Impacts of FuelEU Maritime on the Dutch maritime sector

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Content

Summary

The European Commission has launched the FuelEU Maritime Initiative, which aims to increase the demand for renewable and low-carbon fuels (RLF) from ships sailing to and from EU ports. This report analyses the impacts of the initiative on the Dutch Maritime Sector and addresses the question whether there are benefits of supply-oriented policies in addition to FuelEU Maritime.

The European Commission has put forward three design options for FuelEU Maritime, which each have a different impact on the type of RLF that ships are expected to use to comply. Table 1 summarises the options and their impact on fuel choice and the total cost of ownership of seagoing vessels.

Table 1 - FuelEU Maritime design options and their impact on fuel choice and costs

Policy option	Fuel criteria	Examples of fuel types	TCO cost increase of ships sailing on 100% RLF (relative to ships sailing on fuel oil)
1. Each ship has to use a minimum share of RLF	Cheapest drop-in fuels	BioFAME (Fuel oil ships) Biomethane (LNG ships)	90%-250% 60%-100%
2. Each ship has to meet a limit on GHG emissions per unit of energy	Most cost-effective drop-in fuels for reducing CO_2-intensity	BioFAME (Fuel oil ships) Biomethane (LNG ships)	90%-250% 60%-100%
3. Ships have to meet a limit on GHG emissions per unit of energy as an average across the fleet	Most cost-effective fuels for reducing CO_2-intensity	BioFAME Biomethane e-methanol e-ammonia	90%-250% 60%-100% 150%-330% 200%-280%

Despite the cost increases, the competitiveness of Dutch shipowners engaged in ocean-going shipping will unlikely be affected because the regulation will apply to all ships visiting EU ports, regardless of their flag or ownership. This is different for coastal shipping, where short-sea shipping competes with land transport and inland shipping. Taking into account all agreed climate regulation for these sectors, the relative cost increase in shipping is larger than for land transport and inland shipping. In Option 3, where ships do not have to meet targets individually but collectively, the competitiveness of coastal shipping deteriorates to a lesser extent than in Options 1 and 2.

FuelEU Maritime will increase the demand for renewable and low-carbon fuels. Sustainable biomass, from which biofuels can be produced, is available in greater quantities in other parts of the world, notably in Asia. Renewable e-fuels can be produced against lower costs in other countries, notably China, India, the Arabian Peninsula, North Africa and South America, where renewable electricity from which these fuels are produced is available at lower costs. This suggests that the location of the production of fuels may shift to other regions.

A shift in the location of fuel production need not deteriorate the competitiveness of Dutch ports as bunkering ports. Transport costs for fuels are low in comparison to their value, and it is expected that there will be a significant demand for these fuels in Northwest Europe, also outside the shipping sector. Many of the chemical compounds that are candidates renewable and low-carbon fuels for the shipping sector, and certainly the e-fuels, are base chemicals and their fossil analogues are currently imported in Europe and the Netherlands at scale. This trade will likely continue when the compounds are produced in a climate-neutral way.

As a result, even though many of the fuels may not be produced at the lowest costs in Northwestern Europe, the supply of these compounds in the region will likely be good, due to the demand from other industries. Dutch ports are well equipped to provide the bunkering infrastructure for many of the candidate fuels because the compounds are currently stored and transhipped in Dutch ports.

When demand-side policies to promote the use of renewable fuels are in place, there is little added value in having supply-side policies. Supply-side policies cannot ensure that fuels are produced in The Netherlands because the location of production and the location of supply are not necessarily connected. Moreover, supply-side policies will result in higher bunker fuel costs in The Netherlands, resulting in a change in bunkering location.

1 Introduction

1.1 Policy context

The European Green Deal (EC, 2019b) emphasises the need to accelerate the transition to a low-emission and climate-neutral economy and underlines that all sectors will need to contribute, including maritime shipping. It lays out a number of policy initiatives to address maritime GHG emissions, including action to increase the uptake of low- and zero-emission fuels and Onshore Power Supply (OPS) in ports.

Against this background, the Commission has launched the FuelEU Maritime Initiative, which aims to increase the share in the fuel mix of international maritime transport of sustainable low- and zero-carbon alternative fuels (EC, 2020b).

This initiative fits well in the ambitions of the (Dutch) Green Deal on Maritime and Inland Shipping and Ports, which aims, amongst others, to reduce GHG emissions of shipping by 70% in 2050 relative to 2008 and to promote the use of alternative fuels (Rijksoverheid, et al., 2019).

1.1.1 FuelEU Maritime

The FuelEU Maritime Initiative analyses three policy options (CE Delft; Ecorys, 2020):

1. A minimum share of renewable and low-carbon fuels (RLF) per ship. This can take the form of a requirement to use a minimum share (in mass or energy content) of RLFs for voyages to and from European ports. The RLFs would need to meet certain sustainability criteria in order to be allowed to be used for compliance.

2. A maximum limit on the GHG emissions of the fuel over the life cycle per ship. This would mean that ships have to demonstrate that the fuel mix used on voyages to and from EU ports has GHG emissions per unit of energy that are lower than the limit value.

3. The same as Option 2 above, with additionally options for pooled compliance and rewards for overachievers so that groups of ships can comply collectively.

At the time of writing, the European Commission had not proposed one of these options (or another one) as the preferred option. It is expected that the regulatory proposal will be published in July 2021.

1.1.2 Renewable Energy Directive

The Renewable Energy Directive II (Directive(EU) 2018/2001) requires Member States to oblige fuel suppliers within their jurisdiction to supply a minimum share of renewable energy to the land-transport sector (14% in 2030). While maritime bunkers are not included in the calculations of the total amount of energy consumed by the transport sector, Member States are allowed to opt-in maritime fuels so that fuel suppliers can include renewable fuels supplied to the maritime sector in their obligation. When they do so, fuels sold to the maritime sector can be multiplied with a factor 1.2 for the obligation.

The European Commission is currently reviewing the Renewable Energy Directive II.
A proposal for amendments is expected in July 2021.

1.2 Aim of the study

The aim of this study is to support the Dutch government in preparing a position on proposals of the European Commission related to the supply and use of renewable fuels by the maritime sector. It does so by analysing the impacts of the upcoming proposals on the Dutch maritime sector.

The specific objectives of the study are to analyse whether, and if so how, the different options of the FuelEU Maritime Initiative have different impacts on the competitiveness of Dutch shipping companies, of the competitiveness of Dutch bunker fuel suppliers and of Dutch ports as bunkering ports; and the competitiveness of Dutch producers of marine fuels. In addition, the study analyses whether there are benefits of keeping or extending the opt-in for maritime fuels in a revised Renewable Energy Directive or develop other regulation aimed at fuel suppliers in case demand incentives are in place.

1.3 Scope

The Dutch maritime sector is defined as comprising Dutch shipping companies, producers and suppliers of maritime fuels, and ports.

Dutch shipping companies have diverse activities and are active in many sectors but stand out because they comprise a relatively large number of small companies active in coastal trades, and a very strong dredging sector.

Dutch ports are the major bunker ports in Europe and rank amongst the largest bunker ports worldwide in terms of volume of fuel bunkered.

While the scope of the FuelEU Maritime proposal has not yet been defined, we assume that the requirements will apply to the ships included in the EU MRV Regulation (Regulation (EU) 2015/757): ships above 5,000 GT engaged in commercially transporting cargo or passengers on voyages to and from EU ports.

The competitiveness impacts are assessed for 2030. At the root of the analysis lie calculations of total costs of ownership (see next section). While the level of stringency of FuelEU Maritime has not been announced, we assume for our calculations that about 10% of the fuels have to be renewable low-carbon fuels or that GHG emissions of the fuels have to be some 10% lower than fossil fuels per unit of energy.

A selection has been made of the renewable low-carbon fuels that are included in the analysis (because of time and budget constraints). Two biobased fuels have been selected – bioFAME, which is currently probably the most widely supplied fuel to the marine sector, and (liquefied) biomethane – and two e-fuels – e-ammonia and e-methanol (other low-carbon fuels have not been considered, such as fuels based on blue hydrogen – hydrogen generated from fossil fuels in a process where CO_2 emissions are captured and stored permanently – or recycled carbon fuels). The first two fuels have been chosen because they can be used without modifications to the engine and the fuel system by ships currently sailing on fuel oil or LNG, respectively. The latter are the e-fuels that in various studies appear to have the lowest costs. There are currently a small number of ships sailing on methanol, both methanol tankers and other ship types. Although the fuel is mostly of fossil origin, the fact that ships are using methanol as a fuel means that costs of the required changes to engines and fuel systems can be estimated with a relatively low uncertainty. Ammonia is not yet used as a marine fuel, although multiple trials are currently conducted by a number of engine manufacturers and wider consortia.

The selection of fuels for the analysis implies that, according to the authors of this study, these fuels may become important or dominant fuels when shipping decarbonises. It does not imply that other fuels may not become relevant. Other biobased fuels that may gain market shares include biomethanol, bioethanol, hydrotreated vegetable oil, bio-dimethyl ester, pyrolysis oil, and Fisher-Tropsch biodiesel (CE Delft; Ecorys, 2020). Other e-fuels include liquefied or compressed hydrogen, e-methane and Fischer-Tropsch e-fuels.
In general, all these biofuels have comparable cost prices per unit of energy, and e-fuels have somewhat higher cost prices, although the ranges often overlap (CE Delft; Ecorys, 2020). As such, the selected biobased fuels can be considered to also other represent drop-in bio- or e-fuels, while the selected e-fuels can be considered to also other represent bio- or e-fuels that require modifications to the engine and fuel systems.

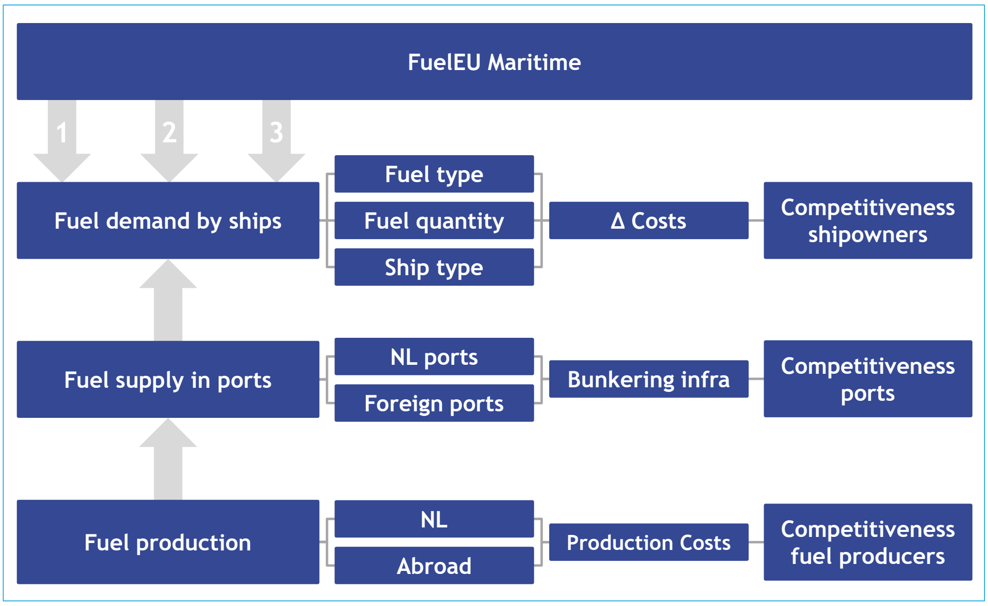
1.4 Methodology

The framework for the analysis is depicted graphically in Figure 1. Each of the three possible options of FuelEU Maritime will affect the fuel demand of ships. Chapter 2 analyses the total cost of ownership of selected renewable low-carbon fuels and determines how each option affects the fuel choice, assuming that shipping companies will opt for the most cost-effective way to comply. Section 3.2 also analyses how the change in total cost of ownership affects the competitiveness of Dutch shipowners.

For each of the fuels that may be used by ships, Section 3.3 analyses where these fuels are likely to be produced, taking into account the costs of the inputs and the availability of technology.

The impact on the competitiveness of Dutch ports is determined by where the fuels are produced, the costs of transporting the fuels, and the available bunkering infrastructure. This is analysed in Section 3.5.

Figure 1 - Framework for the analysis



2 The impacts of FuelEU Maritime on fuel choice

2.1 Introduction

The European Commission is considering three options for increasing the demand for renewable and low-carbon fuels (RLF) in the FuelEU Maritime Initiative.
These are (CE Delft; Ecorys, 2020):

1. A requirement for ships to use a minimum share of selected RLFs in their fuel mix, as well as a requirement for the most polluting ships to use onshore power supply (OPS) at berth.

2. A requirement for ships to use fuels or a fuel mix with GHG emissions over the life cycle of the fuel at or below a limit value, as well as a requirement for the most polluting ships to use onshore power supply (OPS) at berth.

3. As Option 2, with additionally options for pooled compliance and rewards for overachievers:
   - voluntary pooling, i.e. ships can voluntarily form pools under private law to comply; and
   - baseline-and-credit system, in which overperforming ships (ships using fuels with GHG emissions below the limit value) can apply for credits, which underperforming ships can use to compensate for their underperformance.

The options have different impacts on the fuel choice by shipowners, at least initially when they are not required to exclusively sail on RLFs.

Under Option 1, it can be expected that ships initially opt for the cheapest drop-in RLF, i.e. fuels that can be blended with conventional fuels and used without modifications of engines or fuel systems. This is because initially only a small share of their fuels will be RLFs and investments in fuel systems or engines will not be cost-effective (except for possibly dual or multi fuel engines capable of running on different types of fuels and increase the flexibility of a ship). These fuels can be, for example, sustainable liquid biofuels which can be blended with regular maritime fuels like MGO, VLSFO or ULSFO, or, for LNG-fuelled ships, sustainable liquefied biomethane. Ships with dual-fuel engines may mix sustainable biomethanol or bioethanol in their liquid fuels (these fuels are not considered in detail in this report).

Under Option 2, ships will initially opt for the most cost-effective drop-in RLF. This is the fuel with the lowest cost per unit of CO_2 emission reduction. While these can, in principle, be different fuels than under Option 1, the requirement to be drop-in fuels constrains the choice to fuels that mix well with liquid or gaseous fossil fuels, i.e. the biofuels mentioned above or their PtX equivalent.

Under Option 3, it may be financially attractive to equip one ship in a group with engines and fuel systems for the use of the most cost-effective fuels, which doesn't need to be a drop-in fuel, and let other ships in the voluntary pool or in the system continue to sail on fossil fuels.

The next section explores which fuels will be chosen under which option.

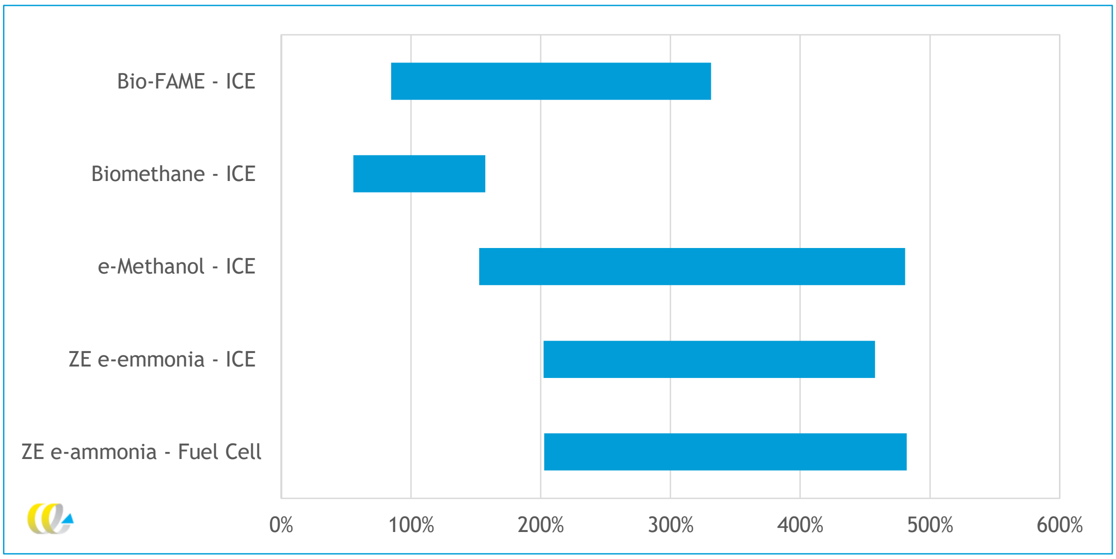
2.2 Fuel demand by ships

We assume that shipping companies aim to maximise their profits and will therefore comply in such a way that the increase in the total costs of ownership is minimal, under the constraints for fuel choice mentioned in the previous Section.

The total cost of ownership are presented as a range to reflect the uncertainty in fuel prices and capital costs. The considered fuels face different factors in production, availability and production costs. The foremost factor causing uncertainty about the cost price of bioFAME and biomethane are the (fluctuating) feedstock costs, which is related to the fact that this fuel can be refined from a variety of resources such as crop-based feedstock, and feedstocks mentioned in Annex IX of the Renewable Energy Directive II (Directive (EU) 2018/2001). For the e-fuels, there are a number of factors causing the (wide) range of uncertainty about the costs. These are uncertainty on the price of electricity for the production, the cost of CO_2 from Direct Air Capture (for methanol) and capital costs for the production facilities, storage and bunkering infrastructure. This is because these fuels are still in development stage and not produced at commercial market scale.

As shown in Figure 2, there are significant cost differences between the fuels. Fuel cost is the most important determinant of the TCO of a ship on RLFs. We used a minimum and a maximum fuel price as predicted for the year 2030. Details of the calculation are presented in Annex A.

Figure 2 - Total cost of ownership in 2030 of ships sailing on different RLF (% of TCO of VLSFO-fuelled ship)



2.2.1 Fuel choice when ships are required to use a minimum share of RLF

For deciding the fuel choice under a policy scenario requiring use of a minimum share of RLF, we calculated the TCO for a new built alternative fuelled ship. In this scenario it can be expected that ships initially opt for the cheapest drop-in RLF. Therefore we select the ship type on the alternative fuel with the lowest additional TCO compared to the TCO of a new built VLSFO-fuelled ship.

The fuel choice under the policy option with a minimum share of RLF, is made according to which fuel has the lowest minimal additional total cost of ownership. For all ship types powered by liquid fuel oils (HFO, VSFLO, ULSFO and MGO), the most cost-effective drop-in alternative is bioFAME. For ships on built to sail on LNG, biomethane is the most cost-effective drop-in option. As biomethane has a lower costs per unit of energy, this is also the drop-in fuel choice for ships with dual-fuel engines (i.e. ships that can sail both on liquefied gas and on fuel oil). Table 2 summarises the fuel choice for different ship- and engine types.

Table 2 - Expected fuel choice when ships are required to use a minimum share of RLF

System type	Fuel choice - cost-effective TCO	Ship types
Conventional ICE	BioFAME	All
Dual-fuel ICE	Biomethane	All
LNG-ICE	Biomethane	All

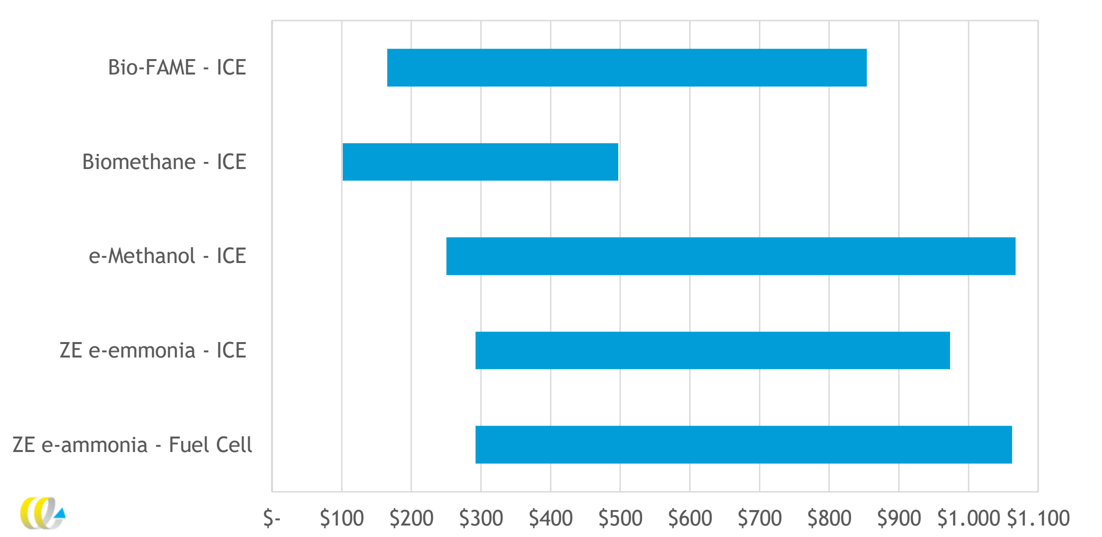
2.2.2 Fuel choice when ships are required to reduce the average GHG emissions of their fuel

When ships are required to use fuels or a fuel mix with GHG emissions over the life cycle of the fuel at or below a limit value, they will most probably opt for the financially most attractive fuel choice with regard to GHG emission reduction. This is the fuel with the lowest cost per unit carbon emission reduction.

We calculated the additional TCO per tonne CO_2 reduction using the amount reduced emissions per alternative fuelled ship, assuming that the activity of each ship[1] would be the same as in 2018. That means that the indicated cost per tonne CO_2 reduction is only for the prevented emissions of the alternative fuelled ship compared to the ship sailing on fuel oil. Because fuel prices in 2030 are yet uncertain and dependent on the available feedstock or renewable electricity at the fuel production location (which may be different than the bunkering location), we have calculated ranges of cost per tonne CO_2 reduction.
The additional TCO per tonne CO_2 reduction per fuel type is presented in the following figure.

[1] For this unit we used the yearly tonne mileage per ship.

Figure 3 - Total cost of ownership of ships sailing on different RLF (USD per tonne CO_2 reduced)



The ranges of the increase in TCO per unit of CO_2 reduced overlap. This means that this analysis cannot conclude that one of the fuels is likely to be selected, neither can any of the fuels be ruled out on the basis of this techno-economic analysis. However, in the initial stages of this policy option it would be more cost-effective to comply using a blend of a conventional and a low-carbon fuel than to sail exclusively on low-carbon fuels. This implies that drop-in fuels will be preferred over other fuels. Therefore, we conclude that the fuel choice will be the same as for the previous policy option (see Table 3).

Table 3 - Expected fuel choice when ships are required to reduce the average GHG emissions of their fuel

System type	Fuel choice - cost-effective TCO	Ship types
Conventional ICE	BioFAME	All
Dual-fuel ICE	Biomethane	All
LNG-ICE	Biomethane	All

2.2.3 Fuel choice when ships are required to reduce the average GHG emissions of their fuel and are allowed to comply collectively

For the fuel choice strategy in a situation where ships are required to reduce the average GHG emissions of their fuel and are allowed to comply collectively in a pool, it may be financially attractive to choose for alternative fuels in the ship types with the lowest cost per unit carbon emission reduction. In practice this means shipping companies may equip one ship in a group with engines and fuel systems for the use of the most cost-effective RLF fuels, which doesn't need to be a drop-in fuel, and let other ships in the voluntary pool or in the system continue to sail on fossil fuels, while achieving the required emission reduction of their fleet as a whole.

For the following illustrative calculation we have assumed that GHG emissions need to be reduced by 10%. If we look at the options for pooled compliance under the low-fuel price scenario, we find bioFAME to be the most cost-effective fuel, for all ship types and sizes, although there is a range of uncertainty which could result in other fuels becoming more cost-effective. As additional costs of bioFAME comprise only fuel costs, this fuel can be used in any ship type as the most cost-effective GHG emission reduction technique. In practical terms, 10% of the fuel demand by the entire shipping sector will be bioFAME, regardless the ship type. The total additional costs for the use of bioFAME as emission reduction technique is approximately 16 billion USD (for the IMO worldwide fleet).

When looking to the price scenario that assumes the maximum prices of the alternative fuels and accompanying system (see Table 7, we find e-ammonia to be the most cost-effective reduction option for a certain number of ship types and sizes. Again, this outcome is far from certain because of the uncertainty about future fuel and equipment costs. These types are small chemical tankers, large cruise ships, liquefied gas tankers, small oil tankers, small liquids tankers, small to mid-sized refrigerated bulkers, and small ro-ro ships. However, the cost-effectiveness to other sized of the mentioned ship types are only a few dollars higher per ton CO_2 reduction. This means that in practice other sizes (or types) of ships may be converted to e-ammonia ships to achieve GHG emission reduction under a pooled compliance structure. The total additional costs for pooled GHG emission reduction under the high-fuel price scenario using e-ammonia is approximately 64 billion USD (for the EU MRV fleet).

In a situation where fuels like ammonia or methanol are not available globally, it would make sense that ships that often visit the same port or ports are the first to adopt these new fuels. These could be ro-ro or RoPax ferries, offshore support vessels, coastal ships, feeders, et cetera.

2.3 Conclusions

The rational choice for a fuel to comply with the requirements of the FuelEU Maritime Initiative depend on the policy option that will be chosen. If ships are required to either use a certain share of RLF or to reduce the average GHG emissions of their fuels by a certain percentage, they are likely to opt for fuels that can be blended or switched with conventional fuels. These are biofuels (especially bioFAME) for ships sailing on liquid fuels and biomethane for ships sailing on LNG.

If ships are allowed to comply as a fleet, using fuels that require dedicated engines and fuel systems becomes an option in addition to the use of drop-in fuels. These fuels include e-ammonia and e-methanol as well as fuels not considered quantitatively in this report, such as biomethanol, bioethanol, liquefied or compressed e-hydrogen, liquefied or compressed blue hydrogen, et cetera. If these fuels turn out to increase the total costs of ownership less than other fuels, there will be a strong incentive to use them. Currently, the uncertainty about the total cost of ownership of ships sailing on any of the four selected fuels is too large to definitely identify a preferred fuel or to rule one out. Our analysis points out that any of the considered fuels could turn out to be the fuel of choice in 2030. According to (CE Delft; Ecorys, 2020), many other renewable fuels can be produced against similar costs. If the required modifications to the ship have similar costs as the modifications for methanol and ammonia, the conclusion would be extended to other fuels as well.

The case for switching to non-drop-in fuels, including e-fuels, will be stronger if the reduction targets are higher or if they will increase in the future. The CE Delft, Ecorys project (2020) that the cost prices of e-fuels will be reduced in the coming decades due to lower renewable electricity prices and innovation in fuel production technology. The cost price of biofuels will also reduce, but to a lower extent. This means that e-fuels will be come more attractive over time.

3 Impacts of FuelEU Maritime on the Dutch maritime sectors

3.1 Introduction

This chapter analyses the impacts of FuelEU Maritime on the Dutch maritime sectors. It builds upon the analysis in Chapter 2 which concludes that shipping companies are likely to choose blending in bioFAME or biomethane to comply when they are required to use a certain share of renewable low-carbon fuels or when they are required to reduce the GHG emissions associated with their fuel use. When ships are allowed to comply collectively, other e-ammonia and e-methanol could also be rational choices. In view of the uncertainty about the total cost of ownership on sailing on either of these fuels, no fuel currently emerges as the best choice and no fuel can be ruled out at present.

Section 3.2 analyses how these fuel choices would affect the competitiveness of Dutch shipping companies. Since all ships sailing to and from EU ports would have to comply with the requirements, impacts on the competitive position vis-à-vis other shipping companies are not to be expected. However, the competitive position of shipping relative to other modes of transport could be affected.

Section 3.3 analyses where the production of renewable low-carbon fuels can be expected to be the most cost-effective. The impacts of the various options of FuelEU Maritime on innovation in maritime fuels are the subject of Section 3.4. Ports are the subject of Section 3.5, which presents an inventory of how well prepared ports are for the new fuels, and of Section 3.6, which analyses the competitiveness of ports. Section 3.7 analyses how Dutch climate policy goals are impacted and Section 3.8 concludes.

3.2 Impacts on the competitiveness of Dutch shipping companies

In order to determine the impact of RLF uptake in shipping on the competitiveness of Dutch shipping companies, we identify changes in costs in competing industries. When the shipping sector is required to use a certain share of renewable low-carbon fuels or ensure that the GHG emissions of the fuels does not exceed a certain level, cost for shipping companies will increase as shown in Chapter 2. In Section 3.2.1 we discuss the consequences for the competitiveness of the coastal goods and cargo shipping sector. In Section 3.2.2 we discuss the competitiveness of the dredging sector, as this sector is an important subsector in the Dutch shipping sector.

3.2.1 Impact on the competitiveness of the coastal shipping sector

For cargo shipping, other transport modes are competing industries. Ocean shipping hardly competes with other modes; the only other mode would be air transport, which has significantly different characteristics in terms of costs, transit times, reliability and frequency and is therefore a poor substitute for shipping. Coastal shipping can in principle compete with more modes, road, rail and inland shipping (COWI, CENIT and VITO, 2015), and the cost difference is smaller than between oceangoing ships and aircraft (Cullinane, et al., 2012). Therefore, this section focusses on long-distance road transport and inland shipping.

In order to get an idea of the competitiveness of the competing sectors of coastal shipping, we provide a short overview of climate policies and consequences for the long-distance road transport sector and inland shipping relative cost levels. The Renewable Energy Directive (RED II) and CO_2 emission performance standards for new road transport vehicles are the two main policies targeting emission reduction in road transport and inland shipping (EC, 2019a). The consequences of the directives for these sectors are estimated in impact assessments and ex-post analysis.

This analysis takes the current legal framework and the targets and stringencies contained therein as a starting point for the analysis, because possible revisions are yet unknown. Regulation (EU) 2019/1242 states that the average CO_2 emissions per kilometre of new heavy-duty vehicles (trucks) must be 30% lower in 2030 than in 2020. These standards are expected to be met partly through further efficiency improvements in diesel engine technology and partly through the use of zero-emission technology, particularly in the form of electric vehicles (PBL, 2020). The cost for more fuel efficient vehicles are spread over time as renewal of the HDV fleet appears at a slow rate. Therefore, cost increases due the increase of emission standards are slower than an ad hoc obligation for a minimum share of RLFs. The Renewable Energy Directive II, Directive (EU) 2018/2001, states that by 2030, at least 14% of the energy used in transport has to be renewable, i.e. either renewable electricity or renewable fuel.

In the so-called WLO scenarios, projections of energy and variable costs for heavy-duty vehicles per kilometre in 2030 are presented (PBL, 2020). The WLO presents two economic scenarios: *low* and *high*. To determine the impact on the competitiveness between the sectors, we use the outcomes of both scenarios, the *low* scenario representing an economic growth of 1%, moderate international cooperation and trust, and moderate technological development. In the *high* scenario, the economic growth is 2% and oil prices are expected to decrease due to strong international cooperation and advanced technological developments. In the scenarios, impact of current set targets from the beforementioned directives is incorporated. The average energy cost per kilometre of the fleet depends on fleet efficiency, fuel mix and energy costs. The average variable costs are for depreciation and maintenance. The WLO figures represent cost increases in the Netherlands. However, because the directives apply equally in all European countries, we can assume that they are representative for European long-distance road transport and inland shipping sector. Differences in cost increases could emerge from additional (fiscal) policies in EU Member States. Therefore, the presented numbers should be understood as indicative figures.

The use of renewable energy by zero-emission vehicles in particularly the personal transport sector fulfils a part of the target for 14% renewable energy use in the transport sector by 2030. The WLO scenario states a biofuel drop-in percentage of 8.5% for road transport.

In order to compare the transport cost increases of the coastal shipping sector against cost increases in other transport modalities, we assumed that the coastal shipping would be required to a similar GHG reduction percentage as long-distance road transport. The WLO considers a 8.5% biofuel drop-in requirement for road transport. This additional costs are reflected in the increase in cost figures for transported goods per kilometre.
The 8.5% drop-in of biofuels results in a GHG emission reduction of 7.47%[2]. We assume for the cost increase calculations this reduction percentage will be valid for the coastal shipping sector in 2030, in order to make a plausible cost increase comparison. A bioFAME drop-in percentage of 8.5% for the coastal shipping sector, similar as the biodiesel and bioethanol drop-in share in road transport, equals a 7.47% GHG emission reduction. With

[2] Assuming the CO_2-intensity of 10 kg/GJ bioFAME, see Table 10.

this hypothetical reduction target we can calculate indicative costs for the coastal shipping sector under the policy options of FuelEU Maritime. Using the minimum and maximum fuel prices, we calculate cost increases in the coastal shipping sector. For the pooled compliance option, we calculated the emission reduction and total costs for the fleet following the 7.47% reduction percentage, in order to compare costs at an equal reduction level. Using the TCO outcomes we calculated the number of ships needed to switch to the (cost-effective) alternative fuel for each fuel price scenario.

We compare the cost increases of the high WLO economic scenario, in which the competing sectors have low-fuel prices, with the minimum fuel cost scenario in shipping. The low WLO economic scenario corresponds with high-fuel prices and can therefore be compared with the maximum fuel cost figures of the coastal shipping. Therefore we can make a tentative comparison of the cost increase figures, as presented in Table 4.

We compare the competitiveness of alternative fuelled ships only from those competing with long-distance road transport and inland shipping. This means, we will not consider cost changes from ocean shipping on RLFs when looking at general cost increases in the shipping sector by using alternative fuels. We make a selection of ships used for short and medium distances seagoing transport under uptake of alternative fuels according to the fuel policy options as presented in Section 2.2. An important sidenote here is that we considered an 11% energy efficiency improvement for the shipping sector, as expected by 2030. Energy efficiency has a significant impact on the fuel use and subsequent GHG emissions. More energy efficient engines result in fuel savings per freight movement, lowering the costs per tonne nautical mile. This is incorporated in the cost increase figures presented in Table 4. Energy efficiency thus can support the performance of the shipping sector by limiting the deterioration of competitiveness.

Table 4 - Change in cost freight transport relative to 2018. Cost per km for road transport and inland shipping. Cost per tonne nautical mile for coast shipping.

Transport sector	2030 cost increase under low-fuel prices	2030 cost increase under high-fuel prices
Long-distance heavy-duty road transport	-7.5%	+12.8%
Inland shipping[3]	+11.3%	+10.7%
Coast shipping under Option 1 and 2	+1.3%	+34.2%
Coast shipping under pooled compliance (Option 3)	-1.8%	+21.2%

Under the fuel policy Options 1 and 2, the coastal shipping sector is bound to the same percentage biofuel drop-in requirement. According to the TCO cost calculations, the average cost per distance transport will increase almost 8%, while the long-distance road transport sector in the *high* scenario (without further stringent climate policies), will face a cost decrease of 7.5% in 2030[4]. In this scenario, assuming that the quality of transport will remain constant, the coastal shipping sectors' competitive position will deteriorate. Moreover, in the high-fuel cost case, the shipping sector will face significantly higher fuel costs than in competing sectors. This may have significant impacts on the competitiveness of the shipping sector and may affect main supply chains and transport routes drastically.

[3] The base year 2018 for the cost of inland shipping is interpolated from 2011 figures, due to lack of more recent data, see (PBL, 2016) table 4.6. Inland shipping costs are including 8.5% drop-in biofuel. The cost increase is higher for inland shipping under low-fuel prices, due to the assumed CO_2 tax for this sector.

[4] This is mainly due to the negative cost that comes with fuel efficient engines, with fuel cost savings exceeding the cost increase of these new engines, see (CE Delft, 2012) figure 6.

When we look at the impact of the use of RLFs under the third policy option, in which pooled compliance is allowed, we observe lower emission reduction cost are needed to comply to the targets. This is because the use of biomethane ships in a fleet has a lower cost per unit emission reduction compared to the previous (drop-in) fuel bioFAME. Therefore, the most cost-effective option if a pool of ships collectively aims for average emission reduction is done by adding a required number of biomethane (bioLNG) ships to the fleet. In practice this means in a fleet of ships which are registered as a pool for emission reduction compliance, a few ships operate solely on biomethane In the maximum fuel cost scenario, biomethane-fuelled ships have (also) the lowest cost per tonne CO_2 reduction. The cost increase of applying a number of biomethane ships is lower than the cost increase in case of the required share of bioFAME for the equal GHG emission reduction, which is the cost-effective reduction strategy under policy Options 1 and 2. Due to the energy efficiency improvement, the total fleet average cost (per tonne nautical mile) decrease by 6% if all ships would sail on the reference fuel. The additional cost for alternative fuelled ships, in this case biomethane powered ships, result in a cost decrease of 1.8% under the low-fuel prices, up to 21% under high-fuel prices.

The ranges for cost increases with the pooled compliance option are lower than the cost ranges under policy Options 1 and 2. Therefore, we can conclude pooled compliance leads to lower cost per unit emission reduction in the shipping sector, while giving incentive for the adoption of alternative fuelled ships rather than using drop-in fuels in the existing fuel mix. However, as shown in Section 0, the cost for fuels in 2030 and thus a ships' TCO is highly uncertain. Depending on future energy and fuel prices, another fuel type may be the cost-effective fuel per unit CO_2 reduction, which may lead to both a different fuel type (and ship type) for the fuel choice for any policy option. Therefore, the outcomes we present must be taken as an indication of the cost-effective fuel choice in under the discussed a policy options.

3.2.2 Impact on the competitiveness of the dredging sector

The dredging sector is of particular relevance to the Dutch shipping sector. Dredgers are designed to take material (sand, clay, rocks) from the sea-, river- or lake bottom and deposit the material at another location. These type of ships can be deployed all over the world, which means that they sometimes operate within and other times outside European waters.

Even though it is currently not certain that dredgers will fall under the FuelEU Maritime Initiative (they are currently exempted from the EU MRV regulation (Regulation (EU) 2015/757), this section briefly analyses to which extent their competitiveness would be affected if they would be required to use RLFs when providing services in European waters and/or for European clients. In such a scenario, the costs for a dredger operating in the EU would increase relative to dredgers elsewhere. Insofar as demand for dredging is price-elastic, this could decrease demand for dredging. This would apply to all dredgers active in Europe, regardless of their nationality (country of registration or location of incorporation). To the extent that Dutch dredging companies have a relatively large market share in the EU, they would be relatively more affected. However, dredging is often a necessity and we do not assume that the price elasticity of demand is high, so this impact is likely to be small.

A secondary impact could be more significant. In the scenario that dredgers would fall under FuelEU Maritime, and again assuming that Dutch dredging companies have a relatively large market share in the EU, they would be required to use more RLF than non-EU dredging companies. This would have two impacts. First, the Dutch dredgers would have a first mover advantage. Because of the requirements they are forced to use RLF causing a head start in their knowledge regarding the use of these type of fuels compared to non-European dredging. Second, when they build ships that are capable of running on RLFs, these ships may become less flexible. Since ships in EU waters have to use these special fuel types, this means that fuel tanks are required which are suitable for these special fuel types. In the event that there is no space on board for additional fuel tanks has this the consequence that conventional fuel tanks have to be sacrificed. As soon as the ship starts operating outside European waters where these special fuel types are not yet available or mandatory, this subsequently has the consequence that there is less fuel tank capacity on board, which makes the ship less flexible in her operation.

3.3 Impacts on the production of sustainable maritime fuels

FuelEU Maritime will increase the demand for renewable and low-carbon fuels by requiring ships to use them on voyages to and from EU ports. The Initiative will probably not prescribe where those fuels are produced or supplied to ships. This means that, in principle, they could be produced in any country. This section analyses which countries and regions are best placed to produce these fuels.

The analysis focuses on three elements that are important for the decision on the location of production: the availability and price of essential inputs, and the availability of technology. We assume that the other production factors – capital, labour – are flexible and that technology is only relevant when existing production capacity can be increased.
The total maritime fuel consumption in the EU was more than 44 million tonnes in 2018, as reported under the EU MRV regulation (EC, 2020a). Assuming an energy density of 40,200 kJ per kg of fuel (the energy density of HFO, Fourth IMO GHG Study), this means that ships under the EU MRV consumed 1.8 EJ of energy in 2018. If fuel consumption would remain at the same level and 10 percent would be replaced by renewable low-carbon fuels, this would amount to a demand of 180 PJ in the EU.

The total amount of fuel or energy used by ships on voyages to and from the Netherlands is not reported under the EU MRV, but according to Eurostat around 18 percent of the gross weight of seaborne freight transported to and from main ports in the EU in 2019 was transported to and from the Netherlands (Eurostat, 2020). Using this as a proxy for fuel usage, around 8 million tonnes of maritime fuels are consumed every year on voyages to and from Dutch ports, and the demand for sustainable maritime fuels would be about 800,000 tonnes, or approximately 32 PJ.

Biofuels

The production conditions for biofuels are related to the local availability of biomass in the Netherlands and the possibilities of import from regions where biomass can be produced cheaply. The most recent numbers on the current production of biomass in the Netherlands have been collected by CE Delft (2020c) and count up to a total of 342-379 PJ per year. The lower and upper limits of this range depend on weather conditions, feedstock choices, and the availability of catch crops. In 2050, 372-454 PJ per year is expected for the Netherlands. The lower limit of this range reflects the minimum sustainable potential for the use of biomass in materials and energy, whereas the upper limit reflects the maximum sustainable potential (CE Delft, 2020c).

In theory, 342 PJ of biomass would be sufficient to supply 20% of the demand for marine fuels in 2018 (approximately 1.8 EJ). However, virtually all biomass is used in other sectors.

Also, there are conversion losses for the production of biofuels and especially for the production of liquid biogas, which also have to be taken into account. Most likely, biomass production in the Netherlands will thus not even be enough to supply this significant share of EU biofuel demand.

In the EU, current biomass production counts up to a total of 9.9 EJ per year. In 2030, biomass production in the EU could increase to 15 EJ per year with highly unfavourable conditions, up to 41 EJ per year with highly favourable conditions. The higher end reflects a situation in which modern agricultural technology is used for the optimisation of crop yield in all parts of the EU (CE Delft, 2020c).

Within the EU, the country with the highest biofuel potential is France, followed by Germany. In the future (until 2050), the biofuel potential of Spain, Italy, and Poland are expected to increase to similar levels. The lowest cost of biomass energy feedstocks are seen in countries in Eastern Europe such as Albania, Romania, and Serbia, both now and in the future (EC, 2015).

Considering the expected worldwide production of biomass in 2030, Asia delivers the highest share (33 percent) with 23.5 EJ per year. The OECD regions follow (26 percent) with 18.5 EJ per year (Daioglou, et al., 2018). This study is an analysis of the expected actual deployment of biomass, making these figures a lower limit of the biomass potential in 2030.

IRENA (2014) estimated all sustainable biomass that is expected to be available in 2030, not considering the economic circumstances. In this study, Asia also has the largest production of 21.7 EJ per year (in the 'low range of supply' scenario) to 39.2 EJ per year (in the 'high range of supply' scenario) (IRENA, 2014). This means that the share of Asia in the world supply will be 22 to 27 percent. Europe has the second largest biomass potential with 18.5-36.2 EJ per year in total (19-25 percent). This is consistent with the 15-41 EJ by CE Delft (2020c), although a narrower range, because CE Delft (2020c) also took other studies into account (in addition to IRENA). Two other regions are also expected to contribute a considerable share to the world's total biomass production: North America with 23.4-27.4 EJ per year (19-24 percent) and Latin America with 20.7-27.4 EJ per year (19-21 percent).

Deng et al. (2015) estimated the global biofuel potential in 2070 at 40 to 190 EJ final energy, of which up to 130 EJ could be made available in primary energy. Depending on the developments of biofuel demand, countries such as Brazil and Russia could become net bioenergy exporters in the second half of this century (Deng, et al., 2015).

All in all, Asia has the largest biomass production potential, followed by Europe. Within Europe, France and Germany have the highest biofuel potential, but countries in Eastern Europe have the lowest cost of biomass energy feedstocks. Considering the economic and environmental costs of fuel transportation, the most feasible countries for biofuel imports are France and Germany. After 2030, it is likely that there will also be imports from Spain, Italy, Poland, and other countries in Eastern Europe. If this will not be enough to meet total biofuel demand, Asia is the most obvious region for imports from outside Europe. This is also in line with the relatively high current production of biofuels in Asia compared to a relatively low expected consumption in 2030, and a high forecast annual production growth of 13.3 percent until 2025 (IEA, 2019). However, the difference in fiscal treatment of biomass feedstocks and (ready-to-use) biofuels might lead to a focus on import of feedstocks, and a production of fuels for end use within Europe.

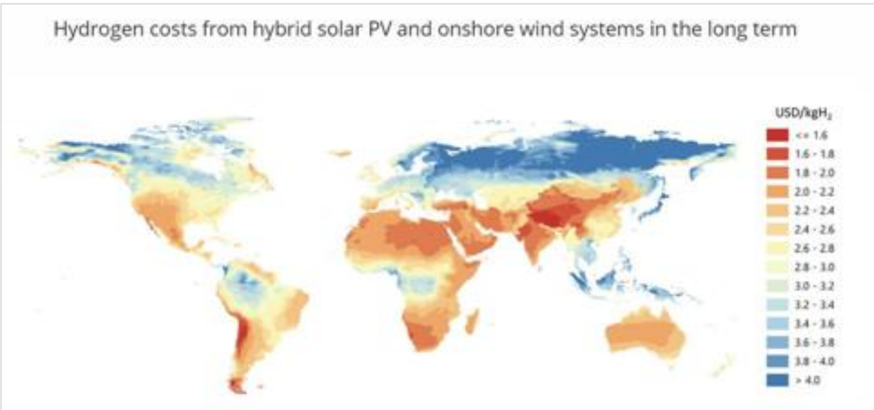
E-fuels

Oxford University (Bañares-Alcántara, et al., 2015) estimated the total costs of an ammonia energy system at 19 million USD/year. Of this, 14.7 million USD/year or 79 percent are OPEX-costs. These costs include only energy costs, not labour and maintenance, and are based on a levelised cost of wind power of 50.8 USD/MWh. With 79 percent energy costs and high inefficiency for the transportation of electricity over long distances, the production conditions for e-fuels depend mainly on the local production costs of sustainable electricity.

The most recent costs of renewable power generation have been estimated by IRENA (2020) Considering onshore wind, China and India have weighted-average total installed costs between 21 to 55 percent lower than other regions, at respectively 1,223 and 1,055 USD/kW in 2019. Brazil, Oceania, and the rest of South America follow, all just above 1,500 USD/kW. Regarding offshore wind, Denmark had the lowest weighted-average total installed cost with 2,928 USD/kW in 2019, followed by China and the rest of Asia (both just above 3,000 USD/kW). For utility-scale solar PV, the lowest total installed costs in 2019 were observed in India (618 USD/kW), followed by China and Italy at around 800 USD/kW (IRENA, 2020).

The International Energy Agency (IEA) estimated the costs of hybrid solar PV and onshore wind systems, looking at hydrogen specifically. According to their analysis, based on wind data from (Peng, et al., 2014) and solar data from (Proost, 2018)), the most promising countries include Chile, Argentina, and China (with costs going below 1.6 USD per kgH_2 in some areas), followed by India, Namibia, South-Africa, and parts of North Africa and the Middle East (mostly around or below 2 USD per kgH_2). A map of these regions with favourable conditions is shown below. Also, 7.5 GW of wind generation and 3.5 GW of solar generation are still expected to be built in Western Australia, with around 8 GW of the generation being dedicated to hydrogen production; this could substantially lower the cost in that area.

Figure 4 The costs of renewable hydrogen across the globe



Source: (IEA, 2019).

These hydrogen costs calculated by the IEA are based on electricity prices. These are estimated at a minimum of 19 USD/MWh today to 52 USD/MWh in 2030 and 55 USD/MWh in the long term. Regarding grid electricity prices, the lowest costs are seen in the United States at 70 USD/MWh today to 100 USD/MWh in 2030 and 108 USD/MWh in the long term.

However, when considering the variable renewable electricity price, the lowest costs are observed in China at 18 USD/MWh and India at 19 USD/MWh, followed by Chile and North Africa at 23 USD/MWh, and the Middle East at 25 USD/MWh. These costs reflect the low hydrogen costs in those countries.

Assuming the current minimum cost of 19 USD/MWh, this means that the OPEX-costs from Oxford University (Bañares-Alcántara, et al., 2015) can be about 67 percent lower now. Keeping the remaining e-ammonia costs at 4.8 million USD/year in 2021USD and with the lower OPEX-costs at 5.5 million USD/year in 2021USD, this means that the current share of energy costs in e-ammonia is around 53 percent. This means that the share of the energy costs in the total production costs of e-fuels is still relatively high, and e-fuels can be best produced in the countries with low local production costs for renewable electricity.

All in all, India and China are the countries with the lowest cost of sustainable electricity (followed by the rest of Asia). Hence, these countries have the best conditions for e-fuel production. According to (IEA, 2019), China is currently already among the frontrunners of hydrogen production. Although the IEA also recognises the favourable conditions in Northwestern India, it is not meeting its e-fuel potential yet and might thus still have a lower technological capacity now.

3.4 Impacts on innovation in fuel production

This section analyses the impacts of the different policy options of FuelEU Maritime on the innovation of fuel production. It builds upon the analysis of fuel choice presented in Chapter 2 and considers for each of the selected fuels what the current production processes are and what innovations are considered in the literature.

Biomethane

Biomethane can be produced by digestion or by biomass gasification. Digestion convert biomass into biogas by bacteria in the absence of oxygen. Biomass gasification produce biomethane by gasification (using a gasifier), cooling, polluting compounds removal, methanation (using a catalytic reactor) and water and CO_2 removal.

A relatively new and innovative digestion technique for the production of biomethane is auto generative high-pressure digestion (AHPD). AHDP produces a gas with relatively pure biomethane (90% CH_4) from wet biomass or sludge, without the production of biogas (with a lower concentration of methane) as an intermediate step, which is common in the traditional digestion process. The high pressure in the AHPD (20 bar) is built up auto generative by specific micro-organisms and is used to concentrate CO_2 in the water phase. A future development is the use of added hydrogen to further increase the concentration of biomethane up to 99%. This technique is developed and patented by a Dutch company and is used on a small scale.

Relatively new and innovative gasification techniques for the production of biomethane are manure gasification, supercritical water gasification and wood gasification. Manure gasification is a gasification technique which focuses on manure.
The first factory with a processing capacity of 185,000 tons of manure is being realised in Emmen in the Netherlands. The system is scalable by adding ovens. With wood gasification, the syngas which is created during the gasification is converted into biomethane via a catalytic process (methanisation). A stable quality of the biomass is important for gasification.

Supercritical water gasification is an innovative thermochemical conversion technology which make use of the water component in wet biogenic waste streams. It concerns a multi-feedstock technology with which all kinds of biomass and plastic waste products which are available in the Netherlands can be processed. A so-called supercritical phase exist when the biomass containing water will be brought under high pressure and temperature. All organic molecules in the biomass decompose and achieve a new equilibrium in the form of biogas (methane, hydrogen, CO_2 and CO). Biomethane is produced after a methanisation step.

In general, the production and use of biomethane has a TRL of 8-9 (LLoyd's Register & UMAS, 2020). However, the above explained innovative production processes of biomethane in the Netherlands are still in pilot phase or in small scale. This means that the production techniques for biomethane are reasonably well developed, but that the innovation mainly lies in the scaling up of the production process (CE Delft, 2020b) (Frontier Economics; CE Delft; THEMA Consulting Group, 2018).

Increased demand for biomethane from the shipping sector could have a positive impact on innovation of marine fuels. However, because of the significant demand for biomethane from other sectors, it is questionable whether additional demand from the shipping sector will increase the speed of innovation (CE Delft, 2020a).

BioFAME

BioFAME is produced from vegetable oils, animal fats and waste from cooking oils by transesterification. In the transesterification process a glyceride reacts with an alcohol (methanol or ethanol) in the presence of a catalyst. Sodium methylate is commonly used as catalyst. This reaction forms a mixture of fatty acid methyl esters (FAME) and an alcohol. The alcohol is produced as side product and therefor need to be removed. The production of bioFAME is a fully developed technique and has a TRL of 9, but there is room for upscaling of the production. (European Biofuels Technology Platform, 2021) (University of Copenhagen, 2017) (LLoyd's Register & UMAS, 2020). In sum, increased demand for bioFAME from the shipping sector will not result in much innovation in fuels production.

E-methanol

There are several options to produce e-methanol through an electrochemical process. The simplest and technologically most mature process is by making hydrogen through the electrolysis of water using renewable electricity, followed by a catalytic reaction with CO_2 to produce e-methanol. The technology for the e-methanol synthesis step is very similar to the one for the production of methanol from fossil fuel-based syngas. It has therefore technology readiness level 8-9.

A second option is to produce both components of syngas, H_2 and CO, through electrolysis, followed by a conversion of syngas into e-methanol as is done for conventional methanol production. Although this second option could achieve a higher conversion efficiency, it is less developed than water electrolysis. Conventional water electrolysis can be executed in megawatt scale, while this production option is still in lab phase at kilowatt scale.

A third option is direct electrocatalytic synthesis of e-methanol from water and carbon dioxide. No use is made of an intermediate step in which H_2 or syngas is formed. The production of e-methanol by this option has a limited efficiency and is at the moment only be achieved at laboratory scale. (IRENA, 2021)

All steps require CO_2 as an input. When point sources of CO_2 are available, it makes sense to use these. CO_2 capture from point sources has a TRL of 7-9, depending on the technology (Global CCS Institute, 2021). If point sources of CO_2 are not available, which is to be expected when fossil fuels are phased out, CO_2 has to be captured from the atmosphere. The TRL of so-called Direct Air Capture is 5-6, depending on the technology (Viebahn, et al., 2019).

The TRL of the production and the use of e-methanol is equal to the lowest TRL of any of the processes involved in the production. Therefore, the production of e-methanol has a TRL of 5-6 (LLoyd's Register & UMAS, 2020).

Increased demand for e-methanol from the shipping sector could have a positive impact on innovation of marine fuels by increasing demand for methanol and incentivising technology development in its production. However, methanol is widely used chemical and similar incentives could come from other sectors as well, depending on the regulation these sectors face (Methanol Institute, 2021).

E-ammonia

The feedstock for e-ammonia is green hydrogen and nitrogen. The most common way to produce e-ammonia consist of two steps. During the first step, nitrogen is produced by air separation and green hydrogen is produced through the electrolysis of water using renewable energy. In the second step of the process synthesis of hydrogen and nitrogen takes place in a Haber-Bosch reactor. Since these are all well-known techniques, the innovation is mainly in the area of scaling up of the electrolysis process. (Smart Port, 2020)

TU Delft is currently investigating the direct electrolytic e-ammonia production from nitrogen and water and whereby no use is made of an intermediate step. This technology is still in its infancy (TU Delft, 2021).

In general the production and use of e-ammonia has a TRL of 7 (LLoyd's Register & UMAS, 2020).

Increased demand for e-ammonia from the shipping sector could have a positive impact on innovation of marine fuels by increasing demand for methanol and incentivising technology development in its production. However, ammonia is widely used chemical, amongst others as a fertiliser, and similar incentives could come from other sectors as well, depending on the regulation these sectors face (The Ammonia Energy Association, 2021).

Availability of green electricity for the production of e-fuels

Renewable electricity is an essential input for the production of e-fuels. The production capacity of renewable electricity is growing fast, but currently most of the electricity is used directly for consumption, rather than for the production of e-fuels. In order to produce large quantities of e-fuels, substantial investments in renewable dedicated electricity capacity are therefore necessary. (CE Delft, 2020a)

Conclusion

In summary, the potential for innovation in the production of fuels is larger for the e-fuels than for the biofuels considered in this report, which have more mature production processes. The e-fuels considered in this report are also used by other sectors, so the incentive for technology development by increased demand from the maritime sector also depends on the regulation and incentives that these other sectors face. If these other sectors already demand e-methanol, e-ammonia and other e-fuels, the additional incentive provided by increased demand for marine fuels may be limited.

3.5 Impacts on the supply of fuels in Dutch ports

Depending on the type of fuel, fuel can be supplied to ports over land and over sea. Before the fuel will be delivered to the ships, it is first temporarily stored in the relevant port or terminal. The following bunker infrastructures are available in ports although not every option is currently suitable for all type of fuels:
- Truck-to-Ship;
- Ship-to-Ship;
- Shore-to-Ship.

Section 3.5.1 provide more information regarding the supply, the storage and the available bunker infrastructure of bioFAME, e-ammonia, e-methanol and bio methane in ports. Section 3.5.2 explains the impact of these fuel types in Dutch ports.

3.5.1 The supply, storage and bunker infrastructure of fuels

BioFAME

BioFAME is a liquid biofuel and can be supplied over land and over sea, like other liquid fuels. Supply over land can be done by trucks and pipelines while ships can be used for supply over rivers and sea. The cargo capacity of a truck is limited, which means that several trucks will often be needed to provide a ship with the required amount of bioFAME. The cargo capacity of ships which supply bioFAME is often larger compared to the cargo capacity of trucks. There is no supply limit for pipelines.

Only in the event that bioFAME is produced in the Netherlands or surrounding countries, it can be transported via land. If the fuel is produced further away, such as in Asia or in the US, transport and supply by ships is the only option.

BioFAME is just like other biofuels and conventional fuels a standard liquid and can be supplied without special cooling and under pressure conditions. This means that the current storage and bunker infrastructure for conventional fuels can be used, after cleaning, for bioFAME. Ships currently bunker their fuels mainly by means of a ship-to-ship bunker infrastructure whereby a bunker barge or bunker vessel is used (Port of Rotterdam, 2021a).

E-ammonia

E-ammonia (or ammonia in general) is not yet in use as maritime fuel, but has the same characteristics as ammonia which is regularly transported as product in liquid form by LPG tankers. Eurostat (2021) reports that over the last five years (2016-2020) an average of about 2,257,000 ton anhydrous ammonia is imported and 74,000 ton is exported every year over sea by the European Union. The Netherlands has an average share of 158,000 ton import and 13,000 ton export of anhydrous ammonia over sea per year.

DNV-GL's Alternative Fuels Insight platform (2021) reports 196 local ammonia storage locations in the world of which four in the Netherlands: Rotterdam, Vlissingen, Terneuzen & Sluiskil. These storage locations are often in the proximity of ammonia producers or of industries that use ammonia as an input.

In addition to the port of Rotterdam, Singapore and Fujairah are the two other largest bunkering ports in the world. However, these ports do not yet have an ammonia storage location. The ammonia storage locations in Europe are shown in the following figure.
From these data it can be concluded that the Netherlands has the knowledge how to store e-ammonia once available as maritime fuel. There are currently no ammonia bunker vessels or truck loading options available in the world, which can be explained by the fact that there are currently no commercial ships operating on ammonia.

Figure 5 - Storage locations of ammonia in Europe (DNV-GL, 2021)

E-methanol

E-methanol is, just like e-ammonia, not yet in use as maritime fuel. However, e-methanol has the same characteristics as methanol which is regularly transported as product by tankers. Eurostat (2021) report that over the last five years (2016-2020) an average of about 5,138,000 ton methanol is imported and 205,000 ton is exported every year over sea by the European Union. The Netherlands has quite a large average annual share of 1,642,000 ton import and 173,000 ton export of methanol over sea.

DNV-GL's Alternative Fuels Insight platform (2021) reports 117 locations in the world where methanol is stored locally. These storage locations are often in the proximity of methanol producers or of industries that use methanol as an input. In some of these locations, trucks and bunker vessels can be loaded. Two of these locations are located in the Netherlands: Rotterdam and Amsterdam. Dedicated methanol bunker vessels are in use in the ports of Kiel (Germany) and Göteborg (Sweden), supplying the Stena Germanica (Ship Technology, 2021), and possibly in other ports.

Two major bunkering ports in the world outside Europe, Singapore and Fujairah, do not have a location were methanol can be stored and where trucks and bunker vessels can be loaded. The methanol storage locations in Europe are shown in Figure 6. From these data it can be concluded that the Netherlands has experience to store e-methanol once available as maritime fuel.

The current bunkering infrastructure for conventional fuels needs only minor modifications to handle methanol. Methanol is very similar to current marine fuels such as heavy fuel oil (HFO) as it is also a liquid. Existing storage, distribution and bunkering infrastructure for conventional fuels can handle methanol with only minor necessary modifications due to methanol being a low-flashpoint fuel (Methanol Institute, 2017).

Figure 6 - Methanol storage and truck & bunker vessel loading locations in Europe

Biomethane

Biomethane is chemically similar to natural gas which in its liquefied state is regularly transported (and used) by LNG tankers. Eurostat (2021) reports that over the last five years (2016-2020) an average of about 33,983,000 ton LNG is imported and 469,000 ton is exported every year over sea by the European Union. In the Netherlands, the Gate terminal has been operational since 2011. The terminal has an annual throughput capacity of 12 billion m^3 of gas per year. The Gate terminal receives LNG by gas tankers, stores it cool and under pressure in well-insulated tanks, heat and regasify it and subsequently supplies it to LNG bunker vessels, small gas tankers and trucks for distribution to households and industry (Gate terminal, 2021).

DNG-GL's Alternative Fuels Insight platform (2021) reports 68 LNG storage locations, 55 truck loading locations, 21 bunker vessel loading locations and 55 LNG bunker vessels in the world. One truck and bunker vessel loading location is located in the Netherlands: the Gate terminal. Several bunker vessels are operating in Dutch waters depending on the demand.

Major port Singapore has LNG bunker availabilities, but major port Fujairah does not have LNG bunker availabilities yet. The LNG bunker vessels and truck & bunker vessel loading locations in Europe are shown in Figure 7.

Figure 7 - LNG bunker vessels and truck & bunker vessel loading locations in Europe

For LNG the truck-to-ship transfer is currently the most frequently used bunker configuration, but in several ports ship-to-ship bunker configurations are possible. Truck-to-ship bunkering is still the most widely used method, because of the still limited demand in combination with the lack of infrastructure and relatively low investment costs. The main disadvantage of truck-to-ship bunkering is the limited capacity of trucks. (WPSP, 2021)

3.5.2 Impact of the fuels in Dutch ports

The impact of increased demand for renewable and low-carbon fuels on the Dutch ports depends on the type of fuels. It is important to distinguish between fuels which can be blended with conventional fuels and fuels which cannot.

For fuels which can be blended with other fuels, such as bioFAME and biomethane, the bunkering structure is already available because these fuels can use the same infrastructure as for fuel oil and LNG, respectively. The bunkering infrastructure for LNG and methanol are in development and several bunker ships are already active in the area of Rotterdam.

As mentioned in Section 3.5.1 there is no bunker infrastructure in the Netherlands available yet for (e-)ammonia. In the event that one ship comes onto the market which can operate on ammonia, truck-to-ship will initially be started because it is not yet worthwhile to invest in a bunker vessel. The investment in a bunker vessel will only become attractive when it is used regularly.

3.6 Impacts on the competitiveness of Dutch ports as bunkering locations

An important aspect in the selection of the fuel type and bunker location of ships are the bunker strategies of shipping companies. Raimonds Aronietis et al. (2017) concluded that the fuel price is the most important attribute to the bunker location. The quality of the fuel provision, which include both the trust in the correct quality and quantity, is the second most important element. In order to optimise the voyage and the associated costs, the fuel is mainly bunkered during loading and discharge operations.

Fuel prices are lowest at ports where there is ample supply. These are usually the same locations where fuels are produced or to where they can be transported easily.

Figure 8 shows the main maritime shipping routes, including all ship types. The Netherlands is located at one of the core routes, which means that many ships pass our country or visit our ports for cargo operations.

Figure 8 - Main maritime shipping routes (Transport Geography, 2021)

Both biofuels and e-fuels can probably be produced at lower costs in other non-EU countries which are located on trade routes that are important for Dutch ports. However, the transport of fuel to Dutch ports entails costs, which has most probably the consequence that cost price of the relevant fuels will be higher in the Netherlands compared to the price of the fuels in the country of production. Since the fuel price for shipowners is one of the most important reasons for the selection of the bunker location, it could become worthwhile for the shipowner to purchase fuel in another country along the trade route instead of in the Netherlands, especially when ships already call at ports in those countries. One could, for example, imagine that the costs of biofuels will be lower in South-East Asia and South America, which would result in a shift in bunkering patterns from the Netherlands to e.g. Singapore and Panama. E-fuels are likely to be cheaper in India, China, the Arabian Peninsula, North-Africa and in South America. This could result in a shift in in bunkering from the Netherlands to Singapore, Fujairah, Port Said, Gibraltar and Panama.[5]

The previous analysis assumes that ships will have the same bunkering frequency as they currently have. However, because the energy density of e-fuels is lower than of fuel oil, new ships may not be able to carry the same amount of energy on board and may need to bunker more frequently. This could mean that the volumes of fuel per bunkering would diminish.

The local availability of fuels is not only a function of where the fuels can be produced against the lowest costs and where ships are, but also of where other industries are located that use the fuels as an input. As shown in Section 3.5.1, the Netherlands currently imports significant quantities of methanol and ammonia. It also has plans to become a hub for the imports of e-hydrogen, either in its elemental form or in the form of e-ammonia (Port of Rotterdam, 2021b). If these plans succeed, the local availability of e-fuels will be good, and possibly better than in other bunkering ports in Europe.

Singapore, Rotterdam and Fujairah are the three largest bunker ports in the world. Although e-fuels can be produced cheaper in the area of Singapore and Fujairah compared to Rotterdam because of the available solar energy, the storage infrastructure of these type of fuels has already been further developed in the Netherlands. At the moment it is not yet clear whether the local production possibilities or the available infrastructure outweigh the competitiveness of Dutch ports as bunkering location for e-fuels. For biofuels, this will be less important since there is already sufficient knowledge available in the Netherlands regarding the storage infrastructure and since biofuels can be imported from countries within Europe.

3.7 Impacts on Dutch climate policy targets

In this section we discuss what possible impact the policy options of the FuelEU Maritime might have on the Dutch climate policy, and specifically for the achievement of Dutch targets for emission reduction. In the Dutch climate policy, emissions from the international aviation- and maritime sector are not part of the national emission reduction targets (Rijksoverheid, 2019).

[5] The size of fuel tanks varies significantly, even for ships with a similar size. For example, the bunker fuel tank size for bulk carriers of around 180,000 dwt varies between 3,000 and 8,300 m^3. In general large ships tend to have larger fuel tanks. However, the fuel tanks of almost all ocean-going ship types and sizes allows them to reach important bunkering ports like Fujairah, Singapore and Houston (respectively 7,000 nm, 9,300 nm and 6,200 nm) from Rotterdam (CE Delft; Ecorys, 2020).

The climate targets for the maritime sector in the Netherlands are, however, mentioned in the Green Deal *Zeevaart, Binnenvaart en Havens*[6]. For the international- and coastal shipping sector, targets for 2024 are to reduce the average emissions per tkm with at least 20% compared to 2008. For 2030, there is the ambition to have at least one zero-emission ship operational. In 2050, the maritime sector must have realised an absolute reduction of 70% compared to the emission level of the entire (Dutch) maritime sector in 2008. The maritime shipping sector should achieve climate-neutral shipping as soon as possible after 2050 and in any case before the end of this century.

FuelEU Maritime can have an impact on the Dutch climate targets when the production of transport fuels changes and therefore the emissions in refineries or other industrial sectors change. Also, when marine fuels are linked to fuels for other sectors (e.g. road transport), the issue of not achieving the Dutch climate targets might arise.

If, as a result of FuelEU Maritime, the use and production of bioFAME will increase significantly, the following consequences may be expected. Emissions from bioFAME production (well-to-tank) are relatively larger than those of the fuel combustion process (tank-to-wheel)[7]. The same is valid for biomethane. If bioFAME and/or biomethane production were to increase in the Netherlands, this could lead to higher domestic emissions associated with the production process. Considering the limitations in the biomass feedstock, we can expect a competition for the available supply of feedstock for these fuels with other modes of transport (inland shipping and road transport) and sectors (residential, power and industry). As the domestic inland shipping- and road transport sector are part of the Dutch climate targets, this competition for biofuels might hamper the absolute emission reductions for these sectors. In the Netherlands, the permission to count biofuel use in the maritime sector for compliance with the RED II drop-in targets[8], leads to a run on biofuels in the maritime sector. This may make it harder for other sectors to meet the Dutch emission reduction goals.

If electro fuels (e-methanol and e-ammonia) were to become a dominant used fuel in maritime transport, the effect this use has on the Dutch climate targets will depend on the location of production of these e-fuels. In case the production of these e-fuels takes place in the Netherlands, using renewable electricity from within the Netherlands, the consequence could be the export of renewable energy. This fact could make the Dutch climate goals harder to achieve, assuming the current situation where the international maritime sector is not part of the national emission reduction targets.

The same principle applies for the production and use of biofuels. If biofuels used in the maritime sector were to be produced in the Netherlands, this might hamper the reduction of emissions within the scope of the Dutch climate goals. However, the availability of feedstock streams for the production of biofuels and presence of renewable energy within the Netherlands determines the potential scale of e- and biofuel production. In Section 3.3 we observed that the likelihood of large scale cost-effective production of (feedstock for) these fuels in Northwestern Europe is low. This is due to the fact a number of overseas areas have a large potential cost-effective production of green hydrogen due to an abundance of low priced renewable electricity. Even considering transportation of the

6 See Green Deal Zeevaart, Binnenvaart en Havens

7 See CO_2 emission factors database.

8 Fuels supplied to the maritime sectors count for 1.2 times their energy content with regard to reaching the minimum drop-in targets. Practice has shown this leads to a (disproportionate) high supply of biofuels to the maritime sector. Details on the regulation see RED II, article 27.

feedstocks or ready-to-use fuels, it is expected the production of renewable energy in the overseas areas are cost-effective.

Overall emission reduction ambitions within the EU are not affected by the use of alternative fuels in the maritime sector, as FuelEU Maritime requires the use of a set amount of low-and zero-carbon fuels for all voyages within and to and from EU waters, resulting in lower total transport GHG emissions.

Concluding, given the climatological circumstances of the Netherlands, the potential for large scale renewable energy and biomass production – with aim for producing maritime fuels is low. Therefore, we could expect a low impact on the achievement of the national emission reduction targets from the use of the discussed bio- and e-fuels. However, it could be the case national or European regulation leads to a high demand (or supply) of low- and zero-carbon fuels in the maritime sector, leading to lower availability for the road transport and inland shipping sector. This could impede reaching emission reduction targets in these sectors and on the national account. The size of this effect is dependent on a number of demand, supply and regulatory factors, which are not within the scope of this study.

3.8 Conclusions

FuelEU Maritime will impact the Dutch maritime sector and the impacts depend on the option chosen.

While the competitiveness of ocean-going shipping will unlikely be affected, the competitiveness of coastal shipping vis-à-vis land transport and inland shipping is likely to deteriorate due to the higher fuel costs caused by the requirements to blend in renewable or low-carbon fuels. When ships do not have to meet targets individually but collectively, the competitiveness of coastal shipping deteriorates to a lesser extent.

FuelEU Maritime will increase the demand for renewable and low-carbon fuels. Sustainable biomass, from which biofuels can be produced, is available in greater quantities in other parts of the world, notably Asia. However, also the supply in Europe vastly exceeds the demands of the maritime sector. Renewable e-fuels can be produced against lower costs in other countries, notably China, India, the Arabian Peninsula, North Africa and South America.

Many of the chemical compounds that are candidates renewable and low-carbon fuels for the shipping sector, and certainly the e-fuels, are base chemicals and their fossil analogues are currently imported in Europe and the Netherlands at scale. This trade will likely continue when the compounds are produced in a climate-neutral way.

As a result, even though many of the fuels may not be produced at the lowest costs in Northwestern Europe, the supply of these compounds in the region will likely be good, due to the demand from other industries. Dutch ports are well equipped to provide the bunkering infrastructure for many of the candidate fuels because the compounds are currently stored and transhipped in Dutch ports.

4 Supply and demand policies

4.1 Introduction

The European Green Deal (EC, 2019b) emphasises the need to accelerate the transition to a low-emission and climate-neutral economy and underlines that all sectors will need to contribute, including maritime shipping. Against this background, the Commission has launched the FuelEU Maritime Initiative, which aims to increase the share in the fuel mix of international maritime transport of sustainable low and zero-carbon alternative fuels (EC, 2020b). The FuelEU Maritime focuses thereby on demand policy which sets requirements for the fuel consumption of ships.

The Renewable Energy Directive II (Directive(EU) 2018/2001) currently requires Member States to oblige fuel suppliers within their jurisdiction to supply a minimum share of renewable energy to the transport sector (14% in 2030). While maritime bunkers are not included in the calculations of the total amount of energy consumed by the transport sector, Member States are allowed to opt-in maritime fuels so that fuel suppliers can include renewable fuels supplied to the maritime sector in their obligation. The Renewable Energy Directive (RED) focuses in this way on supply policy.

This chapter analyses qualitatively whether there are arguments for pursuing a supply policy for sustainable maritime fuels in addition to FuelEU Maritime's demand policy, and if so, whether this supply policy need to be executed in a national or international coordinated form.

4.2 Different forms of supply policies

As mentioned in above introduction, the RED is a form of supply policy. For the maritime industry, this supply policy is currently based on an opt-in situation where the use of renewable energy in shipping voluntarily contribute to the annual obligation for renewable energy transports, which mainly rest on road traffic and as from 2022 also on inland shipping. In this situation, fuel suppliers do not have a specific obligation to the ocean-going shipping industry.

It is also a possibility that the RED will be revised with a separate obligation for the maritime shipping industry. In that case fuel suppliers are imposed to an obligation whereby they have to supply a certain share of renewable energy specifically to the maritime shipping industry.

Above mentioned options have relevant differences which has the consequence that the impact of a certain supply policy can vary. In an opt-in situation the costs for deploying renewable energy in maritime shipping are borne by the sectors subject to the obligation (road traffic and rail). In case of a separate obligation for the maritime industry, the costs would be borne by the maritime fuel suppliers and thereby also by the end users in the sector itself. Because of the high cross-price elasticity for bunkering locations, such a policy would likely result in a decrease in bunkering activity in Europe and an increase in bunkering outside Europe.

In an opt-in situation it is not possible to aim at a specific emission reduction target for the maritime industry since it concerns a voluntary contribution to the obligation sectors.

With a separate obligation for the maritime industry, a target specific to this sector can be imposed, which does not have to be equal to the mandatory percentage for road traffic, rail and inland shipping.

An obligation specific to the maritime industry can relative to a voluntary opt-in situation forcibly accelerate the use of renewable fuels in the maritime industry. The advantages and disadvantages will be discussed in the Section 4.3.

4.3 Qualitative analysis of combined use of supply and demand policies

This section provides a qualitative analysis of combined use of the RED as supply policy and the FuelEU Maritime as demand policy.

Fuel costs

In the event that there is an obligation that all maritime fuels supplied in the Netherlands or in the EU have to contain a certain amount of renewable fuels, this could lead to higher fuel prices for ships bunkering in the Netherlands or in the EU. As a result, the competitive position of the ports and fuel suppliers in the Netherlands or the EU deteriorate. Shipowners are than more likely to bunker fuel in a non-EU port where fuels are cheaper.

This has been proven in the past when a fuel tax was introduced at the port of Long Beach in California. This experience suggest that many ships will easily bunker elsewhere on their route where the fuel is cheaper. Hence it is likely that when making the fuel supplier the responsible entity (which is the case for RED as supply policy) this will lead to bunkering of ships outside the Netherlands/EU and that it would limit the environmental effectiveness of such a supply policy (CE Delft, 2009).

Innovation of marine fuels

Dependent on whether the regulation imposes specific requirements on the type of fuel or on certain properties of the fuel, it is possible that the obligation to supply a certain amount of sustainable fuels stimulates the production of sustainable fuels within Europe. Innovation is stimulated by supply policy if the location of supply and the fuel production location are strongly linked to each other, so that potential high transport costs or difficult transport methods are not necessary. In this way it may be the case that the knowledge in Europe regarding the innovation of marine fuels is developing more quickly compared to the rest of the world, which create a first mover advantage for Europe.

However, it can also happen that because of the production possibilities and costs the sustainable fuels will be imported and therefore not produced within Europe. In that case Europe does not necessarily create a first mover advantage regarding the innovation of marine fuels.

Economic activities

When sustainable marine fuels will be produced in Europe because of the push by a supply policy, will this lead to an increase of economic activities within Europe. In addition to the new production activities, the fuels also need to be transported to ports and terminals where the fuels will be temporarily stored until the fuels will be bunkered by the ships.

Furthermore, the maritime manufacturing industry start participating in the development of associated storage, bunker and propulsion techniques.

Greenhouse gas emissions

The greenhouse gas emissions which will be released during the production and use of sustainable marine fuels are generally lower compared to the greenhouse gas emission released during the production and use of conventional fuels. In the event that a supply policy leads to more use of sustainable fuels compared to a demand policy without supply policy, a supply policy for sustainable marine fuels in Europe will also have a positive effect on global amount of greenhouse gas emissions. However, dependent on the production process the local air emissions may increase at locations where the production process will take place. The emissions released during the transport depends on the mode of transport, the distance and the fuel used. The shorter the transport distance and the more sustainable fuel used, the lower are the greenhouse gas emissions and local air emissions.

EU Green Deal

The EU Green Deal has the objective to set out the trajectory for the EU to be climate neutral by 2050. As a milestone towards this target, the European Commission has proposed to reduce 55% greenhouse gas emissions in 2030 compared to 1990 (EC, 2021a). The use of sustainable maritime fuels contribute to obtain these CO_2 emission reduction targets.

Coordination of policy at national or international level

Policy can be conducted at both national and international level. The larger the area where the policy is in force, the more possibilities there are to set up the fuel infrastructure efficiently, linking production and bunker locations to each other by means of different transport methods.

Furthermore, carbon leakage can arise if ships start bunkering in countries and ports located just outside the area where the relevant policy is in force. To limit carbon leakage as much as possible, it is desirable to make the policy area as large as possible. This can be realised when policy is coordinated at international level.

As mentioned earlier, there is a change that ships decide to bunker in ports outside the policy area. In that event, the market position of the fuel suppliers within the policy area deteriorates. To create a level playing field for all fuel suppliers, it is therefore desirable that policy is coordinated at an international level.

4.4 Conclusion

Supply policy is only of added value in addition to demand policy in the event that it will lead to sustainable fuel production facilities within the supply policy area and when fuel costs will not increase relative to countries outside the area where the supply policy is in effect.
A supply policy is not of added value in the event that ships start bunkering elsewhere outside the supply policy area due to fuel cost increases within the policy area.
Furthermore, a supply policy is not of added value when it only stimulates the supply of sustainable fuels, but not the production of the fuels in the supply policy area.

5 Conclusions

The European Commission has put forward three design options for FuelEU Maritime, which each have a different impact on the type of RLF that ships are expected to use to comply. Table 5 summarises the options and their impact on fuel choice and the total cost of ownership of seagoing vessels.

Table 5 - FuelEU Maritime design options and their impact on fuel choice and costs

Policy option	Fuel criteria	Examples of fuel types	TCO cost increase of ships sailing on 100% RLF (relative to ships sailing on fuel oil)
1. Each ship has to use a minimum share of RLF	Cheapest drop-in fuels	BioFAME (Fuel oil ships) Biomethane (LNG ships)	90%-250% 60%-100%
2. Each ship has to meet a limit on GHG emissions per unit of energy	Most cost-effective drop-in fuels for reducing CO_2-intensity	BioFAME (Fuel oil ships) Biomethane (LNG ships)	90%-250% 60%-100%
3. Ships have to meet a limit on GHG emissions per unit of energy as an average across the fleet	Most cost-effective fuels for reducing CO_2-intensity	BioFAME Biomethane e-methanol e-ammonia	90%-250% 60%-100% 150%-330% 200%-280%

Despite the cost increases, the competitiveness of Dutch shipowners engaged in ocean-going shipping will unlikely be affected because the regulation will apply to all ships visiting EU ports, regardless of their flag or ownership. This is different for coastal shipping, where short-sea shipping competes with land transport and inland shipping. Taking into account all agreed climate regulation for these sectors, the relative cost increase in shipping is larger than for land transport and inland shipping. In Option 3, where ships do not have to meet targets individually but collectively, the competitiveness of coastal shipping deteriorates to a lesser extent than in Options 1 and 2.

FuelEU Maritime will increase the demand for renewable and low-carbon fuels. Sustainable biomass, from which biofuels can be produced, is available in greater quantities in other parts of the world, notably in Asia. Renewable e-fuels can be produced against lower costs in other countries, notably China, India, the Arabian Peninsula, North Africa and South America, where renewable electricity from which these fuels are produced is available at lower costs. This suggests that the location of the production of fuels may shift to other regions.

A shift in the location of fuel production need not deteriorate the competitiveness of Dutch ports as bunkering ports. Transport costs for fuels are low in comparison to their value, and it is expected that there will be a significant demand for these fuels in Northwest Europe, also outside the shipping sector. Many of the chemical compounds that are candidates renewable and low-carbon fuels for the shipping sector, and certainly the e-fuels, are base chemicals and their fossil analogues are currently imported in Europe and the Netherlands at scale. This trade will likely continue when the compounds are produced in a climate-neutral way.

As a result, even though many of the fuels may not be produced at the lowest costs in Northwestern Europe, the supply of these compounds in the region will likely be good, due to the demand from other industries. Dutch ports are well equipped to provide the bunkering infrastructure for many of the candidate fuels because the compounds are currently stored and transhipped in Dutch ports.

When demand-side policies to promote the use of renewable fuels are in place, there is little added value in having supply-side policies. Supply-side policies cannot ensure that fuels are produced in the Netherlands because the location of production and the location of supply are not necessarily connected. Moreover, supply-side policies will result in higher bunker fuel costs in the Netherlands, resulting in a change in bunkering location.

6 Literature

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A Method of total cost of ownership calculation

In order to compare the cost-effectiveness of using low- and zero-carbon fuelled ships, under different policy scenarios, we will calculate the total cost of ownership of 19 ship types and existing size categories as stated to report for the EU MRV (see Table 6). For each of ship type and size category we calculate the TCO for a bioFAME, (liquefied) biomethane, e-methanol and (liquefied) e-ammonia fuelled ship. Moreover, the TCO for ships sailing on very low sulphur fuel oil (VLSFO) is calculated as the baseline cost. The TCO of a ship comprises of several cost elements. We calculate the operational expenditure (OPEX), consisting of fuel costs, bunkering costs and M&R costs. Furthermore, we calculate the capital expenditure (CAPEX) for newbuilt ships. The TCO is representing yearly costs. In the main calculations for the report, we considered an 11% energy efficiency increase by 2030 compared to the performance in 2018.

We calculate the total CAPEX using standard engine, system and storage costs per kW, and the average installed power per ship type. The CAPEX per kW of the alternative fuel technologies are based on the costs predictions for these technologies as stated in (Horvath, et al., 2018). We assume the lifetime of the fuel technology systems is 25 years. We apply a weighted average cost of capital (WACC) of 7%, as this is the average WACC we found for the maritime transport sector[9]. The CAPEX is calculated as an annuity, representing yearly CAPEX in the TCO. The cost of the alternative fuels is derived from the Marginal Abatement Cost analysis of the Fourth IMO GHG Study (CE Delft; Ecorys, 2020) also stated in Table 7. Using the yearly average main engine fuel consumption, we calculate the total yearly fuel costs for a ship type. We also use the yearly fuel consumption to determine the yearly bunkering costs per ship type. The bunkering costs are derived from (TNO, 2020b; TNO, 2020a; TNO, 2020a). The yearly maintenance & repair (M&R) cost is a percentage of the total CAPEX of the ship fuel system: 1.5% for VLSFO, BioFAME, e-ammonia, and 3% for e-methanol (Kim, et al., 2020).

BioFAME is a drop-in fuel and can be used in conventional internal combustion engines (ICE). Bunkering of bioFAME can be done using conventional fuel oil bunkering infrastructure, and storage on board does not require changes to conventional fuel tanks. Therefore, we assume the additional capex, bunkering and M&R costs are zero with respect to a VLSFO-fuelled ship for this fuel. The additional TCO comprises therefore only of the additional fuel costs, which are still significant.

Liquefied biomethane can be used as a drop-in fuel for liquefied gaseous fuels. Dual-fuel engines and LNG engines are suitable for the use of this type of biogas.
For the use of e-methanol, a conventional ICE can be used. However, the system requires additional safety procedures and components may need to be prepared for the use of this highly inflammable liquid. Therefore, the capex for e-methanol engines, storage and piping installation are slightly higher than that of a system for VLSFO/HFO. The energy price of e-methanol is currently and predicted to remain significantly higher than other fuels and the conventional VLSFO in the near future. This causes ship sailing on e-methanol to have the highest additional costs of all alternative fuel options.

[9] As reported ranges of the WACC by several maritime freight operators (Hapag-Lloyd 7.7%-10.1%; Yang Ming Marine Transport 6.4%-8.3%; Moller-Maersk 7.8%)

Ships sailing on e-ammonia using an ICE have different engines, storage and piping technology than conventional ships. Because ammonia needs to be stored at or below the boiling point of -33°C, and because of its corrosiveness, the capex is much higher than for a conventional reference ship on VLSFO (see Table 8 for a comparison). Also fuel costs are high, resulting the total TCO of these ships to amount twice the TCO of the baseline ships.

Finally, e-ammonia on fuel cells are a technology not yet produced and applied at large scale, needing a higher level of market readiness to be a realistic alternative. CAPEX and OPEX of this technology are yet the highest of all considered alternatives.

Table 6 - Ship type data subject to EU MRV (2018)

Ship type	Size category (dwt/gt)	Unit	Avg. yearly main energy use (GJ)	Avg. installed power (kW)
Bulk carrier	0-9999	dwt	56,280	1,796
	10000-34999	dwt	128,640	5,941
	35000-59999	dwt	172,860	8,177
	60000-99999	dwt	237,180	9,748
	100000-199999	dwt	406,020	16,741
	200000-+	dwt	546,720	20,094
Chemical tanker	0-4999	dwt	80,400	987
	5000-9999	dwt	124,620	3,109
	10000-19999	dwt	180,900	5,101
	20000-39999	dwt	281,400	8,107
	40000-+	dwt	285,420	8,929
Container	0-999	teu	148,740	5,077
	1000-1999	teu	281,400	12,083
	2000-2999	teu	402,000	20,630
	3000-4999	teu	627,120	34,559
	5000-7999	teu	932,640	52,566
	8000-11999	teu	1,197,960	57,901
	12000-14499	teu	1,250,220	61,231
	14500-19999	teu	1,246,200	60,202
	20000-+	teu	1,025,100	60,210
General cargo	0-4999	dwt	28,140	1,454
	5000-9999	dwt	76,380	3,150
	10000-19999	dwt	152,760	5,280
	20000-+	dwt	221,100	9,189
Liquefied gas tanker	0-49999	cbm	156,780	2,236
	50000-99999	cbm	510,540	12,832
	100000-199999	cbm	1,109,520	30,996
	200000-+	cbm	1,603,980	36,735
Oil tanker	0-4999	dwt	64,320	966
	5000-9999	dwt	96,480	2,761
	10000-19999	dwt	148,740	4,417
	20000-59999	dwt	289,440	8,975
	60000-79999	dwt	361,800	11,837
	80000-119999	dwt	389,940	13,319
	120000-199999	dwt	534,660	17,446
	200000-+	dwt	775,860	27,159
Other liquids tankers	0-999	dwt	112,560	687
	1000-+	dwt	277,380	2,034
Ferry-pax only	0-299	gt	28,140	1,152

Ship type	Size category (dwt/gt)	Unit	Avg. yearly main energy use (GJ)	Avg. installed power (kW)
	300-999	gt	40,200	3,182
	1000-1999	gt	36,180	2,623
	2000-+	gt	176,880	6,539
Cruise	0-1999	gt	108,540	911
	2000-9999	gt	124,620	3,232
	10000-59999	gt	514,560	19,378
	60000-99999	gt	1,503,480	51,518
	100000-149999	gt	1,825,080	67,456
	150000-+	gt	1,776,840	73,442
Ferry-RoPax	0-1999	gt	52,260	1,383
	2000-4999	gt	112,560	5,668
	5000-9999	gt	196,980	12,024
	10000-19999	gt	418,080	15,780
	20000-+	gt	763,800	28,255
Refrigerated bulk	0-1999	dwt	76,380	793
	2000-5999	dwt	152,760	3,223
	6000-9999	dwt	237,180	6,206
	10000-+	dwt	510,540	11,505
Ro-ro	0-4999	dwt	84,420	1,618
	5000-9999	dwt	317,580	9,909
	10000-14999	dwt	498,480	15,939
	15000-+	dwt	538,680	19,505
Vehicle	0-29999	gt	237,180	7,264
	30000-49999	gt	337,680	11,831
	50000-+	gt	462,300	14,588
Yacht	0-+	gt	16,080	1,116
Service - tug	0-+	gt	20,100	1,086
Miscellaneous - fishing	0-+	gt	24,120	983
Offshore	0-+	gt	44,220	2,010
Service - other	0-+	gt	40,200	1,620
Miscellaneous - other	0-+	gt	108,540	15,301

Table 7 - Fuel cost ranges per GJ in 2030. Based on (Faber, et al., 2020)

Fuel type	Minimal fuel costs ($/GJ)	Maximum fuel costs ($/GJ)
BioFAME	$ 21.00	$ 70.00
Biomethane	$ 14.00	$ 40.00
e-Methanol	$ 9.00	$ 86.00
ZE e-Ammonia	$ 32.00	$ 71.00
VLSFO	$ 9.00	$ 20.00

Table 8 - Reference TCO of VLSFO-fuelled ships in 2030

Ship type	Size category (dwt/gt)	VLSFO reference yearly TCO (Minimum)	VLSFO reference yearly TCO (Maximum)
Bulk carrier	0-9999	$ 597,000	$ 1,227,000
	10000-34999	$ 1,427,000	$ 2,866,000
	35000-59999	$ 1,928,000	$ 3,861,000
	60000-99999	$ 2,567,000	$ 5,219,000
	100000-199999	$ 4,398,000	$ 8,938,000
	200000-+	$ 5,791,000	$ 11,905,000
Chemical tanker	0-4999	$ 756,000	$ 1,655,000
	5000-9999	$ 1,269,000	$ 2,663,000
	10000-19999	$ 1,834,000	$ 3,857,000
	20000-39999	$ 2,862,000	$ 6,009,000
	40000-+	$ 2,940,000	$ 6,132,000
Container	0-999	$ 1,510,000	$ 3,173,000
	1000-1999	$ 2,966,000	$ 6,113,000
	2000-2999	$ 4,387,000	$ 8,882,000
	3000-4999	$ 6,949,000	$ 13,962,000
	5000-7999	$ 10,387,000	$ 20,815,000
	8000-11999	$ 12,915,000	$ 26,311,000
	12000-14499	$ 13,514,000	$ 27,494,000
	14500-19999	$ 13,433,000	$ 27,369,000
	20000-+	$ 11,524,000	$ 22,987,000
General cargo	0-4999	$ 333,000	$ 648,000
	5000-9999	$ 855,000	$ 1,709,000
	10000-19999	$ 1,647,000	$ 3,355,000
	20000-+	$ 2,399,000	$ 4,871,000
Liquefied gas tanker	0-49999	$ 1,493,000	$ 3,246,000
	50000-99999	$ 5,093,000	$ 10,801,000
	100000-199999	$ 11,233,000	$ 23,640,000
	200000-+	$ 15,809,000	$ 33,745,000
Oil tanker	0-4999	$ 615,000	$ 1,335,000
	5000-9999	$ 1,004,000	$ 2,083,000
	10000-19999	$ 1,558,000	$ 3,222,000
	20000-59999	$ 2,978,000	$ 6,214,000
	60000-79999	$ 3,755,000	$ 7,801,000
	80000-119999	$ 4,077,000	$ 8,437,000
	120000-199999	$ 5,546,000	$ 11,525,000
	200000-+	$ 8,147,000	$ 16,822,000
Other liquids tankers	0-999	$ 1,015,000	$ 2,273,000
	1000-+	$ 2,522,000	$ 5,624,000
Ferry-pax only	0-299	$ 314,000	$ 629,000
	300-999	$ 544,000	$ 994,000
	1000-1999	$ 475,000	$ 880,000
	2000-+	$ 1,933,000	$ 3,911,000
Cruise	0-1999	$ 994,000	$ 2,208,000
	2000-9999	$ 1,277,000	$ 2,670,000
	10000-59999	$ 5,645,000	$ 11,399,000
	60000-99999	$ 16,178,000	$ 32,990,000
	100000-149999	$ 19,944,000	$ 40,352,000
	150000-+	$ 19,898,000	$ 39,767,000

Ship type	Size category (dwt/gt)	VLSFO reference yearly TCO (Minimum)	VLSFO reference yearly TCO (Maximum)
Ferry-RoPax	0-1999	$ 537,000	$ 1,121,000
	2000-4999	$ 1,323,000	$ 2,582,000
	5000-9999	$ 2,446,000	$ 4,649,000
	10000-19999	$ 4,589,000	$ 9,264,000
	20000-+	$ 8,348,000	$ 16,889,000
Refrigerated bulk	0-1999	$ 709,000	$ 1,563,000
	2000-5999	$ 1,519,000	$ 3,227,000
	6000-9999	$ 2,433,000	$ 5,085,000
	10000-+	$ 5,123,000	$ 10,832,000
Ro-ro	0-4999	$ 829,000	$ 1,773,000
	5000-9999	$ 3,357,000	$ 6,908,000
	10000-14999	$ 5,293,000	$ 10,867,000
	15000-+	$ 5,691,000	$ 11,714,000
Vehicle	0-29999	$ 2,499,000	$ 5,151,000
	30000-49999	$ 3,650,000	$ 7,426,000
	50000-+	$ 4,769,000	$ 9,939,000
Yacht	0-+	$ 208,000	$ 388,000
Service - tug	0-+	$ 241,000	$ 466,000
Miscellaneous - fishing	0-+	$ 269,000	$ 539,000
Offshore	0-+	$ 506,000	$ 1,001,000
Service - other	0-+	$ 448,000	$ 897,000

B Cost increase coast shipping

In Table 9, the ship types selected for the cost increase calculation in Section 3.2 are presented. We select certain types of ships and generally smaller sized ships for the coast shipping type. In Table 10 we present the well-to-wake emission factors[10] per gigajoule (GJ) for the considered fuels in this report. We used the lower end of the ranges for the emission reduction calculations where applicable to determine the in the cost increases.

Table 9 - Coast shipping ship types

Type	Size	Fleet 2018	Fleet 2030
Bulk carrier	0-9999	696	871.82
Bulk carrier	10000-34999	2014	2604.22
Chemical tanker	0-4999	619	1075.74
Chemical tanker	5000-9999	506	879.77
Container	0-999	861	1255.09
Container	1000-1999	1271	1873.14
Container	2000-2999	668	971.59
General cargo	0-4999	4880	5532.51
General cargo	5000-9999	2245	2545.18
Liquefied gas tanker	0-49999	1085	1309.44
Oil tanker	0-4999	2147	2225.95
Oil tanker	5000-9999	1117	1157.77
Other liquids tankers	0-999	26	26.96
Other liquids tankers	1000-+	27	28.00
Ferry-RoPax	0-1999	1040	1040
Ferry-RoPax	2000-4999	400	400
Ferry-RoPax	5000-9999	227	227
Ferry-RoPax	10000-19999	231	231
Ferry-RoPax	20000-+	282	282
Ro-ro	0-4999	615	697.23
Ro-ro	5000-9999	200	226.74
Ro-ro	10000-14999	135	153.05

Table 10 - Fuel emission factors per GJ (Faber, et al., 2020)

Fuel type	kg CO_2/GJ
BioFAME	10-43
biomethane	27.5-50
e-methanol	0-7.8
ZE e-ammonia	0
VLSFO	82.5

[10] Well-to-wake emission factors comprise of all emissions of the production and use of the product, in this case from the considered fuels.

For the calculation of the competitiveness we used the coastal shipping fleet performance and subsequent costs for the 2018 reference scenario. In this reference, it is assumed all ships are powered by VLSFO. As stated in the report, we follow the same drop-in requirement as in road transport for plausible comparison of cost figures. The 8.5% drop-in of bioFAME correspond with a GHG emission reduction of 7.47% per ship disregarding the performance of the ship in distance and freight transported (this is solely due to the lower carbon content of bioFAME). First, the total tonne mileage, in million tonne nautical miles (Mtnm) was calculated using the ton mileage per ship in 2018 and number of ships in the EU MRV fleet in 2018. For the year 2018, the total fleet total cost of ownership is calculated using the TCO per ship on VLSFO and the number of ships in the category of ships.
By dividing the total fleet TCO by the fleet total ton mileage, we obtain the average cost per ton mileage (in million tonne nautical miles) for the entire fleet, see Table 11.

For policy Options 1 and 2, the cost-effective option for emission reduction is the (drop-in) fuel one with the lowest additional TCO compared to the VLSFO reference TCO per ship. This is bioFAME, as we can observe in Figure 2. The total fleet tonne mileage is higher in 2030 as a result of the growth of the fleet compared to the fleet in 2018. We assumed the tonne mileage per ship to be constant. as a result of the 8.5% drop-in requirement, fuel costs increase for every ship, according to the stated costs for bioFAME. The total fleet TCO is calculated with the TCO per ship including additional fuel cost from bioFAME drop-in, and the number of ships in the fleet in 2030. This is done for the minimal and maximal (fuel) cost cases, as indicated in Table 11. The average TCO per Mtnm in 2030 are calculated as a percentage of the 2018 average TCO. Finally, we obtain cost increases of the coastal shipping sector in terms of transported volume and distance.

Table 11 – Fleet cost increase in 2030 under policy Options 1 and 2 (8.5% drop-in of bioFAME)

	2018	2030 (min. cost)	2030 (max. cost)
Fleet ton mileage (Mtnm)	9,306,000	12,327,000	12,327,000
Total fleet TCO	$ 27,056,868,00	$ 36,313,457,000	$ 48,087,335,000
Average TCO per Mtnm	$ 2,908	$ 2,946	$ 3,901
Increase in average TCO per Mtnm	-	+1.3%	+34.2%

Policy Option 3, pooled compliance of the fleet for the aim of GHG emission reduction, has a slightly different procedure in the cost increase calculation. The reference figures for 2018 are equal to the above presented. The EU MRV fleet acts in the calculation as a large pool of ships that are allowed to average emissions to comply to the required emission reduction target. For the ease of comparison we assume the fleet has to reduce emissions by 7.47% in this case too. The fleet mileage in 2030 is the same as we calculated for the other policy options. We first determine the total fleet emissions if the entire fleet in 2030 would be powered by VLSFO. These hypothetical 'baseline' CO_2 emissions are about 233 mega tonnes (Mt). The fleet needs to achieve a reduction of 7.47% as we stated, which implies an emission reduction of 17 Mt. We determine which fuel (and driveline) type has the lowest TCO per tonne CO_2 reduction. For all ship types in the coastal shipping fleet this is biomethane (dual-fuel ICE or LNG-ICE). Then we select the ships that have the lowest cost per tonne CO_2 reduction within the fleet. In the coastal shipping fleet we consider, 'other liquids tankers' are the ones with the lowest cost per tonne CO_2 reduction, followed by 'chemical-, liquefied gas- and oil tankers'. Using the CO_2 reduction per ship when the ship is operated by biomethane (compared to VLSFO), we can calculate the achieved emission reduction if some (of all) ships within a ship type group are powered by biomethane. We hypothetically 'switch' the most cost-effective groups to the lower-carbon alternative fuel, until we reach a cumulative emission reduction which is equal or (slightly) more than the target (17 Mt). From the fleet of 25,614 ships, 3,257 ships have to sail on biomethane to reach the required emission reduction. Finally, we calculate the total fleet TCO, including both the ships sailing on biomethane, and the rest of the fleet continuing on sailing on VLSFO. By dividing the total fleet TCO by the fleet total ton mileage, we obtain the average cost per ton mileage (in million tonne nautical miles) for the entire fleet for the minimal and maximal (fuel) cost cases, see Table 12. The average TCO per Mtnm in 2030 are calculated as a percentage of the 2018 average TCO. Finally, we obtain cost increases of the coastal shipping sector in terms of transported volume and distance.

Table 12 – Fleet cost increase in 2030 under policy Option 3 (pooled compliance with fuel choice biomethane)

	2018	2030 (min. cost)	2030 (max. cost)
Fleet ton mileage (Mtnm)	9,306,000	12,327,000	12,327,000
Total fleet TCO	$ 27,056,868,000	$ 35,195,696,000	$ 43,433,039,000
Average TCO per Mtnm	$ 2,908	$ 2,855	$ 3,523
Increase in average TCO per Mtnm	-	-1.8%	21.2%