FuelEU Maritime and EU ETS

Sound incentives for the fuel choice?

CE Delft

Committed to the Environment

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Content

Summary

In July 2021 the European Commission presented a comprehensive package of legislative proposals with the aim of making the EU's climate, energy, land use, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55 % by 2030, compared to 1990 levels (European Commission, 2021).

This ‘Fit for 55’ package also addresses the emissions of maritime shipping, especially with the proposal for a revision of the European Emissions Trading System (EU ETS) and with the proposal for a Regulation on the use of renewable and low-carbon fuels in maritime transport (‘FuelEU Maritime’). The ETS proposal incorporates shipping in the existing EU ETS while FuelEU Maritime sets emission requirements for the energy used by ships.

While both proposals address the emissions from maritime shipping, they differ with respect to the GHGs covered as well as the extent to which the life cycle emissions of the fuels are covered. The EU ETS would only cover CO_2 emissions on a Tank-to-Wake basis, while FuelEU Maritime would cover three GHGs on a Well-to-Wake basis.

Therefore, Danish Shipping has commissioned CE Delft to conduct a study to assess whether the incentives provided by the two proposals are well aligned.

This short study analyses both the separate and the combined incentives of the EU ETS and the FuelEU Maritime Regulation for maritime shipping.[1] The incentives set by EU ETS and FuelEU Maritime are analysed in terms EU ETS allowance costs and fuel costs for nine sample ships for the years 2025 and 2030. Different blends of fossil and renewable fuels and different LNG engines that allow meeting the FuelEU Maritime targets are thereby considered.

This analysis allows to identify potential adverse incentives for the fuel choice set by the measures as well as inconsistencies in the proposals.

Capital costs are not considered in the study.[2] This means that not all regulated ships necessarily have an incentive to use a fuel blend/engine option that has been assessed to be advantageous in terms of fuel and/or EU ETS costs. If the use of a fuel blend option requires a ship to be retrofitted, high retrofitting costs can make this option less attractive and the option might only be considered when a ship is replaced.

The analysis shows that both measures, given the expected fuel and EU ETS prices, separately and combined, incentivize the use of LNG. Due to the difference in emissions scope, however, different compliance options are incentivized. The incentive given by the fuel costs for the different blends that allow meeting the FuelEU Maritime target is dominant, setting an incentive to use 100% fossil LNG — with fossil LNG used in a diesel dual fuel slow speed engine, the 2025 and 2030 GHG intensity targets of FuelEU Maritime can be

[1] With separate incentives we mean, for EU ETS, the EU ETS costs given a fuel blend is used with which the FuelEU Maritime requirements can be met and, for FuelEU Maritime, the fuel costs given a fuel blend is used with which the FuelEU Maritime requirements can be met. The combined incentive is the sum of the according EU ETS and fuel costs.

[2] Compared to an earlier version of this report, an editorial typo has been corrected in this sentence, which does not affect the conclusions of the report.

met without using renewable methane. In contrast, EU ETS costs are lowest when using a blend of fossil and renewable LNG in an Otto dual fuel medium speed engine.

This has two implications: First, the production and establishment of the distribution chains of renewable fuels may not be incentivized matching the pace required for the energy transition of the sector. Second, the sector risks partially heading towards a lock-in of assets with high sunk costs unless sufficient renewable methane becomes available which would then be essential for the energy transition of parts of the sector.

Based on our analysis we recommend the following:

1. The incentives given for the choice of fuel by EU ETS and FuelEU Maritime should be aligned. If the EU ETS was implemented with the deviating emissions scope, i.e. with the Tank-to-Wake approach and limited to CO_2 emissions, then the different fuel blend options that are equally fit for meeting the FuelEU Maritime target would be assessed differently in terms of EU ETS costs. Although these blends would be associated with the same Well-to-Wake GHG emissions per ship, EU ETS would reward those blends with the lowest EU ETS costs that feature the lowest Tank-to-Wake CO_2 emissions per MJ of fuel.
2. The measures should set sound environmental incentives:
   - a EU ETS incentives should reflect the renewable fuels' Well-to-Tank emissions, thus e.g. not treating grey and green hydrogen alike.
   - b The CO_2 emission factors applied under both measures should account for the recycled carbon of renewable fuels.
   - c The proposed default emission factors should be thoroughly reviewed to correct for inconsistencies (see Chapter 5). To provide more background information on the selection of the proposed default values would be very useful in this context.
3. It should be thoroughly analysed whether sufficient renewable methane will become available for the sector to avoid a potential lock-in for parts of the sector potentially associated with high sunk costs.
4. Consider how the aim of FuelEU Maritime — the stimulation of the timely production of renewable fuels via the stimulation of the demand for the fuels — can be assured.

1 Introduction

1.1 Aim of study

In July 2021 the European Commission presented the 'Fit for 55' policy package. As part of this policy package, the European Emissions Trading System (EU ETS) is proposed to be revised (COM(2021) 551 final) and a Regulation on the use of renewable and low-carbon fuels in maritime transport (COM(2021) 562 final), in the following referred to as the FuelEU Maritime Regulation, is proposed to be implemented.

Emissions of maritime shipping are proposed to be included in the existing EU ETS and the FuelEU Maritime Regulation would set reduction targets for the GHG emission intensity of the energy used on board ships.

The proposals differ in scope of emissions covered: the FuelEU Maritime Regulation considers Well-to-Wake emissions (i.e. emissions over the life cycle of a fuel) and takes different greenhouse gas emissions into account, whereas the EU ETS only addresses CO_2 emissions on a Tank-to-Wake basis (i.e. emissions from the use of the fuels on board ships).

Because of these differences, incentives for fuel choice diverge. For example, biofuels will probably always have zero CO_2 emissions under the EU ETS, while some types of biofuels are considered to have the same emissions as fossil fuels (or worse) in the FuelEU Maritime Regulation. This raises the question whether the incentives provided by the two proposals are well aligned.

This short study therefore analyses both the separate and the combined incentives of the EU ETS and the FuelEU Maritime Regulation for maritime shipping. The incentives set by EU ETS and FuelEU Maritime are thereby analysed in terms of EU ETS allowance costs and fuel costs for nine sample ships. This allows to identify potential adverse incentives for the fuel choice set by the proposed measures as well as inconsistencies in the proposals.

1.2 Structure of the report

In the following, we will first analyse the proposed FuelEU Maritime Regulation (Chapter 2) and EU ETS revision proposal (Chapter 3) separately, before analysing incentives for the fuel choice set by both measures (Chapter 4) and discussing the potential adverse incentives set by as well as inconsistencies in the proposals (Chapter 5). Chapter 6 provides conclusions and recommendations.

1.3 Scope of study

The incentives set by EU ETS and FuelEU Maritime are analysed in terms of EU ETS emission allowance costs and fuel costs. These costs are analysed for the years 2025 and 2030 for nine sample ships (see Table 1).

Table 1 - Sample ships considered

	Ship type	Ship size (rounded)*
1	Bulk carrier	35,000 dwt
2	Oil tanker	53,200 dwt
3	Oil tanker	109,700 dwt
4	Gas carrier	10,400 dwt
5	Ro-pax ship	6,600 dwt
6	Container ship	17,800 TEU
7	Container ship	20,600 TEU
8	Container ship	15,900 TEU
9	Chemical tanker	Below 5,000 GT

* Deadweight tonnage (dwt), Twenty-foot Equivalent Unit (TEU) and Gross Tonnage (GT) are units used to indicate the size of different ship types.

For eight of the sample ships average THETIS MRV real-world data for the years 2018 to 2020 have been used in the study to determine their energy consumption within the geographical scope of the two measures. THETIS MRV provides fuel consumption and CO_2 emission data reported by ships that fall under the EU MRV (Monitoring Reporting and Verification) Regulation (Regulation (EU) 2015/757). The averages are based on years in which the ships have actually been active within the EU MRV scope, i.e. the consumption is not necessary the full annual consumption of any particular vessel in the sample. The ninth sample ship is smaller than 5,000 GT and thus falls outside the scope of the EU MRV Regulation. For this ship, fuel consumption data has been provided by the client.

The costs are also analysed for different blends of fossil and renewable fuels and different LNG engines that allow meeting the FuelEU Maritime targets (see Table 2).

Table 2 - Blends of fossil and renewable fuels and types of LNG engines considered

<table>
<tr><th>Blend</th><th>Further specification of renewable fuel considered</th><th>Further specification of LNG engine considered</th></tr>
<tr><td>VLSFO/FAME</td><td>FAME from waste cooking oil</td><td></td></tr>
<tr><td rowspan="2">Fossil methanol/ biomethanol</td><td>Biomethanol from farmed wood</td><td></td></tr>
<tr><td>Biomethanol from black liquor</td><td></td></tr>
<tr><td>Fossil methanol/ e-methanol</td><td></td><td></td></tr>
<tr><td rowspan="4">LNG/biomethane</td><td rowspan="2">Biomethane from wet manure</td><td>Otto dual fuel medium speed engine</td></tr>
<tr><td>Diesel dual fuel slow speed</td></tr>
<tr><td rowspan="2">Biomethane from biowaste</td><td>Otto dual fuel medium speed engine</td></tr>
<tr><td>Diesel dual fuel slow speed</td></tr>
<tr><td rowspan="4">LNG/e-methane</td><td rowspan="2">Renewable electricity from Europe</td><td>Otto dual fuel medium speed engine</td></tr>
<tr><td>Diesel dual fuel slow speed</td></tr>
<tr><td rowspan="2">Renewable electricity from North-Africa</td><td>Otto dual fuel medium speed engine</td></tr>
<tr><td>Diesel dual fuel slow speed</td></tr>
</table>

For the blends of fossil LNG and renewable methane (biomethane/e-methane) the following two different types of LNG engines have been accounted for:

1. LNG Otto dual fuel, medium speed 4-stroke, low pressure engine to account for relatively high WTW GHG emissions;

2. LNG Diesel dual fuel, slow speed 2-stroke, high pressure engine to account for relatively low WTW GHG emissions;

resulting in twelve fuel blend/engine combinations in total.

The additional capital expenditures for newbuilds/retrofits is not accounted for in this study.

The following three simplifying assumptions have been made in this short study:

1. Regarding the EU ETS, it has been assumed that the measure does not incentivise the uptake of GHG reduction measures on top of the fuel switch incentivised by the FuelEU Maritime Regulation. This makes the estimation of the EU ETS emission allowance costs a conservative, relatively high estimation.
2. For both methanol and methane fuelled engines, no pilot fuel has been accounted for.[3] If a fossil pilot fuel was accounted for, it would depend on the pilot fuel's WTW emissions, whether more or less renewable fuel than determined in the study would have to be used to comply with the FuelEU Maritime requirements. If for example VLFSO was used as pilot fuel, less renewable methanol would have to be blended with fossil methanol, but more renewable methane would have to be blended into fossil LNG to comply with the FuelEU Maritime targets.
3. The energy consumption of the sample ships is assumed to be the same, independent of the fuel used. This means that we did not consider that a ship might be required to use a different engine when using another fuel, with the engine featuring another efficiency and specific fuel oil consumption. This means that the energy content of the fuels, the emissions per energy unit of the fuels and the fuel prices are the distinguishing factors between the fuel types in this study and that in practice a fuel/fuel blend that can be used in a relatively efficient engine would be more attractive to use.

[3] LNG Otto cycle engines require roughly 1%, whereas LNG diesel cycle engines roughly 5% pilot fuel and LNG spark ignition engines require no pilot fuel at all (CE Delft and TNO, 2017). Methanol engine require around 5% pilot fuel (MAN, 2021).

2 FuelEU Maritime Regulation

2.1 Proposed regulation in a nutshell

2.1.1 Targets

The proposed FuelEU Maritime Regulation sets GHG intensity targets for the energy used on board ships, which become stricter over time.

According to Article 4(2) of the proposed Regulation, the ships would have to meet a GHG intensity target which corresponds to a reduction of the reference value by:
- 2% from 1 January 2025;
- 6% from 1 January 2030;
- 13% from 1 January 2035;
- 26% from 1 January 2040;
- 59% from 1 January 2045;
- 75% from 1 January 2050.

The proposed reference value would thereby correspond to the fleet average GHG intensity of the energy used on board by ships in 2020 determined on the basis of data monitored and reported in the framework of the EU MRV Regulation ((EU) 2015/757) and using the methodology and default values laid down in Annex I to that Regulation.

2.1.2 Ship (activity) scope

In line with the EU MRV Regulation ships of at least 5,000 GT on voyages that serve the purpose of transporting passengers or cargo for commercial purposes would fall under the FuelEU Maritime Regulation.

Warships, naval auxiliaries, fish-catching or fish-processing ships, wooden ships of a primitive build, ships not propelled by mechanical means, or government ships used for non-commercial purposes would be exempt.

2.1.3 Geographical scope

The geographical scope of the Regulation would be narrower compared to the EU MRV Regulation, covering 50% instead of 100% of the emissions released on extra-EEA voyages.

The following emissions from maritime shipping would thus be covered:
- 100% of emissions from ships performing voyages between intra-EEA ports;
- 100% of emissions from ships at berth in an EEA port;
- 50% of the emissions from ships performing voyages departing from an EEA port and arriving at a non-EEA port;
- 50% of the emissions from ships performing voyages departing from a non-EEA port and arriving at an EEA port.

2.1.4 Emissions scope

The FuelEU Maritime Regulation is proposed to cover carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions, determined on a Well-to-Wake basis, thus not only covering the Tank-to-Wake but also the Well-to-Tank emissions. Annex II of the proposed Regulation specifies default emission factors to this end.

2.2 Approach/Assumptions

2.2.1 Emission factors

The proposed FuelEU Maritime Regulation would limit the GHG intensity target of the energy used on board ships.

The energy used on board ships is thereby determined by the energy content of the fuels consumed by the ship. Annex II of the proposal provides default values for the lower calorific value (LCV) of the fuels to allow for a conversion of the mass of the fuels consumed to their energy content. The default value for the LCV of Heavy Fuel Oil (HFO) is for example 40.5 MJ/kg HFO.

Per fuel type, Annex II of the proposal also provides default values for the emission factors (EFs) for the different types of emissions:
- Per fuel type, Well-to-Tank EFs in terms of gramme emissions per MJ fuel are specified to allow the calculation of the emissions associated with 1 MJ of fuel up to the point that the ship bunkers the fuel (e.g. 13.5 g CO_2-eq. per MJ heavy fuel oil consumed by the ship). This for example includes the emissions from the production of the fuels.
- Per fuel type, Tank-to-Wake EFs in terms of gramme emissions per gramme fuel are specified to allow for the calculation of the emissions associated with one gramme of fuel used on board ships (e.g. 3.114 g CO_2 per g heavy fuel oil consumed by the ship). This includes the emissions from the combustion of the fuels as well as methane that can slip when using LNG/methane as fuel and is not combusted.

As explained above, the Regulation is proposed to account for three types of GHG emissions, i.e. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions. To allow for an aggregation of the different EFs, the EFs are summed up applying different weighing factors to account for the different global warming potentials (GWP) of the different emission types. In other words, the emission factors are converted into CO_2 equivalents (CO_2-eq.) to allow for a meaningful aggregation. The aggregated EF is then expressed in g CO_2-eq. per MJ.

Regarding the weighing factors, the Commission proposes to work with factors that reflect the GWP of the emissions over a 100-year period. For this study, we have applied the following GWP_{100} factors, in line with IPCC (2013):
- Fossil CH_4: 30;
- Renewable CH_4: 28;
- N_2O: 265.

The emission factors that we have applied in this study are for the most part based on the default values as specified in Annex II of the proposed FuelEU Maritime Regulation.
The WTT emission factors of the biofuels are based on the Renewable Energy Directive (RED II) to which Annex II refers to; specific biomass conversion routes as specified in Table 3 have been selected to reflect routes with relatively high and low WTT emission factors.

The following default methane slip factors for LNG/methane-fuelled engines are proposed by the Commission and have been applied in the study:
- Otto dual fuel medium speed engine: 3.1% of the mass of the fuel used by the engine;
- Otto dual fuel slow speed engine: 1.7% of the mass of the fuel used by the engine;
- Diesel dual fuel slow speed engine: 0.2% of the mass of the fuel used by the engine.

For this study, the default values as specified in Annex II of the proposed Regulation have been adjusted/complemented as follows:
1. For Lean burn spark ignition (LBSI) LNG/methane-fuelled engines a methane slip default value has not been specified yet. In line with Ushakov et al. (2019) we assumed this factor to be 2.32% of the mass of the fuel used by the engine.
2. For the biofuels, the TTW CO_2 emissions have been assumed to be zero to account for the CO_2 uptake of the biomass, in line with the RED.
3. For the e-fuels, a TTW EF of zero has been assumed. In other words, it has been assumed that the carbon used to produce these fuels is captured from the atmosphere or accounted for in other sectors.
4. For the default value of the WTT EF of e-methane, the proposal refers to the Renewable Energy Directive (2018/2001). The RED, however, does not provide an emission factor for e-methane. For the purpose of the study, we have applied a WTT EF of zero for e-methane, assuming that e-methane would be produced by means of 100% renewable electricity, expecting that the e-fuel plants until 2030 are showcase projects where no electricity from the grid will be used. Just as for fossil LNG, methane might slip along the production and distribution chain, but since the production is fundamentally different, the volume of the slip can be expected to be different. Due to this uncertainty, we decided to apply a WTT CH_4 EF of zero, but the reader should be aware that his is probably an underestimation.
5. In Annex II of the proposed regulation, there seem to be inconsistencies between biomethane on the one hand and fossil LNG and e-methane on the other hand.
   We corrected for these inconsistencies by assuming that the following EFs, as specified for fossil LNG and e-methane, also hold for biomethane:
   a TTW N_2O emission factor is 0.00011 g N_2O/g fuel.
   b TTW CH_4 emission factor (from combustion) is 0 g CH_4/g fuel.
6. For fossil and biomethanol, Annex II of the proposed regulation does not provide default values for CH_4 and N_2O TTW emissions yet. We assumed that these emission factors are in line with the default values as specified for e-methanol.

Please note that, regarding the LNG/methane EFs, that if applied to the energy consumption of a sample ship, higher LNG emission factors have to and are applied in this study, to correct for the higher amount of LNG used, i.e. including methane slip.

Table 3 presents the Well-to-Tank, Tank-to-Wake and Well-to Wake emission factors as applied in this study. The fuels are given in descending order of the WTW EFs.

As Table 3 shows, fossil methanol has the highest and LNG used in diesel dual fuel slow speed engines the lowest WTW GHG emissions per MJ for selected fossil fuels. Regarding the renewable fuels considered, biomethane from biowaste used in an Otto dual fuel medium speed engine has the highest and e-methane used in a diesel dual fuel slow speed engine the lowest WTW GHG emissions per MJ. The emissions of the latter are however still rather uncertain.

Table 3 - WTT, TTW and WTW GHG emission factors per MJ for selected fossil and renewable fuels

	Fossil fuel type (LNG engine used)	WTT EF (g CO_2-eq./MJ)	TTW EF (g CO_2-eq./MJ)	WTW EF (g CO_2-eq./MJ)
Fossil	Fossil methanol	31.3	71.57	102.87
Fossil	VLSFO	13.2	79.40	92.60
Fossil	LNG (Otto dual fuel medium speed)	18.5	73.89	92.39
Fossil	LNG (Lean burn spark ignition)	18.5	69.56	88.06
Fossil	LNG (Otto dual fuel slow speed)	18.5	66.13	84.63
Fossil	LNG (Diesel dual fuel slow speed)	18.5	57.81	76.31
Renewable	Biomethane from biowaste (Close digestate, off-gas combustion) (Otto dual fuel medium speed)	14.0*	18.3***	32.3
Renewable	Biomethane from wet manure (Open digestate, off-gas combustion) (Otto dual fuel medium speed)	1.0*	18.3***	19.3
Renewable	Biomethanol from farmed wood	16.2*	2.5***	18.7
Renewable	E-methane (renewable electricity from Europe/Africa) (Otto dual fuel medium speed)	0.0**	18.3***	18.3
Renewable	FAME from waste cooking oil	14.9*	1.3***	16.2
Renewable	Biomethane from biowaste (Close digestate, off-gas combustion) (Diesel dual fuel slow speed)	14.0*	1.7***	15.7
Renewable	Biomethanol from black liquor	10.4*	2.5***	12.9
Renewable	Biomethane from wet manure (Open digestate, off-gas combustion) (Diesel dual fuel slow speed)	1.0*	1.7***	2.7
Renewable	E-methanol	0.0**	2.5***	2.5
Renewable	E-methane (renewable electricity from Europe/Africa) (Diesel dual fuel slow speed)	0.0**	1.7***	1.7

* Based on Renewable Energy Directive.

** Assumed to be zero.

*** For all renewable fuels, TTW CO_2 emissions are assumed to be zero.

2.2.2 Reference value

In the '2020 Annual Report on CO_2 Emissions from Maritime Transport' the European Commission published the shares of different fuel types as used by the fleet that has been active within the EU MRV scope in 2019. Based on these shares and the WTW GHG EFs as specified above, we have calculated the average 2019 fleet GHG intensity as presented in Table 3.

Table 4 - GHG intensity reference value

	WTW GHG intensity (g CO_2-eq./MJ)
GHG intensity reference value	90.98

For the calculation of the reference value we assumed that all LNG is used in Otto dual fuel slow speed engines which is the dominant engine in the fleet.

2.2.3 Resulting targets

Table 5 gives the GHG intensity targets for 2025 and 2030, applying the reduction factor of 2% and 6% to the reference value respectively.

Table 5 - GHG intensity targets

	WTW intensity target values (g CO_2-eq./MJ)
From 1 January 2025	89.16
From 1 January 2030	85.52

2.2.4 In-scope GHGs

Given the sample ships' energy consumption, the in-scope WTW GHG emissions can be determined for these ships as presented in Table 6, assuming that the ships just meet the GHG intensity targets as specified above (see Table 5).

Table 6 - Resulting WTW GHG emissions (CO_2, CH_4 and N_2O) of the sample ships in the geographical scope of FuelEU Maritime if ships just meet the 2025 and 2030 GHG intensity target

Sample ship number	Ship type	2025 WTW GHG emissions (1,000 t CO_2-eq.)	2030 WTW GHG emissions (1,000 t CO_2-eq.)
1	Bulk carrier	4.0	3.8
2	Oil tanker	5.2	5.0
3	Oil tanker	8.3	8.0
4	Gas carrier	6.1	5.8
5	Ro-pax ship	67.9	65.2
6	Container ship	20.3	19.5
7	Container ship	41.9	40.2
8	Container ship	26.2	25.2
9	Chemical tanker below 5,000 GT	3.9	3.7

* Not corrected for narrower geographical scope of the FuelEU Maritime Regulation.

The different levels of GHG emissions of the ships can be explained by two main factors: first, by the energy efficiency of the ships, which depends on the ship size, its technical and its operational efficiency, and second, by the activity of the ships within the geographical scope of the measures. This means that ships of the same type as the sample ships might have very different GHG emissions in the scope of the measure due to another operational pattern.

As can be expected, the WTW in-scope GHG emissions for Ro-pax ships are highest, since they operate at a relatively high speed and operate almost entirely within the geographical scope of the measure. The container vessels' WTW in-scope GHG emissions are also relatively high — the vessels are large and operate on a regular basis on long distances to and from EEA ports. The WTW GHG emissions of the chemical tanker below 5,000 GT is lowest, followed by that of the bulk carrier. Bulk carriers typically engage in tramp trade, not calling on a regular basis at an EEA port and at the same time bulk carriers operate at a relatively low speed.

2.2.5 Share of fossil and renewable fuels

For the twelve different fuel blends/LNG engine alternatives considered in the study, we have determined the shares of fossil and renewable fuels that are required to meet the 2025 and 2030 GHG intensity targets as specified above (see Table 5).

Table 7 – Share of fossil and renewable fuels to meet 2025 GHG intensity target

Fuel Blend	Share of fossil fuel (%)	Share of renewable fuel (%)
1. VLSFO/FAME blend (fame from waste cooking oil)	95.5	4.5
2. Fossil methanol/biomethanol blend (biomethanol from farmed wood)	83.7	16.3
3. Fossil methanol/biomethanol blend (biomethanol from black liquor)	84.8	15.2
4. Fossil methanol/e-methanol	86.3	13.7
5. LNG (Otto dual fuel medium speed)/biomethane from wet manure	91.8	8.2
6. LNG (Otto dual fuel medium speed)/biomethane from biowaste	90.0	10.0
7. LNG (Otto dual fuel medium speed)/e-methane (renewable electricity from Europe)	91.9	8.1
8. LNG (Otto dual fuel medium speed)/e-methane (renewable electricity from North-Africa)	91.9	8.1
9. LNG (Diesel dual fuel slow speed)/biomethane from wet manure	100.0	0.0
10. LNG (Diesel dual fuel slow speed)/biomethane from biowaste	100.0	0.0
11. LNG (Diesel dual fuel slow speed)/e-methane (renewable electricity from Europe)	100.0	0.0
12. LNG (Diesel dual fuel slow speed)/e-methane (renewable electricity from North-Africa)	100.0	0.0

Table 8 - Share of fossil and renewable fuels to meet 2030 GHG intensity target

Fuel Blend	Share of fossil fuel (%)	Share of renewable fuel (%)
1. VLSFO/FAME blend (fame from waste cooking oil)	90.7	9.3
2. Fossil methanol/biomethanol blend (biomethanol from farmed wood)	79.4	20.6
3. Fossil methanol/biomethanol blend (biomethanol from black liquor)	80.7	19.3
4. Fossil methanol/e-methanol	82.7	17.3
5. LNG (Otto dual fuel medium speed)/biomethane from wet manure	87.0	13.0
6. LNG (Otto dual fuel medium speed)/biomethane from biowaste	84.2	15.8
7. LNG (Otto dual fuel medium speed)/e-methane (renewable electricity from Europe)	87.2	12.8
8. LNG (Otto dual fuel medium speed)/e-methane (renewable electricity from North-Africa)	87.2	12.8
9. LNG (Diesel dual fuel slow speed)/biomethane from wet manure	100.0	0.0
10. LNG (Diesel dual fuel slow speed)/biomethane from biowaste	100.0	0.0
11. LNG (Diesel dual fuel slow speed)/e-methane (renewable electricity from Europe)	100.0	0.0
12. LNG (Diesel dual fuel slow speed)/e-methane (renewable electricity from North-Africa)	100.0	0.0

To give an example: To meet the 2025 GHG intensity target, a blend of 95.5% VSLFO and 4.5% FAME could be used, whereas to meet the stricter 2030 target a blend of 90.7% VLFSO and 9.3% would have to be used.

And the lower the WTW GHG emissions of a renewable fuel, the higher the share of the fossil equivalent that can be used to comply with the FuelEU Maritime target. This explains for example the difference between options 2 and 3.

With fossil LNG used in a diesel dual fuel slow speed engine (see options 9-12), the 2025 and 2030 target can be met without having to blend in any renewable fuel.

The highest share of renewable fuel is required if a blend of fossil and biomethanol was used. This can be explained by the relatively high WTW GHG emissions per MJ fossil methanol.

2.2.6 Fuel costs

We have calculated the sample ships' fuel costs in 2025 and 2030, assuming the shares of fossil and renewable fuels as presented above (Paragraph 2.2.5) which allow the ships to comply with the GHG intensity targets.

For the calculation of the fuel costs, the fuel prices as presented in Table 9 have been assumed. A low and high fuel price scenario have thereby been differentiated.

Table 9 - Low and high fuel prices

Fuel type	Low fuel price (€/GJ)	High fuel price (€/GJ)
VLSFO	4.4	13.3
LNG	4.1	12.4
Fossil methanol	14.0	19.0
FAME (from waste cooking oil)	18.0	61.0
Biomethanol	13.0	31.0
Biomethane	12.0	35.0
E-methanol	33.0	189.0
E-methane (renewable electricity from Europe)	55.4/49.9	62.1/54.3
E-methane (renewable electricity from North-Africa)	43.8/39.1	50.1/43.2

Sources: Historical fossil fuel price data as provided by client; Brynolf et al. (2018), CE Delft and Ecorys (2021); E4tech (2018); Frontier Economics (2018); Joanneum Research Forschungs-GmbH et al. (2016)

The fuel prices for VLSFO and LNG reflect levels that are 50% lower (low fuel price) and 50% higher (high fuel price) than historical averages of Rotterdam prices. For LNG, data from August 2017 until November 2021, and for VLSFO, data from October 2019 until November 2021 have been used to determine the historical averages.

The e-methane prices have been determined by means of an open source calculation tool as published by Frontier Economics (2018). The lower fuel price reflects the price when the carbon is captured at a point source, whereas the higher price reflect the prices when the carbon is captured from the air. The two prices specified per cell show the different prices that are available for 2025/2030.

This tool does not allow for the calculation of potential e-methanol prices. These prices have been based on Brynolf et al. (2018) instead. The uncertainty of this e-methanol fuel price is relatively high, which leads to a rather large price range.

3 EU ETS revision

3.1 Proposed regulation in a nutshell

3.1.1 Target

Maritime shipping is proposed to be included in the existing EU ETS from 2023 on. According to the proposal, the sector would not receive specific allowances, but the Union-wide quantity of allowances would be raised by 79 million allowances to account for the inclusion of maritime transport.

The system functions as an open system, where EU allowances can be used for compliance in any sector that is included.

Each year, a linear reduction factor of 4.2% would be applied to the Union-wide quantity of allowances to allow for a gradual reduction of the emissions cap and thus of the total emissions covered by the system.

Unlike previously included sectors, maritime shipping would receive no free allowances, but, instead, would have a three year phase-in period in which not all emissions would have to be covered by allowances; shipping companies would have to surrender allowances covering:
- 20% of verified emissions reported for 2023;
- 45% of verified emissions reported for 2024;
- 70% of verified emissions reported for 2025;
- 100% of verified emissions reported for 2026 and each year thereafter (see Article 3ga).

3.1.2 Ship (activity) scope

The proposed ship (activity) scope is the same as in the EU MRV Regulation and as proposed for the FuelEU Maritime Regulation (see Paragraph 2.1.2).

3.1.3 Geographical scope

The proposed geographical scope would be the same as proposed for the FuelEU Maritime Regulation (see Paragraph 2.1.3).

3.1.4 Emissions scope

In line with the EU MRV Regulation, Tank-to-Wake CO_2 emissions would be covered.

The emissions scope of the EU ETS would thus deviate from the emissions scope of the FuelEU Maritime Regulation where not only CO_2 emissions, but also CH_4 and N_2O emissions are covered and also the Well-to-Wake emissions are accounted for.

So far, specific emission factors for renewable fuels applied under the EU ETS have not been specified yet.

In the EU ETS revision proposal, it has been proposed to add a subparagraph to Article 14(1) to the EU ETS Directive which would then read: 'The Commission shall adopt implementing acts concerning the detailed arrangements for the monitoring and reporting of emissions and, where relevant, activity data, from the activities listed in Annex I, …’. And ’[t]hose implementing acts shall apply the sustainability and greenhouse gas emission saving criteria for the use of biomass established by Directive (EU) 2018/2001 of the European Parliament and of the Council, with any necessary adjustments for application under this Directive, for this biomass to be zero-rated. They shall specify how to account for storage of emissions from a mix of zero-rated sources and sources that are not zero-rated. They shall also specify how to account for emissions from renewable fuels of non-biological origin and recycled carbon fuels, ensuring that these emissions are accounted for and that double counting is avoided.’

3.2 Approach/assumptions

The 2025 and 2030 EU ETS costs for the nine sample ships have been derived under the following assumptions:
- the EU ETS allowance price is assumed to amount to € 60 and € 70/tonne CO_2 in 2025 and 2030 respectively;
- the phase-in period has been accounted for: in 2025 70% and in 2030 100% of the in-scope emissions would have to be covered by allowances.

4 Analysis of incentives

For each of the sample ships detailed results are provided in the Annex of this report. In this section we summarize these findings.

The incentives provided by the current proposal for the revised EU ETS Regulation and the FuelEU Maritime Regulation, have been analysed by means of the allowance and fuel costs.

The following three aspects should be considered when interpreting the costs derived:
1. In general, the conclusions that can be drawn about the total costs of the regulation are not very firm because of the uncertainty about the prices of renewable fuels.
2. If fuel and EU ETS costs of a fuel (blend) are relatively low, this does not necessarily mean that the fuel (blend) will be applied on a large scale by maritime shipping, since the use of the fuel (blend) may require retrofitting of an existing ship or may be associated with additional capital costs for a new build ship. In addition, the fuel (blend) might not be avaiable in general/in the relevant ports.
3. The costs derived reflect the situation in which ships just meet the targets set by the FuelEU Maritime Regulation and thus do not reflect the costs for overachieving ships.

4.1 Comparison of costs

The fuels considered are assumed to be blended such that each blend allows a ship to just meet the FuelEU Maritime targets (see Table 7 and 8 for the required 2025 and 2030 blending shares). The specific fuel blends considered are thus associated with the same WTW GHG emissions per ship. The relative advantageousness of a fuel blend compared to the other options then lies in the fuel and EU ETS costs. And since both the fuel and EU ETS costs are the same in terms of € per GJ of fuel per fuel blend option, independent of the ship type and size, the relative advantageousness of the fuel options does also not depend on the ship type and size.

The fuel costs required to meet the target however deviate between the ships, given that the absolute amount of energy consumed differs between ship types and sizes.

To illustrate the scale of the costs, Table 14 and Table 15 in Annex A provide an overview of the 2025 and 2030 costs for the different sample ships, giving the highest and lowest EU ETS and total costs (EU ETS and fuel costs) without specifying the underlying fuel (blend).

Compared to the other ships, sample ship 5 (Ro-pax) for example has the highest costs, with
- 2030 EU ETS costs ranging from € 2.52 to 3.78 million;
- 2030 total costs (i.e. fuel and EU ETS costs) ranging from € 6.14 to 16.21 million in the low fuel price scenario; and
- 2030 total costs (i.e. fuel and EU ETS costs) ranging from € 12.43 to 39.90 million in the high fuel price scenario,

depending on the fuel blend used.

And compared to the other ships, sample ship 9 (chemical tanker < 5,000 GT) has the lowest costs, with
- 2030 EU ETS costs ranging from € 0.14 to 0.22 million;
- 2030 total costs (i.e. fuel and EU ETS costs) ranging from € 0.35 to 0.93 million in the low fuel price scenario; and

- 2030 total costs (i.e. fuel and EU ETS costs) ranging from € 0.71 to 2.28 million in the high fuel price scenario,

depending on the fuel blend used.

Comparing the EU ETS costs, the fuel costs of the different blends to comply with FuelEU Maritime and the combined costs, for the different fuel blends considered, it can be concluded that independent of the ship type (see Table 10):
- the EU ETS costs are lowest for the LNG/biomethane blend used in an Otto dual fuel medium speed engine;
- the fuel costs are lowest for LNG used in a diesel dual fuel slow speed engine; and
- the combined, total costs are also lowest for LNG used in a diesel dual fuel slow speed engine.

Table 10 - Fuel (blend) option associated with the lowest/highest EU ETS, fuel and total costs (EU ETS and fuel costs)

	Fuel (blend) with lowest costs	Fuel blend with highest costs
EU ETS costs	LNG/biomethane from biowaste (Otto dual fuel medium speed engine)	VLSFO/FAME from waste cooking oil
Fuel costs (low price scenario)	LNG (Diesel dual fuel slow speed)	Fossil methanol/e-methanol
Fuel costs (high price scenario)	LNG (Diesel dual fuel slow speed)	Fossil methanol/e-methanol
Total costs (low price scenario)	LNG (Diesel dual fuel slow speed)	Fossil methanol/e-methanol
Total costs (high price scenario)	LNG (Diesel dual fuel slow speed)	Fossil methanol/e-methanol

This means that both EU ETS and FuelEU Maritime incentivize the use of LNG.

The EU ETS Regulation only considers TTW CO_2 emissions which is why EU ETS costs are lowest for the fuel option associated with the lowest TTW CO_2 emissions. As Table 10 illustrates, EU ETS costs are lowest for the already mentioned option 6 (LNG/biomethane from biowaste; Otto dual fuel medium speed engine). And as Table 11 illustrates for 2030, this is because the TTW CO_2 emission factor of this blend is lowest — the TTW CO_2 EF for fossil LNG is the lowest and fuel option 6 is associated with the lowest fossil fuel share of the different LNG fuel options, resulting in an overall lowest TTW CO_2 emission factor (47.24 gCO_2/MJ fuel blend = 56.11 gCO_2/MJ fossil LNG * 84.2% + 0 gCO_2/MJ renewable methane*15.8%).

Table 11 - Illustration of the determinants of the 2030 EU ETS costs

	TTW CO_2 EF of fossil fuel (g CO_2/MJ fuel)	Max. fossil fuel share that allows meeting 2030 FuelEU Maritime target (see Table 7)	Resulting TTW CO_2 EF of fossil/renewable* blends with which FuelEU Maritime target can just be met (g CO_2/MJ fuel)
VLSFO	78.2	Fuel option 1: 90.7%	70.93
Fossil methanol	69.1	Fuel option 2: 79.4%	54.87
		Fuel option 3: 80.7%	55.76
		Fuel option 4: 82.7%	57.15
LNG	56.11	Fuel option 5: 87.0%	48.82

	TTW CO_2 EF of fossil fuel (g CO_2/MJ fuel)	Max. fossil fuel share that allows meeting 2030 FuelEU Maritime target (see Table 7)	Resulting TTW CO_2 EF of fossil/renewable* blends with which FuelEU Maritime target can just be met (g CO_2/MJ fuel)
		Fuel option 6: 84.2%	**47.24**
		Fuel options 7-8: 87.2%	48.93
		Fuel options 9-12: 100%	56.11

* TTW CO_2 emission factor of renewable fuels is assumed to be zero.

As a consequence, the use of an engine with a relatively high methane slip as well as the use a of the renewable fuel with the highest WTW GHG emissions of the options considered in the study (see Table 3) is incentivized by EU ETS.

As Table 12 illustrates, the cheapest option in terms of 2030 EU ETS costs (option 6), is associated with 3.31 €/GJ EU ETS costs, whereas the cheapest option in terms of fuel costs (option 9-12) with 4.1 €/GJ fuel blend costs. This option is, with 8.03 €/GJ, also the cheapest option in term of total costs (EU ETS and fuel blend costs): For all the options that have lower EU ETS costs than option 9-12, the additional fuel costs do not outweigh the EU ETS cost saving. The incentive given by the fuel costs are thus dominant, which means that FuelEU Maritime as well as EU ETS in combination with FuelEU Maritime incentivise(s) the use of an LNG engine associated with the relatively lowest methane slip (option 9-12).

Under this option, however, no renewable fuel has to be used at all. With fossil LNG used in a diesel dual fuel slow speed engine, the 2025 and 2030 GHG intensity targets of FuelEU Maritime can be met using 100% fossil LNG. The EU ETS costs for this option are the second highest compared to the other considered.

Table 12 - 2030 EU ETS costs and fuel blend costs in €/GJ if 2030 FuelEU Maritime target is just met

Fuel blend/engine		2030 EU ETS costs* (€/GJ)	Fuel blend costs (€/GJ)**	Total costs (€/GJ)
			Low price scenario	Low price scenario
1	VLSFO/FAME from waste cooking oil	4.97	5.66	10.63
2	Fossil methanol/biomethanol from farmed wood	3.84	13.79	17.63
3	Fossil methanol/biomethanol from black liquor	3.90	13.81	17.71
4	Fossil methanol/e-methanol	4.00	17.29	21.29
5	LNG/biomethane from wet manure/Otto DF MS	3.42	5.13	8.55
6	LNG/biomethane from biowaste/Otto DF MS	3.31	5.35	8.66
7	LNG/e-methane from Europe/Otto DF MS	3.43	9.96	13.39
8	LNG/e-methane from North-Africa/Otto DF MS	3.43	8.58	12.01
9-12	LNG/Diesel DF SS	3.93	4.10	8.03

* 70 €/tonne CO_2; ** Fuel prices as presented in Table 9 and share of fossil and renewable fuels as presented in Table 8.

To give an example of the absolute costs for the fuel option incentivized (option 9-12):
- For sample ship 5 (Ro-pax) we have estimated that
  - 2030 EU ETS costs would amount to € 2.99 million and
  - 2030 in-scope fuel costs would amount to €3.15 to € 9.44 million depending on the fuel price.
- For sample ship 9 (chemical tanker below 5,000 GT) we have estimated that
  - 2030 EU ETS costs would amount to € 0.17 million and
  - 2030 in-scope fuel costs would amount to € 0.18 to € 0.54 million depending on the fuel price.

For the absolute costs of the other sample ships, please see Annex B of the report.

If you compare the three methanol options (options 2 to 4), then option 2 (blend with biomethanol from farmed wood) is more favourable in terms of EU ETS costs. The renewable methanol used in option 2 is however associated with the highest WTW GHG emissions compared to the other renewable methanol options. In terms of fuel costs and the combined costs (i.e. fuel and EU ETS costs), the advantageousness of the options also depends on the fuel prices. In the low price scenario, option 2 (blend with biomethanol from farmed wood) is more advantageous, whereas in a high price scenario, option 3 (blend with biomethanol from black liquor). This illustrates that both, the share of fossil and renewable fuel required and the proportion of the fossil and renewable fuel price determine the advantageous of different options.

4.2 Sensitivity of LNG fuel price

Since the use of fossil LNG has been derived to lead to the lowest total costs, we have analysed the sensitivity of the LNG price for this outcome.

Considering two alternative sets of EU ETS allowances prices, we have derived the ‘break even’ LNG price for which one of the four fuel blends considered in the study that do not include LNG/methane is associated with the same, lowest total costs, i.e. the LNG price at which LNG would not be the preferred option in terms of total costs (EU ETS and fuel costs anymore (see Table 13).

Table 13 - LNG price for which a fuel blend not including LNG/methane has lowest costs (€/GJ)

	2025		2030	
	Low price scenario	High price scenario	Low price scenario	High price scenario
EU ETS price: 2025: € 60/t CO_2; 2030; € 70/t CO_2	5.9	16.3	6.8	18.8
EU ETS price: 2025: € 30/t CO_2; 2030; € 45/t CO_2	5.5	15.9	6.4	18.4

To put these ‘break even’ LNG prices into perspective: the LNG price applied in the study ranges from 4.1 to 12.4 €/GJ and the LNG price peaked in October 2021 at 35 €/GJ.

5 Potential adverse incentives and inconsistencies

5.1 Incentives

From our analysis it can be concluded that EU ETS and FuelEU Maritime set different incentives due to the different emission scopes. Although both incentivise the use of LNG, EU ETS incentivises the use of an LNG/renewable methane blend using a blend with relatively high WTW GHG emissions and the use of an engine with relatively high methane slip, whereas FuelEU Maritime the use of 100% fossil LNG and the use of an engine with relatively low methane slip.

And further, the combined incentive of the two measures in terms of fuel costs and EU ETS allowance costs in 2025 and 2030 is to use 100% fossil LNG in combination with an engine with relatively low methane slip.

This has two implications: First, the production and establishment of the according distribution chains of renewable fuels may not timely be incentivized and, second, the sector runs the risk of partially heading towards a lock-in associated with sunk costs if LNG-fuelled ships could not be used in the long-run anymore. This however would only the case if not sufficient renewable methane will become available which would then be essential for the energy transition of parts of the sector.

5.2 Emission factors

5.2.1 Emission factors FuelEU Maritime Regulation

Our analysis revealed the following potential issues related to the default emission factors as proposed in Annex II of the proposed FuelEU Maritime Regulation:

- The WTT emissions of biofuels are taken from Annex 5 Part C of Directive (EU) 2018/2001. These emissions are often higher than the WTT emissions of biofuels, because the Directive follows the IPCC guidelines so that a plant growing to produce biomass/biofuel is not a sink and the emissions of combustion are zero (Directive (EU) 2018/2001 Annex V Part C Art 13). Together with the stochiometric value for the emissions of these fuels in use proposed in Annex II, this results in emission factors of biofuels that are higher than the comparable fossil fuels. This does not make sense. It would be better to set the emissions of fuels in use (column 6) to zero for biofuels, in line with Directive (EU) 2018/2001 Annex V Part C Art 13 or alternatively introduce a negative WTT value to account for the carbon uptake of the biomass.
- In Annex II of the proposed Regulation, there seem to be inconsistencies between biomethane on the one hand and fossil LNG and e-methane on the other hand. inconsistencies between biomethane on the one hand and e-methane and LNG on the other hand:
  - for fossil LNG and e-LNG, the emission factor for CH_4 (combustion related; column 7) is zero, but for bio-LNG positive;
  - for fossil LNG and e-LNG, the emission factor for N_2O (combustion related; column 8) is 0.00011, but for bio-LNG 0.00018;

— Some of the default emission factors have not been specified yet (indicated by TBM = to be measured or N/A = not available) which makes it difficult to come to a definite weighing of the different options.

When working with the emission factors the following points of attention should be considered:
— emission factors for the dual fuel engines do not account for the use of pilot fuel;
— the MJs to which the emission factors are applied account for the methane slip of LNG engines (see Paragraph 2.2.1 for the methane slip factors applied in the study).

5.2.2 Emission factors EU ETS

CE Delft and DLR (2021) have recently published a thorough analysis of the EU ETS revision proposal with focus on maritime shipping and potential implementation issues.

With regards to the emission factors of alternative bunker fuels it is concluded:

Alternative bunker fuels like hydrogen and ammonia do not lead to any TTW CO_2 emissions, independent of the source of hydrogen used for their production (like coal or water electrolysis). And green, renewable hydrocarbons or alcohols are associated with the same TTW CO_2 emissions as their fossil equivalents, whereas the CO_2 used for the production of the green, renewable hydrocarbons is recycled after being captured at either a (biogenic) point source or directly from the air. (CE Delft and DLR, 2021)

Keeping the WTT emissions of the bunker fuels outside the scope of the EU ETS would therefore mean that the use of green, renewable alternative bunker fuels like hydrogen, ammonia, hydrocarbons or alcohols would be associated with the same in-scope emissions as their fossil equivalents. And since the fossil equivalents can be expected to be much cheaper, the EU ETS would not incentivize the use of green, renewable alternative bunker fuels unless the emission factors used to derive the ships' CO_2 emissions account for this fact. (CE Delft and DLR, 2021)

These aspects should thus be considered for the implementing act in which the emission factors will be specified.

6 Conclusions and recommendations

This short study has analysed the separate and combined incentives of the EU ETS and the FuelEU Maritime Regulation for maritime shipping by calculating the potential EU ETS and fuel costs for nine sample ships for 2025 and 2030. Alternative combinations of blends of fossil and renewable fuels and engines that allow to meet the FuelEU Maritime GHG intensity targets have been considered to this end.

Capital costs have not been considered in the study. This means that not all regulated ships necessarily have an incentive to use a fuel blend/engine option that has been assessed to be advantageous in terms of fuel and/or EU ETS costs. If the use of a fuel blend option requires a ship to be retrofitted, high retrofitting costs can make this option less attractive and the option might only be considered when a ship is replaced.

The analysis shows that the advantageousness of a compliance option compared to the others does not depend on the ship considered, only the level of the costs associated with the option differs between the ships.

The analysis also shows that both measures, separately and combined, incentivize the use of LNG. Due to the difference in emissions scope, however, different compliance options are incentivized. The emissions scope of the two regulations differs: while EU ETS is proposed to cover the TTW CO_2 emissions, FuelEU Maritime is proposed to cover the WTW emissions of different GHGs (CO_2, CH_4, N_2O). EU ETS gives an incentive to use an engine with relatively high methane slip and a blend with a renewable fuel that features the highest WTW GHG emissions per MJ compared to the other renewable fuels considered. FuelEU Maritime on the other hand incentivizes, given the assumed fuel prices, the use of an engine with relatively low methane slips in combination with 100% fossil LNG. With fossil LNG used in a diesel dual fuel slow speed engine, the 2025 and 2030 GHG intensity targets of FuelEU Maritime can be met without using renewable methane. Since the incentive given by the fuel costs associated with the different blends that allow meeting the FuelEU Maritime targets is dominant, the combined incentive of the two measures given by fuel costs and EU ETS allowance costs is to use 100% of fossil LNG in 2025 and 2030.

This has two implications: First, the production and establishment of the distribution chains of renewable fuels may not be incentivized matching the pace required for the energy transition. Second, the sector risks partially heading towards a lock-in of assets with high sunk costs unless sufficient renewable methane becomes available which would then be essential for the energy transition of the sector.

Based on our analysis we recommend the following:

1. The incentives given for the choice of fuel by EU ETS and FuelEU Maritime should be aligned. If the EU ETS was implemented with the deviating emissions scope, i.e. with the Tank-to-Wake approach and limited to CO_2 emissions, then the different fuel blend options that are equally fit for meeting the FuelEU Maritime target would be assessed differently in terms of EU ETS costs. Although these blends would be associated with the same Well-to-Wake GHG emissions per ship, EU ETS would reward those blends with the lowest EU ETS costs that feature the lowest Tank-to-Wake CO_2 emissions per MJ of fuel.
2. The measures should set sound environmental incentives:
   a EU ETS incentives should reflect the renewable fuels' Well-to-Tank emissions, thus e.g. not treating grey and green hydrogen alike.

b The CO_2 emission factors applied under both measures should account for the recycled carbon of renewable fuels.

c The proposed default emission factors should be thoroughly reviewed to correct for inconsistencies (see Chapter 5). To provide more background information on the selection of the proposed default values would be very useful in this context.

3. It should be thoroughly analysed whether sufficient renewable methane will become available for the sector to avoid a potential lock-in for parts of the sector potentially associated with high sunk costs.
4. Consider how the aim of FuelEU Maritime — the stimulation of the timely production of renewable fuels via the stimulation of the demand for the fuels — can be assured.

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A Overview of total costs

Table 14 and Table 15 provide an overview of the 2025 and 2030 costs for the different sample ships, giving the highest and lowest EU ETS and total costs (EU ETS and fuel costs) without specifying the underlying fuel (blend). This is to illustrate the scale of the costs.

Table 14 - 2025 highest and lowest EU ETS and total costs (EU ETS and fuel costs) per sample ship (€ mln.)

2025	EU ETS costs		Total costs (low price scenario)		Total costs (high price scenario)	
	Cost range depending on fuel blend		Cost range depending on fuel blend		Cost range depending on fuel blend	
Sample ship 1	0.09	0.14	0.29	0.85	0.66	2.00
Sample ship 2	0.12	0.18	0.38	1.12	0.87	2.62
Sample ship 3	0.20	0.29	0.61	1.79	1.38	4.18
Sample ship 4	0.15	0.21	0.44	1.31	1.01	3.06
Sample ship 5	1.62	2.39	4.94	14.55	11.23	34.06
Sample ship 6	0.48	0.72	1.48	4.36	3.37	10.20
Sample ship 7	1.00	1.47	3.05	8.97	6.92	21.00
Sample ship 8	0.62	0.92	1.91	5.62	4.34	13.15
Sample ship 9	0.09	0.14	0.28	0.83	0.64	1.95

Table 15 - 2030 highest and lowest EU ETS and total costs (EU ETS and fuel costs) per sample ship (€ mln.)

2030	EU ETS costs		Total costs (low price scenario)		Total costs (high price scenario)	
	Cost range depending on fuel blend		Cost range depending on fuel blend		Cost range depending on fuel blend	
Sample ship 1	0.15	0.22	0.36	0.95	0.73	2.34
Sample ship 2	0.19	0.29	0.47	1.25	0.96	3.07
Sample ship 3	0.31	0.46	0.75	1.99	1.53	4.90
Sample ship 4	0.23	0.34	0.55	1.46	1.12	3.58
Sample ship 5	2.52	3.78	6.14	16.21	12.43	39.90
Sample ship 6	0.75	1.13	1.84	4.86	3.72	11.95
Sample ship 7	1.55	2.33	3.78	9.99	7.66	24.59
Sample ship 8	0.97	1.46	2.37	6.26	4.80	15.41
Sample ship 9	0.14	0.22	0.35	0.93	0.71	2.28

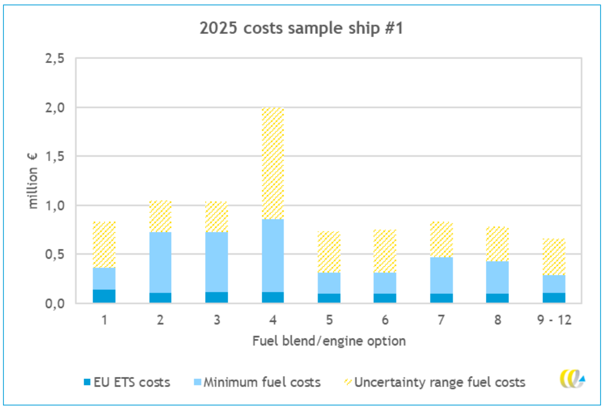
B Appendix

B.1 Detailed results for bulk carrier (sample ship #1)

Table 16 – Annual in-scope fuel costs and EU ETS costs for sample ship # 1 in 2025

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	2.34	59%	0.14	0.23	0.69	0.37	0.83
2	Fossil methanol/biomethanol from farmed wood	1.81	45%	0.11	0.62	0.94	0.73	1.05
3	Fossil methanol/biomethanol from black liquor	1.84	46%	0.11	0.62	0.93	0.73	1.04
4	Fossil methanol/e-methanol	1.87	47%	0.11	0.74	1.89	0.85	2.00
5	LNG/biomethane from wet manure/Otto DF MS	1.61	40%	0.10	0.21	0.64	0.31	0.73
6	LNG/biomethane from biowaste/Otto DF MS	1.58	40%	0.09	0.22	0.66	0.31	0.75
7	LNG/e-methane from Europe/Otto DF MS	1.62	40%	0.10	0.37	0.73	0.47	0.83
8	LNG/e-methane from North-Africa/Otto DF MS	1.62	40%	0.10	0.33	0.69	0.43	0.79
9-12	LNG/Diesel DF SS	1.76	44%	0.11	0.18	0.55	0.29	0.66

* 70% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 60/t CO_2.



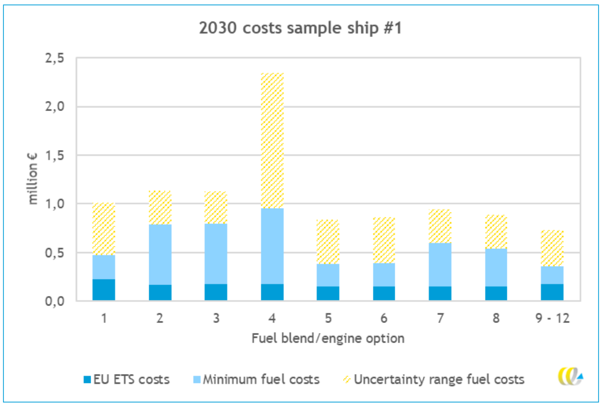


Table 17 – Annual in-scope fuel costs and EU ETS costs for sample ship # 1 in 2030

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	3.18	82%	0.22	0.25	0.79	0.48	1.02
2	Fossil methanol/biomethanol from farmed wood	2.46	64%	0.17	0.62	0.96	0.79	1.13
3	Fossil methanol/biomethanol from black liquor	2.50	66%	0.17	0.62	0.95	0.79	1.13
4	Fossil methanol/e-methanol	2.56	67%	0.18	0.77	2.17	0.95	2.34
5	LNG/biomethane from wet manure/Otto DF MS	2.19	58%	0.15	0.23	0.69	0.38	0.84
6	LNG/biomethane from biowaste/Otto DF MS	2.11	56%	0.15	0.24	0.71	0.39	0.86
7	LNG/e-methane from Europe/Otto DF MS	2.19	58%	0.15	0.45	0.80	0.60	0.95
8	LNG/e-methane from North-Africa/Otto DF MS	2.19	58%	0.15	0.39	0.73	0.54	0.88
9-12	LNG/Diesel DF SS	2.51	66%	0.18	0.18	0.55	0.36	0.73

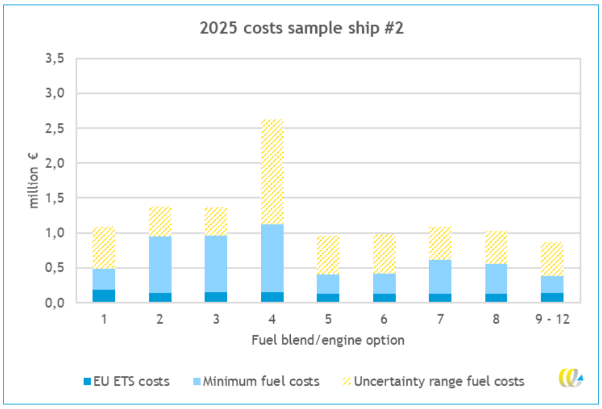
* 100% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1.; EU ETS allowance price: € 70/t CO_2.

B.2 Detailed results for oil tanker (sample ship #2)

Table 18 – Annual in-scope fuel costs and EU ETS costs for sample ship # 2 in 2025

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	3.07	59%	0.18	0.30	0.91	0.48	1.09
2	Fossil methanol/biomethanol from farmed wood	2.38	45%	0.14	0.81	1.23	0.95	1.37
3	Fossil methanol/biomethanol from black liquor	2.41	46%	0.14	0.81	1.22	0.96	1.37
4	Fossil methanol/e-methanol	2.45	47%	0.15	0.97	2.48	1.12	2.62
5	LNG/biomethane from wet manure/Otto DF MS	2.12	40%	0.13	0.28	0.84	0.41	0.96
6	LNG/biomethane from biowaste/Otto DF MS	2.07	40%	0.12	0.29	0.86	0.41	0.98
7	LNG/e-methane from Europe/Otto DF MS	2.12	40%	0.13	0.49	0.96	0.61	1.09
8	LNG/e-methane from North-Africa/Otto DF MS	2.12	40%	0.13	0.43	0.91	0.56	1.03
9-12	LNG/Diesel DF SS	2.30	44%	0.14	0.24	0.73	0.38	0.87

* 70% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 60/t CO_2.



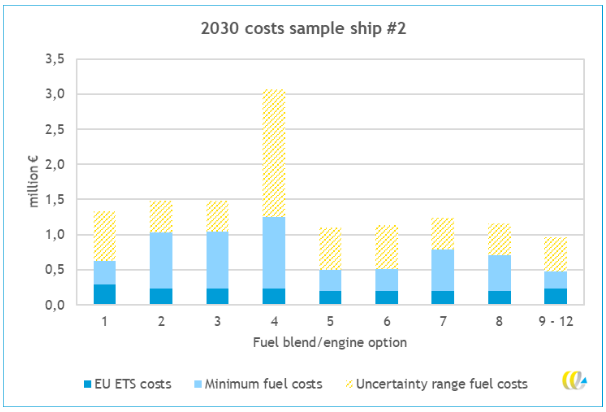


Table 19 – Annual in-scope fuel costs and EU ETS costs for sample ship # 2 in 2030

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	4.16	82%	0.29	0.33	1.04	0.63	1.33
2	Fossil methanol/biomethanol from farmed wood	3.22	64%	0.23	0.81	1.26	1.03	1.49
3	Fossil methanol/biomethanol from black liquor	3.27	66%	0.23	0.81	1.25	1.04	1.48
4	Fossil methanol/e-methanol	3.35	67%	0.23	1.01	2.84	1.25	3.07
5	LNG/biomethane from wet manure/Otto DF MS	2.86	58%	0.20	0.30	0.90	0.50	1.10
6	LNG/biomethane from biowaste/Otto DF MS	2.77	56%	0.19	0.32	0.94	0.51	1.13
7	LNG/e-methane from Europe/Otto DF MS	2.87	58%	0.20	0.59	1.04	0.79	1.24
8	LNG/e-methane from North-Africa/Otto DF MS	2.87	58%	0.20	0.51	0.96	0.71	1.16
9-12	LNG/Diesel DF SS	3.29	66%	0.23	0.24	0.73	0.47	0.96

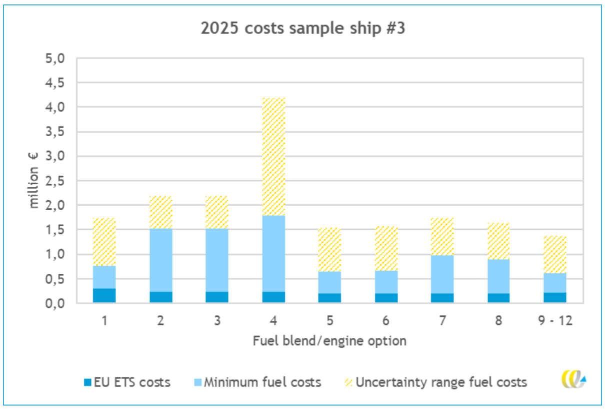
* 100% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 70/t CO_2.

B.3 Detailed results for oil tanker (sample ship #3)

Table 20 – Annual in-scope fuel costs and EU ETS costs for sample ship # 3 in 2025

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	4.89	59%	0.29	0.47	1.44	0.77	1.74
2	Fossil methanol/biomethanol from farmed wood	3.79	45%	0.23	1.29	1.96	1.52	2.19
3	Fossil methanol/biomethanol from black liquor	3.84	46%	0.23	1.30	1.95	1.53	2.18
4	Fossil methanol/e-methanol	3.91	47%	0.23	1.55	3.95	1.79	4.18
5	LNG/biomethane from wet manure/Otto DF MS	3.37	40%	0.20	0.45	1.33	0.65	1.53
6	LNG/biomethane from biowaste/Otto DF MS	3.31	40%	0.20	0.46	1.37	0.66	1.57
7	LNG/e-methane from Europe/Otto DF MS	3.38	40%	0.20	0.77	1.53	0.98	1.74
8	LNG/e-methane from North-Africa/Otto DF MS	3.38	40%	0.20	0.69	1.44	0.89	1.65
9-12	LNG/Diesel DF SS	3.67	44%	0.22	0.39	1.16	0.61	1.38

* 70% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 60/t CO_2.



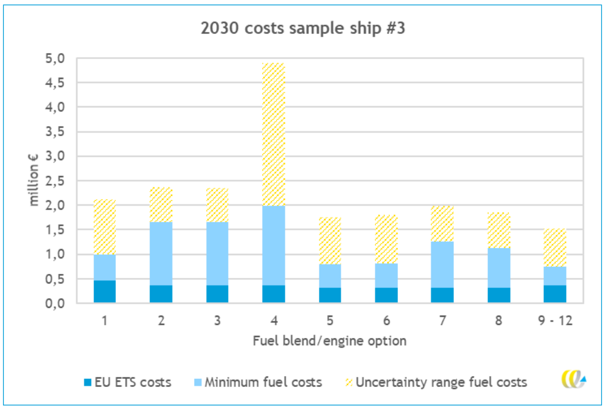


Table 21 – Annual in-scope fuel costs and EU ETS costs for sample ship # 3 in 2030

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	6.64	82%	0.46	0.53	1.66	1.00	2.12
2	Fossil methanol/biomethanol from farmed wood	5.13	64%	0.36	1.29	2.01	1.65	2.37
3	Fossil methanol/biomethanol from black liquor	5.22	66%	0.37	1.29	1.99	1.66	2.36
4	Fossil methanol/e-methanol	5.35	67%	0.37	1.62	4.53	1.99	4.90
5	LNG/biomethane from wet manure/Otto DF MS	4.57	58%	0.32	0.48	1.43	0.80	1.75
6	LNG/biomethane from biowaste/Otto DF MS	4.42	56%	0.31	0.50	1.49	0.81	1.80
7	LNG/e-methane from Europe/Otto DF MS	4.58	58%	0.32	0.94	1.66	1.26	1.98
8	LNG/e-methane from North-Africa/Otto DF MS	4.58	58%	0.32	0.81	1.53	1.13	1.85
9-12	LNG/Diesel DF SS	5.25	66%	0.37	0.39	1.16	0.75	1.53

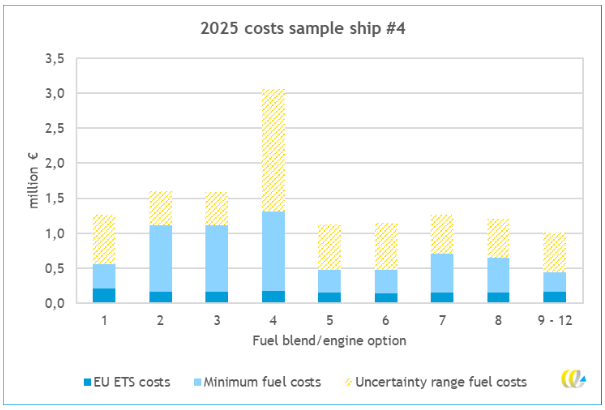
* 100% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 70/t CO_2.

B.4 Detailed results for gas carrier (sample ship # 4)

Table 22 - Annual in-scope fuel costs and EU ETS costs for sample ship # 4 in 2025

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	3.57	59%	0.21	0.34	1.06	0.56	1.27
2	Fossil methanol/biomethanol from farmed wood	2.77	45%	0.17	0.95	1.43	1.11	1.60
3	Fossil methanol/biomethanol from black liquor	2.80	46%	0.17	0.95	1.42	1.12	1.59
4	Fossil methanol/e-methanol	2.86	47%	0.17	1.13	2.89	1.31	3.06
5	LNG/biomethane from wet manure/Otto DF MS	2.47	40%	0.15	0.33	0.97	0.47	1.12
6	LNG/biomethane from biowaste/Otto DF MS	2.42	40%	0.15	0.34	1.00	0.48	1.15
7	LNG/e-methane from Europe/Otto DF MS	2.47	40%	0.15	0.57	1.12	0.71	1.27
8	LNG/e-methane from North-Africa/Otto DF MS	2.47	40%	0.15	0.50	1.06	0.65	1.20
9-12	LNG/Diesel DF SS	2.69	44%	0.16	0.28	0.85	0.44	1.01

* 70% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 60/t CO_2.



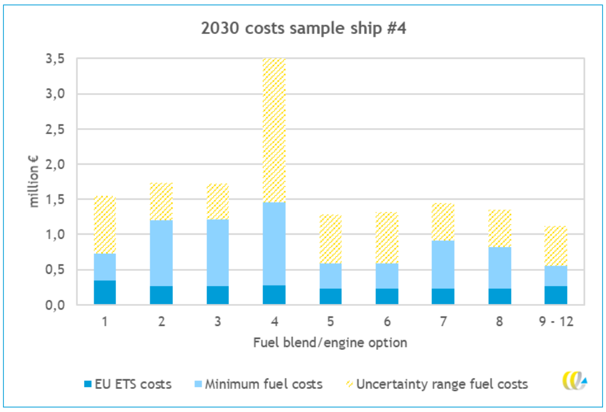


Table 23 – Annual in-scope fuel costs and EU ETS costs for sample ship # 4 in 2030

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	4.85	82%	0.34	0.39	1.21	0.73	1.55
2	Fossil methanol/biomethanol from farmed wood	3.75	64%	0.26	0.94	1.47	1.21	1.73
3	Fossil methanol/biomethanol from black liquor	3.81	66%	0.27	0.94	1.46	1.21	1.72
4	Fossil methanol/e-methanol	3.91	67%	0.27	1.18	3.31	1.46	3.58
5	LNG/biomethane from wet manure/Otto DF MS	3.34	58%	0.23	0.35	1.05	0.59	1.28
6	LNG/biomethane from biowaste/Otto DF MS	3.23	56%	0.23	0.37	1.09	0.59	1.32
7	LNG/e-methane from Europe/Otto DF MS	3.34	58%	0.23	0.68	1.22	0.92	1.45
8	LNG/e-methane from North-Africa/Otto DF MS	3.34	58%	0.23	0.59	1.12	0.82	1.35
9-12	LNG/Diesel DF SS	3.84	66%	0.27	0.28	0.85	0.55	1.12

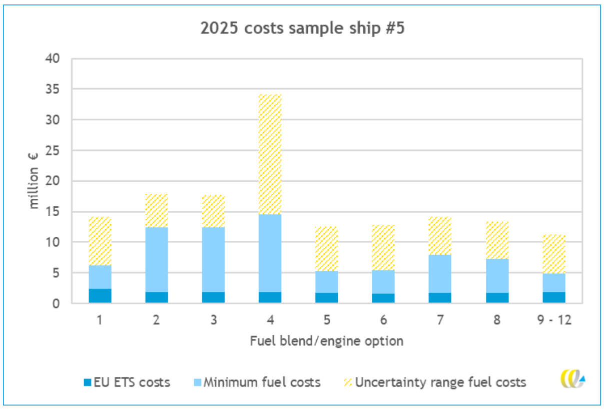
* 100% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 70/t CO_2.

B.5 Detailed results for Ro-pax vessel (sample ship # 5)

Table 24 – Annual in-scope fuel costs and EU ETS costs for sample ship # 5 in 2025

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	39.83	59%	2.39	3.84	11.76	6.23	14.15
2	Fossil methanol/biomethanol from farmed wood	30.85	45%	1.85	10.54	15.96	12.39	17.81
3	Fossil methanol/biomethanol from black liquor	31.24	46%	1.87	10.55	15.87	12.42	17.74
4	Fossil methanol/e-methanol	31.82	47%	1.91	12.64	32.16	14.55	34.06
5	LNG/biomethane from wet manure/Otto DF MS	27.47	40%	1.65	3.64	10.85	5.29	12.50
6	LNG/biomethane from biowaste/Otto DF MS	26.94	40%	1.62	3.74	11.15	5.36	12.77
7	LNG/e-methane from Europe/Otto DF MS	27.51	40%	1.65	6.30	12.49	7.95	14.15
8	LNG/e-methane from North-Africa/Otto DF MS	27.51	40%	1.65	5.59	11.76	7.24	13.41
9-12	LNG/Diesel DF SS	29.92	44%	1.80	3.15	9.44	4.94	11.23

* 70% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 60/t CO_2.



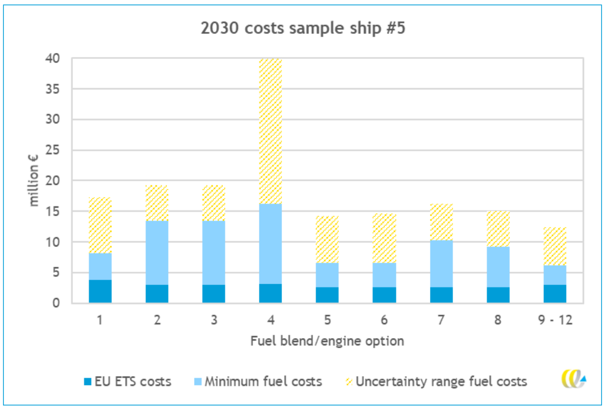


Table 25 – Annual in-scope fuel costs and EU ETS costs for sample ship # 5 in 2030

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	54.06	82%	3.78	4.33	13.50	8.12	17.28
2	Fossil methanol/biomethanol from farmed wood	41.80	64%	2.93	10.51	16.36	13.43	19.28
3	Fossil methanol/biomethanol from black liquor	42.50	66%	2.97	10.52	16.24	13.49	19.21
4	Fossil methanol/e-methanol	43.55	67%	3.05	13.17	36.85	16.21	39.90
5	LNG/biomethane from wet manure/Otto DF MS	37.19	58%	2.60	3.93	11.68	6.53	14.28
6	LNG/biomethane from biowaste/Otto DF MS	35.98	56%	2.52	4.09	12.16	6.61	14.68
7	LNG/e-methane from Europe/Otto DF MS	37.26	58%	2.61	7.62	13.54	10.23	16.15
8	LNG/e-methane from North-Africa/Otto DF MS	37.26	58%	2.61	6.56	12.45	9.17	15.06
9-12	LNG/Diesel DF SS	42.75	66%	2.99	3.15	9.44	6.14	12.43

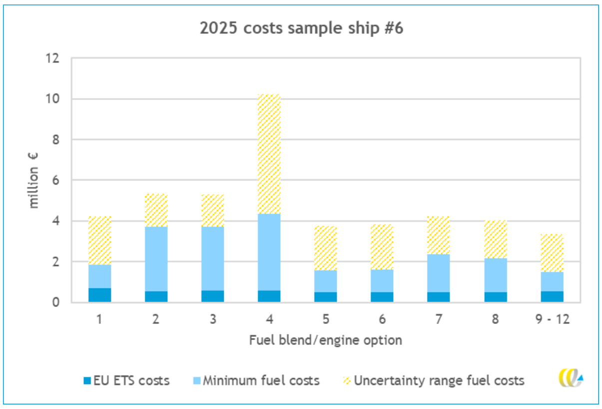
* 100% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 70/t CO_2.

B.6 Detailed results for container vessel (sample ship #6)

Table 26 - Annual in-scope fuel costs and EU ETS costs for sample ship # 6 in 2025

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	11.93	59%	0.72	1.15	3.52	1.87	4.24
2	Fossil methanol/biomethanol from farmed wood	9.24	45%	0.55	3.16	4.78	3.71	5.34
3	Fossil methanol/biomethanol from black liquor	9.36	46%	0.56	3.16	4.75	3.72	5.31
4	Fossil methanol/e-methanol	9.53	47%	0.57	3.79	9.63	4.36	10.20
5	LNG/biomethane from wet manure/Otto DF MS	8.23	40%	0.49	1.09	3.25	1.58	3.74
6	LNG/biomethane from biowaste/Otto DF MS	8.07	40%	0.48	1.12	3.34	1.61	3.83
7	LNG/e-methane from Europe/Otto DF MS	8.24	40%	0.49	1.89	3.74	2.38	4.24
8	LNG/e-methane from North-Africa/Otto DF MS	8.24	40%	0.49	1.67	3.52	2.17	4.02
9-12	LNG/Diesel DF SS	8.96	44%	0.54	0.94	2.83	1.48	3.37

* 70% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 60/t CO_2.



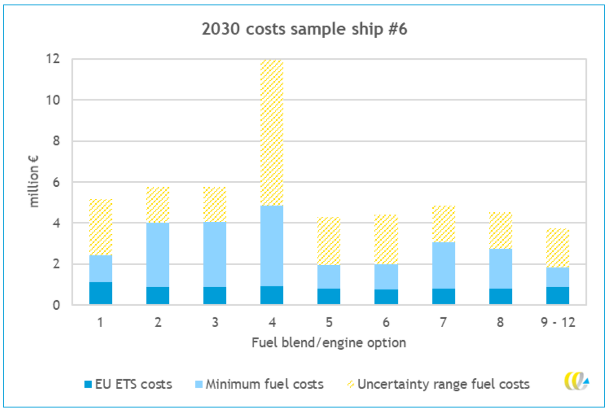


Table 27 – Annual in-scope fuel costs and EU ETS costs for sample ship # 6 in 2030

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	16.19	82%	1.13	1.30	4.04	2.43	5.18
2	Fossil methanol/biomethanol from farmed wood	12.52	64%	0.88	3.15	4.90	4.02	5.78
3	Fossil methanol/biomethanol from black liquor	12.73	66%	0.89	3.15	4.86	4.04	5.76
4	Fossil methanol/e-methanol	13.05	67%	0.91	3.94	11.04	4.86	11.95
5	LNG/biomethane from wet manure/Otto DF MS	11.14	58%	0.78	1.18	3.50	1.96	4.28
6	LNG/biomethane from biowaste/Otto DF MS	10.78	56%	0.75	1.23	3.64	1.98	4.40
7	LNG/e-methane from Europe/Otto DF MS	11.16	58%	0.78	2.28	4.06	3.06	4.84
8	LNG/e-methane from North-Africa/Otto DF MS	11.16	58%	0.78	1.97	3.73	2.75	4.51
9-12	LNG/Diesel DF SS	12.81	66%	0.90	0.94	2.83	1.84	3.72

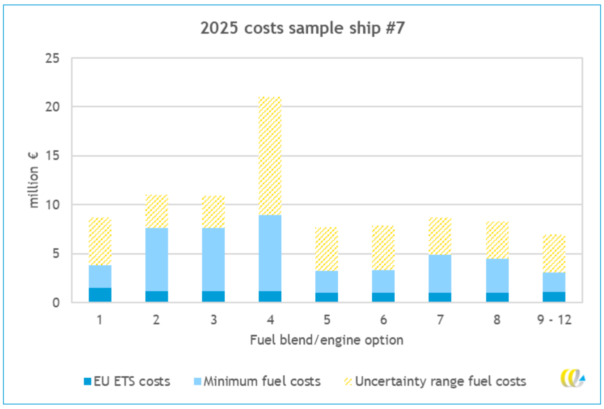
* 100% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 70/t CO_2.

B.7 Detailed results for container vessel (sample ship #7)

Table 28 – Annual in-scope fuel costs and EU ETS costs for sample ship # 7 in 2025

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	24.55	59%	1.47	2.37	7.25	3.84	8.72
2	Fossil methanol/biomethanol from farmed wood	19.02	45%	1.14	6.50	9.84	7.64	10.98
3	Fossil methanol/biomethanol from black liquor	19.25	46%	1.16	6.50	9.78	7.66	10.94
4	Fossil methanol/e-methanol	19.61	47%	1.18	7.79	19.82	8.97	21.00
5	LNG/biomethane from wet manure/Otto DF MS	16.93	40%	1.02	2.24	6.69	3.26	7.70
6	LNG/biomethane from biowaste/Otto DF MS	16.61	40%	1.00	2.31	6.87	3.30	7.87
7	LNG/e-methane from Europe/Otto DF MS	16.95	40%	1.02	3.88	7.70	4.90	8.72
8	LNG/e-methane from North-Africa/Otto DF MS	16.95	40%	1.02	3.45	7.25	4.46	8.27
9-12	LNG/Diesel DF SS	18.45	44%	1.11	1.94	5.82	3.05	6.92

* 70% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 60/t CO_2.



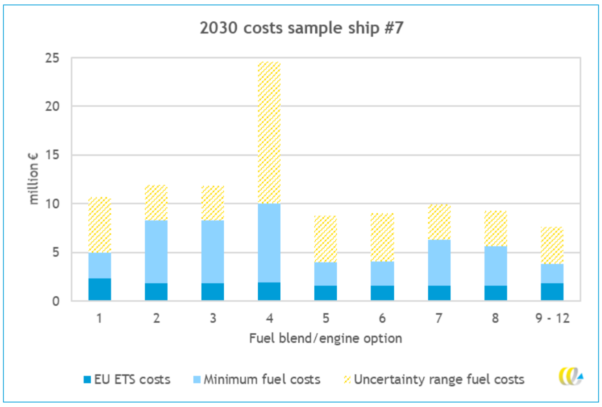


Table 29 – Annual in-scope fuel costs and EU ETS costs for sample ship # 7 in 2030

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	33.32	82%	2.33	2.67	8.32	5.00	10.65
2	Fossil methanol/biomethanol from farmed wood	25.76	64%	1.80	6.48	10.08	8.28	11.89
3	Fossil methanol/biomethanol from black liquor	26.19	66%	1.83	6.48	10.01	8.32	11.84
4	Fossil methanol/e-methanol	26.84	67%	1.88	8.12	22.71	9.99	24.59
5	LNG/biomethane from wet manure/Otto DF MS	22.92	58%	1.60	2.42	7.20	4.02	8.80
6	LNG/biomethane from biowaste/Otto DF MS	22.18	56%	1.55	2.52	7.50	4.08	9.05
7	LNG/e-methane from Europe/Otto DF MS	22.97	58%	1.61	4.70	8.35	6.30	9.95
8	LNG/e-methane from North-Africa/Otto DF MS	22.97	58%	1.61	4.05	7.67	5.65	9.28
9-12	LNG/Diesel DF SS	26.35	66%	1.84	1.94	5.82	3.78	7.66

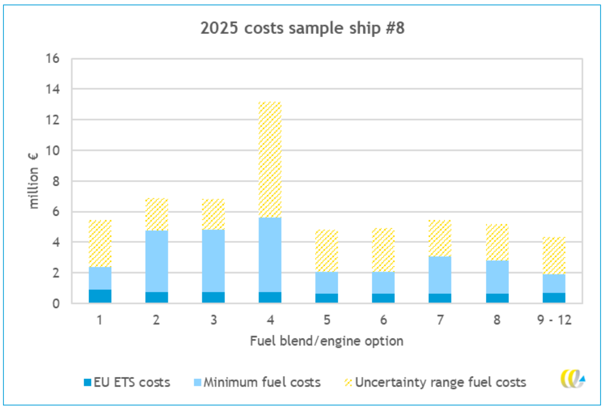
* 100% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 70/t CO_2.

B.8 Detailed results for container vessel (sample ship #8)

Table 30 – Annual in-scope fuel costs and EU ETS costs for sample ship # 8 in 2025

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	15.38	59%	0.92	1.48	4.54	2.41	5.47
2	Fossil methanol/biomethanol from farmed wood	11.91	45%	0.71	4.07	6.16	4.79	6.88
3	Fossil methanol/biomethanol from black liquor	12.06	46%	0.72	4.07	6.13	4.80	6.85
4	Fossil methanol/e-methanol	12.29	47%	0.74	4.88	12.42	5.62	13.15
5	LNG/biomethane from wet manure/Otto DF MS	10.61	40%	0.64	1.40	4.19	2.04	4.83
6	LNG/biomethane from biowaste/Otto DF MS	10.40	40%	0.62	1.45	4.31	2.07	4.93
7	LNG/e-methane from Europe/Otto DF MS	10.62	40%	0.64	2.43	4.83	3.07	5.46
8	LNG/e-methane from North-Africa/Otto DF MS	10.62	40%	0.64	2.16	4.54	2.80	5.18
9-12	LNG/Diesel DF SS	11.56	44%	0.69	1.21	3.64	1.91	4.34

* 70% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 60/t CO_2.



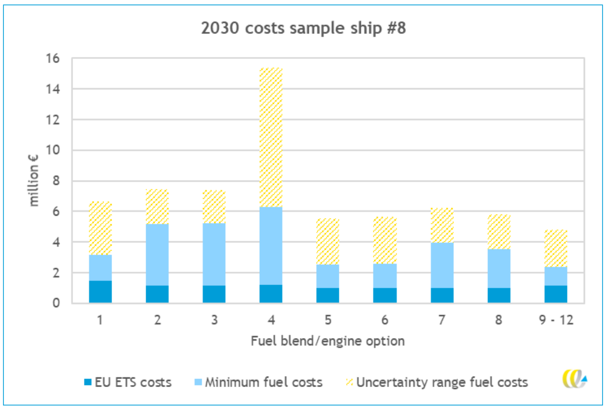


Table 31 – Annual in-scope fuel costs and EU ETS costs for sample ship # 8 in 2030

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	20.88	82%	1.46	1.67	5.21	3.13	6.67
2	Fossil methanol/biomethanol from farmed wood	16.14	64%	1.13	4.06	6.32	5.19	7.45
3	Fossil methanol/biomethanol from black liquor	16.41	66%	1.15	4.06	6.27	5.21	7.42
4	Fossil methanol/e-methanol	16.82	67%	1.18	5.08	14.23	6.26	15.41
5	LNG/biomethane from wet manure/Otto DF MS	14.36	58%	1.01	1.52	4.51	2.52	5.52
6	LNG/biomethane from biowaste/Otto DF MS	13.90	56%	0.97	1.58	4.70	2.55	5.67
7	LNG/e-methane from Europe/Otto DF MS	14.39	58%	1.01	2.94	5.23	3.95	6.24
8	LNG/e-methane from North-Africa/Otto DF MS	14.39	58%	1.01	2.53	4.81	3.54	5.81
9-12	LNG/Diesel DF SS	16.51	66%	1.16	1.21	3.64	2.37	4.80

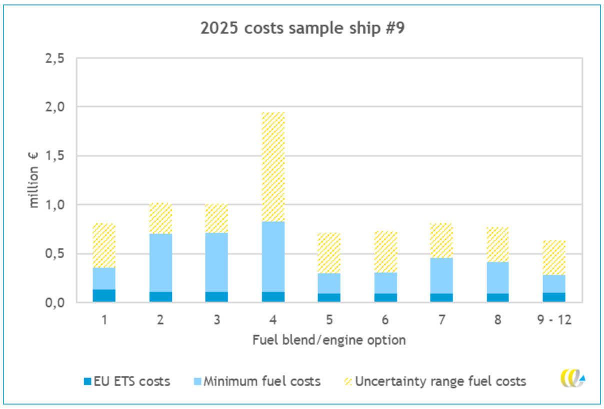
* 100% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 70/t CO_2.

B.9 Detailed results for chemical tanker below 5,000 GT (sample ship #9)

Table 32 – Annual in-scope fuel costs and EU ETS costs for sample ship # 9 in 2025

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	2.28	59%	0.14	0.22	0.67	0.36	0.81
2	Fossil methanol/biomethanol from farmed wood	1.76	45%	0.11	0.60	0.91	0.71	1.02
3	Fossil methanol/biomethanol from black liquor	1.79	46%	0.11	0.60	0.91	0.71	1.01
4	Fossil methanol/e-methanol	1.82	47%	0.11	0.72	1.84	0.83	1.95
5	LNG/biomethane from wet manure/Otto DF MS	1.57	40%	0.09	0.21	0.62	0.30	0.71
6	LNG/biomethane from biowaste/Otto DF MS	1.54	40%	0.09	0.21	0.64	0.31	0.73
7	LNG/e-methane from Europe/Otto DF MS	1.57	40%	0.09	0.36	0.71	0.45	0.81
8	LNG/e-methane from North-Africa/Otto DF MS	1.57	40%	0.09	0.32	0.67	0.41	0.77
9-12	LNG/Diesel DF SS	1.71	44%	0.10	0.18	0.54	0.28	0.64

* 70% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 60/t CO_2.



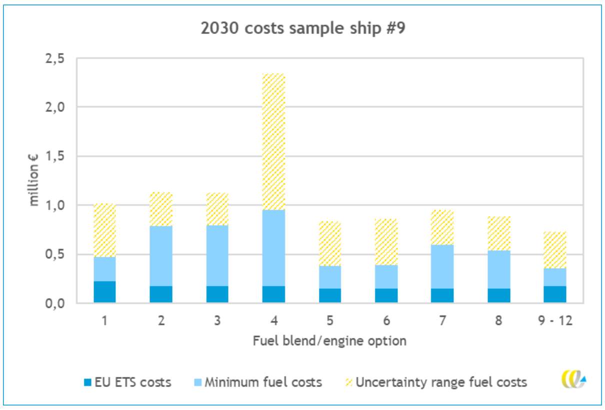


Table 33 – Annual in-scope fuel costs and EU ETS costs for sample ship # 9 in 2030

Fuel blend/engine		EU ETS CO_2 emissions* (1000 t)	EU ETS CO_2 vs FuelEU WTW GHG emissions	EU ETS costs (mln. €)	Annual fuel costs (mln. €)		Total costs (mln. €)	
					Low	High	Low	High
1	VLSFO/FAME from waste cooking oil	3.09	82%	0.22	0.25	0.77	0.46	0.99
2	Fossil methanol/biomethanol from farmed wood	2.39	64%	0.17	0.60	0.94	0.77	1.10
3	Fossil methanol/biomethanol from black liquor	2.43	66%	0.17	0.60	0.93	0.77	1.10
4	Fossil methanol/e-methanol	2.49	67%	0.17	0.75	2.11	0.93	2.28
5	LNG/biomethane from wet manure/Otto DF MS	2.13	58%	0.15	0.22	0.67	0.37	0.82
6	LNG/biomethane from biowaste/Otto DF MS	2.06	56%	0.14	0.23	0.70	0.38	0.84
7	LNG/e-methane from Europe/Otto DF MS	2.13	58%	0.15	0.44	0.77	0.58	0.92
8	LNG/e-methane from North-Africa/Otto DF MS	2.13	58%	0.15	0.38	0.71	0.52	0.86
9-12	LNG/Diesel DF SS	2.44	66%	0.17	0.18	0.54	0.35	0.71

* 100% of CO_2 emissions in the geographical scope, calculated by applying TTW CO_2 EFs as described under Paragraph 2.2.1; EU ETS allowance price: € 70/t CO_2.