Cost of clean shipping is negligible

Case study for 6% green e-fuels and stringent ETS

June 2022

Executive summary

This briefing provides the summary of quantitative analysis assessing the likely cost increase in seaborne transport if the ambition of the proposed FuelEU Maritime (FEUM) and the Maritime ETS is substantially strengthened. Specifically, the briefing assesses the likely cost impact of increasing the overall 2030 fuel greenhouse gas (GHG) intensity target under FEUM from -6% to -14%, mandating an additional 6% sub-quota for renewable fuels of non-biological origin (RFNBOs, or e-fuels) and incorporating a well-to-wake (WtW) CO_2 equivalent emissions into the maritime ETS, which currently only covers tank-to-wake (TtW) CO_2 emissions.

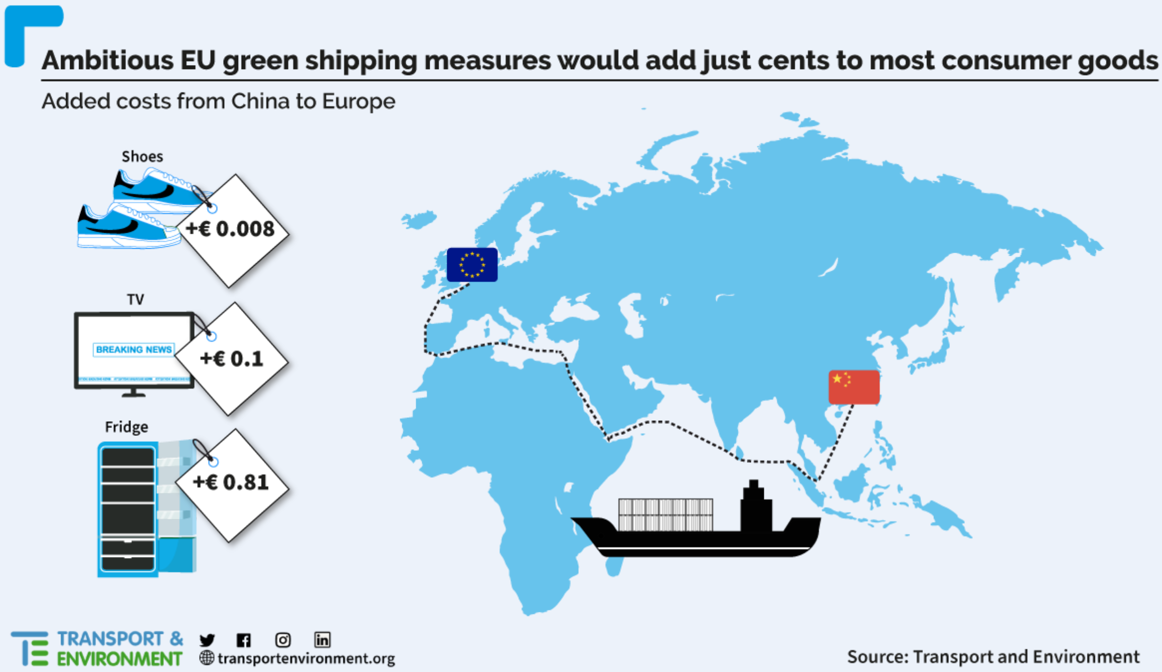

Figure 1: extra cost of ambitious FF55 shipping regulations on products imported from China

Based on a real-world example of a voyage of an average large container vessel sailing between China and Belgium, the analysis concluded that the likely impact on seaborne transport costs would be negligible. Specifically, under the analysed high ambition scenarios as described above, shipping a single standard container (TEU) from China to Belgium would be between €8.2/TEU and €40.5/TEU more expensive under historical prices, representing approximately a 1.04% and 5.15% increase in the seaborne freight costs from the historical average of about €800/TEU. Vis–à-vis the current average freight rates ranging between €4200/TEU and €6200/TEU, this would mean less than 0.8% increase in transport costs (Annex I). When it comes to daily consumer goods that are normally transported by these vessels, the cost increase is totally negligible, measured in (EURO) **cents**.

E-fuels/RFNBO scenarios that comply with the most stringent FEUM and ETS proposals would result in a maximum of €0.0081 (or 0.81 euro cents) cost increase for a pair of shoes shipped from China to Europe. Extra costs on bananas would be at most €0.0008 (or 0.08 euro cents). Similarly an average TV and refrigerator shipped to Europe would respectively cost a maximum of €0.1011 (or 10.01 euro cents) and €0.8091 (or 80.91 euro cents) more. For an average TV that costs about €300 or a pair of shoes worth €50, this would represent a maximum of 0.03% in price if all the costs are passed on to the final consumer. Given the highest historical earnings of the container carriers, it can be assumed that part of these costs, even if insignificant, can be assumed by the shipping operators.

NOTE: *This analysis was updated on July 18, 2022 in order to fix an unintended error in relation to ETS costs in the calculations. The original analysis included ETS cost estimations; however, given that carbon costs were inadvertently added both to baseline and alternative fuel-mix scenarios, this had cancelled out the impact of ETS costs in the final results. The impact of this revision on the overall conclusions of the analysis remains minor.*

1. Introduction

In July 2021, the European Commission proposed a suite of regulatory measures to ensure that the EU economy meets the newly set economy-wide target of achieving 55% emissions reduction by 2030 vis-à-vis the 1990 level. The so-called *Fit for 55* (FF55) package includes two measures specifically targeting international maritime transport; namely, EU emissions trading scheme (ETS) and FuelEU Maritime (FEUM) Regulation. While the former aims to price carbon emissions from ships, the latter sets GHG standards on fuels used by ships in operation in order to gradually squeeze out the fossil fuels from the sector.

While the EC proposal on ETS was widely welcomed by the majority of stakeholders, FEUM was largely criticised by the entire shipping industry and the NGO community alike.[1] As these draft laws go through the EU legislative process, there are several improvements proposed by the members of the European Parliament and the EU Member States. The main objective of this briefing is to analyse, using the best available data, the extra costs on seaborne transportation of staple consumer products of the most ambitious proposals to revise maritime ETS and FEUM.

The following subsections will initially provide a brief description of the proposed improvements to ETS and FEUM, followed by a methodology section explaining the main input assumptions and methodological choices. The last section will provide the findings of the quantitative analysis.

1.1. EU ETS

According to the EC proposal, maritime ETS will apply to the entirety of the voyages between EU ports and 50% of the emissions taking place on voyages between the EU and non-EU ports (in either direction). While the EC proposal will technicall cover only the tailpipe CO_2 emissions, there are calls to apply carbon pricing on a well-to-wake CO_2 equivalent (WtW CO_2e) basis that would also price emissions of methane (CH_4) and nitrous oxide (N_2O). In order to take this into account, this analysis will apply WtW CO_2e emissions factors from Annex I of the FEUM proposal to maritime carbon pricing under the ETS in order estimate total carbon costs of an example voyage between China and EU.

1.1.1. FEUM

The EC proposed to apply FEUM to the entirety of energy consumed on the voyages between EU ports, but only to 50% of the energy used on board during the voyages between the EU and non-EU ports. Being guided by a technology and fuel neutral approach, FEUM requires ships to achieve the onboard fuel GHG

[1] Joint statement: *European shipowners and T&E warn proposed EU shipping law could do more harm than good*, May 31, 2022. Accessible at: https://www.transportenvironment.org/discover/european-shipowners-and-te-warn-proposed-eu-shipping-law-could-do-more-harm-than-good/

improvements (GHGIE) below the 2020 baseline as presented in Table 1 below. The proposal does not achieve full decarbonisation by 2050, contrary to what is supported by the European Commission and 27 EU Member States at the International Maritime Organisation.[2] Nor does it include any dedicated mechanisms, such a minimum sub-quotas, to promote sustainable and scalable marine fuels, i.e. renewable fuels of non-biological origin (RFNBOs). This is despite the EC proposal for ReFuelEU Aviation explicitly recognising the need to mandate sub-quotas to assure the uptake of e-kerosene and other e-fuels by airlines taking off from EU airports. Without a dedicated sub-quota, the EC recognised that the uptake of these synthetic aviation fuels would be very challenging due to high costs associated with their production despite their emissions reduction potential and scalability.[3] To rectify these deficiencies, several EU Member States in the EU Transport Council and MEPs in the European Parliament's Environment committee (ENVI) and the Industry, Research and Energy committee (ITRE) have proposed an increase in ambition both for the overall GHG intensity targets, as well as setting minimum sub-quotas for the use of RFNBOs (table 1).

Target year	**Fuel GHG intensity targets (GHGIE)**			**Minimum sub-quotas for RFNBOs**		
	EC proposal	**EP Environment Committee proposal**[4]	**Germany - Denmark proposal**[5]	**EC proposal**	**EP Environment Committee proposal**	**Germany - Denmark proposal**
2025	*-2%*	*-5%*	*-3%*	-	*0%*	*0%*
2030	*-6%*	*-14%*	*-10%*	-	*6%*	*2%*
2035	*-13%*	*-26%*	*-20%*	-	*12%*	*5%*
2040	*-26%*	*-55%*	*-40%*	-	*24%*	*12%*
2045	*-59%*	*-80%*	*-75%*	-	*48%*	*29%*
2050	*-75%*	*-100%*	*-100%*	-	*70%*	*70%*

Table 1: FuelEU GHG intensity reduction and minimum RFNBO targets under FEUM

[2] MEPC 78/7/20, *Reduction of GHG Emissions From Ships, Commenting on documents MEPC 77/7/15 and MEPC 77/7/3*. Submitted to MEPC78 on 1 October 2021 by Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and European Commission.

[3] COM(2021) 561 final, 2021/0205 (COD) Proposal for a Regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport, Brussels, 14.7.2021, Recital 19, page 17.

[4] 2021/0210(COD), Opinion of the Committee on the Environment, Public Health and Food Safety for the Committee on Transport and Tourism on the proposal for a regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC (COM(2021)0562 – C9-0333/2021 – 2021/0210(COD)).

[5] See Annex II to this briefing.

2. Methodology

This analysis followed a quantitative methodology to assess the possible increase in seaborne transport costs if the most ambitious proposals on FEUM and ETS were to be incorporated into the final legislations. These specific proposals are:

1. Increasing the overall 2030 fuel GHG intensity reduction target (GHGIE) from 6% to 14% below the 2020 baseline.
2. Mandating a 6% sub-quota for the use of RFNBOs by 2030.
3. Application of WtW CO_2 equivalent emissions factors to carbon pricing under the EU ETS that takes account of both tailpipe and upstream emissions.

The analysis used a real-world voyage by a large (14,354 TEU) container vessel TAURUS (IMO number: 9728942) travelling between Port of Shenzhen in China and Port of Antwerp in Belgium as case study for calculations. 2019 automated identification system (AIS) data for voyage identification was provided by ExactEarth and emissions were calculated using T&E's SEA (Ship Emissions Analysis) model. The calculation was validated by comparing the voyage energy intensity of the ship in (gfuel/nm) to the yearly average energy intensity of the same vessel as reported under the EU THETIS MRV database. According to the AIS data, the vessel made a port call at the Port of Colombo (Sri Lanka) before continuing to Belgium.[6] Given that the EU MRV and consequently, the ETS and FuelEU will only cover 50% of the fuels/emissions of the last/first leg of the entire journey to Europe, the fuel and ETS cost analysis was limited to the Colombo-Antwerp leg of the original China-Belgium trip. However, the effect on the transport costs was applied to the entire China-Belgium route because it was assumed that the majority of cargo loaded onto the vessel in China was destined to the European market. Indeed, Sri Lanka remains a relatively small economy, AIS data showed more cargo (in net terms) was actually loaded in Colombo and no other port call was seen in AIS after that.

WtW emissions factors were calculated using ANNEX II of the draft proposal for FuelEU Maritime Regulation and fuel costs were compiled via a literature review on historical and post-COVID fossil fuel prices and production costs for alternative marine fuels (see Annex I to this briefing).

The analysis assumes a €80/tonne of CO_2e WtW carbon pricing under the EU ETS applied to 50% of the voyage between Sri-Lanka and Belgium for the China-Belgium trade route. Then the cost implications of the high ambition ETS and FEUM were analysed in five fuel mix scenarios as presented in table 2. Development of the fuel mix scenarios assume the following decisions by the operators:

1. Ships chose the least costly fuel mix combinations to minimise the voyage fuel costs;
2. Given that e-fuels/RFNBOs are considerably more costly than other alternatives (i.e. LNG or biofuels), ships aim to satisfy only the minimum 6% e-fuels sub-quota. Given that the analysed overall GHGIE target for 2030 (i.e. -14%) cannot simply be met with a 6% e-fuels sub-quota, ships

[6] As identified by its position in the port of Colombo, Sri Lanka, and the change in draught from 13.8m to 14.2m, which shows it loaded more cargo overall.

use either LNG or biofuels to make up for the remaining GHG reduction effort. For vessels using e-LNG to comply with the sub-quota, no additional biofuel uptake is assumed as e-LNG blend to fossil LNG as a main fuel is sufficient to meet the required GHGIE target.

3. Ships use pilot fuels in dual-fuel engines in the amount of a min of 6.8% (by energy content) of the total fuel used. Only two fuels - biodiesel and VLSFO, are assumed to be used as pilot fuels.
4. The remaining fuel beyond the minimum e-fuel sub-quota and additional biodiesel mix is assumed to be either VLSFO or fossil LNG.
5. All the costs are compared to a voyage using fossil VLSFO.

It is important to note that this is a very simplified approach. In reality, given that ships will be required to comply with FEUM at the company/fleet level (through a pooling mechanism), it is most likely that they would deploy zero-emission vessels running on maximum amount of e-Fuels and average out the compliance and share the costs at the company level using the pooling mechanism.

Scenario name	Attained GHGIE	Analysed compliance status	Fuel mix (by energy content)					
			Biodiesel (WCO)	e-NH_3	e-LNG	e-Methanol	VLSFO	Fossil LNG
VLSFO	*93.63*	- non-compliant with GHGIE target - non-compliant with RFNBO sub-quota	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*100%*	*0.00%*
Full fossil LNG	*77.43*	- compliant with GHGIE target - non-compliant with RFNBO sub-quota	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*6.8%*	*93.2%*
Biodiesel mix	*78.89*	- compliant with GHGIE target - non-compliant with RFNBO sub-quota	*17.68%*	*0.00%*	*0.00%*	*0.00%*	*82.32%*	*0.00%*
e-NH_3 mix	*78.89*	- compliant with GHGIE target - compliant with RFNBO sub-quota	*10.53%*	*6.00%*	*0.00%*	*0.00%*	*83.47%*	*0.00%*
e-LNG mix	*74.72*	- compliant with GHGIE target - compliant with RFNBO sub-quota	*0.00%*	*0.00%*	*6.00%*	*0.00%*	*6.8%*	*87.02%*
e-Methanol mix	*78.89*	- compliant with GHGIE target - compliant with RFNBO sub-quota	*10.87%*	*0.00%*	*0.00%*	*6.00%*	*83.13%*	*0.00%*

Table 2: Scenarios of fuel mix under FEUM and ETS geographical scope. (All scenarios assume ships pay for ETS costs. Both LNG and e-LNG scenarios have a sensitivity analysis taking account of the recent price fluctuations of LNG)

Once the extra costs incurred by switching to alternative marine fuels[7] are calculated, total costs are divided by the number of standard containers (TEU) carried on board and the amount of analysed products (e.g. pair of shoes) carried in each container (TEU). The assessment assumes a conservative load factor of 70% for the analysed vessel. Figure 2 aims to represent cost calculations.

[7] The analysis does not include CAPEX-related costs or foregone revenue due to low-density fuels. According to the most comprehensive research, the contribution of these costs to total cost operation (TCO) is rather limited. See: UMAS-Lloyd's Register, "Techno-economic assessment of zero-carbon fuels" (2020), Figures 4a and 4b, presented in figure A.1. in Annex I to this briefing.

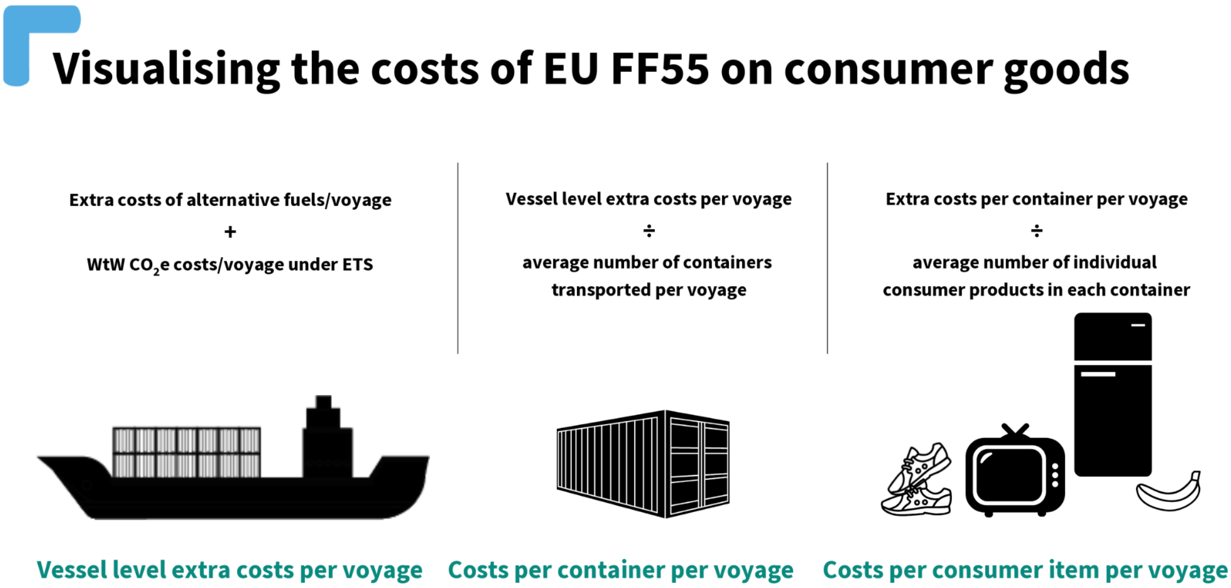

Figure 2. Visualising the cost calculations

3. Results and discussions

The results of the analysis are presented in table 3 below. As can be seen, an ambitious EU FF55 could represent between €8.2/TEU and €40.5/TEU cost increase on seaborne transport costs depending on the chosen fuel pathway that complies with e-fuels/RFNBO sub-quota, GHGIE targets and ETS carbon pricing. Compared to about €786 that would cost cargo owners to transport a standard container from China to Northern Europe in 2020, this means between 1.04% and 5.15% transport cost increase assuming historical fuel prices. Even under the unusually high fossil fuel prices the sector experiences recently, the cost increase per TEU would be about €79.1. It is essential to contextualise this finding with the recent fluctuations in transport costs and fuel prices. Over the course of the past 12 months, freight costs between Asia and Northern Europe varied significantly, jumping from €786/TEU in 2020 to €6,267/TEU (or €12,534/FEU) on January 6, 2022 and stabilising at around €4,217/TEU (or €8,435/FEU) on May 19, 2022.[8] In the context of such a huge spread in transport costs, even a €79.1/TEU increase in freight costs would most likely be unnoticable to the cargo owners (see Figure A.5 in annex I).

As expected, with pre-COVID historical prices, fossil LNG would be the most economical way to comply with the overall fuel GHG intensity targets (GHGIE), but not with e-fuels/RFNBO sub-quota. The next cheapest options to comply with GHGIE targets are blending of 6% e-LNG and fossil LNG, and blending biodiesel with VLSFO. However, if the post-COVID fossil LNG price hikes persist, then both fossil LNG or blended e-LNG/ pathways would be the least economic ways to comply with GHGIE target of FEUM.

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[8] Latest freight rates were obtained from https://xsi.xeneta.com/ and converted to €/TEU using 0.82 USD to EUR exchange rate. FEU values were divided by 2 to obtain freight costs per TEU.

Among the e-fuels scenarios which comply with both the overall GHGIE and 6% RFNBO sub-quota, e-LNG would be the least costly option if fossil LNG prices go back to historical levels. This is rather because the analysis assumes that ships would limit their e-LNG uptake to the minimum 6% sub-quota only and use fossil LNG for the rest of the time. However, if the current fossil LNG prices persist, then e-NH_3 becomes the most attractive option, costing about €35.8 more to ship a standard container from China to Europe. E-methanol is estimated to be more costly than e-NH_3 resulting in €40.5/TEU more. These conclusions are taken from the average cost increase due to the different fuel mixes but it must be noted that the uncertainty on the price of the different fuels is higher than the cost difference between the different mixes.

Scenario name	Average transport cost increase per container (TEU) vis-à-vis 100% VLSFO-based voyage		Average price increase per consumer product			
	Extra costs per TEU	% increase in freight rate per TEU vis-a-vis 2020	Pair of shoes	Banana	TV	Fridge
VLSFO	*€ 27.1*	*3.45%*	*€ 0.0054*	*€ 0.0006*	*€ 0.0678*	*€ 0.5420*
Full fossil LNG *	-€ 1.6	*-0.20%*	*-€ 0.0003*	*€ 0.0000*	*-€ 0.0039*	*-€ 0.0311*
Full fossil LNG **	*€ 71.7*	*9.13%*	*€ 0.0143*	*€ 0.0015*	*€ 0.1794*	*€ 1.4348*
Biodiesel blend	€ 31.7	*4.04%*	*€ 0.0063*	*€ 0.0007*	*€ 0.0794*	*€ 0.6349*
e-NH_3 mix	€ 35.8	*4.56%*	*€ 0.0072*	*€ 0.0007*	*€ 0.0896*	*€ 0.7167*
e-LNG blend *	€ 8.2	*1.04%*	*€ 0.0016*	*€ 0.0002*	*€ 0.0204*	*€ 0.1636*
e-LNG blend **	*€ 79.1*	*10.07%*	*€ 0.0158*	*€ 0.0016*	*€ 0.1978*	*€ 1.5823*
e-Methanol mix	€ 40.5	*5.15%*	*€ 0.0081*	*€ 0.0008*	*€ 0.1011*	*€ 0.8091*

Table 3: Costs of high ambition in FF55 on consumer products *(*historical LNG prices; **post-COVID LNG prices)*

The impact of the analysed fuel scenarios (and ETS costs) on the price of the seaborne consumer products is also presented in Table 3. Accordingly, the analysed scenarios demonstrate that the cost impact will likely be negligible, largely measured in (Euro) **cents**. E-fuels scenarios that comply with the most stringent FEUM proposals of the Environment Committee of the European Parliament as well as maritime ETS would result in a maximum of €0.0081 (or 0.81 euro cents) cost increase under historical prices for a pair of shoes shipped from China to Europe. Extra costs on a banana would be at most €0.0008 (or 0.08 euro cents). Similarly an average TV and refrigerator shipped to Europe would respectively cost a maximum of €0.1011 (or 10.01 euro cents) and €0.8091 (or 80.91 euro cents) more. For an average TV that costs about €300 or a pair of shoes worth €50, this would represent a maximum of 0.03% in price if all the costs are passed on to the final consumer.

Analysis also demonstrates that the relative cost-effectiveness of different fuel pathways for shipping can change as the uptake of sustainable and scalable fuels increases. For example, while e-LNG appears to be the most economical method to meet a 6% e-fuels sub-quota, e-NH_3 provides the most cost-effective pathway if vessels were to run entirely on e-fuels (see table 4). This is rather because in the case of 6% e-LNG sub-quota, ships would normally use fossil LNG for the majority (above 87%) of remaining of their energy needs for a given voyage, while in the case of e-NH3 and e-methanol, VLSFO would provide for the remainder of the energy needs (see table 2). As a result, given that *historically* LNG has been cheaper than VLSFO, any cost advantage of e-NH_3 over e-LNG would be offset by the historical cost difference between fossil LNG and VLSFO. However, as ships increase the share of e-LNG and e-NH_3 reaching almost 100%, then the impact of larger quantities of a more pricey e-LNG offsets the ever diminishing cost-discounts that fossil LNG has over VLSFO. This means that for fully zero-emission vessels (on a life cycle basis), e-NH_3 offers a more cost-effective pathway than e-LNG and e-Methanol (see Figure A.2 in ANNEX I).

Scenario name	Average transport cost increase per container (TEU) vis-à-vis 100% VLSFO-based voyage		Average price increase per consumer product			
	Extra costs per TEU	% increase in freight rate per TEU	Pair of shoes	Banana	TV	Fridge
100% e-NH_3	€ 253.1	*32.22%*	*€ 0.0506*	*€ 0.0053*	*€ 0.6327*	*€ 5.0616*
93.2% e-LNG, 6.8% biodiesel	€ 318.3	*40.52%*	*€ 0.0637*	*€ 0.0066*	*€ 0.7958*	*€ 6.3667*
100% e-Methanol	€ 402.9	*51.29%*	*€ 0.0806*	*€ 0.0084*	*€ 1.0072*	*€ 8.0577*

Table 4: Costs of full zero-emission shipping under FF55 (scope) on consumer products

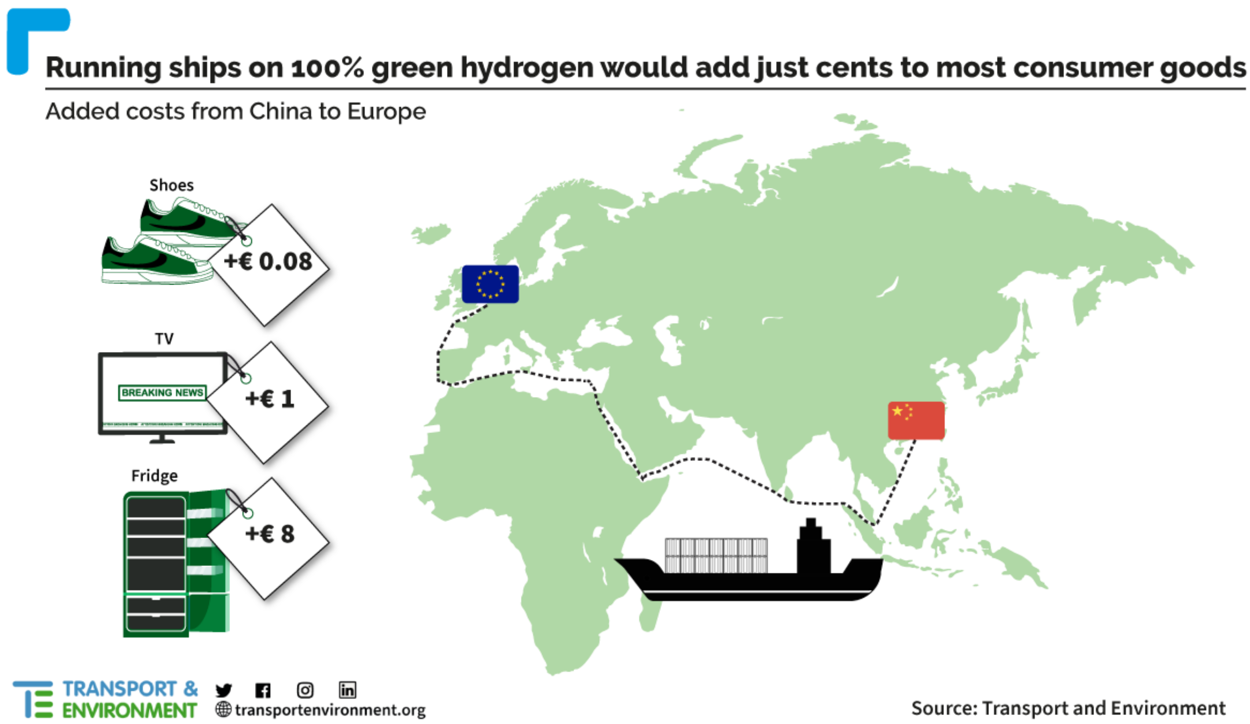

Figure 3. extra cost of fully e-fuel powered shipping on products imported from China

Further information

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Annex I: Input assumptions

Fuel name	Gravimetric density -LCV (MJ/kg)	WTW (gCO2e/MJ)	WTW (gCO2e/g fuel)
VLSFO	41.00	92.59	3.80
MDO MGO ISO 8217 Grades DMX to DMB	42.70	90.63	3.87
LNG (DF low-pressure 4 stroke) - with 1% pilot MGO	49.10	92.24	4.53
LNG (DF low-pressure 2 stroke) - with 1% pilot MGO	49.10	84.63	4.16
LNG (DF high-pressure 2 stroke) - with 8% pilot MGO	49.10	77.61	3.81
H2 (natural gas based)	120.00	132.00	15.84
NH3 (natural gas based)	18.60	121.00	2.25
Methanol (natural gas based)	19.90	100.40	2.00
Biodiesel - Waste cooking oil biodiesel (UCO)	37.20	14.90	0.55
Hydrotreated oil from waste cooking oil (HVO)	44.00	16.00	0.70
BioLNG (DF low-pressure 4 stroke) (Biomethane from biowaste, Close digestate, off-gas combustion) - with 1% pilot biodiesel	50.00	30.54	1.53
BioLNG (DF low-pressure 2 stroke) (Biomethane from biowaste, Close digestate, off-gas combustion) - with 1% pilot biodiesel	50.00	23.07	1.15
BioLNG (DF high-pressure 2 stroke) (Biomethane from biowaste, Close digestate, off-gas combustion) - with 8% pilot biodiesel	50.00	15.06	0.75
E-methanol EU electricity mix (F49 as per RED II)	19.90	4.47	0.09
e-LNG EU electricity mix (DF low-pressure 4 stroke) (F50 as per RED II)[9]	49.10	47.18	2.32
e-LNG EU electricity mix (DF low-pressure 2 stroke) (F51 as per RED II)	49.10	39.48	1.94
e-LNG EU electricity mix (DF high-pressure 2 stroke) (F52 as per RED II)	49.10	31.22	1.53
e-H2	120.00	3.60	0.43
e-NH3	18.60	0.00	0.00
Electricity - EU electricity mix 2020		106.30	0.00
Electricity - EU electricity mix 2030	0.00	72.00	0.00
EU 2020 fuel mix - baseline		**91.73**	

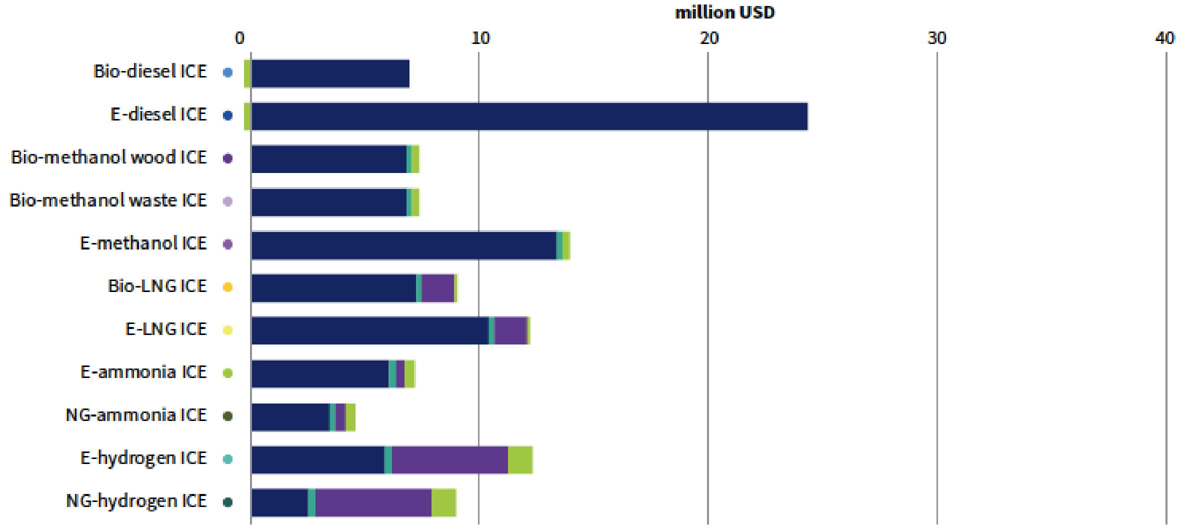
Table A.1 - WtW CO_2 equivalent factors for different marine fuels *(source: Annex I of Draft FuelEU Maritime regulation and FuelEU Maritime: T&E analysis and recommendations, February 2022)*

[9] WtT emission values for e-LNG were taken from a FuelEU document leaked before the actual proposal. The actual proposal doesn't provide explicit WtT values for e-diesel, e-methanol and e-LNG but refers to the RED. These WtT factors will be determined in a future delegated act by the European Commission.

Fuel name	Range	fuel price (€/t)	Fuel price (€/GJ)	Source
Fuel Oil (VLSFO)	min	479.7	11.7	CE Delft (2020), Availability and costs of liquefied bio- and synthetic methane, (p68), range: 15-17 USD/MMBtu.
Fuel Oil (VLSFO)	max	541.2	13.2	
bio-diesel	min	733	19.7	ICCT (2020), HVO from waste vegetable oil, range: 0.024-0.039 USD/MJ.
bio-diesel	max	1190	32	
e-NH_3	min	500	26.9	Ash, N., Davies, A., & Newton, C. (2020). Renewable electricity requirements to decarbonise transport in Europe with electric vehicles, hydrogen and electrofuels.
e-NH_3	max	1250	67.2	UMAS-LR (2020), Techno-economic assessment of zero-carbon fuels (p42). Upper bound: 82$/GJ.
LNG (historical)	min	417	8.5	CE Delft (2020), Availability and costs of liquefied bio- and synthetic methane (p70), 2030 range: 11-12 USD/MMbtu.
LNG (historical)	max	457	9.3	
LNG (post-COVID)	min	329	6.7	ShipandBunker.com Rotterdam, November 20, 2020. ($401/Mt)
LNG (post-COVID)	max	1601	32.6	ShipandBunker.com Rotterdam, April 4, 2022. ($1952/Mt)
e-LNG	min	1639	33.37	Ash, N., Davies, A., & Newton, C. (2020). Renewable electricity requirements to decarbonise transport in Europe with electric vehicles, hydrogen and electrofuels.
e-LNG	max	3946	80.36	UMAS-LR (2020), Techno-economic assessment of zero-carbon fuels (p42). Upper bound: 98$/GJ.
e-Methanol	min	755	37.94	Ash, N., Davies, A., & Newton, C. (2020). Renewable electricity requirements to decarbonise transport in Europe with electric vehicles, hydrogen and electrofuels.
e-Methanol	max	1926	96.76	UMAS-LR (2020), Techno-economic assessment of zero-carbon fuels (p42). Upper bound: 118$/GJ.

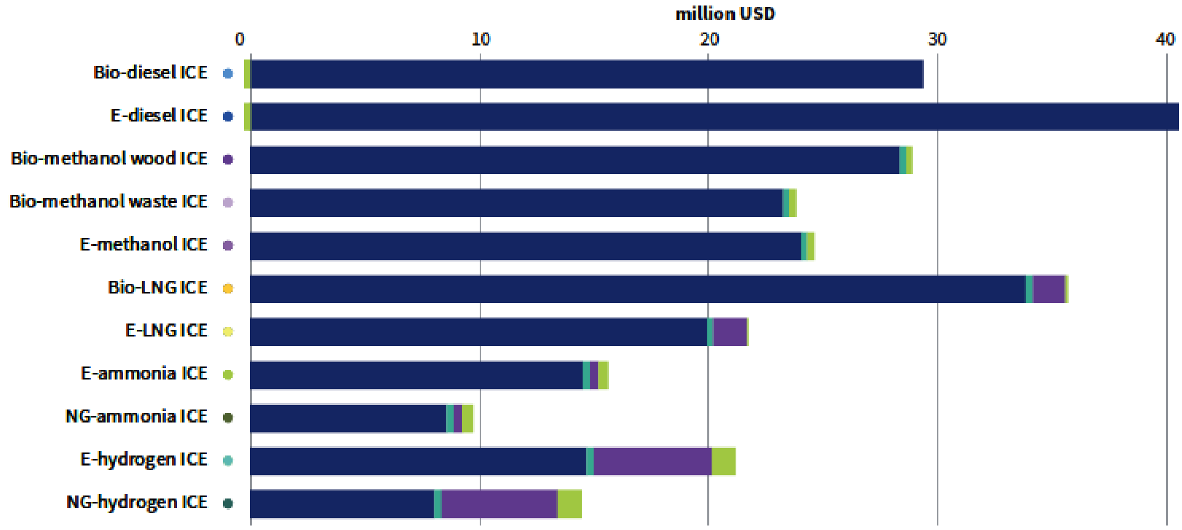
Table A.2 - Fuel prices and production costs.

2050 (low price scenario)



Figures 4a – Relative cost implications of ZEV technologies for bulk carrier under low-price scenario and no carbon price.

2050 (high price scenario)

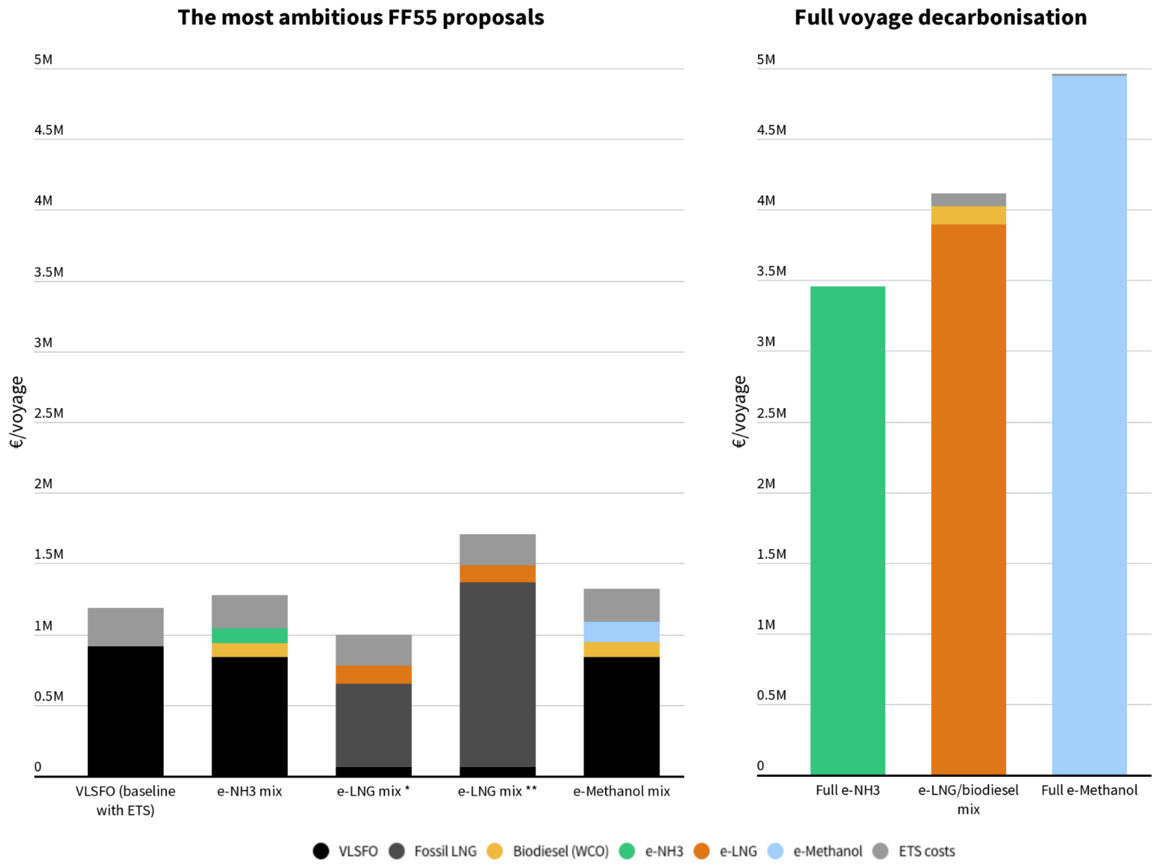


Figures 4b – Relative cost implications of ZEV technologies for bulk carrier under high-price scenario and no carbon price.

Voyage Engine Storage Storage impact

Figure A.1. - Total cost of operation (TCO) of zero-emission vessels *(source: UMAS-LR (2020), Techno-economic assessment of zero-carbon fuels (p16)).* ***Note****: Storage means capital cost of fuel storage system. Storage impact means revenue impact due to loss of cargo capacity. Hydrogen storage is "as liquid".*

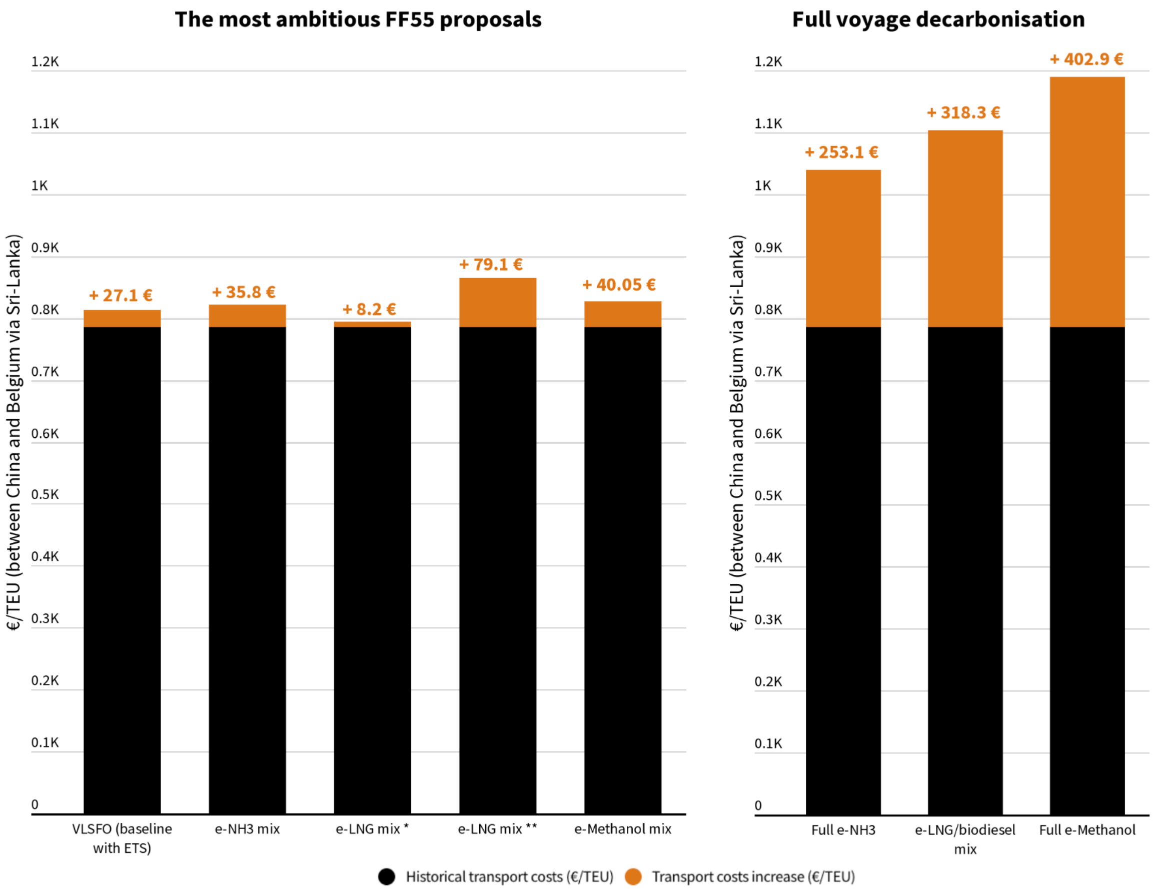
Voyage fuel and GHG costs breakdown (2030)



Note: * historical fossil LNG prices; ** post-COVID fossil LNG prices. The scenarios on the left graph assume that ships meet (except for the baseline) a 14% fuel GHG intensity (GHGIE) reduction target by 2030 and also comply with a 6% of e-fuels/RFNBOs sub-quota. The delta between GHGIE and e-fuels sub-quota is assumed to be met by biodiesel. e-LNG scenarios assume 6.8% biodiesel or VLSFO use as a pilot fuel. Analysis uses China-Belgium voyage Sri-Lanka.

Figure A.2. | Voyage cost breakdown of the estimates for the analysed scenarios

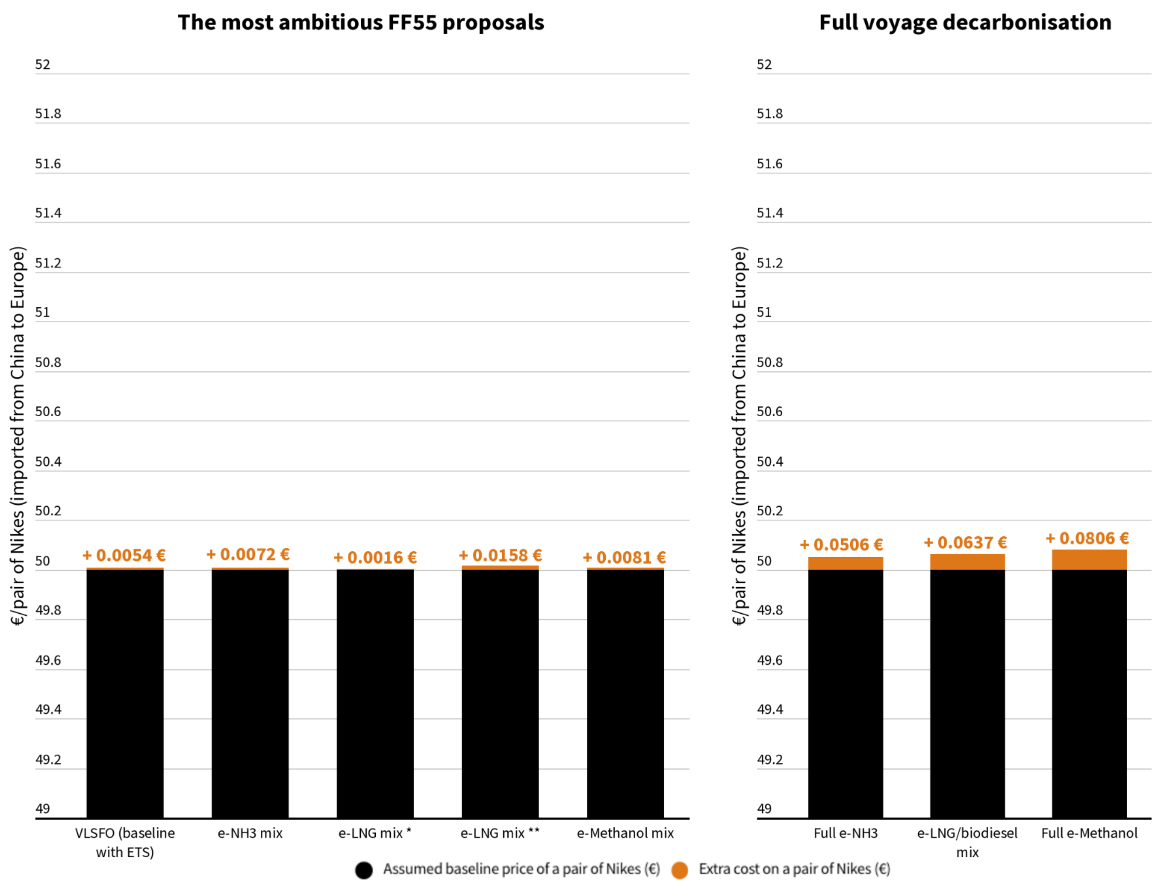
Impact of FF55 on maritime transport costs (2030)



Note: * historical fossil LNG prices; ** post-COVID fossil LNG prices. The scenarios on the left graph assume that ships meet (except for the baseline) a 14% fuel GHG intensity (GHGIE) reduction target by 2030 and also comply with a 6% of e-fuels/RFNBOs sub-quota. The delta between GHGIE and e-fuels sub-quota is assumed to be met by biodiesel. e-LNG scenarios assume 6.8% biodiesel or VLSFO use as a pilot fuel. Analysis uses average 2020 freight rates between Far East and Northern Europe.

Figure A.3. | Impact of FF55 on maritime transport costs (2030)

Impact of FF55 on the price of a pair of Nikes (2030)



Note: * historical fossil LNG prices; ** post-COVID fossil LNG prices. The scenarios on the left graph assume that ships meet (except for the baseline) a 14% fuel GHG intensity (GHGIE) reduction target by 2030 and also comply with a 6% of e-fuels/RFNBOs sub-quota. The delta between GHGIE and e-fuels sub-quota is assumed to be met by biodiesel. e-LNG scenarios assume 6.8% biodiesel or VLSFO use as a pilot fuel. The assumed baseline price of shoes is €50/pair.

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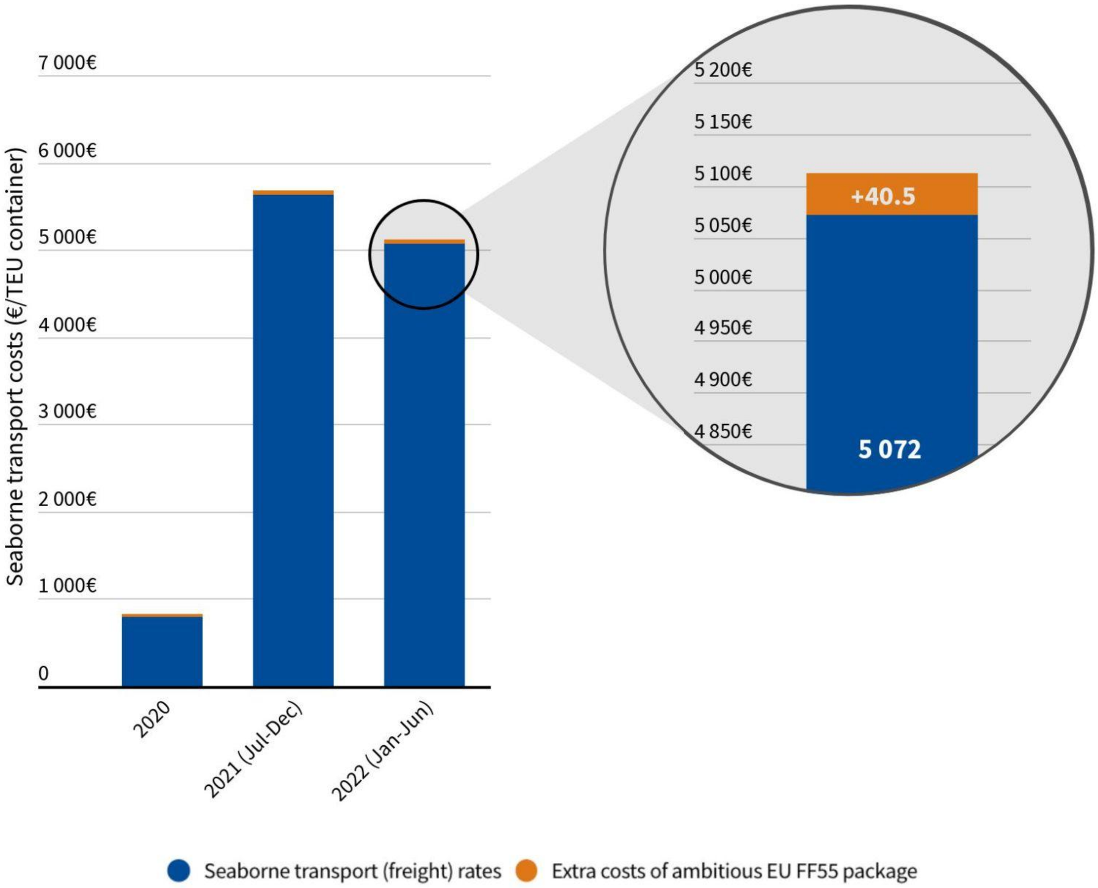
Figure A.4. | Impact of FF55 on the price of a pair of Nikes (2030)

Costs of green shipping of a container (China to Europe)



Source: Transport & Environment 2022. **Note**: Ambitious EU FF55 package includes a €80/tonne WtW CO2e ETS charge, 14% overall fuel GHGIE reduction target, 6% RFNBO subquota using e-methanol as a pathway. The geographical scope is limited to the 50% of the emissions/fuel consumption on the last leg (i.e Sri-Lank to Belgium) of an example China-Belgium container ship voyage using Vessel Taurus (IMO: 9728942) as an example.

Figure A.5. | Impact of FF55 on fluctuating maritime transport costs (2030)

ANNEX II: Proposal by Germany and Denmark for RFNBO sub-quota and multipliers and higher targets under FEUM

Proposal for raising the ambitions in FuelEU Maritime and meeting the 2050 climate targets

The Fit for 55 package is a cornerstone in the European Union's efforts to combat climate change. For shipping to contribute to the objectives of a 55% reduction in GHG emissions by 2030 and reaching net-zero by 2050, ensuring a greater uptake of zero-emission fuels is key. We support the objectives of FuelEU Maritime (FEUM) to ensure greenhouse gas emission reductions, but believe that the level of ambition must be strengthened in order to ensure that we meet the 2050 climate targets.

The problem:

As the FEUM proposal stands now, we see a great risk of not meeting the 2050 climate goals mainly due to the fact that fuels with a real CO2e reduction potential are expensive and not the natural economic choice in the business case for shipping companies before 2040-45[1]. The current regulation/incentive approach in the FEUM regulation reduces its impact on promoting sufficient sustainable and scalable renewable fuels. This is because:

1) Ships will be allowed to use cheap lower-carbon fossil fuels, such as LNG or other transitional fuels with limited long-term potential and still comply with the emissions reduction targets, and

2) Ship owners and operators will continuously have a possibility and potentially an economic interest in choosing the least costly, and yet in the short term compliant, fuel option.

If we do not set the right regulatory framework with clear incentives for promoting the cleanest alternative fuels, we might indirectly promote short-term solutions with long-term implications on infrastructure investments.

The solution:

This proposal intends to ensure that FEUM creates a real demand, and early uptake of the cleanest and least CO2e intensive alternative fuel types, which are considered to be Renewable fuels of non-biological origin (RFNBOs). RFNBOs are to be defined in RED-II and a delegated act under this directive. Therefore, this proposal and specifically the sub-quotas should be reviewed in context with the adoption of the delegated act. For the purpose of this proposal under FEUM, RFNBOs include green hydrogen, green ammonia (produced from green hydrogen and nitrogen that is obtained by an air separation unit), green synthetic methanol (produced from green hydrogen and CO2 captured from the atmosphere or biogenic CO2[2]), and green synthetic methane (also produced from green hydrogen and CO2 captured from the atmosphere[3]).

RFNBOs are necessary fuels for long-term scalable and <u>sustainable</u> solution for the maritime industry, but in order to promote an early uptake of these, we must create the right regulatory framework. This proposal includes three main elements, which in combination will ensure:

1) A higher long-term climate impact thus also ensuring that the EU meets its climate obligations

2) Ensure the early uptake by introducing sub-quotas of RFNBOs and by bridging the price cost between fossil fuels, "conventional" alternative fuels such as LNG and RFNBOs.

The three components of the proposal are summarized in figure 1:

1) Increase the greenhouse gas intensity reduction targets as defined in article 4.
2) Introduce sub-quotas on the use of RFNBO's in article 4
3) Introduce a multiplier on over-compliance on the use of RFNBOs

[1] This conclusion also includes the effects of the proposed EU Emissions Trading System

[2] Biogenic CO2 includes CO2 released as a result of the combustion or decomposition of organic material, that is biomass and its derivatives

[3] Only CO2 from Direct Air Capture and biogenic point source capture (CO2 from a biagas power plant) are considered as green CO2 .

Figure 1

	2025	2030	2035	2040	2045	2050
Original FuelEU emission intensity reduction target	2%	6%	13%	26%	59%	75%
New proposed emission intensity reduction target	3%	10%	20%	40%	75%	100%
Sub-quota: Minimum share of RFNBO	0%	2%	5%	12%	29%(*)	70%(*)
Multiplier (to encourage RFNBO usage)	4x	4x	3x	(?)x	(?)x	(?)x

(Note: (*) these values are currently under reservation)

1) Raising the targets in Article 4 (2) and avoid a lock-in in fossil fuels and stimulate the early uptake of RFNBOs

We believe that stimulating the early use of long-term renewable fuels in maritime transport is important to facilitate the long-term energy transition. The current short-term targets in the FuelEU Maritime proposal risks being met mainly using fuels with only low greenhouse reduction potential or limited long-term impact. This could result in a possible lock-in of these less ambitious fuels – and the roll-out of their infrastructure – at the expense of the uptake and transition to more innovative renewable fuels (RFNBOs). We see the need for raising the overall reduction targets instead of waiting for the FEUM evaluation, as foreseen in article 28. As the evaluation is foreseen to be reported to the Parliament by 1 January 2030, this moment would be too late for an amendment to the reduction targets of 2025 and 2030. Consequently, we see a high priority in raising these targets already now. However, we also see the need for amending the long-term targets, especially in the light of the discussions regarding the revision of the Initial GHG Strategy of IMO where EU has an ambition of zero emission shipping in 2050. If the EU on a regional level decides on a less ambitious target, it will undermine our credibility in the IMO negotiations.

2) Introducing sub-quotas for RFNBO's

We propose to introduce sub-quotas for RFNBO's in FuelEU Maritime for several reasons.

- *Costs of RFNBOs are significantly higher than e.g. transitional fuels and biofuels, but their GHG reduction potential is much greater*

When RFNBOs are produced from additional renewable electricity in a carbon-neutral way (closed carbon cycle without any additional CO_2 emissions), the potential emission savings are highest (compared to biofuels or transitional fossil fuels such as LNG). However, the cost of RFNBOs today are significantly higher than biofuels and LNG. Without a sub-quota there is great risk that industry players may simply continue to compare future fuel cost projections to the existing alternatives and choose the least costly, yet compliant, option. Without a clear incentive like a sub-quota, it is likely that the industry will ramp-up demand for (and therefore, also production of) RFNBOs too late to meet the fit-for 55 emission reduction target.

- *Incentivizing investments and driving down the production costs*

Introducing a sub-quota for RFNBOs will have various positive and needed effects for securing the green transition of the maritime sector in a cost efficient way. The accelerated use will contribute to earlier scaling of production and drive down production costs as demand and supply increases. To accelerate the uptake of RFNBOs and thereby reduce costs via economies of scale production, improving technologies and developer experience, their use needs to be incentivized as early as possible[4]. Moreover, a sub-quota will incentivize the needed retrofitting/building of ships able to use RFNBOs and incentivize investments in the dedicated bunkering infrastructure for RFNBOs.

- *Risk that the shipping sectors share of RFNBOs is used by other transport sectors*

A sub-quota for RFNBOs will assist in ensuring, that the maritime sector is not bypassed by other sectors (which could be electrified) in the ramp-up of RFNBOs. RED II sets a minimum share of 2.6 percent for RFNBOs in all modes of transport. If demand for RFNBOs is not actively stimulated for the shipping sector, other subsectors of transport could use their shares of RFNBOs to the detriment of the share for maritime shipping. A sub-quota for RFNBOs will possibly also secure that RFNBOs are used in sectors that do not have other alternatives.

3) Introducing a multiplier for RFNBO over-compliance

Presently and in the decades to come, RFNBOs are an expensive solution both in terms of fuel costs and in terms of investments in ships and port infrastructure. In order to bridge the price difference on fuels, we propose to introduce a multiplier, which incentivizes the use of RFNBOs. With the multiplier, we reward ships who have a RFNBO compliance surplus, by giving these a bonus, which can help them meeting the increased GHG intensity reduction targets of article 4, 2. Thus, the multiplier should be seen in conjunction with the increase in the overall reduction targets as a means to ensure that progress is attained and that the effect of the multiplier does not undermine the overall objective of reducing GHG intensity targets. The value of the multiplier should be set until 2035. In 2035, the multiplier should be part of the review clause and determined based on the market development of RFNBOs.

Effects of the proposal

By adding the sub-quota system combined with a multiplier on over-compliance, a higher share of renewable fuels from non-biological origins (RFNBOs) emerge as part of the fuel mix, as illustrated in figure 2. The high/low ranges show the up-take of RFNBO arising from this proposed regulation. The lower bound is the proposed sub-quota, whereas the upper bound illustrates the potential effect of the multiplier. It is calculated as the level of RFNBO necessary to comply with the overall reduction target, if no other low carbon alternatives are used and the multiplier is used. The range arise from the different ways to comply with the regulation using RFNBOs compared to other emissions reduction alternative fuels such as bio-fuels, blue fuels and lower-emission fossil fuels (LNG, LPG). Without the new regulation there would be no regulation directly promoting RFNBO. Note that no exact multiplier for 2040 onwards is set. For illustrative purposes a multiplier of 3 is used for 2040, and 2 is used for 2045 and 2050.

[4] A comparable example of this is how renewable power generation costs have fallen sharply over the past decade, driven by steadily improving technologies, economies of scale, competitive supply chains and improving developer experience. Costs for electricity from utility-scale solar photovoltaics (PV) fell 85% between 2010 and 2020.

Figure 2
Uptake of RFNBOs