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Biofuels for low carbon shipping

HULDA WINNES, ERIK FRIDELL, JULIA HANSSON AND KARL JIVÉN,
IVL SWEDISH ENVIRONMENTAL RESEARCH INSTITUTE

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Preface

This study has been funded by the TripleF project and conducted by IVL Swedish Environmental Research Institute together with Tärntank Ship Management AB and Lighthouse. Tärntank Ship Management AB was assisted by the energy service company Wega Group Oy.

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Sammanfattning

I den här studien undersöker vi möjligheterna att introducera biobaserat bränsle i sjöfarten. Studien är främst inriktad mot tanksjöfarten. Den innehåller kvantitativa bedömningar av tillgänglighet och pris på biobaserade alkoholer, hydrerad vegetabilisk olja (HVO), fettsyrametylestrar (FAME) och förvätskad biogas (LBG). Mer detaljerat studerar vi HVO, FAME och LBG. De tekniska och logistiska hindren kopplade till användning av HVO och LBG i fartygsmotorer är små och kan inte förväntas stoppa en övergång. Däremot är kostnadsökningen svårare att angripa ur ett företagsekonomiskt perspektiv. FAME är ett mer attraktivt alternativ ur kostnadsperspektiv men har historiskt varit förknippat med tekniska problem.

Vi genomför fallstudier på två tankfartyg i trafik runt Norden och beräknar de totala transportkostnaderna, inklusive tidscharter-kostnader, farleds- och hamnavgifter, och bränslekostnader. De fall som studeras baseras på två existerande fartyg och tänkbara rutter, men generiska uppgifter används för exempelvis för ”timecharter”-kostnad. Vid en övergång från fossila bränslen till HVO och LBG ökar de totala transportkostnaderna med cirka 40 % per transporterad lastvolym. Om FAME kan användas som ett fullgott alternativ till MGO blir den totala ökningen i transportkostnad istället 2-7 % för de studerade rutterna.

För tidscharter-avtalen, som är av särskilt intresse för denna studie, bärs bränslekostnaderna av kunden. Vi drar slutsatsen att pilottester och mer långsiktig användning av biobränslen i fartyg kräver att lastägaren har ambitiösa hållbarhetsmål och ett nära samarbete mellan redare och kund. Rabatter på hamn- och farledsavgifter kan inte som enda incitament driva övergången från fossila bränslen till förnybara alternativ. Detta beror på att kostnaderna för bränslebytet med dagens prisnivåer på bränsle är högre än de totala avgifterna i hamnar och farleder under en rundresa. Flera parter behöver dela kostnaderna i de fall bränslebyten görs på frivillig basis. Vid lägre kostnadsökningar bör denna fördelning vara lättare att genomföra. Ur detta perspektivet är FAME det mest attraktiva alternativet.

I en översikt över biobränsleproduktionen framgår det att tillgången på biobränslen behöver öka avsevärt för att täcka en eventuell framtida efterfråga från sjöfarten. Mängden tillgängligt biobränsle kan inte täcka bränsleanvändningen i tanksjöfarten till och från Sverige. Särskilt tydligt blir detta om man också tar hänsyn till existerande efterfrågan från landtransporter och en eventuell kommande efterfrågan från övrig sjöfart. En omfattande användning av biobränslen i sjöfarten skulle kräva betydligt högre produktionsvolymer. Långsiktiga avtal kan ändå göra det möjligt för enskilda redare att övergå till biobaserade bränslen. Det finns tillräckliga mängder av alla de studerade bränslena för enskilda fartygsägare. Sammanfattningsvis är tillgången på biobränsle idag otillräcklig för en storskalig introduktion i sjöfarten och det bidrag som biobränsle kan ge för att nå sjöfartens mål att sänka CO_2-utsläppen beror till stor del på hur produktionen av biobränslen utvecklas.

I fallstudierna är de externa kostnaderna mellan 50% och 72% när fartygen går på förnybara bränslen jämfört med fossilt bränsle, beroende på rutt och bränsle. De externa kostnader som undviks vid byte till ett icke fossilt bränsle är dock lägre än de ökade transportkostnaderna. Detta indikerar att förändringar måste göras på en politisk nivå för att även inkludera sjötransporter i omvandlingen till det fossilfria samhället.

Summary

This study contains analyses on the potential to use biobased fuel for marine use, with a focus on the tanker sector. It includes quantitative assessments of availability and price of biobased alcohols, Hydrotreated Vegetable Oils (HVO), Fatty Acid Methyl Esters (FAME), and Liquefied Biogas (LBG). In more detail we study HVO, FAME and LBG. While technical and logistic aspects on the introduction of HVO and LBG cause none or minor implications, the increased fuel costs are more difficult to approach from a business perspective. FAME is more attractive from a cost perspective but less so from a technical point of view.

We conduct case studies on two product tankers in traffic around the Nordic countries and assess total transport costs including time charter costs, fairway and port dues, and fuel costs. The cases are based on real ships and routes although generic input on e.g. time charter costs are used. The result showed an increased total transport costs close to approximately 40% per transported cargo volume for both vessels, at shifts from MGO and liquefied natural gas (LNG) to HVO and LBG, respectively. If FAME, which is a biofuel of lower quality than HVO, is considered as a viable alternative, the increased cost is instead 2-7% at a 100% shift from MGO to biodiesel on the studied routes.

For the time charter segment of the industry, which is of particular interest in this study, the fuel costs are born by the customer. We conclude that pilot projects and more long-term usage of biofuels in time-chartered vessels require ambitious sustainability targets of the customer and a close collaboration between the shipowner and the customer. At lower increases in total costs it should be more feasible to distribute them among stakeholders. From this perspective, FAME is the favorable option. Existing policies do not offer regulatory or systematical support for the introduction of bio-based fuels in shipping and rebates on port and fairway dues cannot alone significantly push towards a shift to biofuels in the industry if price levels of today prevail. Several parties need to aim at emission reduction in the supply chain and be willing to share the added costs. The International Maritime Organization IMO does not yet have a method or data on how to treat biofuels in emission monitoring or in regulations.

An overview of the availability of biofuels shows that biofuel production needs to be significantly increased to cover a potential future demand from shipping. There is a gap between total biofuel production and the energy demand of the tanker segment in traffic to and from Sweden. Especially when considering also demands from mainly land-based transport and, potentially, other shipping segments. An introduction of biofuels in a large scale to many actors in shipping would require significantly higher overall production volumes. However, arrangements with long-term agreements may still make the shift to bio-based fuels possible for individual shipowners. The study shows that there are enough quantities available for single shipowners, of all of the studied fuels. We thus conclude that a large-scale introduction of bio-fuels for shipping is unachievable at present and that the contribution of bio-based fuels to reaching the CO_2 emission targets of the industry depends on the development of bio-fuel production.

In the case studies, the external costs from ship routes on renewable fuels are reduced by 50-72% compared with the fossil fuels, depending on route and fuel. The external costs that are avoided when changing to a non-fossil fuel are still lower than the increased transport costs.

This indicates that changes need to be made on a policy level in order to include also shipping in the transformation to a fossil free society.

Innehållsförteckning

Glossary / definitions

ARA	Amsterdam-Rotterdam-Antwerp region
Biodiesel	Non-petroleum alkylate esters (e.g. FAME) that can be used as a non-fossil alternative fuel for diesel engines
Biofuel	Fuel from renewable resources
CAPEX	Capital expenditure
CBG	Compressed biogas
CCWG	Clean Cargo Working Group
CFPP	Cold filter plugging point. The lowest temperature, expressed in degrees Celsius (°C), at which a given volume of diesel type of fuel still passes through a standardized filtration device in a specified time when cooled under certain conditions.
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent, greenhouse gases other than CO_2 are recalculated and expressed as carbon dioxide equivalents based on their warming potential I defined time perspectives
CP	Cloud point. Temperature below which wax in diesel or biowax in biodiesels forms a cloudy appearance.
CSI	Clean Shipping index, a rating system based on environmental performance of ships
DCS	Data Collection System, implemented by the IMO to collect information on ships' CO_2 emissions
DMA	Distillate fuel according with ISO 8217, DMA (also called marine gas oil, MGO) is a general purpose marine distillate that must be free from traces of residual fuel
DMB	Distillate fuel according with ISO 8217, DMB (i.e. marine diesel oil, MDO) is allowed to have traces of residual fuel, which can be high in sulfur.
DMX	Distillate fuel according with ISO 8217, DMX is a distillate that is used only in smaller engines (lifeboats/emergency units) and is intended for use outside the engine room
DMZ	Distillate fuel according with ISO 8217, DMZ must not contain residual fuel constituents, has a higher aromatics content and a slightly increased viscosity at 40°C compared with the other distillate fuels
drop-in fuel	A high-end biofuel (e.g. HVO) that is exchangeable in parts or in full with refined petroleum-based diesel fuel
DWT	Deadweight tonnage

EEDI	Energy Efficiency Design Index, Mandatory requirements on energy efficiency on all ships constructed from 2013 and forward, set by the IMO
EEOI	Energy Efficiency Operational Index, Voluntary requirements on energy efficiency on all ships constructed from 2013 and forward, set by the IMO
EMSA	European Maritime Safety Agency
ESI	Environmental Ship Index, a rating system based on environmental performance (emissions to air) of ships
External costs	External costs are costs carried by the society for e.g. environmental deterioration. E.g. Health care costs for increased cases of asthma due to air pollution
FAME	Fatty acid methyl ester, a bio diesel.
FOB	Free on board
Fuel blend	A blend of fuels with similar but not necessarily identical characteristics
GHG	Green house gases
GTL	Gas to liquid, a liquid fuel produced from gas
HDRD	hydrogenation-derived renewable diesel
HFO	Heavy fuel oil, a conventional fuel in shipping that mainly consists of residual oil from refineries
HVO	Hydrotreated vegetable oil, often used as a drop-in fuel in fuel for diesel engines
ICE	Intercontinental exchange
IEA	International Energy Agency
ILUC	Indirect Land Use Change
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standardisation Organization
LBG	Liquefied biogas
LNG	Liquefied natural gas
LSFO	Low sulphur fuel oil
MARPOL	International Convention for the Prevention of Pollution from Ships, adopted in 1973 at IMO
MEPC	Marine Environmental Protection Committee, of the IMO
MGO	Marine gasoil
MRV	Mandatory requirements for ships on monitoring, reporting and verification of CO_2 emissions from ships
MTG	Methanol to gasoline
NM	nautical mile
NMVOC	Non-Methane Volatile Organic Compounds
NO_X	

	Nitrogen oxides
OME	Oil Methyl Ester
PP	Pour point. Temperature below which the liquid loses its flow characteristics.
REDII	The EU Renewable Energy Directive II, revises RED I and establishes an overall policy for the production and promotion of energy from renewable sources in the EU
RM	Residual marine oil
RME	Rapeseed methyl ester
SECA	Sulphur emission control area, IMOs denomination of zones where stricter regulations on sulphur emissions from ships apply.
SEEMP	Ship Energy and Emission Monitoring Plan, Mandatory requirements on energy efficiency procedures on all ships constructed from 2013 and forward, set by the IMO
SFC	specific fuel consumption
SME	Soybean methyl ester
SOLAS	International Convention for the Safety of Life at Sea, adopted in 1914 at IMO
SO_x	Sulphur oxide
T/C	Time charter (or time charterparty), a contract between a shipper and a shipowner which gives the shipper right to rent a ship for a limited period of time
TEU	twenty-foot equivalent unit; an inexact unit of cargo capacity used to describe the capacity of container ships
TTF	Title Transfer Facility, a virtual trading point for natural gas in the Netherlands
TTW	Tank to wheel

1 Introduction

There is an urgent need for society to reduce carbon dioxide (CO_2) emissions. Emissions from shipping have proven difficult to target in international agreements on climate efforts since all-encompassing regulations are missing. Individual initiatives from single shipowners or ship operators will result in competitive disadvantages. The purpose of this study is to identify possibilities for business models and incentives that could facilitate for shipowners that are ready to start using low carbon fuels, without too significant negative economic consequences.

About 80% of worldwide trade by volume and 70% of its value is carried out by ships (UNCTAD, 2017). Marine freight is often a more favourable option from a climate perspective than land-based transport, with low emissions of CO_2 per unit transport work. The IEA estimates that international shipping consumed 265 million tonnes of bunker fuel in 2015. Of these, the absolute majority is fossil oils and approximately 6.5 million tonnes liquefied natural gas (LNG) (Le Fevre, 2018). Biofuels are currently only occassionaly used as marine fuels, mainly in pilot and demonstration projects.

The choice of fuel used in international shipping is, to a large extent, guided by regulations on sulphur content in fuel. In Sulphur Emission Control Areas (SECAs), where the sulphur content cannot exceed 0.1%, mainly three options have prevailed:

1. Most of the ships in these areas operate on low sulphur fuels: marine gasoil (MGO) or low sulphur fuel oils (LSFO);
2. Many ships (approximately 3000 ships in 2019 (DNVGL, 2019) have continued operations on the high sulphur heavy fuel oil (HFO) together with exhaust gas cleaning systems (scrubbers);
3. Yet others are built or redesigned to use LNG as fuel. Around 170 ships that are not LNG carriers use LNG as fuel (DNVGL, 2019). These ships are almost exclusively in traffic in the SECAs.

In 2020, the global standard for sulphur in marine fuel is set to 0.5%. The lower sulphur content contributes to an increased use of distillate fuels in shipping, and consequently reduced air pollution. The regulation however has no direct effect on emissions of greenhouse gases (GHGs) from ships.

There is a need to have efficient regulations on emissions of GHGs originating from ships. The existing regulations on emissions of CO_2 in the MARPOL convention include mainly two measures. One is the Energy Efficiency Design Index (EEDI) that prescribes stepwise reductions of CO_2 emissions in relation to ship size and transported goods. The regulation refers only to ship designs and does not cover actual emissions from ship operations, although a consequence of an energy efficient design is a good prerequisite for energy efficient operations. Another part of the regulation is the Ship Energy Efficiency Management Plan (SEEMP), which does not dictate any compliance levels but rather suggests how ship energy consumption and emissions can be managed. The SEEMP also contain a reporting function for CO_2 emissions. According to the estimates presented in the third IMO GHG study, international shipping emitted around 800 million tonnes of CO_2 in 2012, that is, about 2.2% of the total global CO_2 emissions for that year (IMO, 2014b).

In April 2018, the IMO agreed on quantified targets for the reduction of GHG emissions from shipping (IMO, 2018a). The goal consists of three main parts:

1. To strengthen existing rules for more energy-efficient ship designs.
2. To reduce CO_2 emissions of transport work by 40% or more until 2030 and striving to reach 70% by 2050, compared with the 2008 level.
3. To reduce shipping's total emissions of climate gases as soon as possible and to release half as much GHG in 2050 as in 2008.

Specific measures to reach the goals are to be worked out. The timetable is not yet set, but references are made to the Paris Convention's temperature target (International Maritime Organization, 2018).

The transport sector on land has gradually increased its share of renewable fuels to reduce its CO_2 emissions with fossil origin. Ethanol is the dominating biofuel used for land-based transport as a component or substitute for gasoline. Land-based transports are also introducing electrification, bio-based diesel and biogas as replacements for petroleum-based diesel and natural gas. This process can be expected to have been driven by regulations referring to international agreements to abate global climate change. The shipping sector has not been included in the Kyoto protocol or the Paris agreement, and the transition to non-fossil marine fuel is merely starting and on a very small scale. Examples include trials on biofuel by shipowners (Florentinus et al., 2012, Mofor et al., 2015, and Good Fuels, 2018), electricity-driven ferries, e.g. ForSea's ferries between Helsingborg and Helsingör, and business models between cargo owners and shipowners. Many of these initiatives have been demonstration projects only (Bäckström et al., 2018).

This study focuses specifically on time-charter shipping and includes case studies on two ships from Terntank's tanker fleet. The vessels in this study are assumed to be chartered for approximately one year. Characteristic of this segment, and important from the perspective of low carbon shipping, is that the customer pays fuel costs. Further, only one customer is involved in the transport as opposed to container or ro-ro shipping, where many different customers use the same ship.

With the aim to contribute to the introduction of low carbon energy carriers or energy sources in maritime freight services, we outline a report building on a case description for the tanker time charter segment. We include a general overview of the policy framework, availability and price for biofuels for low carbon shipping in Chapter 2. In Chapter 3, the biofuel types considered in this study are presented from a generic perspective. Chapter 4 includes an overview of fuel costs and prices. In Chapter 5, environmental issues relating to different biofuels are discussed. The two following Chapters, 6 and 7, are more specific for applications in shipping and contain overviews of the practical, logistical and technical characteristics concerning the fuel logistics and potential technical issues with the fuel use on board. In Chapter 8, we present calculations on the economics of fuel shifts from a company perspective in case studies. This chapter also includes the results from environmental calculations. The final Chapter 9 is a discussion and conclusion chapter including analysis and comprised findings from the report.

2 Policy framework for biofuels

2.1 IMO regulations

IMO has two mandatory systems where CO_2 emissions are relevant: Energy Efficiency Design Index (EEDI) and the Data Collection System (DCS). EEDI is a system to steer new ships to be more fuel efficient. It requires shipowners to prove that new ships are designed to emit less CO_2 per distance sailed compared with a reference level. The EEDI is part of the International Convention for the Prevention of Pollution from Ships, MARPOL (International Maritime Organisation, 2011). The reference line of EEDI considers the size of the vessel (deadweight tonne) and distinguishes between different ship types. Further, the requirements in the regulation become more demanding in three steps over time.

The DCS is a system for international shipping to collect data on fuel consumption. The DCS requires ships of, or over, 5 000 gross tonnage to collect and report data on fuel consumption from 2019 onwards. The DCS plan must be created within the Ship Energy Efficiency Management Plan (SEEMP).

IMO has produced a table with factors for CO_2 emissions from different fuels that are used in EEDI and DCS. The table can be found in MEPC245(66) and is replicated in full in Table 1.

Table 1. CO_2 emission factors from IMO resolution MEPC245(66)

Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-fuel)
Diesel/Gas oil	ISO 8217 Grades DMX through DMB	0.8744	3.206
Light Fuel Oil	ISO 8217 Grades RMA through RMD	0.8594	3.151
Heavy Fuel Oil	ISO 8217 Grades RME through RMK	0.8493	3.114
Liquefied Petroleum Gas (LPG)	Propane	0.8182	3.000
	Butane	0.8264	3.030
Liquefied Natural Gas (LNG)		0.7500	2.750
Methanol		0.3750	1.375
Ethanol		0.5217	1.913

C_F is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content. C_F corresponds to the fuel used when determining specific fuel consumption (SFC) listed in the applicable test report included in a Technical File as defined in paragraph 1.3.15 of NO_X Technical Code.

As can be seen, Table 1 does not contain any defined biofuels, nor does it take into account emissions from production and transport of fuels or GHGs other than CO_2. Thus, the conclusion is that IMO does not yet have a method or data on how to treat biofuels in emission monitoring or in regulations. A report for the European Maritime Safety Agency (EMSA) on biofuels for shipping emphasises that EEDI treats all CO_2 (biogenic and fossil) the same way (Florentinus et al., 2012). IMO's work following the goal to reduce GHG emissions considers non-fossil fuels but only in a discussive and qualitative manner. In October 2018, the 73rd session of the Marine Environment Protection Committee (MEPC) approved a follow-up program, intended to be used as a planning tool in meeting the timelines identified in the initial strategy (IMO, 2018b). In May 2019, the MEPC 74 pushed forward with several measures aimed at supporting the achievement of the objectives set out in the initial strategy. MEPC adopted resolution MEPC.323(74) on "Invitation to the Member States" to encourage voluntary cooperation between the port and shipping sectors to contribute to reducing GHG emissions from ships. This could include regulatory, technical, operational and economic actions, such as safe and efficient bunkering of alternative low-carbon and zero-carbon fuels and incentives promoting sustainable low-carbon and zero-carbon shipping (IMO, 2019).

MEPC also considered concrete proposals on candidate mid-/long-term measures, in particular, measures aimed at encouraging the uptake of alternative low-carbon and zero-carbon fuels. The Intersessional Working Group on Reduction of GHG Emissions from Ships will further consider concrete proposals to reduce methane slip and to encourage the uptake of alternative low-carbon and zero-carbon fuels, including the development of lifecycle GHG/carbon intensity guidelines for all relevant types of fuels and incentive schemes, as appropriate.

2.2 EU regulations

The EU has a system called MRV (Monitoring, Reporting, Verification) for monitoring CO_2 emissions and fuel consumption for ships entering the EU (EU 2015/757). In Annex 1, section A it says "Those default values for emission factors shall be based on the latest available values of the Intergovernmental Panel for Climate Change (IPCC). Those values can be derived from Annex VI to Commission Regulation (EU) No 601/2012". Thus, the regulation refers to IPCC, and in this document, the emission factors for CO_2 for biofuels are set to zero. This is the method used by IPCC in which emissions occurring from the production of biofuels are counted in other sectors than transportation.

However, there is ongoing work to develop MRV and to align it with DCS. In a working paper (Faber and Behrends, 2016), Implementation of Shipping MRV Regulation Third Working Paper on monitoring (possible amendments to Annex I and II)) it is concluded that the IMO emission factors (those in Table 1) should be used exclusively also in MRV. The Commission published changes to MRV in 2019 (COM(2019) 38 final) where no changes are suggested for emission factors, but the alignment to DCS is emphasised. For EU and MRV it is at present therefore unclear how biofuels are treated, but it is reasonable to set the emission factors to zero given the reference to IPCC.

The driver of the European biofuel legislation is the Renewable Energy Directive (RED). The original RED I (2009/28/EC) sets a total renewable energy share goal to 20% and transport renewable energy share to 10% by 2020. It does not set any quotas for first-generation or second-generation biofuels. Double counting and minimum GHG reduction targets exist. Double counting indicates that a fuel is produced in a more sustainable way. In the emissions calculations these biofuels count twice their real energy value in terms of their contribution to the national mandates.

The updated Renewable Energy Directive RED II (2018/2001/EU; European Parliament and Council, 2015; European Parliament and Council, 2018) sets the target of 32% total renewable energy share and 14% renewable fuels in the road and rail transport sectors by 2030. The aviation and maritime sectors can opt in to contribute to the 14% transport target but are not subject to an obligation. The maximum amount for crop-based first-generation biofuels is 7% in 2020. From 2020, the share of biofuels produced from food and feed crops that are considered to have high Indirect Land Use Change (ILUC) risk shall not exceed the national 2019 levels, unless they are certified to be low ILUC-risk biofuels, and from 2023 until 2030 they should be phased out. The quota for second-generation biofuels is gradually increasing, being 0.2% by 2022, 1% by 2025 and 3.5% by 2030.

The procedure of double counting remains in RED II, and minimum GHG reduction targets have been increased related to the facilities where consumed biofuels were produced. Advanced biofuels will be double counted towards both the 3.5% target and the 14% target. Biofuels produced from feedstocks listed in Part B of Annex IX will be capped at 1.7% in 2030 and will also be double counted towards the 14% target. Biofuels and bioenergy produced from waste and residues listed in Annex IX of the directive only need to comply with the GHG emission sustainability criterion (European Parliament and Council, 2018).

The RED II includes sustainability criteria that bioliquids used in transport must comply with. Some of these criteria are the same as in the original RED, while others are new or reformulated, mainly to also cover sustainability for forestry feedstocks as well as GHG criteria for solid and gaseous biomass fuels.EU has set biofuel mandates for member states, but national mandates can be higher than the baseline set by the EU, depending on the national legislation. In general, the country-specific ambitions with mandatory biofuel blending rates and energy share percentage from biofuels have increased. National mandates can have a separate mandate for second-generation biofuels, or they can be CO_2 equivalent based. National biofuel mandates usually define the total demand for biofuels.

In Sweden, the requirements to use biofuels originates from the law of GHG reduction in road transport fuels, and double counting does not exist. Sweden did not have a biofuels mandate or target until 2018. Its primary support mechanism for biofuels has been exemptions from energy and carbon taxes, which apply to fossil fuels. In 2017, almost 21% of the energy used for road vehicles came from biofuels. Sweden has increased the share of biofuels sold significantly, and especially the consumption of HVO has expanded in recent years, both as a blend with fossil diesel and as a pure fuel. Almost all of the HVO consumed in Sweden is imported.

2.3 Environmental Indexes for ships

Several shipping indexes are today available to rate ships' environmental performance and to reach sustainability goals. Indexes are tools to differentiate e.g. port fees and fairway dues or used by shippers to choose more sustainable shipping alternatives. Three examples of indexes that have a relatively wide spread use for differentiation of port fees are the Clean Shipping Index (CSI), the Environmental Ship Index (ESI), and the Green award, which mainly applies to bulk and tanker shipping.

Clean Shipping Index (CSI) ranks vessels based on environmental performance beyond regulatory compliance. In addition to the ports, the Swedish Maritime Administration has chosen the CSI as a practical tool for differentiating fairway dues. In CSI, biogenic CO_2 should be subtracted when calculating the emissions of CO_2 per transport work that is the basis for CO_2-scoring; “Clean Shipping Index applies a carbon factor of zero (0) for renewable fuels when calculating CO_2 emissions per tonne NM (EEOI[1]) or TEUkm (CCWG)”. Thus, a ship using only biofuels would get maximum points for CO_2 in CSI.

Environmental Ship Index (ESI) identifies seagoing ships that perform better in reducing air emissions than required by the current emission standards of IMO. In ESI, there is no mention of renewable or biofuels. Scoring is given for improvements in fuel efficiency with reference to IMO’s MEPC.1/circ.684 for calculations. Based on the guidelines, all fuels should be included, although no emission factors are given for non-fossil fuels.

Green Award is a voluntary quality assessment certification scheme for ships. Green Award incentive providers are ports, shipping organisations and maritime service and products suppliers that want to support and enhance the environmental and safety performance of ships and to promote the highest quality standards. In Green Award there is no mention of renewable or biofuels.

The Clean Cargo Working Group (CCWG) or “Clean Cargo” is an initiative that involves major brands, cargo carriers, and freight forwarders promoting environmentally responsible shipping. Clean Cargo represents around 80% of global container cargo capacity and constitutes a buyer-supplier forum for sustainability in container cargo shipping industry. The CCWG does not mention renewable fuels and references are instead made to the IMO methodology.

3 Biofuel types

Biofuel is a common name for a broad portfolio of fuels produced from biomass. A variety of liquid and gaseous biofuels can be produced from various biomass feedstocks using a range of conversion pathways. The most widespread and commonly used biofuels are bioethanol and biodiesel fuels. Several different biomass-based fuels are relevant to assess from a shipping perspective: biomass-based alcohols such as ethanol and methanol, biodiesel in the form of FAME (Fatty Acid Methyl Ester) and HVO (Hydrotreated Vegetable Oil), and liquefied biogas (LBG).

Globally, ethanol is the dominating biofuel used for land-based transport as a component or substitute for gasoline, followed by biodiesel. The global ethanol production is almost twice that of biodiesel (IEA, 2017). However, in the EU, biodiesel represents 80% of the total biofuel use and ethanol 18% (EurObserv’ER, 2018). The total use of biofuels for transport in Sweden (also including low blending) is dominated by HVO and FAME, followed by biogas and ethanol.

Biofuels can be produced on a stand-alone basis, or they can be co-processed in existing petroleum refineries. Petroleum refineries are likely locations for renewable fuels production. They are built for the production of advanced fuels by the most cost-effective means to deliver appropriate products for surrounding societies and demand. A petroleum refinery is an industrial process plant where crude oil is transformed and refined into more useful products such as

[1] Energy Efficiency Operational Indicator (EEOI) is a voluntary part of the MARPOL convention’s CO_2-regulation

petroleum naphtha, gasoline, diesel fuel, asphalt base, heating oil, kerosene, liquefied petroleum gas, jet fuel and fuel oils. Most oil refineries focus on producing transportation fuels.

Table 2 includes an overview of the production of a selection of bio-based fuels. The selected fuels and their properties are further explained in the following paragraphs.

Table 2. Available energy as biofuels currently on the market. Figures are approximate.

	SUM production	Density (kg/L)	Energy conversion	SUM production of energy TJ	Comment
Ethanol (Europe)	3 610 ML	0.79	27 MJ/kg	77 000	High production outside Europe that is not included in the 3 610 ML. In total approximately twice the biodiesel production
Methanol (Europe)	450 kt	0.81	20.1 MJ/kg	9 000	Major feedstock is biogas
FAME (EU)	2 000 kt	-	37 MJ/kg	74 000	Large amounts imported to the EU
HVO (EU)	4 000 kt		43 MJ/kg	170 000	HVO mostly used in transport
LBG (EU)	1 712 GWh	-	3.6 MJ/kWh	6 200	40% of the 1 712 GWh is from planned capacity

3.1 Biomass-based alcohols

Alcohols from biomass of primary interest in the context of this study are methanol that has been successfully tested as a marine fuel, and ethanol that is used in combustion engines on land on a large scale.

3.1.1 Ethanol

Today ethanol is primarily used as a land-based transportation fuel, mostly mixed with gasoline in blends. The largest markets for ethanol include the USA, Brazil, the EU, and China where the USA and Brazil represent also the dominating producers with more than half of the total global production (Energimyndigheten, 2018a; IEA, 2017). Most of the ethanol is produced from corn in the USA and sugar cane in Brazil. Other ethanol feedstocks include sugar beets and other agricultural crops. Also, ethanol production from mainly lignocellulosic material, including forest-based biomass, agricultural residues (corn stover, wheat straw), and grasses has started in recent years.

The main ethanol producers in Europe include:

- *Crop Energies* with plants in Germany, Belgium, France, and the UK that produce ethanol from sugar juice, wheat, and maize with a total production capacity 1 300 ML;

- *Tereos* with plants in France, the Czech Republic, the UK, and Italy that produce ethanol from sugar juice and wheat with a total production capacity of 1 260 ML;
- *Cristanol* with plants in France that produce ethanol from sugar juice and wheat with a total production of 380 ML;
- *Vivergo* with plants in the UK that produce ethanol from wheat with a total production capacity of 420 ML;
- and *Agrana* with plants in Austria that produce ethanol from wheat and maize with a total production capacity of 250 ML (EurObserv'ER, 2018).

In Sweden, Lantmännen Agroetanol in Norrköping is a major producer of ethanol (from mainly wheat grain). Also, Domsjö Fabriker and St1 refinery in Gothenburg produce ethanol fuel from food waste. However, the major part of the ethanol used as fuel in Sweden is imported and based on corn and wheat.

3.1.2 Methanol

Biomass-based methanol is produced in the Netherlands, by BioMCN that converts biogas into methanol (production capacity 450 kt/year) and in Canada, where Enerkem produces methanol from municipal solid waste[2] with a production capacity of 38 ML/year (IEA, 2017). There are also plans for a methanol plant in the Port of Rotterdam using waste and producing approximately 220 000 tonnes (270 ML) of methanol with Nouryon and Shell being the expected buyers[3]. In Sweden, there have been plans for a methanol plant in Hagfors in Värmland for several years, but with relatively slow progress[4]. Methanol is one of the top five chemical commodities shipped around the world each year. It is readily available through existing global terminal infrastructure. Methanol could be used in existing marine 2-stroke and 4-stroke engines with some adjustments of injectors and fuel rail systems.

3.2 FAME

FAME can be produced from several plant and animal-based feedstocks. Rapeseed, for production of Rapeseed Methyl Ester (RME), is the most commonly used feedstock in the EU, soybean for production of soybean methyl ester (SME) is most common in the US and South America, and coconut and palm are common in Southeast Asia (IEA, 2017). Globally, most of the FAME is produced in the EU and the US (OECD & FAO, 2016). Lately, the EU countries have imported FAME mainly from Malaysia and Argentina. However, in 2013-2017 anti-dumping duties blocked Argentinian imports.

The major FAME producers in the EU include:

- Avril with plants in France, Germany, Italy, Austria, Belgium with a total production of 1 800 000 tonnes;
- Infinita with plants in Spain with a total production capacity of 900 000 tonnes;

[2] https://enerkem.com/facilities/enerkem-alberta-biofuels/

[3] http://biomassmagazine.com/articles/15999/w2c-rotterdam-project-welcomes-shell-as-partner

[4] http://www.varmlandsmetanol.se/index.htm

- Marseglia Group that includes Ital Green oil and Ital Bi Oil with plants in Italy with a total production capacity of 560 000 tonnes;
- Verbio AG with plants in Germany with a total production capacity of 470 000 tonnes.

Perstorp BioProducts (producing for Adesso BioProducts AB) is the major Swedish FAME producer. The Swedish FAME is exclusively RME made from rapeseed oil (Energimyndigheten, 2018c). However, most of the FAME used in Sweden is imported with raw material originating in Germany, Lithuania, Denmark and Latvia.

3.3 HVO and co-processed distillates with renewable feedstock

HVO and co-processed distillates from renewable feedstock can be used as drop-in fuels or as a replacement of diesel oil (HVO100). Drop-in biofuels are liquid hydrocarbons that are functionally equivalent and as oxygen-free as petroleum-derived transportation blendstocks (fuels). Drop-in biofuels are attractive from the existing infrastructure perspective.

Globally, HVO is produced from several different sources including, e.g. vegetable and animal waste oil (including, e.g. residues from slaughterhouses), palm seed oil, Palm Fatty Acid Distillate (PFAD) and crude pine oil. Neste is a major global HVO producer (with a product called NexBtL) with production units in Finland, the Netherlands and Singapore (Energimyndigheten, 2018a). There is also production of HVO in France, Spain, and Italy (Energimyndigheten, 2018a). Plants with significant production capacities are planned in the USA and in Asia.

Major HVO producers in the EU include

- Neste with plants in Finland and the Netherlands with a production capacity of 2 600 000 tonnes. In 2017 grease and waste oil accounted for 76% of the feedstock used, and the rest used cooking oil or animal fats;
- ENI with plants in Italy with a total production capacity of 360 000 tonnes;
- and Total[5] with co-processing plants in France with a total production capacity of 500 000 tonnes. The intention is to use mainly palm oil but also waste cooking oil and animal fat as feedstock (EurObserv'ER, 2018).

Further, several other biodiesel producers in the EU have smaller production capacity. Swedish HVO production uses crude tall oil and vegetable and animal waste oils for feedstock. Preem is a significant producer in Sweden with HVO production capacity of 200 ML from crude tall oil and other raw materials. Other examples of producers of 2nd generation drop-in renewable diesel are Finnish UPM that produces approximately 100 000 tonnes of wood-based renewable diesel from tall oil annually (IEA, 2017), and Swedish SunPine in Port of Piteå. SunPine extracts tall oil from the pulp and paper industry as a raw material for their renewable products portfolio.

Sweden imports HVO primarily from facilities in the Netherlands and Finland that use raw material originating mainly from Indonesia, Germany, the USA and the UK (Energimyndigheten, 2018a). St1 together with the forest company SCA is also planning to initiate production of HVO

[5] https://www.total.com/en/energy-expertise/projects/bioenergies/la-mede-a-forward-looking-facility

from tall oil[6]. Sweden uses a substantial share of the total global HVO production to fulfil national mandates.

The hydrotreated vegetable oil (HVO) is the biofuel that most resembles the marine gasoil used by many ships in traffic in the Northern European waters. Part of the HVO market belongs to companies doing co-processing. It is a technique allowing for HVO production using the desulfurization unit where vegetal oils are directly mixed with fossil diesel. This process is much easier to implement than pure HVO production and has also lower CAPEX. It mainly uses the hydrogen produced on site in the fossil refining units thus limiting the sourcing needs. However, it requires the use of already refined oils which, in turn, increases the feedstock price. At the same time the HVO is already blended into the final product so it cannot be sold as pure HVO or used for improving the diesel quality by blending in higher amounts. Among the companies that use the co-processing technique are: Total in France, Preem in Sweden, ConocoPhillips at its refinery in Ireland, Cepsa and Repsol in Spain and Galp in Portugal.

3.4 Biogas

Biogas can be produced by anaerobic fermentation from almost any biological raw materials including agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste. The raw biogas that is produced has low methane (CH_4) content, and it can be used as an energy source as such, e.g. in heat and power production. For more advanced use, the raw biogas needs to be purified.

Purified (refined) biogas may be injected directly to the natural gas transmission network. It could also be compressed or liquefied to be used as a transport fuel. Compressed biogas (CBG) can be used instead of compressed natural gas (CNG) in passenger cars and smaller distribution vehicles like postal service vans. Liquefied biogas (LBG) can be used instead of liquefied natural gas (LNG) in heavy trucks and vessels. LBG is transported as a liquid and has an identical chemical composition as LNG.

Biogas produced in Sweden originates mainly from wastes and residues, primarily sewage sludge, manure and domestic and industrial food residues (Energimyndigheten, 2018b). For Swedish road transport, the gas fuel used is called vehicle gas (Fordonsgas) and consist of biogas, natural gas or a combination. In total, the renewable share amounts to 85-90% at present (Energimyndigheten, 2018a). About 90% of the biogas used in Sweden is produced domestically from domestic resources, and the rest is imported from the Netherlands and Denmark (Energimyndigheten, 2018a).

In Sweden, there is one plant producing LBG from biogas, located in Lidköping (Energimyndigheten, 2018b). The biogas plant is owned by Gasum, and the liquefaction process is owned by Air Liquide. The yearly production corresponded to 52 GWh in 2017 (Energimyndigheten, 2018b). There is also one LBG plant under construction in Linköping (Tekniska Verken). Several other LBG plants are planned in Sweden, where Gasum and Scandinavian Biogas are in the lead (Hjort et al., 2019, forthcoming). Gasum is planning to produce LBG in three plants in Sweden. In total, projects corresponding to about 500 GWh LBG production per year have been granted investment support in Sweden for the coming years by

[6] https://www.di.se/nyheter/sca-tar-viktigt-kliv-framat-som-hvo-tillverkare/

the so-called Klimatklivet[7] and Innovationsklustret for LBG[8], and there are plans for additional production of 500 GWh per year (Hjort et al., 2019). There are two projects for liquefying smaller amounts of biogas transported by pipes in connection to terminals for LNG or ferries running on LNG, in Gothenburg and Gotland (Hjort et al., 2019). In Sweden, LBG has primarily been used as back up at larger fueling stations for vehicle gas that are not connected to the natural gas transmission network, and smaller amounts have been used for heavy trucks, industry and shipping. The trend is that the demand from trucks will increase in the short-term, but the production is also expected to increase as indicated above. Currently, there are about six locations where it is possible to fuel road vehicles with LBG today of which two are in Stockholm, and one in Västra Götaland, Jönköping, Skåne and Örebro respectively.

There is LBG production in Finland corresponding to ca. 260 GWh/year, and in Norway to ca. 200 GWh per year. There are plans for additional LBG production in these countries at ca. 200 GWh per year (Hjort et al., 2019, forthcoming).

3.5 Other biomass-based fuels

There are several other biofuels under development but not yet available in commercial scale. The following paragraphs give an overview of possibilities to use of lignin, tall oil, pyrolysis oil and hydrogenated pyrolysis oil, fuel from hydrothermal liquefaction, and electrofuels.

3.5.1 Lignin

One possible source of energy with large potential volumes is the lignin-containing black liquor, a by-product of the pulping process. Black liquor consists of more than half of lignin and is usually burned in the pulp boilers of the pulp mill to generate energy. The recovery process of lignin from black liquor is technically straightforward, with several equipment options[9,10]. However, the initial investment cost is substantial and if a large proportion would be utilized in biofuel production, some substitute energy for the pulp and paper industry is required. Currently, only a few pulp mills in Northern Europe recover lignin[11,12]. The solid lignin that is recovered is converted into lignin oil via thermal conversion (e.g. pyrolysis) using catalysts. The lignin oil can be further co-processed at refineries with petroleum feedstock to produce biodiesel or bio-gasoline with a varying share of renewable feedstock. Currently, several companies including RenFuel[13], SunCarbon[14] and Preem[15] are developing lignin-based biofuels.

[7] https://www.naturvardsverket.se/klimatklivet
[8] http://www.energimyndigheten.se/nyhetsarkiv/2018/nytt-innovationskluster-for-flytande-biogas/
[9] https://www.andritz.com/products-en/group/pulp-and-paper/pulp-production/kraft-pulp/lignin-recovery
[10] https://www.valmet.com/pulp/chemical-recovery/lignin-separation/
[11] https://www.storaenso.com/en/products/lignin
[12] http://www.innventia.com/en/Our-Ways-of-Working/Demonstration-and-pilot/Lignoboost-demonstration-plant-/#
[13] https://renfuel.se/technology/?lang=en
[14] https://www.suncarbon.se/
[15] https://www.preem.com/in-english/investors/corral/sustainability-report-2017/focus-areas/sustainable-products/

3.5.2 Tall oil

Besides lignin, another by-product of pulp production is tall oil. Tall oil is a dark viscous liquid generated during Kraft pulping[16] as a by-product after treating the spent cooking liquor. The primary feedstocks for extraction of tall oil are currently from Scandinavian forests, e.g. pine, spruce, and birch. There have been efforts to convert tall oil into renewable diesel for blending with diesel fuel.

Forchem produces liquid biofuel in its biorefinery in Rauma, Finland, in close vicinity of the Port of Rauma. Fortop600[17] is a pitch fuel made from tall oil pitch and other monomer tall oil distillates. It is a low-sulphur content biofuel to be used in communal and industrial boilers instead of HFO. However, due to its corrosiveness and high water content, its utilisation as marine bunker is limited, but could be considered via blending. This will require some adjustments and investments to piping and fuel systems.

3.5.3 Pyrolysis oil and hydrogenated pyrolysis oil

Pyrolysis treatment involves subjecting biomass to high temperature and short residence time in the absence of oxygen and often in the presence of inert gas. The biomass is treated at 500°C for a few seconds, after which a fraction enters a gas phase, and another fraction is converted to pyrolysis oil. Pyrolysis oil is a dark brown liquid with higher energy density than the original starting material. Pyrolysis technology cannot yet produce synthetic diesel fuel, but the pyrolysis oil produced can be used as an intermediate material to produce a substitute fuel for petroleum. Pyrolysis oil on its own is very prone to oxidation, and it still contains a level of oxygen too high to be considered a hydrocarbon. The high oxygen content also gives pyrolysis oil a short storage life, and the energy density is low compared with bunker fuel. Depending on the pyrolysis parameters, the final water content can be as high as 30%, enough to decrease the thermal energy and promote phase separation during storage periods of less than 6 months at room temperature.

Moreover, pyrolysis oil has a low pH, requiring pipes and tanks made of stainless steel. For marine fuel applications, pyrolysis oil can be used as a component in emulsion biofuels to increase its thermal efficiency and reduce particulate emissions when used in diesel engines. Emulsifying pyrolysis oils not only enhances the stability of the fuel, but the addition of emulsifiers (surfactants) act as viscosity modifiers to create more optimal fuel properties.

A catalytic upgrading step is needed to remove oxygen in the pyrolysis oil and to increase its storage stability in order to meet the specifications for drop-in fuel. Hydrogenation converts the pyrolysis oil to hydrogenated pyrolysis oil (HPO) which then can be suitable for diesel engines. This process can take place in dedicated facilities or as co-processing in traditional petroleum refineries, though it is not yet fully commercialised. Chemically, the difference between HVO and HPO is that HPO contains a small number of aromatic compounds, which is beneficial for aviation fuel, but not necessarily for marine fuel.

In Sweden, a joint venture company Pyrocell AB owned by major wood product companies Setra Group and Preem AB is investing in a new plant at Setra's Kastet sawmill outside Gävle. The

[16] The dominant method for conversion of wood into wood pulp for producing paper

[17] https://www.forchem.com/tall_oil_products/fortop600

plant will be the first in Europe to produce pyrolysis oil using sawdust as feedstock. Construction is scheduled to begin during 2019, and the plant is expected to be operational by the end of 2021. The plant is expected to provide about 30 000 tonnes of pyrolysis oil per year. The pyrolysis oil will be used as a renewable biocrude feedstock in the production of biofuels at Preem's refinery in Lysekil.[18]

3.5.4 Fuel from hydrothermal liquefaction

Hydrothermal Liquefaction (HTL) process uses high pressure (5-25 Mpa) and moderate temperature (250-500 °C), along with catalysts, to convert biomass into a crude-like bio-oil (Hsieh and Felby, 2017). The product has a high energy density (LHV of 34-37 MJ/kg) and moderate oxygen content (5-20 wt-%). The advantage of HTL over pyrolysis is that it can process wet biomass and results in a product with a high energy density (Hsieh and Felby, 2017). The process is able to use a wide range of feedstocks including woody biomass, aquatic biomass, urban sewage and animal manures, as well as waste streams from industrial processes such as sugar refining, oilseed milling or food processing. Water present in the biomass is sub- or supercritical at these temperatures and pressures and acts as a solvent, reactant and catalyst in the liquefaction process. Oxygen is removed from the biomass through dehydration (loss of H_2O) or decarboxylation (loss of CO_2). The end product is a fuel with a high H/C ratio and low viscosity that is suitable for use directly in heavy engines or can be upgraded further to produce fuels like gasoline, diesel or jet fuel (Hsieh and Felby, 2017). Production is currently at pilot-scale with a plant operated by Steeper Energy in Denmark with 4 750 hours of operation since its start in 2013.

3.5.5 Electrofuels

Another future fuel option is so-called electrofuel. Electrofuels are produced from CO_2 and water with electricity as the main energy source. If the CO_2 originates from biomass and the electricity used is produced from biomass or other renewable energy sources the fuel could be considered a renewable fuel (Brynolf et al., 2018; Hansson et al., 2017). The process could be used to produce, for example, methane and methanol, but also diesel, gasoline and other alcohols. The potential implementation of these fuels is uncertain at present, but it is expected that they will not become commercial in large-scale before 2030 (SOU 2019:11). The current production cost of electrofuels is about 20-28 SEK per litre (SOU 2019:11), but there are substantial possibilities for reducing this cost, potentially reaching 10 SEK/litre (Brynolf et al., 2018; Grahn and Jannasch, 2018). The production of electrofuels is not limited to the same extent as other biofuels by the supply potential for sustainable biomass. However, how the GHG emissions from electrofuels should be estimated still needs to be specified within the EU policy framework.

[18] https://bioenergyinternational.com/biofuels-oils/setra-and-preem-first-in-europe-with-renewable-fuel-from-sawdust

4 Fuel costs/prices

The development of the prices of fossil-based bunker fuels at ARA (Amsterdam-Rotterdam-Antwerp) in EUR/MWh during 7.6.2018-7.6.2019 are seen in Figure 1. Fluctuations in fuel price of close to a factor of two can occur within a year.

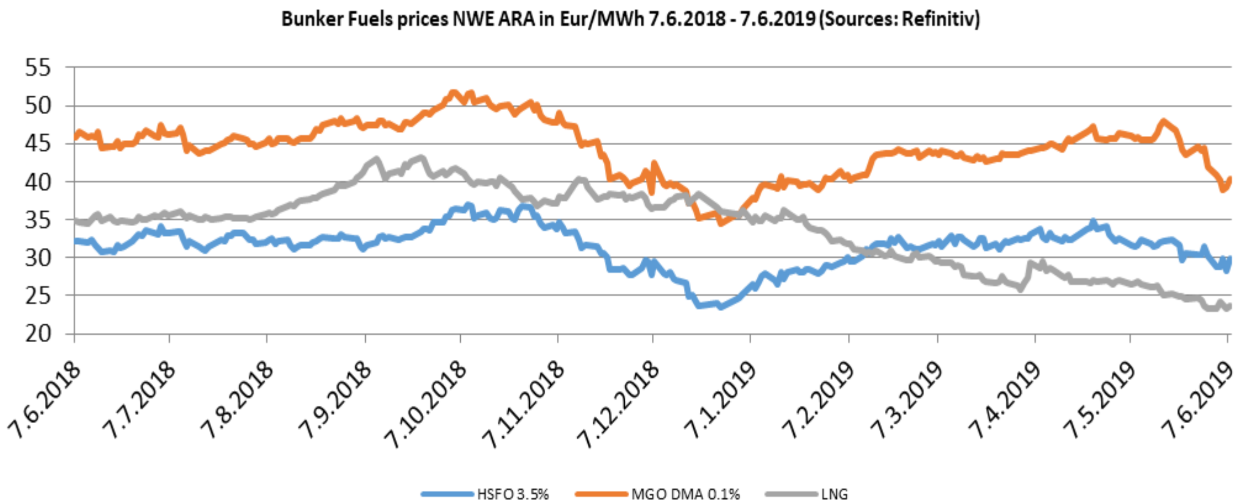


Figure 1. Bunker fuel prices for HFO, MGO and LNG (lower heating value, based on TTF and estimated premium) in EUR/MWh from June 2018 to June 2019.

Prices of biofuels can follow seasonal variations and are highly dependent on feedstock. In Table 3, an overview of the prices of bioalcohols, FAME, HVO, and LBG is presented and related to the energy content of the fuel and also benchmarked against fossil counterparts. The prices are elaborated upon in the following paragraphs.

Table 3. Comparison of fuel prices, and indicative production costs (if available), in relation to their energy content and related to fossil counterpart. Ethanol, methanol, FAME, and HVO are compared with MGO and LBG is compared with LNG. Exchange rate for EUR/SEK = 10.4; Exchange rate for USD/SEK = 9.25.

	Price per mass unit	**Energy content****	**Price per energy content (GJ)**	**Price per energy content (MWh)**	**Price compared with MGO/LNG**	**Indicative production cost compared with MGO**/LNG**
	USD/tonne	MJ/kg	USD/GJ	USD/MWh	Times/energy content	Times/energy content
European ethanol	610-880	27	22-32	81-120	1.4-2.8	2-3
Imported ethanol	470-650	27	17-24	62-86	1.1-2.1	no data on production cost
Methanol	~430 (2019)	20	~22	~78	1.3-1.9	~2
FAME	820-1 600	37	22-44	80-160	1.4-3.8	n.d.
HVO	1 500-2 300	43	35-54	130-190	2.1-4.6	1-3
MGO	**~500-700**	**43**	**12-16**	**42-59**	**1**	**1**
LBG	1 470-2 300	49	30-46	110-170	1-6	no data on production cost
LNG	**~400-2 000**	**49**	**~8-40**	**~29-150**	**1**	**1**

** Ref REDII
**Maniatis et al., 2017

4.1 Ethanol pricing

The price on ethanol produced in Europe (or in specific countries without taxes to the EU) in January and February 2019 was in the range 5.8-6.0 SEK per litre, which corresponds to about 21-22 USD/GJ or 77-80 USD/MWh (F.O. Licht, 2019 as presented in Energimyndigheten, 2019). Since January 2017 the price on European ethanol has varied from 4.4 to 6.4 SEK per litre (about 16-24 USD/GJ or 58-85 USD/MWh). The price of imported ethanol (produced outside the EU except for the specific countries without taxes to the EU) was about 3.6-4 SEK per litre (about 13-15 USD/GJ or 48-53 USD/MWh) in January and February 2019 (F.O. Licht, 2019 as presented in Energimyndigheten, 2019). Since January 2017 the price on imported ethanol has varied from 3.4 to 4.7 SEK per litre (about 13-17 USD/GJ or 45-63 USD/MWh).

4.2 Methanol pricing

In February 2019, the trading price for methanol in the EU amounted to 320-400 USD/tonne[19] (fossil fuel-based methanol included), about 6.4-8.0 USD/GJ or 23-29 USD/MWh. The methanol price on the European market during 2019 was 360 Euro/tonne[20] (about 8.1 USD/GJ or 29 USD/MWh).

4.3 FAME pricing

The price on FAME in January and February 2019 was in the range 8.6-10.1 SEK per litre, which corresponds to about 28-33 USD/GJ or 102-120 USD/MWh (F.O. Licht, 2019 as presented in Energimyndigheten, 2019). Since January 2017 the price on FAME has varied from 6.7 to 13.2 SEK per litre (22-44 USD/GJ or 80-160 USD/MWh), with the high price only remaining for a short period due to logistical problems. The Argus FAME 0 (CFPP 0°C) price is widely used in the Central European biodiesel markets. The primary basis for the FAME 0 price assessment is FOB (free on board) Rotterdam. FAME -10 (CFPP -10°C) has better cold properties and is traded with significant premium (50-100 USD) compared with FAME 0. FAME -10 is more suitable in some cases for winter conditions in Northern Europe. The price of FAME generally depends on the feedstock (IEA, 2017) and has seasonal variations (Figure 2).

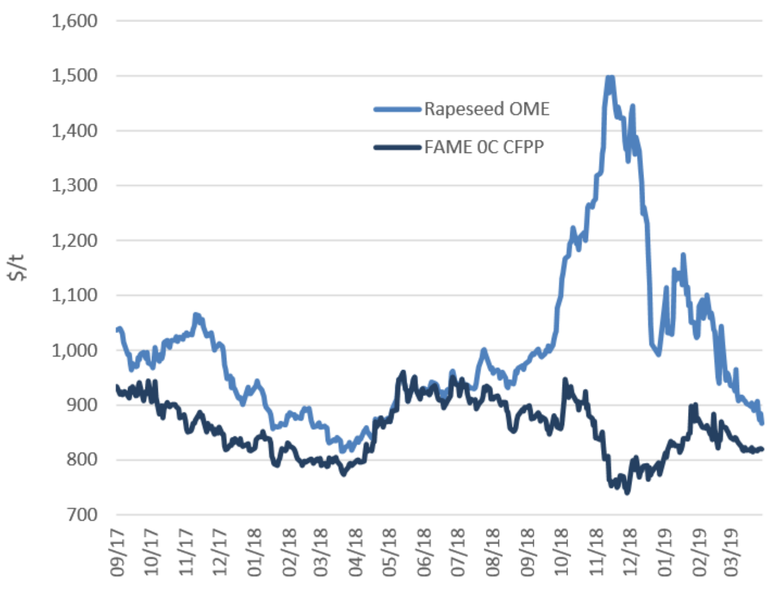


Figure 2. FAME 0 and RME prices in USD/tonne (source: Argus 2019).

[19] https://www.methanol.org/methanol-price-supply-demand/
[20] https://de.statista.com/statistik/daten/studie/730823/umfrage/durchschnittlicher-preis-fuer-methanol-auf-dem-europaeischen-markt/

4.4 HVO pricing

The HVO feedstock prices depend on the raw material used (IEA, 2017), see Figure 3. In 2016, the price of palm oil and waste cooking oil was USD 650 and USD 400 per tonne (Agricultural Marketing Service, 2016, as presented in IEA, 2017), corresponding to 15 and 9 USD/GJ or 54 and 33 USD/MWh, respectively. HVO pricing is closely linked to biofuel mandates and reduction obligation.

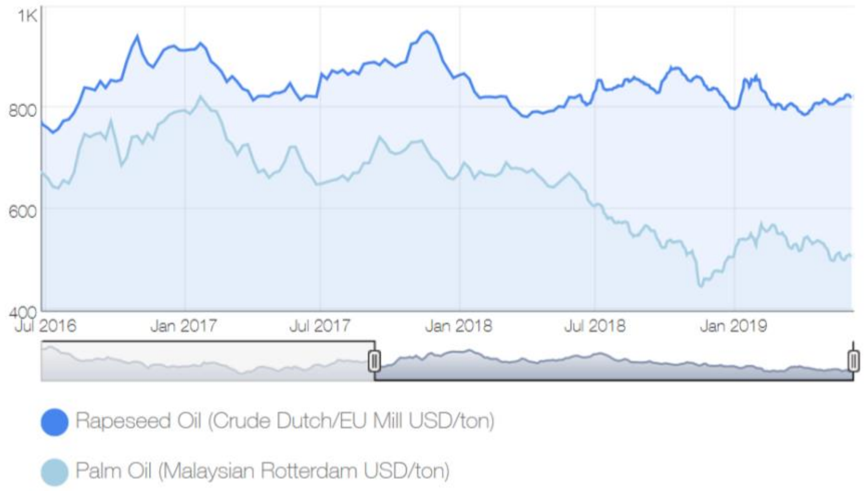


Figure 3. Palm and rapeseed oil prices in USD/tonne (Neste, 2019). Palm and rapeseed oils are used as a feedstock of HVO.

The price of 100% renewable HVO diesel for trucks was 16.65 SEK/litre on 1 of April 2019[21], which corresponds to about 54 USD/GJ or 190 USD/MWh. Based on information from Preem for co-processed HVO in 2018, a premium of 1 000 USD/tonne compared with MGO can be expected. This results in HVO price per energy content of 35-40 USD/GJ or 130-140 USD/MWh.

4.5 LBG pricing

The price level of LBG depends on feedstock, production and logistics costs. In general, the price of LBG is higher than CBG (compressed biogas) due to the costs related to the liquefaction process. Recent prices correspond to about 19-21 SEK/kg[22,23], which equals 42-46 USD/GJ or 150-170 USD/MWh. It is also possible to buy a blend of LBG and LNG where the price depends on the amount of LNG and LBG. According to the available sources and further assessment, a price of LBG has been estimated to be around 1 470 USD/tonne for the calculation purpose of this study, corresponding to 30 USD/GJ or 110 USD/MWh.

[21] https://www.biofuel-express.com/listprice/?lang=en
[22] https://www.okq8.se/foretag/priser/#/
[23] https://fordonsgas.se/tanka-gas/vad-kostar-det-att-tanka-gas/

5 Environmental impact of different fuels

Marine biofuels have the potential to substantially reduce GHG emissions from shipping. GHG emissions from selected alternative marine fuels from various sources and different approaches are presented in Table 4. Forest biomass-based and waste-based biofuels generally have a better GHG emission reduction potential than crop-based biofuels (Furusjö and Lundgren, 2017). To ensure long-term sustainability and availability of biomass-based feedstocks, they should include waste residues or non-food crops, e.g. lignocellulosic material as forest biomass (hardwoods, softwoods, pulp and sawmill residues) and agricultural residues as well as municipal solid waste, used cooking oils, and waste animal fat (IEA, 2017).

Table 4. GHG emissions of selected alternative marine fuels from different sources and for different approaches including LNG, LBG, biomass-based methanol and ethanol, and HVO.

Fuel	Climate change (g CO_2-eq./MJ fuel, entire lifecycle)[1]
LNG	**80–91** (Brynolf et al., 2014; Gilbert et al., 2018; Verbeek et al., 2011; Lowell et al., 2013; Winnes et al., 2019)
LBG/biogas	**50** (Brynolf et al., 2014; Gilbert et al., 2018) **8-44** (biogas) (8-23 for biogas from waste and manure whereas the high end represent biogas from crops) (Furusjö and Lundgren, 2017)
Bio-ethanol	**18-37** (18-28 for ethanol from sugar cane) (Furusjö and Lundgren, 2017)
Bio-methanol	**20** (Brynolf et al., 2014, assuming the use of forest-based biomass)
HVO	**30** (Martin et al., 2017 assuming the use of forest-based biomass) **8-48** (8-25 for HVO from tall oil, waste oil and slaughter wastes) (Furusjö and Lundgren, 2017)
FAME	**38-48** (Furusjö and Lundgren, 2017)
MGO	**85–88** (Winnes et al., 2019; Bengtsson et al., 2012)
HFO	**92** (Bengtsson et al., 2012)

[1] The characterisation factors used for finding the global warming potential: 1 g CH_4 =25 g CO_2-eq., 1 g N_2O =298 CO_2-eq., over a 100-year timescale and 1 g CH_4 =72 g CO_2-eq., 1 g N_2O =289 CO_2-eq. over a 20-year timescale.

A recent study by Furusjö and Lundgren (2017) compared the cost of GHG reduction for different types of biofuels available in Sweden and for future biofuels. The study found that biogas produced via digestion of waste and sugarcane-based ethanol obtain the lowest reduction cost while FAME based on rapeseed oil results in highest reduction costs. Since HVO is currently produced from several different feedstocks, it results in a broad reduction cost range (Furusjö and Lundgren, 2017). In the future, more advanced biofuels have the potential to achieve lower reduction costs than many of the current. Primarily, this is true for biofuels produced by thermochemical conversion processes, such as pyrolysis, followed by refineryintegrated upgrading and gasification-based technology (Furusjö and Lundgren, 2017). However, there are uncertainties linked to the need for hydrogen in the processes.

The production of HVO from palm seed oil and Palm Fatty Acid Distillate (PFAD) is accompanied with sustainability issues during production since it may cause deforestation, directly or indirectly. For this reason, PFAD is reclassified in Swedish legislation from July 1 2019 and will in the reporting have lower GHG reduction potential. It is also the reason for the limit of high indirect land-use change (ILUC) risk of biofuel in REDII. This policy demand will limit the supply potential for HVO and new production processes and raw materials will likely be needed.

Like for crop-based ethanol, the supply and demand of FAME depend on the EU limit of crop-based biofuels. In general, FAME and HVO from rapeseed and palm oil reach lower GHG reduction level than many other biofuels (Furusjö and Lundgren, 2017).

LBG is primarily produced from residual feedstocks and is therefore not pesenting the same sustainability issues as many other biofuels concerning land use change risks. A concern with biogas is however potential methane emissions during production and transport. During the distribution and use of biogas and LBG, there is a risk for methane leakage. Since methane has a stronger climate impact than CO_2, it is essential to limit this leakage in order to not limit the climate benefit of LBG.

Compared with spills of fossil fuels, spills of biodegradable fuels pose a smaller threat to the environment (Sendzikiene et al., 2007; Demirbas, 2008). Biofuels biodegrade more rapidly and renewable diesel fuel blends has been seen to also accelerate the rate of petroleum diesel degradation through co-metabolism (Sendzikiene et al., 2007; Demirbas, 2008)..

6 Biofuels for the shipping sector: availability and logistics

For all biofuels, there is demand and competition from other sectors. The demand and supply of biofuels, for all transport sectors, are strongly related to biofuel policies. The future demand and supply of biofuels from for example grain in the EU depends on the regulations of the share of grain-based biofuels in REDII. The supply of pure biofuels in Sweden in the future will depend on what happens when the current approval for tax exemptions expires. The Swedish mandate to reduce emissions of fossil CO_2 from diesel fuels used in road transport, also referred to as a reduction quota or reduction mandate, presently dictates the demand for biofuels in Sweden. The mandate currently demands 20% biofuel blend-in in land-based diesel fuel for transport. The cost-competitiveness of HVO to fulfil the mandate, has initially influenced the supply of HVO100 for trucks, since most available HVO is used as drop-in fuel. In the short-term, this will also affect the possible supply of biofuels for the marine sector.

In Winnes and Styhre (2016), a calculation indicated a fuel consumption of all liquid bulk transport by tankers to and from Swedish ports of 360 kt per year. The fuel consumption for all ships to and from Swedish ports was calculated to be around 1 500 kt per year. Expressed in energy units, the tanker fuel consumption corresponds to approximately 15 000 TJ. One TJ corresponds to approximate 23 tonnes MGO if a lower heating value of 43 kg/MJ is assumed. In the longer term, it is expected that biofuels might primarily be used in applications where fossil fuels are difficult to replace, such as long-distance ship transportation (Berndes et al., 2018).

Further, a governmental investigation recently proposed the introduction of a quota policy for biomass-based aviation fuels in Sweden (SOU 2019:11). The level of this quota will influence the availability of biofuels for other transport sectors.

European biofuel production sites are indicated in the map in Figure 4. Several sites and feedstocks exist and are planned in the Baltic Sea and North Sea regions.

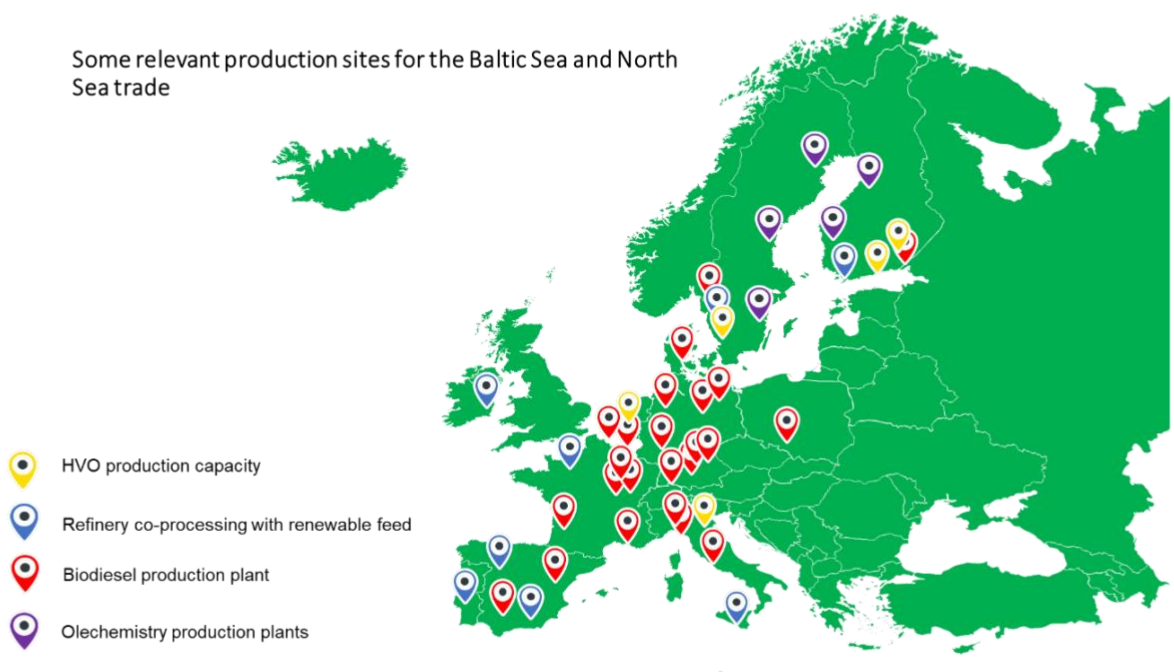


Figure 4. Existing and planned biofuel or renewable feedstock production sites for the Baltic Sea and the North Sea trade.

Shipping of renewable fuels at sea is accompanied by international regulatory requirements, mainly relating to routines on tank cleaning. If it were possible to transport technically suitable biofuels as pure products under Annex I, prewash procedures could be avoided (IMO, 2014a). Therefore, in 2018, MEPC, recognising the need to clarify how biofuels or their blends with petroleum oils can be shipped in bulk under the correct annex of MARPOL, and approved the Guidelines for the carriage of energy-rich fuels and their blends (MEPC.1/Circ.879). Energy-rich fuels are comparable to fossil fuels with their chemical composition, but they are obtained from biological origin or non-petroleum sources (e.g. algae, vegetable oils) or are a blend of petroleum-based fuel and a product obtained from biological origin or non-petroleum sources (e.g. algae, GTL process, HVO, co-processing; MEPC.2/Circ.24). When carrying energy-rich fuels or a blend containing 75% or more of energy-rich fuel, the requirements of Annex I of MARPOL are applied. When the fuel containing less than 75% of energy-rich fuel, the biofuel blends are subject to Annex II of MARPOL. The guidelines entered into force on January 1st, 2019.

In case of using blends of biofuels (other than drop-in fuels) and fossil fuels, there are various ways to blend the biocomponent to fuel, see Table 5. The blending can occur at the refinery, at the fuel storage facility, the ship itself or on the bunker ship or bunker truck. According to current market practices, it is however often done at the bunker barge or the delivering truck, as biofuels have a different supply chain than fossil-based fuels. The bunker tanks need to be emptied and cleaned before the next bunker fuel is loaded.

Table 5. Different blending methods for marine biofuels.

Type	Description
Splash blending	With splash blending, biodiesel and diesel fuels are loaded into a tank / truck / railcar separately. Require proper planning to avoid product settling.
In-tank blending	Biodiesel and petroleum diesel are loaded separately through different incoming sources to the blending tank. The tank should be fitted with suitable blending equipment's to ensure a stable mix of products.
In-line blending	In-line blending occurs when the biodiesel is added to a stream of diesel fuel as it flows through a pipe or hose and the biodiesel and diesel fuel become thoroughly mixed by the turbulent movement through the pipe.
Rack blending	Rack blending is the most straightforward approach to blend bio-based fuels. It enables users to inject biodiesel directly at the rack into the tank truck, similar to current performance fuel additives and red dye.

An advantage of biofuel blending onboard ships is that biofuels can be stored separately from fossil-based fuels, thus maintaining better fuel properties. Biofuels can be kept in separate storage tanks, and blended with fossil fuels in the piping system when needed. However, handling and maintaining a separate fuel tank requires additional operational costs for shipowners. Therefore, blending at the bunker barge level would require the least amount of infrastructural changes to the supply chain.

HVO is a drop-in fuel and it behaves like traditional fossil diesel. There are no restrictions when using 100% HVO or a blend at fuel changeover procedures. Further, there are no additional issues related to storage stability, water separation and microbiological growth with HVO.

FAME has some limitations and requirements for fuel changeover procedures, such as tank cleaning, in case it is not suitable for mixing with previously used fuel. Most often a shipowner prefers not to execute tank cleaning during voyage. Tank cleaning causes longer port stays and extra costs for either the shipowner or the cargo owner.

The locations of refineries and blending facilities for the Baltic Sea and the North Sea trades are indicated on the map in Figure 5. Distribution terminals and barge operations are shown in Figure 6. In general, every European refinery has different types of biofuels available due to the existing blending mandates. In the blending and export terminals, there is capacity available for product blending. There is already a sufficient terminal capacity in the region for future marine biofuel supply.

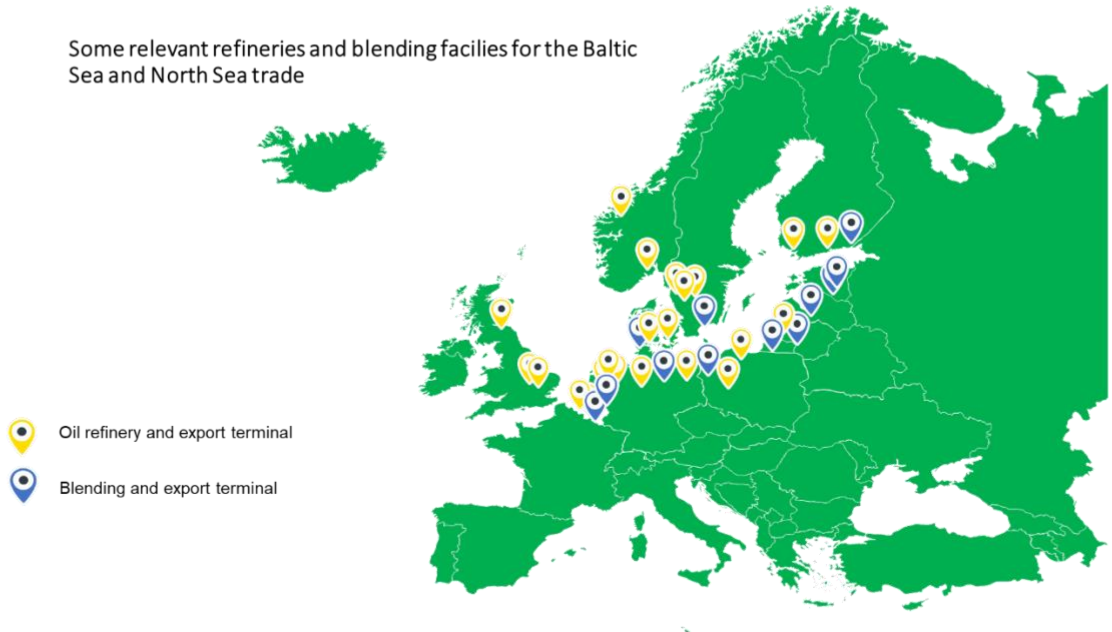


Figure 5. Refineries in the Baltic Sea and the North Sea region and blending facilities for the Baltic Sea and the North Sea trade.

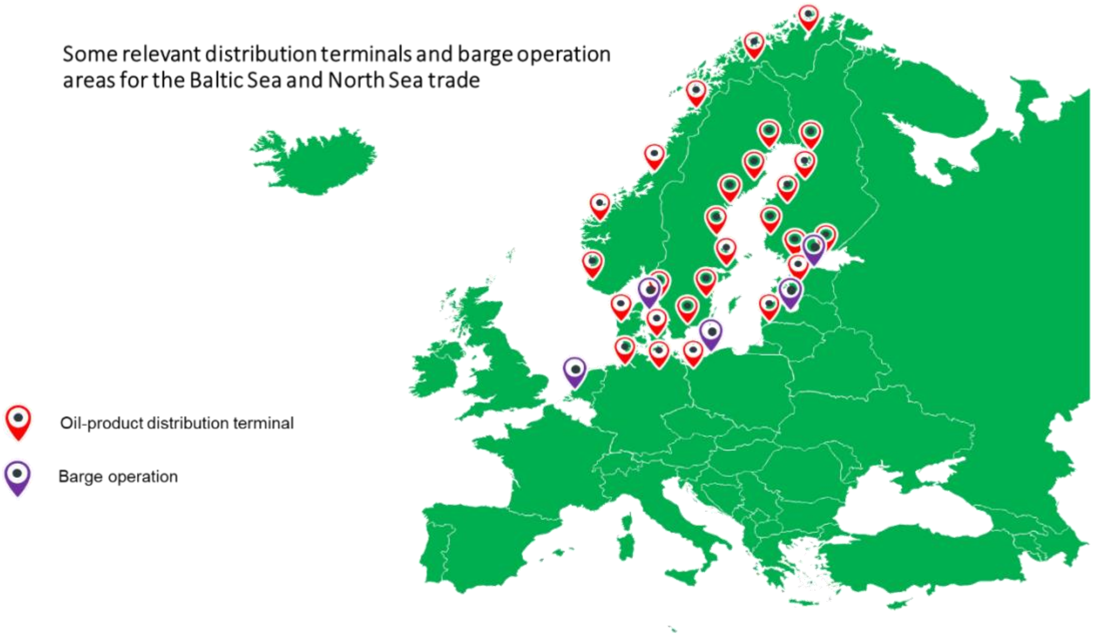


Figure 6. Distribution terminals and barge operation areas for biofuel bunkering in the Baltic Sea and the North Sea.

In general, access and availability of marine fuels depend on the port location. Ships are typically supplied with fuel from bunker ships or barges. Sufficient barge capacity is available in the Baltic Sea area and the North Sea area.

Several trials have been completed with blends of biofuels in marine fuels (Bäckström et al., 2018; Hansson et al., 2018) indicating that bunkering can be solved at least in small scale. Most experiences of bunkering ships with biofuel in Sweden (e.g., HVO for Swedish road ferries) are from bunker supply with trucks (Bäckström et al., 2018). The biofuels sold by GoodFuels are claimed to be available in most SECA ports[24]. GoodFuels is a bunkering company based in Rotterdam that delivers bio-derived hydrocarbons that can be used as a direct replacement (100%) in the existing fleet[25]. They are agent for a variety of fuel suppliers and marine users and deliver renewable fuel to the marine market. This is unique from the European perspective.

HVO is fully compatible with the current logistic systems and practices. Its tendency to absorb water is lower than that of traditional diesel fuels. During long-term storage, HVO behaves like conventional diesel fuels without preservation limitations. HVO could be blended with fossil fuels in any proportion. No special considerations are needed regarding microbiological growth. Well known practices used for fossil diesel fuels also apply for pure or blended HVO. The flash point of HVO is above 55°C, meaning that it can be stored and transported like standard diesel fuel (IMO, 2014a). Specific adjustments to suit marine use might however be needed since marine safety regulations prescribe flash points over 60 °C in fuels for marine use (IMO, 2014c). HVO meets ISO 8217 specifications without any blending with conventional petroleum diesel. The blending of HVO can be done at various points in the supply chain, at onshore storage, on the bunkering vessel or on board the actual vessel. Even though the energy density per unit mass of HVO is similar to diesel and HFO, its lower volumetric density leads to a 7% and 13% lower

[24] https://goodfuels.com/marine/

[25] https://goodfuels.com/

energy content on a volumetric basis compared with fossil diesel and HFO, respectively. Hence, slightly more storage volume is required compared with fossil diesel and HFO (E4tech UK Ltd 2018).

The volumetric density of FAME is similar to fossil diesel but with lower heating value. The energy content on a volumetric basis is 6% and 13% lower compared with fossil diesel and HFO, respectively. Hence, slightly more storage volume is required compared with fossil diesel and HFO (E4tech UK Ltd 2018).

LBG and biogas can be transported over long distances, but an option is to implement a system in which LBG is bought from suppliers of LNG/LBG by permits. A permit is based on the amount of biogas added to the pipeline network, but without considering whether the actual methane molecules bought and used are of renewable or fossil origin. The mass balance principle is used, and the system is similar to the one used for “green electricity”. This kind of system is not applied today for gas in Sweden but is operational in Finland. Finland has had a biogas certificate system since 2013. The system is operated by Gasum, and the original certificates are governed by a certificate registry. The system is open for all biogas producers and users. The certificates are admitted only to biogas produced in Finland.

7 Technical feasibility of biofuels as marine fuels

In order to have a rapid introduction of renewable fuels in marine bunker we consider the alternatives FAME, HVO and LBG as the most favourable options. In this report we have investigated their technical feasibility as marine fuels.

According to a study conducted for the European Maritime Safety Agency (EMSA), biobased methyl and ethyl alcohol fuels, also referred to as methanol and ethanol, could be potential alternatives for reducing both the emissions and carbon footprint of ship operations (Ellis and Tanneberger, 2015). An issue is however that the flashpoints of methanol and ethanol are both below the minimum flashpoint for marine fuels specified in the IMO Safety of Life at Sea Convention (SOLAS). Although the production of ethanol and methanol is well established, these biofuels are not fully compatible with the existing inventory of marine engines. Ethanol has not been tried as a marine fuel, and only a few examples of vessels converted to methanol use exist. Methanol used as a bunker requires suitable engine technology and separate bunkering logistics (Ellis and Tanneberger, 2015). In respect to the studied ship sector, we consider that biobased alcohols are not ready for widespread implementation.

The ISO 8217 standard for marine fuels includes the following types:

- hydrocarbons from petroleum crude oil, oil sands and shale;
- hydrocarbons from synthetic or renewable sources, similar in composition to petroleum distillate fuels;
- blends of the above with a fatty acid methyl ester(s) (FAME) component where permitted.

According to the standard, the fuel composition shall consist predominantly of hydrocarbons primarily derived from petroleum sources while it may also contain hydrocarbons from the following:

- synthetic or renewable sources such as Hydrotreated Vegetable Oil (HVO), Gas to Liquid (GTL) or Biomass to Liquid (BTL);
- co-processing of renewable feedstock at refineries with petroleum feedstock.

7.1 FAME in marine engines

The distillate fuel grades, as defined in ISO 8216, include up to 7.0 volume % FAME, where FAME at the time of blending shall be in accordance with the requirements of the international standards EN 14214 and ASTM D6751 (ISO, 2017; CIMAC, 2017). DMX shall be free of FAME. The DMA, DMZ, DMB and RM grades shall not include FAME other than a “de minimis” level, i.e. an amount that does not render the fuel unacceptable for use in marine applications that are not designed or suited to handling fuels containing FAME. Specifications related to oxidation stability have been included in the standards in order to avoid diesel engine performance and maintenance problems from oxidative degradation of biodiesel, particularly in the engine fuel system (Pullen and Saeed, 2012). Another risk that is linked to the use of FAME blends is related to its high solvency compared with conventional marine diesel oils; they can wash out deposits from the fuel supply lining and thereby cause an increase in fuel filter clogging (CIMAC, 2017). Tests on marine engines show stable results at blends up to 10% FAME as long as the production has fulfilled the standard EN14214 (Bäckström et al, 2018).

The viscosity of vegetable oils is highly temperature dependent. Under certain conditions, a polymerisation can form insoluble polymers, which can clog fuel lines, filters and pumps. As an example, oil may form wax in a too cold environment, and fuel polymerises in too high temperatures (Wärtsilä, 2007).

FAME 0 type is sufficient for maritime use, since the fuel tanks of ships are under the water surface, and hence cold temperatures are not an issue. Also FAME -10 could be used, but it is more expensive due to its cold qualities. The cold weather characteristics of FAME are generally poor and dependent on feedstock. A diesel fuel's cold-weather characteristics are measured by the cloud point (CP), the cold filter plugging point (CFPP), and the pour point (PP).

To avoid clogging and wax formation, the International Council on Combustion Engines (CIMAC) recommends the following procedures when using FAME-blends, in addition to procedures performed when using conventional fossil fuels (CIMAC 2013):

- Monitor fuel filter condition for any increased rate of clogging by checking for increased back pressure or any increase in the automated back-flushing cycles.
- B100 biodiesel (100% FAME/RME) generally has a higher wax forming temperature than conventional diesel. In blends of B7 (7% FAME/RME) or less this should not be a problem as the cold weather parameters of the diesel fuel controlled in the specification should dominate. It is a good idea to take appropriate measures if B100 and/or biodiesel blends are exposed to outside conditions before entering storage on the ship. Measures that could be considered include; keeping the fuel temperature at least 10° C above the pour point and locating the fuel in storage tanks away from potential cold ambient

temperature interfaces. Ships operating in cold areas should include ship specific cold flow requirements in the bunker purchasing contract.

FAME as a fuel has good ignition and lubricity properties. One of the main advantages of FAME is that it restores lubricity of the engine and reduces smoke, soot, and burnt diesel odour from engine exhaust, at the same time protecting against wear in fuel and injector pumps. The use of FAME in automotive diesel engines has been shown to reduce sulphur oxides (SO_X), carbon monoxide (CO), and unburned particulate matter. However, the acid degradation products of FAME are suspected of causing damage to fuel pumps, injectors, and piston rings, leading to an acid number limit in marine fuel specifications (IEA, 2017).

FAME typically has a lower heating value than fossil fuels. Therefore, according to the manufacturer of main engines in Terntank's vessels, the capacities of the fuel system of the engine should be checked individually for every case. The company has pre-defined distillate fuel specifications for specific engine types that the used fuels or fuel blends with various blending ratios need to comply with. Wärtsilä has not experienced any restrictions regarding the use of FAME in their engines, as long as the fuels are in accordance with the predefined specifications. In addition, engine warranties are not affected by the use of FAME if the defined specifications are met (based on discussion with Wärtsilä, 2019a).

The auxiliary engine manufacturer Power House AB has experienced problems related to the use of FAME. A representative of Power House mentions that the first generation biofuels are not stable over time and that the oxidation and growth of bacteria have caused severe problems in the fuel system (based on discussion with Power House AB, 2019).

According to the research department of Wärtsilä (2019b), they have performed a short-term (tens of hours) performance test by using pure B100. Customers have used blended fuels in the field, like B5 – B20 but Wärtsilä representatives are not aware that someone would have used B100 continuously. Wärtsilä's engine test didn't experience any operating problems. They consider that if the B100 quality fulfils EN 14214 standard requirements, operating problems can be avoided provided that fuel features and behaviour are taken into account. They have pointed out possible pros and cons summarised in Table 6 at the use of B100 or blends with ~ B20+. B1-B20 blends have been considered like pure fossil diesel. Issues that they are aware of have been related to defective function of esterification process (remains of glycerides / glycerol or water) in fuel which causes corrosion, deposits in fuel injection equipment and poor cold flow properties.

Table 6. Pros and Cons of FAME as a marine fuel (Wärtsilä 2019b)

PROS	CONS
+ Practically no SO_X emissions	- Slightly increased NO_X emissions
+ Reduction in total CO_2 emissions	- Contains ~10% less energy than petroleum diesel
+ Lower particulate emissions	- Separation of water more challenging
+ Biodiesel mixes well with petroleum diesel	- Solvent characteristics may degrade rubber and attack certain metals
+ Good lubrication properties	- Can foster heightened microbial activity
	- Long-term storage period can be shorter than with fossil diesel (Acid number increases -> oxidation takes place)
	- Cold flow properties can be poorer than with fossil diesel

7.2 HVO in marine engines

HVO works well in marine diesel engines. Ignition and combustion properties are slightly different compared with fossil fuels, and depending on engine type, minor tuning may be needed in order to achieve an optimum engine performance in terms of fuel consumption and emissions. HVO meets the European diesel fuel standard EN 590 except density, which is below the lower limit. The American diesel fuel standard ASTM D975 and Canadian CGSB-3.517 are also met. HVO is considered equal to petroleum-derived fuel, and there is for that reason no limit on drop-in/blend percentage of HVO.

Confirmed by the research department of Wärtsilä, there are no negative effects related to the use of HVO in marine engines, and no restrictions have been experienced so far, regardless of the ratio between marine distillate oil and the HVO (Bäckström et al, 2018; Wärtsilä 2019a). From the engine manufacturer's perspective, prerequisites are that the engines have undergone regular maintenance as per their maintenance manual and that the fuel and the blends meet Wärtsilä's predefined specifications. Then there is no influence on engine warranty. Wärtsilä also mentions the low density of HVO, and therefore, the capacity of the fuel system should be reviewed case by case (based on discussion with Wärtsilä, 2019a).

Auxiliary engine supplier Power House AB confirms that there are no adverse effects related to the use of HVO, or blends thereof. The company has not tested the products themselves but Volvo Penta, whose engines Power House is using, has made several evaluated field tests with positive results and approved HVO. Also, local customers have tested HVO with positive results. Mitsubishi, another engine supplier, has however not yet approved HVO since the fuel is not yet very well known. According to Power House, HVO seems stable and with a performance fully comparable with traditional diesel oil. Furthermore, the company does not see any limitations on warranty when using HVO (based on discussion with Power House AB, 2019).

7.3 LBG in marine engines

LBG is produced from upgraded biogas and has a close to identical chemical composition as LNG. Both fuels consist mainly of methane, CH_4, often close to 99%. LBG can therefore use the same bunkering infrastructure and marine engines as LNG.

The main engine manufacturer Wärtsilä has done less testing on LBG than on other biofuels, but they still have experience on some tests on marine engines with LBG blending into LNG. According to Wärtsilä there should not be any problems with using LBG in their Dual Fuel (DF) and Spark ignition engine model series given that the LBG meets Wärtsilä gas specification and generally accepted quality for pipeline natural gas (based on discussion with Wärtsilä, 2019a).

Terntank confirms, based on their recent tests on fueling their gas-driven vessels with LBG blend, that the gas was technically suitable for the two-stroke engines in their vessels (Tärntank Ship Management AB, 2019). Terntank bunkered LBG in the Port of Gothenburg in November 2018. The LNG and LBG that was bunkered at the port were supplied by the Norwegian company Barents NaturGass which has a supply deal with Swedegas for the Port of Gothenburg.

7.4 Limitations in the use of biofuels

In general, there are no limitations in the use of biofuels or biofuel blends regarding the functionality of the ship's engines, but the properties of bunkered biofuel should be evaluated on a case-by-case basis. Issues of biofuels in marine use typically relate to their low density and low energy content that might cause a challenge with the fuel volume through the existing jerk pumps or the gas fuel system, and further the temperature dependent viscosity of vegetable oils (Wärtsilä, 2007 & 2019a). Attention should also be paid to external fuel system, i.e. heating, cooling, filtration, and separation of water from the liquid biofuels. Liquid biofuels in the maritime sector should also have a flashpoint in accordance with SOLAS rules. In addition, solvent characteristics of liquid biofuels may degrade rubber or attack certain metals. Another important issue is the storage time of liquid biofuels substuting MGO, which typically is significantly lower for biofuels than for fossil fuels (Wärtsilä, 2019a).

In LBG, impurities can cause corrosion, and therefore the engine and boiler manufacturers require precise specifications on the LBG used (Göteborgs Energy Systems AB, 2019; Wärtsilä 2019a). Furthermore, if the methane number or energy content of LBG is too low, engines need to be derated (Wärtsilä, 2019a).

The biofuel sludge should be treated the same way as normal sludge from the vessels. The tank will be cleaned by the crew and cleaning residues will be disposed of in a port in a similar way to engine sludge. The usage of FAME requires tank cleaning procedures, biocides and bunker tank heating.

8 Case study – Comparisons between operations on fossil fuels and biofuels

One of the purposes of this study is to produce examples of the economic framework for shipowners and cargo owners in the shift from fossil to renewable energy sources for propulsion and electricity use on-board. The benefits to the environment of such a change are further important aspects in the decision-making for investments and policy making. Therefore, a case study of four roundtrips have been carried out, including calculations of costs and emissions.

The calculations assume typical characteristics for vessels engaged in operations in the North Sea and the Baltic Sea transporting petroleum products and liquid biofuels. Two different vessels are used as models in our calculations. One is a product tanker with conventional diesel engines built in 2005 and one is a more modern LNG powered product tanker. The sizes of the vessels are approximately the same being able to transport approximately 16 000 m_3 of cargo.

The transport cases were based on real transport needs that the vessels are engaged in comprising substantial cargo quantities. There are cargo owners related to the studied transports, who have an interest in a shift towards renewable fuel for their transport. The purpose of the case studies is to show how the costs and environmental performance change if the vessels are operated on biofuels instead of conventional fossil fuels. It has been relevant to include relations in different Nordic countries since the structure of port fees differ between them. Further, one of the cases is specifically chosen to study cost changes on voyages that require cargo discharged at multiple ports.

The case study calculations have been made for trips with either 100% fossil fuels used or 100% biofuels used on-board. This is done to show clearly how costs and benefits will be influenced by the choice of fuel. It is more likely that biofuels will be introduced as drop-in fuels or blends containing MGO and LNG as main fuel at much lower levels. Another more plausible option is to use a separate tank and a single engine as test engine.

All transport cases assume that cargo is loaded in Gothenburg and unloaded at the following locations:

A. Stavanger (STA) + Bergen (BER) + Trondheim (TRO)
B. Vaasa
C. Gävle
D. Norrköping (NRK) + Södertälje (SÖD)

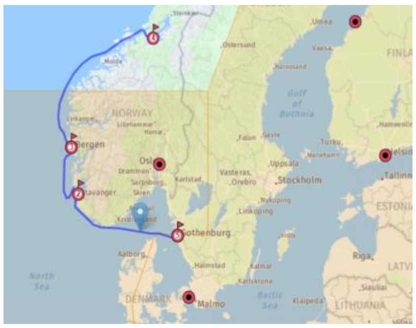
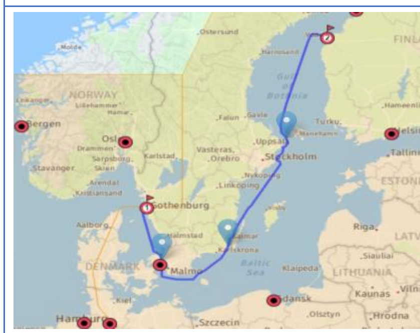
The cargo will be partly unloaded at each location for the routes that include more than one port of discharge. Routes including multiple discharge ports are common scenarios in real operations.

The transport is assumed to either be performed with a vessel with a conventional compression ignition engine for oil combustion (Reference *Conventional tanker*) or with a dual fuel engine that runs on liquefied methane gas and marine distillate oil for ignition fuel (Reference *LNG tanker*).

The *Conventional tanker* is calculated to either operate on fossil MGO or on HVO. It might be possible to use also FAME. FAME is less expensive but assessed a less mature marine fuel, and therefore only HVO has been used in the calculations. Although we have not carried out a full case study on FAME as alternative fuel, we include a discussion on the effects on transport cost from using FAME as alternative to MGO and HVO. The *LNG tanker* is calculated to operate main engines on either LNG or LBG. Fuel used in auxiliary engines on both vessels are assumed to be either fossil MGO, or HVO in the cases including calculations on biofuels.

The studied routes are presented in Table 7.

Table 7. Route A-D descriptions

<table>
<tr><td></td><td>ROUTE A
Göteborg - Stavanger 247 NM
Stavanger - Bergen 145 NM
Bergen - Trondheim 304 NM
Trondheim - Göteborg 630 NM
1 326 NM</td></tr>
<tr><td></td><td>ROUTE B
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Vaasa - Göteborg 797 NM
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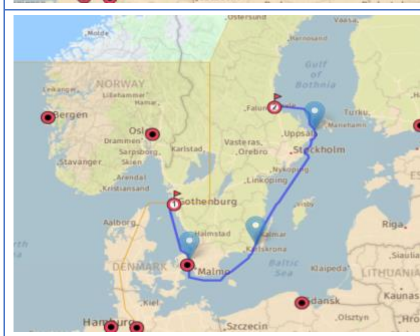
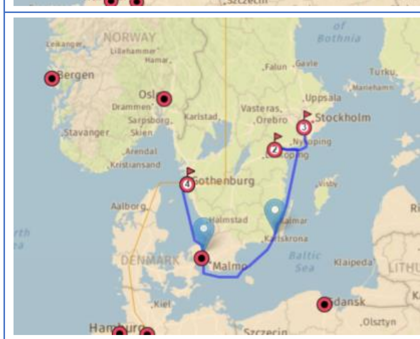
<tr><td></td><td>ROUTE C
Göteborg - Gävle 663 NM
Gävle - Göteborg 663 NM
1 326 NM</td></tr>
<tr><td></td><td>ROUTE D
Göteborg - Norrköping 489 NM
Norrköping - Södertälje 82 NM
Södertälje - Göteborg 491 NM
1 062 NM</td></tr>
</table>

All in all, 16 different roundtrip cases are being compared in Table 8.

Table 8 Transport cases and routes

Route	Transport case
A	1. Conventional tanker on MGO - STA+BER+TRO
A	2. Conventional tanker on Biodiesel - STA+BER+TRO
A	3. LNG tanker on LNG - STA+BER+TRO
A	4. LNG tanker on LBG - STA+BER+TRO
B	5. Conventional tanker on MGO – Vaasa
B	6. Conventional tanker on Biodiesel - Vaasa
B	7. LNG tanker on LNG - Vaasa
B	8. LNG tanker on LBG - Vaasa
C	9. Conventional tanker on MGO – Gävle
C	10. Conventional tanker on Biodiesel - Gävle
C	11. LNG tanker on LNG - Gävle
C	12. LNG tanker on LBG - Gävle
D	13. Conventional tanker on MGO - NRK+ SÖD
D	14. Conventional tanker on Biodiesel - NRK+ SÖD
D	15. LNG tanker on LNG - NRK+ SÖD
D	16. LNG tanker on LBG - NRK+ SÖD

Typical time charter (T/C) rates have been based on the available annual market data for a 16 500 DWT IMO II coated tanker from industrial sources (e.g. Clarksons Platou, 2019). Further, adjustments have been made for the expected difference in T/C rates between the *LNG tanker* and the *Conventional tanker*. T/C rates will be affected by e.g. market conditions, the energy efficiency performance of the vessel, the track record of the shipping company related to safety and factors such as ice class, to give a few examples.

Typical port fees, fairway dues, speed, time spent per terminal, and bunker consumption were provided by the shipping company. Fuel costs were calculated based on assumptions on cost levels from the best available data. The representativeness of the assumed fuel costs for actual fuel costs is changing over time. Their general applicability is also dependent on whether the fuel is offered to the maritime sector today or if it is a potential fuel that is not, or merely on separate occasions, offered as a bunker fuel.

All costs, emissions and external costs are presented as total costs per transported amount of cargo (per m^3).

8.1 Biofuel availability and logistics for the case studies

The most suitable distribution terminal and barge operation area for this study is Gothenburg. In Port of Gothenburg, where approximately 50% of all bunkering operations in Sweden take place, a barge is normally used. In other ports in Sweden, bunkering is made mainly by trucks. LBG has been supplied both by trucks and pipe in Port of Gothenburg. Liquefied gas is supplied by pipe on one quay in the port, where LNG/LBG is transferred from a container on the quay along a 300 m pipe to the vessel. During 2018 the ship Fure Vinga by Furetank was supplied with LBG from a truck[26] , and later the same year Terntank bunkered LBG from a pipeline supplied by Swedegas in the Port of Gothenburg[27].

The price estimate of delivered bio-based marine fuel consists of several price components. The pricing is based on the market price benchmark of fossil fuel and price premium of biofuel, and storage, shipping costs etc. HVO pricing is closely linked to sustainability criteria of the feedstock, biofuel mandates and reduction obligation.

8.2 Economic impact of fuel shifts

Fuel costs are described further in Chapter *4 Fuel costs/prices.* The cost levels vary over time, and there is no fixed ratio between the different fuels. Because of this, the level of costs used in our calculations is merely an indication of a likely cost level. The price of biofuels is dependent on feedstock and has seasonal variations. The levels chosen for the case studies are valid for the spring and summer 2019, and are presented in Table 9.

Table 9 Marine fuel price used in the case study calculations, based on available sources.

Fuel	Price level	
MGO	560	USD/tonne
HVO	1 650	USD/tonne
LNG	400	USD/tonne
LBG	1 470	USD/tonne

The full cost picture for the transport of a m^3 cargo loaded in Gothenburg and unloaded in the respective destinations is shown in Figure 7. We distinguish between fuel costs, T/C, and port fees (including fairway dues). Together these constitute total transport costs. On average, the more modern *LNG tanker* is significantly more energy efficient. It is approximately 10% lower in total cost per moved cargo quantity than the conventional vessel when comparing the fossil fuel alternatives, all costs included. The difference in total cost between the vessels is similar when comparing operations on renewable fuels. Differences in costs between the cases are presented in Figure 8.

[26] https://www.goteborgshamn.se/press/nyheter/forsta-fartyget-i-sverige-bunkrat-med-flytande-biogas-i-goteborgs-hamn/
[27] https://www.swedegas.se/sv-SE/Aktuellt/First_bunkering

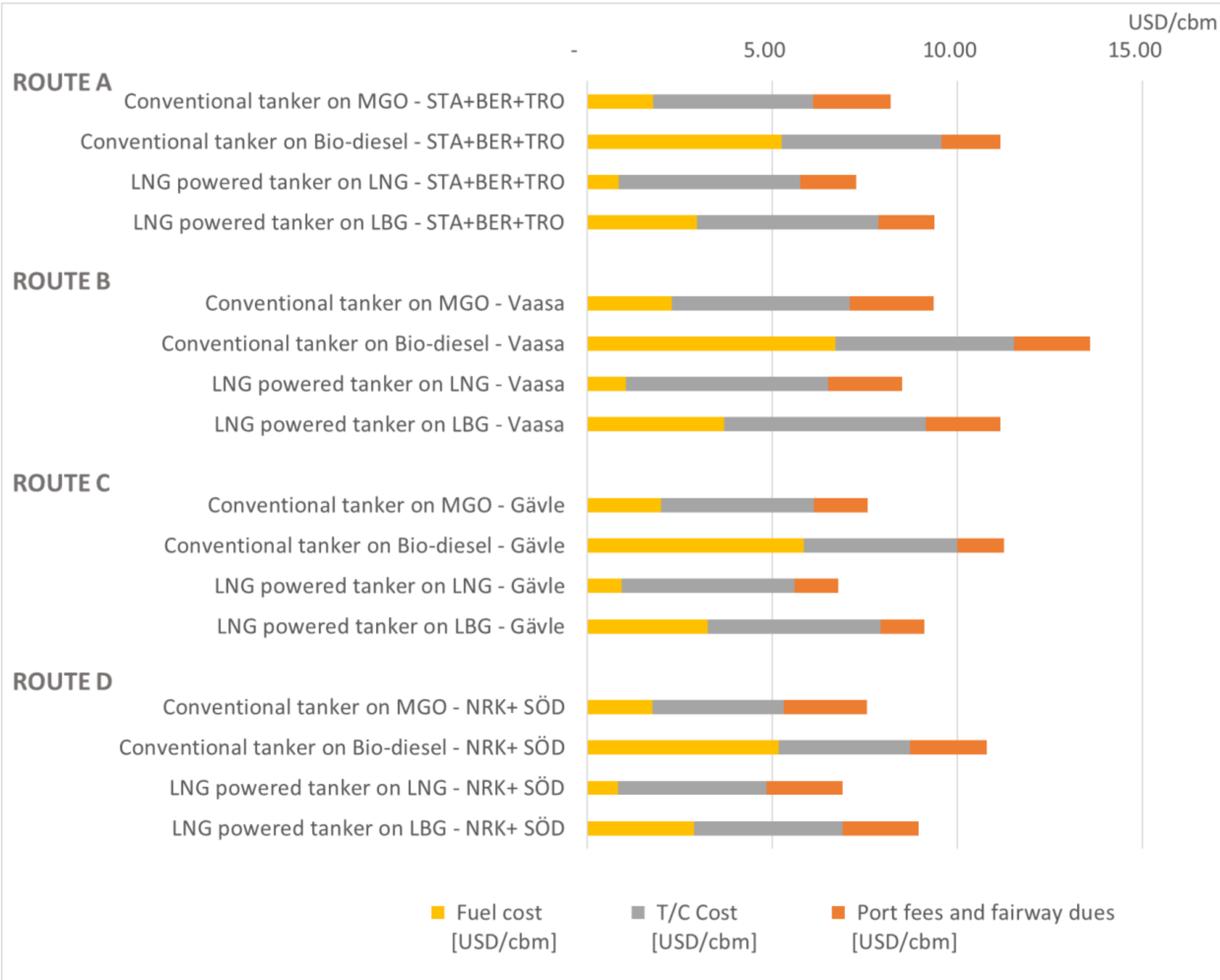


Figure 7 Total transport cost per transported cubic meter cargo including fuel costs, time charter costs and port fees and fairway dues for each of the 16 cases.

Figure 8 The difference in costs between a trip performed with fossil fuels versus renewable fuels. Note that the port discount for running on renewable fuels is shown as a negative figure (rebate). Difference in T/C costs = 0 since the fuel change is not assumed to change T/C costs.

The fuel premium for any of the studied trips including a shift from fossil fuels is approximately 40% of the total transport cost. This is based on present cost levels and includes port discounts for ships with better environmental performance. If paid in full, the port and fairway dues account for 10-30% of the total transport costs in the studied cases. The rebate on port dues in this case study varies between 0 and 5% of the transport cost for the full journey. As per today, the rebates on port dues and fairway dues are the main economic incentives that exist to stimulate investments and use of green technologies on ships. The extra fuel cost of running the vessels on renewables is higher than the dues in full. Accordingly, not even a 100% discount rate on port and fairway dues would cover the current biofuel premium cost.

For a full picture of costs and potential to introduce biofuels, the value of transported goods was also entered into the calculations. The increase in total costs related to the transported volume of cargo is approximately 2-4 USD/cubic meter of gasoline, depending on fillrates. The approximate 0.003 USD per litre in relation to a retail price in Sweden of 1.6-1.7 USD per litre, corresponds to 0.2%. This indicates that the increased fuel costs could perhaps partially be transferred to the price of the transported product without a significant effect.

New, more efficient vessel generations can to a certain degree compensate for an increased biofuel premium. In a comparison between the case in which the older vessel (*Conventional tanker*) operates on fossil marine gasoil and the case in which the new, more energy efficient vessel (*LNG tanker*) is operated on LBG or HVO (in auxiliary engines), the total transport cost will be 1.2-1.8 USD/cbm higher (~20% more expensive). This is about half of the increase that is calculated for total costs associated with the shift from fossil fuel towards biofuel on the same vessel.

As an alternative to HVO, FAME could be used in the marine diesel engines. There remains technical challenges with the fuel under cold conditions and long storage periods and the fuel is therefore not considered a drop-in fuel equal in quality to MGO and HVO. By avoiding the non favourable conditions, the FAME is on the other hand the most economically favourable alternative. Assuming a 100% use of FAME, bought to a price of 770 USD/tonne, the change from fossil to bio-diesel cause significantly less change in transport costs. The total transport cost would at these conditions increase by between 2%, 7%, 7%, and 6% for routes A, B, C, and D, respectively.

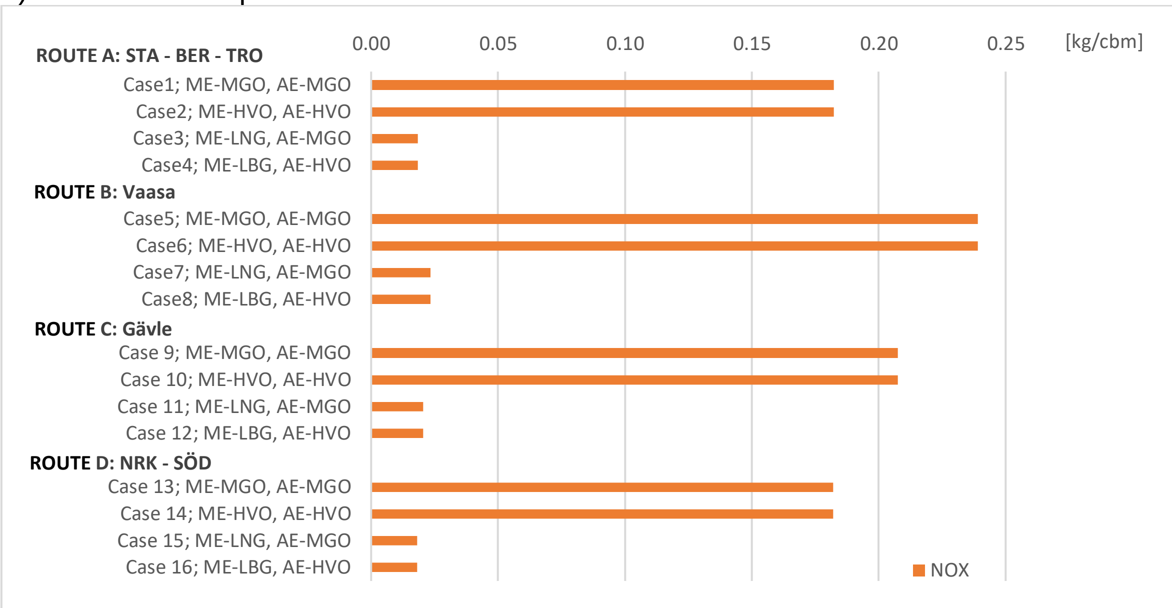
8.3 Environmental impacts in the studied cases

The major benefits of using biofuels are fewer pollutants and lower GHG contribution from operations. Emission levels have been calculated for the reference vessels with fossil fuels (LNG and MGO) and compared with biofuels (HVO and LBG) for the 16 transport cases. The system boundary has been set to fuels used in the vessels' engines. Emissions and GHG emitted during fuel production have not been included in the analysis.

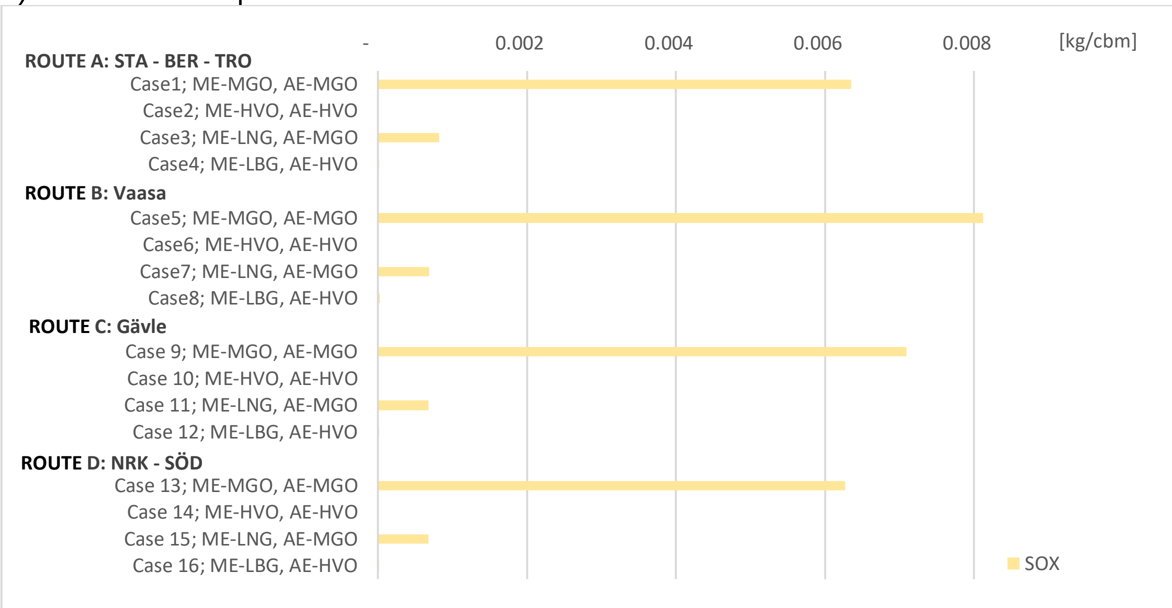
Emissions are calculated based on typical fuel consumption given by the shipping company for the routes included in the case studies. Emission factors are taken from best available sources for the specific engines installed on-board and for the fuel used (Cooper and Gustavsson, 2004; Stenersen and Thonstad, 2017; IMO, 2014b; Yaramenka et al., 2019).

An overview of emissions of NO_X, SO_X, and particles in relation to the transported amount of cargo is presented in Figure 9 a-c. Emissions of NO_X and particulates are significantly lower in the case with a dual fuel engine (LNG powered vessels) than when the ship operates with a conventional diesel engine concept. SO_x are also significantly reduced with the change from diesel fuel to LNG as fuel. The SO_x emissions for biofuels (LBG and HVO), are close to zero.

a) NO_x emissions per cbm.



b) SO_x emissions per cbm.



c) Particle emissions per cbm.

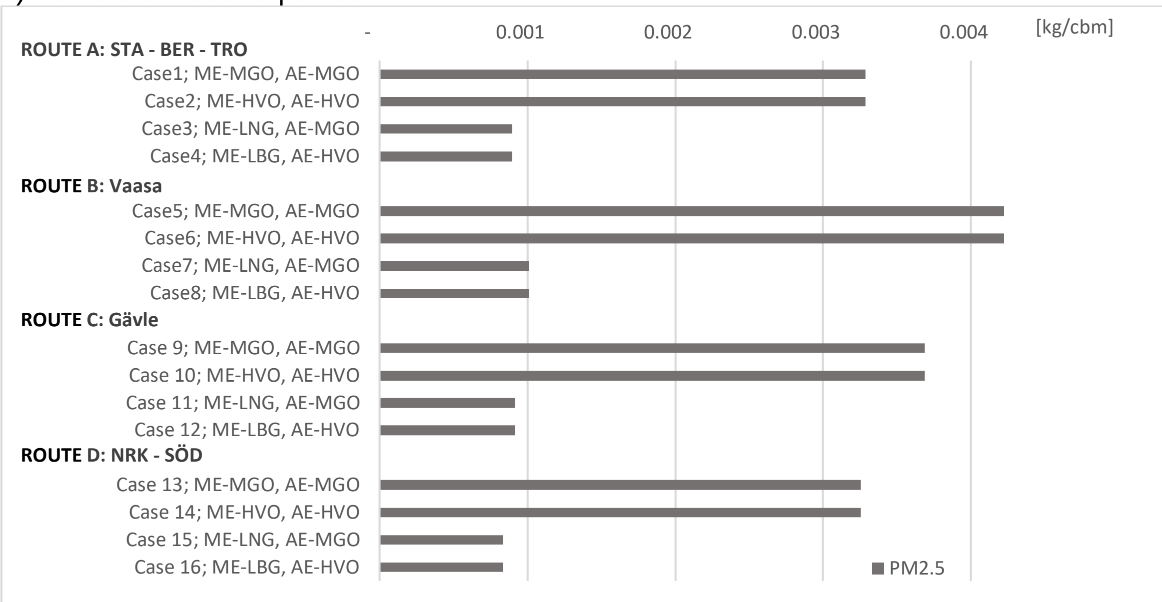
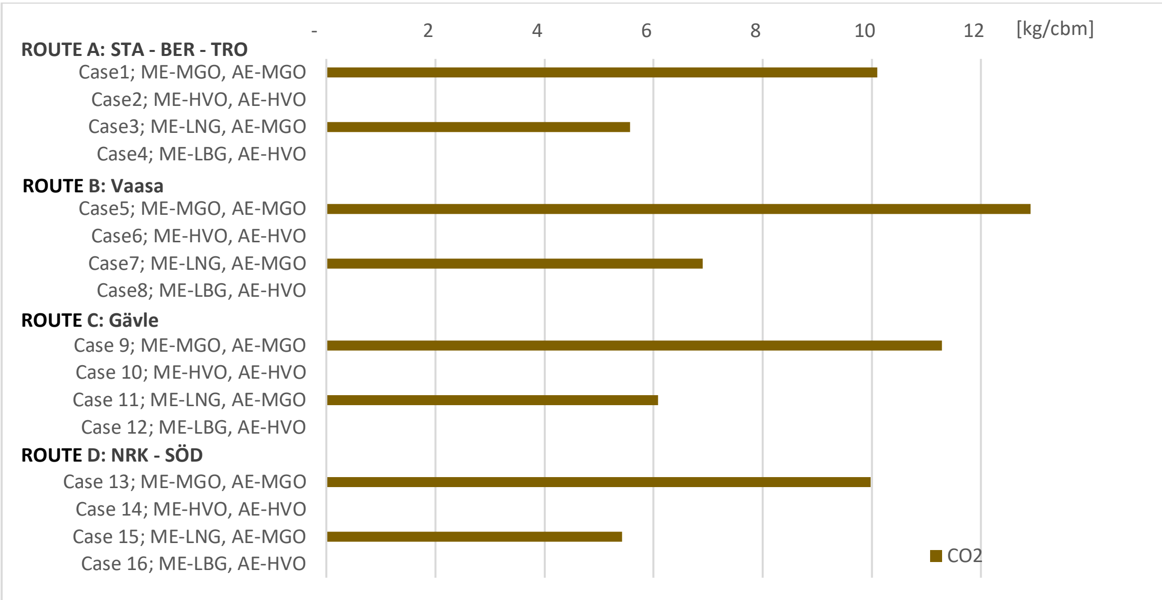


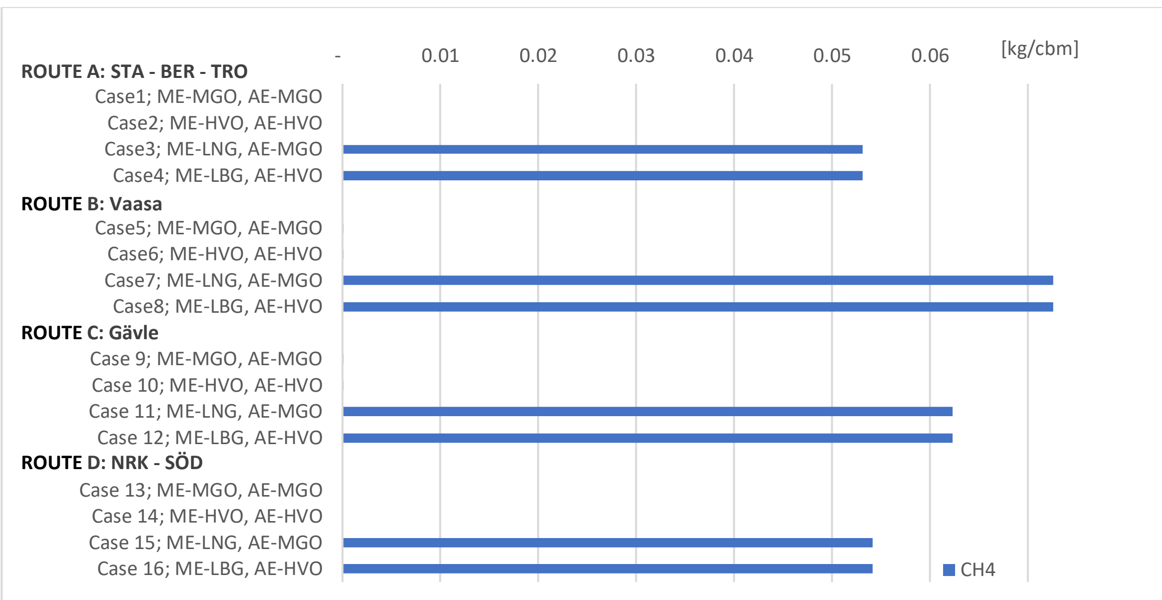
Figure 9 Emissions per transported cargo volume for the 16 transport cases of NO_X (a), SO_X (b) and particles (c). Only end of pipe emissions - tank to wheel (TTW) have been considered.

Due to the system boundary where a tank to wheel perspective is applied, the CO_2 emissions from biofuels is set to zero. There are also emissions from the production and transport of both fossil fuels and biofuels that are not included. The reason for excluding the production emissions is that emission calculations from transportation in most cases use this approach. Emissions of CO_2 from the 16 studied cases are presented in Figure 10a. The dual fuel engines running on methane (LNG or LBG) will also emit a so-called methane slip of unburned methane. Methane is a GHG which contributes to global climate change. The methane slip is calculated and presented in Figure 10 b. Total global warming potential is presented as carbon dioxide equivalents (CO_2-ekv) in Figure 10c. The global warming potential for CH_4 has been calculated with a 100 years perspective.

a


- 2 4 6 8 10 12 [kg/cbm]
ROUTE A: STA - BER - TRO
Case1; ME-MGO, AE-MGO
Case2; ME-HVO, AE-HVO
Case3; ME-LNG, AE-MGO
Case4; ME-LBG, AE-HVO
ROUTE B: Vaasa
Case5; ME-MGO, AE-MGO
Case6; ME-HVO, AE-HVO
Case7; ME-LNG, AE-MGO
Case8; ME-LBG, AE-HVO
ROUTE C: Gävle
Case 9; ME-MGO, AE-MGO
Case 10; ME-HVO, AE-HVO
Case 11; ME-LNG, AE-MGO
Case 12; ME-LBG, AE-HVO
ROUTE D: NRK - SÖD
Case 13; ME-MGO, AE-MGO
Case 14; ME-HVO, AE-HVO
Case 15; ME-LNG, AE-MGO
Case 16; ME-LBG, AE-HVO
CO2

b


- 0.01 0.02 0.03 0.04 0.05 0.06 [kg/cbm]
ROUTE A: STA - BER - TRO
Case1; ME-MGO, AE-MGO
Case2; ME-HVO, AE-HVO
Case3; ME-LNG, AE-MGO
Case4; ME-LBG, AE-HVO
ROUTE B: Vaasa
Case5; ME-MGO, AE-MGO
Case6; ME-HVO, AE-HVO
Case7; ME-LNG, AE-MGO
Case8; ME-LBG, AE-HVO
ROUTE C: Gävle
Case 9; ME-MGO, AE-MGO
Case 10; ME-HVO, AE-HVO
Case 11; ME-LNG, AE-MGO
Case 12; ME-LBG, AE-HVO
ROUTE D: NRK - SÖD
Case 13; ME-MGO, AE-MGO
Case 14; ME-HVO, AE-HVO
Case 15; ME-LNG, AE-MGO
Case 16; ME-LBG, AE-HVO
CH4

c

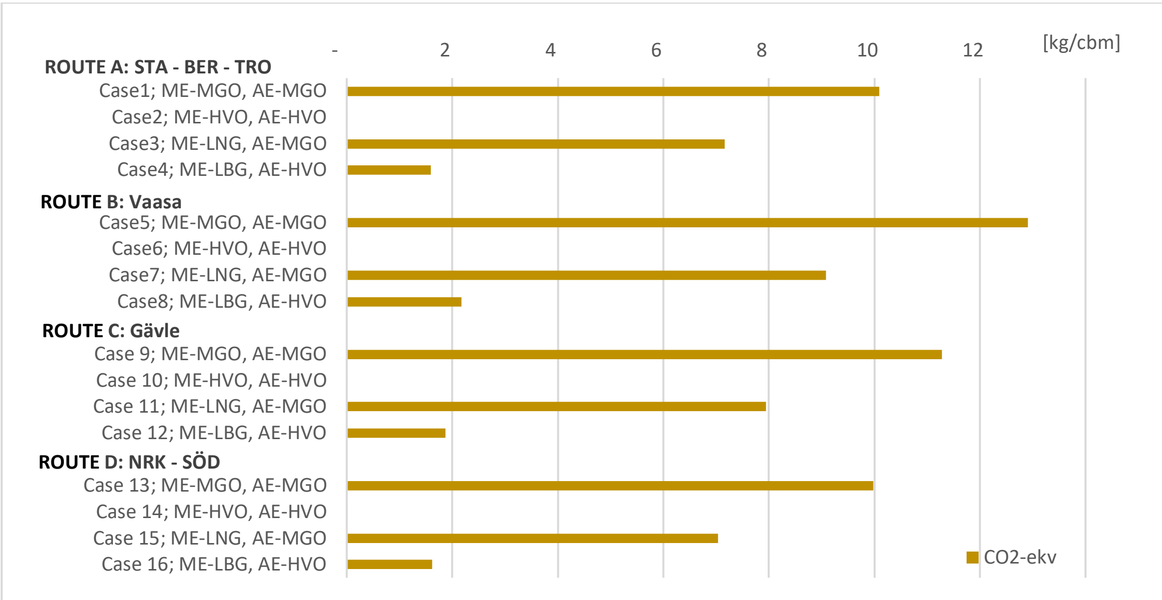


Figure 10 GHG emissions per transported cargo volume for the 16 transport cases of CO_2 (a), methane slip (b) and CO_2-equivalents (c). Only end of pipe emissions - tank to wheel (TTW) has been considered.

External costs for the emitted pollutants, NO_x, SO_x, particulate matter, as well as GHG have been calculated with methodology and cost levels presented in the Handbook on External Costs of Transport, by RICARDO-AEA for the European Commission 2014. Cost levels have been updated with GDP growth adjusted with harmonised indexes of consumer prices. The damage costs presented in the Handbook include values specific for shipping activities where emissions occur at sea and in coastal areas (RICARDO-AEA, 2014). The damage costs used for further calculations are presented in Table 10.

Table 10 Damage costs of main pollutants in sea areas from RICARDO-AEA for the European Commission (2014) updated to the cost level of 2018.

Sea region Adjusted to meet 2018 cost level	NMVOC	NO_x	PM2.5	SO_2	CO_2	
Baltic Sea	1 112	4 753	13 954	5 309	90	USD/tonne
Black Sea	506	4 247	22 802	8 039	90	USD/tonne
Mediterranean Sea	758	1 871	18 707	6 775	90	USD/tonne
North Sea	2 123	6 016	26 088	7 685	90	USD/tonne
Remaining North-East Atlantic	708	2 275	5 612	2 932	90	USD/tonne

NMVOC – Non -methane volatile orcanic compounds
NO_x- Nitrogen oxides
$PM_{2.5}$ – Particulate matter with less than 2.5µm diameter
SO_2 – sulphur dioxide
CO_2 – carbon dioxide

An overview of external costs per transported volume is presented in Figure 11. The emissions of NO_x and carbon dioxide and methane calculated as carbon dioxide equivalents (CO_2-e) dominate external costs from the studied transport routes. The conventional tankers with MGO as main fuel are accompanied by the highest cost (transport cases 1, 5, 9, and 13). If MGO is exchanged for HVO, the costs from CO_2 emissions are removed, and external costs are reduced by around 50% (transport cases 2, 6, 10, and 14). In the cases with the modern LNG driven ship, the costs from NO_X emissions compose a significantly smaller part of total costs (transport cases 3, 7, 11, and 15). The total external costs from these transports are also significantly lower than when these transports are conducted with the traditional MGO driven ship. The lowest total external costs are seen for the cases using LBG instead of LNG as fuel in the modern vessels (cases 4, 8, 12, and 16). The LBG results in low NO_X emissions, and the CO_2 emissions are removed. The share of the CO_2-e emissions that relate to the methane slip, however, prevails in the case with LBG.

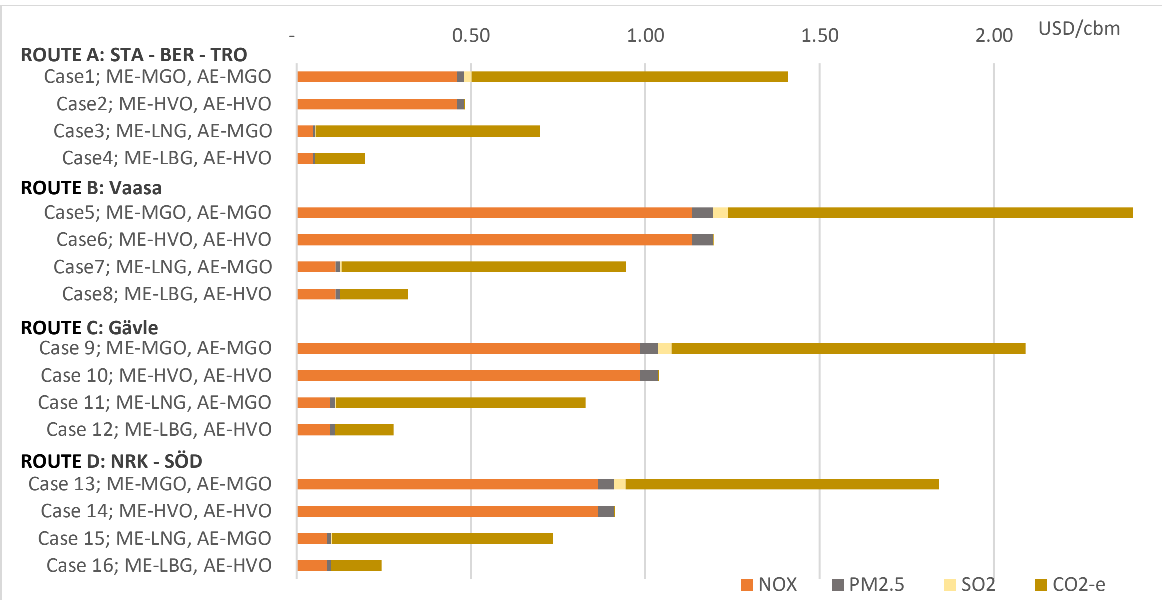


Figure 11 Calculated external costs for pollution and climate change costs per transported amount of cargo. Only end of pipe emissions - tank to wheel (TTW) has been considered.

9 Discussion and conclusions

This study maps prerequisites for a potential introduction of biofuels in the tanker shipping. From a company perspective, the use of renewable fuels will elevate fuel costs. In the time charter segment of the industry, the fuel costs are born by the customer. Pilot projects and long term usage of biofuels in time chartered vessels require ambitious sustainability targets of a customer and a close collaboration between the shipowner and the customer. A shipowner has limited possibilities to make definitive choices alone. Possibilities to carry the increased fuel premium rely on cooperation between shipowner and cargo owner where the shipowner controls the technical options to use a specific fuel on board and the cargo owner's options to handle increased fuel prices. The increased cost for the shift to renewable fuels are in the investigated cases approximately 40%, which is higher than normal business margins in shipping and many industry sectors. Therefore, it seems not to be an option that one of the parties in the transport chain would accept all costs. Rather, several parties need to share the costs as long as such measures are taken on a voluntary basis. If FAME, which is a biofuel of lower quality than HVO, is considered as a viable alternative, the increased cost is instead 2-7% at a 100% shift from

MGO to biodiesel. The opportunities to distribute these cost increases between stakeholders are thus more feasible for this alternative.

From the case studies we also draw the conclusion that the respective contribution of T/C costs, fuel costs, and port fees and fairway dues, to total costs differ to some extent between the routes. However, none of the cases have a significantly different structure than the others despite the different approaches to port fees and fairway dues in the Nordic countries. This implies that new business models would be required for all the studies relations to promote the introduction of bio-based fuels on a large scale.

International regulations do not include quantitative standards for the use of renewable fuels in shipping. Further, incentives that so far are implemented by national authorities and ports are not on levels that stimulate a shift towards renewable fuels on their own. The fuel premium of operating vessels on renewable fuel is in the cases we calculated higher than the dues in full. Accordingly, if port and fairway due discounts were set to 100% for biofuel use, it would still not cover the entire fuel premium cost for transport on HVO or LBG.

If the increased costs were allocated to the carried goods, the price increase per litre gasoline, should gasoline be the transported commodity, would be ~0.003 USD/litre. The share of the biofuel premium cost on end customer costs (0.2 %) is thus significantly lower than its share of transport costs (40%). Possibilities to forward these costs to end customers are not explored in this project but might suggest a future focus for policy incentives and business models.

Fuel availability in ports and the technical logistical feasibility are largely determined by the actors in the shipping industry, such as bunkering companies, shipowners and infrastructure owners. The technical and logistic aspects around the biofuels that are studied in detail are not introducing significant obstacles for the shift towards renewables. Yet other parameters, mainly fuel price, can decide if a fuel is a viable option from a financial point of view:

- HVO could be used without issues in MGO-powered main and auxiliary engines. It has in large similar characteristics and chemical composition as traditional diesel. It is instead the price and availability that set the limits for marine use of HVO. Because of the drop-in characteristics of HVO, there is likely to be strong competition from both the road transport and aviation sectors. This could limit the fuel available to the shipping sector, especially as the price premium in road transport and aviation is higher. Due to the ambitious targets and national mandates for land-based transport fuels, cost-efficient availability of HVO for marine use will be a significant problem.
- The use of biofuels will require a separate agreement with the cargo owner according to the T/C agreement.
- FAME has traditionally been considered to be less suitable for marine use due to, e.g. poor cold characteristics and microbial growth in the fuel supply system on board. Still, research from leading engine manufacturers indicates that FAME could be used if it is produced according to the applicable ISO standards. In a practical setup, the first step to test FAME onboard could be a test with an auxiliary engine in order to avoid operational risk on the main engine. This will require a dedicated tank for FAME and also cleaning of tank, piping and auxiliary engine after the test has been completed. This also requires a separate agreement with the cargo owner according to the T/C agreement. Still, FAME is the most attractive biofuel from a price perspective, and if uncertainties of its performance on board are reduced and the standards are followed, this fuel can prove to

be a potential future alternative fuel for shipping although the demand for FAME from other transport modes can also be expected to increase.

- The introduction of biogas in the form of LBG could also be made smoothly. Tests to run LNG-powered ships on LBG have already been conducted. Since LBG is significantly more expensive than the fossil LNG, this also requires a separate approval from the cargo owner according to the T/C agreement. Currently, the availability of LBG is very limited and the sizes of the production units are relatively small. With increased capacity of LBG production, the price will be more competitive towards the traditional fuels.

There is a clear indication that the biofuel production needs to be significantly increased to cover the potential future demand from shipping. Comparisons of required energy amounts for the tanker segment and total biofuel production show a deficit when considering also other demands such as land-based transport and, possibly, other shipping sectors. These are mainly related to the biofuel demands from other sectors, targets and mandates. Industry and transport on land have more far-reaching policies to comply with to reduce CO_2 emissions.

A large-scale introduction of biofuels to many actors in shipping would require higher production rates. Arrangements with long-term agreements may still make the shift to bio-based fuels possible for individual shipowners. The large production quantities of biodiesel and the possibility to exchange petroleum diesel with it makes this option favourable from a long-term perspective. There are enough quantities available for single shipowner arrangements of all of the studied fuels.

The external costs that are avoided when changing to a non-fossil fuel are lower than the increased transport costs. This possibly indicates that changes need to be made on a policy level in order to include also shipping in the transformation to a fossil free society.

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