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# Potential environmental effects of Fuel EU Maritime focusing on Swedish related shipping

Greenhouse gases and selected air and water  
pollutants

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## Summary

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For the shipping sector to phase out its greenhouse gas (GHG) emissions by 2050, low-carbon fuels and ships must be scaled up significantly in the coming years. To support this development, the EU has introduced policy instruments such as FuelEU Maritime, which aim to gradually reduce the GHG intensity of maritime fuels. The EU has also expanded its emissions trading scheme (EU ETS) to drive the transition in shipping.

In this report, we analyse the environmental implications of FuelEU Maritime for Swedish-related shipping, focusing on GHG emissions, selected air pollutants, and water pollution associated with scrubber use. Emissions of carbon dioxide (CO<sub>2</sub>) and other pollutants on annual basis from 2024 to 2050 in a European perspective are estimated, using a calculation model, following constraints illustrating the FuelEU Maritime regulation. It is assumed that each ship category needs to follow the reduction rate in the regulation. Emissions for Swedish related shipping are presented for scenarios representing (i) the introduction of different fuel mixes and (ii) the introduction of one main fuel alternative i.e., single fuel pathways (all scenarios are set to fulfil the FuelEU Maritime). The model draws primarily on the 2023 EU Monitoring, Reporting and Verification (MRV) dataset, covering voyages within the European economic area (EEA).

Results show that while GHG emissions converge across scenarios due to the regulation's design, other pollutants may differ substantially based on the fuel and fuel mixes used to comply with the FuelEU Maritime requirements. The use of fuels with very low GHG intensity may lead to higher emissions of sulfur oxides (SO<sub>x</sub>) and particulate matter (PM) than fuels with higher GHG intensity at the fleet level. This, as fewer vessels need to transition from conventional fuels to meet the requirements in the former case. Scenarios using alternative fuels with higher GHG-intensity (which require a faster fleet turnover), result in lower emissions of several air pollutants. LNG deployment is found to reduce emissions of nitrogen oxides, SO<sub>x</sub> and PM, but its long-term climate performance is highly sensitive to methane slip assumptions. Scrubber water discharge is primarily influenced by regulatory assumptions on scrubber use rather than fuel choice.

## Sammanfattning

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För att sjöfartssektorn ska kunna fasa ut sina växthusgasutsläpp till 2050 krävs en betydande uppskalning av fartyg och bränslen med låga koldioxid(CO<sub>2</sub>)-utsläpp under de kommande åren. För att stödja denna utveckling har EU infört styrmedel såsom FuelEU Maritime, som syftar till att successivt minska växthusgasintensiteten i marina bränslen. EU har även utvidgat systemet för handel med utsläppsrätter (EU ETS) för att driva omställningen inom sjöfarten.

I denna rapport analyseras miljöeffekterna av FuelEU Maritime för svenskrelaterad sjöfart, med fokus på växthusgasutsläpp, utvalda luftföroreningar samt vattenföroreningar kopplade till användning av skrubbrar. Årliga utsläpp av CO<sub>2</sub> och andra föroreningar från 2024 till 2050 uppskattas i ett europeiskt perspektiv med hjälp av en beräkningsmodell som inkluderar antaganden som speglar regelverket inom FuelEU Maritime. Det antas att samtliga fartygskategorier följer den reduktionstakt som anges i regelverket.

Utsläpp från svenskrelaterad sjöfart redovisas för scenarier med olika bränslemixar samt scenarier där ett enskilt bränslealternativ introduceras (samtliga scenarier uppfyller kraven i FuelEU Maritime). Modellen baseras huvudsakligen på EUs Monitoring, Reporting and Verification (MRV)-databas för 2023, som omfattar resor inom europeiska ekonomiska samarbetsområdet (EES).

Resultaten visar att växthusgasutsläppen konvergerar i scenarierna till följd av regelverkets utformning, medan utsläppen av andra föroreningar kan skilja sig avsevärt beroende på vilka bränslemixar som används för att uppfylla kraven. Bränslen med mycket låg växthusgasintensitet kan på flottnivå leda till högre utsläpp av svaveloxider (SO<sub>x</sub>) och partiklar. Detta eftersom färre fartyg behöver ställa om från konventionella bränslen för att uppfylla kraven jämfört med om bränslen med högre växthusgasintensitet hade använts. Scenarier med alternativa bränslen med högre växthusgasintensitet innebär ett snabbare utbyte av flottan, vilket resulterar i lägre utsläpp av flera luftföroreningar.

Användning av LNG bedöms minska utsläppen av kväveoxider (NO<sub>x</sub>), SO<sub>x</sub> och partiklar, men dess långsiktiga klimatprestanda är starkt beroende av antaganden om metanslip. Utsläpp till vatten från skrubbrar påverkas främst av regulatoriska antaganden kring användningen av skrubbrar, snarare än bränsleval.

## Table of contents

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<b>Summary</b>	<b>3</b>
<b>Sammanfattning</b>	<b>4</b>
<b>1 Introduction</b>	<b>7</b>
1.1 Aim and context	7
<b>2 The FEMAR Model</b>	<b>10</b>
2.1 MRV data	11
2.1.1 Emissions from ships below 5000 GT	12
2.1.2 Ship types	13
2.2 Ship replacement and fuel consumption mechanisms	14
2.2.1 FuelEU Maritime mechanisms relevant for the model constraints	14
2.2.2 Modelling fleet replacement	16
2.2.3 Fuel consumption development	17
2.2.4 Allocation of emissions for Swedish shipping	18
2.3 Modelling scenarios	19
2.4 Emission factors	22
2.4.1 GHG emission factors	22
2.4.2 Estimation of other pollutants	23
2.5 Sensitivity assessments	28
2.5.1 Methane slip assumption	28
2.5.2 GHG emissions factors and NO <sub>x</sub> emissions assumptions	29
2.5.3 Alternative fuel mix scenario	30
<b>3 Results</b>	<b>32</b>
3.1 Single fuel scenarios	32
3.2 Fuel mix scenarios	37
3.3 The role of retrofitting	44
3.4 Sensitivity analysis	45
3.4.1 Scrubber use scenarios	45
3.4.2 Influence of alternative emission factors for NO <sub>x</sub> and GHGs	47

**POTENTIAL ENVIRONMENTAL EFFECTS OF FUEL EU MARITIME FOCUSING**

Greenhouse gases and selected air and water pollutants  
June 2026

3.4.3	Influence of methane slip assumption	51
3.4.4	Alternative fuel mix scenario	53
<b>4</b>	<b>Discussion and conclusions</b>	<b>55</b>
<b>5</b>	<b>Reference list</b>	<b>60</b>
	<b>Appendix</b>	<b>64</b>

# 1 Introduction

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Reducing greenhouse gas (GHG) emissions from shipping is necessary to meet the EU's climate targets for 2050. For the shipping sector to phase out its GHG emissions by 2050, low-carbon fuels and ships must be scaled up significantly in the coming years. Maritime transport remains dependent on fossil fuels and contributes to both climate change and other environmental impacts, including air pollution and effects on the marine environment. At the same time, previous research has shown that measures targeting climate impacts may have unintended consequences for other environmental indicators, highlighting the need for integrated assessments (Fridell et al., 2020; Hansson et al., 2022).

The EU has introduced policy instruments such as the FuelEU Maritime regulation, which aims to gradually reduce the Well-To-Wake (WTW) GHG intensity of maritime fuels (Regulation (EU) 2023/1805). The EU has also expanded its emissions trading scheme (EU ETS) to drive the transition in shipping (Directive 2003/87/EC, 2003). The idea behind these instruments is to create economic incentives to reduce GHG emissions.

The FuelEU Maritime regulation can be met through a range of fuels and strategies. While different mitigation strategies may meet the same GHG intensity requirements, they vary in their levels of emissions of other pollutants, such as nitrogen oxides (NO<sub>x</sub>), sulfur oxides (SO<sub>x</sub>), and particulate matter (PM), as well as differences in scrubber-related water pollution (Fridell et al., 2020; Hansson et al., 2022).

## 1.1 Aim and context

The aim of this study is to assess the potential environmental effects, in terms of GHGs, selected air pollutants, and water pollution linked to the use of scrubbers, of Fuel EU Maritime, focusing on Swedish related shipping. The objective is to provide a transparent and consistent model for estimating emissions of GHGs, selected air pollutants, and scrubber water discharges, with a particular focus on Swedish-related shipping.

This report presents the design and application of the so-called FEMAR model, developed to analyse the environmental implications of FuelEU Maritime for

Swedish-related shipping, which is defined as 100% of carbon dioxide (CO<sub>2</sub>) emissions from voyages between Swedish ports, and 50% of CO<sub>2</sub> emissions from voyages where one port is outside Sweden (see *Section 2.2.4* for more details). The report describes the model structure, key assumptions, and scenarios, and illustrates how the model can be used to assess the environmental effects of different compliance pathways. The FEMAR model represents the development of the shipping fleet under regulatory constraints, combining empirical data from the EU Monitoring, Reporting and Verification (MRV) system with assumptions on fleet turnover, fuel use, and compliance behaviour. By linking policy design to fleet dynamics and emission outcomes, the model provides a consistent framework for assessing both GHG emissions and a broader set of environmental impacts across different compliance pathways.

The FuelEU Maritime regulation is based on a required stepwise reduction in GHG intensity for ships at or above 5000 gross tonnage (GT) (see Figure 2), where non-compliance will incur substantial fees. The general expectation is a shift away from conventional fuels to renewable alternatives in the shipping sector (Transport & Environment, 2023).

Transport & Environment (2023) modelled how the fleet would change over time where operators minimized their cost while complying with the FuelEU Maritime regulation. Pathways then differ mainly depending on cost assumptions of fuels, technologies etc. Ammonia was projected to become the dominant fuel in most of the scenarios of that study due to its low price. However, LNG was deemed to become the primary option for compliance throughout the 2030s.

DNV (2024) similarly assesses different compliance strategies, but with the focus on a case study of a single ship instead of studying the whole fleet. DNV (2024) determined that switching to LNG was the cheapest compliance option for the 80 000 deadweight tonnage (dwt) bulk case study vessel but other options were not much costlier. However, simply paying the penalty was deemed to be the most expensive option. LNG is however not seen as a viable long-term option for defossilization.

On a global scale, discussions are ongoing within IMO for the implementation of a Net-Zero Framework (NZF) with similarities to FuelEU Maritime. How these may interact in the future is not yet known and the design of the NZF is under discussion. Differences between the NZF proposed in 2025 and FuelEU Maritime/EU ETS have been assessed by DNV (2025a).

Raucci et al. (2023) performed fuel forecasts in response to the NZF using two broad scenarios; one where hydrogen-based fuels dominate and one where bio-based fuels dominate. Ammonia is found to be the most common fuel based on hydrogen, while biodiesel and biomethane/LBG are projected to be the primary bio-based options. It is important to keep in mind that ammonia and hydrogen, for example, have yet to overcome technical and safety concerns before reaching large-scale deployment. While “winners” can always be determined based on input assumptions, the actual future fuel market remains unpredictable.

Pollutants other than GHGs depend on the choice of fuel, and the environment can be influenced in different ways. For example, ammonia leakage can lead to decreased air quality and eutrophication (Esquivel-Elizondo, 2025). Renewable fuels also differ in how much they will decrease emissions of NO<sub>x</sub>, SO<sub>2</sub>, PM etc. compared to fossil fuels, and thereby also have different effects on human health. This was for example demonstrated by Barregard et al. (2019), who estimated that more than 1000 yearly premature deaths from Baltic shipping emissions were avoided in 2016 after new sulphur regulations came into place. While renewable fuels are universally better for the environment than fossil fuels, the perspective of other negative effects apart from global warming risk being lost in frameworks focusing solely on GHG emissions.

## 2 The FEMAR Model

The model used in this report, called the FEMAR model, is based on a model created for the so-called EMERGE project (Fridell et al., 2022). In this work, it has been further developed and updated to suit an analysis of the FuelEU Maritime regulation. The model updates the shipping fleet each year based on the constraint that each ship type (bulk, container etc.) should comply with the FuelEU Maritime reduction requirement on a fleet-wide scope. Figure 1 gives an overall flowchart of the FEMAR model. The details are described in the following sections.

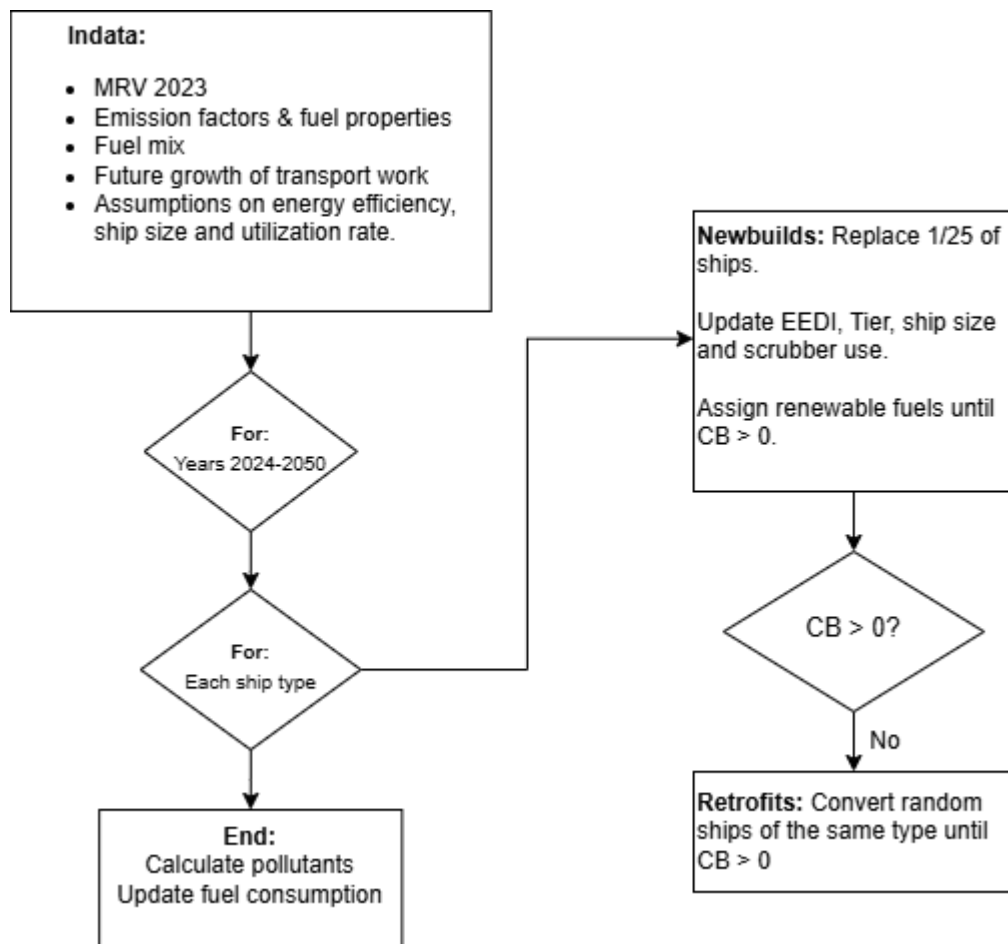


Figure 1: Overall flowchart description of the FEMAR model. MRV refers to the Monitoring, Reporting and Verification database. CB means “compliance balance” (see explanation in Section 2.2.1), EEDI represent Energy Efficiency Design Index and Tier refers to level for NOx emissions standards for ship engines.

## 2.1 MRV data

As a basis, the model uses the 2023 dataset from the EU MRV database (THETIS-MRV, 2023). For example, this dataset contains information on CO<sub>2</sub> emissions (Tank-to-Wake) and fuel consumption for ships which have called a port in the European economic area (EEA) at least once that year. Voyages between the EEA and UK ports are also included. In cases where a ship travels outside the EEA, e.g., from Sweden to USA, the EU MRV database covers the total CO<sub>2</sub> emissions caused by that journey. To limit the scope to “European emissions”, only 50% of the emissions for the voyages where one port is outside the EEA is considered in the FEMAR model. However, for voyages between EEA ports, 100% of the emissions are included.

Ships below 5000 GT are not included in the MRV dataset used. General cargo ships between 400 and 5000 GT as well as offshore ships above 400 GT are to be included from 2025 onward, but this data was not available at the time of writing.

The MRV dataset used contains 12 369 vessels for 2023 (12 353 after removing ship types *Tug*, *Yacht*, *Ferry – pax only* and *Other*). The fuel consumption for each vessel reported to MRV is used as basis for the emission calculation. However, CO<sub>2</sub>-emissions reported in MRV are not used. Instead, emission factors taken from FuelEU Maritime are applied to the fuel consumption to avoid reporting inaccuracies and to make sure the calculation methodology is aligned with FuelEU Maritime. This further allows the CO<sub>2</sub>-emissions for each vessel to be calculated on a WTW basis which is required for the analysis<sup>1</sup>.

Because the MRV database does not include the fuel type used for each ship, this is estimated by dividing the reported total CO<sub>2</sub> emissions for each vessel in MRV with its total fuel consumption from MRV, yielding a “carbon ratio” which can be used to deduce which fuel mix the ship runs on (as different fuels have different CO<sub>2</sub> emissions per amount of fuel used). The carbon ratios used are shown in Table 1.

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<sup>1</sup> Well-To-Wake emissions were not included in MRV until January 1, 2025.

Table 1: Carbon ratios used for determining fuel type in MRV.

Fuel mix	Carbon ratio	Comment
100% MGO	>3.206	
MGO/LFO	3.151 - 3.206	
MGO/HFO	3.114 - 3.151	
MGO/LNG	2.75 - 3.206	Also marked as using LNG in Sea-web
100% LNG	2.5 - 2.75	
MGO/MeOH	1.375 - 3.206	Also marked as using MeOH in Sea-web

Based on the reported fuel consumption and the identified fuel type of each vessel, GHG emissions including also methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O), are calculated as CO<sub>2</sub>-equivalents (CO<sub>2</sub>e)<sup>2</sup> using the GWP factors 1 for CO<sub>2</sub>, 28 for CH<sub>4</sub> and 265 for N<sub>2</sub>O, for a 100 year time span, taken from Regulation (EU) 2023/1805.

### 2.1.1 Emissions from ships below 5000 GT

Ships below 5000 GT are not included in the MRV 2023 dataset and are not included in the model. General cargo ships below 5000 GT and above 400 GT, as well as offshore vessels above 400 GT are included in MRV starting from 1 January 2025. Ships below 5000 GT are not covered by FuelEU Maritime. However, it is still interesting to understand the size of the emissions from these vessels. A 2022 dataset from IVL also contains port calls from ships below 5000 GT, as well as some ships above 5000 GT that do not appear in MRV. For these ships, default emission factors have been used. Hansson et al. (2022) estimated that the inclusion of ships below 5000 GT would increase CO<sub>2</sub> emissions covered in MRV by 7% based on data for 2019. However, ships below 5000 GT are estimated to make up about 21% of Swedish shipping related CO<sub>2</sub> emission according to the IVL dataset (see Section 2.2.4 for the definition of Swedish emissions).

General cargo ships especially stand out, being the only ship type where ships below 5000 GT cause most of the CO<sub>2</sub> emissions for that ship type (64% in this case). Even if the emission factors for ships below 5000 GT ships in the IVL dataset were to be overestimated, a significant share of the emissions seem to come from ships below 5000 GT.

Like the EU MRV, ships that do not make official port calls are not covered by the IVLs dataset. This includes for example bunker ships, tugs, public transport ferries and offshore vessels.

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<sup>2</sup> CO<sub>2</sub>-equivalents is a method of reporting emissions where the mass of other emitted GHGs is converted to the equivalent mass of emitted CO<sub>2</sub> such that they have the same global warming potential (GWP), i.e., cause the same amount of global warming over a specific time span.

Performing the analysis in this report after the inclusion of general cargo <5000 GT and offshore vessels >400 GT in EU MRV, would thus result in higher emissions than estimated in this report. This is however outside the scope of this study.

## 2.1.2 Ship types

How ship types used in the MRV database are mapped into the ship type categories used within the FEMAR model is described in Table 2. The FEMAR ship type categories are taken from Parsmo (2026)<sup>3</sup>. Ships classed as “Other” in the FEMAR ship types list are not included in the calculation. The reason is the very low number of vessels in these categories (in total 16) and they are therefore not included as an own category.

Table 2: Conversion from ship types in MRV to ship types in the FEMAR model.

MRV ship types	FEMAR ship types
Bulk carrier	Bulk
Chemical tanker	Product tanker
Container ship	Container ship
Cruise DE	Cruise ship
Cruise DM	Cruise ship
Cruise GE	Cruise ship
General cargo	General cargo
LG tanker	LG tanker
Oil tanker	Oil tanker
Reefer	Reefer
RoRo	RoRo Cargo
RoRo/Ferry	RoPax
Vehicle carrier	Vehicle carrier
Yacht	Other
Sailing Vessel	Other
Tug	Other
Other	Other
Offshore Vessel	Other
Ferry - pax only	Other

<sup>3</sup> Ships types in “Alternative\_ship\_type” from Supplementary Material B.

## 2.2 Ship replacement and fuel consumption mechanisms

Fleet development in the FEMAR model is driven by ship replacement, retrofits, and changes in fuel consumption over time. These processes are modelled in relation to the FuelEU Maritime requirements, which determine how the fleet composition and fuel use must evolve to meet the target GHG intensity. The resulting fleet and fuel demand form the basis for the emission calculations.

### 2.2.1 FuelEU Maritime mechanisms relevant for the model constraints

In the FuelEU Maritime, the reduction intensity target for a given year is acquired by applying the required reduction factor (Figure 2) to the base GHG intensity of 91.6 gCO<sub>2</sub>e/MJ (specified in the regulation).

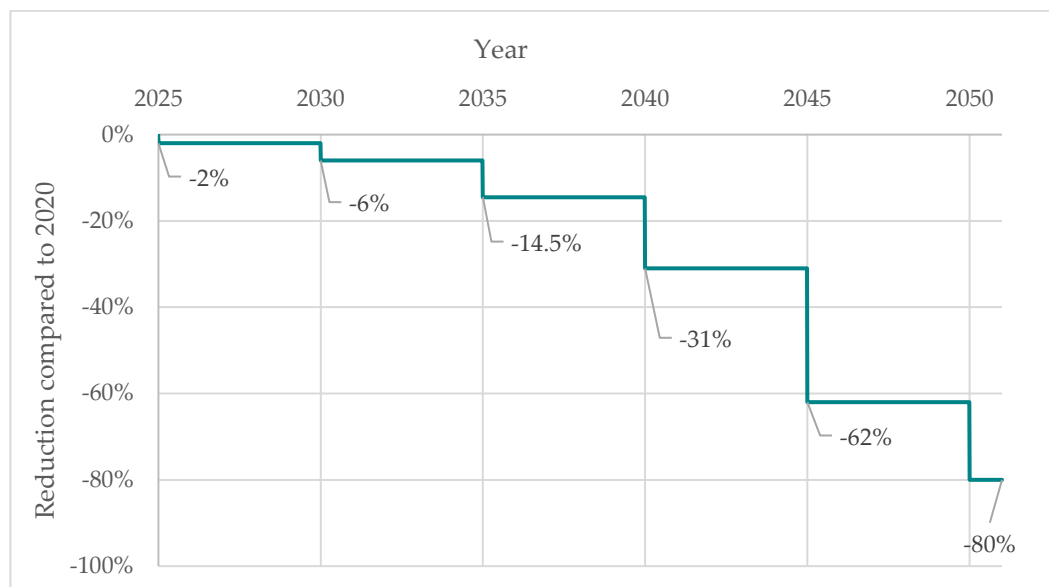


Figure 2: FuelEU Maritime reduction factor used for calculating yearly target GHG intensity, and in turn the compliance balance.

The ship replacement mechanism in the FEMAR model depends on the so-called compliance balance (CB) in the FuelEU Maritime regulation. CB is a mechanism that shows how much a vessel over- or underperforms in relation to the yearly target intensity. It functions by multiplying the difference between the target GHG intensity (GHGIE<sub>target</sub>) and the actual fuel GHG intensity (GHGIE<sub>actual</sub>) of a vessel

with its total energy consumption. The following equation is used for calculating compliance balance, taken from Regulation (EU) 2023/1805.

$$CB [gCO_2e] = (GHGIE_{target} - GHGIE_{actual}) \times (\sum_i^{n_{fuel}} M_i \times LCV_i + \sum_k^c E_k)$$

where  $M_i$  and  $LCV_i$  are the mass of fuel consumed and lower calorific value of fuel  $i$ ,  $n_{fuel}$  is the number of different fuels,  $E_k$  is the supplied electric energy from each connection point  $k$ , and  $c$  is the number of connection points and considers potential use of electricity. The MRV data provides fuel consumption ( $M_i$ ) for each ship, while LCV values are taken from FuelEU Maritime (Regulation (EU) 2023/1805).  $E_k$  is estimated from the MRV data.

Ships that need to be replaced for the model to fulfil the FuelEU Maritime requirements are denoted as *Newbuilds*. The model allocates renewable fuels to *Newbuilds* until the total CB for all ships of the current ship type (e.g. Container ship) is above 0 and lets the remaining ships keep the conventional fuel they already use. This constraint means that the total fleet fulfils the reduction goals of FuelEU Maritime, shown in Figure 2. Also, this way of counting includes an explicit assumption of *Pooling* within each segment, which is a mechanism in FuelEU Maritime where several ships can create a pool where they do not need to pay penalties if their combined compliance balance is above 0.

To summarize, a key assumption in the model is that the whole fleet, via pooling, will reduce its emissions just enough to avoid paying penalties. In reality, actors can underperform and “pay to pollute” to the policy system. As this is costly, it is assumed to not happen in the model which assumes pooling instead. For example, in a case study by DNV (2025b), the direct pay-to-pollute approach was deemed to be the least economical option for an 80 000 deadweight tonnage vessel. Thus, we assume that the included ships, per segment, i.e., via pooling comply with the FuelEU Maritime regulation.

There is also a reward factor within FuelEU Maritime for RFNBOs (Renewable Fuels of Non-Biological Origin) valid until 2034. What this means is that RFNBOs have their calculated  $GHGIE_{actual}$  levels halved every year before 2034 to incentivize the uptake of these fuels. Within the FEMAR model, this applies to e-ammonia, e-methanol and hydrogen and thus represents an additional modelled regulatory mechanism.

## 2.2.2 Modelling fleet replacement

The total amount of ships in the fleet is fixed at the original value. Increases in transport work and the number of ships over time is instead modelled by increasing ships' fuel consumption to reach equivalent emission levels caused by such developments (further explained in *Section 2.2.3*).

An average lifetime of 25 years is assumed for all ships, same as in the 4<sup>th</sup> IMO GHG Study (2020). In the model this is translated to 1/25 of the oldest ships within each ship type being replaced each year. These ships are assumed to use alternative fuels until the total compliance balance for each ship type is above zero, remaining ships are replaced by ships using conventional fuels.

For the individual ship, being replaced this means that:

1. The newbuilt ship may switch to renewable fuel.
2. The fuel consumption changes based on updates in the EEDI regulation for energy efficiency, ship size, transport work and utilization rate (see *Section 2.2.3*).
3. Tier III (as defined by IMO MARPOL Annex VI) is assigned, which affects NO<sub>x</sub> emissions.

*Example:*

There are 4000 bulk ships, and 1/25 are replaced each year (160 ships). The model gives 50 of them a renewable fuel before reaching  $CB > 0$  for all ship types for that specific year, meaning that 110 of the newbuilds will remain conventional that year.

Which renewable fuel that is given to a specific ship is based on the scenarios used and probability (Tables 4-7 in *Section 2.3*) except for in the case a single fuel is assumed then that fuel is applied for all vessels replaced with a vessel using renewable fuels. Ships that are assigned a renewable fuel are also assumed to use MGO as pilot fuel (5% of total fuel consumption on an energy basis). For ships that are either not replaced or are replaced but remain conventional, the old fuel mix based on MRV data is kept.

If replacing 1/25 of the vessels for a certain ship type is not enough to reach  $CB > 0$ , the model will change fuels for random ships within that ship type despite not being 25 years of age. These are denoted as *Retrofits*, and the model will retrofit ships within each ship type until  $CB > 0$  or there are no more conventional ships to retrofit.

With replacement and retrofits done across all ship types, this ensures that the total compliance balance for all vessels in the fleet is above 0 every year. This means that the CO<sub>2e</sub> emission results in the model will, as expected, always closely follow the

FuelEU Maritime reduction curve. Emissions of other pollutants will, however, differ depending on what types of renewable fuels are used.

### 2.2.3 Fuel consumption development

At the end of each year, the fuel consumption (FC) for all ships in the fleet is updated. The fuel consumption depends on changes in transport work (TRW), energy efficiency design index (EEDI) regulations, ship size increases and a yearly utilization rate increase.

$$FC_{Year+1} = FC_{Year} * (1 + \Delta TRW) * (1 - \Delta EEDI) * (1 - \Delta ship\ size) / (1 + \Delta utilization\ rate)$$

These are applied yearly, apart from EEDI which is only updated when a ship is replaced as this regulation only covers newbuilt ships. Changes in transport work are based on the low-growth and high-growth scenarios from DNV (2020), in which fuel consumption is considered to change proportionally. This simulates the effect that increased transport work has on emissions while avoiding, for example, the complexity of adding more ships to the modelled fleet.

Ship sizes are assumed to change according to DNV (2020), with bulk ships growing by 10%, container by 30%, and gas tankers by 40% until 2050.  $\Delta ship\ size$  in the equation is referring to a difference in fuel consumption rather than physical ship size. An increase in ship sizes on a fleet-wide scale means that a fixed amount of cargo can be transported with less fuel. Therefore, increases in ship size actually lead to less fuel consumption from a calculation point of view.  $\Delta ship\ size$  is estimated to be  $\approx 0.7\%$  for container ships and LG tankers, and 0 for bulk and other ship types.

Finally, a higher utilization rate also leads to lower fuel consumption. This is because filling ships more efficiently leads to a shorter distance having to be travelled to transport the same amount of cargo. A 25% increase in utilization is assumed from 2020 to 2050, resulting in a yearly increase utilization rate modelled as:

$$\Delta utilization\ rate = e^{\frac{\ln(1.25)}{2050-2020}} - 1$$

## 2.2.4 Allocation of emissions for Swedish shipping

The allocation of emissions relevant for the Swedish scope is based on an IVL dataset containing all voyages to, from, and between Swedish ports in 2022 (Parsmo, 2025). This dataset is based on Swedish port call statistics but uses the same emission factors as in MRV by matching ships via their IMO number. Only ships >5000 GT covered by MRV are included.

Voyages in MRV where one port is outside the EEA originally include 100% of the emissions from that route. However, to make the comparison between Sweden and Europe possible, the emissions are instead allocated as follows.

### *EU emissions:*

100% of CO<sub>2</sub> emissions from voyages between ports within the EEA

50% of CO<sub>2</sub> emissions from voyages where one port is outside the EEA

### *Swedish emissions:*

100% of CO<sub>2</sub> emissions from voyages between Swedish ports

50% of CO<sub>2</sub> emissions from voyages where one port is outside Sweden (inside or outside the EEA)

By comparing CO<sub>2</sub> emissions from Swedish voyages to the total MRV emissions within Europe, the share of Swedish emissions can be defined. This is, however, done for each ship type via the shares presented in Table 3. For example, by dividing all Swedish emissions from bulk carriers with the total amount of emissions from bulk carriers in EU MRV, the Swedish share of emissions within that ship category is obtained. The reason for this comparison is to indicate which ship types that dominate Swedish shipping emissions in comparison to EU shipping.

Furthermore, because TTW CO<sub>2</sub> emissions are directly linked to the amount of fuel burned and because the 2022 MRV data is dominated by fossil fuels with similar TTW emission factors, it is fair to use the TTW CO<sub>2</sub> shares as proxies for fuel consumption. This can then be used for allocating other pollutants to Swedish related shipping as well. Emission Control Areas (ECAs) also need to be considered, however, which is discussed in each pollutant's subchapter under Section 2.4.2.

It can be noted that for Swedish related shipping, the share of emissions from general cargo, RoPax and reefer vessels are high, while the share for container ships is relatively low. In the model these shares (based on data for 2022), are assumed to remain constant for the years included.

Table 3: Swedish shares of direct CO<sub>2</sub> emission for each ship type in the model, acquired by dividing total Swedish emissions from a certain ship type with the total EU emissions of the same ship type. Used as a proxy for fuel consumption when allocating emissions of other pollutants to Sweden.

Ship type	Swedish share of EU TTW CO <sub>2</sub> emissions (fuel consumption proxy)
Bulk	2.10%
Container	0.68%
Cruise ship	1.75%
General cargo	11.83%
LG tanker	2.90%
Oil tanker	3.03%
Product tanker	5.83%
Reefer	8.85%
RoPax	9.99%
RoRo cargo	6.73%
Vehicle carrier	3.33%
All ships	4.02%

## 2.3 Modelling scenarios

Eleven different scenarios are used alongside a business as usual (BAU) scenario. Table 4 presents an overview of the scenarios. The scenarios stipulate which fuels are prioritized in the set of newbuilds in the model each year. In the BAU scenario the fuel mix from the 2023 MRV dataset remains constant over time and no further renewable fuels are introduced. Ships are replaced when reaching 25 years as in the other scenarios, and their EEDI, size, utilization rate and engine Tier are updated. No ships are retrofitted, and no changes are made to comply with the FuelEU Maritime regulation. As the ship traffic increase over time this means that the emissions in this scenario also increase.

POTENTIAL ENVIRONMENTAL EFFECTS OF FUEL EU MARITIME FOCUSING

Greenhouse gases and selected air and water pollutants  
June 2026

Table 4: Overview of assessed scenarios. E- stands for electro- and refers to electrofuels produced using hydrogen (produced via electricity) and carbon dioxide or nitrogen.

Scenario	Type
BAU	Reference
Mixed	Fuel mix
RFNBO (Renewable fuels of non-biological origin)	Fuel mix
Biobased	Fuel mix
Gas	Fuel mix
Biomethanol	Single fuel
E-Ammonia	Single fuel
E-Hydrogen	Single fuel
E-Methanol	Single fuel
Electricity	Single fuel
Biodiesel	Single fuel
LBG	Single fuel

There are seven single-fuel scenarios examining one main fuel at a time, and four scenarios where a mix of various fuels are used. The latter are based on scenarios developed in Storm et al (2026). The single-fuel scenarios give an approximate span of the maximum emission reductions and relationships for specific technologies while the fuel mix scenarios provide a span for a mix of fuels.

The fuel mix scenarios provide fuel mixes for 2025, 2030 and 2050. Fuel shares have been interpolated for the years in-between and included in the FEMAR model. The scenarios serve to illustrate different possibilities of marine fuel mixes which all fulfil the FuelEU Maritime reduction goals. All fuel mix scenarios except *Mixed* represent cases where certain types of fuels are assumed to be mainly introduced. The *Mixed* scenario is instead a mix of the other fuel mix scenarios with substantial shares of several different renewable fuels.

In the gas scenario, which is introduced to analyse the consequences of a substantial use of gas, all newbuilt conventional ships (i.e. ships that are not required to use renewable fuels in the model since the FuelEU maritime target was already met) are assigned LNG in the model, while in the other scenarios they are assumed to use the same fossil fuel as before. As LNG combustion results in lower CO<sub>2</sub> emissions than combustion of fuel oil, this scenario sometimes over-complies the FuelEU Maritime emission reduction targets (other scenarios just reach the required levels).

Tables 5-8 shows the shares the model uses for assigning renewable fuels to newbuilt (and retrofitted) ships. The shares are based on the estimated annual shares for renewable marine fuels in Storm et al. (2026) and the share assumed for 2025 is the same in all scenarios. To clarify, 60% LBG in 2025 means that 60% of newbuilt ships set to use a renewable fuel were assigned LBG in the model for that year. Because the model renews the fleet yearly, shares for in-between years have been linearly interpolated.

Table 5: Shares for assigning renewable fuels to newbuild and retrofits in 2025, 2030 and 2050 for the Mixed scenario.

Renewable fuel input shares (Mixed scenario)			
Fuel	2025	2030	2050
LBG	60%	27%	23%
Biodiesel	40%	36%	6%
Electricity	0%	9%	2%
Hydrogen	0%	0%	2%
e-Methanol	0%	14%	21%
Biometanol	0%	14%	21%
e-Ammonia	0%	0%	25%

Table 6: Shares for assigning renewable fuels to newbuild and retrofits for the RFNBO scenario.

Renewable fuel input shares (RFNBO scenario)			
Fuel	2025	2030	2050
LBG	60%	25%	5%
Biodiesel	40%	39%	5%
Electricity	0%	8%	2%
Hydrogen	0%	1%	5%
e-Methanol	0%	26%	42%
Biometanol	0%	0%	0%
e-Ammonia	0%	1%	42%

Table 7: Shares for assigning renewable fuels to newbuild and retrofits in for the Biobased scenario.

Renewable fuel input shares (Biobased scenario)			
Fuel	2025	2030	2050
LBG	60%	25%	38%
Biodiesel	40%	40%	7%
Electricity	0%	8%	2%
Hydrogen	0%	0%	0%
e-Methanol	0%	0%	0%
Biometanol	0%	27%	53%
e-Ammonia	0%	0%	0%

Table 8: Shares for assigning renewable fuels to newbuild and retrofits for the Gas scenario.

Renewable fuel input shares (Gas scenario)			
Fuel	2025	2030	2050
LBG	60%	46%	97%
Biodiesel	40%	15%	2%
Electricity	0%	39%	1%
Hydrogen	0%	0%	0%
e-Methanol	0%	0%	0%
Biometanol	0%	0%	0%
e-Ammonia	0%	0%	0%

## 2.4 Emission factors

Emission factors are used to calculate emissions of GHGs, air pollutants, and scrubber-related discharges based on fuel consumption in the model. This section describes the sources, assumptions, and values applied for different fuels and pollutants, and how they are used to estimate emissions across scenarios.

### 2.4.1 GHG emission factors

Emission factors (expressed as CO<sub>2</sub>-equivalents) are mainly based on FuelEU Maritime (Regulation (EU) 2023/1805), Table 9. In case the WTT value depends on several factors linked to its production, or WTT data is not available, other sources have been used, Table 9.

In this study Heavy Fuel Oil (HFO), Marine Diesel Oil/Marine Gas Oil (MDO/MGO), Light Fuel Oil (LFO) and Liquefied Natural Gas (LNG) are denoted conventional fuels. Biobased fuels included are Biodiesel, Liquefied Bio-Gas (LBG) and biomethanol. Included fuels produced via electrolysis (i.e., electrofuels) are e-ammonia, e-methanol and e-hydrogen.

Table 9: GHG emission factors (in CO<sub>2</sub>eq) for the fuels used in the model. Biogenic emissions of CO<sub>2</sub> are modelled as negative emissions in well-to-tank (WTT) and emitted during tank-to-wake (TTW), resulting in net-zero well-to-wake (WTW).<sup>4</sup>

Fuel type	LCV (MJ/gFuel)	Emission factor WTT (gCO <sub>2</sub> e/MJ)	Emission factor TTW (gCO <sub>2</sub> e/MJ)	Emission factor WTW (gCO <sub>2</sub> e/MJ)	Source
HFO	0.0405	13.50	78.10	91.60	FuelEU Maritime
MDO/MGO	0.0427	14.40	76.23	90.63	FuelEU Maritime
LFO	0.041	13.20	78.05	91.25	FuelEU Maritime
E-Ammonia	0.0186	25.70	0.00	25.70	WTT from Brynolf et al. (2023)
Biodiesel	0.037	-65.49	76.59	11.10	WTW from JRC dataset, WTT derived as (JRC WTW - FuelEU Maritime TTW)
LNG	0.0491	18.50	56.60	75.10	FuelEU Maritime
LBG/Biogas	0.0491	-46.60	56.60	10.00	WTW from Holmgren et al. (2025) WTT derived as (IVL WTW - FuelEU Maritime TTW)
E-Methanol	0.0199	-41.10	69.10	28.00	WTT from Brynolf et al. (2023)
Biomethanol	0.0199	-63.10	69.10	6.00	WTT from Brynolf et al. (2023)
E-Hydrogen	0.12	21.70	0.00	21.70	WTT from Brynolf et al. (2023)
Electricity	-	0.00	0.00	0.00	FuelEU Maritime

## 2.4.2 Estimation of other pollutants

The emissions of NO<sub>x</sub>, PM, SO<sub>2</sub> and scrubber water are also estimated. These emissions are not covered by the FuelEU Maritime which only include emissions of the GHGs CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O.

<sup>4</sup> The emission factors well-to-tank (WTT) assumed for renewable fuels containing carbon are: 11 gCO<sub>2</sub>e/MJ for Biodiesel, 9.4 gCO<sub>2</sub>e/MJ for LBG, 27.7 gCO<sub>2</sub>e/MJ for e-methanol, and 5.7 gCO<sub>2</sub>e/MJ for bio-methanol

## Particulate matter (PM)

PM emission factors for fuel oils are taken from Fridell et al. (2020). Emissions differ based on whether a vessel has scrubbers or not. Information on which vessels currently are fitted with scrubbers is retrieved from IHS Sea-web (S&P GLOBAL, 2025), which is matched against the MRV dataset. If a vessel does not have a scrubber but uses heavy oil (HFO) according to the MRV data, it is assumed that the fuel used is very low sulphur fuel oil (VLSFO). Emission factors for PM for other fuels are taken from Kanchiralla et al. (2024), the values differ slightly based on if the engine is 2- or 4-stroke, see Table 10. Information on stroke type for each vessel is based on IHS Sea-web and matched with the MRV data. Ships that are replaced in the model is assumed to keep its original stroke type, as to retain the 2-stroke to 4-stroke ratio across the fleet. In the MRV 2023 data, 80% of ships have 2-stroke main engines.

The emission factors in Fridell et al. (2020) are for PM<sub>2.5</sub> while those from Kanchiralla are for PM<sub>10</sub>. Because PM<sub>2.5</sub> emissions make up most of PM<sub>10</sub> emissions, these are treated as equivalent in the model and are noted as “PM”.

Table 10: Assumed emission factors for PM. MD/MGO: Marine gas oil, HFO: Heavy fuel oil, VLSFO/LFO: very low/low sulphur fuel oil, LNG: Liquefied natural gas, and LBG: liquefied biogas.

Fuel type (oil)	PM with scrubber (g/kWh)	PM without scrubber (g/kWh)	Source
MD/MGO	0.22	0.22	Fridell et al. (2020)
HFO	0.98	-	Fridell et al. (2020)
VLSFO/LFO	0.43	0.43	Fridell et al. (2020)
Biodiesel	0.22	0.22	Assumed same as MD/MGO
Fuel type (other)	PM 2-stroke (g/kWh)	PM 4-stroke (g/kWh)	Source
LNG/LBG	0.020	0.000	Kanchiralla et al. (2024)
Hydrogen	0.010	0.011	Kanchiralla et al. (2024)
Methanol	0.093	0.093	Kanchiralla et al. (2024)
Ammonia	0.010	0.011	Kanchiralla et al. (2024)

## SO<sub>x</sub>

SO<sub>x</sub> emissions are calculated based on the sulphur content of the fuels, unless a scrubber is used. The sulphur content is taken from IMO’s average yearly values for 2023 (IMO, 2023). This means that for fuels with sulphur content ≤ 0.10% the

average is 0.06%, and for fuels with sulphur content > 0.10% and <= 0.5% the average is 0.45% (Table 11).

Sulphur oxide emissions are lower within SECAs due to the regulations. These are met either by using low-sulphur fuels or by using high sulphur fuels in combination with scrubbers. To account for this, the “sulphur content” (functioning as an emission factor) of HFO, VLSFO and LFO are adjusted to represent a SO<sub>x</sub> exhaust volume equivalent to if MGO was used instead i.e., SO<sub>x</sub> emissions from higher sulphur fuels are scrubbed down to MGO levels. The model may estimate two different SO<sub>x</sub> emissions totals, for traveling either within or outside SECAs. The proportion of fuel consumed by ships outside SECAs is relevant when calculating European emissions, but because Sweden is located within the Baltic Sea ECA only the SECA values are applicable in this case.

Table 11: Emission factors for SO<sub>x</sub> used in the FEMAR model.

Fuel type	Sulphur content* (inside SECA)	Sulphur content (outside SECA)	Source
MD/MGO	0.06%	0.06%	IMO (MEPC 82/INF.2)
HFO	0.06%	0.45%	IMO (MEPC 82/INF.2)
VLSFO/LFO	0.06%	0.45%	IMO (MEPC 82/INF.2)
LNG/LBG	0.000829%	0.000829%	IMO 4th GHG Study

\*Not actual sulphur content for HFO, VLSFO and LFO. Values represent the use of scrubbers that reduce the emissions to a level equivalent to 0.06% sulphur content.

Emission factors on an energy basis are calculated by combining the sulphur fraction of each fuel with its lower calorific value of fuel (LCV):

$$EF_{SO_x} \left[ \frac{g}{MJ} \right] x = \left( 2 \left[ \frac{gSO_2}{gS} \right] x FSC \left[ \frac{gS}{gFuel} \right] \right) / LCV \left[ \frac{MJ}{gFuel} \right]$$

Where FSC is fuel sulphur content in mass of sulphur per mass of fuel. The sulphur content is multiplied by 2 because SO<sub>2</sub> molecules have twice the weight of a single sulphur atom. As SO<sub>2</sub> makes up an overwhelming majority of SO<sub>x</sub> emissions during combustion (Moldanova, 2009) they are used as a proxy for SO<sub>x</sub> emissions.

## NO<sub>x</sub>

Emission factors for NO<sub>x</sub> are taken from Kanchiralla et al. (2024). Ships running on renewable fuels are assumed to always fulfil Tier III requirements (as defined by IMO MARPOL Annex VI). All renewable fuels have an emission factor of 3.4 g

NO<sub>x</sub>/kWh if the engine is 2-stroke. 4-stroke engines using LBG or hydrogen have lower emission factors than when using other fuels. NO<sub>x</sub> emissions factors for engines using fossil fuels and biodiesel are assumed to follow the Tier formulas of Regulation 13 from MARPOL Annex VI (IMO, n.d.). The NO<sub>x</sub> emission factors are presented in Table .

Also, NO<sub>x</sub> emissions are calculated within and outside nitrogen emission control areas (NECAs). As Sweden is located within the North Sea ECA, only Tier III is assumed when calculating Swedish related shipping emissions. In a European scope, ships are assumed to operate as Tier II outside NECAs, not running the selective catalytic reduction (SCR) reducing NO<sub>x</sub> emissions from the exhaust emissions more than needed. Emissions from Tier I ships are calculated using Regulation 13 outside NECAs, while Tier 0 uses emission factors from IMO 4<sup>th</sup> GHG study (Faber et al., 2020).

Table 12: Emission factors for NO<sub>x</sub>. "Tier" means Tier III relevant for the Swedish scope. See text for references.

Fuel type	2-stroke: gNO <sub>x</sub> /kWh	4-stroke: gNO <sub>x</sub> /kWh
MD/MGO	Tier	Tier
HFO	Tier	Tier
VLSFO/LFO	Tier	Tier
Biodiesel	Tier	Tier
LNG	3.4	0.7
LBG	3.4	0.7
Hydrogen	3.4	0.7
e-methanol	3.4	2.6
Biomethanol	3.4	2.6
e-ammonia	3.4	2.6
(Electricity)	0	0

## Methane slip

For LNG and LBG, the amount of non-combusted fuel must be considered as these fuels consist primarily of CH<sub>4</sub>, having considerably higher global warming potential than CO<sub>2</sub>. Thus, the potential CH<sub>4</sub> slip may greatly affect the CO<sub>2eq</sub> emission factor. Most of the slip occurs due to incomplete combustion but may also be caused by leakages.

For LNG and LBG a methane slip of 3.1% is assumed, meaning that 3.1% of the fuel mass is released into the air. In FuelEU Maritime, this is the default value for medium speed engines. The impact of the assumed slip is further discussed in the uncertainty analysis (see *Section 2.5.1*). The model does not specifically consider that at a higher slip may mean higher fuel consumption.

## Scrubber emissions

Scrubbers are used on ships to reduce SO<sub>x</sub> emissions from the combustion of sulphur-containing fuels, allowing continued use of high-sulphur fuel oils while meeting regulatory limits. Scrubbers remove SO<sub>2</sub> from exhaust gases by transferring it to water, normally sea water. In the process, the scrubber water not only become acidic but also captures PM, metals and hydrocarbons from the exhausts. As a result, the pollution is thereby shifted from air to water through discharge of acidic and contaminated water. Many scrubber systems being “open-loop” discharge the water directly to the sea (while closed-loop captures the water). Marine ecotoxicity is expressed as 1,4 dichlorobenzene equivalents (1,4 DCB-eq), a standard indicator that aggregates the toxic potential of different contaminants into a single comparable measure.

Ships with scrubbers have been identified by matching “Scrubber fitted” ships in IHS Sea-web with the MRV dataset. All scrubbers are modelled as being open-loop. Assumptions of wash water discharge of 90 m<sup>3</sup>/MWh and a marine ecotoxicity of 0.23 kg 1,4-DCB-eq/m<sup>3</sup> are used (Ytreberg, 2001). Scrubber discharge is zero for all ships using renewable fuels, meaning that the amount of scrubber water depends on the number of remaining conventional ships.

It is assumed that ships fitted with a scrubber always use them, even when operating outside of SECAs. Therefore, ships are assumed to always run their scrubbers when calculating the total European scrubber water discharge. The volume of discharged scrubber water linked to Swedish related shipping is allocated proportional to the fuel consumption shares in Table 3. This corresponds to voyages to/from and within Sweden always using a scrubber if it is fitted with one.

Because future scrubber emission will depend heavily on regulations (scrubber bans etc.), three different cases for scrubbers have been defined:

<b>Default:</b>	Ships remove their scrubber when switching to a renewable fuel (or LNG), and no newbuilt ships are fitted with scrubbers.
<b>High scrubber use:</b>	All newbuilt conventional ships are equipped with a scrubber.
<b>Low scrubber use:</b>	All newbuilt ships are built without a scrubber.

Default is how scrubbers are treated in all scenarios defined in *Section 2.3*. However, for the *Mixed* scenario, the High scrubber use and Low scrubber use cases are also ran separately, with all other input data kept constant. This gives three different results for scrubber water discharge in the *Mixed* scenario.

## 2.5 Sensitivity assessments

Model-based assessments inevitably involve uncertainties related to input data, parameter values, and methodological choices. To support a transparent interpretation of the results, an uncertainty analysis was conducted to assess how these uncertainties influence the model outcomes. The analysis focuses on uncertainties associated with key input parameters and assumptions that may affect the results. Where relevant, parameter values were varied within ranges considered plausible based on available literature, datasets, and expert judgement. This approach allows for an assessment of the extent to which the model results depend on specific parameter choices and underlying assumptions.

The purpose of the uncertainty analysis is to indicate the potential variability of the results and to identify which parameters that contribute most to overall uncertainty. The findings therefore help clarify the robustness of the results.

### 2.5.1 Methane slip assumption

The magnitude of the methane slip (e.g. unburned CH<sub>4</sub>) in real operations of methane-driven (LNG, LBG, electro-methane) vessels are uncertain (Lehtoranta et al, 2025). Engine load factors and operational patterns greatly affect the actual methane emissions from vessels, and measurement data is still emerging (Comer et al., 2024). To test how this uncertainty influences the model results, the methane-slip assumption is varied across a plausible range in a sensitivity assessment while all other parameters are held constant.

The default regulatory factor in the FuelEU Maritime policy framework is for 4 stroke engines set at 3.1 % of fuel input (corresponding IMO default emission factors are at 3.5% (MEPC.391(81))), while recent real-world measurements of low-pressure dual-fuel engines have reported average values around 6%, with higher values observed at low engine loads. ICCT (Comer et al., 2024) reported in 2024 ranges of methane slip (corresponding to an average of 6.4% from low-pressure 4-stroke engine, with peak values at 13.7% for low engine loads) and recommended policy maker to raise the default emission factor to at least 6%.

Methane slip in the model is varied between 0.2% (representative for reported values from some high-pressure 2-stroke engines also included in the FuelEU Maritime) and 6.4% of the fuel input.

## 2.5.2 GHG emissions factors and NO<sub>x</sub> emissions assumptions

Values for GHG emission factors vary within fuel categories, between power trains and between studies. To account for the influence of these variations, we have tested a set of low and high GHG emission factors, respectively (see Table 13).

The set of low upstream GHG emission factors are based on the lower range of values found in the EU Renewable Energy Directive REDIII (Directive (EU) 2023/2413). The set of high upstream GHG emission factors are based on the highest WTW values where the fuels are still categorized as renewable within the RED framework. This corresponds to a 70% reduction from 94 g CO<sub>2e</sub>/MJ for electrofuels, e.g. 28.2 g CO<sub>2e</sub>/MJ, and a 65% reduction for biomass-based fuels, e.g. 33 g CO<sub>2e</sub>/MJ, (EU 2018/2001, Article 29(10)). The high WTT values are derived by taking the difference between the high WTW and the default TTW emission factors used in the model.

For the TTW emission factors most estimates are in line with an assumption of full combustion to estimate GHG emission factors. However, for ammonia-based propulsion options there are uncertainties linked to future N<sub>2</sub>O emissions. Some sources report emission factors for dual fuel combustion engines operating on ammonia of 1.75 g N<sub>2</sub>O/kWh (Zhou et al., 2023), which is equivalent to 59.72 g CO<sub>2e</sub>/MJ (when using IPCC AR6 and an engine efficiency of 45%). Others describe technologies and operational strategies to reduce these emissions to close to zero (Chen et al., 2026). Which emission factors to apply for ammonia in legislation are still under discussion both in FuelEU Maritime and IMO (MEPC 83/7/23). We

therefore adjust emission factors TTW for ammonia in the high emission factor WTW case. For all other fuels, the values in this case are the same as the base values used.

Table 13: Emission factors for GHG emissions used in related sensitivity analysis.

Fuel type	Low EF WTT (gCO <sub>2</sub> e/MJ)	High EF WTT (gCO <sub>2</sub> e/MJ)	Low EF WTW (gCO <sub>2</sub> e/MJ)	High EF WTW (gCO <sub>2</sub> e/MJ)
E-Ammonia	0	28.2	0	28.2
Biodiesel	-65.49	-43.59	11.10	33
LBG/Biogas	-146.60	-46.60	-90.00	33 (see methane slip analysis)
E-Methanol	-63.10	-36.10	6.00	28.2
Biomethanol	-63.10	-36.10	6.00	33
E-Hydrogen	0	28.2	0	28.2

The base case emission factors for NO<sub>x</sub> used in the model are based on prospective life cycle inventory data (Kanchiralla et al., 2024). However, for some of the fuels and engine combinations there are other emission factors present in literature and for early technologies such as ammonia propulsion estimates are uncertain. A sensitivity analysis is therefore performed where Tier III values are assumed for all technologies.

### 2.5.3 Alternative fuel mix scenario

As the future deployment of alternative marine fuels, such as LBG, methanol, ammonia and hydrogen, is still uncertain, an additional fuel mix scenario is tested that avoids gaseous fuels and instead relies heavily on electricity and biodiesel. The build shares for renewable fuels in this scenario (see Table 14) have been chosen to approximately achieve the fuel split used in the energy forecast by DNV (2025c), developed to meet a CO<sub>2</sub> emission reduction of 77% by 2050. The original forecast also contains nuclear driven ships, which is not an option in our model. Instead, this is covered by electricity which, like nuclear, has an emission factor of zero. The electricity share can also be viewed as a proxy for including wind-based propulsion, which is not included in the model.

Table 14: Alternative renewable fuel mix scenario based on DNV (2025c).

Renewable fuel build shares (Alternative fuel mix scenario)			
Fuel	2025	2030	2050
LBG	0%	0%	0%
Biodiesel	75%	75%	30%
Electricity	25%	25%	10%
Hydrogen	0%	0%	0%
e-Methanol	0%	0%	30%
Biomethanol	0%	0%	0%
e-Ammonia	0%	0%	30%

As the fleet is already moving towards LNG as an alternative fuel, a development towards biodiesel might seem unlikely. Also, the electricity implementation assumed in this scenario is possibly larger than technically possible. In any case, having this scenario broadens the possible outcome range and provides insights into the limits of the fuel mix scenarios, which is beneficial as the future mix of marine fuels is very uncertain.

## 3 Results

This section presents the emission results for Swedish shipping (as defined in *Section 2.2.4*) for the assessed scenarios (defined in Table 4 and in *Section 2.3*).

### 3.1 Single fuel scenarios

The single fuel scenarios (marked single fuel in Table 4) represent scenarios where only one alternative fuel option is used for newbuilds and retrofits. In Figure 3, the GHG emissions from Swedish shipping for 2025-2050 from a WTW perspective is shown for all single fuel scenarios. Every scenario except the base case has the same overall GHG emissions development over time, as the model is set to just reach the FuelEU Maritime GHG emission requirements. Increases in emissions between the FuelEU Maritime reduction “steps”, i.e. in between every 5 years, are due to increased fuel consumption (as described in *Section 2.2.3*). The energy demand is similar across all scenarios (around 6.4 PJ in 2024 and increases to around 8.6 PJ in 2050).

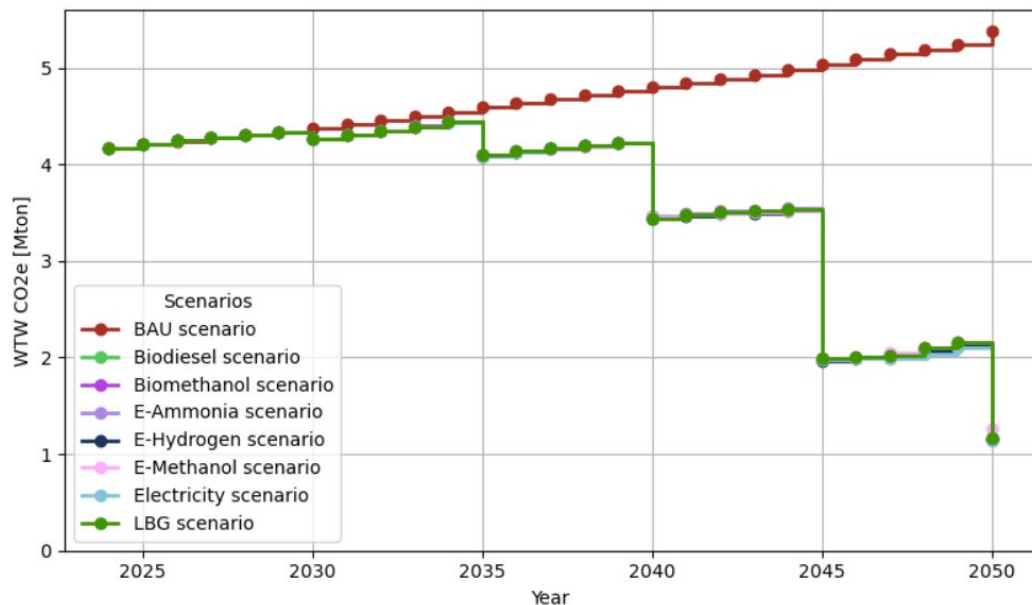


Figure 3: Estimated GHG emissions from Swedish shipping for 2025-2050 (in CO<sub>2e</sub>) from a WTW perspective for the single fuel scenarios developed to meet the FuelEU Maritime requirements.

In single fuel scenarios where the introduced renewable fuel has a relatively low GHG emission factor, e.g., electricity and biomethanol, fewer vessels need to adopt

a renewable fuel for compliance to be reached. This is illustrated in Figure 4 which showing the remaining number of conventional ships. This is presented on a European level as the methodology used does not allow for a simple classification of Swedish vessels, but the trend is the same for the entire fleet as for the Swedish fleet.

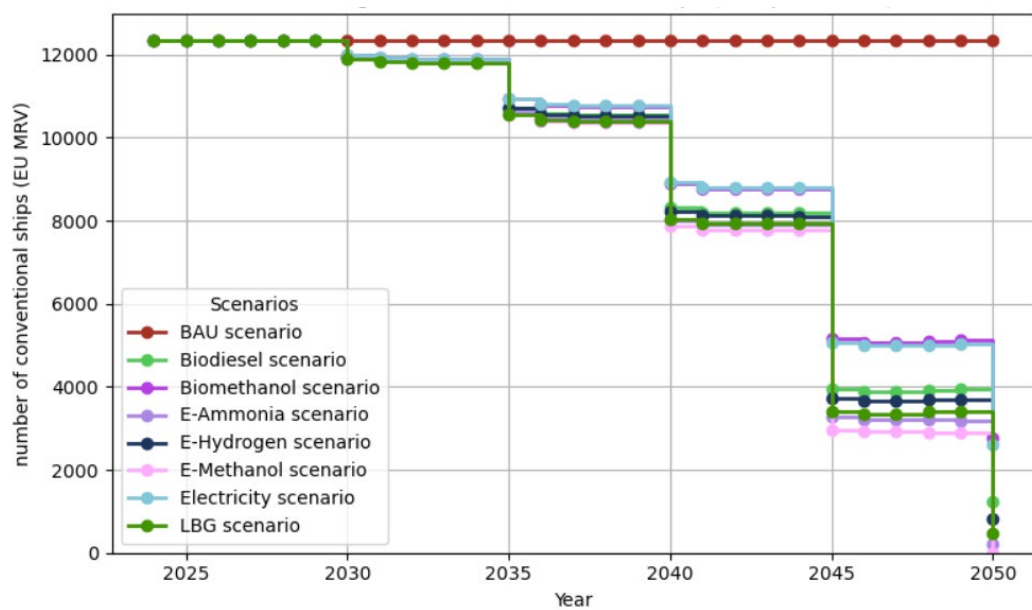


Figure 4: Number of remaining conventional ships (on European level) from 2024 to 2050 in the single fuel scenarios developed to meet the FuelEU Maritime requirements.

The estimated emissions of non-GHG pollutants (i.e., NO<sub>x</sub>, SO<sub>x</sub>, PM and scrubber water) between 2024 and 2050 for single fuel scenarios, in the scope of Swedish related shipping, are shown in Figures 5-8.

In terms of NO<sub>x</sub>, emissions decrease over time when LBG, hydrogen, and electricity is introduced. While newbuilds and retrofits are always assumed to comply with Tier III, the emission factors of LBG, hydrogen, and electricity result in even lower emissions than what is required by Tier III. The electricity scenario (in which the electricity causes zero NO<sub>x</sub> emissions) shows the most pronounced decline, with emissions decreasing to around 25 000 tons, 11 500 tons and 6 500 tons in 2035, 2045, and 2050, respectively.

For the other single fuel scenarios, the NO<sub>x</sub> emissions increase over time and follows the base case scenario until 2045. The reason is that the adoption of Tier III

in newbuilds (and retrofits) which reduce the NO<sub>x</sub> emissions of the individual vessels does not offset the fleet's estimated yearly fuel consumption increase. Fuels such as ammonia or methanol result in similar NO<sub>x</sub> emissions as biodiesel, which in the model is assumed to have similar emissions as conventional fuels.

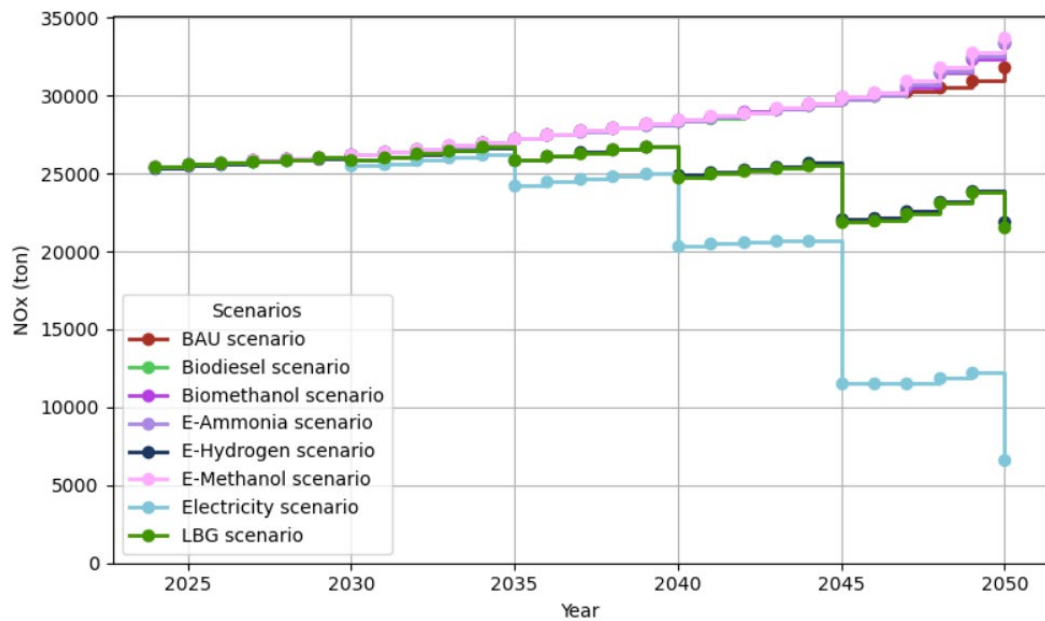


Figure 5: Estimated NO<sub>x</sub> emissions from 2024 to 2050 for Swedish related shipping in the single fuel scenarios developed to meet the FuelEU Maritime requirements.

For SO<sub>x</sub> emissions (see Figure 6), the decrease over time is caused by the replacement of fuel oils with high sulphur content. The only renewable fuel containing sulphur is LBG, which has a very minor sulphur content (assumed to be 0.000829% on a mass basis). Thus, the SO<sub>x</sub> emissions depend on the amount of remaining conventional ships (which depend on the GHG emission factor). The electricity scenario has the highest SO<sub>x</sub> emissions due the relatively high number of remaining conventional ships in that scenario (see Figure 4).

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Greenhouse gases and selected air and water pollutants  
June 2026

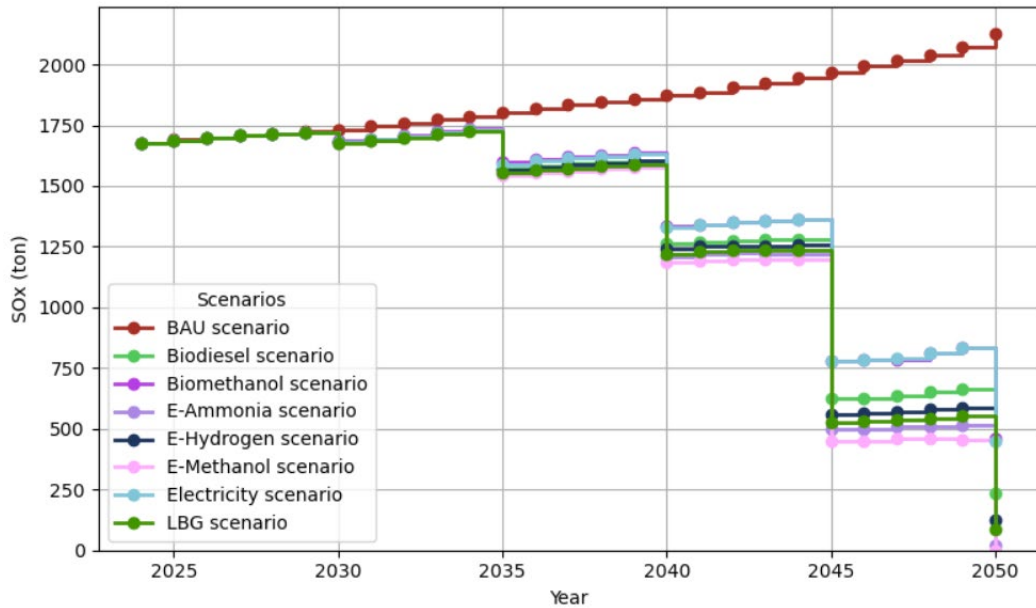


Figure 6: Estimated SO<sub>x</sub> emissions from 2024 to 2050 for Swedish related shipping in the single fuel scenarios developed to meet the FuelEU Maritime requirements.

Figure 7 illustrates the estimated total annual PM emissions from Swedish shipping between 2024 and 2050. The PM emissions decrease for most renewable fuel pathways. Emissions vary based on the PM emission factors for renewable fuels, and the GHG emission factor influencing the number of remaining conventional ships.

The PM emission factors for conventional fuel oils are higher than for renewable fuels (see Section 2.4.2), but there are also differences among the fossil fuels as LFO and HFO cause higher emissions than MGO and LNG. Biodiesel is assumed to have the same PM emissions as MGO per MJ fuel, which is why the use of biodiesel results in higher emissions than the other renewable fuels, but lower than the BAU scenario which has more ships running on LFO and HFO. Biomethanol and e-methanol have the highest PM emission factors of the renewable fuels and therefore achieve the lowest reductions.

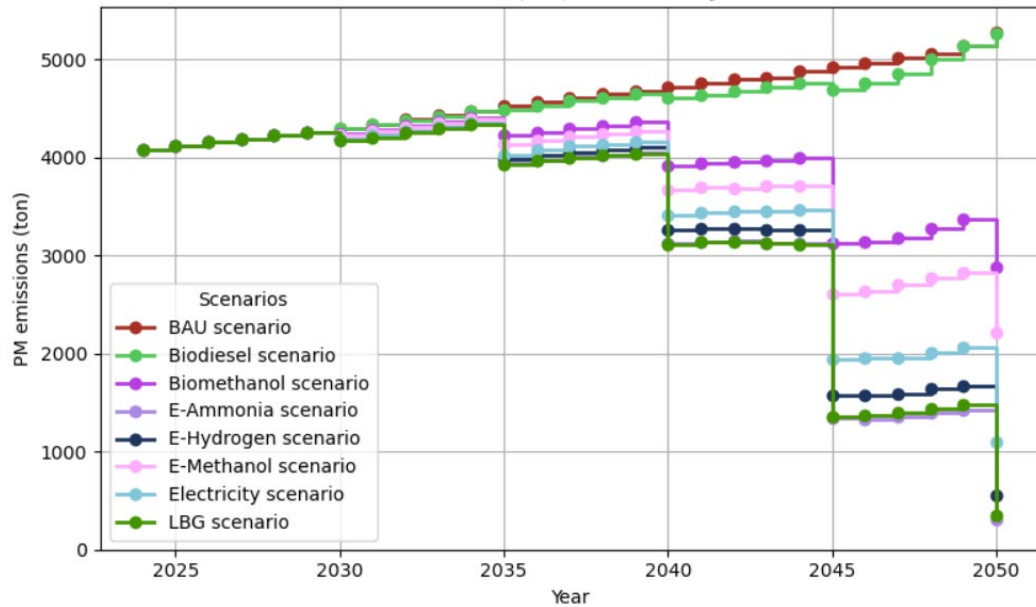


Figure 7: Estimated emissions of PM from 2024 to 2050 for Swedish related shipping in the single fuel scenarios developed to meet the FuelEU Maritime requirements.

The emissions of scrubber discharge to water due to SO<sub>x</sub> emission mitigation are presented in Figure 8. The estimated emissions represent emissions linked to Swedish-related shipping, but the release location varies considerably.

The emissions of scrubber discharge to water reflects continued reliance on high-sulphur fuels combined with scrubber-based compliance. The amount of scrubber water discharge (shown in Figure 8) closely follows the number of remaining conventional ships in each scenario as ships with alternative fuels do not use scrubbers. Under the BAU scenario, scrubber water discharge increases over the entire period, rising from approximately 230 Mm<sup>3</sup> in 2024 to just above 310 Mm<sup>3</sup> by 2050.

Scenarios such as the single fuel biomethanol and electricity cases stabilize around 210 Mm<sup>3</sup> scrubber water discharge by 2040. This is due to the remaining fossil fuel use in the scenarios and continued scrubber reliance in parts of the fleet. The e-ammonia, e-methanol, biodiesel, hydrogen and LBG scenarios have a higher uptake of alternative fuels and therefore lower remaining scrubber use leading to somewhat lower levels by 2040 (180–200 Mm<sup>3</sup>). By 2045 the uptake of low-emission alternatives in all scenarios have led to a substantial decline of scrubber discharge, even though the differences described remain.

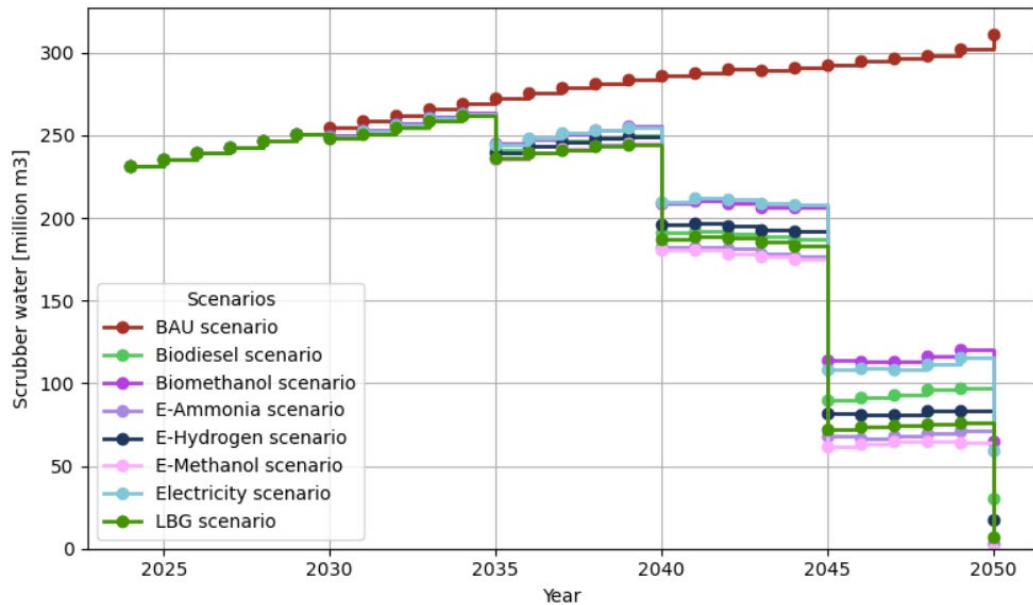


Figure 8: Estimated emissions of scrubber water discharge from 2024 to 2050 for Swedish related shipping in the single fuel scenarios developed to meet the FuelEU Maritime requirements.

### 3.2 Fuel mix scenarios

In the fuel mix scenarios, a mix of different fuels are introduced that in combination reach the FuelEU Maritime requirements (see Section 2.3). In Figure 9, the GHG emissions from Swedish shipping for 2024-2050 from a WTW perspective for the fuel mix scenarios are illustrated. The reason why the overall GHG emissions are the same over time in most of the scenarios (like in the single fuel scenarios) is because the model is set to just reach the FuelEU Maritime GHG emission requirements. The gas scenario is unique, however, having slightly lower GHG emissions due to the modelled requirement for all newbuilt conventional ships to shift to LNG in this scenario.

POTENTIAL ENVIRONMENTAL EFFECTS OF FUEL EU MARITIME FOCUSING

Greenhouse gases and selected air and water pollutants  
June 2026

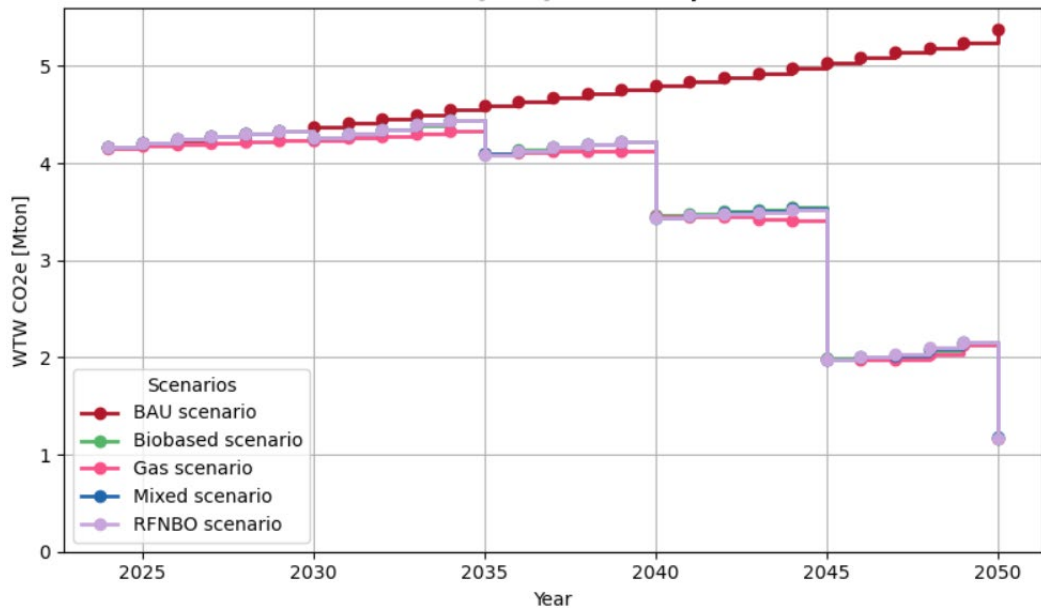


Figure 9: Estimated GHG emissions of Swedish shipping from 2024-2050 from a WTW perspective for the fuel mix scenarios developed to meet the FuelEU Maritime requirements. For scenario descriptions see the text.

The total number of conventional ships over time in the fuel mix scenarios are illustrated in Figure 10.

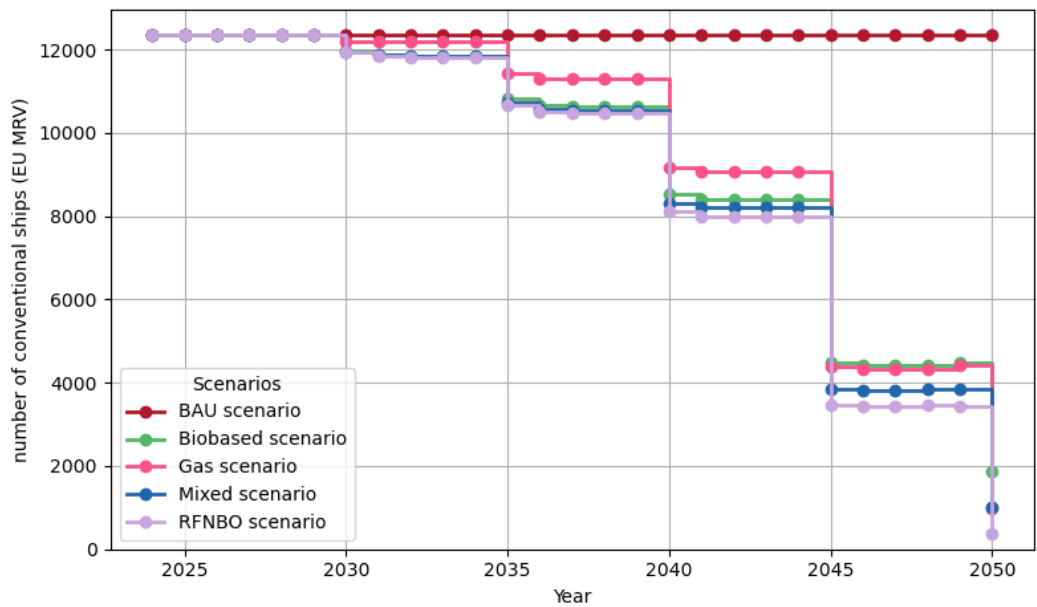


Figure 10: Number of remaining conventional ships (on European level) from 2024 to 2050 in the fuel mix scenarios developed to meet the FuelEU Maritime requirements.

Of the fuel mix scenarios, the RFNBO scenario has the lowest number of remaining conventional ships. This is because of the large-scale deployment of e-methanol and e-ammonia which have higher WTW GHG emission factors than biofuels (which are more prominent in the other fuel mix scenarios). As explained earlier, higher emission factors mean that more conventional ships need to be replaced to comply with the FuelEU Maritime requirements.

Figure 11 shows the fuel consumption of Swedish related shipping per fuel type in the *Mixed* scenario. The fuel consumption is split fairly evenly among the renewable fuels, with the exception of electricity and hydrogen which represent minor shares.

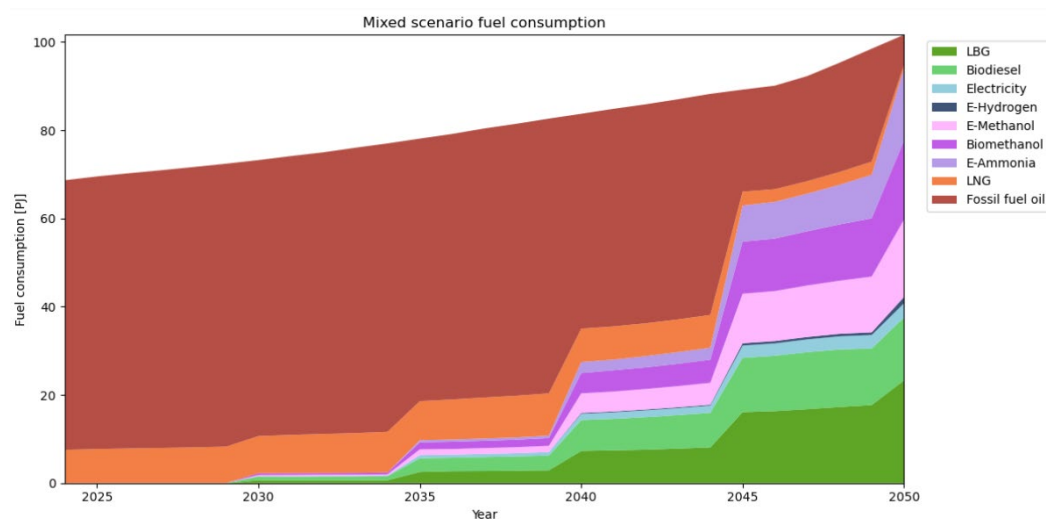


Figure 11: Fuel consumption from 2024 to 2025 for Swedish related shipping in the *Mixed* scenario.

The fuel consumption for the *BAU*, *RFNBO*, *Biobased* and *Gas* scenarios are shown in Figure 12 below.

POTENTIAL ENVIRONMENTAL EFFECTS OF FUEL EU MARITIME FOCUSING

Greenhouse gases and selected air and water pollutants  
 June 2026

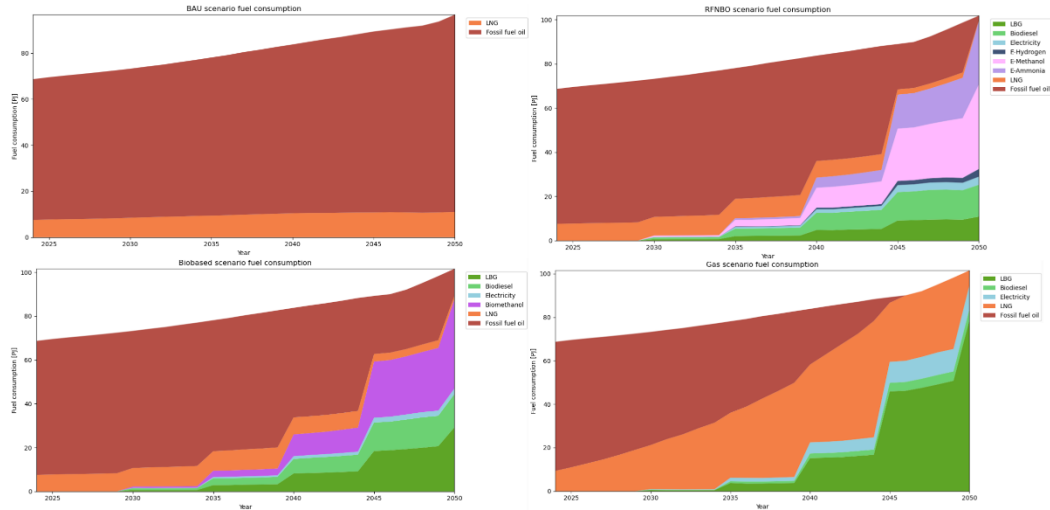


Figure 12: Fuel consumption from 2024 to 2025 for Swedish related shipping in the BAU, RFNBO, Biobased and Gas scenarios.

The estimated emissions of NO<sub>x</sub>, SO<sub>x</sub>, PM and scrubber water from Swedish shipping for 2024-2050 in the fuel mix scenarios are illustrated in Figures 13-16

Figure 13 presents the NO<sub>x</sub> emissions in tonnes per year. All scenarios begin at approximately 25.5–26 ktons in 2024, followed by a gradual increase to around 26.5–27 ktons by 2035. This reflects growing transport demand and limited early impact of fuel switching. Because the NO<sub>x</sub> emission factor for LNG and LBG in 4-stroke engines is lower than for methanol and ammonia, NO<sub>x</sub> emissions are reduced more in the gas scenario where LNG and LBG make up a large majority of the renewable fuels. This can be seen mostly after 2040 when the uptake of renewable fuels increases.

The fuel mix scenarios have slightly lower NO<sub>x</sub> emissions than the BAU scenario. The reason is that in the BAU scenario, NO<sub>x</sub> emissions are calculated according to Tier III for all fuels, i.e., fossil fuel oils and LNG whose Tier III NO<sub>x</sub> emission factors span from 2.0 g/kWh to 3.4 g/kWh depending on the engine characteristics<sup>5</sup>.

<sup>5</sup> Based on the legal emission limits from Regulation 13 of MARPOL Annex VI.

However, in the renewable fuel mix scenarios the NO<sub>x</sub> emission factors span from 0.7 g/kWh to 3.4 g/kWh.

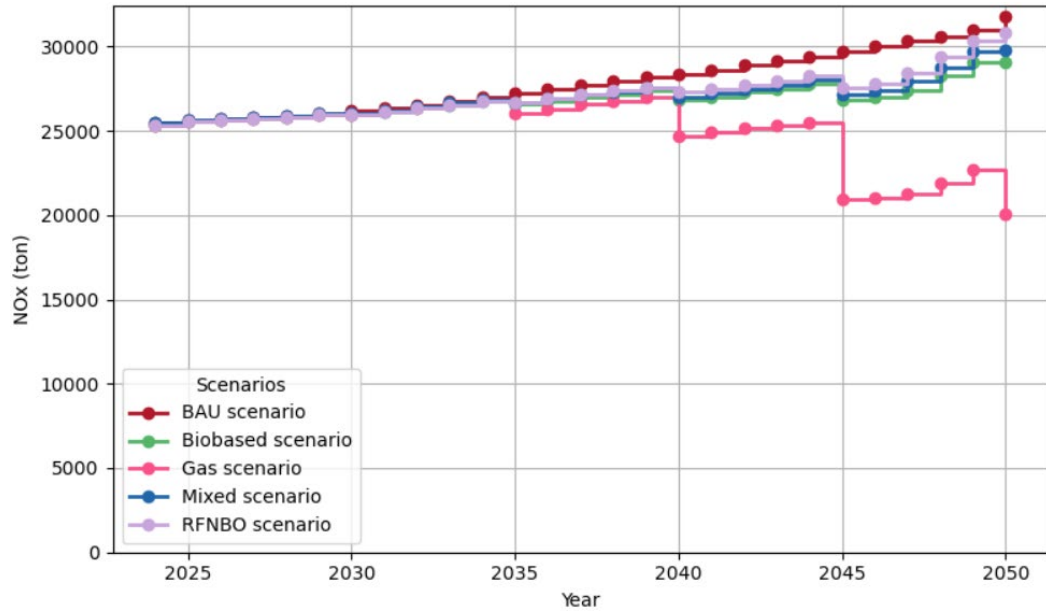


Figure 13: Estimated NO<sub>x</sub> emissions in 2025 to 2050 for Swedish related shipping in the fuel mix scenarios developed to meet the FuelEU Maritime requirements.

Figure 14 shows the development of SO<sub>x</sub> emissions from 2024 to 2050 across the fuel mix and BAU scenarios. For most scenarios the emissions decrease to around 1.2–1.3 ktons, in 2035–2040 and in 2045 the emissions fall to around 0.5–0.7 ktons for the *Biobased*, *Mixed*, and *RFNBO* scenarios. The gas scenario shows a continuous decline throughout the period, reaching near-zero SO<sub>x</sub> emissions by 2045. This is because for SO<sub>x</sub>, the reduction is directly linked to the reduced use of fuel oils, which is faster in the gas scenarios.

POTENTIAL ENVIRONMENTAL EFFECTS OF FUEL EU MARITIME FOCUSING

Greenhouse gases and selected air and water pollutants  
June 2026

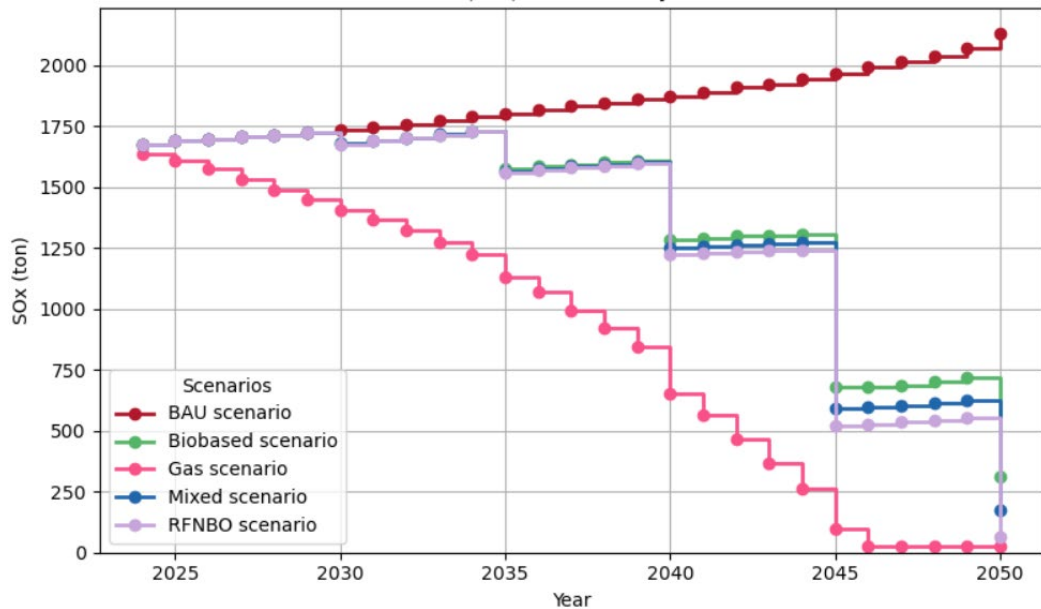


Figure 14: Estimated SO<sub>x</sub> emissions in 2025 to 2050 for Swedish related shipping in the fuel mix scenarios developed to meet the FuelEU Maritime requirements.

Figure 15 shows the estimated PM emissions from 2024 to 2050 in the fuel mix scenarios. The PM emissions increase slightly until 2035 in all scenarios except the gas scenario. The PM emissions in the BAU scenario continues to rise steadily, exceeding 5 ktons by 2050, however the PM emissions are reduced for all other scenarios. The Biobased, Mixed, and RFNBO scenarios show reductions to between 1.8 and 3.2 ktons PM emissions by 2050.

The emissions of PM, like for SO<sub>x</sub>, decline substantially when conventional ships start using LNG. The gas scenario exhibits a steep decline in emissions, reaching below 0.5 ktons by 2050.

POTENTIAL ENVIRONMENTAL EFFECTS OF FUEL EU MARITIME FOCUSING

Greenhouse gases and selected air and water pollutants  
June 2026

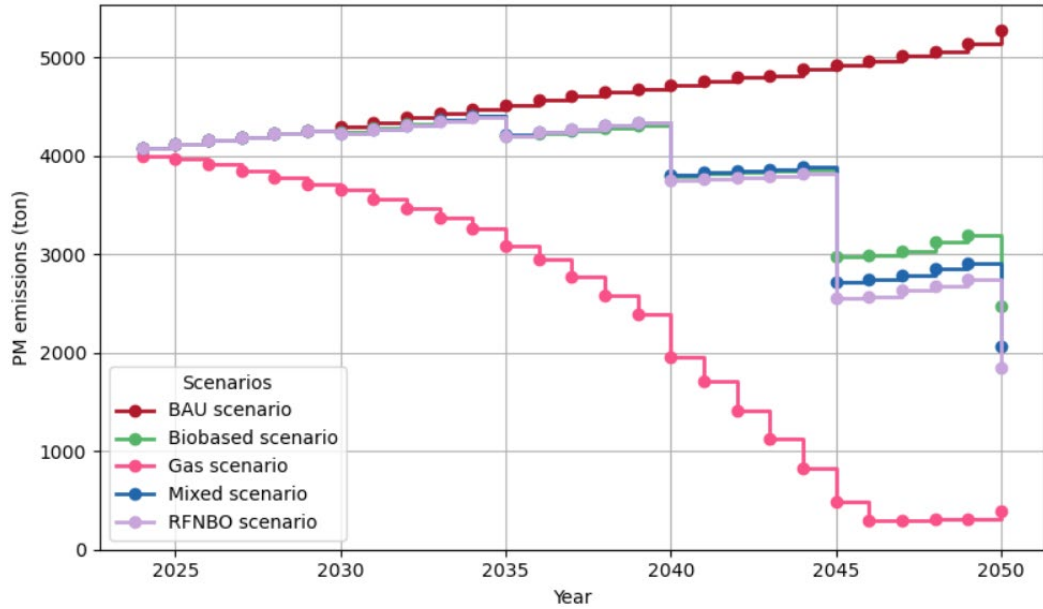


Figure 15: Estimated emissions of PM in 2025 to 2050 for Swedish related shipping in the fuel mix scenarios developed to meet the FuelEU Maritime requirements.

Figure 16 illustrates the modelled change in scrubber water volumes. The results mirror the SO<sub>x</sub> and PM emissions trends. Discharge of scrubber water decreases as ships stop using LFO, VLSFO and HFO, which requires use of scrubbers.

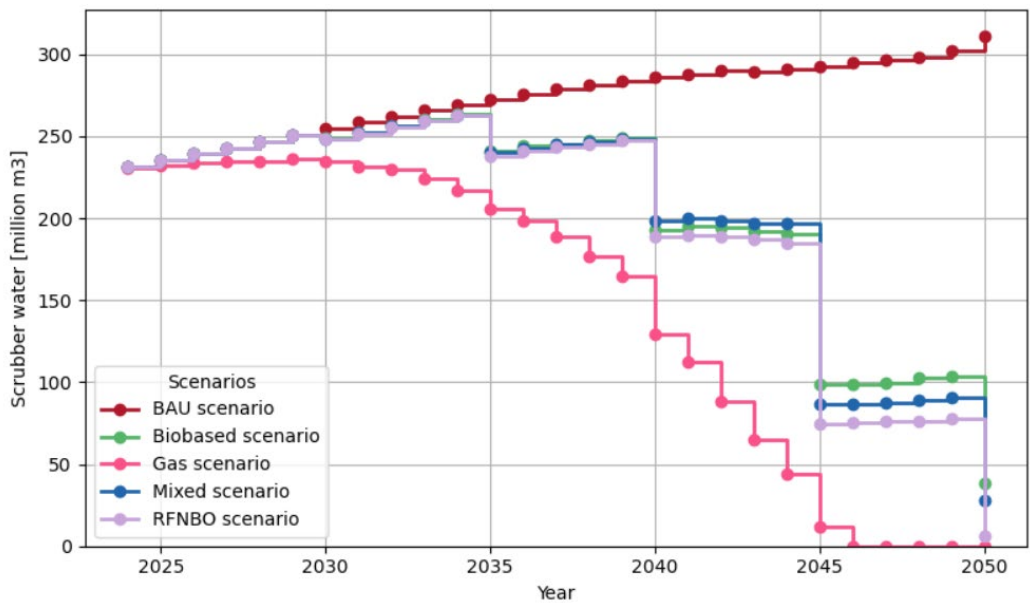


Figure 16: Estimated amount of scrubber water in 2025 to 2050 for Swedish related shipping in the fuel mix scenarios developed to meet the FuelEU Maritime requirements.

### 3.3 The role of retrofitting

In all the scenarios, spikes of retrofits will appear for the years when the FuelEU Maritime reduction target shifts to a lower level. It is only at these times retrofits are necessary to reach compliance. As the model aims to reach positive compliance within each ship category for each year, essentially all changes to the fleet including retrofits happens the same years as the reduction target is lowered. For these years, assigning newbuilds renewable fuels is not sufficient to reach a positive compliance balance, which is why the model starts retrofitting ships.

In Figure 17, the total number of retrofits and newbuilds per year for the mixed scenario is shown as an example. Newbuilds stay constant at 494 per year, corresponding to 1/25 of the entire MRV fleet based on the assumed vessel lifetime of 25 years. The number of retrofits represent the additional shift needed.

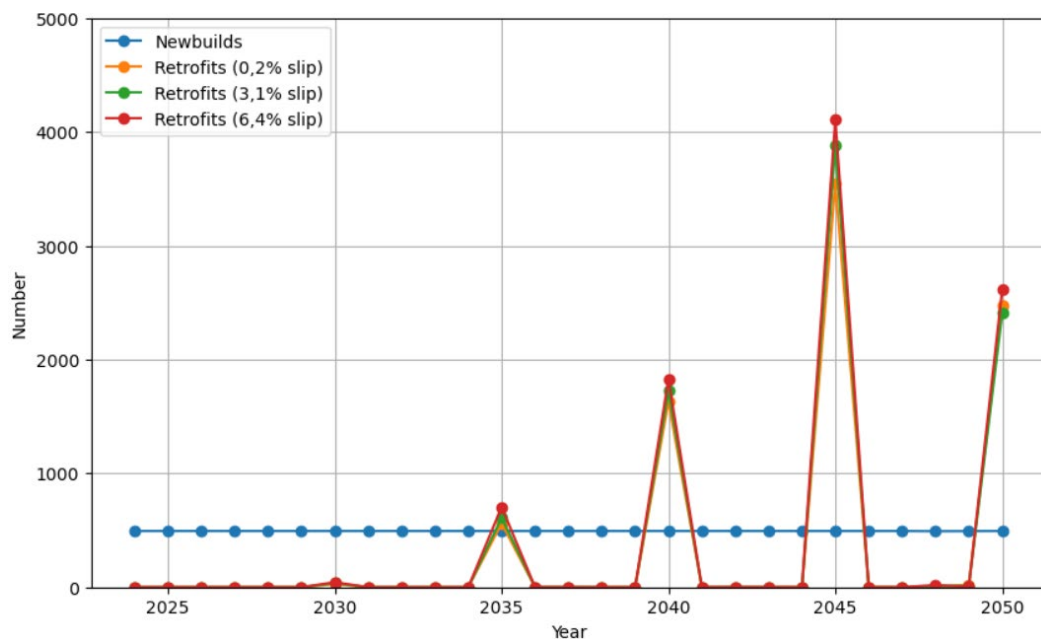


Figure 17: Number of retrofits and newbuilds per year for the Mixed scenario.

To check if retrofits could be theoretically avoided, the mixed scenario was run assuming all newbuild were assigned renewable fuels. As shown in Figure 18, the GHG intensity falls well below the reduction requirement in this case, meaning that no retrofits would be necessary in this case.

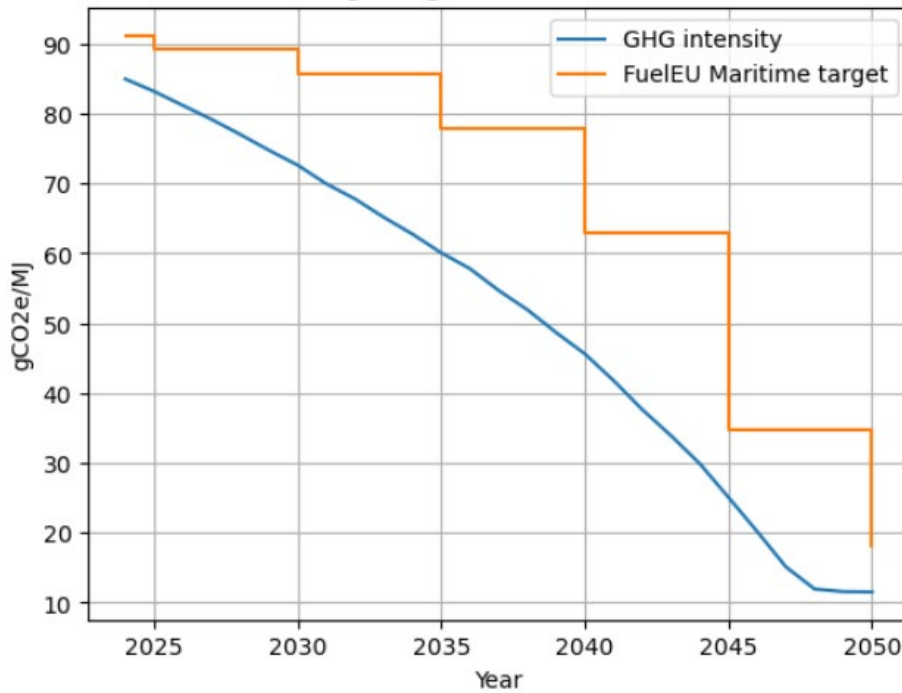


Figure 18: Estimated GHG emissions from Swedish shipping for 2025-2050 (in CO<sub>2</sub>e) for the Mixed scenario when assuming all newbuild are assigned renewable fuels, compared to the FuelEU Maritime GHG intensity target.

## 3.4 Sensitivity analysis

This section presents the results from the sensitivity analysis.

### 3.4.1 Scrubber use scenarios

Figure 19 illustrates the development of total scrubber water discharge for Swedish related shipping from 2024 to 2050 in the mixed fuel scenario under three assumptions regarding scrubber uptake: default, high scrubber use, and low scrubber use. The results highlight the strong dependence of wash water volumes on the extent of scrubber adoption.

The emissions in all three scenarios start from a similar level of approximately 230–250 Mm<sup>3</sup> in 2025. In the high scrubber use scenario, wash water volumes increase dramatically reaching ~450 Mm<sup>3</sup> by 2035 and over 500 Mm<sup>3</sup> in the years 2039 and 2044. This represents more than a doubling compared to the initial level and

reflects extensive reliance on scrubbers as a compliance strategy. The total amount of scrubber water discharge from 2024 to 2050 is 83.7% higher in the High scrubber use scenario and 29.8% lower in the Low scrubber use scenario.

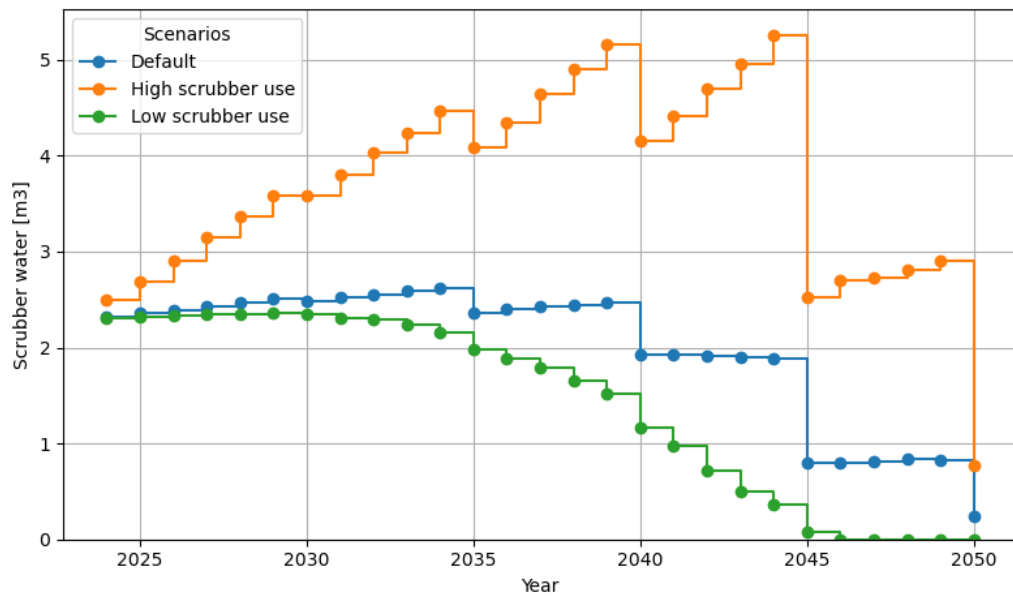


Figure 19: Estimated amount of scrubber water in 2025 to 2050 for Swedish related shipping in the three scrubber variants for the fuel mix scenario.

For the high scrubber use case, the scrubber discharge does not drop below 2024 levels until 2050. Figure 19 demonstrates that scrubber water discharge is highly sensitive to assumptions about scrubber uptake, particularly in the period before large-scale fuel transitions occur. High reliance on scrubbers can lead to substantial increases in marine pollutant discharge, more than doubling volumes relative to current levels. Conversely, limiting scrubber uptake results in earlier and more pronounced reductions.

To determine the marine ecotoxicity for each scenario, the amount of scrubber water discharge in m<sup>3</sup> can be multiplied by the marine ecotoxicity factor of 0.23 kg 1,4-DCB-eq/m<sup>3</sup>.

Table 15: Aggregated scrubber water discharge and marine ecotoxicity potential from 2024 to 2050 for the different Mixed scenario scrubber use cases. The Default case is the same as the result presented for the Mixed scenario in Figure 16.

Scrubber use case (within Mixed scenario)	Total scrubber water (million m3)	Total marine ecotoxicity potential (1.4-DCB-eq / million m3)
Default	541	124
High scrubber use	993	228
Low scrubber use	380	87

### 3.4.2 Influence of alternative emission factors for NO<sub>x</sub> and GHGs

As shown in Section 3.1 and Section 3.2, the GHG emission factors of renewable fuels (which influence the number of remaining conventional ships, see Figure 4 and Figure 10) are inversely correlated with emissions of other pollutants. This section presents a combination of variations in GHG emissions and NO<sub>x</sub> emissions to illustrate this connection more closely.

Figure 20 presents the development of the number of conventional ships in the fleet under the mixed scenario, with different upstream (WTT) GHG emission factor assumptions (base, high, and low). The assumptions on WTT emissions have a substantial impact on transition dynamics. While early developments are largely unaffected, differences become clear after 2035 and especially after 2045.

All three scenarios start with approximately 12 300–12 500 conventional ships in 2025 (on European level), which are reduced to about 12 000 in 2030, reflecting the

limited uptake of renewable fuels during this period. In 2045, the low WTT scenario has 2.7 times more conventional vessels than the high WTT scenario.

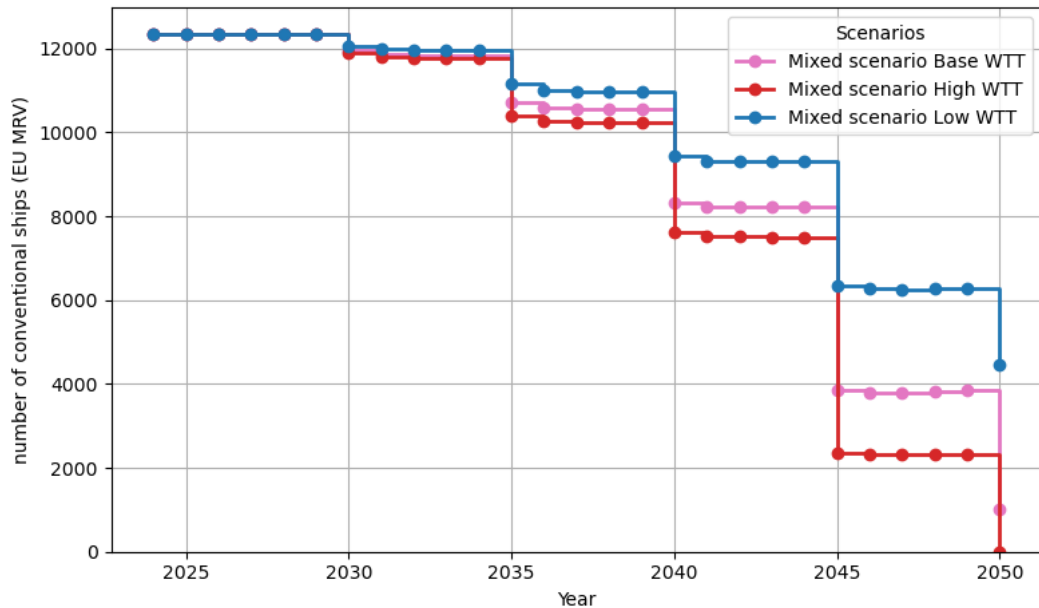


Figure 20: Number of conventional ships over time (on European level) for the mixed scenario with three different sets of GHG emission factors.

By 2050 the high WTT scenario reaches near-zero conventional vessels. In 2050, all renewable technology options except electricity fail to meet the reduction requirements in this scenario due to the total WTT emission factors being higher. This force ships to retrofit to electric drive to comply in this case. The estimated GHG emissions of Swedish shipping 2024 to 2025 for the Mixed scenario when varying the WTT emissions factors are shown in Figure A8 in the Appendix

The emissions of  $SO_x$  (see Figure 21) are by 2050 eliminated for *Mixed scenario high WTT* but remain at 750 tonnes per year for the *Mixed scenario low WTT*. For  $SO_x$ , the aggregated emissions over the entire period are 10.6% higher for *Mixed scenario low WTT* scenario and 6.2% lower for *Mixed scenario high WTT* compared to when using the base WTT emission factors. Emissions of PM and scrubber water follow similar trajectories (see Figure A9 and A10 in the Appendix).

POTENTIAL ENVIRONMENTAL EFFECTS OF FUEL EU MARITIME FOCUSING

Greenhouse gases and selected air and water pollutants  
June 2026

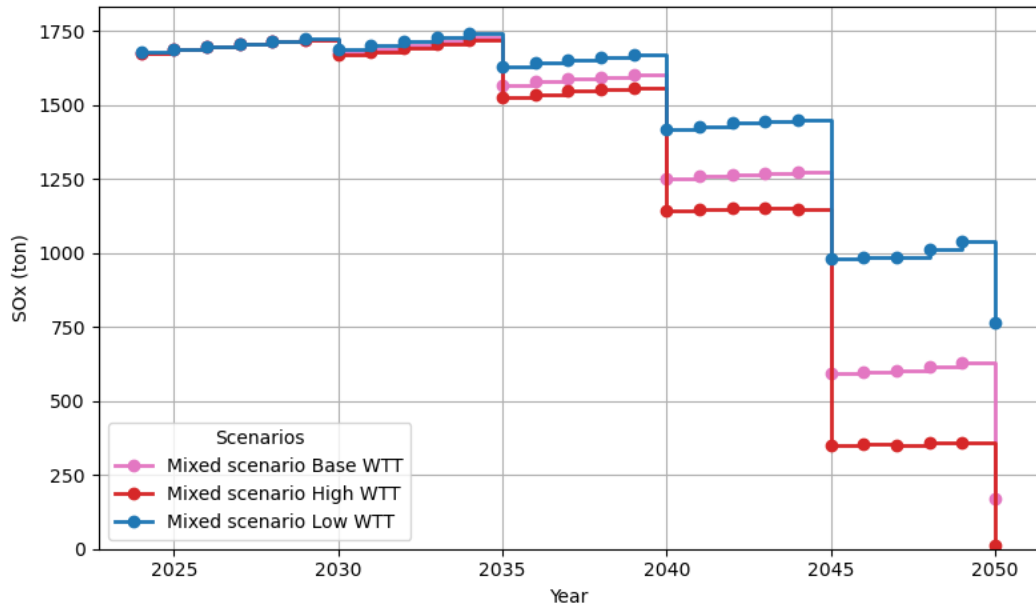


Figure 21: Differences in SO<sub>x</sub> emissions for the Mixed scenario when varying the WTT emissions factors.

The NO<sub>x</sub> emission results for combined GHG and NO<sub>x</sub> emission factor sensitivity analysis are shown in Figure 22. Using only Tier values instead of NO<sub>x</sub> emission factors for the renewable fuels has the expected effect of leading to higher emissions (as the NO<sub>x</sub> emission performance for the renewable fuels is not improved). Other pollutants than NO<sub>x</sub> emissions see a much larger impact from changing the WTT factors. NO<sub>x</sub> emissions are less affected by changes in WTT factors since newbuilds and retrofits are assigned Tier III whether they run on renewable fuels or not.

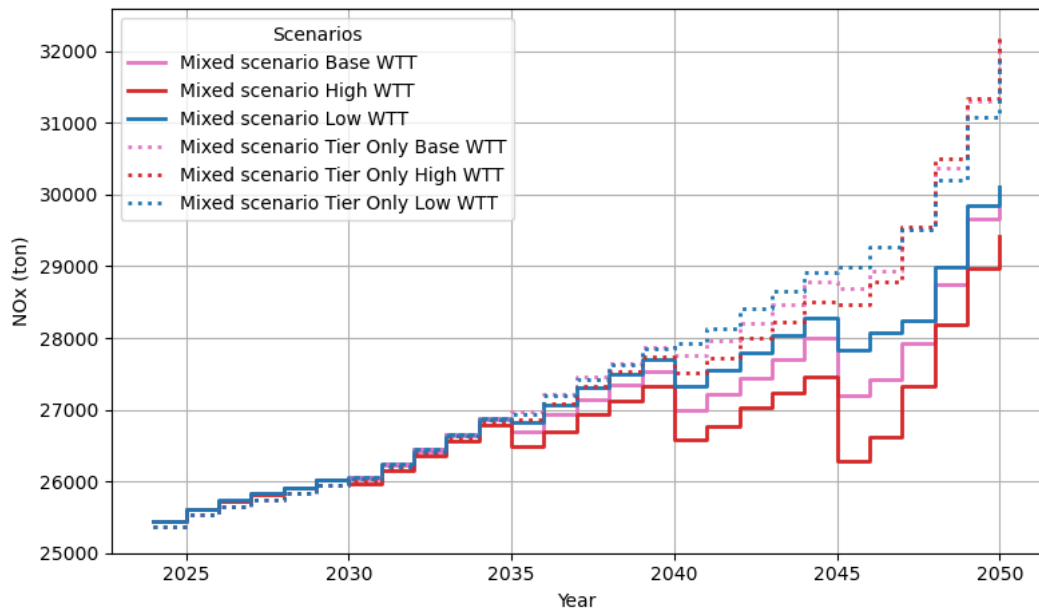


Figure 22: NO<sub>x</sub> results for the Mixed scenario when alternating the set of WTT GHG emission factors, as well as comparing the default set of NO<sub>x</sub> emission factors (see Table 10) against using Tier III values for all fuels, calculated according to Regulation 13 of MARPOL Annex VI. Note that the y-axis is cut off.

Mixed scenario Tier Only Low WTT has the highest aggregated emission from 2024 to 2050. However, the tier only scenario with base WTT factors (i.e. Mixed scenario Tier Only Base WTT) emits almost the same amount. The scenario with the lowest NO<sub>x</sub> emissions is Mixed scenario High WTT, which results in 1.1% lower NO<sub>x</sub> emissions than Mixed scenario Base WTT.

When comparing the base, low and high WTT scenarios with their Tier Only counterparts there is a slightly larger difference, which demonstrate increased emissions of 1.5% (low WTT), 2.1% (base WTT) and 2.9% (high WTT). Choice of NO<sub>x</sub> emission factors may therefore impact the results more than the upstream GHG emission factors. The maximum difference in aggregated emission is between and Mixed scenario High WTT and Mixed scenario Tier Only Low WTT, with 3.3% higher NO<sub>x</sub> emissions in the latter case.

Upstream GHG factors influence the results more when using fuel-specific NO<sub>x</sub> emission factors rather than Tier values as the difference between emission factors for conventional and renewable fuels is larger. However, NO<sub>x</sub> emissions are not particularly sensitive to differences in WTT and NO<sub>x</sub> emission factors overall.

### 3.4.3 Influence of methane slip assumption

The sensitivity of the results for different assumptions on methane slip was investigated both for the *Mixed* and *Gas* scenarios, see Figure 23. The corresponding number of conventional ships over time (on European level) for these scenarios with different levels of methane slips are indicated in Figure A11.

The 0.2%, 3.1% and 6.4% methane slip values correspond to WTW emission factors of 1.43, 17.68 and 36.5 g CO<sub>2e</sub>/MJ respectively, which are added to the assumed WTW emission factors of LNG and LBG. The higher value does not meet the 2050 reduction targets at 18.23 g CO<sub>2e</sub>/MJ<sup>6</sup>.

With 3.1% slip, LBG ends up with a total emission factor of 25.92 g CO<sub>2e</sub>/MJ, meaning it would not be compliant with the FuelEU Maritime reduction target for 2050. The model compensates for this by retrofitting more ships to electricity, which is assumed to have an emission factor of zero.

Variation in slip makes no significant difference in GHG emissions for the mixed scenario as the model adapts and assigns more renewable fuel. However, in the gas scenario, a slight negative compliance is reached for 6.4% slip since LNG in this case gets a higher emission factor than the fuel oils it replaces, and because it is assumed to be assigned to all newbuilds. For 0.2% slip, the scenarios are even more over compliant.

For other pollutants, higher slip leads to less emissions due to more ships being assigned renewable fuels to compensate for higher GHG emissions, and vice versa. Figure 24 shows differences in SO<sub>x</sub> emissions for the *Mixed* and *Gas* scenarios. For the *Mixed* scenario, the aggregated SO<sub>x</sub> emissions from 2024 to 2050 differ around 1.6% from the 3.1% slip baseline in both directions, increasing for 0.2% slip and decreasing for 6.4% slip. For the Gas scenario, the difference is around 2.8% more for the 0.2% slip compared to the 3.1% slip baseline, and 3.5% less than the baseline for 6.4% slip.

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<sup>6</sup> Calculated as  $0.8 \times 91.16$  g CO<sub>e</sub>/MJ (80% reduction in 2050 compared to the baseline value).

POTENTIAL ENVIRONMENTAL EFFECTS OF FUEL EU MARITIME FOCUSING

Greenhouse gases and selected air and water pollutants  
June 2026

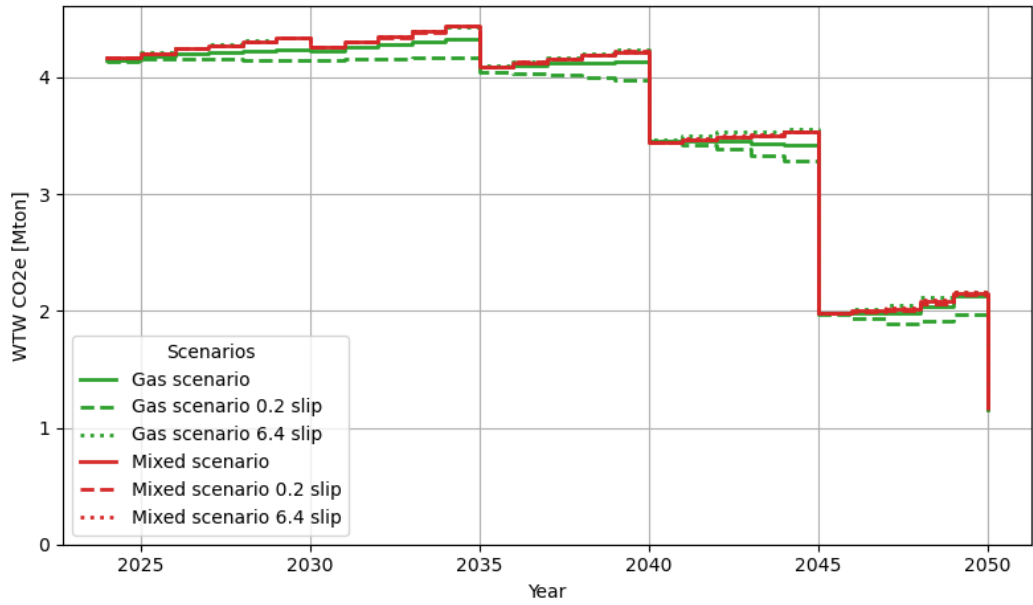


Figure 23: Development of WTW greenhouse gas emissions in the gas and mixed scenario for different assumptions on methane slip.

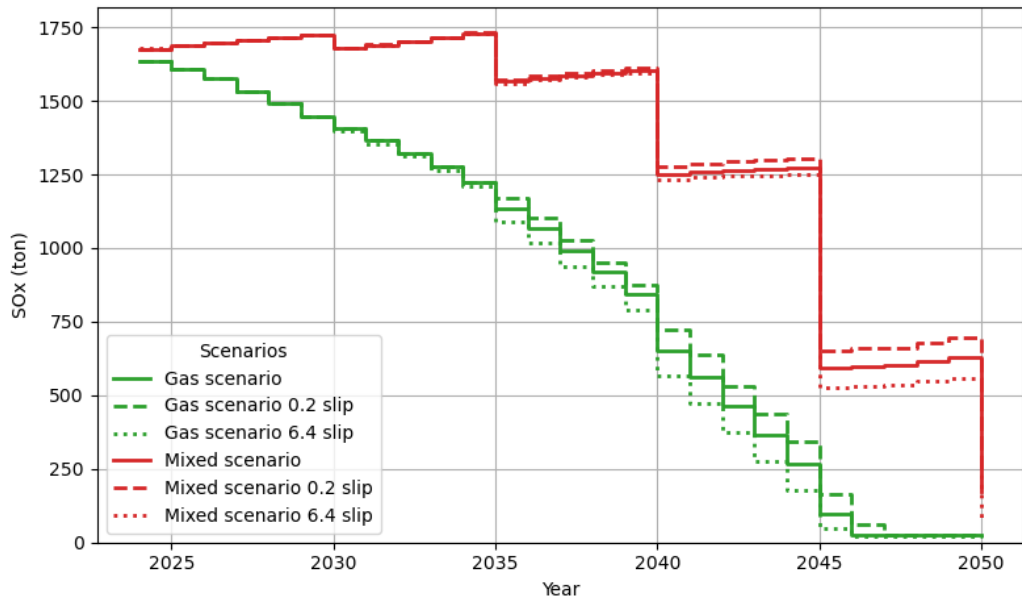


Figure 24: SO<sub>x</sub> emissions for the Mixed scenario and Gas scenario for different slip assumptions.

### 3.4.4 Alternative fuel mix scenario

The fuel consumption in the Alternative fuel mix scenario is presented in Figure 25. In terms of number of conventional ships per year and emissions of GHGs, SO<sub>x</sub> and scrubber water this scenario only differs slightly from the Mixed scenario. For PM (Figure 26) and NO<sub>x</sub> (Figure 27), the emissions differ, however. The *Alternative fuel mix* scenario uses high amounts of biodiesel, which leads to higher PM emissions than in the other fuel mix scenarios.

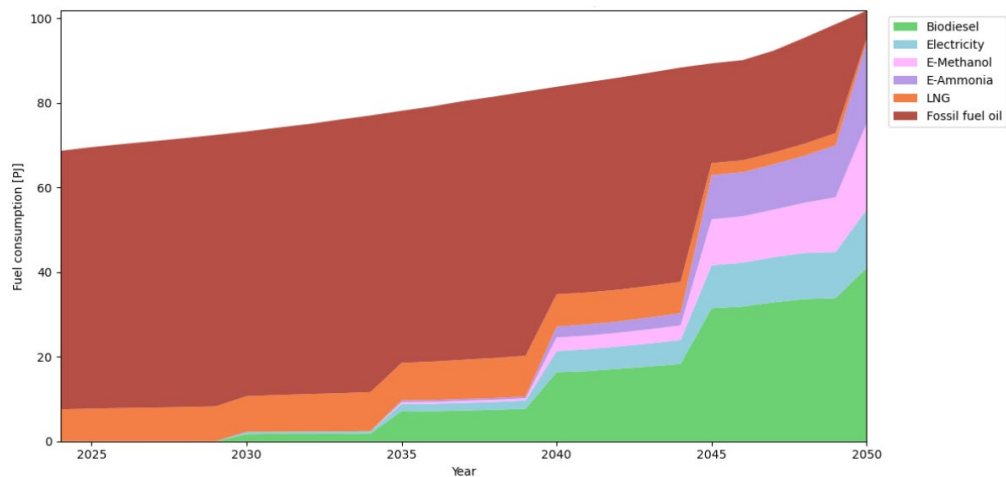


Figure 25: Fuel consumption from 2024 to 2025 for Swedish related shipping in the Alternative fuel mix scenario.

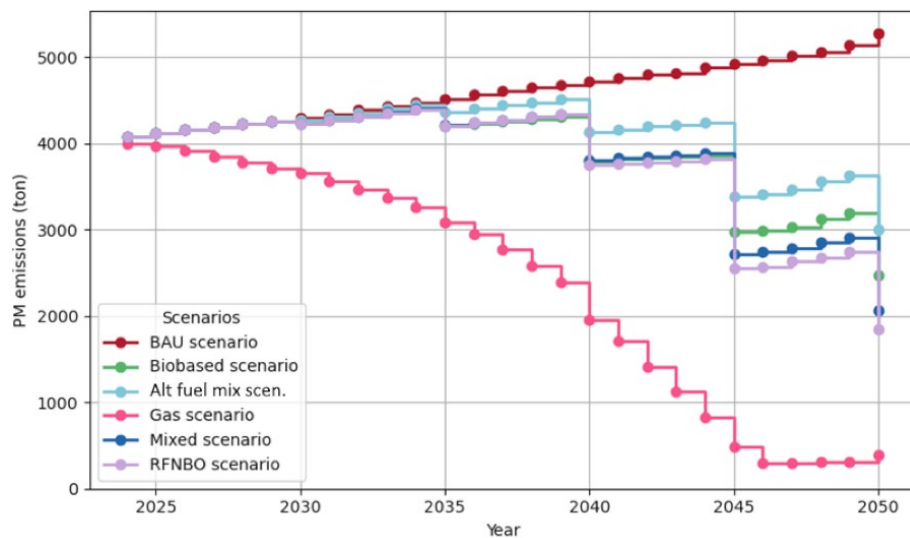


Figure 26: PM emissions of the Alternative fuel mix scenario, in comparison to the PM emissions in the BAU and fuel mix scenarios.

POTENTIAL ENVIRONMENTAL EFFECTS OF FUEL EU MARITIME FOCUSING

Greenhouse gases and selected air and water pollutants  
June 2026

For NO<sub>x</sub>, the Alternative fuel mix scenario instead has the lowest emissions, except for the Gas scenario (see Figure 27). This is because of the high numbers of electric ships in the alternative fuel mix scenario, which have zero NO<sub>x</sub> emissions. The model results are thereby overall sensitive to the assumed fuel mix but does not change the model dynamics.

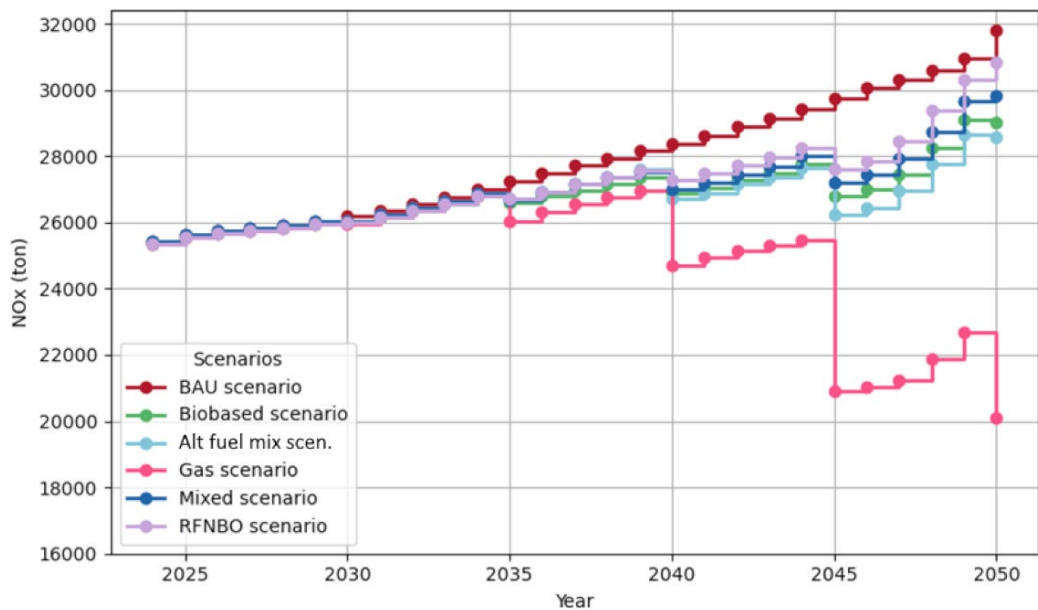


Figure 27: NO<sub>x</sub> emissions of Alternative fuel mix scenario compared to the BAU and fuel mix scenarios.

## 4 Discussion and conclusions

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This report presents the FEMAR model and its application to assess the environmental implications of the FuelEU Maritime regulation for Swedish-related shipping. The results show that, while GHG emissions converge across scenarios due to the structure of the regulation, other pollutants vary substantially depending on the chosen compliance pathway i.e., fuels introduced. Emission reductions for GHGs and all pollutants except NO<sub>x</sub> are largely concentrated in the later part of the period, with most changes occurring after 2040–2045, while limited reductions observed before 2035.

The results show a stepwise introduction of renewable fuels, following the regulation, with pronounced changes in emissions around regulatory milestones, particularly around 2040 and 2045. This pattern is a direct consequence of the compliance balance formulation in FuelEU Maritime, where the fleet is modelled to meet the GHG intensity target each year with minimal deviation. As a result, the FEMAR model reproduces the intended regulatory effect, with GHG emissions closely following the policy trajectory largely independent of the chosen fuel mix. The amounts of renewable fuels used per year are limited for all scenarios assessed until 2035, but the differences in uptakes begin to differ between scenarios after 2035 (as the targets become stricter).

This is consistent with insights on the influence of long vessel lifetimes and capital stock inertia in the shipping sector. However, real-world actors may anticipate future regulatory tightening, potentially leading to earlier adoption of alternative fuels and a more gradual transition than represented in this report. Thus, the timing of emission reductions is not only a function of technology availability, but also of regulatory design and compliance behaviour. There are many different fuel mixes for Swedish related shipping which fulfil the requirements of FuelEU Maritime. Which fuels are adopted are not regulated by the legislation and aspects such as fuel price, market mechanism, availability and other legislations will influence which fuels enter the market (Styhre et al, 2025).

A key mechanism captured by the FEMAR model is the connection between fuel-specific emission factors and the number of vessels required to transition to meet compliance. If the shipping fleet follows the reduction requirements in FuelEU Maritime, the GHG emissions, from a WTW perspective, will be almost the same regardless of the fuel mix implemented. Fuels with lower well-to-wake GHG intensities require fewer vessels to switch fuel, resulting in a slower phase-out of

conventional ships and, consequently, higher emissions of SO<sub>x</sub> and PM emissions associated with fossil fuel combustion than in the case of a more substantial vessel replacement due to renewable fuels with higher GHG emissions. This effect is consistently observed across both the single-fuel and fuel-mix scenarios assessed.

SO<sub>x</sub> emissions are highly sensitive to fuel switching and fleet composition, and near-zero emissions are achievable under all transition pathways that phase out fuel oils containing sulphur. SO<sub>x</sub> emissions are strongly and consistently reduced across all FuelEU Maritime compliance scenarios, but the magnitude and timing of reductions depend on the extent and speed of the phase-out of sulphur-containing fuels. Across scenarios, SO<sub>x</sub> emissions decrease from approximately 1 650–1 700 tons in 2025 to around 500–700 tons by 2045–2050, corresponding to a reduction of roughly 65–75% compared to BAU. In the *Gas* scenario, emissions approach near-zero levels already around 2045. The sensitivity analysis further confirms that SO<sub>x</sub> emissions are influenced by assumptions affecting fleet turnover. Varying upstream emission factors results in a cumulative change of +10.6% (low WTT) and –6.2% (high WTT) in total SO<sub>x</sub> emissions over the period compared to the baseline WTT scenario. This reflects the strong dependence of SO<sub>x</sub> emissions on the number of conventional ships remaining in operation rather than on marginal changes in fuel properties. The timing of actual SO<sub>x</sub> emission reduction depends on both regulatory design and behavioural assumptions. While FuelEU Maritime enables long-term SO<sub>x</sub> reductions, earlier reductions would require either faster fleet turnover or complementary policy measures targeting sulphur emissions more directly.

PM emissions decrease across all FuelEU Maritime compliance scenarios, but the extent of reduction varies significantly depending on fuel type and combustion characteristics. PM emissions are reduced by approximately 40–65% in liquid fuel scenarios (*Biobased*, *Mixed*, and *RFNBO*) and up to 90% in the *Gas* scenario. These differences highlight that PM emissions are not only linked to the phase-out of conventional fuels, but also strongly influenced by fuel composition and combustion processes. Liquid fuels, including biofuels and electrofuels, provide moderate reductions but do not eliminate particulate formation, whereas gaseous fuels result in significantly lower emissions due to reduced soot formation. The *Alternative fuel mix* scenario further illustrates that even ambitious fuel mixes dominated by liquid fuels may not achieve substantial PM reductions.

The coupling between SO<sub>x</sub> emissions and scrubber water discharge is particularly clear in the results as scrubbers are only used on vessels operating on sulphur-

containing fuels. The FEMAR model captures this relationship explicitly, showing that reductions in SO<sub>x</sub> emissions are mirrored by reductions in scrubber water volumes. Increased adoption of renewable fuels leads to decreased scrubber water discharge and as such a similar relationship can be shown as for PM and SO<sub>x</sub> emissions. However, the sensitivity analysis demonstrates that scrubber-related impacts are highly dependent on behavioural assumptions regarding scrubber uptake. Scrubber water discharge varies by more than a factor of two depending on scrubber uptake assumptions, exceeding 500 Mm<sup>3</sup> annually under high-use scenarios. Increased scrubber use is consistent with earlier projections showing that, in the absence of strong policy or fuel switching, scrubber adoption leads to sustained or increasing scrubber discharges. This reinforces the interpretation that scrubbers represent a trade-off mechanism, shifting emissions from air to water, and that regulatory treatment of scrubber use is a critical determinant of environmental outcomes.

Scrubber use could realistically increase above the default level if scrubber water discharge is not banned to a greater extent and if the industry keeps deeming it profitable. Something closer to the lower level is also reasonable if more bans are put in place. Some countries (such as Sweden, Finland and Denmark) have banned all release of scrubber water within their territorial seas, and many countries have some form of limitation in place. If it becomes too difficult to discharge the scrubber water, ships are likely to opt out.

The modelled characteristics of NO<sub>x</sub> emissions differs from that of other pollutants. Across most scenarios, emissions remain relatively stable or increase over time, despite compliance with FuelEU Maritime. NO<sub>x</sub> emissions vary by only 1–2% under different lifecycle emission assumptions and remain within 10–20% across most fuel pathways. This reflects how modelled newbuilds comply with Tier III standards, but that fuel switching alone does not significantly alter emission factors for most fuels. For NO<sub>x</sub> emissions, a shift to electricity i.e., battery electric propulsion and increased on shore power supply, leads to the largest emission reduction. The BAU scenario results in a remaining 31 700 tonnes of NO<sub>x</sub> emissions in 2050, and as the national inventory for NO<sub>x</sub> emissions in Sweden 2024 was 99 000 tonnes (excluding international shipping and air travel) (Naturvårdsverket, 2026), this is a significant remaining source of pollution.

These findings underscore the importance of integrating air pollution policy with decarbonization strategies, as climate-oriented fuel transitions do not inherently deliver co-benefits for NO<sub>x</sub> emissions without complementary technical and

regulatory measures. While alternative fuels can influence NO<sub>x</sub> emission levels, substantial reductions are typically achieved through technologies such as SCR or zero-emission onboard technologies (Åström et al., 2018; Fridell and Windmark, 2018).

The sensitivity analysis demonstrates how variations in upstream emission factors (WTT), methane slip, and fuel mix assumptions influence the pace of fleet transition and the resulting pollutant emissions. WTW assumptions were found to significantly affect the number of conventional ships remaining in the fleet, thereby influencing SO<sub>x</sub>, PM, and scrubber water emissions. At the same time, the NO<sub>x</sub> emissions were relatively insensitive to these assumptions. Overall, the uncertainty analysis shows that while quantitative results vary, the qualitative relationships identified in the study are robust.

This study includes analysis of fuel technologies where public measurements of emissions are not yet available, for example ammonia propulsion. E-ammonia has potential additional emissions of NO<sub>x</sub> emissions and ammonia leakage from the engine which can lead to higher amounts of NO<sub>x</sub> as well as increased marine eutrophication (Kanchiralla et al., 2023). Public measurement on ammonia ICEs is therefore required to validate the findings for this fuel pathway.

Not all shipping segments are currently covered by the FuelEU Maritime legislation. For Sweden, most of the vessels not included are in the General Cargo segment (see 2.1.1) and if not included in the FuelEU Maritime legislation in the future these emissions will likely not be mitigated without other regulations.

The results point to that GHG intensity-based regulation combined with pooling leads to partial fleet transition, where only a subset of vessels adopt low-emission fuels. Recent development in the Swedish fleet shows that the early adoption of FuelEU Maritime is in line with this, where LBG is adopted on individual vessels with high fuel consumption to compensate for conventional fuel use in the fleet (Grahm et al, 2025).

From a policy perspective, the results indicate that FuelEU Maritime, while effective for reducing GHG emissions, does not ensure improvements in other environmental indicators. The technology-neutral design allows for compliance pathways with substantially different impacts on air quality and marine ecosystems. This suggests that achieving broader environmental objectives will require complementary measures, such as stricter NO<sub>x</sub> reductions policies,

regulation of scrubber use, or incentives for technologies that deliver co-benefits across multiple pollutants.

In conclusion, this study demonstrates that the FEMAR model can analyse the environmental implications of maritime fuel transitions under regulatory constraints. GHG emissions converge across all scenarios due to regulatory constraints, while non-GHG pollutants vary considerably depending on fuel pathway. Thus, while FuelEU Maritime effectively drives GHG reductions, the broader environmental performance of the shipping sector depends on the actual choice of renewable fuels and technologies.

## 5 Reference list

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Bastos, J., Monforti-Ferrario, F., Melica, G. (2024). *GHG Emission Factors for Electricity Consumption*. European Commission, Joint Research Centre (JRC) [Dataset] PID: <http://data.europa.eu/89h/919df040-0252-4e4e-ad82-c054896e1641>

Brynolf, S., Hansson, J., Kanchiralla, F., Malmgren, Elin., Fridell, Erik., Stripple, H., Nojpanya, P. (2023). *Life Cycle Assessment of Marine Fuels in the Nordic Region – Task 1C (version 1.1) - Roadmap for the introduction of sustainable zero-carbon fuels in the Nordic region*. Gothenburg, Sweden. <https://futurefuelsnordic.com/life-cycle-assesment-of-selected-fuels/>

Chen, W., Cui, J., Zhang, Z., Wang, Q., Dong, P., Meng, X., Tian, J., Tian, H., Long, W., & Liu, S. (2026). *Near-Zero NH<sub>3</sub>/N<sub>2</sub>O emissions enabled in two-stroke ammonia-diesel dual-direct-injection engines: An experimental study via synergistic diesel multiple injection strategy*. *Fuel*, 411, 137926. <https://doi.org/10.1016/j.fuel.2025.137926>

Comer, B., Beecken, J., Vermeulen, R., Sturup, E., Paschinger, P., et al. (2024). *Fugitive and unburned methane emissions from ships (FUMES)*. International Council on Clean Transportation: Washington, DC, USA.

Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003. (EU ETS). <https://eur-lex.europa.eu/eli/dir/2003/87/oj/eng>

DNV (2020). *Maritime Forecast to 2050 - Energy Transition outlook 2020*. <https://www.dnv.com/maritime/maritime-forecast/>

DNV (2024). *FuelEU Maritime – Requirements, Compliance Strategies, and Commercial Impacts*. <https://www.dnv.com/publications/fueleu-maritime-white-paper/>

DNV (2025a). *Energy Transition Outlook 2050 - Maritime Forecast to 2025*. [https://www.dnv.com/energy-transition-outlook/download/?utm\\_medium=search&utm\\_source=google&utm\\_campaign=eto\\_2025\\_download%2F](https://www.dnv.com/energy-transition-outlook/download/?utm_medium=search&utm_source=google&utm_campaign=eto_2025_download%2F)

DNV (2025b). *Strategies for navigating FuelEU Maritime compliance*. <https://www.dnv.com/expert-story/maritime-impact/strategies-for-navigating-fueleu-maritime-compliance/>

DNV (2025c). *Maritime forecast to 2050* (Energy Transition Outlook 2025). DNV.

Esquivel-Elizondo, S., Walkowiak, B., Sartrezakis, S., Buma, B. (2025). *Climate Impact of Direct and Indirect N<sub>2</sub>O Emissions from the Ammonia Marine Fuel Value Chain*. American Chemical Society. doi: <https://doi.org/10.1021/acs.est.4c13135>

Faber, J., Hanayama, S., Zhang, S., Comer, B., Hauerhof, E., et al. (2020). *Fourth IMO GHG Study*. CE Delft.  
<https://www.imo.org/en/ourwork/environment/pages/fourth-imo-greenhouse-gas-study-2020.aspx>

Fridell, E., & Windmark, F. (2018). *Shipping emissions in the Baltic Sea and the North Sea: Current levels and future scenarios*. IVL Swedish Environmental Research Institute Report, Gothenburg, Sweden.

Fridell, E., Winnes, H., Eklund, V. (2020). *Emission factors for shipping in scenarios*.

Fridell, E., R. Parsmo, J.P. Jalkanen, E. Majamäki, and J. Borken. (2022). *Deliverable 1.4, "Description of scenarios to be used in EMERGE". Evaluation, control and Mitigation of the EnviRonmental impacts of shippinG Emissions*.

Grahn, D., Malmgren, E., Hjort, A., Styhre, L., & Samuelsson, B. (2025). *Frivilliga klimatmål och dess inverkan på användning av LBG till sjöfart*.

Hansson, J., Zetterberg, L., Rootzén, J., Parsmo, R., Fridell, E., et al. (2022). *Impact of including maritime transport in the EU ETS*.

Hermansson, A. L., Hassellöv, I.-M., Grönholm, T., Jalkanen, J.-P., Fridell, E., Parsmo, R., Hassellöv, J., & Ytreberg, E. (2024). *Strong economic incentives of ship scrubbers promoting pollution*. *Nature Sustainability*, 7, 812–822.  
<https://doi.org/10.1038/s41893-024-01347-1>

Holmgren, K., Hao Chen, B., Wickman, C., Hansson, J., Malmgren, E., Olsson, M., & Lundblad, M. (2025). *Transportrelaterade utsläpp av växthusgaser för godstransporter i Sverige – Nutid och scenarier under omställning för att nå klimatmål (2022.5.2.3)*.

Holmgren, K., Hao Chen, B., Wickman, C., Hansson, J., Malmgren, E., Olsson, M., & Lundblad, M. (2025). *Transportrelaterade utsläpp av växthusgaser för godstransporter i Sverige – Nutid och scenarier under omställning för att nå klimatmål (2022.5.2.3)*.

IMO. (2008). *Nitrogen Oxides (NO<sub>x</sub>)* (Regulation 13 of MARPOL Annex VI).  
[https://www.marpoltraininginstitute.com/MMSKOREAN/MARPOL/Annex\\_VI/r13.htm](https://www.marpoltraininginstitute.com/MMSKOREAN/MARPOL/Annex_VI/r13.htm)

IMO. (2023). *Information related to the global 0.50% sulphur limit (IMO 2020) and outcome of the sulphur monitoring for 2023 (MEPC 82/INF.2)*. Note by the secretariat.

Lehtoranta, K., Vesala, H., Flygare, N., Kuittinen, N., & Apilainen, A.-R. (2025). *Measuring Methane Slip from LNG Engines with Different Devices*. *Journal of Marine Science and Engineering*, 13(5), 890. <https://doi.org/10.3390/jmse13050890>

Moldanova, J., Fridell, E., Popvicheva, Olga, Demirdjian, B., Tishkova, Victoria, Faccinetto, Alessandro, Focsa, Cristian, F. (2009). *Characterisation of particulate matter and gaseous emissions from a large ship diesel engine*.  
doi:10.1016/j.atmosenv.2009.02.008

Naturvårdsverket (2026)., *Informative Inventory Report Sweden 2026, SWEDISH ENVIRONMENTAL PROTECTION AGENCY REPORT*.

Parsmo, R. (2025). *Evaluating environmental policy instruments for ships*. [Licentiate thesis, Chalmers University of Technology].  
[https://research.chalmers.se/publication/544763/file/544763\\_Fulltext.pdf](https://research.chalmers.se/publication/544763/file/544763_Fulltext.pdf)

Parsmo, R., Hansson, J., Brynolf, S., Fridell, E., & Ytreberg, E. (2026). Shipping, emissions and EU emissions trading system (ETS): *Evaluation of abatement strategies in different scenarios (in manuscript)*.

Raucci C., McKinlay C., Karan A. (2023). *The future of maritime fuels. What you need to know*. Lloyd's Register Maritime Decarbonisation Hub.

Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023. (FuelEU Maritime). Regulation - 2023/1805 - EN - EUR-Lex

Regulation (EU) 2023/1805 *on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC (Text with EEA relevance)*. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1805>

S&P GLOBAL. (2023). *Seaweb - Maritime Portal: Ship database*.

Storm, B., Hansson, J., Jivén, K., Hernández Leal, M., 2026. Local versus regional production of hydrogen-based fuels and port infrastructure with focus on the Port of Gothenburg. Hydrogen, Ammonia and Methanol in hydrogen hubs in the Nordic region (H2AMN) project report. [www.ivl.se](http://www.ivl.se).

Styhre, L., Malmgren, E., Jivén, K., Stalmokaitė, I., Jutblad, N., & Priestley, M. (2025). *H2-Derivatives Market Demand Analysis for Baltic Sea Ports* (B11075 Nos. 978-91-7883-780-9). IVL Swedish Environmental Research Institute.

Transport & Environment (2023). *The Impact Of FuelEU Maritime On EU Shipping*. <https://www.transportenvironment.org/articles/the-impact-of-fueleu-maritime>

Ytreberg, E., Åström, S., Fridell, E. (2021). *Valuating environmental impacts from ship emissions – The marine perspective*. J. Environ. Manage. 282. <https://doi.org/10.1016/j.jenvman.2021.111958>

Zhou, X., Li, T., Chen, R. et al. (2024). *Ammonia marine engine design for enhanced efficiency and reduced greenhouse gas emissions*. *Nat Commun* **15**, 2110. <https://doi.org/10.1038/s41467-024-46452-z>

Åström, S., Yaramenka, K., Winnes, H., & Fridell, E. (2018). *The costs and benefits of a nitrogen emission control area in the Baltic and North Seas*. *Transportation Research Part D: Transport and Environment*, 59, 223–236.

## Appendix

This appendix includes additional estimates of fuel consumption and emissions of GHGs and other pollutants.

The total energy consumption from 2024 to 2025 for all single fuel scenarios are shown in Figure A1. The total energy consumption from 2024 to 2025 for fuel mix scenarios are shown in Figure A2-A5. Figures A6 and A7 illustrates the total energy consumption from 2024 to 2025 for the alternative fuel mix scenario and the Mixed scenario when varying the WTT emissions factors in the sensitivity assessment, respectively. The PM and Scrubber water emissions for the Mixed scenario when varying the WTT emissions factors are illustrated in Figures A9 and A10. The corresponding number of conventional ships over time (on European level) for these scenarios with different levels of methane slips are indicated in Figure A11. NO<sub>x</sub> and PM emissions for the Mixed and Gas scenarios with different levels of methane slip are illustrated in Figures A12 and A13, respectively.

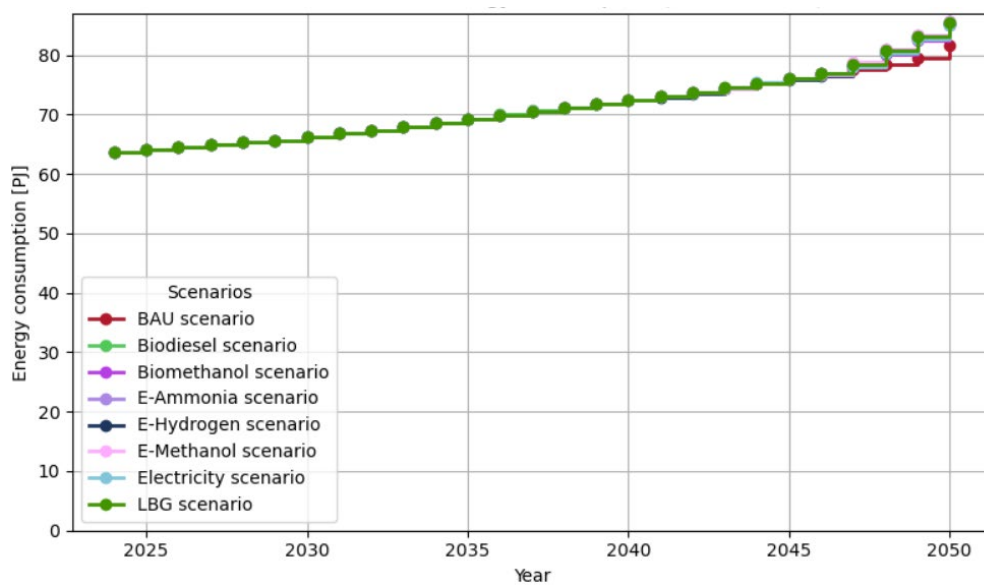


Figure A1: Total energy consumption from 2024 to 2025 for all single fuel scenario.

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Greenhouse gases and selected air and water pollutants  
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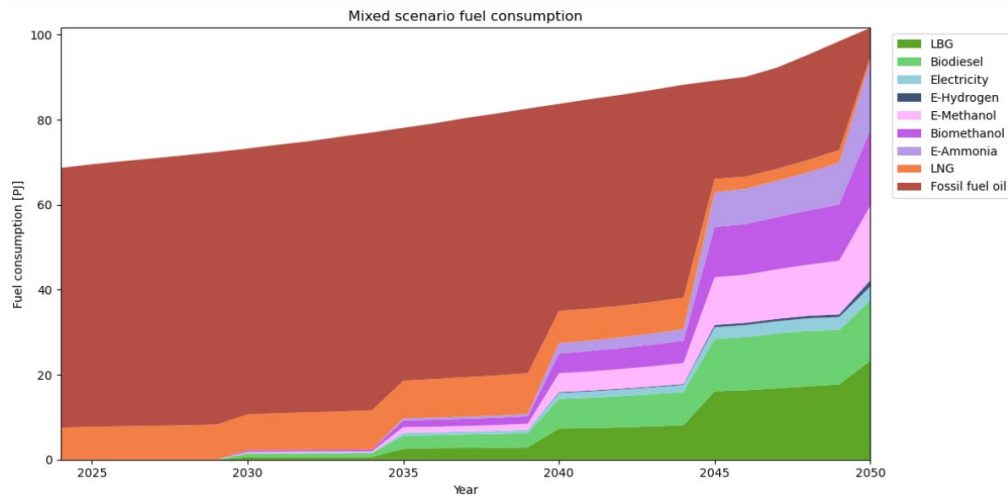


Figure A2: Fuel consumption from 2024 to 2025 for Swedish related shipping in the Mixed scenario.

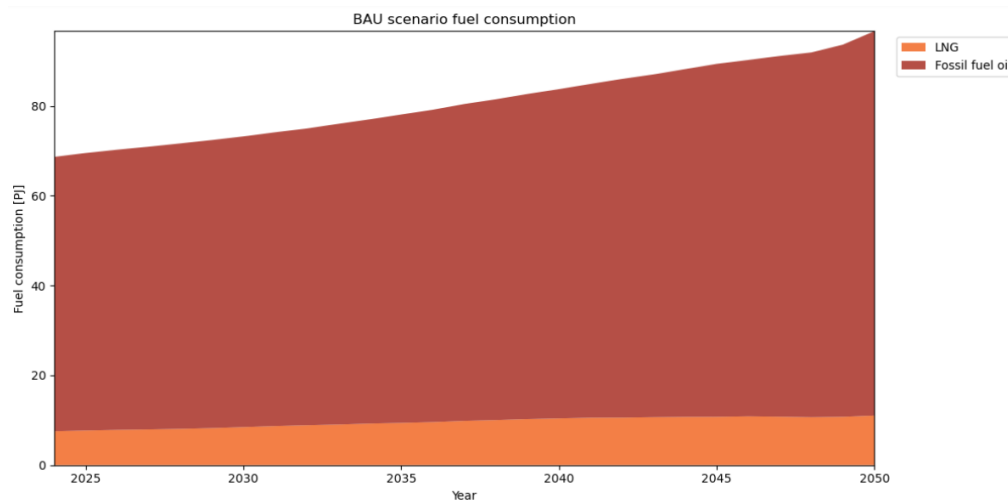


Figure A3: Fuel consumption from 2024 to 2025 for Swedish related shipping in the BAU scenario.

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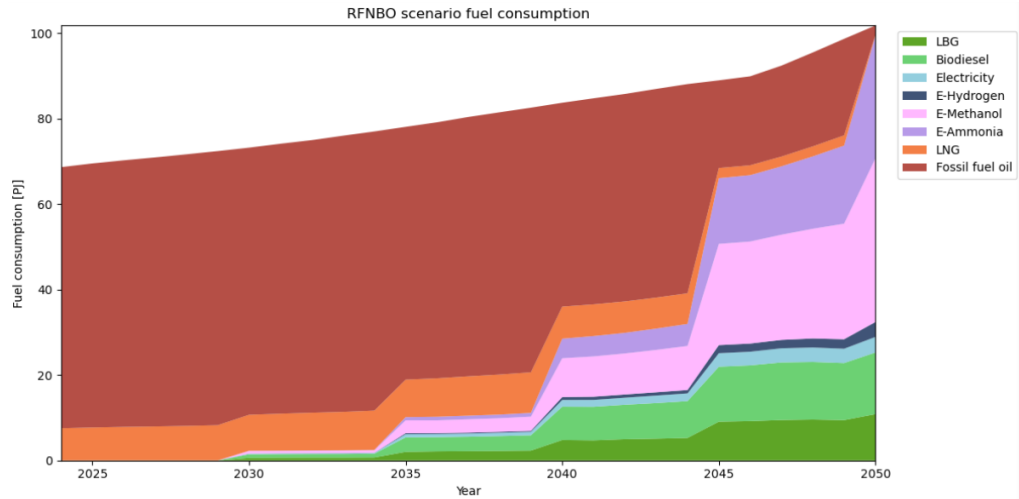


Figure A4: Fuel consumption from 2024 to 2025 for Swedish related shipping in the RFNBO scenario.

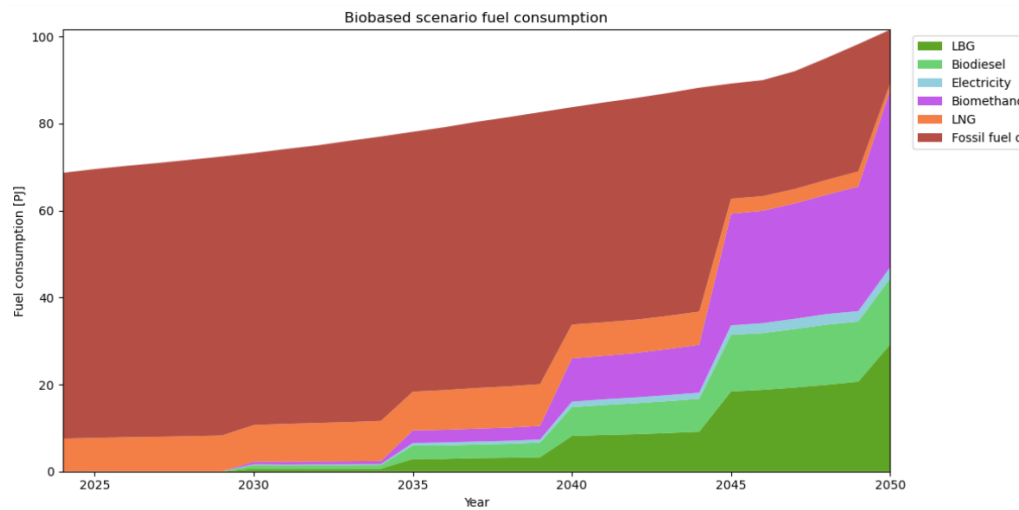


Figure A5: Fuel consumption from 2024 to 2025 for Swedish related shipping in the Biobased scenario.

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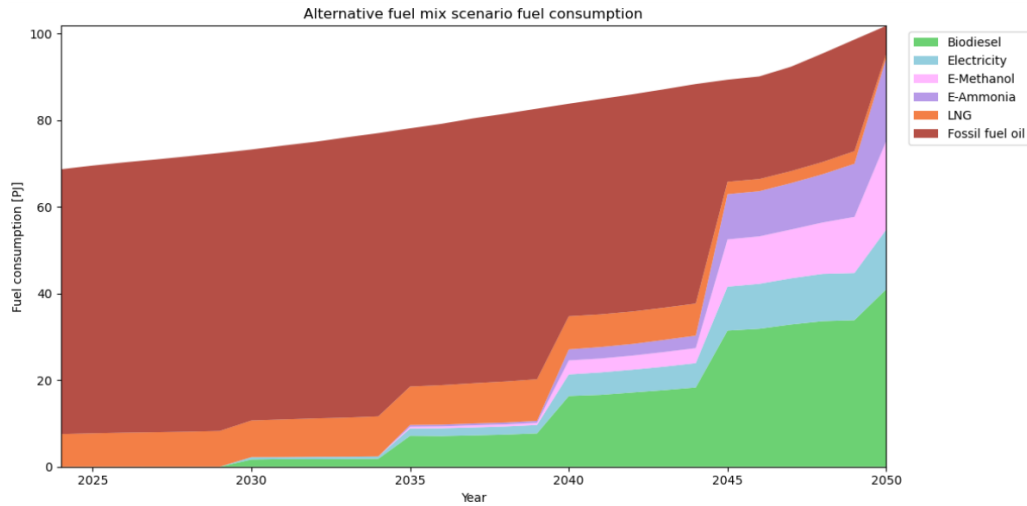


Figure A6: Fuel consumption from 2024 to 2025 for Swedish related shipping in the Alternative fuel mix scenario.

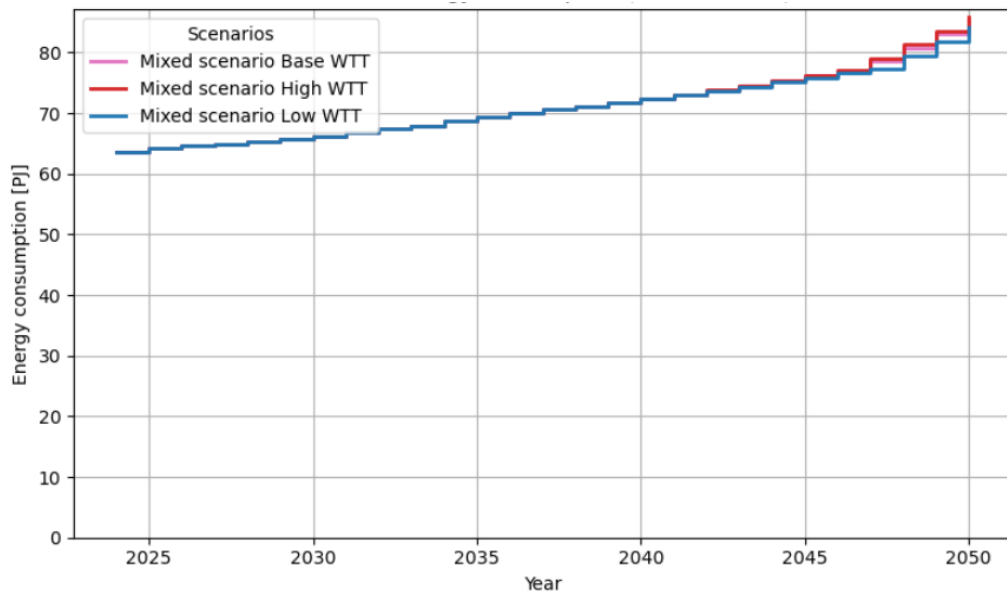


Figure A7: Fuel consumption from 2024 to 2025 for Swedish related shipping for the Mixed scenario when varying the WTT emissions factors in the sensitivity assessment.

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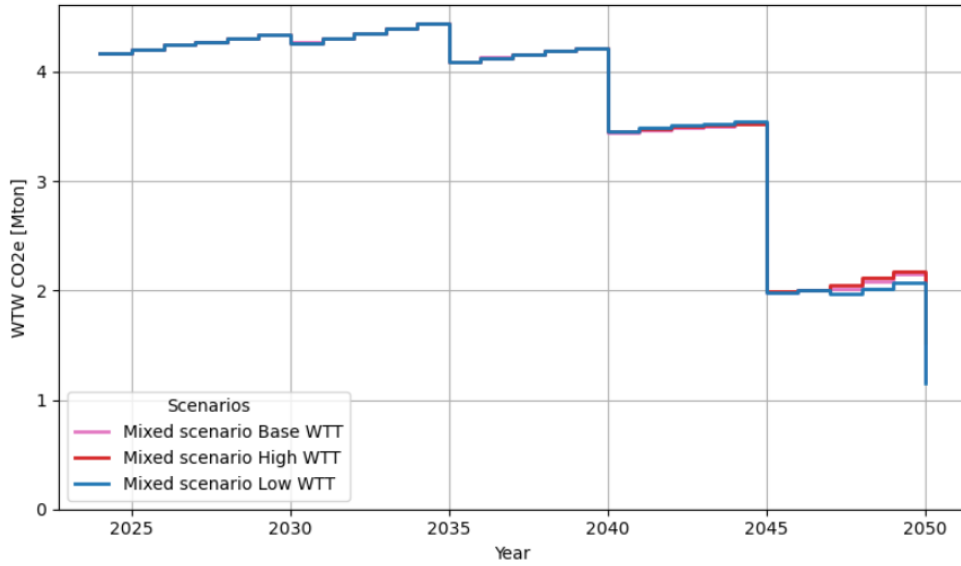


Figure A8: Estimated GHG emissions of Swedish shipping 2024 to 2025 for Swedish related shipping for the Mixed scenario when varying the WTT emissions factors in the sensitivity assessment.

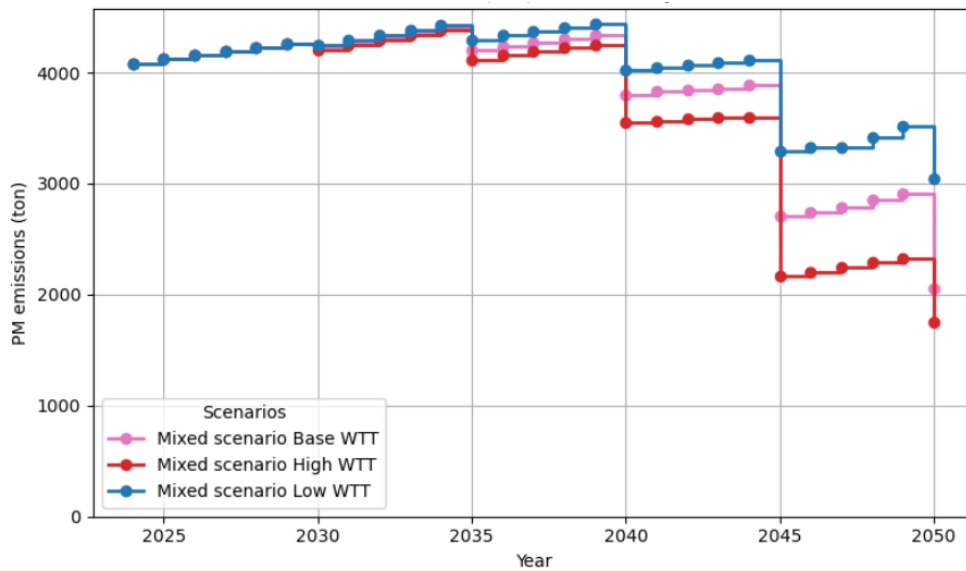


Figure A9: PM emissions for the Mixed scenario when varying the WTT emissions factors.

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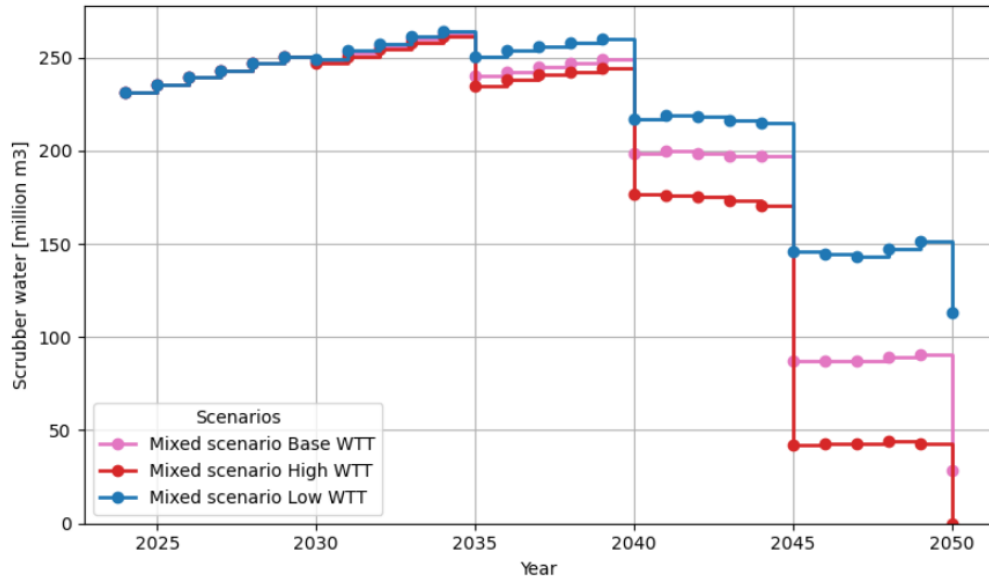


Figure A10: Scrubber water emissions for the Mixed scenario when varying the WTT emissions factors.

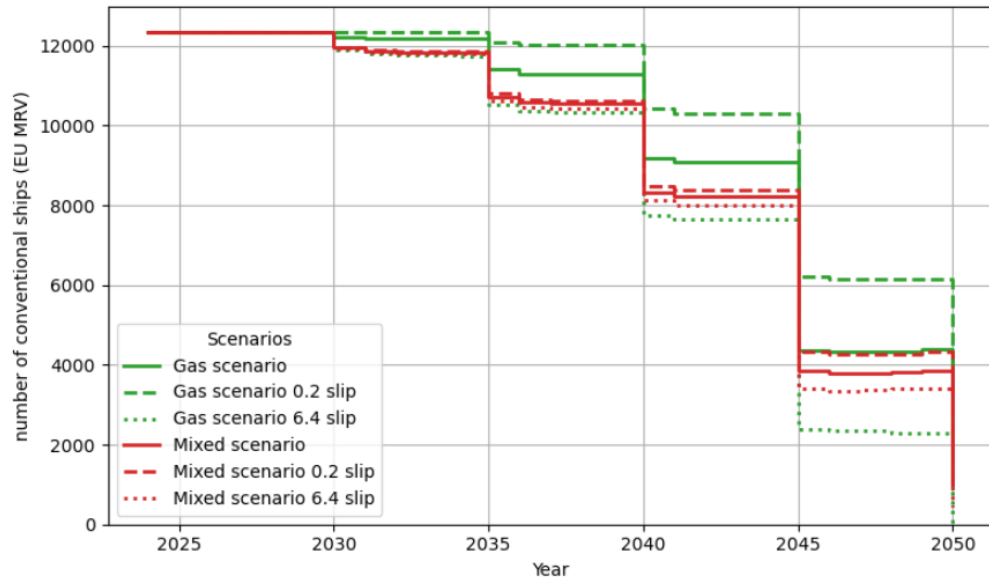


Figure A11: Number of conventional ships over time (on European level) for the Mixed and Gas scenarios with different levels of methane slips.

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Greenhouse gases and selected air and water pollutants  
June 2026

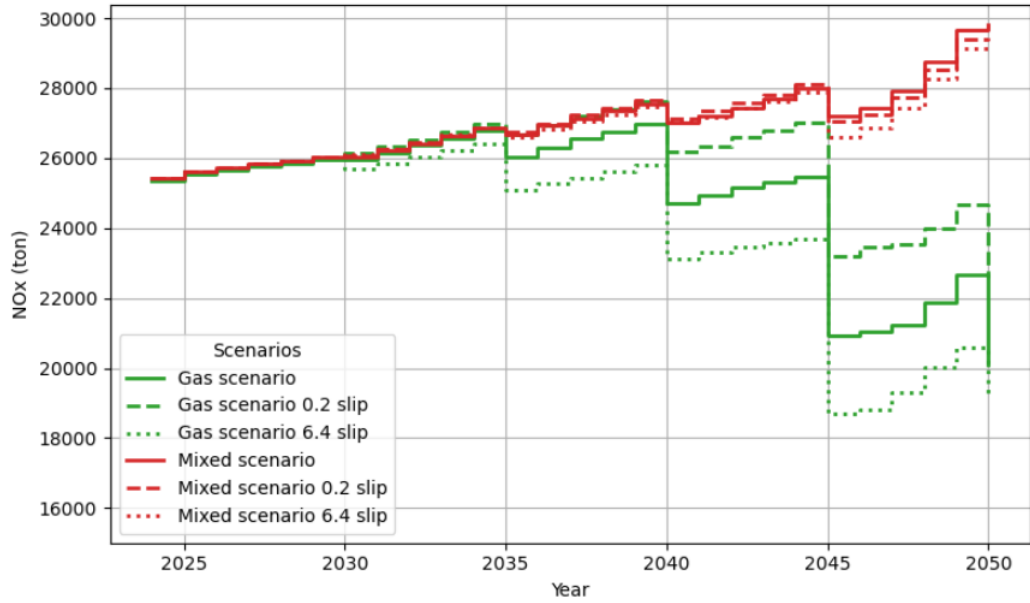


Figure A12: NO<sub>x</sub> emissions for the Mixed and Gas scenarios with different levels of methane slip. Note that the y-axis is cut off

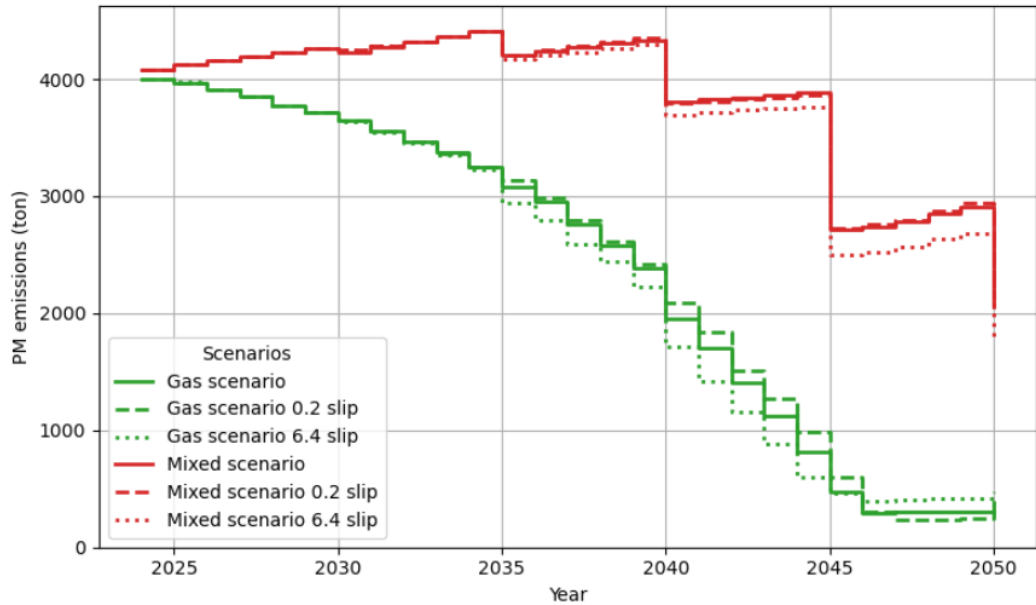


Figure A13: PM emissions for the Mixed and Gas scenario with different levels of methane slip

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