RED3, FuelEU, RefuelEU

New Perspectives on 2030 Energy Demand

V2 - November 2024

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SQUARECO

About SQUARECO

Based on the Leman Lake shores in Switzerland, SquareCo develops market intelligence solutions designed to help players active in renewable fuels markets to gain a deeper understanding of regulatory frameworks, market dynamics and industry developments.

SquareCo delivers high-quality expertise through the publication of articles, market reports and thematic studies displayed on our Web Platform. Our strong emphasis on data monitoring allows us to supply our clients with access to a comprehensively organized database.

We help energy suppliers to the road, maritime and aviation sectors to navigate serenely the complexity of regulations applying to low carbon fuels markets. Relying on 15 years of experience and an extensive network of contacts at ministries and companies around the world, we keep our clients constantly updated about the current and coming rules.

Executive summary

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Table of contents

RED3, Fuel EU, Refuel EU

New Perspectives on 2030 Energy Demand

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SAMPLE - Not For Use or Distribution

1.Introduction: Objectives of V2

Building on the foundation of last year's inaugural edition, this study represents a thoroughly revamped step forward in the depth and precision of our modelling, with a corresponding enhancement in the clarity and rigour of our insights and analysis.

The SquareCo team has dedicated hundreds of hours to refining every aspect of our models, delivering a significantly more comprehensive perspective on the 2030 demand for low-carbon fuels required to fulfil the mandates of RED III, FuelEU Maritime, and ReFuelEU Aviation.

The first version of the study (V1) was released only a few weeks after the RED3, Fuel EU and ReFuel EU texts' publication, it was based on our first reading of the texts. Since November 2023, we have accumulated clinical expertise that allowed us to better understand the calculation methodologies, applicable penalties, and implications arising from the different regulatory layers (often applicable to similar but not exactly the same energy pools and CO2e emissions).

Numerous regulatory elements, including multipliers accounting, GHG savings calculations, and caps' scope, have been clarified through consultations with leading experts in ministries (many of whom are working in their country's RED3 transpositions), significantly sharpening our level of proficiency in the analysis.
As we refined our modelling of both renewable energy share and GHG reduction targets under RED3, we exposed how much they differ when it comes to the resulting renewable fuel demand requirements. Member States (MS) choices will be decisive to inform the final low-carbon fuels demand, and the demand for the lowest CI fuels across the continent.

We have completely overhauled our models describing the evolution of energy demand in EU transport by 2030. While V1 was dependent on external studies, we have now created an in-house, bottom-up model. Through informed assumptions for the numerous variables that define transport energy demand, we now have remarkable flexibility to develop demand scenarios and perform what-if and sensitivity analyses. Our team has meticulously integrated comprehensive sets of statistics on vehicle (2-wheels, passenger cars, vans, buses, and trucks) fleets' evolution (new sales and turn-over), their fuel efficiency, CO2 performances, kilometres travelled, and more. From this foundation, we have crafted three scenarios that illustrate potential trajectories for transport energy demand. These allow us to analyse the sensitivity of low-carbon fuels demand relative to the EU road electrification pace by 2030.

With very few concrete plans for RED3 transposition available at the time of writing, the scope of the study had to remain at the EU-27 level. This study establishes how much FAME, HVO, ethanol, bionaphtha, SAF, biomethane and (renewable) electricity will be required in 2030 at the EU-27 level to meet the RED3 either the 29% e.c. or 14.5% GHG reduction targets (and the vast differences resulting from each choice), the 6% volumetric target for SAF at Union Airports in ReFuel EU, and the 6% GHG reduction target in Fuel EU. Their corresponding impact on carbon emissions are also discussed, along with the implications of ETS (1 and 2) on alternative fuels price gap to fossil, and the current status of Energy Tax Directive (ETD).

This refined version of the study contains fascinating findings, key to understanding the evolution of the low-carbon fuels markets until 2030 and beyond.

2. Improved modelling of energy used in transport by 2030

2.1 New in-house model

In V1, we did an extensive search for available studies that were forecasting energy demand throughout EU-27 and relied heavily on the International Energy Agency (IEA) World Energy Outlook (WEO) 2022, BP's Energy Outlook 2023 and DNV Transport in Transition report. We started from our own records regarding past consumption, using our own forecasts for the 2022-2024 period, bridging these into the more forward-looking studies mentioned.

For this revised version, SquareCo developed its own model of transport energy demand. Designed with flexibility in mind, it allows us to explore 'what-if' scenarios and clearly present our assumptions, guiding the reader through our thought process. We've structured our analysis around key sectors—road, aviation, maritime, rail, and domestic navigation—providing a comprehensive view of the transport landscape.
When it comes to projecting energy demand beyond the short term, the difference between forecasting and the scenario-based approach we chose is essential to understand.

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BASE: Baseline Scenario

In our BASE scenario, we model road transport demand under the assumption that the key EU targets set through regulations such as the new vehicle OEM standards and the Fit for 55 package are all successfully met. [redacted]

ELEC: Accelerated Electrification Scenario

[redacted]

RENF: Renewable Fuel Reliance Scenario

[redacted]

2.2 Road sector

In our modelling work, we delved deepest into the road sector, which accounts for approximately three-quarters of total transport energy demand. This focus is essential because the road sector is in the midst of a profound transformation, shifting from over a century dominated by internal combustion engines (ICE) to an era increasingly defined by battery-electric motors.

[redacted]

2.2.1 Active fleet

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- [redacted]

For each vehicle type, we further differentiated by powertrain, covering diesel, gasoline, mild-hybrid (HEV), plug-in hybrid (PHEV), battery electric (BEV), and a category labelled as 'others,' which mainly consists of gas-powered types such as LPG, CNG, and LNG.

For each vehicle type, we researched available official records from Eurostat and data provided by the European Automobile Manufacturers' Association (ACEA) and European Association of Motorcycle Manufacturers (ACEM) to determine the registered vehicles in each class and power train.

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2.2.2 Kilometres driven

[redacted]

[redacted]

[redacted]

2.2.3 Pace of EU electrification

In 2024, the rate of growth for the share of BEV out of new sales in 2024 has decreased considerably in 2024 in Europe, mainly pushed by the phase-out of incentives in Germany. This has brought a lot of headlines but should not block the reader's understanding of the bigger picture.

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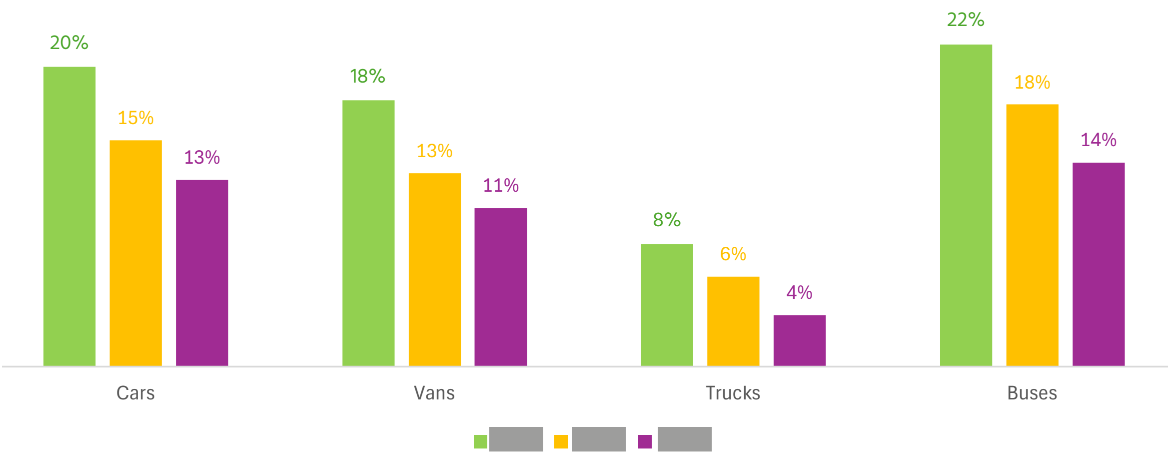

Chart 1: BEV share of fleet per senario in 2030 (%)

2.2.4 Gas fuels and hydrogen

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[redacted]

[redacted]

Table 1: Energy pools per scenario (EJ) for road sector

	2023	2024	2025	2026	2027	2028	2029	2030
ELEC								
Diesel	7.67	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
Gasoline	2.94	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
Electricity	0.06	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
NG/LPG	0.32	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
TOTAL	**11.00**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**	**X.XX**
BASE								
Diesel	7.67	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
Gasoline	2.94	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
Electricity	0.06	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
NG/LPG	0.32	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
TOTAL	**11.00**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**
RENF								
Diesel	7.67	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
Gasoline	2.94	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
Electricity	0.06	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
NG/LPG	0.32	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
TOTAL	**11.00**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**	**XX.XX**

2.3 Rail

In our analysis of the rail sector's energy demand, a key observation emerges: despite the growing recognition of rail transport's efficiency and sustainability, its activity demand profile remains relatively stable. This stems from the electrification dynamic seen in the years leading to 2020. Electric rail systems are significantly more efficient compared to their diesel counterparts, leading to a gradual decline in overall energy demand. In the years leading to the pandemic outbreak, a tendency to see declining diesel use (-3.0% CAGR 2013-2019) in the sector was offset by the increasing use of electricity.

[redacted]

Table 2: Road pool (PJ)								
	2023	2024	2025	2026	2027	2028	2029	2030
Diesel	53.0	XX.X	XX.X	XX.X	XX.X	XX.X	XX.X	XX.X
Electricity	171.0	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
Total	**224.0**	**XXX.X**	**XXX.X**	**XXX.X**	**XXX.X**	**XXX.X**	**XXX.X**	**XXX.X**

2.4 Maritime

Fuel bunkering in Europe has declined since 2007, when 2.18 EJ of fuel (with 90% consisting of fuel oil) was supplied to international maritime bunkers. Although there was some growth in the 2016-19 period, total demand had still decreased by 18% compared to 2007 levels, reaching 1.80 EJ. Demand had mostly recuperated from the pandemic hit by 2022 (which was the latest year of available data in Eurostat at the time of writing). We assume that demand fully recovered in 2023.

Thereafter, our model describes 0.6% CAGR decline for 2023-30, with steeper downturns in crucial years, given additional regulatory costs imposed through FuelEU and ETS.

2.4.1 Fuel EU

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[redacted]

[redacted]

[redacted]

[redacted]

We used DNV AFI database on alternative fuels to estimate the growth rate for LNG use in shipping according to the orderbook of new vessels. We also split the vessels according to their combustion technology (LP 4-stroke, LP stroke and HP 2-stroke) in order to estimate the implied CI of the LNG being utilised according to the standard methane slip assumed in the FuelEU legislation for each type of vessel.

Table 4: RED III maritime pool (PJ)

	2023	2024	2025	2026	2027	2028	2029	2030
HFO	665.4	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
LFO	544.5	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
MGO	478.7	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
LNG	111.0	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
LPG	0.4	X.X	X.X	X.X	X.X	X.X	X.X	X.X
MeOH	0.1	X.X	X.X	X.X	X.X	X.X	X.X	X.X
Total	**1800.1**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**

Table 3: Fuel EU pool (PJ)

	2023	2024	2025	2026	2027	2028	2029	2030
HFO	482.0	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
LFO	408.1	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
MGO	122.6	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
LNG	111.2	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
LPG	0.4	X.X	X.X	X.X	X.X	X.X	X.X	X.X
MeOH	0.1	X.X	X.X	X.X	X.X	X.X	X.X	X.X
Total	**1124.5**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**

Table 5: V1 maritime pool (PJ)								
	2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Fuel Oils	1469.7	XXXX.X	XXXX.X	XXXX.X	XXXX.X	XXXX.X	XXXX.X	XXXX.X
Distillates	574.8	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
LNG	88.3	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X	XXX.X
Methanol	0.0	X.X	X.X	X.X	X.X	X.X	XX.X	XX.X
Pool	**2132.8**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**	**XXXX.X**

2.4.2 Bunkering under RED3

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Table 6: [redacted]

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]		[redacted]	[redacted]
[redacted]	XXX XXX	XX.X%	XX.X%	XX.X%	XXX XXX
[redacted]	X XXX	X.X%	X.X%	X.X%	-
[redacted]	-	X.X%	X.X%	X.X%	-
[redacted]	XX XXX	XX.X%	X.X%	X.X%	-
[redacted]	XX XXX	X.X%	X.X%	X.X%	-
[redacted]	XX XXX	XX.X%	XX.X%	XX.X%	X XXX
[redacted]	X XXX	X.X%	X.X%	X.X%	-
[redacted]	XX XXX	XX.X%	XX.X%	XX.X%	XX XXX
[redacted]	XXX XXX	XX.X%	XX.X%	XX.X%	XXX XXX
[redacted]	XX XXX	X.X%	X.X%	X.X%	-
[redacted]	XXX	X.X%	X.X%	X.X%	-
[redacted]	XXX XXX	X.X%	X.X%	X.X%	-
[redacted]	XX XXX	XX.X%	X.X%	XX.X%	XX XXX
[redacted]	X XXX	X.X%	X.X%	X.X%	-
[redacted]	X XXX	X.X%	X.X%	X.X%	-
[redacted]	-	X.X%	X.X%	X.X%	-
[redacted]	-	X.X%	X.X%	X.X%	-
[redacted]	XX XXX	XX.X%	X.X%	XX.X%	XX XXX
[redacted]	XXX XXX	XX.X%	XX.X%	XX.X%	XXX XXX
[redacted]	XXX	X.X%	X.X%	X.X%	-
[redacted]	XX XXX	X.X%	X.X%	X.X%	-
[redacted]	XX XXX	X.X%	X.X%	X.X%	-
[redacted]	XXX	X.X%	X.X%	X.X%	-
[redacted]	-	X.X%	X.X%	X.X%	-
[redacted]	-	X.X%	X.X%	X.X%	-
[redacted]	XX XXX	X.X%	X.X%	X.X%	-
[redacted]	XX XXX	XX.X%	XX.X%	XX.X%	XX XXX
[redacted]	**X XXX XXX**	**XX.X%**		**XX.X%**	**XXX XXX**

2.4.3 Domestic navigation

For the domestic navigation sector, we applied a straightforward modelling approach grounded in the compound annual growth rate (CAGR) observed over the last 15 years. This method allows us to capture the sector's historical trends while providing a baseline trajectory for future energy demand. Domestic navigation have shown relatively steady decline in energy consumption, reflecting gradual improvements in both vessel efficiency and logistics constrains due to droughts and more severe weather events in domestic navigation. This is also apparent when analysing the tonne-kilometres performance for freight transport through domestic navigation, available in the EU Transport Statistical Pocketbook

[redacted]

2. Improved modelling of energy used in transport by 2030

2.5 Aviation

The aviation sector represents a little bit over 10% of the transport sector energy demand in Europe and has experienced considerable growth in the past decades. We built a rather simple model, compared to that of road or maritime, as the aviation industry is less transparent regarding aircraft information and relies on only one fuel. Nonetheless, we informed this effort with industry experts at IATA to properly identify key variables.

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3. Understanding regulatory drivers further

In this section, we clarify the main rules in the three pieces of law and develop some aspects of the regulations not detailed in V1.

3.1 RED3 compliance paths

The Directive (EU) 2023/2413 – RED3 – was published on October 31, 2023 at the EU Official Journal. It amends the Directive (EU) 2018/2001 – RED2 – and repeals Council Directive (EU) 2015/652, ruling the FQD Directive obligation to reduce by 6% the carbon intensity of fuels sold in the EU.

[redacted].

Table 7: RED III targets		
Year	**GHG reduction**	**Renewable Energy Content share**
2030	XX.XX%	XX%

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[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

3.1.2 Multipliers

We summarize here the various multipliers to apply for each category of low-carbon fuels, depending under which regulation they are reported.

Table 8: multipliers for renewable energy content target

Feedstock	Sector	RED3	Fuel EU	Refuel EU
Crop	Road	1	-	-
	Rail	X	-	-
	Maritime	X	X	-
	Aviation	X	-	X
9A & 9B	Road	X	-	-
	Rail	X	-	-
	Maritime	X.X	X	-
	Aviation	X.X	-	X
Uncategorized	Road	X	-	-
	Rail	X	-	-
	Maritime	X.X	X	-
	Aviation	X.X	-	X
RFNBO (green)	Road	X	-	-
	Rail	X	-	-
	Maritime	X	X	-
	Aviation	X	-	X
Renewable Electricity	Road	X	-	-
	Rail	X.X	-	-
	Maritime	X	X	-
	Aviation	X	-	-
H2 (green)	Refineries	2	-	-

The reliance on multipliers for the RED3 energy target will be an important variable for renewable energy demand: the higher the share of multiple counted (MC) volumes, the lower the physical demand required.

RED3 does not mention any multiplier for renewable electricity used in maritime and aviation sectors, when it does for road and rail, suggesting legislators assumed no electric-powered ships and planes would fall in the 2030 scope.

[redacted]

[redacted]

[redacted]

3.1.3 Targets reductions and caps

[redacted]

[redacted]

Table 9: Member states' choice and target reduced			
	Likely choice	**Reason of choice**	**Target reduced (crop use)**
Austria	GHG	[redacted]	XX.XX%
Belgium	GHG	[redacted]	XX.XX%
Bulgaria	E.C	[redacted]	XX.XX%
Croatia	E.C	[redacted]	XX.XX%
Cyprus	E.C	[redacted]	XX.XX%
Czechia	GHG	[redacted]	XX.XX%
Denmark	GHG	[redacted]	XX.XX%
Estonia	E.C	[redacted]	XX.XX%
Finland	E.C	[redacted]	XX.XX%
France	GHG	[redacted]	XX.XX%
Germany	GHG	[redacted]	XX.XX%
Greece	-	[redacted]	-
Hungary	E.C	[redacted]	XX.XX%
Ireland	E.C	[redacted]	XX.XX%
Italy	E.C	[redacted]	XX.XX%
Latvia	E.C	[redacted]	XX.XX%
Lithuania	E.C	[redacted]	XX.XX%
Luxembourg	E.C	[redacted]	XX.XX%
Malta	E.C	[redacted]	XX.XX%
Netherlands	GHG	[redacted]	XX.XX%
Poland	E.C	[redacted]	XX.XX%
Portugal	E.C	[redacted]	XX.XX%
Romania	E.C	[redacted]	XX.XX%
Slovakia	E.C	[redacted]	XX.XX%
Slovenia	E.C	[redacted]	XX.XX%
Spain	E.C	No change suggested	25.40%
Sweden	GHG	Existing GHG mandate	14.41%

[redacted]

[redacted]

Table 10: Caps comparison

	RED3	Fuel EU	Refuel EU
Crop	[redacted]	[redacted]	[redacted]
High ILUC	[redacted]	[redacted]	[redacted]
9B	[redacted]	[redacted]	[redacted]
Uncategorized	[redacted]	[redacted]	[redacted]

[redacted]

[redacted]

Table 11: Caps per country based on shares

	Food 2020	Food 2030	High ILUC cap (2030 = 2019)
Austria	5.34%	6.34%	5.34%
Belgium	6.71%	7.00%	2.19%
Bulgaria	X.XX%	X.XX%	X.XX%
Croatia	X.XX%	X.XX%	X.XX%
Cyprus	X.XX%	X.XX%	X.XX%
Czechia	X.XX%	X.XX%	X.XX%
Denmark	X.XX%	X.XX%	X.XX%
Estonia	X.XX%	X.XX%	X.XX%
Finland	X.XX%	X.XX%	X.XX%
France	X.XX%	X.XX%	X.XX%
Germany	X.XX%	X.XX%	X.XX%
Greece	X.XX%	X.XX%	X.XX%
Hungary	X.XX%	X.XX%	X.XX%
Ireland	X.XX%	X.XX%	X.XX%
Italy	X.XX%	X.XX%	X.XX%
Latvia	X.XX%	X.XX%	X.XX%
Lithuania	X.XX%	X.XX%	X.XX%
Luxembourg	X.XX%	X.XX%	X.XX%
Malta	X.XX%	X.XX%	X.XX%
Netherlands	X.XX%	X.XX%	X.XX%
Poland	X.XX%	X.XX%	X.XX%
Portugal	X.XX%	X.XX%	X.XX%
Romania	X.XX%	X.XX%	X.XX%
Slovakia	X.XX%	X.XX%	X.XX%
Slovenia	X.XX%	X.XX%	X.XX%
Spain	X.XX%	X.XX%	X.XX%
Sweden	X.XX%	X.XX%	X.XX%

[redacted]

3.1.4 Limitation of bunkering at the denominator

[redacted]

[redacted]

Table 12: RED III bunkering cap between member states					
2022 bunker fuel per EU country	**International maritime bunkers (TJ)**	**Bunker share of all transport (%)**	**Cap**	**Share bunker not under RED3**	**Bunker not under pool (TJ)**
Belgium	320 134	42.0%	13.0%	79.7%	255 238
Bulgaria	2 862	2.0%	0.0%	0.0%	-
Czechia	-	X.X%	X.X%	X.X%	-
Denmark	XX XXX	XX.X%	X.X%	X.X%	-
Germany	XX XXX	X.X%	X.X%	X.X%	-
Estonia	XX XXX	XX.X%	XX.X%	XX.X%	X XXX
Ireland	X XXX	X.X%	X.X%	X.X%	-
Greece	XX XXX	XX.X%	XX.X%	XX.X%	XX XXX
Spain	XXX XXX	XX.X%	XX.X%	XX.X%	XXX XXX
France	XX XXX	X.X%	X.X%	X.X%	-
Croatia	XXX	X.X%	X.X%	X.X%	-
Italy	XXX XXX	X.X%	X.X%	X.X%	-
Cyprus	XX XXX	XX.X%	X.X%	XX.X%	XX XXX
Latvia	X XXX	X.X%	X.X%	X.X%	-
Lithuania	X XXX	X.X%	X.X%	X.X%	-
Luxembourg	-	X.X%	X.X%	X.X%	-
Hungary	-	X.X%	X.X%	X.X%	-
Malta	XX XXX	XX.X%	X.X%	XX.X%	XX XXX
Netherlands	XXX XXX	XX.X%	XX.X%	XX.X%	XXX XXX
Austria	XXX	X.X%	X.X%	X.X%	-
Poland	XX XXX	X.X%	X.X%	X.X%	-
Portugal	XX XXX	X.X%	X.X%	X.X%	-
Romania	XXX	X.X%	X.X%	X.X%	-
Slovenia	-	X.X%	X.X%	X.X%	-
Slovakia	-	X.X%	X.X%	X.X%	-
Finland	XX XXX	X.X%	X.X%	X.X%	-
Sweden	XX XXX	XX.X%	XX.X%	XX.X%	XX XXX
EU 27 total	X XXX XXX	XX.X%		XX.X%	XXX XXX

[redacted]

[redacted]

[redacted]

[redacted]

3.2 Fuel EU insights

The main regulatory items are summarized in the table below.

Table 13: FuelEU main regulatory items

	Renewable share obligation (GHG reduction)	Target CI (gCO2eq/MJ)	Cap Crop food/ feed	RFNBO sub-target
Baseline		91.16		
2025	2%	89.34	0%	
2030	X%	XX.XX	X%	
2031	X%	XX.XX	X%	X%
2033	X%	XX.XX	X%	
2034	X%	XX.XX	X%	X%
2035	XX%	XX.XX	X%	
2040	XX%	XX.XX	X%	
2045	XX%	XX.XX	X%	
2050	XX%	X.XX	X%	

[redacted]

[redacted]

[redacted]

As confirmed since V1, shipping companies will be allowed to create pools for their compliance under Fuel EU, according to article 21 of the regulation. They can pool part of their fleet, the whole of it, individually or with other companies, as long as they record properly the pooling scope at the "Fuel EU database". Note that so far, the EC has emitted no sign about creating this database, which should be key to allow full compliance.

[redacted]

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3.3 ReFuel EU insights

3.3.1 Elements clarified since V1

The EC clarified that national mandates can't be imposed on jet fuel suppliers on top of the ReFuel EU obligations, summarized here.

Table 14: ReFuelEU main regulatory items

	Renewable share obligation (% vol)	Synthetic aviation fuels sub-target (% vol, no DC)	Cap Crop food/ feed	Cap uncategorized (% vol. jet fuels pool)
2025	2%	-	0%	3%
2030/31	X%	X.X%	X%	X%
2032/33	X%	X%	X%	X%
2034	X%	X%	X%	X%
2035	XX%	X%	X%	X%
2040	XX%	XX%	X%	X%
2045	XX%	XX%	X%	X%
2050	XX%	XX%	X%	X%

The main change since V1 is the confirmation that the 3% vol. cap imposed on uncategorized feedstocks (mainly animal fats (AF) C3) is expressed regarding the total jet fuels pool. It implies that AF C3 SAF could potentially cover the whole 2025-2029 target (2%) and half of the 2030 target (6%).

We assessed with Eurostat data that the share of jet fuel consumption in Union Airports, and thus falling under ReFuel EU compliance, is close to 98% of the total, a higher share than our previous estimate in V1 (95%). Strong public data on the jet fuel consumption per airport is limited but sources working on jet fuel demand at IATA indicated this figure is appropriate.

The text of the regulation refers to RED2 for the definition of a "fuel supplier", reads an "entity supplying fuel to the market that is responsible for passing fuel through an excise duty point". Since the application of it is different from one country to another, only an aviation fuel supplier active in one specific country will be recognized as the obliged one under ReFuel EU. This has important consequences on the pooling options.

Article 15 of EU establishes that "by way of derogation from Article 4(1), from 1 January 2025 until 31 December 2034, for each reporting period, an aviation fuel supplier may supply the minimum shares of SAF defined in Annex I as a weighted average over all the aviation fuel it supplied across Union airports for that reporting period."

We confirmed with a Ministry source that, because of the fuel supplier definition, pooling by one entity will be possible at the MS level, not the whole EU. A jet fuel distributor in one country will be able to deliver

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3.3.2 Union Airports and jet fuel tankering

An important consideration in our baseline scenario is the focus on "Union Airports" subject to the SAF blending mandates under the ReFuel EU legislation. According to the 2024 list, 144 of over 550 airports in EU-27 countries met the criteria set in the regulation (>800 000 passenger traffic or >100 000 tons of freight). Eurostat data indicates that these airports account for an estimated 98% of jet fuel demand, effectively covering the bulk of aviation activity intended by the legislation. Nonetheless, we have identified a set of 12 airports not currently listed as Union Airports that are on track to meet the passenger traffic threshold soon.

Table 15: Potential airports to be included into RefuelEU regulation

Country	ICAO Code	Airport	Annualised 6M24 passengers carried
Austria	LOWG	Graz Airport	748 982
Austria	LOWI	Innsbruck Airport	1 243 194
Germany	EDLP	[redacted]	XXX XXX
Spain	LEAM	[redacted]	XXX XXX
Finland	EFRO	[redacted]	XXX XXX
France	LFRB	[redacted]	XXX XXX
Ireland	EIKN	[redacted]	XXX XXX
Italy	LIBP	[redacted]	XXX XXX
Italy	LIPQ	[redacted]	X XXX XXX
Poland	EPRZ	[redacted]	XXX XXX
Sweden	ESNU	[redacted]	XXX XXX
Slovakia	LZKZ	[redacted]	XXX XXX

[redacted]

[redacted]

Our consultations with industry experts revealed divided opinions on the impact of this clause. Most experts dismissed the likelihood of short-term severe disruptions, highlighting that the EU is currently receiving requests from air operators to exclude certain routes. However, there is broader concern about long-term effects, as higher SAF mandates kick-in around 2035, particularly regarding long-haul routes through eastern cost-competitive hubs outside the EU, such as in the Middle East. An EU-East Asia itinerary would save costs if it does a layover in these non-Union hubs, as they would be avoiding EU SAF mandates for a high share of the energy required. This concern points towards potential restructuring of fuel sourcing strategies over time, and a considerable impact in total jet fuel demand in EU (more efficient use of fuel and potential re-routes as described above). We aim to explore further these effects in subsequent iterations of our study.

Table 16: ReFuel EU aviation pool (EJ)

	2025	2026	2027	2028	2029	2030
Jet fuel	1.94	X.XX	X.XX	X.XX	X.XX	X.XX
SAF	0.04	X.XX	X.XX	X.XX	X.XX	X.XX
TOTAL	1.97	X.XX	X.XX	X.XX	X.XX	X.XX

3.4 Regulations impacting fossil fuel prices: ETS 1/2and ETD

Since V1, the situation on the Emissions Trading Scheme (ETS 1 and 2), and the Energy Tax Directive (ETD) did not change. As we explained one year ago, these legislations contribute to a lower gap between the price of fossil fuels and their low-carbon fuel alternatives.

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3.5 MS scope of action is limited

Since V1, we confirmed with Ministry and EC sources that MS will not be authorized to promote renewable energy in maritime and aviation sectors above Fuel and ReFuel EU levels. **This reinforces our V1 assumption: renewable shares in those two sectors will likely not exceed the 6% GHG reduction and 6% volume mandated respectively.**

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4. Improved modelling of renewable energy required

4.1 Fuel EU Compliance

4.1.1 Methanol low-carbon options

During the summer 2024, the abandonment of Orsted's FlagshipONE 50kt e-methanol project in Sweden came as a symbolic blow to the market segment. The company - one of the largest renewable energy companies in the world to transition from fossil fuels - commented that "the business case has deteriorated during maturation due to the inability to sign long-term offtake contracts at sustainable pricing and significantly higher project costs." The Final Investment Decision (FID) was taken in 2022, and the company broke ground in May-24, but this ultimately didn't stop the decision to write-off a massive EUR 200 M investment. Despite bleak profitability perspectives, some projects remain under construction and will hopefully see operation. In Denmark, the Solar Park Kasso (SPK) will start its 32 kt/y e-methanol plant by year-end, becoming the largest PtX plant in the world. In China, Goldwin started the construction of a 250 kt/y biomethanol facility based on "biomass conversion with green hydrogen". Both companies have offtake agreements with Maersk, which is growing its methanol-gasoil dual engines fleet.

The Methanol Institute (MI) lists hundreds of announced projects. Limiting those to that are currently operational or under construction, the following table summarises near-term capacities across regions:

Table 17: Near-term capacity	Europe	North America	China
Bio-methanol	[redacted]	4 plants operational - 396 kt. 1 plant under consutrction - 100 kt in 2025	[redacted]
e-methanol	[redacted]	-	[redacted]

[redacted]

- [redacted]
- [redacted]

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4.1.2 Bio-LNG

The Bio-LNG outlet in shipping is still in its infancy but is taking-off. The most recent data showed that about 2 kt of bio-LNG will be bunkered in 2024 in Rotterdam, the same as in Singapore.

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4.1.3 HVO and FAME

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[redacted]

[redacted]

[redacted]

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4.1.4 Effect of global bio bunkering and feedstock mix

As we highlighted in V1, the respective shares of 9A and 9B within the biodiesel mix will depend on several factors. The impact of the revision of Annex 9 in March 2024 has opened the way to cover and energy crops to be potentially used in shipping. Our "New Annex 9" study demonstrated that those feedstocks are not physically available yet. Their development will be strongly limited in the medium term under the established definitions. Assuming no fraudulent volumes will be generated, they will not impact significantly the wastes market by 2030.

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[redacted]

[redacted]

[redacted]

Table 18: Final FuelEU pool (kt)									
	2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Feedstock**
HFO	11 865	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX	Fossil
LFO	9 660	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX	Fossil
MGO	2 836	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX	Fossil
FAME	405	XXX	XXX	XXX	XXX	XXX	XXX	XXX	9A
FAME	-	-	XX	XXX	XXX	XXX	XXX	XXX	9B
HVO	-	-	-	-	-	X	XX	XX	9A
HVO	-	-	-	-	-	X	XX	XX	9B
LNG	2 265	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX	Fossil
Bio LNG	-	X	XX	XX	XX	XX	XXX	XXX	9A
LPG	9	XX	XX	XX	XX	XX	XX	XX	Fossil
Bio LPG	-	-	-	-	-	-	-	-	9B
MeoH	7	XX	X	X	X	X	X	X	Fossil

4.1.5 LNG pool to account for 35% of savings in 2030

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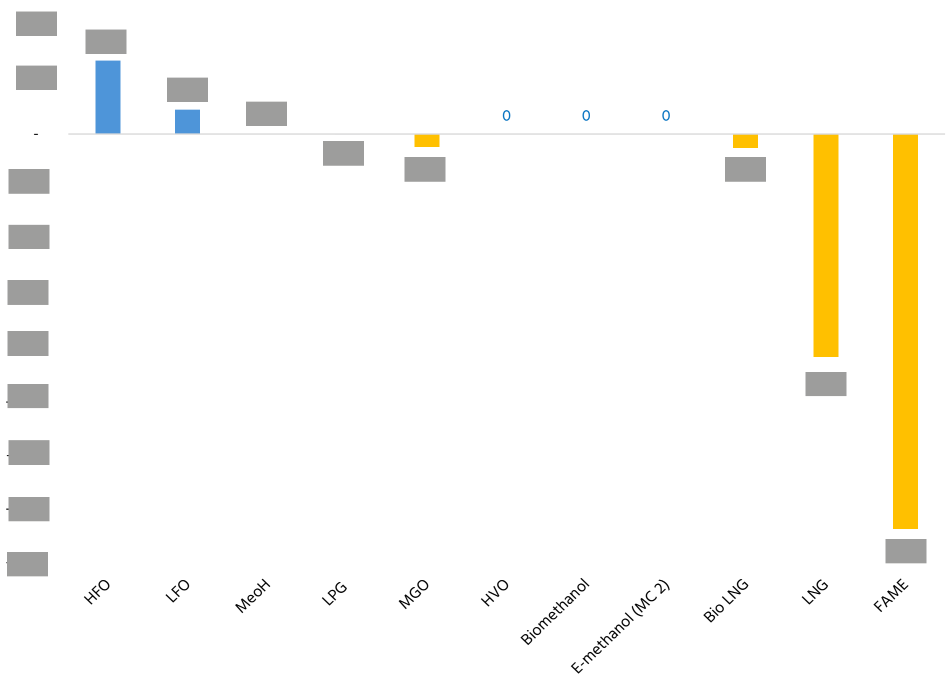

Chart 2: 2025 savings

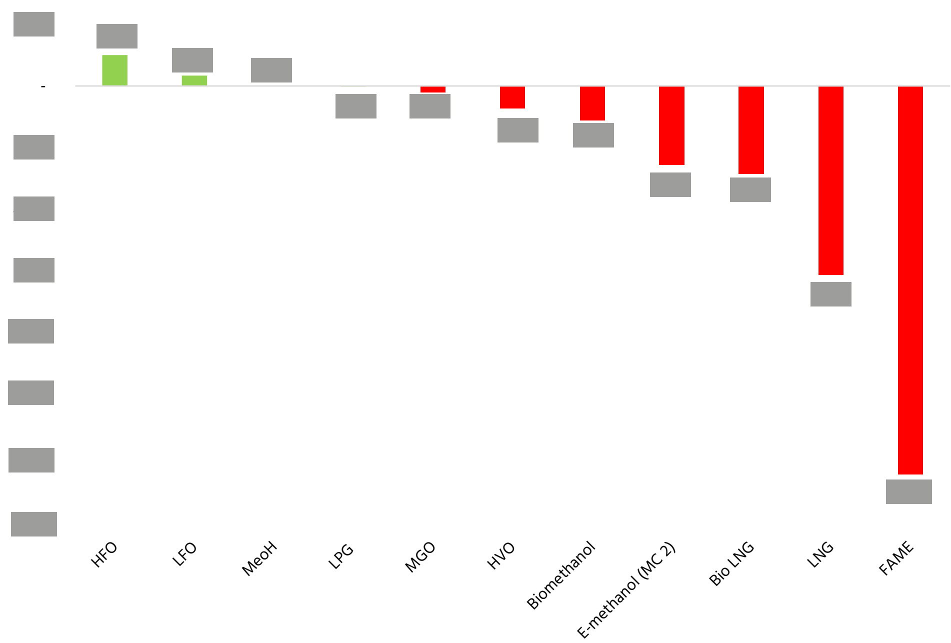

Chart 3: 2030 savings

The table below summarizes the amount of savings generated by each product, depending on their carbon intensity (CI) and energy content (EC) for our assumed 2025 levels.

Table 19: Final FuelEU pool (kt)				
Product	CI (gCO2eq/MJ)	EC (MJ/kg)	Savings (t CO2eq/t)	Ratio vs FAME
LNG	84.09	49.1	-347	11%
Bio-LNG	XX	XX.X	-X XXX	XXX%
Bio-LNG	-XX	XX.X	-X XXX	XXX%
MeOH	XXX.XX	XX.X	XXX	-X%
Bio-methanol	XX.XX	XX.X	-X XXX	XX%
HFO	XX.XX	XX.X	XX	-X%
LFO	XX.XX	XX	XX	X%
FAME	X	XX	-X XXX	XXX%
HVO	X	XX	-X XXX	XXX%

[redacted]

4.2 Maritime renewable energy under RED3

The maritime pool to fall under the RED3 scope is different from the FuelEU one. All fuels and electricity to be supplied in the Union to international and domestic transport will be included.

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Table 20: Maritime pool under RED III								
	2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
FAME 9A	405	485	XXX	XXX	XXX	XXX	XXX	XXX
FAME 9B	-	-	XX	XXX	XXX	XXX	XXX	XXX
HVO 9A	-	-	-	-	-	X	XX	XX
HVO 9B	-	-	-	-	-	X	X	XX
Bio LNG	-	3	X	XX	XX	XX	XX	XXX
Bio LPG	-	-	-	-	-	-	-	-
Biomethanol	-	-	-	X	X	XX	XX	XXX
E-methanol	-	-	-	X	XX	XX	XX	XXX
FAME 9A domestic	10	12	XX	XX	XX	XX	XX	XX
FAME 9B domestic	10	12	XX	XX	XX	XX	XX	XX

[redacted]

4.3 RefuelEU Compliance

4.3.1 Feedstock mix

Since V1, we confirmed with EC sources that the cap of 3% e.c. for "uncategorized" feedstocks mentioned in the ReFuel EU text would apply from 2025 on the total jet fuel pool under compliance.

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[redacted]

4.3.2 RFNBO sub-target compliance

[redacted]

[redacted]

4.3.3 Overall compliance

The development of the ATJ technology achieved a significant milestone in 2024 with the start-up of the first commercial-scale 30 kt/y Lanzajet Freedom Pines Fuels project in the US. Although other projects are in the pipeline, we decided to maintain our cautious stance about waste-based ATJ availability relative to HEFA by 2030. Our model does not include any ATJ contribution to ReFuel EU compliance during 2025-2030.

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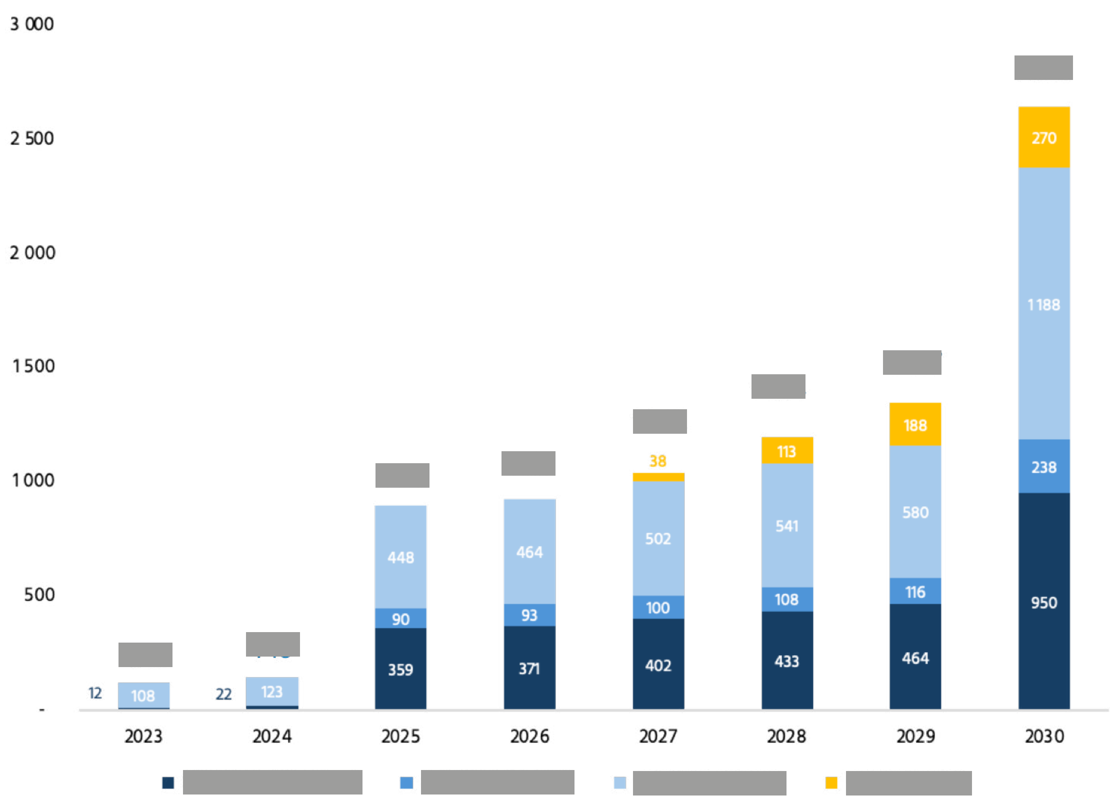

Chart 4: Estimated SAF structure to 2030 (kt)

4.4 Aviation renewable energy under RED3

The aviation pool under RED3 is slightly greater than under Refuel EU, which covers 98% of the total jet fuels. Our model ignores aviation gasoline.

[redacted]

4.5 Green H2 used at refineries

We adjusted the amount required to the fulfilment of the 1% e.c (after MC) sub-target, after e-fuels used in maritime and aviation are accounted for. The resulting figure is slightly higher than in V1: 443 kt in 2030.

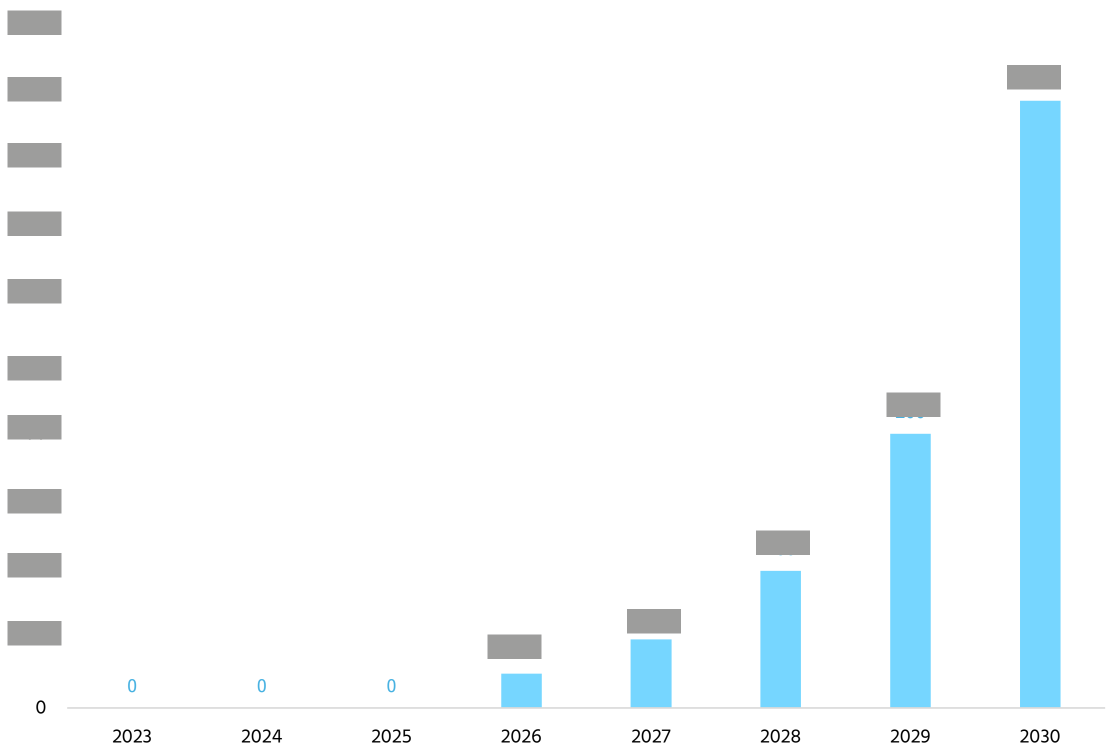

Chart 5: Projected hydrogen use at refineries (kt)

4.6 Electricity mix

The latest official figure of the renewable share in the EU-27 electricity mix was published by the EC in February 2024: 41.2% in 2022, up from 37.7% in 2021. Fossil generation is in structural decline in the EU since the invasion of Ukraine. Data from specialised institutions suggests that RE share was above 44.2 % in 2023, and close to 50% during H1-24.

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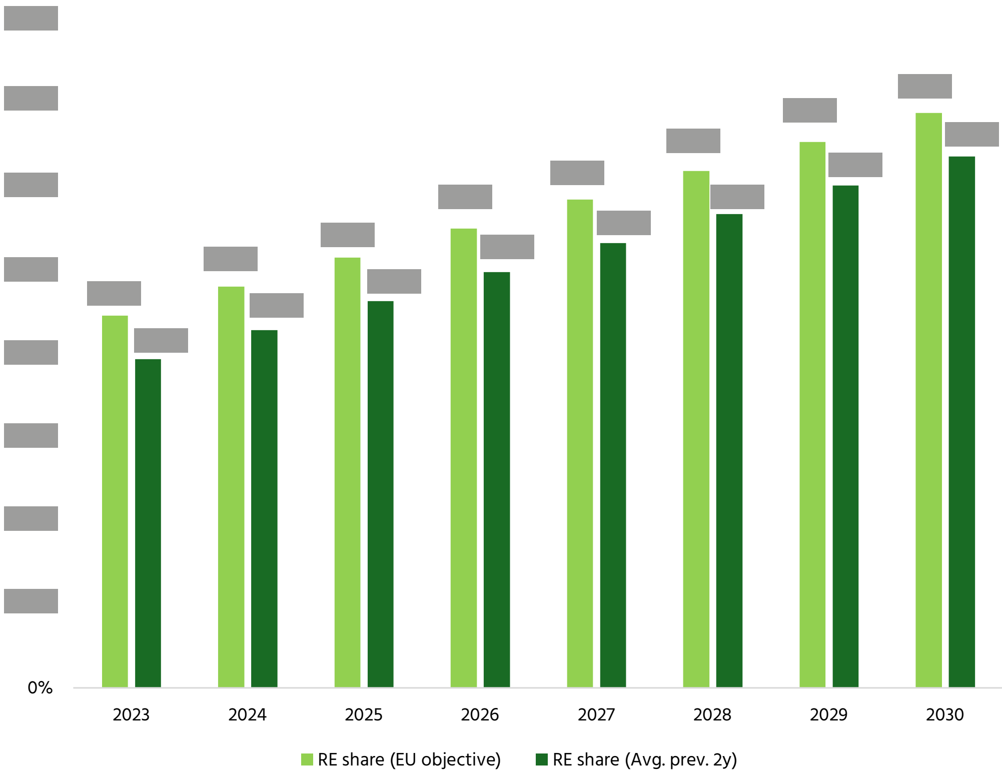

Chart 6: Electricity mix projection to 2030

4.7 Rail

Estimating the renewable energy use in the rail sector is straightforward, as it depends mainly on the RE mix evolution of the Union by 2030.

[redacted]

Table 21: Energy pool of rail sector

Fuel	Unit	2023	2024	2025	2026	2027	2028	2029	2030
Diesel fossil	kt	2 188	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX
Fame	kt	78	XX	XX	XX	XX	XX	XX	XXX
Elec non renewable	TWh	29	XX	XX	XX	XX	XX	XX	XX
Elec renewable	TWh	19	XX	XX	XX	XX	XX	XX	XX

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4.8 Road

IV.8.1 Non-road machinery pool excluded in RED3

The RED3 scope includes all energy used in the four transport sectors. The Eurostat (SHARES) definition confirms that non-road machinery is excluded.

[redacted]

[redacted]

[redacted]

4.8.2 Blend walls

[redacted]

Table 22: Blend wall per scenario (kt)								
	2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
ELEC								
B7	13 304	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX
E10	7 155	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX
ETBE 33%	238	XXX	XXX	XXX	XXX	XXX	XXX	XXX
BASE								
B7	13 304	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX
E10	7 155	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX
ETBE 33%	238	XXX	XXX	XXX	XXX	XXX	XXX	XXX
RENF								
B7	13 304	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX	XX XXX
E10	7 155	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX	X XXX
ETBE 33%	238	XXX	XXX	XXX	XXX	XXX	XXX	XXX

[redacted]

[redacted]

4.8.3 Gas road fuels

[redacted]

[redacted]

[redacted]

Table 23: Gas fuel pool for road sector per scenario (PJ)

	2023	2024	2025	2026	2027	2028	2029	2030
ELEC								
CNG	72.67	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX
Bio CNG/LNG	28.26	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX
LPG	220.93	XXX.XX	XXX.XX	XXX.XX	XXX.XX	XXX.XX	XXX.XX	XXX.XX
Bio LPG	2.23	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
BASE								
CNG	72.67	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX
Bio CNG/LNG	28.26	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX
LPG	224.17	XXX.XX	XXX.XX	XXX.XX	XXX.XX	XXX.XX	XXX.XX	XXX.XX
Bio LPG	1.58	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX
RENF								
CNG	72.67	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX
Bio CNG/LNG	28.26	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX	XX.XX
LPG	220.93	XXX.XX	XXX.XX	XXX.XX	XXX.XX	XXX.XX	XXX.XX	XXX.XX
Bio LPG	2.23	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX

4.8.4 FAME, ethanol, biogases feedstock mixes

In 2025, SquareCo forecasts for the EU-27 display the following shares for feedstock categories:

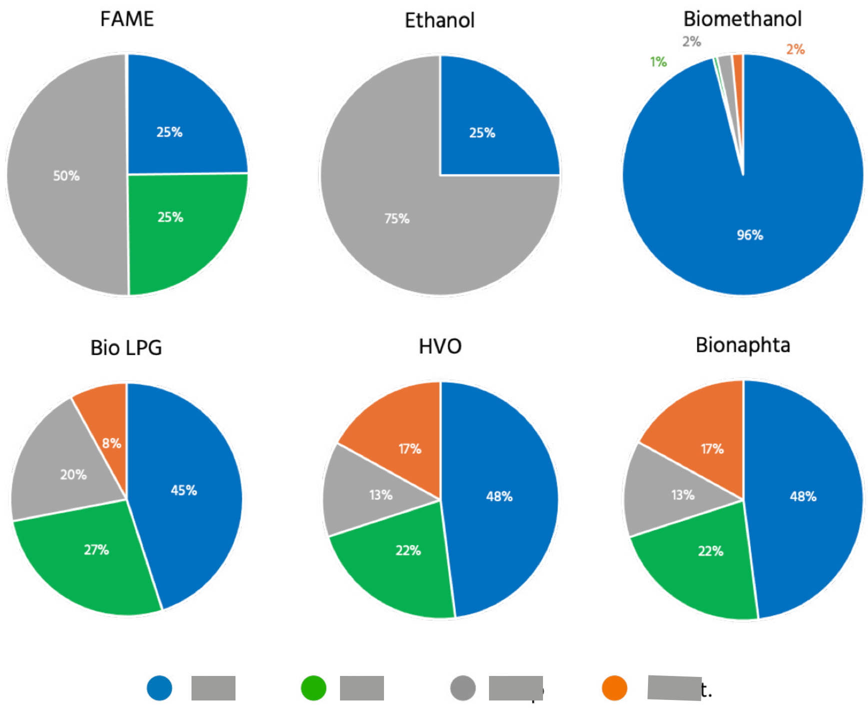

Chart 7: Feedstock category mix for each product

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4.8.5 RFNBOs still absent

[redacted]

4.8.6 Levels of energy targets in 2026-2030

[redacted]

[redacted]

[redacted]

Table 24: Energy overall share 2023-2030									
TARGETS	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2030**
ENERGY	9.6%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
RFNBO	-	-	-	-	-	-	-	X.X%	XXX

4.8.7 Two variables to adjust demand to targets: HVO and bionaphhta

In our model, **HVO and bionaphtha quantities are the latest variables set to resolve the RED3 equation**. As all other compliance options are either limited by technology development, blend walls or driven by other regulations, those two will be the ultimate ways to meet the RED3 targets.

[redacted]

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4.8.8 GHG target and CIs

We built a stronger model to calculate the savings generated by the fulfilment of the 29% e.c. savings, in line with the methodology explained at the section III.1.1. It clearly shows that the amount of renewable energy to meet the energy target translates in an over-fulfilment of the GHG target.

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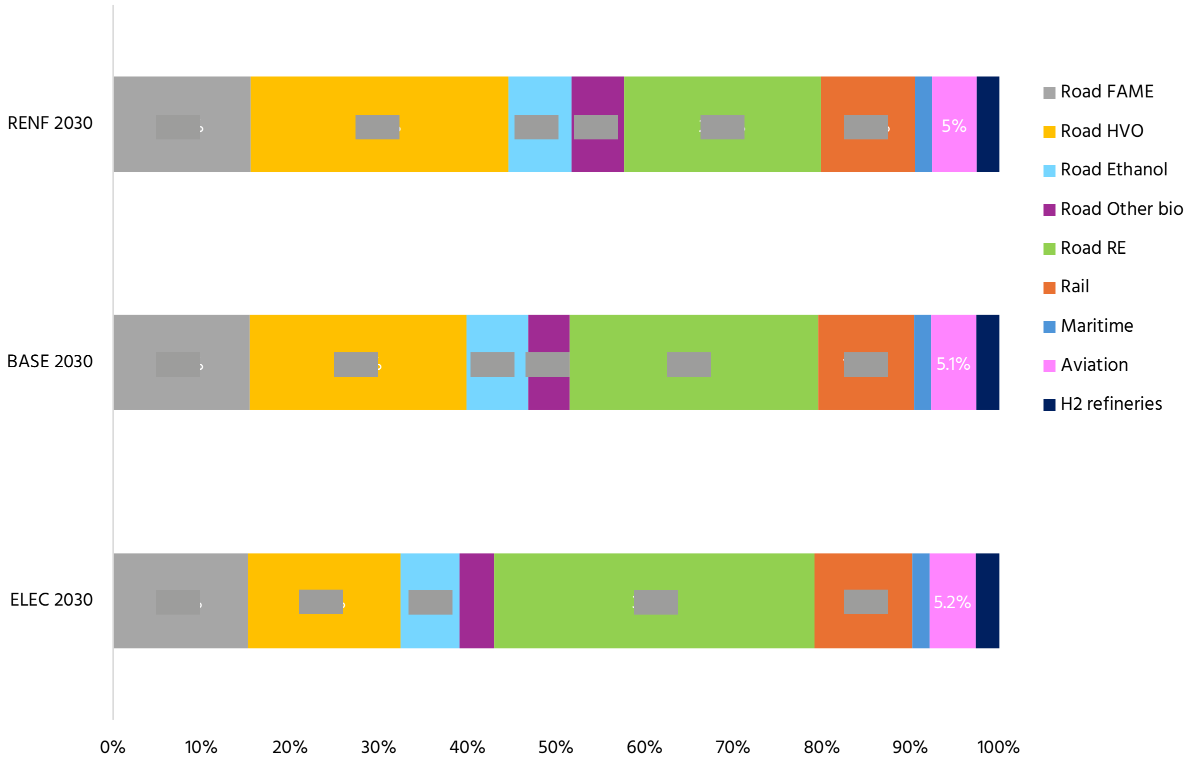

Chart 8: Share of savings in 2030 per scenario

4. Improved modelling of renewable energy required

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5. Findings

Our research highlighted two key findings in RED3 methodology, not applied in our models for V1, that have major repercussions on the final outcome:

- **Applying the multipliers to the denominator of the energy target** has two key effects.
  - ◊ [redacted]
  - ◊ [redacted]

- **Calculating savings from renewable electricity under the GHG target against a higher comparator (183 gCO2eq/MJ)** than all other compliance options (94)
  - ◊ [redacted]
  - ◊ [redacted]
  - ◊ [redacted]

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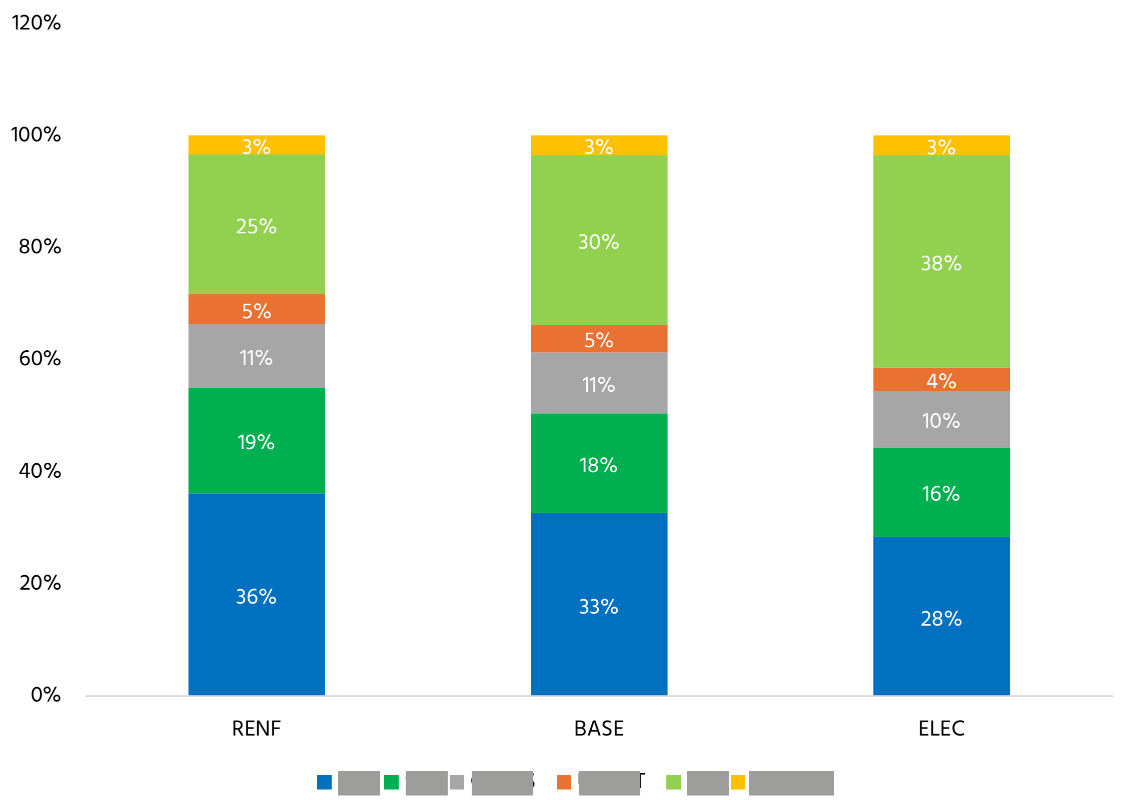

Chart 9: Energy ontribution by each category per scenario

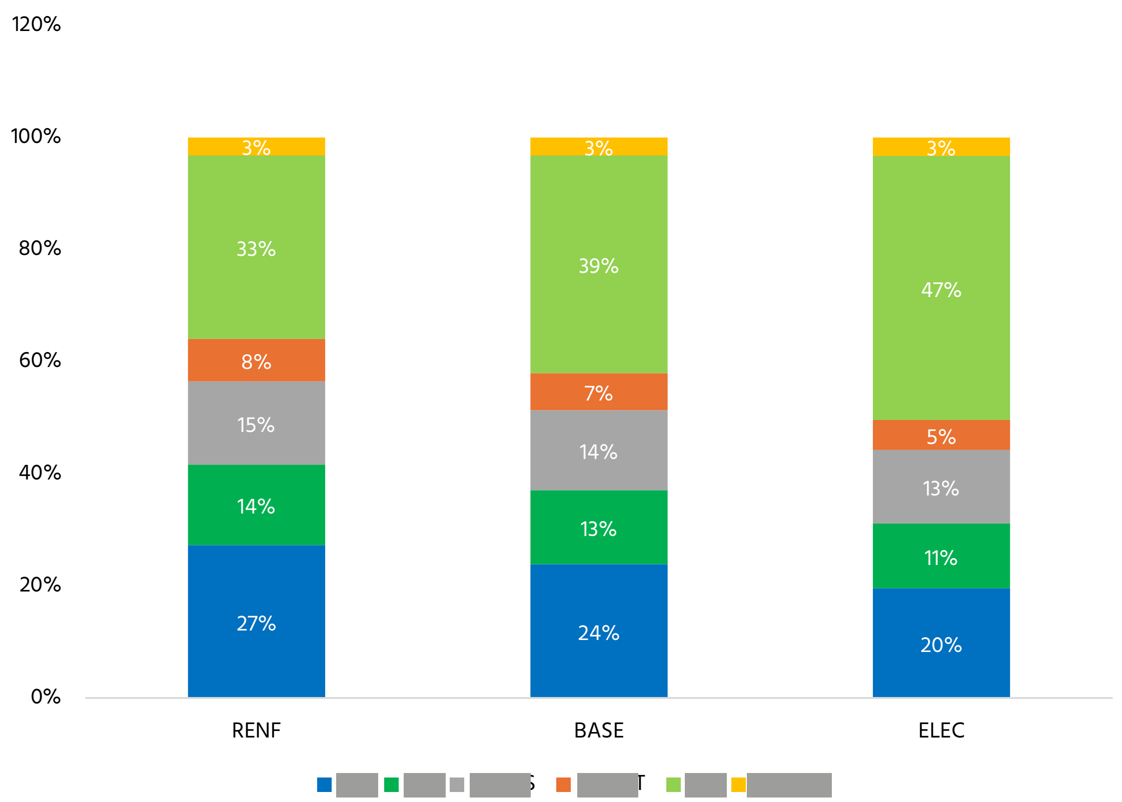

Chart 10: GHG ontribution by each category per scenario

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As shown in V1, the fact that the maritime and aviation sectors will not cover the targets' level implies that road and rail sectors will compensate for the missing amounts of renewable energy, or savings.

Table 25: Surplus/deficit of each sector (EJ)			
	29% (MC)	**BASE**	**Surplus**
Road	X.XX	X.XX	X.XX
Rail	0.08	0.17	0.09
Maritime (net)	X.XX	X.XX	-X.XX
Aviation	X.XX	X.XX	-X.XX
H2	X.XX	X.XX	X.XX

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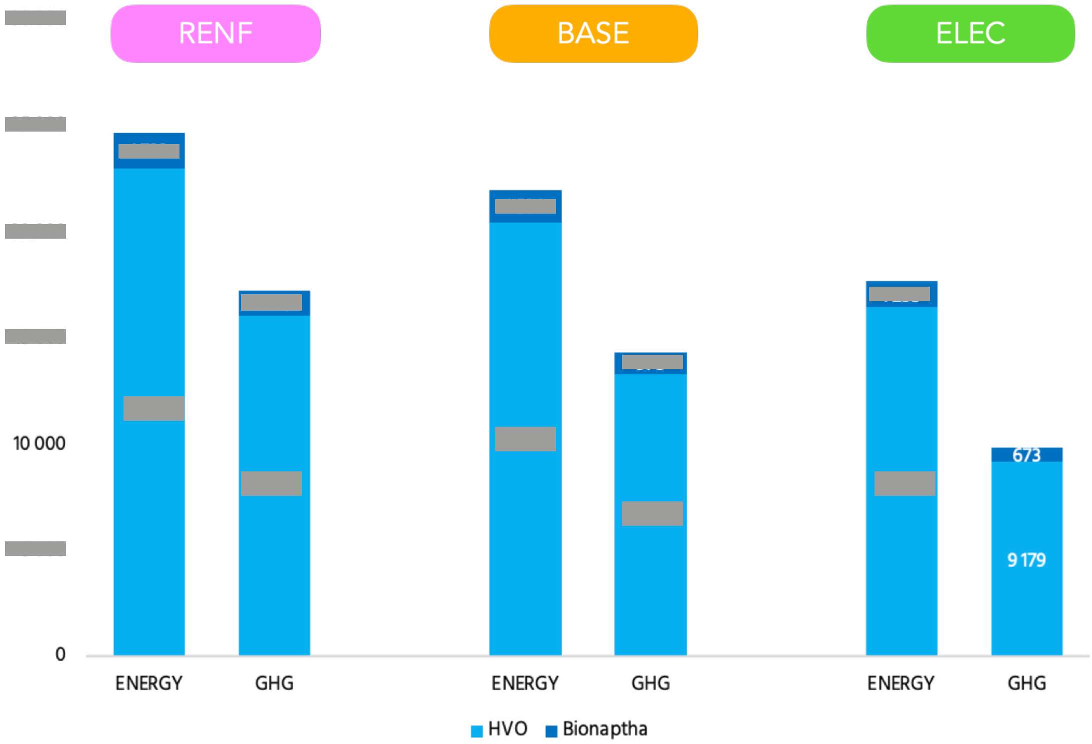

Chart 11: Energy vs GHG Target 2030 (HVO and Bionaphtha volumes)

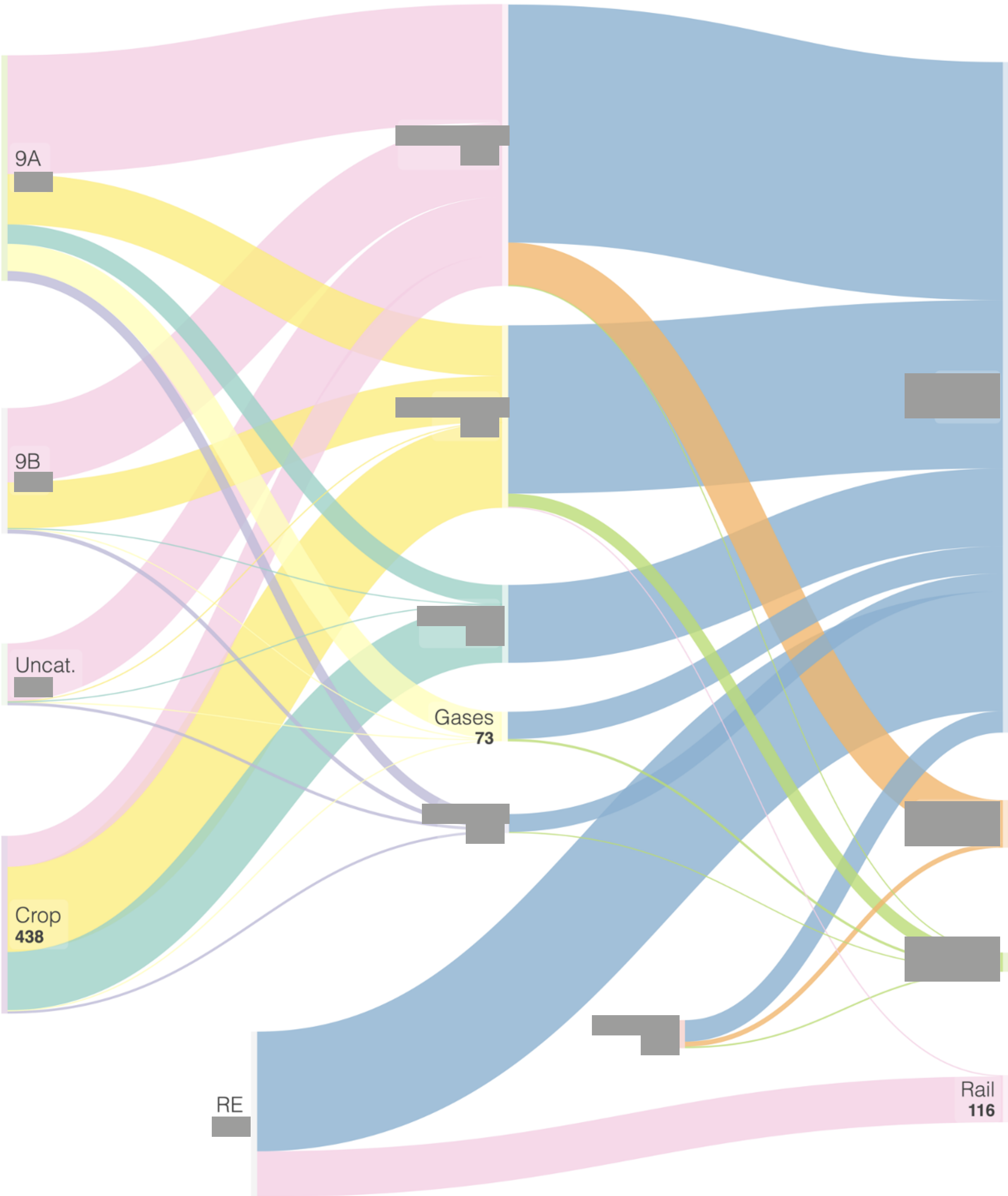

Chart 12: Renewable feedstocks and biofuels in transport sectors (PJ) for BASE scenario under the 14.5% emissions reduction target

6. Limits to our new models

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7. Conclusion

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Annexes

Annex 1 : Fuel EU Maritime penalty

A1.1. Understanding the Fuel EU penalty

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[redacted] $[\Sigma_i^{nfuel} M_i \times LCV_i]$ [redacted]

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[redacted]

$$FuelEU\ Penalty = \frac{\text{[redacted]}}{\text{[redacted]}} \times \text{[redacted]}$$

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$$FP = \text{[redacted]}$$

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A1.2. Case study of the Fuel EU penalty

[redacted]

A1.2.1 Marine fuel consumption in 2022

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$$Annual\ average\ CI_{ship} = \Sigma_i^{n\ fuel} a_i \times CI_i$$

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Table 26: Average CI for each type of ship in 2022										
Ship type	Fuel share (%EC)								Average CI	vs 2025 CI target
	MDO / MGO	Ethanol	HFO	LFO	LNG	LPG	MeOH	Others		
Bulk carrier (BC)	8%	0%	55%	38%	0%	0%	0%	0%	91.5	2.4%
Combination carrier (CC)	6%	0%	77%	17%	0%	0%	0%	0%	91.6	2.5%
Container ship (CS)	X%	X%	XX%	XX%	X%	X%	X%	X%	XX.X	X.X%
Cruise passenger ship (Cru)	XX%	X%	XX%	X%	X%	X%	X%	X%	XX.X	X.X%
Gas carrier (GC)	XX%	X%	XX%	XX%	XX%	X%	X%	X%	XX.X	X.X%
General cargo ship (Car)	XX%	X%	XX%	XX%	X%	X%	X%	X%	XX.X	X.X%
LNG carrier (LC)	X%	X%	X%	X%	XX%	X%	X%	X%	XX.X	X.X%
Others (O)	XX%	X%	XX%	XX%	X%	X%	X%	X%	XX.X	X.X%
Passenger ship (PS)	XX%	X%	XX%	X%	X%	X%	X%	X%	XX.X	X.X%
Refrigerated cargo carrier (RC)	XX%	X%	XX%	XX%	X%	X%	X%	X%	XX.X	X.X%
Ro-ro cargo ship (RRC)	XX%	X%	XX%	X%	X%	X%	X%	X%	XX.X	X.X%
Ro-ro cargo ship (vehicle carrier) (RRVC)	XX%	X%	XX%	XX%	X%	X%	X%	X%	XX.X	X.X%
Ro-ro passenger ship (RRP)	XX%	X%	XX%	XX%	X%	X%	X%	X%	XX.X	X.X%
Tanker (T)	XX%	X%	XX%	XX%	X%	X%	X%	X%	XX.X	X.X%
Global	XX%	X%	XX%	XX%	X%	X%	X%	X%	XX.X	X.X%

[redacted]

[redacted]

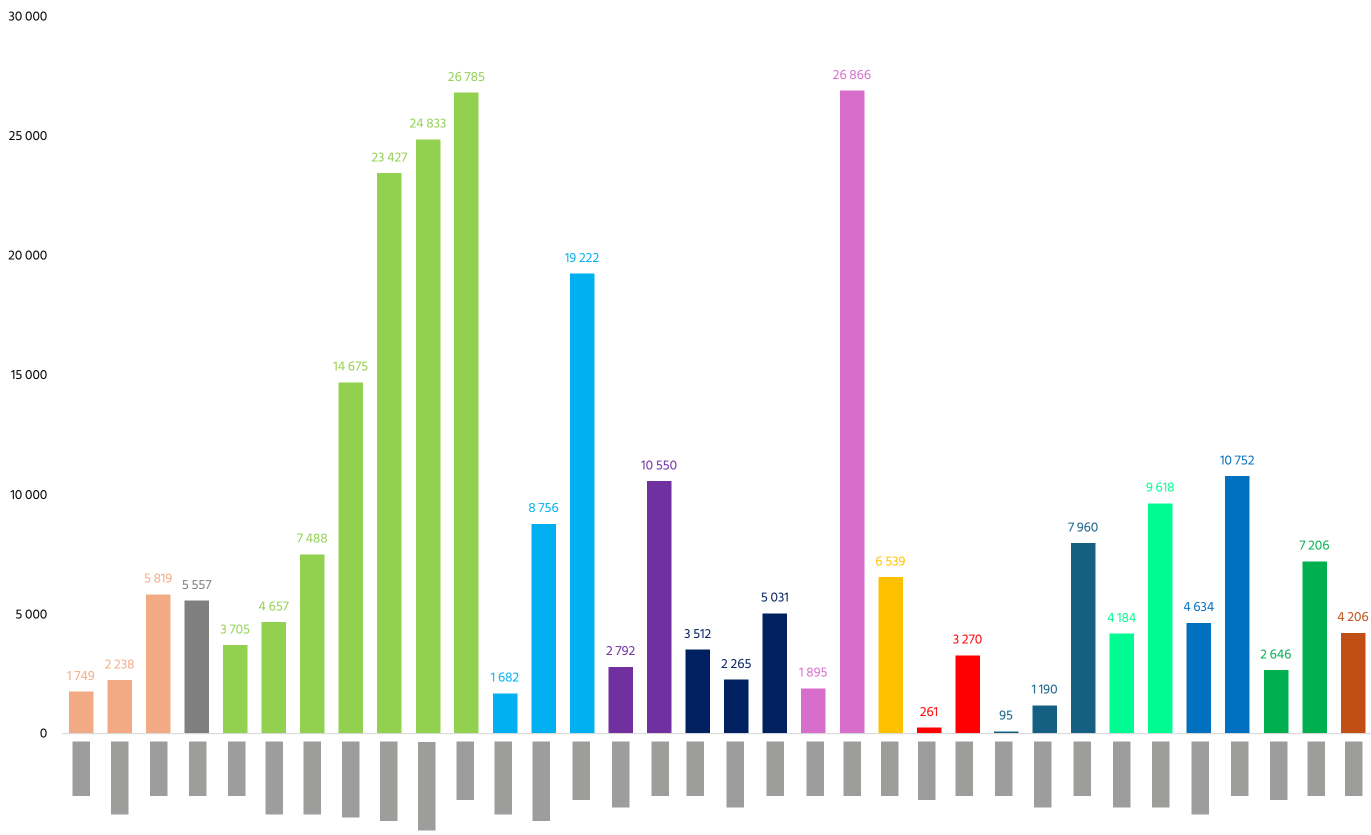

Chart 13: Average fuel demand by ship type (t)

[redacted].

A1.2.2 Penalty estimation

[redacted]

[redacted]

[redacted]

Table 27: Average penalty amount according to 2022 MEPC data		
Ship type	**Fuel type**	**Penalty amount (EUR)**
Bulk carrier < 10k	MDO	XX XXX
	HFO	XXX XXX
	LFO	XX XXX
Bulk carrier 10k - 20k	MDO	XX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Bulk carrier > 20k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Combi carrier > 20k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Container < 10k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Container 10k - 15k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Container 15k - 40k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Container 40k - 80k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Container 80k - 120k	MDO	XXX XXX
	HFO	X XXX XXX
	LFO	X XXX XXX
Container 120k - 200k	MDO	XXX XXX
	HFO	X XXX XXX
	LFO	X XXX XXX
Container > 200k	MDO	X XXX XXX
	HFO	X XXX XXX
	LFO	X XXX XXX
Cruise 5k - 25k	MDO	XX XXX
	HFO	XXX XXX
	LFO	XX XXX
Cruise 25k - 85k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Cruise > 85k	MDO	XXX XXX
	HFO	X XXX XXX
	LFO	X XXX XXX
Gas carrier 2k - 10k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX

Annex 1 : Fuel EU Maritime penalty

Gas carrier > 10k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Cargo 3k - 15k	MDO	XX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Cargo > 15k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
LNG <10k	MDO	XX XXX
	HFO	XXX XXX
	LFO	XXX XXX
LNG >10k	MDO	X XXX XXX
	HFO	X XXX XXX
	LFO	X XXX XXX
Passenger > 5k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Refrige cargo > 5k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Ro-ro cargo > 2k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Ro-ro vehicle < 10k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Ro-ro vehicle >10k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Ro-ro passenger 250 < 1k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Ro-ro passenger > 1k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Tanker 4k - 20k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Tanker > 20k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX
Others > 5k	MDO	XXX XXX
	HFO	XXX XXX
	LFO	XXX XXX

[redacted]

$$Penalty\ premium(EUR/t_{fuel}) = \text{[redacted]}$$

A1.2.3 Biofuel requirement in 2025

[redacted]

$$Biofuel\ share_{min} = \text{[redacted]}$$

[redacted]

Table 28: CI of each type of fuel calculated from FuelEU annex II			
	Fuel	**CI (gCO2/MJ)**	**Compare to target CI 2025-2029**
Fossil fuel	HFO	91.74	2.7%
	LFO	XX.XX	X.X%
	MDO/MGO	XX.XX	X.X%
	LNG otto-med	XX.XX	-X.X%
	LNG otto-slow	XX.XX	-X.X%
	LNG diesel-slow	XX.XX	-XX.X%
	LBSI	XX.XX	-X.X%
	LPG	XX.XX	-X.X%
	H2 (NG) ICE	XXX.XX	XX.X%
	NH3 (NG)	XXX.XX	XX.X%
	Methanol (NG)	XXX.XX	XX.X%
Biofuel	Ethanol	30.13	-66.3%
	Biodiesel	12.68	-85.8%
	HVO	47.05	-47.3%
	Bio-LNG otto-med	45.43	-49.1%
	Bio-LNG otto-slow	39.21	-56.1%
	Bio-LNG diesel-slow	32.54	-63.6%
	Biomethanol	16.24	-81.8%

[redacted]

Table 29: Biofuel requirement to meet the FuelEU target							
Fossil fuel	**Biofuel**	**2025-2029 Min share of biofuel (%ec)**	**2030-3034 Min share of biofuel (%ec)**	**2035-2039 Min share of biofuel (%ec)**	**2040-2044 Min share of biofuel (%ec)**	**2045-2049 Min share of biofuel (%ec)**	**2050+ Min share of biofuel (%ec)**
HFO	UCOME	3.0%	7.7%	17.5%	36.5%	72.2%	93.0%
LFO	UCOME	2.6%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%
MDO/MGO	UCOME	1.8%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%
LNG (otto-med)	Bio-LNG	0	X.X%	XX.X%	XX.X%	NA	NA
LNG (otto-slow)	Bio-LNG	0	X	XX.X%	XX.X%	NA	NA
LNG (diesel-slow)	Bio-LNG	0	X	X	XX.X%	XX.X%	NA
Methanol (NG)	Biomethanol	15.9%	XX.X%	XX.X%	XX.X%	XX.X%	XX.X%

[redacted]

[redacted]

$$WtP\ biofuel\ price(EUR/t) = \frac{\text{[redacted]}}{\text{[redacted]}} \times \text{[redacted]}$$

[redacted]

Table 30: Evolution of the "willingness to pay" amount to the FAME CI

FAME CI (gCO2/MJ)	Based fossil fuel	2025-2029 Min share of biofuel (%ec)	2030-3034 Min share of biofuel (%ec)	2035-2039 Min share of biofuel (%ec)	2040-2044 Min share of biofuel (%ec)	2045-2049 Min share of biofuel (%ec)	2050+ Min share of biofuel (%ec)	WtP FAME 2025 - 2029 (EUR/t)
12.68	MDO	3.0%	7.7%	17.5%	36.5%	72.2%	93.0%	1 863
	HFO	2.6%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	LFO	1.8%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
12	MDO	1.8%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	HFO	3.0%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	LFO	2.6%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
11.5	MDO	1.8%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	HFO	3.0%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	LFO	2.6%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
11	MDO	1.8%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	HFO	3.0%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	LFO	2.6%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
10.5	MDO	1.8%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	HFO	3.0%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	LFO	2.5%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
10	MDO	1.8%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	HFO	2.9%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	LFO	2.5%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
9.5	MDO	1.8%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	HFO	2.9%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	LFO	2.5%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
9	MDO	1.7%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	HFO	2.9%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX
	LFO	2.5%	X.X%	XX.X%	XX.X%	XX.X%	XX.X%	X XXX

[redacted]

A1.3. Impact of the EU ETS on shipping company's decision

A1.3.1 Fuel EU and ETS overlaying

In Section II.3, we discussed the penalty amounts based on fuel type and ship type.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

$$TOC_{ship} = Qty \times r_{ff} \times P_{ff} + Qty \times r_{bf} \times P_{bf} + FP + ETS, \ (ETS = Qty \times r_{ff} \times E_{ff} \times P_{CO_2})$$

$$if \ r_{bf} < r_{bf\ (min)} \ for \ GHG_{target}: \ TC_{ship} = C_{ff} + C_{bf} + FP + ETS \quad \text{(part I)}$$

$$if \ r_{bf} \geq r_{bf\ (min)} \ for \ GHG_{target}: \ TC_{ship} = C_{ff} + C_{bf} + ETS \quad \text{(part II)}$$

[redacted]

[redacted]

- [redacted]

- [redacted]

P_{ff}: fossil fuel price.

P_{bf}: biofuel price.

P_{CO2}: carbon price determined by the EU ETS market.

C_{ff}: the cost of fossil fuel, it is expressed by Qty* r_{ff} * P_{ff}

C_{bf}: means the cost of biofuel fuel, it is expressed by Qty* r_{bf} * P_{bf}

FP: the FuelEU penalty cost.

E_{ff}: Emission factor of the fossil fuel, for example, that for HFO (TtW) is 3.17 tCO2eq/t.

ETS: the EU ETS cost. It can be calculated by multiplying the emission factor of fossil fuel with the quantity of fossil fuel consumed and the carbon price fixed by EU ETS carbon market.

[redacted]

[redacted]

[redacted] Part II is concerned, so there is no penalty cost)

Knowing that: [redacted]

When: [redacted] $= 0$, is the critical point for ship owners to make their decision.

It can be developed as: $\frac{\partial\, TOC_{ship}}{\partial\, r_{bf}} =$ [redacted] $= 0$

$\frac{\partial\, TOC_{ship}}{\partial\, r_{bf}} =$ [redacted] $= 0$

Knowing that Qty cannot be zero, so the result obtained is: [redacted]

And it can be reformed as: [redacted]

[redacted]

[redacted]

[redacted]: [redacted]

[redacted]: [redacted]

A1.3.2 Case study

[redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

Table 31: Total operational cost of the ship to biofuel blending ratio

Fuel	ratio (%ec)	Energy demand of the ship (MJ/y)	CI actual	ec of fuel (MJ)	Qty of fuel (t)	Penalty amount (EUR)	ETS amount(EUR)	fuel cost (EUR)	Total cost (EUR)
HFO	100%	235 683 091	91.74	235 683 091	5 819	362 014	1 143 332	2 676 894	4 182 240
FAME	0.0%			0	0		0	0	
HFO	99%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	XXX	X XXX XXX	X XXX XXX	X XXX XXX
FAME	1%			X XXX XXX	XX	XXX	X	XX XXX	
HFO	98%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	XXX	X XXX XXX	X XXX XXX	X XXX XXX
FAME	2%			X XXX XXX	XXX	XXX	X	XXX XXX	
HFO	97%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	X XXX	X XXX XXX	X XXX XXX	X XXX XXX
FAME	3%			X XXX XXX	XXX		X	XXX XXX	
HFO	97%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	X	X XXX XXX	X XXX XXX	X XXX XXX
FAME	3.04%			X XXX XXX	XXX		X	XXX XXX	
HFO	96%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	X	X XXX XXX	X XXX XXX	X XXX XXX
FAME	4%			X XXX XXX	XXX		X	XXX XXX	
HFO	95%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	X	X XXX XXX	X XXX XXX	X XXX XXX
FAME	5%			XX XXX XXX	XXX		X	XXX XXX	
HFO	94%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	X	X XXX XXX	X XXX XXX	X XXX XXX
FAME	6%			XX XXX XXX	XXX		X	XXX XXX	
HFO	93%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	X	X XXX XXX	X XXX XXX	X XXX XXX
FAME	7%			XX XXX XXX	XXX		X	XXX XXX	
HFO	92%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	X	X XXX XXX	X XXX XXX	X XXX XXX
FAME	8%			XX XXX XXX	XXX		X	XXX XXX	
HFO	91%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	X	X XXX XXX	X XXX XXX	X XXX XXX
FAME	9%			XX XXX XXX	XXX		X	XXX XXX	
HFO	90%	XXX XXX XXX	XX.XX	XXX XXX XXX	X XXX	X	X XXX XXX	X XXX XXX	X XXX XXX
FAME	10%			XX XXX XXX	XXX		X	XXX XXX	

The information highlighted in yellow represents the simulation result using the FuelEU critical ratio when the ship’s actual CI meets the target CI.

The evolution of the total cost is shown in the following graph:

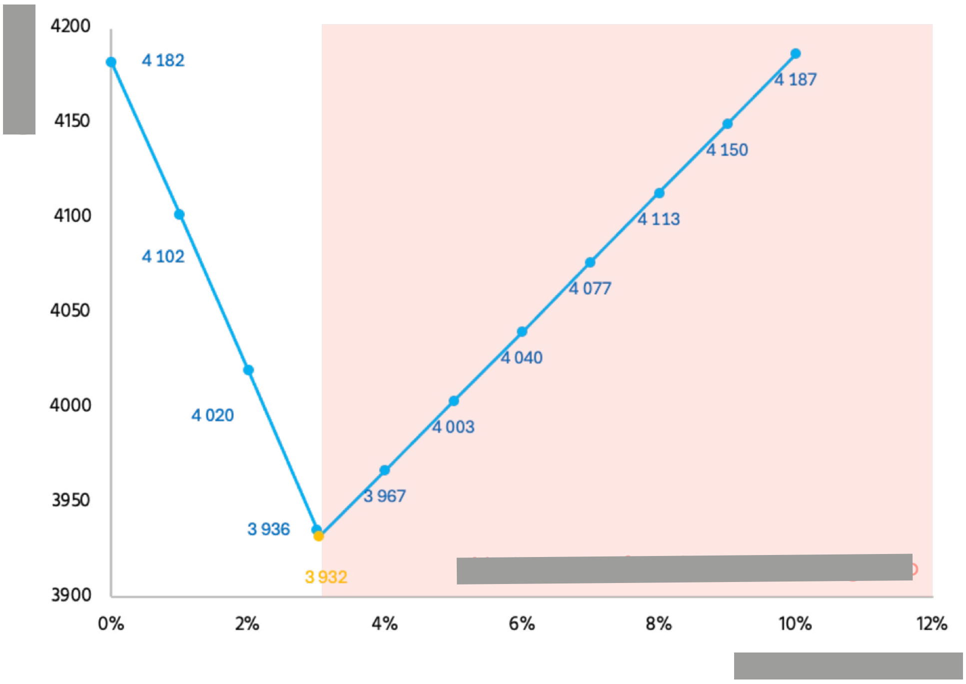

Chart 14: Evolution of the Total operational cost of ship

[redacted]

[redacted]

Situation 1: Both HFO and EU ETS CO2 prices are fixed

[redacted]

Situation 2: Both HFO and UCOME prices are fixed

[redacted]

[redacted]

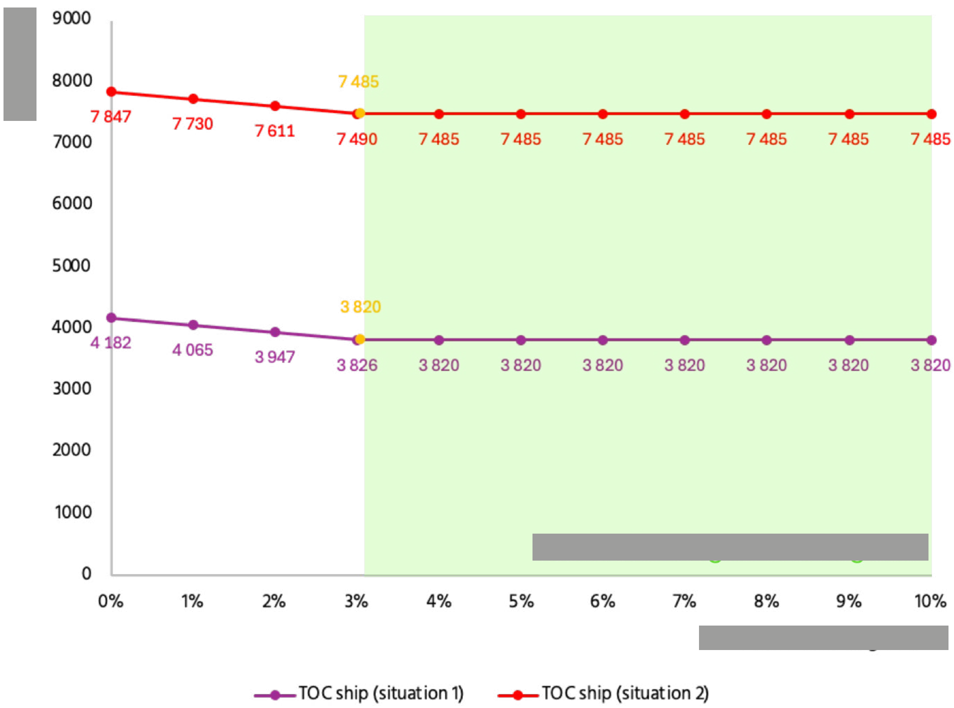

Chart 15: Total operational cost of ship with border prices

[redacted]

ANNEX 2: FuelEU pooling

Article 21 of the FuelEU Maritime regulation states that non-compliant vessels can form a pool with compliant vessels to help them achieve the decarbonization target. In this case, the total compliance balance is calculated for each pool, allowing over-compliant ships to compensate for non-compliant ones.

[redacted]

- [redacted]

[redacted]

- [redacted]

- [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Company	Ship name	Fuel demand in 2023 (t)	Fuel/n mile (kg)	Distance traveled (km)	Ship type	Note*	Itinery	Fuel EU coverage (%)
Wasaline	Aurora Botnia	X XXX	XX.XX	XXX XXX	Ro-pax ship	OC	FIN-SWE	XXX%
COSCO	CSCL Mercury	XX XXX	XXX.XX	XX XXX	Container ship	OC	Asia-EU	XX%
MSC	MSC Fantasia	XX XXX	XXX.XX	XXX XXX	Passenger ship	NC	FR-IT-SP	XXX%
Maersk	Maersk Makutu	X XXX	XXX.XX	XX XXX	Container ship	NC	US-EU	XX%

Table 32: Parameters of the selected vessels according to 2023 MRV database

** OC: over-compliant, NC: non-compliant*

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

[redacted] $nbr = \frac{\text{[redacted]}}{\text{[redacted]}}$

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Table 33: Average CI and compliance balance of each vessel					
Ship name	**Ship type**	**Fuel type**	**CI (gCO2/MJ)**	**CB (gCO2)**	**Note for CB**
Aurora Botnia	[redacted]	[redacted]	XX	X XXX XXX XXX	[redacted]
Aurora Botnia	[redacted]	[redacted]	XX	X XXX XXX XXX	[redacted]
Aurora Botnia	[redacted]	[redacted]	XX	X XXX XXX XXX	[redacted]
Aurora Botnia	[redacted]	[redacted]	XX	X XXX XXX XXX	[redacted]
Aurora Botnia	[redacted]	[redacted]	XX	XX XXX XXX	[redacted]
CSCL Mercury	[redacted]	[redacted]	XX	X XXX XXX XXX	[redacted]
CSCL Mercury	[redacted]	[redacted]	XX	X XXX XXX XXX	[redacted]
CSCL Mercury	[redacted]	[redacted]	XX	X XXX XXX XXX	[redacted]
CSCL Mercury	[redacted]	[redacted]	XX	XX XXX XXX XXX	[redacted]
CSCL Mercury	[redacted]	[redacted]	XX	XX XXX XXX XXX	[redacted]
MSC Fantasia	[redacted]	[redacted]	XX	-X XXX XXX XXX	[redacted]
Maersk Makutu	[redacted]	[redacted]	XX	-XXX XXX XXX	[redacted]

[redacted]

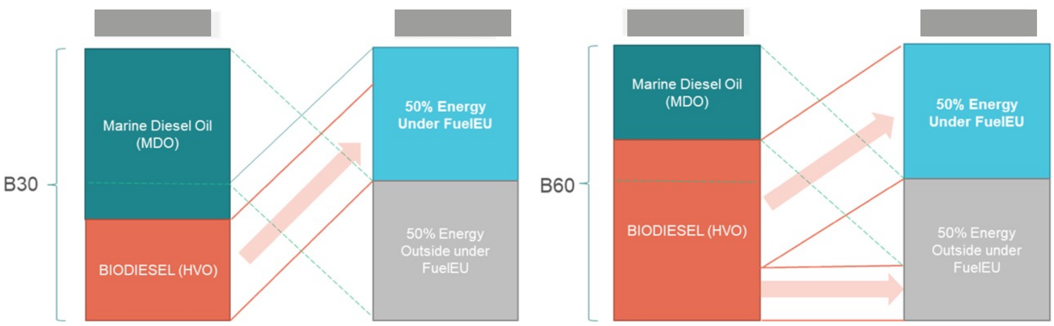

Chart 16: Method of accounting Energy under FuelEU for international voyage ships

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The results showing the maximum number of non-compliant ships that each over-compliant ship can be pooled with are displayed in the following graphs:

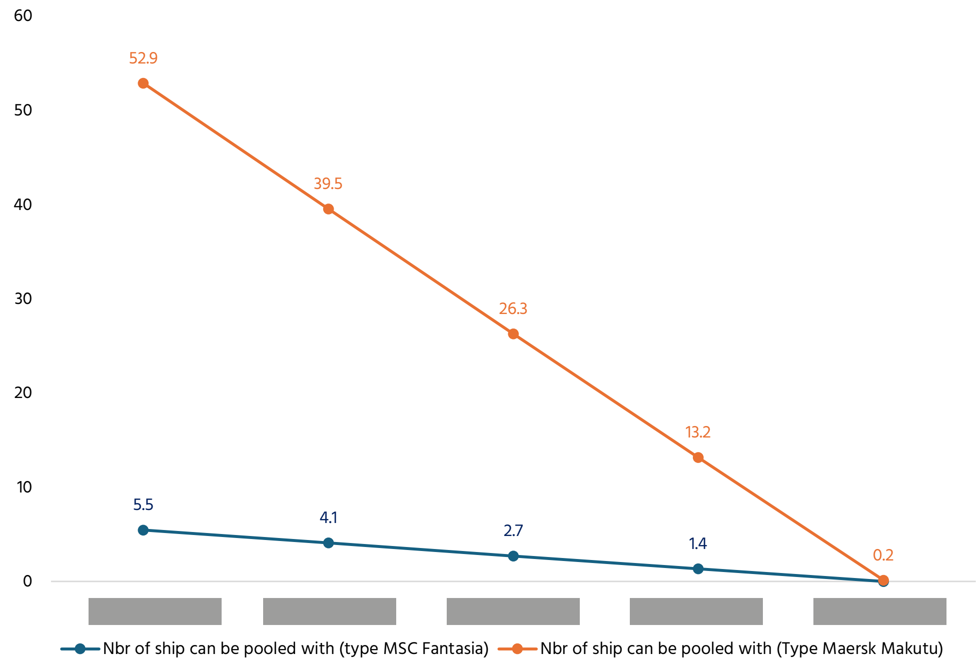

Chart 17: Aurora Botnia pool

[redacted]

ANNEX 2: FuelEU pooling

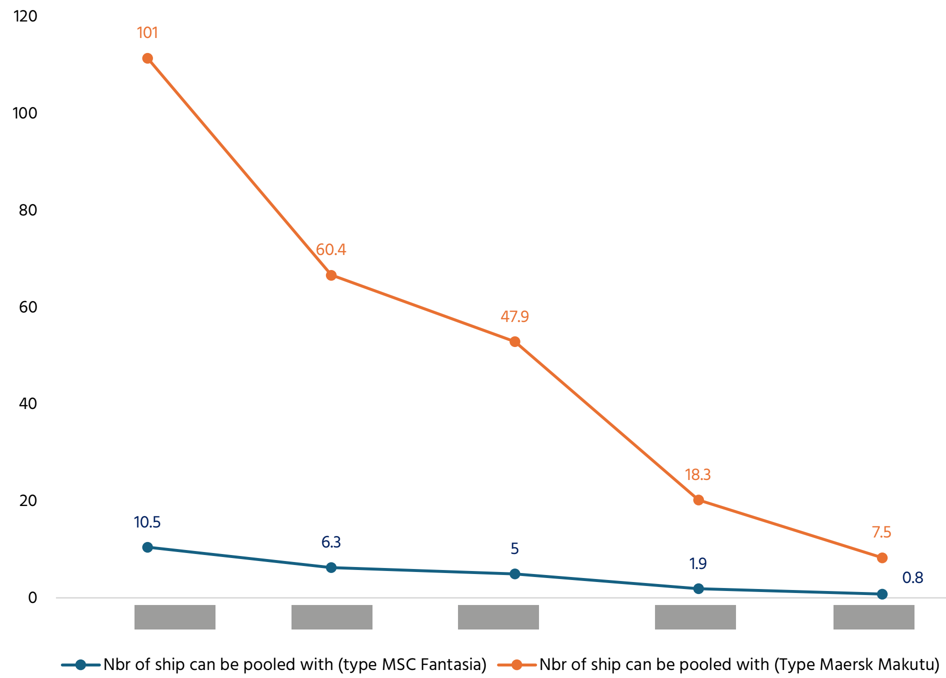

Chart 18: CSCL Mercury pool

[redacted]

Appendix

Tables Index

Chart Index

Contact us

Square Commodities SARL
admin@squarecommodities.com

Editor in Chief
Olivier Pellegrinelli
olivier@squarecommodities.com
Tel: +41 79 676 88 87

Visit us on
www.squarecommodities.com

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