment of proposals in reaching milestones	Suggestions for improvement
Types of renewable and low-carbon fuels and energy sources.	Wide range of fuels to be considered and tested: Refined pyrolysis oil, blue ammonia, LPG, LNG, biomethane, methanol-DAC.	FuelEU Maritime, RED III, EU ETS	LNG becomes more attractive. And to a lesser extent biofuels. Hardly any uptake of the use of RFNBOs.	Partly sufficient	Restrict attractiveness of LNG to reach the FuelEU Maritime targets so that demand for other fuels increases; Consider RFNBO subtarget in FuelEU Maritime or support to close the cost-gap between RFNBOs and advanced biofuels on the one hand and unscalable biofuels on the other.
	Decision on role of biomass.	RED III, FuelEU Maritime	No dedicated cultivation foreseen	Partly sufficient	Impact of dedicated cultivation needs to be assessed.
Requirements for ships and supply chain caused by renewable and low-carbon fuels and energy sources. Entry in the fleet of ships that can run on non-conventional fuels.	First ships in the fleet that are powered by hydrogen or ammonia.	Not addressed	Not addressed	Insufficient	Dedicated financial support for innovative ships, e.g. in the Innovation fund.

Literature

Agora Energiewende, 2019. *European Energy Transition 2030: the big picture,* sl: sn

Austria, et al., 2022. *Proposal for a GHG Fuel Standard.* London: IMO.

B. Stolz, M. H. G. G. K. B., 2021. The CO2 reduction potential of shore-side electricity in Europe. *Energy science, 285.*

Bangladesh, China, India & Panama, 2021. *Importance of developing GHG reduction measures for international shipping within a global regulatory framework.* London: International Maritime Organization.

Bradford, A., 2020. *The Brussels Effect: How the European Union Rules the World.* Oxford: Oxford University Press.

CE Delft, 2016. Study on the analysis of market potentials and market barriers for wind propulsion technologies for ships.

CE Delft, 2020. *Bio-Scope. Toepassingen en beschikbaarheid van duurzame biomassa,* sl: sn

CE Delft, 2020. *Used Cooking Oil (UCO) as biofuel feedstock in the EU,* sl: sn

CE Delft, 2021. *Fleet-level compliance with the CII Regulation,* Delft: CE Delft.

CE Delft, 2021. *Impacts of FuelEU Maritime on the Dutch maritime sector.* Delft: CE Delft.

CE Delft, 2021. *Kosten van 'Fit for 55' voor de Nederlandse zeevaart & -havens.* Delft: CE Delft.

CE Delft, 2021. *The aviation and maritime sectors and the EU ETS: challenges and impacts,* sl: sn

CE Delft, 2022. *50% green hydrogen for Dutch industry. Analysis of consequences draft RED3,* sl: sn

CE Delft, 2022. *FuelEU Maritime and EU ETS. Sound incentives for the fuel choice?,* Delft: CE Delft.

CE Delft, 2022. *Maritime shipping and EU ETS; an assessment of the possibilities to evade ETS costs,* sl: sn

CE Delft, 2022. *The impacts of the ETD proposals on shipping and bunkering,* Delft: CE Delft.

DNV GL, 2019. *Comparison of alternative maritime fuels,* sl: sn

DNV, sd *Alternative Fuels Insight.* [Online]
Available at: https://afi.dnv.com/Statistics?repId=1
[Geopend 3 June 2022].

Earsom, J. & Delreux, T., 2021. A Nice Tailwind: The EU's Goal Achievement at the IMO Initial Strategy. *Politics and Governance,* 9(ISSN: 2183-2463), pp. 401-411.

EEA, 2021. *Final energy consumption in Europe by mode of transport,* sl: sn

European Commission, 2013. *Impact Assessment of the Proposal for the inclusion of GHG emissions from maritime transport in the EU's reduction commitment,* Brussels: European Commission.

European Commission, 2020. *2030 Climate target action plan,* sl: sn

European Commission, 2021. *2020 Annual Report on CO2 Emissions from Maritime Transport,* Brussels: European Commission.

European Commission, 2021. *Amendment to the Renewable Energy Directive to implement the ambition of the new 2030 climate target,* sl: sn

European Commission, 2021. *Commission delegated regulation (EU) 2021/2139,* sl: sn

European Commission, 2021. *Offshore Renewable Energy Strategy,* sl: sn

European Commission, 2021. *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC.* Brussels: European Commission.

European Commission, 2021. Revision of the EU emission trading system.

European Commission, 2021. *FuelEU Maritime,* sl: sn

European Commission, 2021. *Revision of the Energy Tax Directive,* sl: sn

Faber, J. et al., 2020. *Fourth IMO Greenhouse Gas Study 2020,* London: International Maritime Organization.

Getting to zero coalition, 2021. *Alternative fuels: retrofitting ship engines,* sl: sn

Guidehouse, 2022. *ReFuel, FuelEU and RED III: Discrepancies in the proposals and potential impacts on the Dutch transport sector,* Den Haag: Rijksdienst voor Ondernemend Nederland.

IMO, 2018. *Initial IMO Strategy on Reduction of GHG Emisisons from Ships. Resolution MEPC.304(72).* sl:sn

IRENA, 2021. *A pathway to decarbonise shipping by 2050,* sl: sn

J. Allen, S. P. A. B., 2021. *Electrochemical ammonia: power to ammonia ratio and balance of plant requirements for two different electrolysis approaches,* sl: sn

Lloyd's Register & UMAS, 2019. *Zero-Emission Vessels Transition Pathways,* London: LR.

Mærsk Mc-Kinney Møller Center for Zero Carbon Ship, 2021. *We show the world it is possible: Industry Transition Strategy,* Kopenhagen: Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping.

McKinsey, 2022. *Driving decarbonization: Accelerating zero-emission freight transport,* sl: sn

NEa, 2021. *Rapportage energie voor vervoer in Nederland 2020,* sl: sn

Norway, 2022. *Proposal for an Emission Cap-and-Trade System (ECTS).* London: IMO.

Öko Institut, CE Delft & DLR, to be published. *Roadmaps for decarbonisation,* Dessau: Umwelt Bundesamt.

Öko-Institut, CE Delft & DLR, 2021. *Climate protection in aviation and maritime transport: Roadmaps for achieving the climate goal,* sl: sn

Statista, 2020. *Age distribution of the world merchant fleet.* [Online]
Available at: https://www.statista.com/statistics/1102442/age-of-world-merchant-fleet-by-vessel-type/

Stenman, C., 2005. *The Development of the MARPOL and EU Regulations to Phase out Single Hulled Oil Tankers,* Göteborg: Göteborg University School of Economics and Commercial Law.

Technical University of Denmark, 2021. *MarE-Fuel: Sustainable Maritime Fuels,* sl: sn

TNO, 2021. *Verkenning brandstoftransitie zeevaart,* sl: sn

Transport & Environment, 2022. *Climate Impacts of Exemptions to EU's shipping proposals,* sl: sn

Transport & Environment, 2022. *FuelEU Maritime: T&E analysis and recommendations,* sl: sn

UMAS, 2021. A strategy for the transition to zero-emission shipping.