The Impact Of FuelEU Maritime On EU Shipping

Current EU shipping policies leave Europe dependent on fossil fuels beyond 2050

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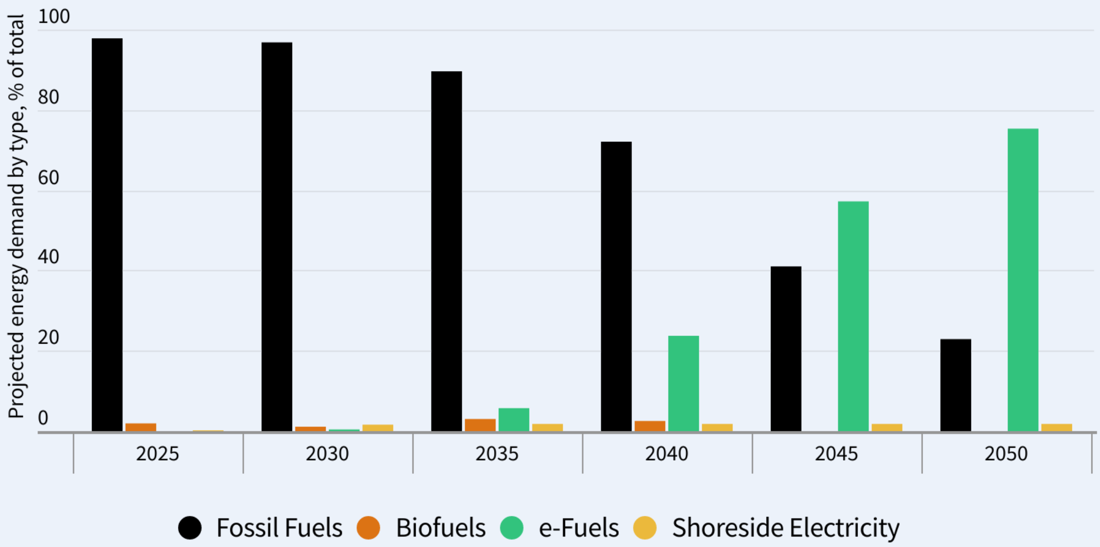
Executive Summary

In spring 2023 the EU finalised a political agreement on FuelEU Maritime (FEUM), arguably the most important shipping-related legislation in its 'Fit for 55' package. The regulation is a welcome step in tackling shipping's emissions problem, as the first global regulation to effectively mandate the industry to transition towards low carbon fuels across the next 30 years. Despite this, the ambition and scope of the regulation still leave huge room for improvement, and more needs to be done to put shipping on a Paris-compliant trajectory. Given the limited ambition of the GHG intensity reduction targets, FEUM green-lights a slow-motion transition away from fossil fuels in shipping, with oil-based fuels and fossil gas still likely to make up the majority of fuel demand until 2045.

This paper models the potential impact of FuelEU Maritime (in conjunction with the EU ETS), by showing how shipping companies might behave across the next 30 years in response to the legislation and future fuel pricing. We find that under the existing regulation, the industry would see a slow transition away from polluting fossil fuels such as LNG, which ships could continue using into the 2050s, towards more sustainable e-fuels.

Fossil fuels could still power up to three-quarters of EU shipping in 2040



The sub-target on renewable fuels of non-biological origin (RFNBOs) in the legislation provides a useful signal to fuel suppliers (in conjunction with supply-side measures in RED III/AFIR), although under 'base case' pricing it is unlikely to encourage much extra demand for RFNBOs beyond what is already incentivised by GHG intensity targets. However, if biofuel prices are lower than expected, or feasibility of ammonia engines is delayed, the sub-target provides a vital guarantee of demand.

In this report we also tested a wide range of alternative scenarios, firstly to show the potential impact of the regulation under different future fuel prices, which remain highly uncertain. While LNG and e-ammonia are the main fuels demanded by shipping companies in our main scenario, the alternative scenarios show how demand for other shipping fuels, including bio-methanol, e-methanol, e-diesel and e-methane could also evolve under different pricing situations. Our modelling also shows that even a significant increase in carbon pricing makes minimal difference to fuel choices; the shift to cleaner fuels is likely to be driven almost entirely by the progressive reduction in GHG intensity targets.

We also ran a number of scenarios to compare different proposals for the FuelEU Maritime regulation, and to show how it could be reviewed and improved under the next Commission, most notably in order to set the industry on the path towards Paris-compliant emissions. This included scenarios aligning the regulation's GHG intensity targets with a 1.5°C-compliant emissions trajectory. Under 'base case' demand and efficiency assumptions, we find this could lead to unsustainable volumes of biofuel demand (equivalent to 114% of current consumption by all EU transport). Our modelling shows that a more sustainable transition is possible under an alternative scenario with lower demand growth and improved energy efficiency; e-fuels' share of shipping fuel demand would still need to reach 18% and 85% in 2035 and 2040 respectively in order to decarbonise the shipping sector on time.

This analysis, alongside wider consideration of the regulation, has led us to a number of recommendations:

1. Align the greenhouse gas intensity (GHG) targets of FuelEU Maritime with a 1.5°C-compliant emissions trajectory from the global Science-based-targets-initiative (SBTi).
2. Set higher and additional RFNBO sub-targets to provide clarity to suppliers on sustainable e-fuels, and remove the option for ships to use any advanced biofuels in place of RFNBOs.
3. Set stronger penalties for non-compliance, in order to discourage 'paying-to-comply'.
4. Expand the FuelEU Maritime to include cargo and passenger vessels under 5,000 GT, as well as offshore vessels and other non-cargo ships.
5. Replace the LNG bunkering infrastructure mandate in AFIR with mandates for more sustainable fuels such as ammonia, methanol and hydrogen.
6. Make the RFNBO supply target in RED III mandatory to provide a minimum floor for the supply of sustainable fuels in maritime ports across Europe.
7. Implement mandatory energy efficiency requirements on European shipping to bring down total fuel demand for a smooth transition.

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1. Introduction

1.1. Overview of Shipping's Emissions Problem

The shipping sector emits around 1.1Gt of GHG, equivalent to 3% of global human-made carbon emissions,[1] a share which is on track to grow as other industries decarbonise more quickly under existing policies and commitments. Owing to an ongoing lack of action at international level, shipping's existing framework on reducing greenhouse gas emissions is woefully inadequate to tackle its emissions and put the industry on a 1.5°C-compliant trajectory. This is typified by the International Maritime Organisation's (IMO) initial target of a 50% reduction in greenhouse gas emissions by 2050, (from 2008 levels), in contrast to the Paris-aligned requirement to reach zero emissions on a well-to-wake basis (WtW) by the same point. Moreover, given that IMO regulations cover only a little under 60% of the global shipping emissions, the impact of IMO policies to decarbonise the global fleet is even more modest.[2]

EU-related shipping emissions, i.e. vessels on voyages to or from and in-between EU ports are estimated to have totalled 185 Mt CO_2e on a WtW basis in 2021,[3] accounting for a little under 20% of the global total. This has given the EU an opportunity to regulate a large proportion of shipping emissions independently of the IMO as part of its wider 'Fit for 55' package. Without effective regulation, emissions from EU shipping were expected to grow by at least 10% by 2050 under a 'business as usual' (BAU) policy and realistic seaborne trade growth scenario, as modelled by T&E [2].

Container shipping, the focus of this report, accounts for a third of emissions under the EU-MRV scope, making it the largest segment for European shipping emissions. Moreover, unlike some other ship types, where shipping demand could plateau or decline over the next 30 years as a result of the energy transition and declining demand for transport of energy commodities [3], container shipping emissions are set to continue rising under a business-as-usual scenario, given increasing demand in line with global economic growth.[4]

1.2. Regulatory Context

Earlier this year, the EU finalised a political agreement on FuelEU Maritime (FEUM) regulation, one of the four key pieces of shipping-related legislation contained within the 'Fit for 55' package, alongside the Emissions Trading System (ETS), Renewable Energy Directive (RED III) and Alternative Fuels Infrastructure Regulation (AFIR). The potential effectiveness of FuelEU Maritime is in mandating the vital transition to lower and zero-carbon fuels; this is the first ever regulation to drive the demand for sustainable marine fuels by requiring a progressive reduction in the GHG intensity of shipping fuels over time.

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[1] UK Parliament briefing, 2022 [1]

[2] The IMO data collection system (DCS) only covers emissions from cargo and passenger ships above 5000 gross tonnage (GT) sailing internationally, which are responsible for about 614 Mt of CO_2 per year. This represents about 58% of global maritime emissions (as calculated by the IMO 4th GHG study) of 1,056 Mt CO_2/year.

[3] T&E analysis, based on 'full scope' emissions data from EU-MRV and AIS data from Marine Benchmark.

[4] Under the SSP2 scenario in the IMO's 4th Greenhouse Gas Study, global containership fuel demand is set to rise 78% between 2020 and 2050.

This is in contrast to the existing Carbon Intensity Indicator (CII) imposed by the IMO, which requires improvement in vessels' general operating efficiency, but is currently unlikely to drive much change in fuel choices unless there is an improvement in the clarity and ambition of future targets. Over the longer-term, efficiency improvements alone will not be sufficient to solve shipping's GHG emissions; driving a fuel transformation is crucial. Carbon pricing schemes, including the EU ETS, can also have an impact, but in sectors with high marginal abatement cost curve (MACC) like shipping,[5] politically realistic carbon pricing is generally insufficient to bridge the gap between fossil fuels like VLSFO/LNG, and renewable alternatives like e-ammonia, e-hydrogen or e-methanol.

	2020	2025	2030	2035	2040	2045	2050
FEUM GHG targets (gCO2e/MJ)	**Baseline** (91.16 CO2e/MJ)	**-2%**	**-6%**	**-14.5%**	**-31%**	**-62%**	**-80%**
FEUM RFNBO multiplier = 2		→	→	(< 2034)			
FEUM RFNBO sub-target				(2034 <) **2%**			
FEUM pooling mechanism		→	→	→	→	→	→
FEUM SSE mandate (contr. to targets)			→	→	→	→	→

The FuelEU Maritime regulation applies to vessels of 5,000+ GT and includes 100% of emissions on voyages between EU ports, 100% of at-berth emissions and 50% of emissions on voyages between an EU port and one outside the EU (a.k.a. 'semi-full scope' emissions). The main provisions of the FuelEU Maritime agreement include:[6]

1. Progressive reduction in the greenhouse gas (GHG) intensity of ships' fuel consumption, at 5-year intervals from 2025 to 2050.
2. A requirement that ships (initially only containership and passenger vessels) connect to shore-side electricity (SSE) or use alternative zero emission technology when at berth in ports.
3. A sub-target which mandates ships to use at least 2% renewable fuels of non-biological origin (RFNBOs) from 2034 if a minimum of 1% uptake of RFNBOs has not been achieved by 2031 (the 'sunrise' clause).
4. A 'multiplier' of 2 for RFNBOs (up until the sub-target comes into force), which means a lower volume of RFNBOs is needed to comply with the GHG intensity targets, reducing the costs of using RFNBOs.
5. The regulation includes a pooling mechanism such that emissions and RFNBO consumption can both be pooled within or between operators (as long as they have the same data verifier), allowing targets to be achieved on a fleet-wide rather than an individual vessel basis.
6. Companies can also shift their 'compliance balance' from one year to another (within limits) via a 'banking and borrowing' mechanism, rather than complying fully within every individual year.

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[5] IMO *4th Greenhouse Gas Study*, section 4.4 [4]

[6] T&E's FuelEU Maritime explainer provides a more comprehensive explanation of the regulation.

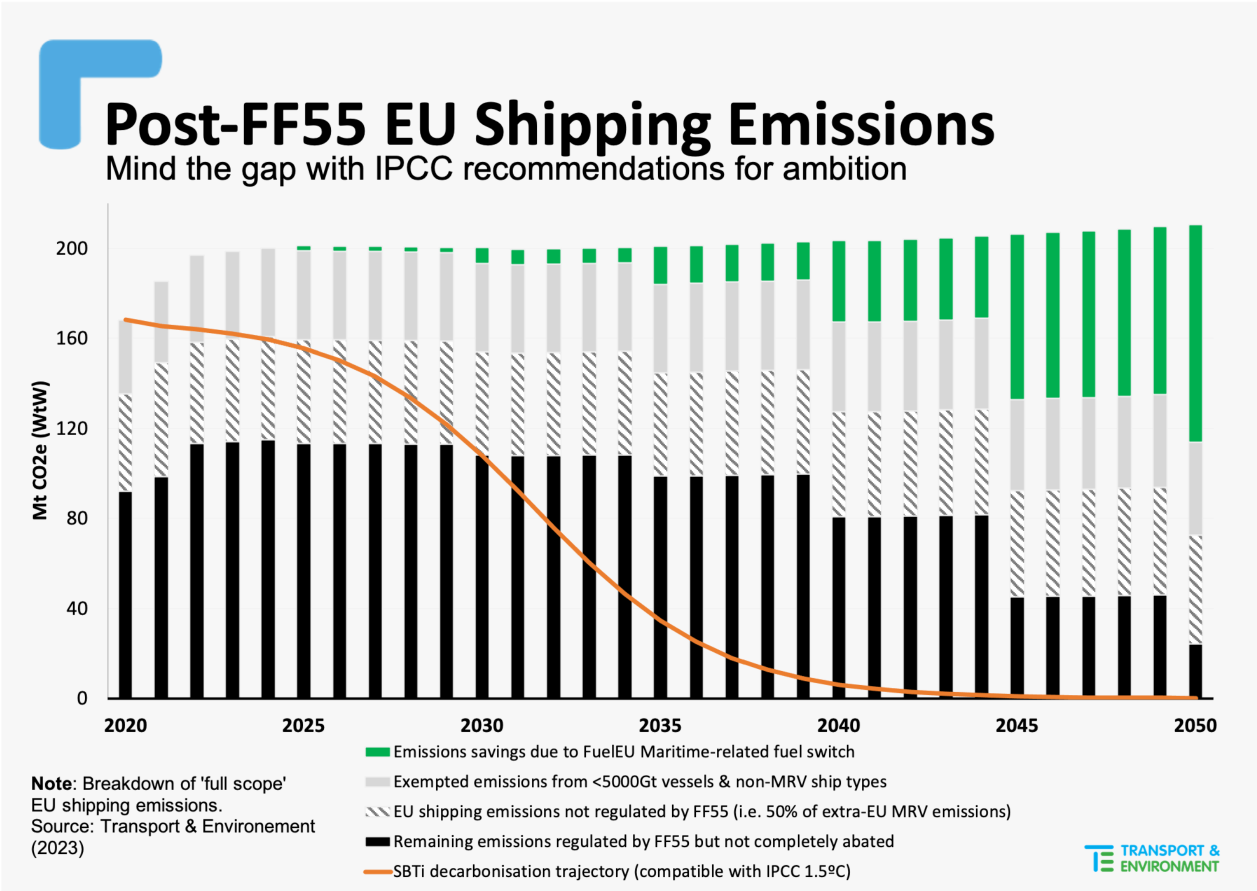

Figure 1: FuelEU Maritime within the context of all European shipping emissions

Whilst the potential effectiveness of the regulation will be discussed in more detail in Section 2 of this paper, there are number of clearly identifiable weaknesses in the final FuelEU Maritime agreement that should be addressed upon its revision by the end of 2027:

1. As shown in Fig. 1, a large proportion of European emissions remain unregulated by either FuelEU Maritime or the EU ETS, including vessels under 5,000 GT, offshore vessels, fishing and other non-cargo ships. These ships made up an estimated 20% of 'full scope' WtW emissions in the EU in 2021; this share is likely to grow if they remain unregulated.
2. While the principle of reducing the emissions intensity of shipping fuels over time is a strong one, the targets set out in the regulation are relatively weak: in the late 2030s, the regulation still only requires a 14.5% reduction in emissions intensity (full list of factors in Table 1 below), which does not require any shift to truly sustainable fuels. This is exacerbated by the 'banking and borrowing' mechanism, which allows operators to effectively shift compliance back by three years.
3. The RFNBO target in the final agreement is less ambitious than existing industry plans, following recent announcements on e-methanol production, which alone could meet up to 3% of European shipping fuel demand in 2030 [5].
4. The penalties for non-compliance in FuelEU Maritime are generally weak; depending on fuel prices, this may allow operators to 'pay-to-comply' instead of effectively incentivising them to shift to cleaner fuels.

1.3. Purpose of This Study

This study aims to analyse the impact of FuelEU Maritime by modelling how shipping companies are most likely to act in the face of different regulatory constraints and pricing. The model allows us to predict potential demand from container operators in the EU for a range of marine fuels. This is done using an optimisation approach: in the model, companies minimise their total costs while taking into account the constraints of the regulation, the price of a range of fuels and carbon, the cost of building new vessels, and a range of other factors. A full explanation of the modelling approach can be found in the Annex.

This allows us to project what mix of technologies and fuels will be in *demand* from the containership segment across a period of 30 years from 2025, as well as the primary costs involved. It should be noted that this paper does not cover the supply side of the fuelling equation; unless otherwise stated, we assume full availability of each fuel and relevant bunkering infrastructure in every period.

The analysis is split into two main sections. Section 2 examines the potential impact of the final FuelEU Maritime agreement under a number of different pricing scenarios (to account for uncertainty over future fuel prices). This provides projections of how much fuel demand there will be for various marine fuels (and engine types) from the EU containership segment across the 30 years after the regulation comes into force (i.e. 2025-2054). For simplicity, we focus on engine technologies and did not model any impacts from fuel cells or batteries, which remain uncertain. We also outline the potential implications for total sectoral CO_2e emissions and costs.

Section 3 looks at a number of alternative scenarios for the regulation in order to examine the impact of different aspects of FuelEU Maritime, and test how the regulation could be improved to more effectively tackle EU shipping's climate problem during the upcoming revision of the law before the end of 2027. This includes modelling using the Science Based Targets Initiative (SBTi) [6], to show how the regulation could be aligned with a 1.5°C-compliant trajectory.

Explainer: T&E's Containership Fuel Optimisation Model

T&E's containership optimisation model allows us to predict how shipping companies would behave when faced with different regulatory constraints, incentives, fuel prices or other factors. The modelling approach is outlined in detail in the Annex to this report.

We assign each operator a technology mix in 2025 based on its current fleet and orderbook of new vessels. For new vessels to be built from 2030 onwards (not yet on the orderbook), in our model operators can choose between 4 engine technologies, each of which allows ships to use a subset of 9 fuels (Fig. 2), focusing on those with most technological and emissions reduction potential. For each technology there is at least one fossil-based, biofuel and e-fuels pathway (with the exception of ammonia DF engines where we did not include a bio-ammonia fuel option). Operators can also use shoreside electricity (SSE) to meet part of their energy requirements.

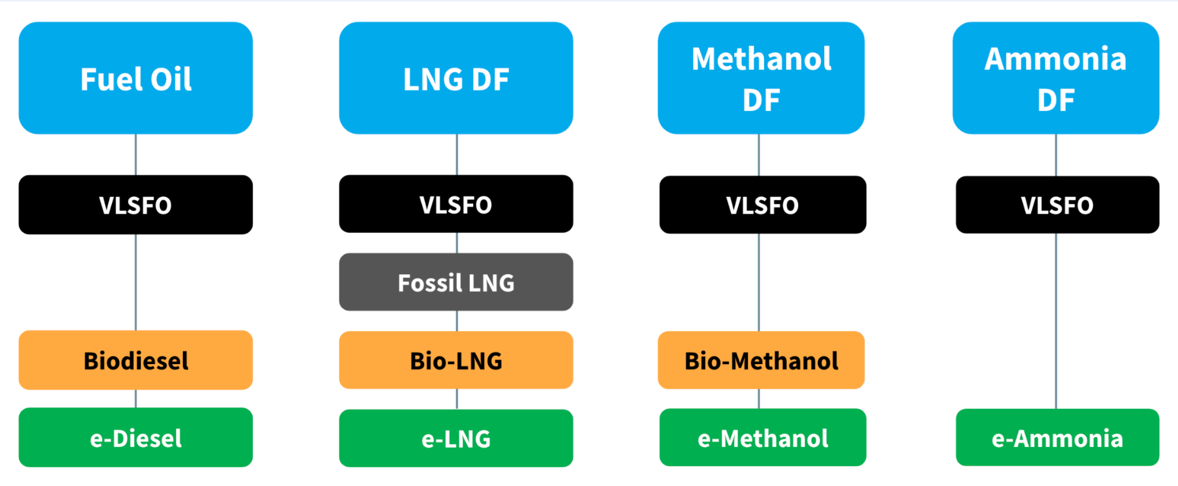

Figure 2: Available technology and fuel pathways in the model

The model is split into 5-year periods; in each period, every operator chooses its mix of technologies and fuels in order to minimise its combined fuel costs (calculated from projected fuel consumption and prices) and newbuilding costs (generated by adding capacity to its fleet) while meeting its projected fuel demand and complying with the FuelEU Maritime and EU ETS. The WtW emissions intensity of fuels used in each period must be no higher than the limit permitted under FuelEU Maritime. The analysis also takes into account the impact of an RFNBO sub-target and multiplier, where relevant. Carbon prices under the EU ETS are included in fuel pricing.

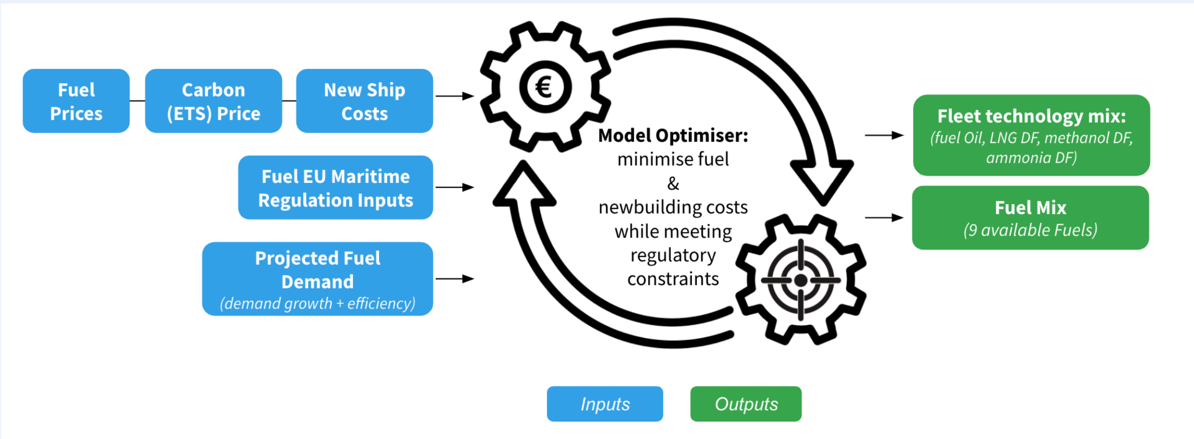

Figure 3: High level summary of T&E fuel optimisation model

A number of aspects of the regulation are simplified for the purposes of the analysis:

- This report focuses predominantly on the containership segment; the potential implications for the whole EU shipping sector are discussed in Section 2.1.4.
- The impact of other regulations at IMO or national level is not modelled.

- Pooling of emissions takes place within each operator's fleet, not between companies. This is only done in order to reduce the complexity of the optimisation without much affecting the results.
- The analysis does not include 'banking and borrowing' of emissions as we assume that ships fully comply with the regulatory constraints, and that there are no fuel supply constraints.
- Operators in the model switch fuels as required and do not resort to a 'pay-to-comply' mechanism.

Fuel demand for each operator is estimated by calculating their 2021 fuel consumption from EU-MRV data (based on 100% of intra-EU, 50% of inbound/outbound fuel consumption and 100% of at berth emissions, as per the scope of FuelEU Maritime and the EU ETS) and applying projections on containership demand growth and BAU efficiency improvements from the IMO 4th Greenhouse Gas Study (2020) [4].

We estimate future shipping fuel prices by averaging prices from selected external sources derived from literature review. Where possible, we focus on sources that include a wide range of fuels in order to ensure more consistency in input assumptions. All scenarios in this report use the 'base case' prices detailed in Annex A.3.1 unless otherwise specified.

Code	Scenario Description
1A	FuelEU final Agreement, base case pricing
1B	FuelEU final Agreement, Low e-fuels Pricing
1C	FuelEU final Agreement, Low biofuels Pricing
1D	FuelEU final Agreement, Late Ammonia Feasibility
1E	FuelEU final Agreement, High ETS Prices
2A	'Business As Usual' (no EU regulation), base case pricing
2B	'ETS-only', base case pricing
3A	FuelEU EU Commision Proposal, base case pricing
4A	Denmark & Germany EU Council Proposal, base case pricing
5A	SBTi 1.5°C-compliant Emissions, base case pricing
5B	SBTi 1.5°C-compliant Emissions, base case pricing, 'Low Demand', high efficiency

For a detailed description of regulation and fuel price/cost scenarios, see Annex to this report.

2. FuelEU Maritime Impact Assessment

2.1. FuelEU Maritime Impact: 'Base Case' Scenario

In this section we analyse the potential impact of the final FuelEU Maritime agreement on fuel demand in the shipping sector, using T&E's fuel optimisation model. This allows a preliminary assessment of what fuels should be demanded by containership operators across the period 2025-54 if the regulation remains in its current state.

In scenario 1A we input the emissions intensity reductions, RFNBO sub-target (assuming that the 'sunrise clause' comes into place from 2034,[7] RFNBO multiplier (until the introduction of the sub-target) and the SSE mandate agreed by the EU in the FuelEU Maritime regulation. This scenario uses the 'base case' pricing assumptions outlined in the Annex, which take an average of a range of sources on future marine fuels pricing. Please see the Annex for a detailed description of the assumptions used. Annex B contains a summary table of the assumptions included in every scenario in this report.

2.1.1. Technology & Fuels

Based on the results of scenario 1A, the final FuelEU Maritime agreement encourages continued uptake of LNG DF HP 2-stroke engines well into the 2030s, before Ammonia DF ships take over as the technology of choice in the following decade (Fig. 4). LNG-powered ships are favoured by operators in the model because of the low price of fossil LNG (which in the base case pricing scenario is assumed to gradually reflect historical prices across the remainder of the 2020s). Despite the potential for lower WtW emissions from LNG-powered ships through Bio-LNG or e-LNG, all types of LNG fuel have the potential for harmful 'methane slip', with early onboard measurements suggesting that observed methane slip tends to be above assumed default levels in the FuelEU Maritime regulation [7]. Under scenario 1A, ships based on Fuel Oil and LNG DF technology would still make up 72% of the EU container shipping fleet (in terms of total fuel consumption) in 2040 and 37% in 2050. Given that methanol-fuelled ships are available today and ammonia-fuelled vessels are likely to become feasible within the next few years [8], FuelEU Maritime is unnecessarily slow in pushing the shipping industry to shift to more advanced propulsion technologies.

[7] We also assume that operators use RFNBOs and not 'equivalent' RED-III compliant 'advanced' biofuels, as is also permitted under the final FuelEU Maritime Agreement, for which pricing is uncertain.

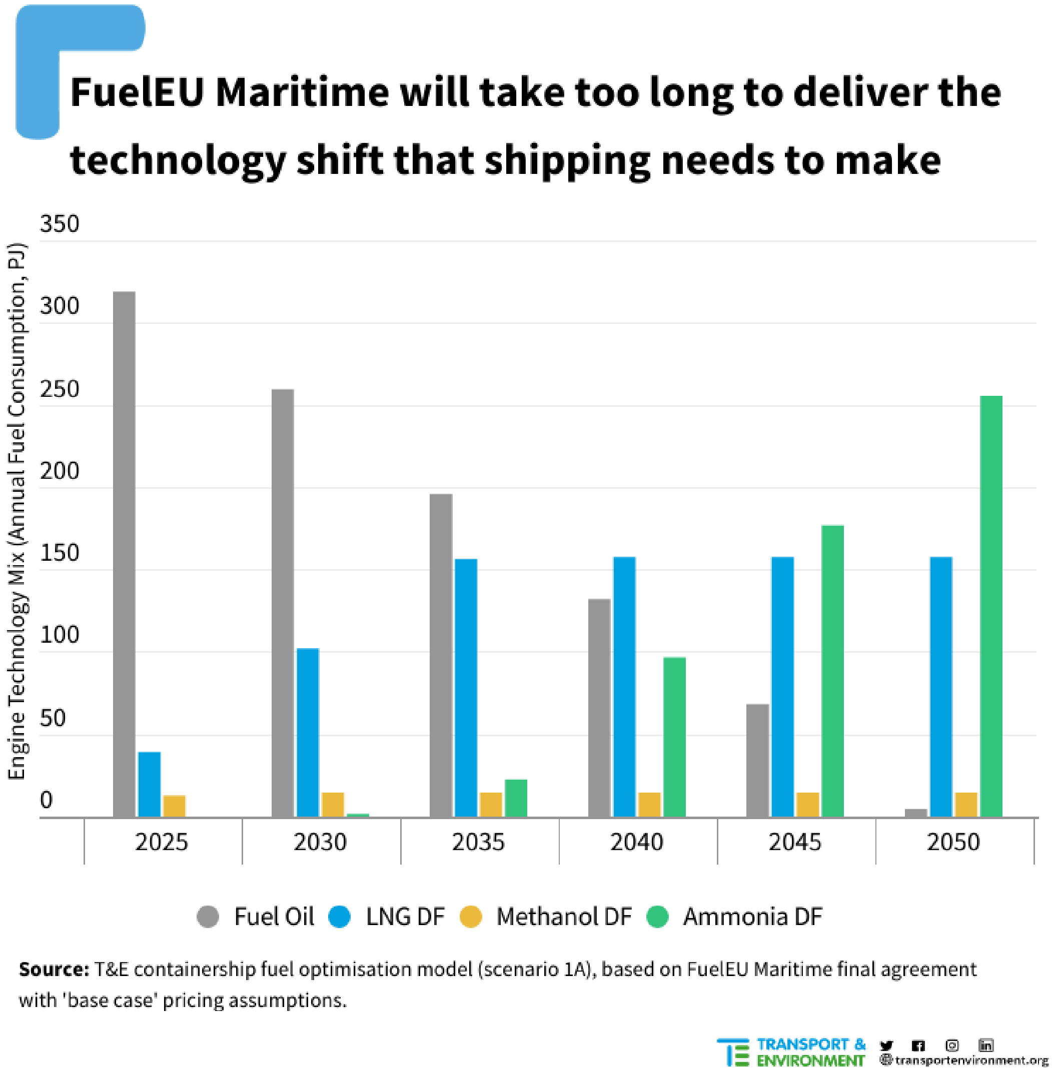

Figure 4: Technology mix projected in Scenario 1A

Figure 5 shows the projected fuel demand across the period. Under scenario 1A, the share of fossil LNG in total fuel demand increases from 10% in 2025-29 to 39% by 2035-39. The final agreement clearly pushes an increase in the uptake of LNG in the early years, given the limited ambition of the emissions intensity targets and the expected low cost of fossil LNG. Even by 2050, fossil LNG is still projected to make up 22% of total consumption. LNG is marketed as a 'transition fuel', but containerships could be burning it well into the 2050s.

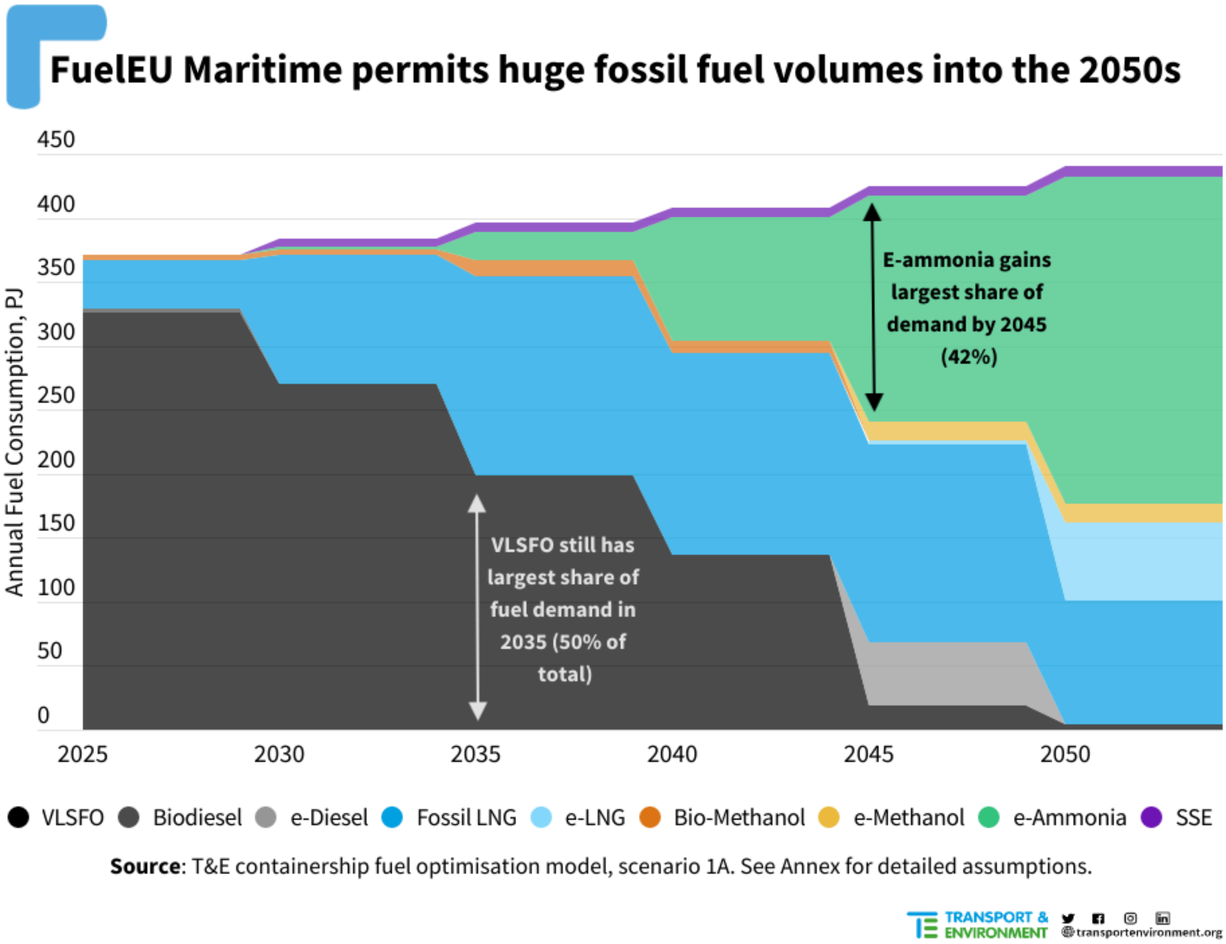

Figure 5: Fuel mix projected by year in scenario 1A

If technically feasible, as in this scenario, e-Ammonia begins to take over as the primary fuel for new ships to comply with FuelEU maritime from 2040 onwards. Although price estimates for all e-fuels vary, there is an emerging consensus in the literature that e-ammonia will be the most cost-effective e-fuel for shipping, providing that its potential operational and safety issues can be overcome. Elsewhere, there is a limited uptake of biofuels in scenario 1A: emissions targets are weak enough that cheap fossil LNG can be used as the main method of compliance in the 2030s.

While the model predicts some demand for e-LNG later in the period, recent technical analysis shows that this fuel still has a low ‘production readiness’ compared to alternatives [9]. According to the authors, ‘the path to technical maturity remains unclear’ given the existing lack of investment in e-LNG plants compared to other e-fuels, which have attracted more investment from other transport sectors (or from shipping in the case of e-methanol). In scenario 1A, e-LNG is not economically feasible in the model until the final period; as such, relying on e-LNG to solve shipping’s emissions problem is likely to extend the lifetime of fossil LNG into the 2050s.

Under scenario 1A, it appears that there is less incentive to use RFNBOs between 2025-2035 despite the multiplier. The RFNBO sub-target also makes little difference in the period 2035-39; in this period it is already optimal for most operators to use some e-ammonia (6% of the fuel mix) in order to comply with the GHG intensity targets (by replacing a proportion of their demolished Fuel Oil ships with Ammonia DF ships). However, other scenarios in this report (see Section 2.2) demonstrate the importance of a sub-target for ensuring the scaling up of sustainable fuels, in the event that e-ammonia does not quickly become a price-competitive way of meeting the emissions intensity targets.

E-methanol and e-ammonia engines are expected to be widely available to use on ships from the late 2020s [10][11], with a range of ongoing projects pushing forward operators' and regulators' understanding. The EU should use the forthcoming revision of FuelEU Maritime regulation to advance the mandate for uptake of these fuels, instead of waiting until the 2040s to enact serious emissions intensity targets that drive the rapid technology change needed to cut emissions.

2.1.2. Emissions

The emissions improvements required by FuelEU Maritime, while an important first for shipping, are not expected to be significant enough to bring down total emissions significantly until the 2040s. In Scenario 1A, based on the final FuelEU Maritime agreement, the total WtW CO_2e emissions of containerships operating in the EU are projected to increase slightly or remain similar to current levels (30.3 Mt CO_2e in 2021[8]) until 2040-44, when they begin to decline significantly.

[8] 'Semi-fullscope' emissions (100% intra-EU, 100% at-berth, 50% inbound/outbound) are estimated by scaling EU-MRV TTW emissions to WtW emissions using the factors in FuelEU Maritime Annex II, assuming a fuel split of 80% VLSFO and 20% MGO, with negligible share of alternative fuels.

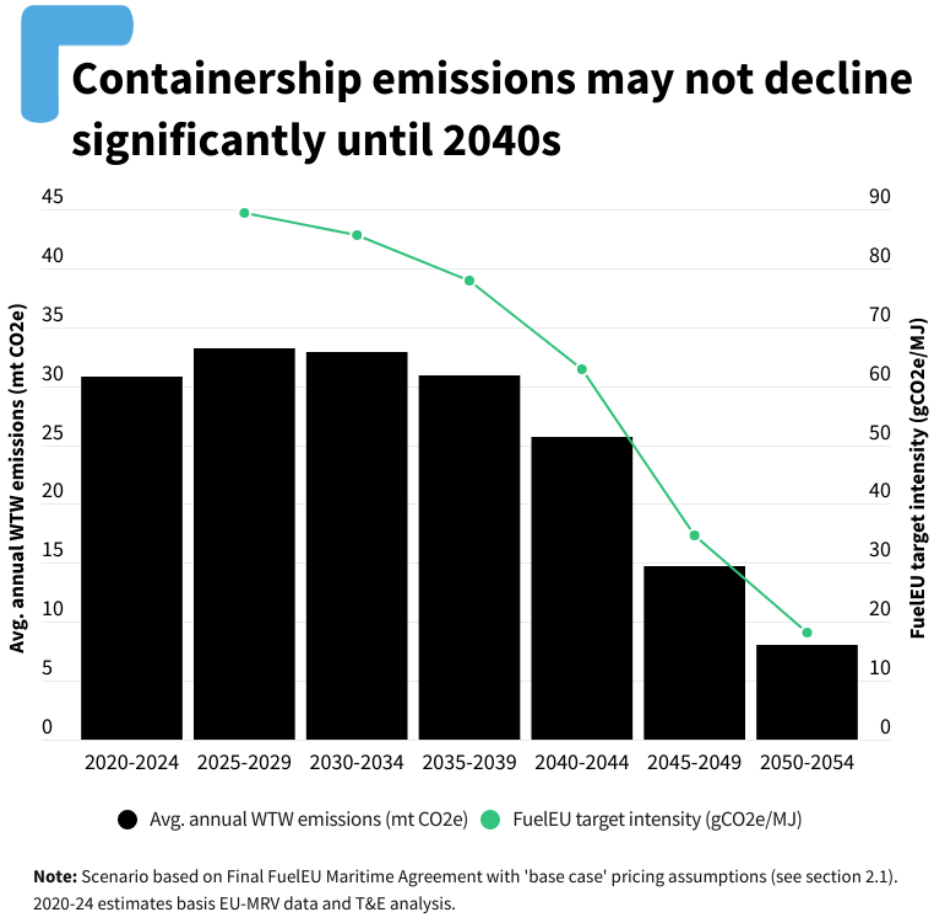

Figure 6: Annual WtW containership emissions by period

Across the first 10-15 years of implementation, the emissions intensity reductions under FuelEU Maritime may not be enough to outweigh the potential increase in fuel demand[9] in the containership segment. In any scenario in which fuel demand continues to grow or even remains steady, the provisions in FuelEU Maritime will fall well short of driving the kind of emissions cuts required to put shipping on a Paris-compliant trajectory (see Section 3.3 for more detail). Independent of demand growth, the lack of a 100% emissions reduction target means that fossil fuels may not be fully phased out by 2050, when emissions are still projected to remain at 27% (8mt CO_2e) of their current level.

[9] See Annex A.7 for detailed description of demand assumptions. Lower fuel demand could for example result from lower European containership demand growth, higher uptake of energy efficiency technologies, or speed reduction. Other shipping segments will also have different demand trajectories.

2.1.3. Costs of Decarbonising Container Shipping

The optimisation model also allows us to examine the potential fuel (including carbon pricing) and newbuild costs of complying with the FuelEU Maritime regulation and EU ETS (this does not include additional costs such as port fees, container handling and maintenance costs which are not directly affected by these EU laws[10]).

Under scenario 1A, total costs included in the model increase from €9.7bn per year in 2025-29 to €15.7bn per year in the final period 2050-54. Fuel costs are the most important consideration for shipping companies in the model, accounting for 53% of total costs across the whole period (with ETS costs making up 23%, newbuild costs 21% and shoreside electricity costs 2%). The importance of fuel costs increases throughout the period as a result of the required transformation to more expensive, sustainable fuels, with the share of fuel costs rising from 47% in 2025-29 to 71% in 2050-54. Although the newbuild costs of alternative fuel technology vessels are higher (see Annex), this difference is much smaller in proportional terms than the expected increase in the cost of fuels. It is important to note that part of the cost increase is due to the projected increase in transport work in the model (see further below).

As a result of the shoreside electricity (SSE) mandate in FuelEU Maritime, the projected total cost of electricity to EU containership operators increases from just €38m in 2025-29,[11] to €264m per year in 2030-34 once the mandate begins.

[10] These costs are also likely to be more consistent between scenarios, in which case the variation in total costs would be lower than in the above graphs.

[11] Based on a constant electricity price of €0.15/MWh; future prices will fluctuate significantly.

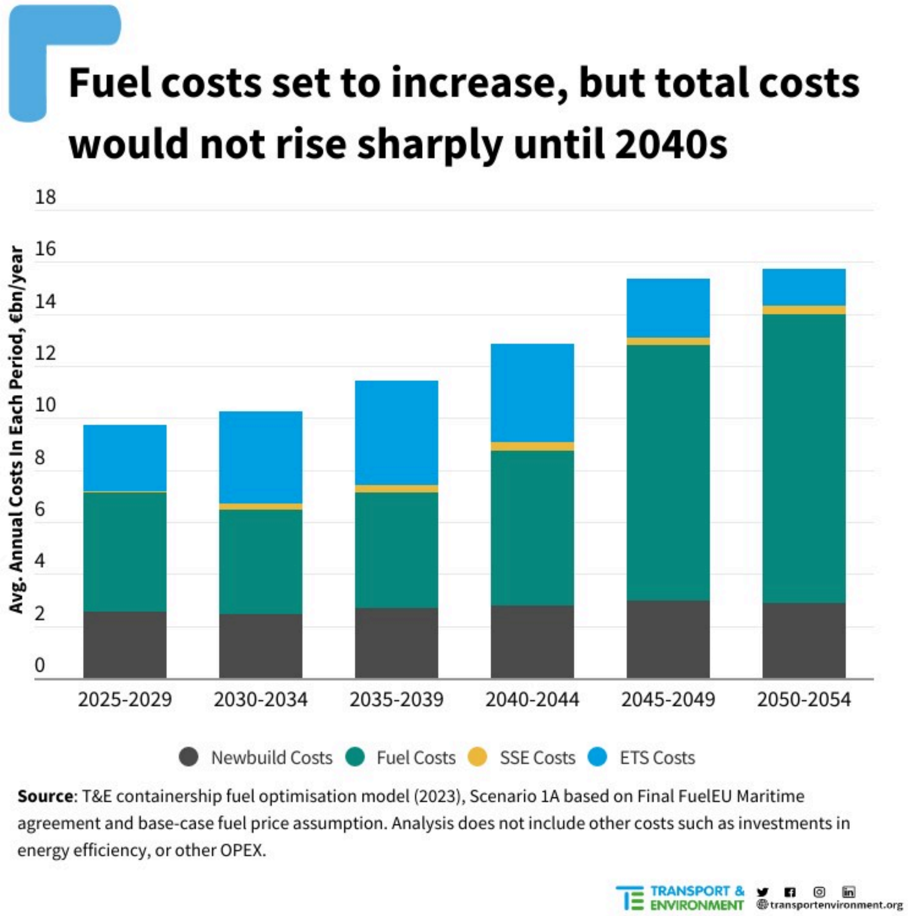

Figure 7: Cost breakdown by period under final FuelEU Maritime agreement

Weighting by total containership demand (expressed as 'transport work' in TEU-nm) as in Fig. 8 shows a more moderate increase in costs. Fleetwide average costs per mile of container transport actually declines early in the model period, as a result of switching to low cost LNG; this is not outweighed by the increased costs of switching to low carbon fuels and ETS carbon costs until 2045. Given that operators' income should generally correlate with containership demand, this puts the potential cost increase into context.

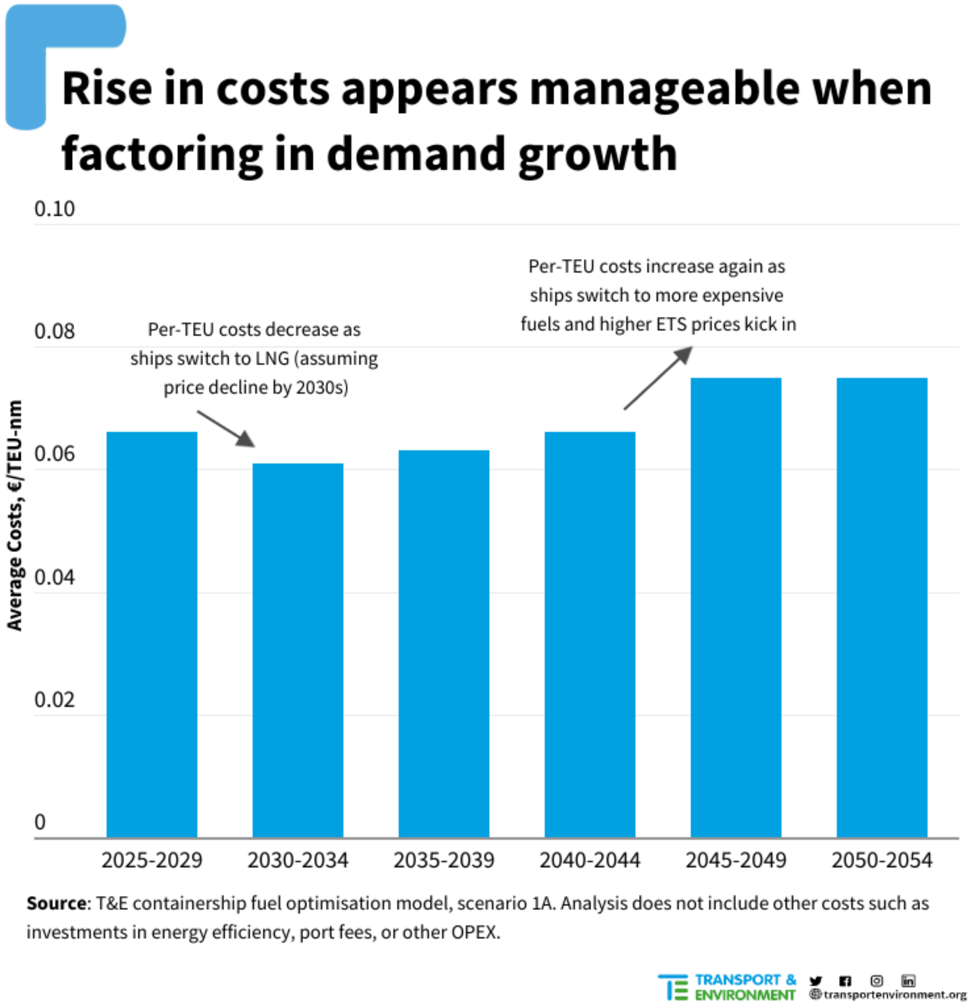

Figure 8: Costs in scenario 1A weighted by containership demand

Both the EU ETS and FuelEU will have an impact on shipping companies' costs. Fig. 9 shows that the ETS has a much greater impact in the early period of the model when operators' fossil fuel share remains high; in scenario 1A, ETS costs in 2035-39 are still four times the value of the extra fuel and newbuild costs implied by FuelEU Maritime. Although it is expected to have a limited impact on fuel choices early on, the ETS may help to narrow the gap in fuel costs as the price of e-fuels comes down, while also raising significant revenue for the EU's Innovation Fund and member states, which can be reinvested in shipping technologies. From 2045 onwards, the costs of FuelEU Maritime become more significant as operators switch to clean fuels.

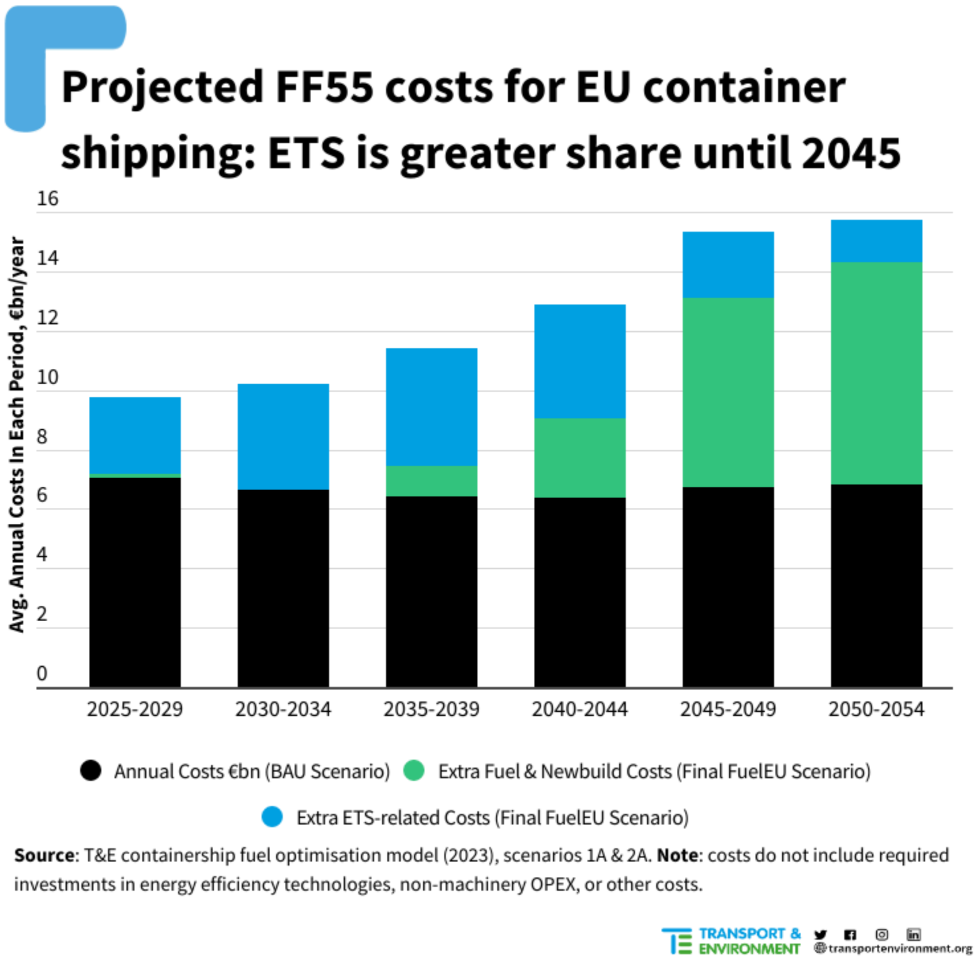

Figure 9: Costs under FuelEU Maritime and the EU ETS compared to a 'business as usual' scenario

It is worth noting that although costs roughly remain flat in the 'business as usual' scenario, this does not factor in any effect from IMO or other regulations. This could potentially impact fuel choices during the period and will likely generate costs that would have to be met regardless of EU regulation, but remains highly uncertain. The costs of investment in energy efficiency technologies required to meet the 'base case' energy efficiency assumptions in both scenarios are also out of the scope of the modelling.

2.1.4. Implications For The European Shipping Sector

While fuel choices and behaviour in other shipping segments may differ from containerships, we also provisionally scaled the results of scenario 1A to cover the full EU shipping sector, in order to provide a clearer estimate of the fuel volumes that could be needed in Europe following the FuelEU Maritime agreement.[12] Projected fuel demand across European shipping is projected to rise more slowly for the

[12] This analysis again uses global projections of transport work and efficiency improvements from the IMO 4th Greenhouse Gas Study[4] (using a combined factor for all cargo sectors) to project total fuel demand.

sector as a whole than for containerships, as a result of slower expected demand growth in other shipping segments.[13]

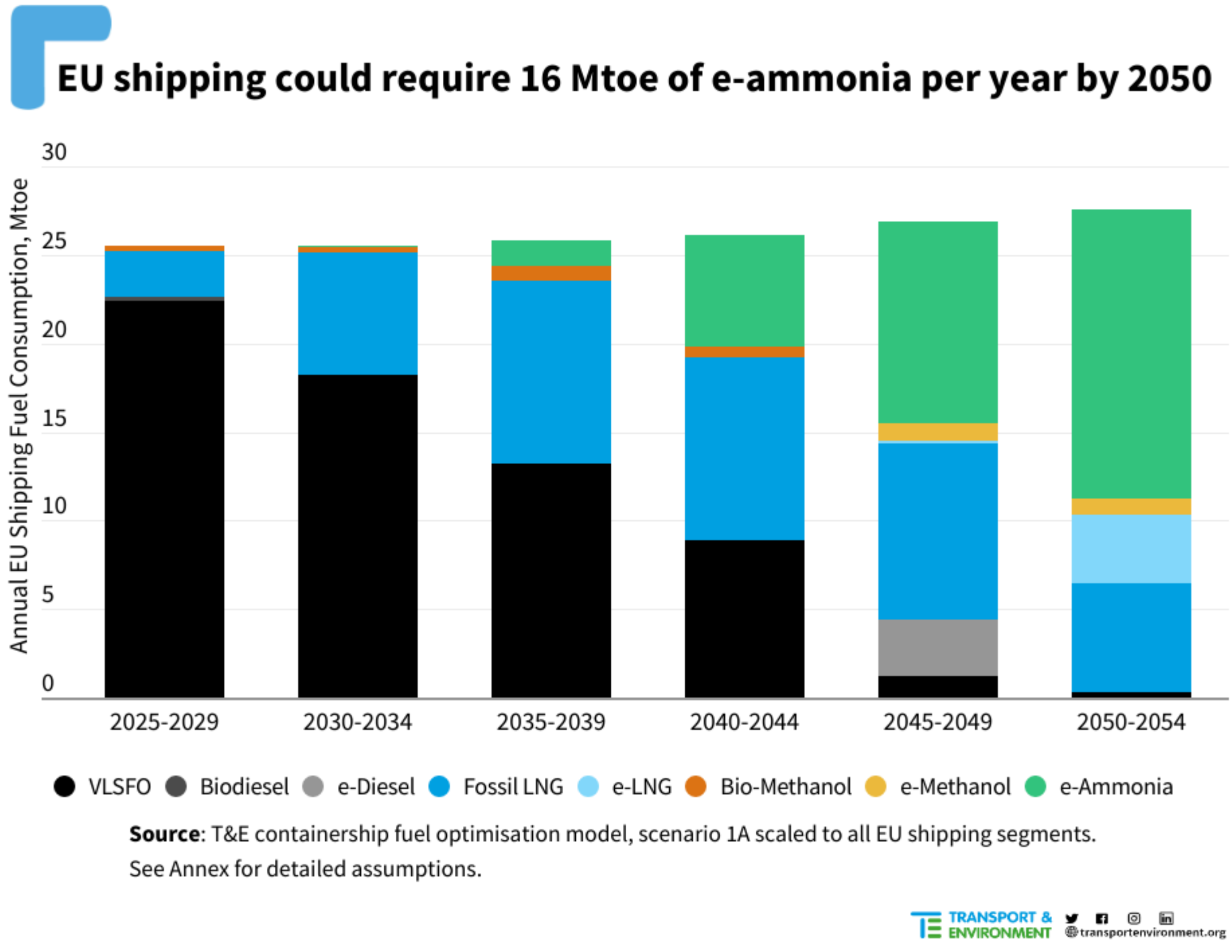

Figure 10: Potential annual fuel demand in the EU shipping sector

Fig. 10 shows the volume of fuels, in million tonnes oil equivalent (Mtoe), that would be required if fuel demand in the EU shipping sector as a whole was equivalent to the proportions estimated for containerships in Scenario 1A. Current EU shipping fuel demand of c.25 Mtoe per annum ('semi-full' MRV scope') is met almost exclusively by VLSFO and other oil-based fuels such as marine gas oil (MGO). Under Scenario 1A, annual consumption of VLSFO by the shipping industry would decline to 0.3 Mtoe by 2050; LNG consumption peaks at 10.4 Mtoe in the period 2035. In 2050, annual demand for e-ammonia from EU shipping would reach 16.3 Mtoe; although rapid transformation is required, this is still only 21% of current global (fossil fuel-powered) production of ammonia,[14] which has well established supply chains.

[13] The approximate share of fuels is likely to be similar in other sectors, although lower growth in fuel demand is likely to imply less technological switching (by operators building new, alternative fuel ships), and more existing ships instead switching fuels (e.g. to biodiesel or e-diesel) in order to meet targets.

[14] Based on global production of 176 Mt in 2020 [12]

2.2. Alternative Fuel Scenarios

2.2.1. Impact Of e-Fuels Pricing

The future pricing of fuels remains uncertain, with large variation between sources, and any projections on fuel demand are clearly sensitive to fuel price assumptions. In this section we model a number of scenarios with alternative fuel and carbon pricing assumptions in order to look at the potential effect this could have on the impact of the fuelEU Maritime regulation.

In scenario 1B, we input the same regulatory constraints as scenario 1A, as well as the same pricing for fossil and biofuels. However, for all four e-fuels, instead of averaging the selected sources (see Annex A.3.1), we use the minimum value from the same sources; these are outlined in Table 1.

Year	E-Diesel Price (€/GJ)		E-LNG Price (€/GJ)		E-Methanol Price (€/GJ)		E-Ammonia Price (€/GJ)	
	1A	1B	1A	1B	1A	1B	1A	1B
2025	65.3	58.3	52.7	50.7	59.0	45.6	36.3	29.8
2030	59.6	54.5	48.0	47.1	53.4	42.1	33.5	27.1
2035	57.2	54.6	45.9	44.4	51.0	42.3	32.2	26.1
2040	54.7	54.6	43.8	41.7	48.5	42.5	30.9	25.2
2045	52.3	49.6	41.7	38.1	46.1	42.6	29.6	24.2
2050	49.8	44.5	39.6	34.5	43.7	42.8	28.3	23.2

Table 1: Fuel price comparison between scenarios 1A and 1B (not including carbon prices)

As shown in Fig. 11, this scenario leads to an increase in RFNBO uptake compared to the 'base case' pricing in scenario 1A, notably from 6% to 10% in 2035-39 and 24% to 26% in 2040-44, showing the potential for increased demand for e-fuels. This is largely contingent on the lower prices for e-ammonia, which make it competitive with other fuels earlier in the model period; in this scenario other e-fuels may still be too expensive to drive up RFNBO uptake.

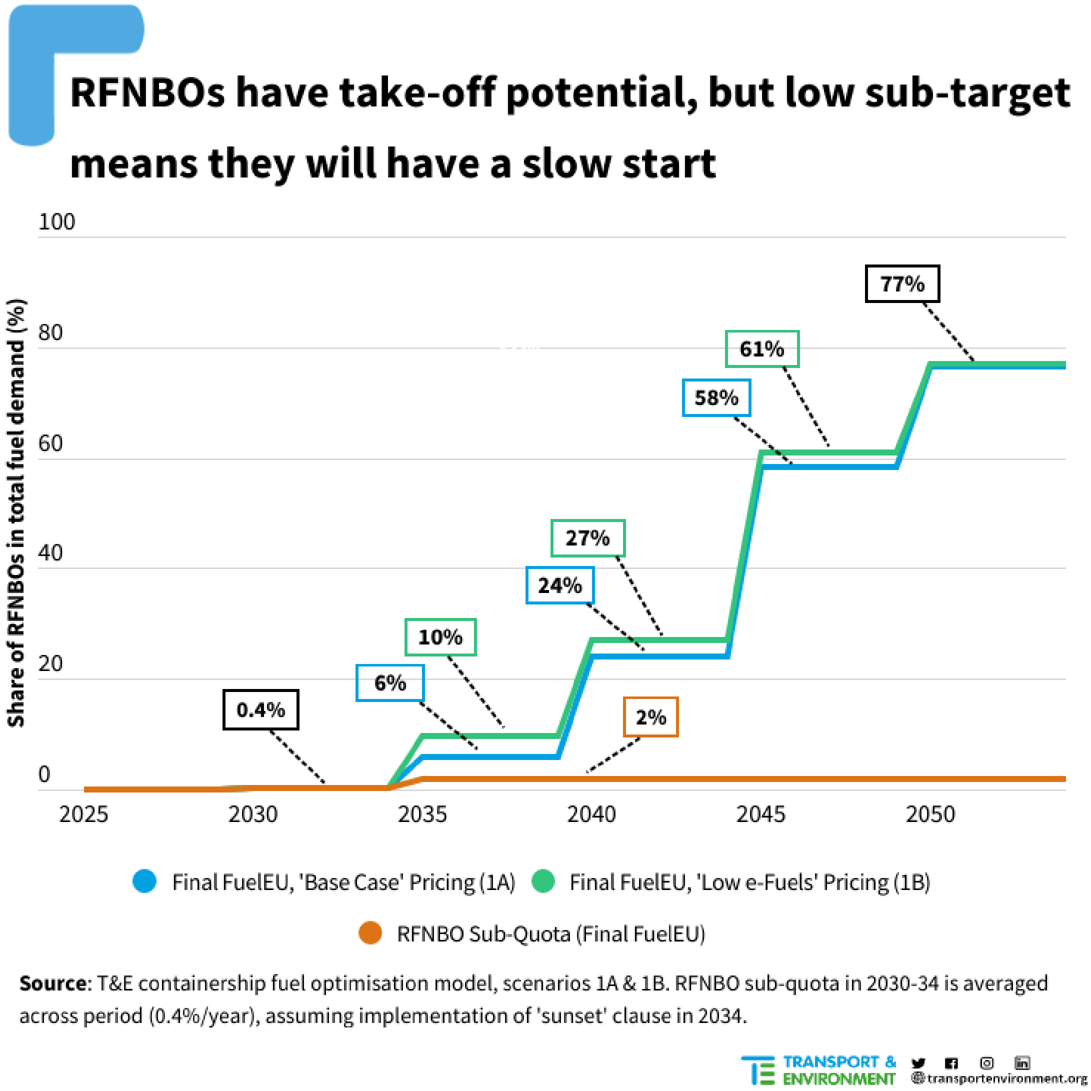

Figure 11: Share of e-fuels in 'base case' and 'low e-fuels' price scenarios

Even under the lower prices in this scenario, the RFNBO sub-target is what pushes uptake of e-fuels before 2035 (albeit only for a single year under the agreed 'sunrise' clause). Increasing the sub-target from 2030 would provide more certainty to producers and should encourage scaling up of production and technological learning, which are likely to lead to lower costs coming down sooner.

2.2.2. Impact Of Biofuels Pricing

We also tested the sensitivity of the model by running another scenario (1C) to examine the impact of the final FuelEU agreement with lower biofuel prices. Similarly to scenario 1B, prices represent the minimum values from the same selection of sources as summarised in Table 2. As in the majority of scenarios, there are no restrictions here on fuel availability. Under FuelEU Maritime, biofuels must be non-feed/food based, but there remain issues over the scalability and sustainability of these fuels; restricting the supply of compliant biofuels to feasible volumes is outside the scope of the model. Although 'average' bio-LNG prices are lower than bio-methanol prices in scenario 1A, bio-methanol prices are lower in scenario 1C as they have a lower floor throughout the model period.

Year	Biodiesel Price (€/GJ)		Bio-LNG Price (€/GJ)		Bio-Methanol Price (€/GJ)	
	1A	1C	1A	1C	1A	1C
2025	28.0	19.8	33.4	26.4	24.7	18.0
2030	33.7	22.1	38.3	24.3	28.1	19.4
2035	40.1	23.5	38.7	31.7	33.4	20.3
2040	46.6	24.9	39.0	39.0	38.7	21.2
2045	52.6	25.8	39.1	39.1	43.8	22.1
2050	58.6	26.8	39.1	39.1	48.9	23.1

Table 2: Biofuels price comparison between scenarios 1A and 1C (not including carbon prices)

In this scenario, operators still generally choose to lower their average GHG intensity in the 2030s by replacing old Fuel Oil ships (as required in each period in the model) with LNG DF ships and increasing their use of fossil LNG. However, it should be noted that replacement of ships does not generally happen at uniform rates as it does in the model; in reality, some operators may for example have low fleet replacement rates in the period 2030-34. In this case, they may be more likely to meet the FuelEU emissions intensity requirements by switching their existing Fuel Oil ships to use biodiesel, rather than building new LNG DF ships.

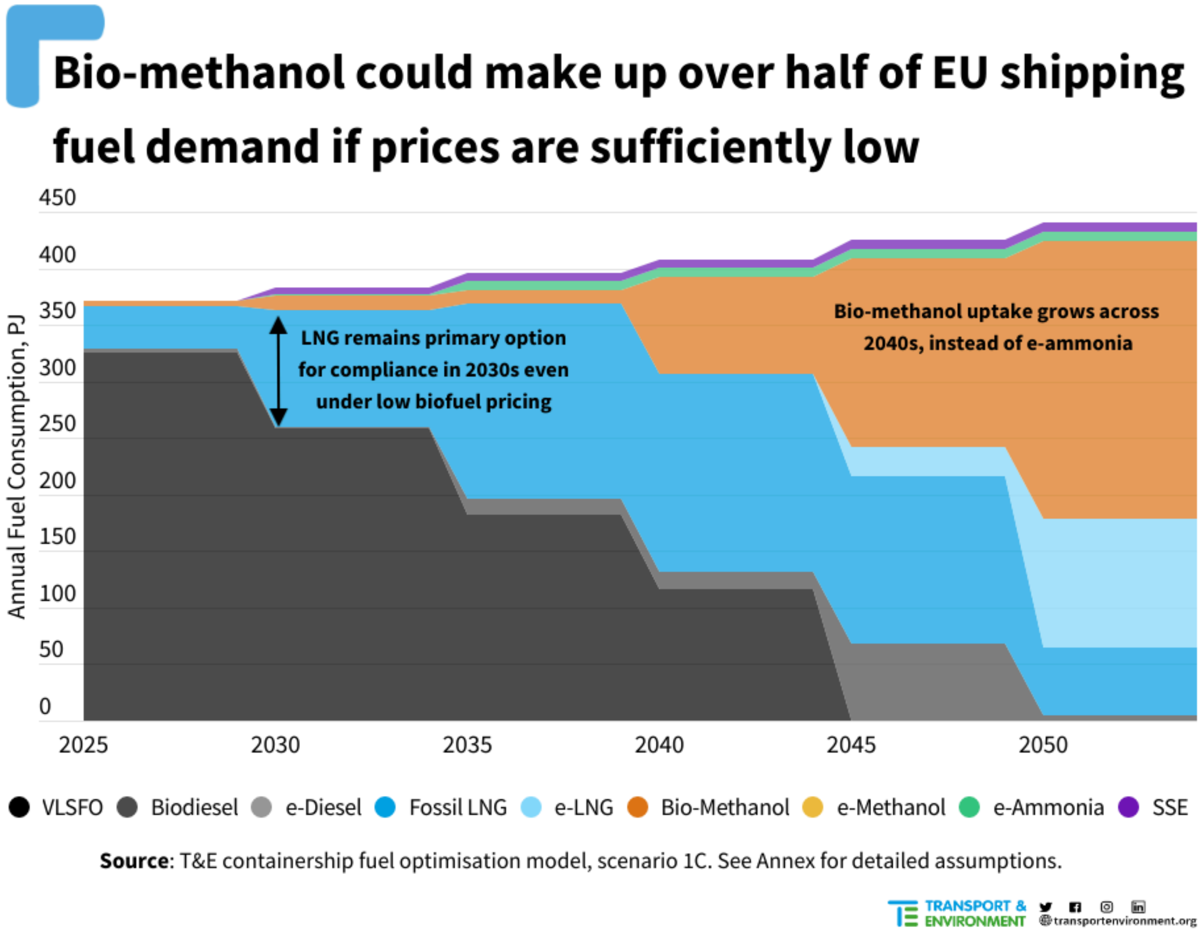

Figure 12: Projected fuel demand under scenario 1D

From 2040 onwards, as a result of low pricing, bio-methanol takes over as the fuel of choice for new ships, meaning a much higher share of methanol DF engine technology than in other scenarios. This is in contrast to rapid uptake of e-ammonia in scenarios 1A and 1B. This potential to use low cost bio-methanol is one of the factors behind the recent increase in uptake of methanol DF containerships.[15] In scenario 1C, even late in the model period e-ammonia uptake is restricted to the 2% required by the RFNBO sub-target. Given the sustainability and scalability issues around biofuels, this highlights the need for a stronger RFNBO target to provide certainty to e-fuel suppliers.

[15] According to Clarksons Research data, 26% of containership capacity in TEU ordered since the start of 2022 will be capable of using methanol as a fuel.

2.2.3. Feasibility Of Ammonia

As well as the potential to use low cost bio-methanol, interest in methanol engines can also be explained in part by its relative readiness as a technology compared to ammonia. Further ordering of methanol ships (beyond the current orderbook) is not predicted in scenario 1A, notably because e-methanol is projected to be more costly than e-ammonia across the model period. However, there are other advantages to operators from ordering methanol-fuelled ships now which are not defined within the scope of the model, such as hedging against the possibility that the risks of using e-ammonia cannot be overcome, establishing fuel supply chains and potentially lowering the risk of ordering fossil fuel ships that end up as 'stranded' assets.

Scenario 1D models an alternative pathway for further ordering of methanol DF vessels by assuming 'minimum' e-methanol prices (taking the low e-methanol price from Scenario 1B), and delaying e-ammonia uptake until 2040.[16] This reflects a scenario in which the potential safety and operational issues surrounding ammonia fuelling are not solved in the short-term.

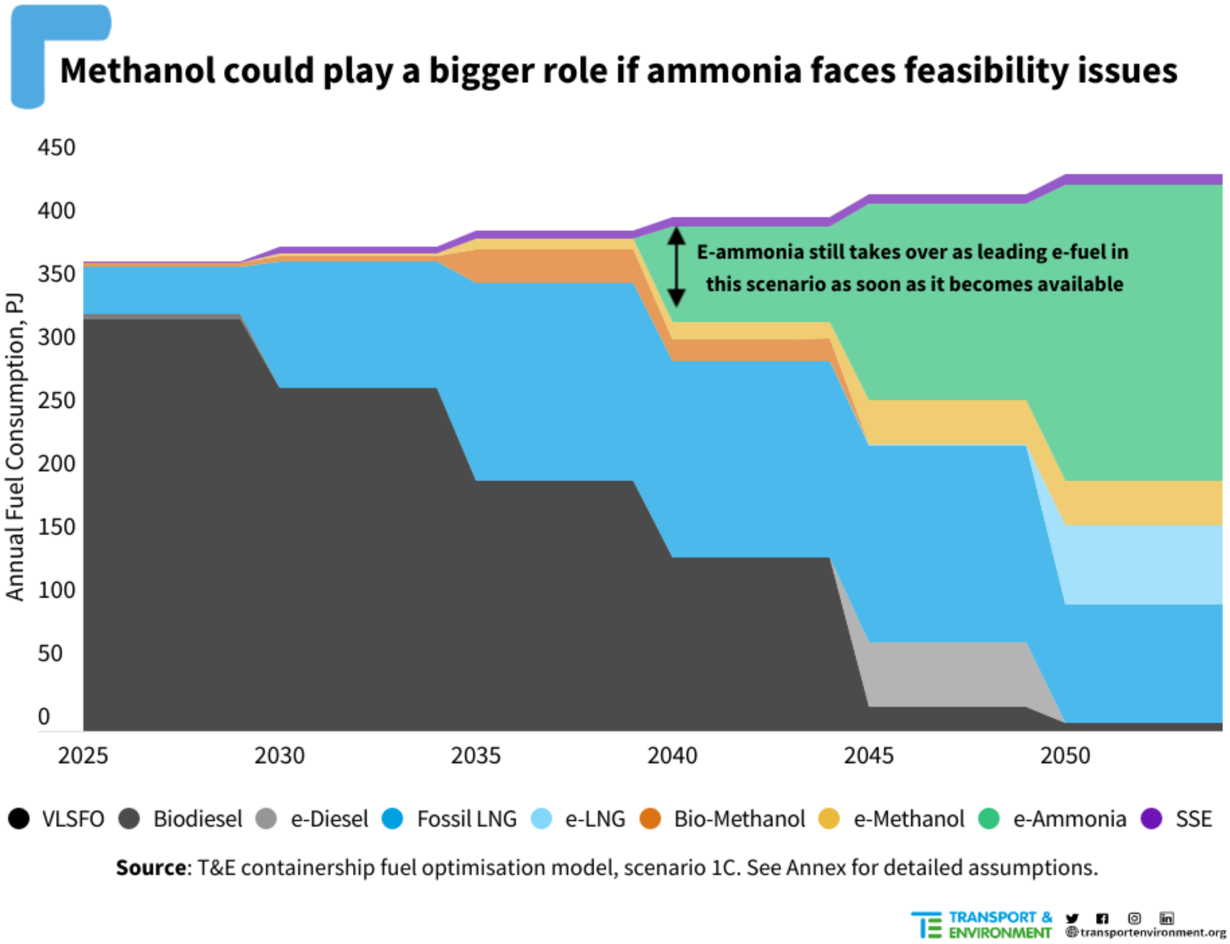

Figure 13: Projected fuel demand under scenario 1D

[16] Other assumptions are unchanged from scenario 1A

If the technical feasibility of Ammonia DF engines is delayed, methanol sees a higher uptake. In this scenario, the Methanol DF fleet would reach three times the size of the current orderbook of methanol fuelled vessels, but methanol is still superseded as the primary e-fuel used in shipping from 2040. Methanol fuels (bio-methanol and e-methanol) peak at 8% of total fuel consumption in this scenario, compared to 3% in scenario 1A, with methanol effectively acting as a 'bridging' e-fuel until e-ammonia becomes available. Given the potential competitiveness of methanol in the 2030s if ammonia is unavailable, a strengthening of EU or global regulation in the short-term could also encourage a greater role for methanol as a marine fuel.

From 2025-2039, uptake of methanol engines in this scenario is predominantly through using bio-methanol as fuel. In the event of delayed e-ammonia feasibility, the RFNBO sub-target is what motivates the introduction of renewable fuels, acting as a guarantee of demand.

3. Alternative Policy Ambition Scenarios

This section uses T&E's fuel optimisation model to look at the impact of various aspects of the FuelEU Maritime regulation, and show how the next EU Commission and co-legislators could improve the ambition.[17] In order to ensure a fair comparison with the final agreement, all of the scenarios in this section use the same 'base case' fuel and carbon prices as scenario 1A, as outlined in Annex A.3 & A.5.

3.1. Improvements on the Original EU Commission Proposal

In scenario 3A we ran the model using assumptions based on the EU Commission's initial FuelEU Maritime Agreement, with weaker emissions intensity targets and no RFNBO target or multiplier. The technology and fuel mix are largely similar to the 'final agreement' scenario 1A in Section 2.1, given the similarity of the final agreement to the initial proposal in most respects. However, the Commission proposal would have allowed longer persistence of fossil fuels (which still make up 28% of fuel demand in 2050 in this scenario), given the weaker targets, and slower uptake of RFNBOs.

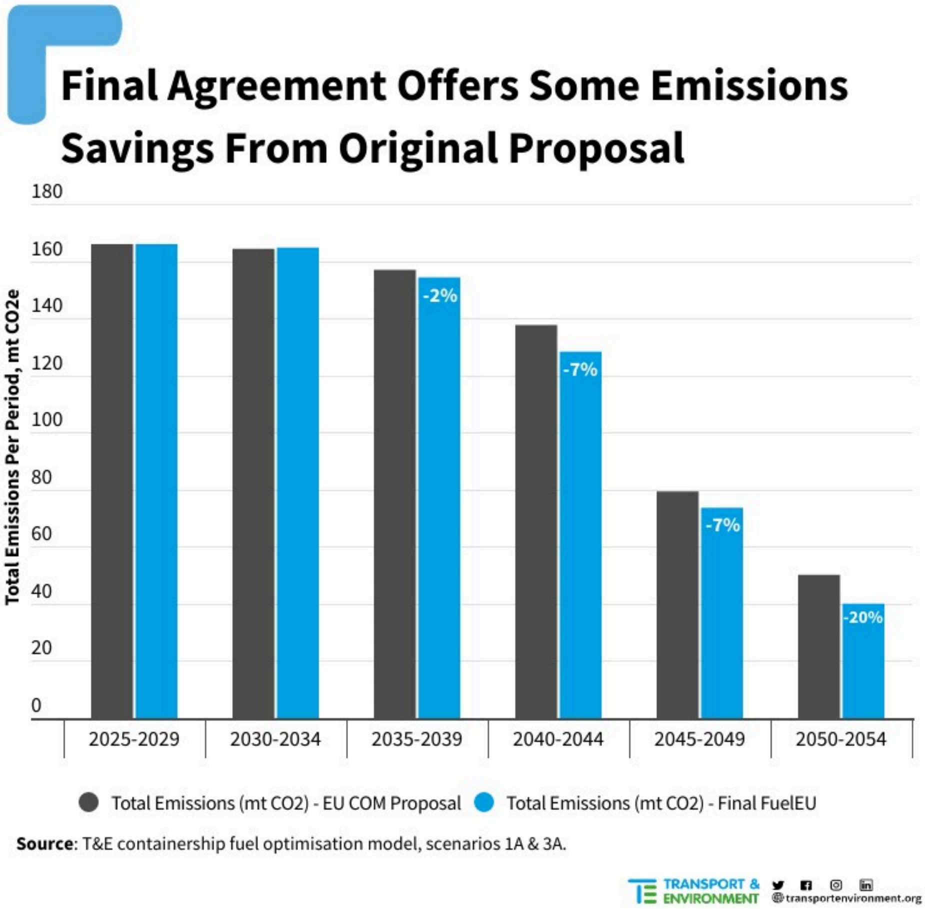

Figure 14: Annual emissions comparison between FuelEU Maritime proposal and final agreement

[17] See Annex A.9 for a detailed description of scenarios.

Without an RFNBO target, operators must still ramp up RFNBO production as quickly as they do in scenario 1A (from 0-19% of total fuel demand between 2035 and 2040 in scenario 1B, compared to 2-21% in 1A). In any scenario, we believe a well-calibrated RFNBO sub-target should increase the likelihood that fuel suppliers can rapidly scale up production as demand for these sustainable fuels rises in later periods.

The stricter emissions intensity targets in the final agreement should lead to some savings in total emissions, increasing proportionally from 2% in 2035-39 to 20% from 2050 onwards, under the current targets. Given equivalent fuel demand in these scenarios, the final FuelEU agreement is expected to cut total WtW emissions in 2025-2054 by an extra 4% compared to the EU Commission proposal.

3.2. Germany & Denmark's Council proposal

We also ran a scenario (4A) based on a submission by Germany & Denmark [13] to the European Council during the negotiations, proposing stronger emissions intensity targets, RFNBO sub-target and multiplier in FuelEU Maritime, as summarised in Table 3.

Period	Required Emissions Intensity Reduction	RFNBO Sub-target	RFNBO Multiplier
2025-2029	3%	0%	4
2030-2034	10%	2%	4
2035-2039	20%	5%	3
2040-2044	40%	12%	-
2045-2049	75%	29%	-
2050+	100%	75%	-

Table 3: Regulatory inputs in scenario 4A, based on DE/DK EU Council proposal

Under scenario 4A, the more ambitious GHG intensity and RFNBO targets would successfully limit demand for fossil LNG (peaking at 23% of fuel demand in 2035-39, down from 39% in scenario 1A). RFNBO uptake also increases more rapidly, reaching 2.2% of fuel demand in 2030-34, with the multipliers stimulating further demand above the level of the sub-target, increasing to 25% in 2040-44 and 76% in 2045-49 (compared to 24% and 58% in scenario 1A). As such, the required technological transformation in the 2040s is extremely rapid in this scenario; a more realistic shift could be encouraged by increasing the ambition of the targets in the 2030s. In any case, achieving 100% emissions reduction by 2050 would be a bare-minimum requirement of moving towards a Paris-compliant regulation.

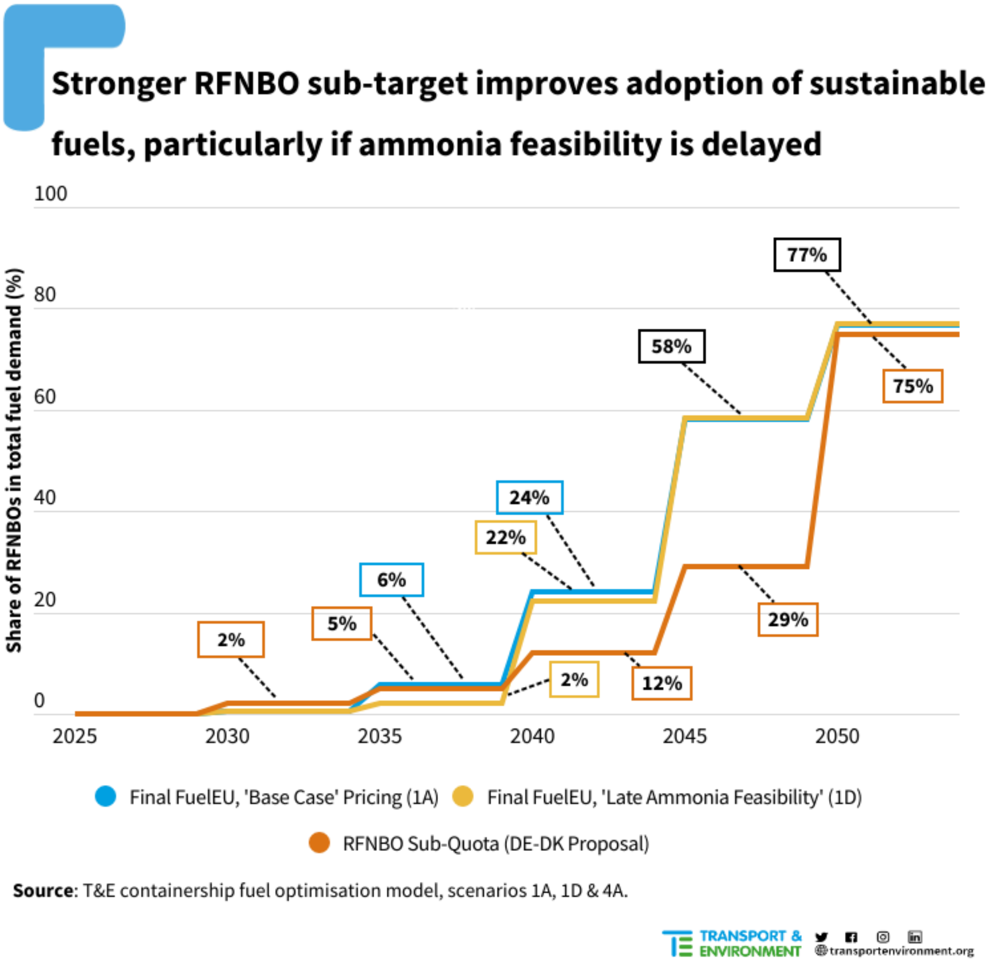

Figure 15: Comparing RFNBO uptake to the DE-DK proposed sub-target

Although the sub-targets proposed eventually rise much higher than those mandated in the final agreement, the analysis shows that they are far from being unrealistic. Fig. 15 shows that the RFNBO shares projected under the final agreement in scenarios 1A (‘base case’ pricing) and 1D (‘late ammonia feasibility’ are still well above Denmark and Germany’s proposed sub-targets. The key impact of the DE-DK sub-target proposals would be the push to adopt RFNBOs earlier. Even a minimal 2% sub-target from 2030 would provide a clearer signal to fuel suppliers to kick-start dedicated production of RFNBOs for shipping. Moreover, the analysis shows that a stronger sub-target would mean that RFNBO uptake is not stalled if ammonia feasibility is delayed; instead, this process begins to happen regardless.

3.3. SBTi 1.5°C-compliant Scenarios

The emissions modelled using scenario 1A show that the FuelEU intensity targets may not be enough to drive container shipping emissions down until the 2040s, let alone bring them down to sustainable levels. In this section we look at how the intensity targets of FuelEU Maritime could be calibrated to meet the 1.5°C compliant pathways modelled by the Science Based Targets Initiative (SBTi).

Fig. 16 shows 3 potential decarbonisation pathways for the EU container shipping industry. These show the clear gap in ambition between the current FuelEU Maritime agreement and what would be required to achieve Paris-compliant emissions.

1. The current expected pathway under the FuelEU final agreement (see Section 2.1.2).
2. An 'S-curve' trajectory modelled in line with the EU's proposal to IMO MEPC regarding new GHG targets for 2030, 2040 and 2050 [14]
3. 'S-curve' trajectory based on modelling by the Science Based Targets Initiative (SBTi), compatible with limiting the rise in global temperature to 1.5°C [6].

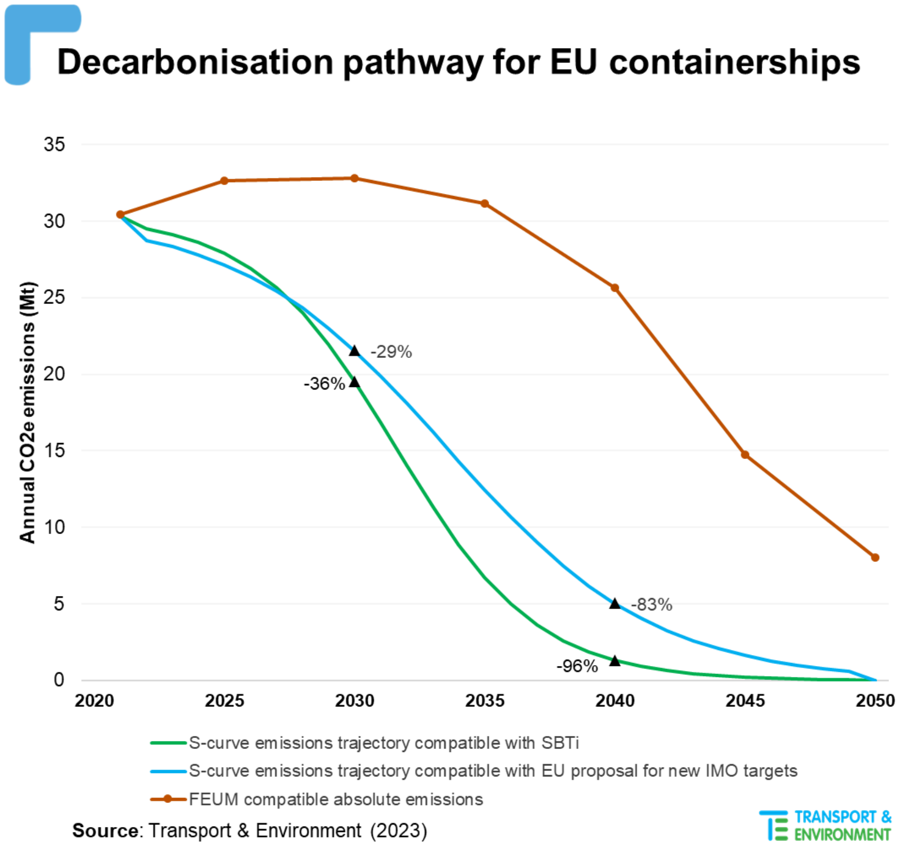

Figure 16: Potential decarbonisation pathways

In order to assess how FuelEU Maritime could be modified to achieve 1.5°C compliant emissions, we used this analysis to generate a corresponding FuelEU Maritime GHG Intensity pathway, as shown in Fig. 17. We then input these GHG intensity targets into a new scenario (5A), in order to look at the implications for fuel demand.[18] An alternative, 'low demand' scenario (5B) is also discussed in the next section.

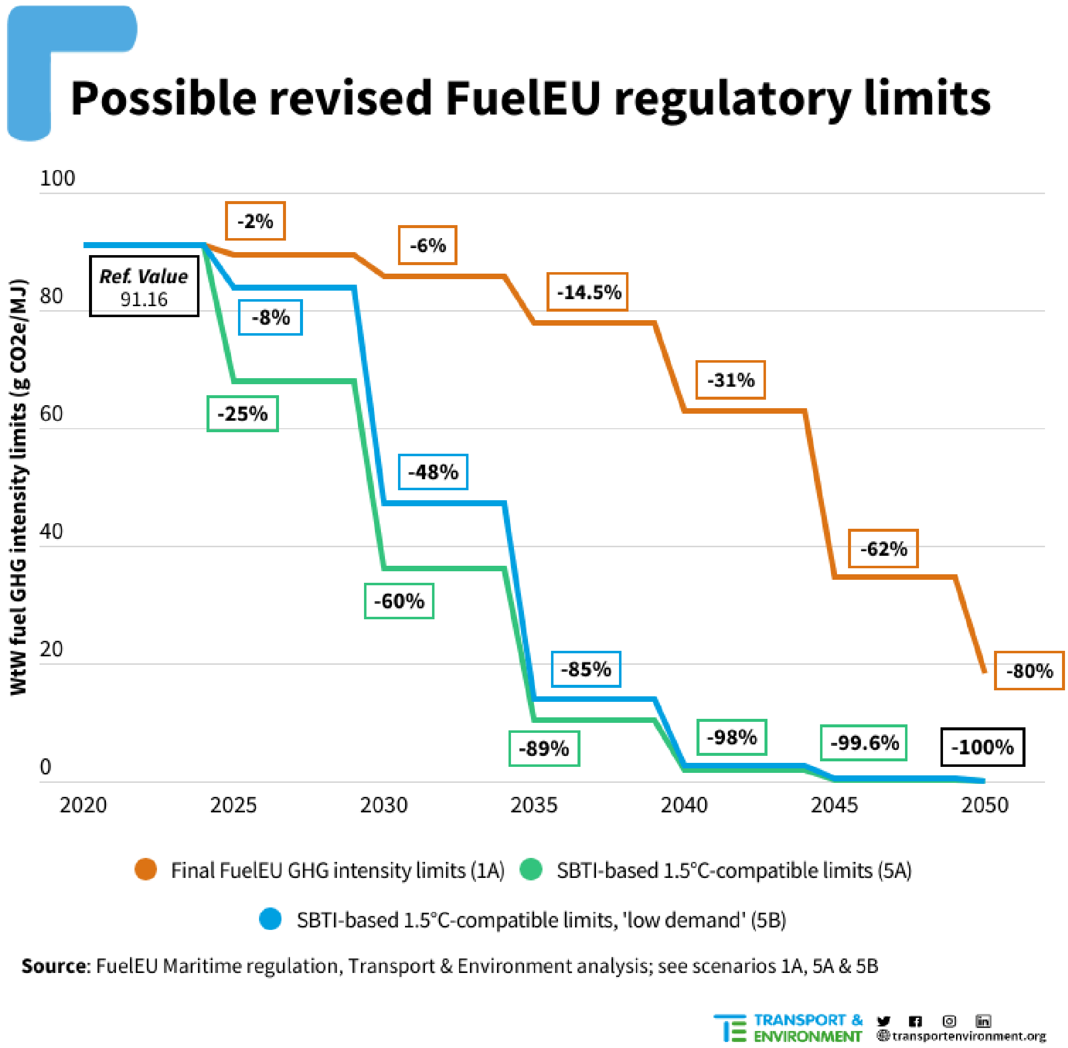

Figure 17: Potential FuelEU GHG limits matched to pathways

The results of scenario 5A are shown in Fig. 18.[19] In this scenario a rapid switch between fuels is required in every period, from biofuels in 2025-34, a mix of e-fuels in the 2040s, to full uptake of e-ammonia by 2050 (e-ammonia is the only available zero-emissions option in the model; all other e-fuels, which contain carbon, options assume a small amount of WtW emissions). For EU container shipping, costs under this

[18] In scenario 5A, the emissions reductions are achieved solely through the GHG intensity targets; we assumed no RFNBO target or multiplier. ETS prices are identical to scenario 1A.
[19] The scenario requires a more rapid transition to e-Fuels to meet 1.5°C-compliant targets. In contrast to other scenarios, where minimum emissions levels for e-Fuels are assumed to be reached in 2050 (See Annex A.3), in scenario 5A, we assume these minimum levels can be achieved from 2040 onwards.

scenario[20] are 37% higher (averaging €16.9bn per year) than in scenario 1A, owing to the rapid transformation required, but remain at comparable levels.

Compared to earlier scenarios, extremely high volumes of biofuel are needed; in 2030-34, biodiesel makes up 50% of total fuel demand, while biofuels as a whole account for 69% (262 PJ per year). If scaled up to the whole EU shipping sector (794 PJ per year), this would be equivalent to 114% of current EU biofuels consumption by all transport modes [15].

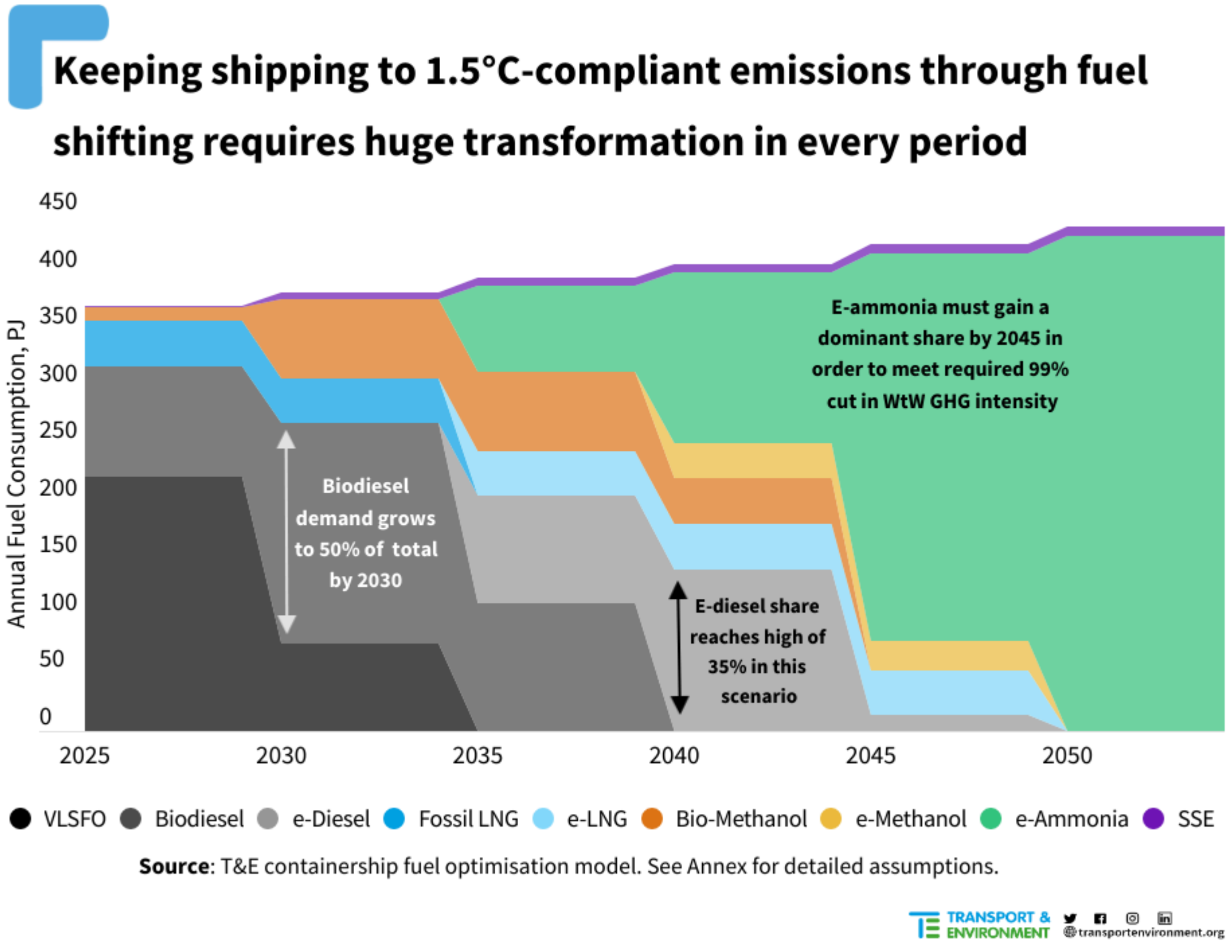

Figure 18: Projected annual fuel demand under scenario 5A

In order to look at the potential role of demand reduction in meeting 1.5°C-compliant emissions, we also modelled at an alternative scenario (5B) using the SBTi-based emissions targets discussed above, but with lower fuel demand, derived by using:

- An alternative demand growth (SSP3: 'regional rivalry') scenario from the IMO 4th GHG Study, the lowest of the report's main demand scenarios [4].

[20] Includes newbuild, fuel, ETS and SSE costs; see section 2.1.3.

- Efficiency improvements from the 'optimistic' scenario in T&E's *'Decarbonising European Shipping'* roadmap [2].[21]

As in scenario 5A, the required GHG intensity targets in this scenario were set at the required level to meet a 1.5°C compliant emissions pathway. The resulting fuel demand is shown below in Fig. 19. This scenario offers a more realistic pathway by which FuelEU Maritime could be used to put EU container shipping on a Paris-compliant pathway. As total fuel demand is reduced by 19-27% through the period, the volume of potentially unsustainable biofuels is slightly lower than scenario 5A and does not ramp up as quickly, peaking at 232 PJ per year in 2035-39 (as well as being 40% lower in 2030-34).

The total volume of e-fuels required for EU container shipping also grows on a more achievable trajectory; e-fuels demand in 2035-39 is estimated at 51 PJ per year (up from 22 PJ in scenario 1A, under the final FuelEU Agreement), before increasing more rapidly in the 2040s. This compares to 208 PJ in the same period in scenario 5A.

LNG has a limited role in a 1.5°C-compliant transition; more radical GHG intensity cuts are needed early on in these scenarios than are provided by fossil LNG, while other e-fuels are generally more competitive than e-LNG later in the period. In both scenarios 5A and 5B, operators only use the LNG ships they already have in their fleets in 2025 (based on the current fleet and orderbook).[22]

[21] 'Non-cruise' sector efficiency improvements (30% by 2030, 39% by 2050).
[22] Scenario 5B is the only scenario in this report in which bio-LNG is included in the fuel demand mix, with operators of LNG ships using fossil LNG from 2025-34, bio-LNG from 2035-39 and e-LNG from 2040 onwards.

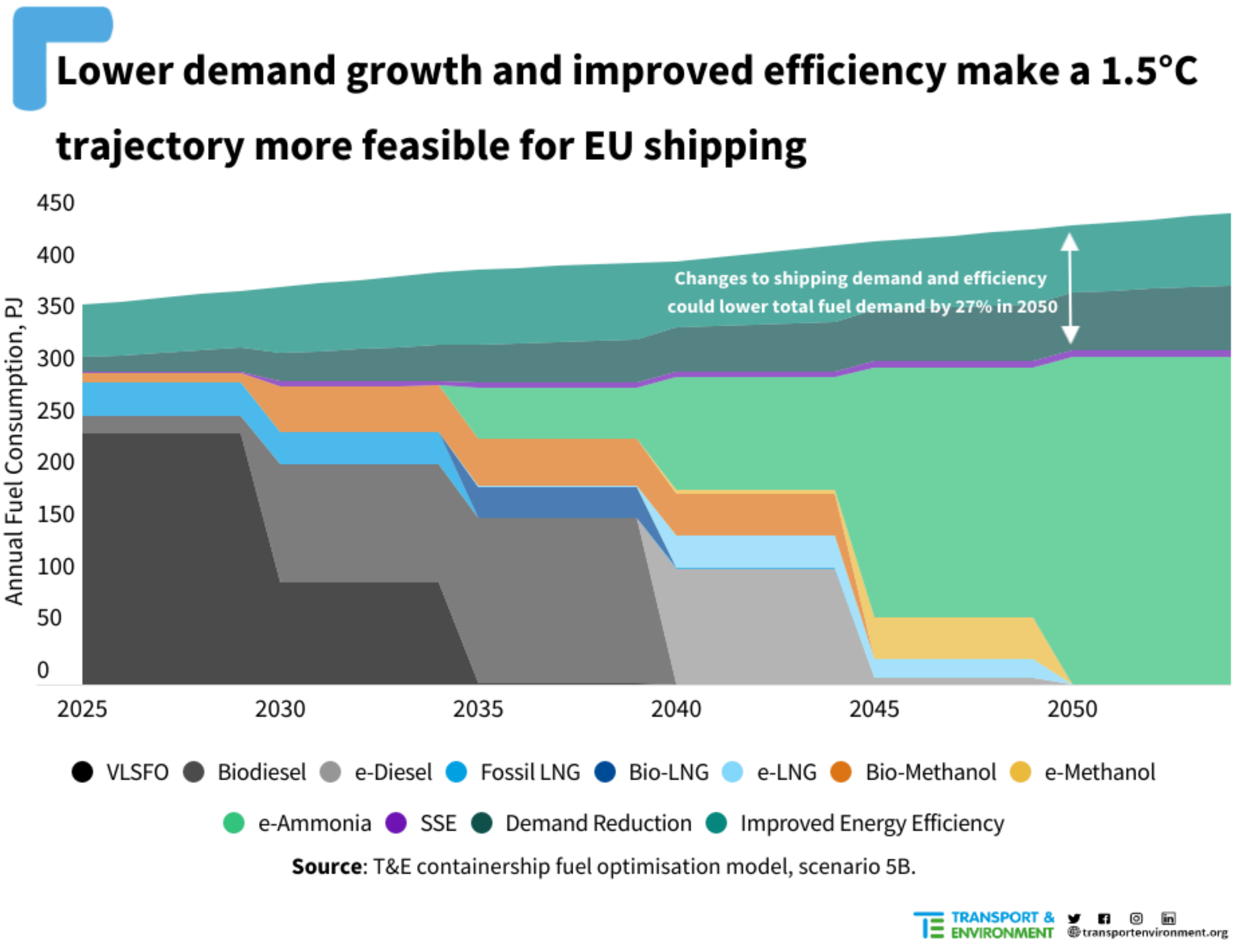

Figure 19: Projected fuel demand under scenario 5B

3.4. Cost Impacts Of Fuel EU Maritime & The EU ETS

In all of the above scenarios, EU ETS price projections are unchanged; the analysis so far has focussed on the impact of the FuelEU Maritime regulation. EU ETS prices in these scenarios are based on analysis by the IEA (2022) [16] (see Annex A.5 for further detail). We also modelled a scenario (1E) which includes hypothetical, much higher ETS prices in order to test the sensitivity of fuel demand in the model to carbon pricing. These prices are given in Table 4 below; prices for 2035 and 2045 are interpolated.

Year	EU ETS price (€/t CO_2)	
	Scenario 1A and Others	Scenario 1E
2025	€97	€97
2030	€129	€150
2040	€189	€275
2050	€231	€400

Table 4: Carbon prices used in scenarios

Even with these higher carbon prices, changes in fuel demand are relatively limited, as shown in Fig. 20. Even though compliant biofuels and e-fuels are expected to be zero-rated under the EU ETS (in terms of the TtW CO_2 emissions factors applied), the gap between the expected costs of fossil and alternative fuels is still likely to be too large to be bridged by ETS costs until later in the model period, by which point FuelEU Maritime already requires significant fuel switching by operators to meet GHG intensity targets. A more significant jump in prices by 2030 would be required for the EU ETS to have a significant impact on demand for sustainable fuels.

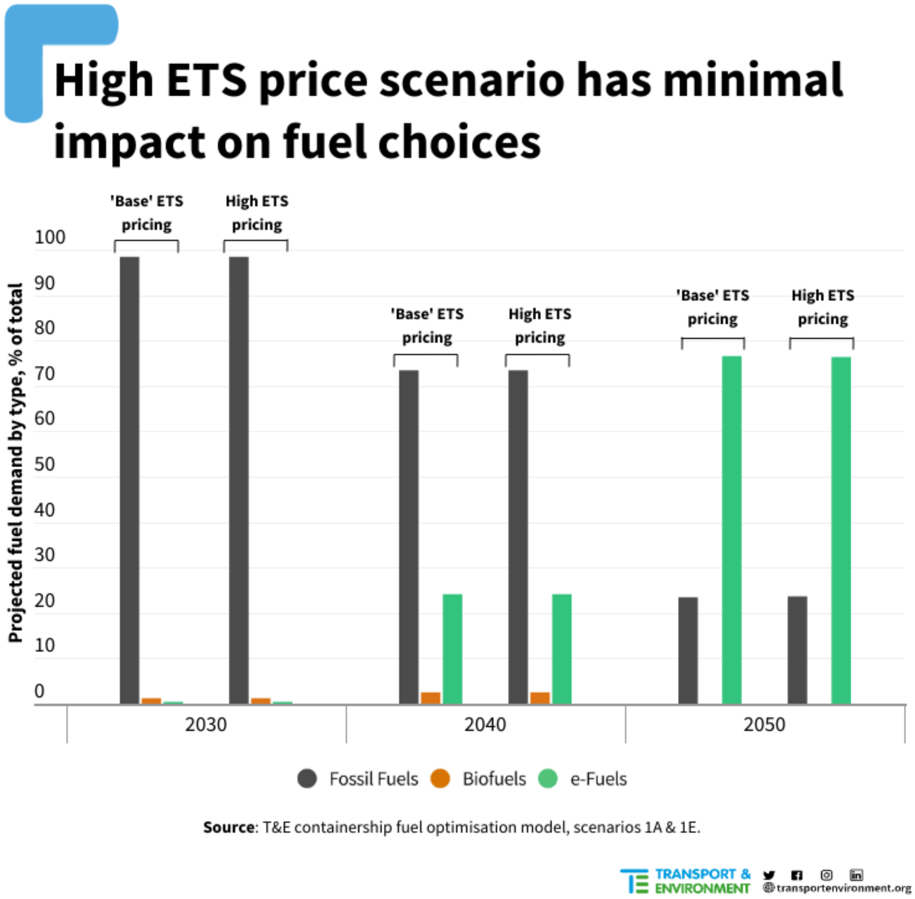

Figure 20: Fuel demand by type under scenarios 1A & 1E

4. Conclusion And Policy Recommendations

The FuelEU Maritime regulation is in many ways a positive step for regulation of the shipping industry, introducing fuel standards that will mandate a transition to lower carbon fuels, as well as a small RFNBO sub-target which will kick-start the use of sustainable e-fuels in shipping in the 2030s. This report has outlined a number of different scenarios showing how the final agreement could play out in the containership segment, with our 'base case' suggesting that under expected pricing, demand for fossil LNG would continue to grow across the next decade, before uptake of e-ammonia begins to grow rapidly from 2035. However, the alternative pricing scenarios modelled in this report also show the potential demand from EU operators for other shipping fuels, including bio-methanol and e-methanol, under different price conditions.

Although the ambition of the regulation has improved from the initial EU Commission proposal, there remains significant room for improvement, and FuelEU Maritime as it stands is a long way from putting EU shipping on a 1.5°C-compliant emissions trajectory. The regulation also green-lights unacceptably heavy use of fossil LNG and also does too little to guarantee demand for RFNBOs, which could be threatened if prices are not competitive with less sustainable biofuel alternatives. As such, Transport & Environment recommends the next Commission and co-legislators to make a number of improvements to the 'Fit for 55' package in the shipping sector:

1. Align the greenhouse gas intensity (GHG) targets of FuelEU Maritime with a 1.5°C-compliant emissions trajectory from the global Science-Based Targets Initiative (SBTi).
2. Set higher and additional RFNBO sub-targets for shipping, and remove the option for ships to use any advanced biofuels in place of RFNBOs; this would act as a stronger guarantee of demand for renewable fuels in the face of uncertainty over fuel prices, providing clarity to fuel suppliers.
3. Set stronger penalties for non-compliance with the GHG intensity limits and RFNBO sub-targets in FuelEU Maritime, in order to discourage 'pay-to-comply' as a viable alternative to fuel switching.
4. Expand the FuelEU Maritime to include cargo and passenger vessels under 5,000 GT, as well as offshore vessels and other non-cargo ships. These ships made up an estimated 20% of WtW emissions in the EU in 2021.
5. The LNG bunkering infrastructure mandate in the Alternative Fuels Infrastructure (AFIR) should be discontinued and replaced with mandates for fuels with a clearer pathway to sustainability, namely ammonia, methanol and hydrogen.
6. The RFNBO supply target in RED III should be made mandatory in order to provide a minimum floor for the supply of sustainable fuels in maritime ports across Europe.
7. Implement mandatory energy efficiency requirements on European shipping to bring down total fuel demand for a smooth transition.

Annex A: Detailed Methodology

A.1. Fuel Optimisation Model

T&E's containership fuel optimisation model encompasses containerships operating within the EU-MRV system from 2025 to 2054. The model is split into 5 year periods. In each period, every operator minimises total costs while fulfilling its given fuel demand (in terms of required energy) and complying with limits on emissions intensity (as well as any fuel sub-targets and multipliers) as mandated by the Fuel EU Maritime regulation.

Within the model, operators can choose from 4 vessel technologies (Fuel Oil, LNG Dual Fuel, Methanol Dual Fuel and Ammonia Dual Fuel) to make up their fleet. Each of these technologies allows them to use a subset of the 9 available fuels (see Annex A.3). In the first period (2025-29), we assign operators a mix of technologies based on their existing fleet and orderbook, and the model optimises the choice of fuels. In subsequent periods, the model optimises the combination of both technologies and fuels. Each operator chooses its mix of technologies and fuels in order to minimise its total combined newbuilding costs (generated by adding capacity to its fleet) and fuel costs (calculated from projected fuel prices, including carbon pricing). Operators can only change their fleets by building new vessels, not by retrofitting vessels from one technology to another.

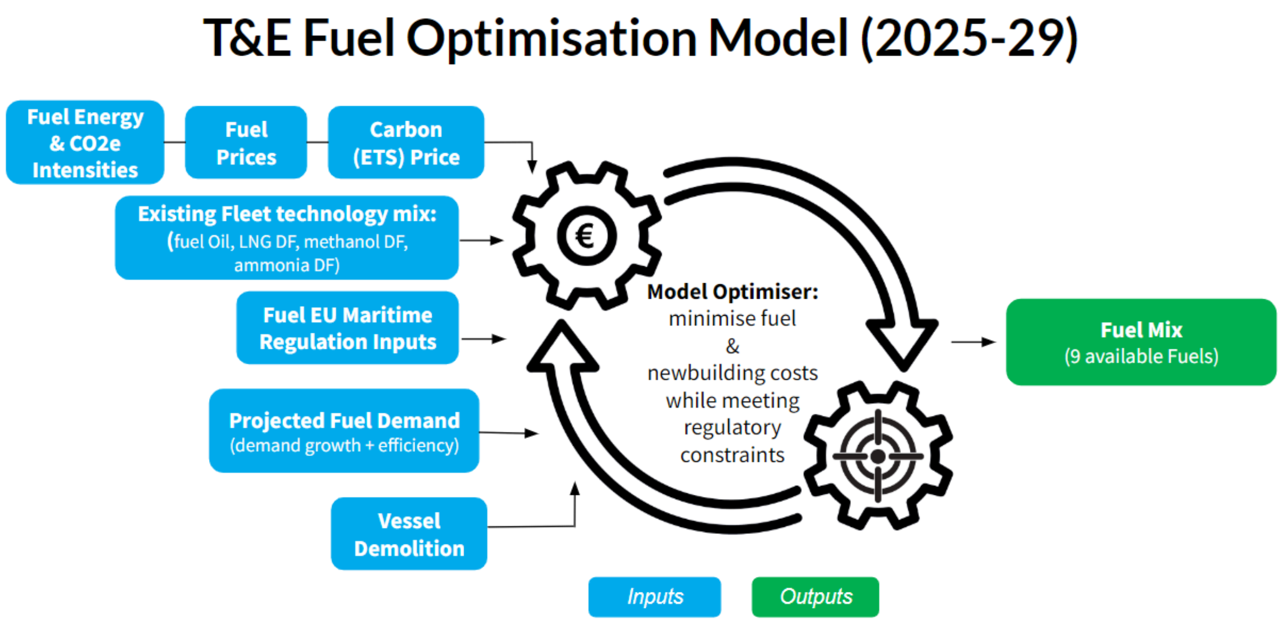

Figure 21: Diagram of model inputs and outputs (2025-2029)

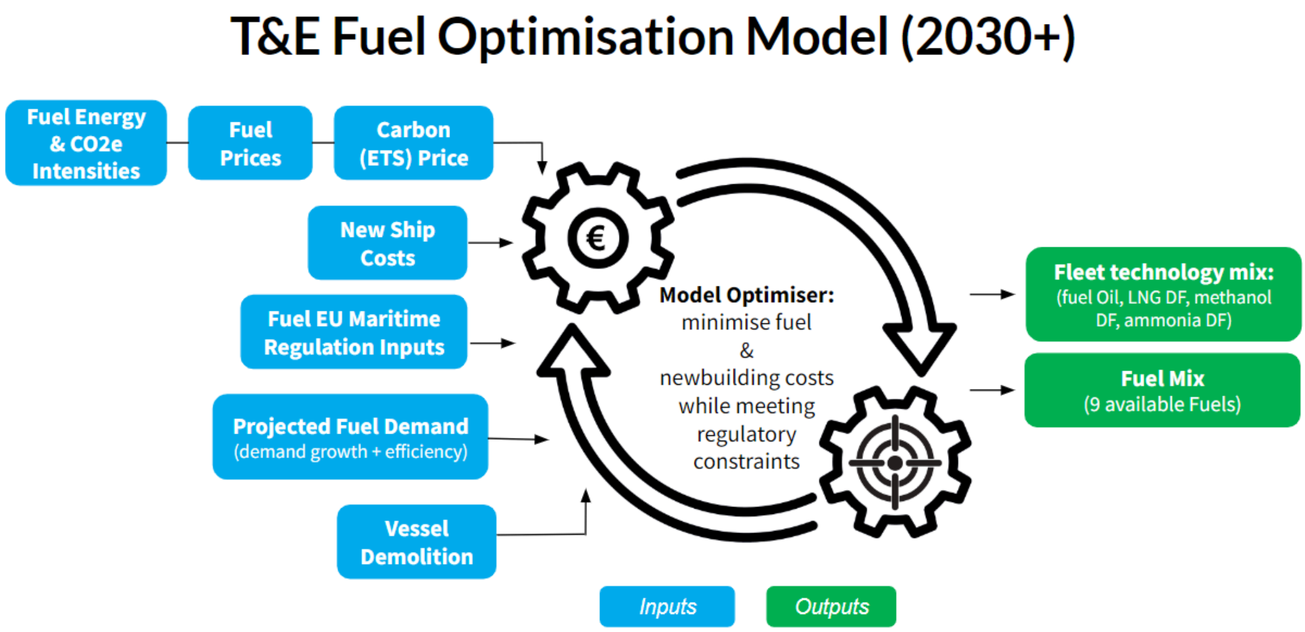

Figure 22: Diagram of model inputs and outputs (2030 onwards)

Some aspects of the regulatory environment are simplified in the model:

- Regulation at IMO or national level does not have an impact on fuel choices; we only look here at the impact of EU regulation. In reality, the extent of IMO regulation is still highly uncertain beyond 2026.
- Pooling of emissions under FuelEU Maritime is assumed to be within operators only; in reality vessel emissions can potentially be pooled with those of other operators using the same data verifier.
- In the model, the 'compliance balance' under Fuel EU Maritime cannot be shifted between years, and so operators must comply with emissions intensity limits within each period.
- Operators in the model comply fully with the regulation; there is no 'pay-to-comply' mechanism.

Alongside its significant impact on emissions (33% of EU emissions in 2021) the analysis focuses on the containership segment because a number of market properties make it feasible to model within the context of the FuelEU Maritime regulation:

- High levels of consolidation make it likely that most operators, who typically control a large number of vessels, will 'pool' their ships internally when reporting their emissions under FuelEU Maritime. In other ship types with less consolidation, pooling behaviour is expected to be more complex and varied.
- A high proportion of owner-operators, in contrast to other market segments where ships are operated or chartered by different companies to those that own them. Owner-operators may be more likely to make optimal choices over technology and fuel choices as they have better visibility over a vessel's operating patterns.

- The majority of containerships operate on regular 'liner' services. In other segments, where 'tramp shipping' is more prevalent, owners do not necessarily know where their vessels will be deployed when they build them, and so are less likely to invest in high CAPEX solutions.

A.2. Regulation Inputs

Operators in the model must comply with a number of inputs based on the FuelEU Maritime regulation, namely emissions intensity (at 5-yearly reductions from a baseline of 91.16g CO_2e/MJ), and the agreed RFNBO sub-target and multiplier. We assume that the proposed RFNBO sub-target enters into force in 2034 following the triggering of the 'sunrise clause' (to be enacted if uptake of RFNBOs is less than 1% of total fuel consumption in 2031) in the final agreement, with the RFNBO multiplier ending at the same time. These assumptions can be altered in the model, as in the alternative policy scenarios in Section 3. Table 5 provides the input assumptions used for all scenarios based on the FuelEU 'final agreement'. Within the model, operators can choose to 'over-comply' with these regulatory constraints if this decreases their overall costs.

Period	Required Emissions Intensity Reduction	Maximum Emissions Intensity (g CO_2e/MJ)	RFNBO sub-target (Averaged Across Period)	RFNBO Multiplier (Averaged Across Period)
Reference Value	-	*91.16*	-	-
2025-2029	2.0%	89.34	0.0%	2.0
2030-2034	6.0%	85.69	0.4%	1.8
2035-2039	14.5%	77.94	2.0%	1.0
2040-2044	31.0%	62.90	2.0%	1.0
2045-2049	62.0%	34.64	2.0%	1.0
2050+	80.0%	18.23	2.0%	1.0

Table 5: FuelEU Maritime policy inputs into all 'final agreement' scenarios

A.3. Technologies & Fuels

Operators in the model are able to build their fleet from 4 vessel technologies (Fuel Oil, LNG Dual Fuel, Methanol Dual Fuel & Ammonia Dual Fuel), each of which allow them to use a subset of 9 shipping fuels (VLSFO, fossil LNG, Biodiesel, Bio-LNG, Bio-Methanol, e-diesel, e-LNG, e-methanol and e-ammonia) as outlined in Table 6. All technologies allow operators to use a biofuel and an e-Fuel option, with the exception of Ammonia; bio-Ammonia is not commercially produced today [17] and is not generally proposed as a future shipping fuel, so available price forecasting is extremely limited. In the model, VLSFO (which makes up the majority of current global shipping fuel demand) is used as a proxy for all oil-based shipping fuels including MGO. The model does not include grey (fossil) ammonia and methanol as these fuels have much higher WtW GHG intensity than VLSFO while being more expensive; as a result, it is highly unlikely that companies will resort to these fuels for FEUM compliance.

Engine Technology	Fuel Oil	LNG Dual Fuel	Methanol Dual Fuel	Ammonia Dual Fuel
Available Fuels	VLSFO	VLSFO	VLSFO	VLSFO
	Biodiesel	LNG	Bio-methanol	e-ammonia
	e-diesel	Bio-LNG	e-methanol	
		e-LNG		

Table 6: Technologies & fuels included in the model

This study does not include an analysis of fuel supply or the technical feasibility of fuels. Unless otherwise specified in a given scenario, operators can use each technology and fuel in any quantity during each period; there are no hard constraints on the supply of fuels, or the capacity to build new vessels with any engine technology.

At the start of the first period, each operator's fleet is split according to current data on its containership fleet and orderbook, in TEU terms.[23] We use this as a proxy to split each operator's fleet by vessel technology (in terms of fuel consumption) at the start of the model period in 2025.

Operator	Fuel Oil	LNG DF	Methanol DF	Ammonia DF
MSC	80.9%	19.1%	0.0%	0%
Maersk	90.6%	0.0%	9.4%	0%
CMA CGM	70.0%	21.9%	8.2%	0%
COSCO Group	91.5%	0.0%	8.5%	0%
Hapag-Lloyd	84.8%	15.2%	0.0%	0%
Evergreen Group	100.0%	0.0%	0.0%	0%
ONE	100.0%	0.0%	0.0%	0%
UniFeeder	100.0%	0.0%	0.0%	0%
HMM Co Ltd	98.6%	1.4%	0.0%	0%
Zim (ZISS)	66.0%	34.0%	0.0%	0%
X-Press Feeder Group	96.2%	0.0%	3.8%	0%
BG Freight	100.0%	0.0%	0.0%	0%

[23] Source: Clarksons Research

Eimskip	100.0%	0.0%	0.0%	0%
Boluda Lines	100.0%	0.0%	0.0%	0%
Borchard Lines	100.0%	0.0%	0.0%	0%
Yang Ming	100.0%	0.0%	0.0%	0%
Eucon	100.0%	0.0%	0.0%	0%
Samskip	100.0%	0.0%	0.0%	0%
ICL	100.0%	0.0%	0.0%	0%
JSV Logistic	100.0%	0.0%	0.0%	0%
Remainder	*92.6%*	*7.3%*	*0.1%*	*0%*
TOTAL	**87.3%**	**9.6%**	**3.1%**	**0%**

Table 7: Technology mix for each operator in 2025

In order to calculate compliance with FuelEU Maritime emissions intensity limits, we estimate well-to-wake (WtW) emissions intensities for each of the available fuels; for some fuels, this also varies between periods. These factors are shown in Table 8. The emissions factors for VLSFO, Biodiesel (waste cooking oil), fossil LNG and Bio-LNG (from biowaste) are calculated using the values in FuelEU Maritime Annex II [18] and the Renewable Energy Directive III. For LNG, containerships in this model are assumed to use a high-pressure 2-stroke Diesel-cycle engine, as this is the engine type for most recently-built or ordered case for the majority of ships currently on order.[24] For Bio-methanol, final emissions intensity factors are not yet established in the FuelEU Maritime regulation and so an alternative value is used [19].

Emissions factors for all four e-fuels were calculated as such:

- For 2025-29, by using the RED II fossil fuel comparator for transport fuels (70% reduction from the comparator value of 94g CO2e/MJ) in 2025-29.
- For 2030-34, we assume an improved reduction of 85% from this baseline.
- For the remainder of the model period, GHG intensity is trended downwards linearly to reach estimated minimum potential emissions factors[25] in 2050.

Electricity can also be used by operators (see Annex A.4) in the model and is assumed to be zero-emission as per Annex I of the FuelEU Maritime regulation.

[24] Vessels with other LNG DF engine types (more common in other segments, such as cruise ships) are assumed to have higher WTW emissions in FuelEU Maritime Annex II due to higher methane slip.
[25] Calculated using data from EU RED Delegated Act on RFNBOs [20], assuming 100% renewable electricity and direct air capture (DAC, where required) as inputs.

Fuel	WTW Emissions Intensity (g CO_2e/MJ)					
	2025-29	2030-34	2035-39	2040-44	2045-49	2050-54
VLSFO	92.63	92.63	92.63	92.63	92.63	92.63
Biodiesel (WCO)	14.90	14.90	14.90	14.90	14.90	14.90
e-diesel	28.20	14.10	10.87	7.65	4.42	1.19
Fossil LNG	77.43	77.43	77.43	77.43	77.43	77.43
Bio-LNG	20.24	20.24	20.24	20.24	20.24	20.24
e-LNG	28.20	14.10	11.00	7.89	4.79	1.68
Bio-Methanol	12.60	12.60	12.60	12.60	12.60	12.60
e-methanol	28.20	14.10	11.21	8.32	5.43	2.54
e-ammonia	28.20	14.10	10.58	7.05	3.53	0.00
Electricity	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*

Table 8: WtW emissions intensities by fuel and period

Sources: FuelEU Maritime Annex II [18] , EU RED Delegated Act on RFNBOs [20], T&E calculations, Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping [19] (Bio-Methanol only; the factor for 2020 is used in all periods to keep the approach consistent with other biofuels).

Tank-to-wake emissions factors (also on a CO_2 equivalent basis) used in the model to calculate the cost of complying with the EU Emissions Trading Scheme (ETS) are given in Table 9. Biofuels (assumed to be compliant with RED III) and e-Fuels compliant with the relevant legislation[26] are assigned zero TtW emissions.

Fuel	TTW Emissions Intensity (g CO2e/MJ)
VLSFO	79.43
Biodiesel (WCO)	0
e-diesel	0
Fossil LNG	59.28
Bio-LNG	0
e-LNG	0

[26] EU MRV Delegated Acts (2023, ongoing)

Fuel	TTW Emissions Intensity (g CO2e/MJ)
Bio-Methanol	0
e-methanol	0
e-ammonia	0
Electricity	*0.00*

Table 9: TtW emissions intensities for each fuel. Source: FuelEU Maritime, T&E calculations.

A.3.1. Fuel Prices

Pricing of fuels in the model is based on the available literature on projected future European fuel prices. This literature review was focused mainly on sources that include a wide range of fuels, to ensure more consistency in input assumptions. Table 10 shows the estimated fuel prices used in all of the 'base case' pricing scenarios in this report. Where projected prices are unavailable for a given fuel at any point, data is estimated using linear interpolation (including use of historical/'current' estimates for 2020 prices in some cases).

Fuel	Fuel Prices Used In 'Base Case' Pricing Scenarios (€/GJ)						
	2020	2025	2030	2035	2040	2045	2050
VLSFO	n/a	12.7	11.3	10.6	10.0	10.0	10.0
Notes - 2025: Average of Q1 2023 Clarksons Research Rotterdam prices. 2030: Average of CEDelft (2020) midpoint, LR/UMAS (2020) and MMMCZCS (2021) baseline. 2040, 2050: Average of LR/UMAS (2020) and MMMCZCS (2021) baseline. Other values interpolated.							
Biodiesel (WCO)	22.3	28.0	33.7	40.1	46.6	52.6	58.6
Notes - 2020: Average of ICCT (2020) midpoint (FAME) and LR/UMAS (2020) midpoint. 2030, 2040, 2050: LR/UMAS (2020) midpoint only. Other values interpolated.							
e-diesel	71.1	65.3	59.6	57.2	54.7	52.3	49.8
Notes - All periods: Average of Ricardo (2020, High DAC case) and CONCAWE (2022, Southern Europe prices); CONCAWE interpolated in 2040. Other values interpolated.							
Fossil LNG	n/a	17.4	8.7	8.3	7.8	8.0	8.1
Notes - 2025: Average of Q1 2023 Clarksons Research NW Europe prices. 2030: Average of CEDelft (2020) midpoint and MMMCZCS (2021) Baseline. 2040, 2050: MMMCZCS (2021) Baseline only.							
Bio-LNG	28.5	33.4	38.3	38.7	39.0	39.1	39.1
Notes - 2020: Sea-LNG (2022) estimate only. 2030: Average of CE Delft (2020) midpoint and Ricardo/CONCAWE (2022). 2040: Ricardo/CONCAWE (2022) only							

e-LNG	57.5	52.7	48.0	45.9	43.8	41.7	39.6
Notes - All periods: Average of Ricardo (2020, High DAC case) and CONCAWE (2022, Southern Europe prices); CONCAWE interpolated in 2040. Other values interpolated.							
Bio-Methanol	21.2	24.7	28.1	33.4	38.7	43.8	48.9
Notes - 2020: Average of ICCT (2020) midpoint and LR/UMAS (2020) midpoint. 2030, 2040, 2050: LR/UMAS (2020, waste source) midpoint only.							
e-methanol	64.5	59.0	53.4	51.0	48.5	46.1	43.7
Notes - All periods: Average of Ricardo (2020, High DAC case) and CONCAWE (2022, Southern Europe prices); CONCAWE interpolated in 2040. Other values interpolated.							
e-ammonia	39.2	36.3	33.5	32.2	30.9	29.6	28.3
Notes - All periods: Average of Ricardo (2020, High DAC case) and CONCAWE (2022, Southern Europe prices); CONCAWE interpolated in 2040. Other values interpolated.							

Table 10: Fuel prices used in 'Base Case' model scenarios, not including carbon prices (see Annex A.5)

Sources: T&E Calculations, Clarksons Research [21], CE Delft (2020) [22], LR/UMAS (2020) [23], Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (2021) [24], ICCT (2020) [25]], Ricardo/T&E (2020) [26], CONCAWE (2022) [27], SEA-LNG (2022) [28], Ricardo (2022) [29]

For each period in the model, fuel prices are taken as an average of values at the start and end of the period. For each estimate, sources are weighted equally (even if multiple prices are averaged for a given source). In general, the sources used are based on projected fuel costs; the differential between costs and end-user pricing is extremely uncertain. Most price estimates are based on expected prices/costs in Europe; while bunkering can take place outside of Europe, shipping fuel prices have historically had limited regional variation and this is assumed to remain the case.

A.4. Shoreside Electricity (SSE)

Operators can also use shoreside electricity (SSE) to meet some of their energy requirements in the model. Under FuelEU Maritime and the Alternative Fuels Infrastructure Regulation (AFIR), 90% of electrical power supply at berth (not including power currently supplied by auxiliary boilers) is required to be met by SSE from 2030 at major 'TEN-T' ports. From 2035, operators must use SSE at ports where it is available, which may encourage further uptake. As a result of the increased efficiency of using onshore power compared to an auxiliary engine [30], we assume in the model that only 50% as much energy is required from SSE as would be otherwise be generated by auxiliary engines onboard.

All operators are assumed to meet the same proportion of their energy demand using SSE in each period, and electricity costs are not included in the model optimisation. Table 11 shows the proportion of energy met by SSE in each period in all scenarios, unless stated otherwise.

Period	Electricity Use At Berth (% Of Total Energy)	% Of Port Calls Assumed To Use SSE	% Of Total Energy To Be Supplied By SSE	Notes
2025-2029	4.8%	10.0%	0.5%	Assume low-level uptake of SSE
2030-2034	4.8%	65.7%	3.2%	SSE to be used at 90% of port calls at TEN-T ports (c.73% of port calls)[27]
2035-2039	4.8%	72.0%	3.5%	We assume the proportion of ports with SSE available increases to 80% (again with a usage factor of 90%) during the remainder of the model period.
2040-2044	4.8%	72.0%	3.5%	
2045-2049	4.8%	72.0%	3.5%	
2050-2054	4.8%	72.0%	3.5%	

Table 11: Assumptions on shoreside electricity (SSE) use by period

Note: Electrical power at berth calculated using EU-MRV data (emissions at berth account for 7.3% of 'semi-full scope' MRV emissions); Auxiliary engines assumed to account for 65.7% of fuel consumption at berth [4].

A.5. Carbon Prices

In order to incorporate the impact of the EU Emissions Trading System (ETS) into the analysis, carbon pricing is also added to the fuel prices in Annex A.3.1, to calculate the final price of fuels used by operators. These prices are applied to each fuel using the TtW emissions factors in Annex A.3. As per the EU ETS, the carbon price is only applied to 70% of emissions in 2025, and 100% thereafter.

For 2025, we use the current price of EU Allowances (EUAs) under the EU ETS of €97/tonne [31]. Thereafter, carbon prices for 2030, 2040 and 2050 are based on the 'Advanced Economies: Net Zero Pledges' scenario in the IEA's *World Energy Outlook* (2022, original prices in USD) [16]. Prices for 2035 and 2045 are interpolated; the prices in Table 12 below are used in all scenarios in this report unless otherwise stated.

	Carbon Price Used In 'Base Case' Pricing Scenarios (€/t CO_2)					
	2025	2030	2035	2040	2045	2050
Carbon Price (€/t CO_2)	96.7	129.1	159.1	189.1	209.9	230.6

Table 12: TtW emissions intensities for each fuel. Source: FuelEU Maritime, T&E calculations

[27] T&E calculation using AIS data.

In order to test the relative impact of carbon pricing and fuel standards, we also ran a scenario (2B) in which the EU ETS is enforced (with the above 'base case' carbon prices), but FuelEU Maritime is not implemented. The results of this are shown below in Fig. 23. Although, as discussed elsewhere, the EU ETS will be a significant revenue raising measure and can drive change in combination with other policies, carbon pricing alone in this scenario is not sufficient to drive a transition to clean fuels. Instead, under this scenario, operators transition over time to using 73% fossil LNG (which generates slightly higher CAPEX, but lower fuel and ETS costs) by 2050, but uptake of e-fuels (and indeed biofuels) is zero.

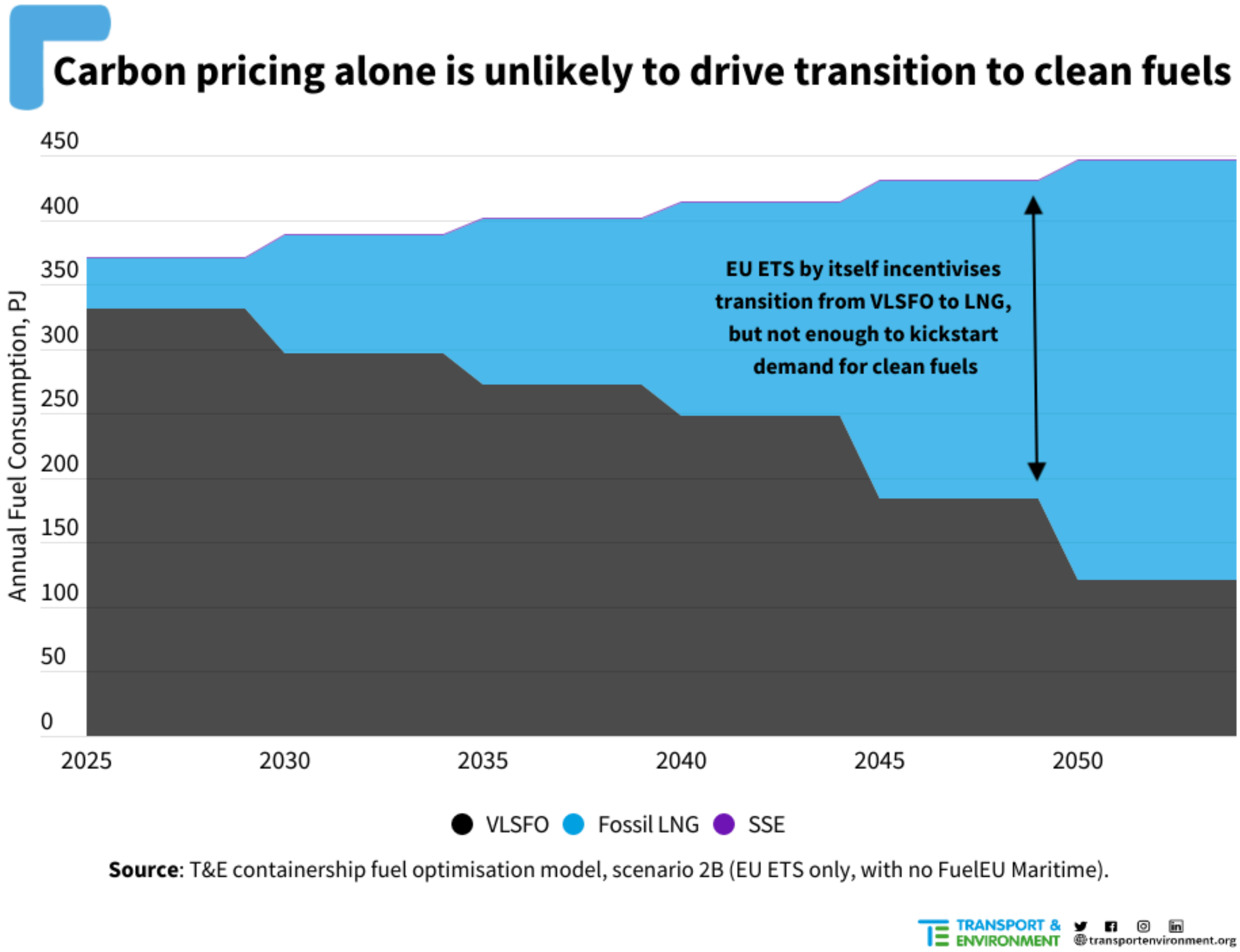

Figure 23: Projected fuel demand under scenario 2B

A.6. Newbuild Costs

We estimate the cost of new ships in the model on a €/MJ basis by calculating the newbuild cost and annual energy use of an 'average' Fuel Oil technology vessel (6,600 TEU[28]). The vessel cost is estimated using 'benchmark' market prices for a new vessel,[29] and annual fuel use in MJ terms is calculated from EU-MRV data (2021). Newbuild costs are paid in full in the period immediately following the vessel's construction (there is no lifetime spreading of capital costs).

Newbuild costs for other technologies are estimated by assuming an additional premium for each technology type (starting at 15% for LNG DF, 10% for methanol DF and 25% for ammonia DF). The costs for new vessels of each technology type, estimated in €/MJ (annual consumption) are given in Table 13. We treat fuel oil and LNG DF as 'mature' technologies and assume no change in newbuild costs throughout the model period. In contrast, the cost of methanol DF and ammonia DF ships comes down later on.

Technology Type	Newbuild Costs By Period (€/Annual MJ)					
	2025-29	2030-34	2035-39	2040-44	2045-49	2050-54
Fuel Oil	0.152	0.152	0.152	0.152	0.152	0.152
LNG DF	0.175	0.175	0.175	0.175	0.175	0.175
Methanol DF	0.168	0.166	0.165	0.163	0.161	0.160
Ammonia DF	0.190	0.189	0.187	0.186	0.184	0.183

Table 13: Newbuild costs by engine technology type

A.7. Fuel Demand

We estimate the relevant fuel demand for each operator by calculating their fuel consumption using EU-MRV data from 2021 (based on 100% of intra-EU, 100% at-berth and 50% of inbound/outbound fuel consumption, as per the scope of FuelEU Maritime and the EU ETS).

Future fuel demand in the model is estimated by combining projections on containership demand growth and efficiency improvements from the IMO's 4th Greenhouse Gas Study [4]. These growth rates are then applied to each operator's calculated 2021 fuel demand. We assume that Europe's share of global containership demand, and each operator's share of total European containership demand, both remain constant over time.

[28] c.50% of energy consumption in the EU-MRV (on a 'half-scope' basis) is by containerships larger than this size, and c.50% below

[29] Source: Clarksons Research

A.7.1. Containership Fuel Demand

We use EU-MRV data for 2021 to calculate the initial fuel demand in the model for each company in MJ terms, by aggregating emissions for each vessel on a 'semi-full scope' basis and accounting for any estimated use of LNG fuel. In order to project fuel demand across the model period, we use containership demand growth projections from the IMO 4th Greenhouse Gas Study, specifically the SSP2 ('Middle of the Road') scenario. Total fuel demand for each operator is treated solely as an input into the model; the potential impact of pricing and regulation on shipping fuel demand is beyond the scope of this analysis.

Table 14 shows the estimated demand growth in each period (including the period 2021-24, used to scale emissions from 2021 to the start of the model period in 2025) in the 'base case'. The right hand column shows the equivalent percentages when using the IMO's SSP3 ('Regional Rivalry - A Rocky Road') scenario.

Period	Fuel Demand Growth: 'Base Case'	Fuel Demand Growth: 'Low Demand' SBTi-Compliant Scenario (5B)
2021-2024	3.8%	2.8%
2025-2029	2.5%	1.9%
2030-2034	1.8%	1.4%
2035-2039	1.4%	1.1%
2040-2044	1.2%	0.9%
2045-2049	1.0%	0.7%
2050-2054	1.0%	0.7%

Table 14: Projected annual growth in containership demand (compound annual growth rate)

A.7.2. Vessel Energy Efficiency

The model incorporates improvements in vessel efficiency (not including shoreside electricity, which is outlined in Annex A.4) based on the efficiency assumptions in the IMO 4th Greenhouse Gas Study [4] (*OECD_RCP2.6_G* scenario). These improvements, converted to annual rates, are given in Table 15 below. The right hand column shows the alternative 'optimistic' energy efficiency improvements from T&E's own analysis [2], as used in scenario 5B.

Wind technology is not analysed in detail in this paper but could have an increased impact on operating efficiency of vessels in Europe, as a result of the adjustment factors included in the FuelEU Maritime GHG intensity formula.

Period	Vessel Efficency Improvement: 'Base Case'	Vessel Efficency Improvement: 'Low Demand' SBTi-Compliant Scenario (5B)
2021-2024	1.5%	5.1%
2025-2029	1.6%	1.9%
2030-2034	1.0%	2.0%
2035-2039	1.0%	0.4%
2040-2044	0.3%	0.2%
2045-2049	0.3%	0.1%
2050-2054	0.3%	0.0%

Table 15: Projected annual improvements in containership vessel efficiency by period

A.8. Vessel Lifecycle

The lifecycle of the fleet is simplified by incorporating into the model a minimum demolition level for the 'fuel oil' technology ships which are in the fleet at the start of the period. Unless otherwise specified in a given scenario, these ships are demolished at a rate of 20% in each 5-year period, equivalent to an approximate ship lifespan of 25 years. Ships with other technologies are not demolished in the model unless it is optimal for an operator to replace them with ships of another technology (for example, if an operator replaces LNG DF ships with Ammonia DF ships in order to be able to use e-ammonia in a later period). New ships enter the fleet at the start of each 5-year period, rather than on a continuous annual basis.

Annex B: Summary of Scenarios

Code	Scenario Description	FuelEU Emissions Intensity Reduction						RFNBO sub-target	RFNBO Multiplier	Demand Growth & Efficiency	Fuel Prices	Carbon Prices
		2025	2030	2035	2040	2045	2050					
1A	FuelEU final agreement, base case pricing	2%	6%	14.5%	31%	62%	80%	2% from start-2034 onwards (assume 'sunset' clause activated)	2025-33: 2x 2034-2054: None (assume 'sunset' clause activated)	IMO 4th GHG study, demand scenario: SSP2_RCP2.6_G; efficiency: OECD_RCP2.6_G	'Base case' pricing assumptions (See Section A.3)	IEA 'Net Zero Pledges' scenario (see A.5)
1B	FuelEU final agreement, low e-fuels Pricing	As in **1A**						As in **1A**	As in **1A**	As in **1A**	As in **1A** for fossil/biofuels. E-fuels take min. value of base case sources	As in **1A**
1C	FuelEU final agreement, low biofuels pricing	As in **1A**						As in **1A**	As in **1A**	As in **1A**	As in **1A** for fossil/e-fuels. Biofuels take min. value of base case sources	As in **1A**
1D	FuelEU final agreement, late ammonia Feasibility	As in **1A**						As in **1A**	As in **1A**	As in **1A**	As in **1A** except for e-Methanol which takes min. value of base case sources	As in **1A**
1E	FuelEU final agreement, high ETS Prices	As in **1A**						As in **1A**	As in **1A**	As in **1A**	As in **1A**	2030: €150/t 2040: €275/t 2050: €400/t
2A	'Business as usual', base case pricing	0%	0%	0%	0%	0%	0%	None	None	As in **1A**	As in **1A**	None
2B	'ETS-only', base case pricing	0%	0%	0%	0%	0%	0%	None	None	As in **1A**	As in **1A**	As in **1A**
3A	FuelEU EU Commision proposal, base case pricing	2%	6%	13%	26%	59%	75%	None	None	As in **1A**	As in **1A**	As in **1A**
4A	Denmark & Germany EU Council proposal, base case pricing	3%	10%	20%	40%	75%	100%	2030: 2% 2045: 29% 2035: 5% 2050: 70% 2040: 12%	2025-2034: 4x 2035-2039: 3x 2040-2054: None	As in **1A**	As in **1A**	As in **1A**
5A	SBTi 1.5°C-compliant emissions, base case pricing	25.5%	60.4%	88.7%	97.8%	99.6%	100%	None	None	As in **1A**	As in **1A**	As in **1A**
5B	SBTi 1.5°C-compliant emissions, base case pricing, low demand + high efficiency	25.5%	60.4%	88.7%	97.8%	99.6%	100%	None	None	Demand basis IMO 4th GHG study: SSP3_RCP2.6_G; efficiency: T&E Roadmap (2021) 'optimistic' scenario	As in **1A**	As in **1A**

Table 16: Summary of scenarios generated for this report using T&E's containership optimisation model

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