When will we admit that maritime transport will not be decarbonised by 2050?

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Abstract

This paper reviews the current progress towards decarbonisation in the maritime transport sector and discusses the prospects of alternative fuels to enable the sector to reach net zero by 2050. It begins with an overview of current fuel usage and emissions in maritime transport, which account for 2.8% of global anthropogenic carbon emissions. The latest study from the IMO predicts that the current level of emissions is expected to increase by 50% by 2050, with the best-case scenario only able to maintain the current level. The paper then discusses the alternative fuels that may contribute towards decarbonisation of the sector, such as hydrogen, ammonia and methanol, revealing that only a tiny number of vessels have renewable fuel capability, and that is mostly dual fuel engines that will continue to burn fossil fuels. Next, the paper evaluates shipping policies and governance mechanisms seeking to drive a trend towards net zero, including the roles of key institutions such as the EU and the IMO. As a result of this review, the paper concludes that, despite a proliferation of small-scale industrial trials, there is currently no credible pathway to net zero for maritime transport outside of major policy intervention aligned with significant reduction in demand for goods transport.

Keywords
decarbonisation, alternative fuels, maritime transport policy, shipping governance, climate change

1 Introduction

The maritime transport sector is not on target for decarbonisation by 2050. Policy targets remain vague regarding a commitment to full decarbonisation by 2050, while there is currently no prospect of replacing the existing fossil-fuelled fleet by this date. Even if this were likely, there is as yet no evidence of the availability of sufficient alternative fuel to power these engines. It is becoming common to describe shipping, like aviation, as a “harder-to-abate” sector (Energy Transitions Commission, 2018). Excuses are already in place and industry representatives expect the sector to be largely fossil fuelled well past 2050, probably until around 2070 (McKinsey, 2023).

The role of maritime transport in a net zero economy is dependent on the available energy mix. If net zero shipping fuels are abundant, then the supply of shipping could meet demand (which in any case is likely to be lower in a net zero economy due to reduced production and consumption of goods). If net zero fuels are not widely available (and carbon fuels are not permitted) then the supply of maritime transport could be much reduced and international trade significantly limited as a result. As this trade limitation is not likely to be politically acceptable, it is difficult to imagine that in this scenario fossil fuels would actually be forbidden. Thus it is likely that, unless and until zero carbon fuel is widely available, the maritime industry will continue to operate on fossil fuels for decades to come, a view widely held in the industry (Duru, 2019; McKinsey, 2023).

This paper will outline the current fuel usage of the sector and then review the potential alternatives, evaluating their advantages and disadvantages. As the primary disadvantage is that the major alternative fuels require green electricity as a feedstock, the likely consequences of a limited supply will then be considered. The role of policy in managing this situation will then be discussed before drawing final conclusions on the likely progress towards the decarbonisation of the maritime sector. This progress is dependent on the need for strong policy support such as banning fossil fuels, mandating that the industry channel their efforts into a single alternative (hydrogen) and the need to devote more resources to wind power, being the only fully green alternative.

2 Overview Of shipping demand and supply, fuels used and emissions

The global commercial shipping fleet totals 105,500 vessels over 100 gross tonnes (including 56,500 ships over 1,000 gross tonnes) with a total volume of 2.3 billion dead weight tonnes, triple the level observed in 2000 (UNCTAD, 2023). The primary specialised vessel types are dry bulk carriers (43% of the fleet), oil tankers (29%) and container ships (13%). The remainder of the fleet is made up of general cargo and other vessels, including 0.4% of tonnage represented by passenger vessels and ferries. Despite a lot of focus in society on decarbonisation by reducing consumer demand, it is notable that only 13% of maritime transport capacity is devoted to containerised goods (including but not limited to consumer items). The majority of freight transported is bulk goods that fuel industry such as iron ore for steel production, coal for energy production, oil and gas for domestic uses such as heating and transport fuel and grain for animal feed. A corollary of the above is that around 40% of maritime transport consists of fossil fuels (oil, gas and coal), meaning that, in a net zero economy, if the world economy were to decarbonise and such inputs were no longer needed, maritime transport demand would thus shrink by an equivalent amount, which would make the decarbonisation task much smaller. On the other hand, some of this lost demand is likely to be replaced by transportation of alternative fuels such as hydrogen and ammonia.

The greenhouse gas (GHG) emissions produced by this current level of demand amounted to 1,076m tonnes (in CO_2e) in 2018, 9.6% more than 2012 (977m tonnes), representing 2.89% of total anthropogenic GHG emissions (IMO, 2020).[1] The IMO study predicts a best-case scenario of the same level of carbon emissions in 2050, with a worst-case scenario of up to 50% increase. These figures depend on the total demand for shipping, the efficiency of the vessel engines and operational practices and the mix of fuels used.

The IMO GHG study shows the total amount and types of fuel used across the sector. The vast majority (79%) of fuel used is heavy fuel oil (HFO), which used to be refinery waste after the other types of oil were refined, until it was realised that it can be used as fuel itself. It is so thick that it needs to be heated before it can be used in the engine. The remaining 21% is split between marine diesel oil (MDO) and liquefied natural gas (LNG). These fuels differ in their levels of Sulphur Oxides (SOx), Nitrogen Oxides (NOx) and Particulate Matter (PM) produced, therefore they produce less local air pollution and can be used to meet certain clean air regulations such as Emission Control Areas (some control for SOx only, some cover both SOx and NOx). However, they are mostly identical in terms of carbon emissions (as a gas, LNG produces lower carbon emissions than oil when combusted but, from the lifecycle perspective, partly due to methane slip, its overall carbon emissions are similar to or potentially even higher than oil).

[1] The IMO GHG study is usually published every 4 years, based on data from two years before, hence the most comprehensive analysis was most recently published in 2020 based on 2018 data. While this is rather old, it is the best quality data available. However, it is certain that emissions continue to increase. According to OECD (2023), emissions increased from 840m tonnes in 2019 (thus their baseline is around 20% less than the IMO report) to 866m tonnes in 2022.

3 Overview of alternative fuel options

In order to replace the currently used fossil fuels, a range of options has been proposed and trialled in recent years. These can broadly be divided into zero carbon fuels (i.e., those that produce no carbon emissions when combusted, although there will always be "upstream" lifecycle emissions from the production) and carbon neutral fuels (i.e., those that produce carbon emissions when combusted, but that carbon was already taken from the air to produce the fuel, therefore there is no net increase in carbon in the atmosphere). Carbon neutral fuels can further be split into biofuels and e-fuels (Table 1).

Table 1 Tank to wake emissions of the primary alternative zero-carbon and carbon-neutral fuels

Zero-carbon or carbon-neutral	Fuel type	Tank to wake emissions (g CO_2 / g fuel)
Zero carbon	Electricity	0
	E-Hydrogen	0
	E-Ammonia	0
Carbon neutral (biofuels)	Bio-Ethanol	1.913
	Bio-Methanol	1.375
	Bio-Diesel	2.834
	Bio-LNG	2.755
Carbon neutral (synthetic fuels produced using electricity and captured carbon)	E-Diesel	3.206
	E-Methanol	1.375
	E-LNG	2.755

Source: author, based on European Commission (2021a). Note: Well to tank (i.e. upstream) emissions are not provided as they depend significantly on different production factors thus a full analysis is beyond the scope of this paper.

Zero carbon fuels are the first priority. Electricity (stored in batteries) is already being seen in small ships such as supply vessels (Lindstad et al., 2017) and ferries (Bach et al., 2020). For example, several fully-electric car and passenger ferries are already in operation in Norway.[2] Due to charging issues and battery sizes, using electricity is only favourable where engine loads are relatively light, distances are relatively short and the vessel operates a regular route between a limited number of ports, which have shore-side electricity installed for recharging (thus providing an additional incentive for a port to introduce shore-side electricity). Therefore, coastal and inland shipping routes can more easily be

[2] The first was the *Ampere* which entered operation in 2015 and the largest is the 143-metre *Bastø Electric* which entered operation in 2021. https://www.siemens-energy.com/global/en/home/stories/electrifying-the-sea.html

switched to electric than long-distance international routes. The 80-metre, 120-TEU capacity *Yara Birkeland*, a fully electric (and autonomous) ship was delivered in Norway in November 2020, where it operates an 11 nautical mile route twice a week. In 2023 Cosco Shipping launched an electric vessel to be used for inland shipping between coastal port Shanghai and Wuhan on the Yangtze River. The vessel is 120 metres long, 24 metres wide and has a draft of 5.5 metres. It has a carrying capacity of 700 TEU and a range of 600 nautical miles on a single charge. The batteries are contained in 23 TEU containers which can be swapped with charged batteries instead of waiting to recharge.

The two primary contenders as fuels to power the industry at significant scale are zero-carbon hydrogen and ammonia, both of which are produced from electricity. Hydrogen is the most attractive, as its emissions are only water vapour, and it can either be combusted or used in a fuel cell. While both already exist in small applications such as short distance ferries, it is the latter that is most often proposed for shipping, as with other modes of transport.[3] The main disadvantage is that, as a new fuel for the maritime sector, it will need to be produced in large volumes, transported to refuelling facilities at ports, and the existing ships will need to adapt or retrofit their engines to be able to use it. As it is not expected to take a serious share of the market until at least the 2030s, ports and supply chains need to be developing now, which will require policy direction and support. The other challenge is that the production of green hydrogen must be greatly scaled up, since the majority of hydrogen currently being produced is from fossil fuel sources. From an operational perspective, being less dense than fuel oil, it requires around four times more storage space on a vessel, thus reducing cargo capacity and influencing the economics of shipping. Moreover, before it can be adopted worldwide, more regulatory work needs to be done to establish global standards on safety and handling regulations.

Ammonia (NH_3) is the other most widely considered fuel, which is produced by combining hydrogen and nitrogen through the Haber Bosch process. Its main advantage is that it can be stored in a smaller space thus not impacting cargo capacity as much as hydrogen. There is also an existing supply chain in place as it is produced for fertiliser (albeit this is currently produced from "grey" hydrogen, i.e., hydrogen produced from fossil gas). Ammonia can be used either by reconverting back to hydrogen for use in a fuel cell or it can be combusted in the engine, the latter being the currently

[3] The MF Hydra ferry in Norway, which uses liquid hydrogen to power fuel cells ship, was launched in 2023 (Ballard, 2023). The Hydrobingo ferry in Japan, which uses a dual-fuel diesel-hydrogen engine, was launched in 2023.

https://www.volvopenta.com/en-gb/about-us/news-page/2023/jun/volvo-penta-and-cmb-tech-collaborate-to-power-the-worlds-first-hydrogen-fueled-commercial-ferry preferred option (see later discussion of new vessels). However, many significant problems remain with regard to ammonia. Not only does it require yet more large use of energy to produce in addition to that used to produce the hydrogen, it is highly toxic both to humans and marine life, and when combusted produces more N_2O (a powerful GHG) than conventional fuel, hence it could undermine the carbon emission savings from using ammonia (Tomos et al., 2024). Technologies such as selective catalytic reduction (SCR) or exhaust gas recirculation (EGR) are already used by ships to reduce NOx emissions when required by Emission Control Areas, but they do not remove them entirely. It is possible that, unless both the toxicity problem due to nitrogen slip and the GHG increases due to N_2O emissions can be resolved soon, ammonia could be abandoned as a possible shipping fuel. As ammonia is included as a key option in many reports and studies (Global Maritime Forum, 2021; Transport and Environment, 2022), this question needs to be answered urgently in order to inform future shipbuilding strategies.

Carbon neutral fuels are less desirable because they only recycle emissions, but at least they do not produce any new emissions. They can either be biofuels or e-fuels. Biofuels have the advantage in that (in theory but not always in practice) they use existing organic waste from crop waste, food waste, animal waste, sewage and used cooking oil. Another attractive point is that they can be used as drop-in fuels in engines that already use the conventional non-bio version. Bio-diesel is already widely used in trucks, for example. Bio-methanol is proving particularly popular at the moment, with Maersk announcing its intention to commit large investments to bio-methanol and even establishing their own company to produce it. Maersk has 25 dual-fuel methanol container ships on order, ranging from a small 2,100 TEU to a large 17,000 TEU (Maersk, 2023).

One of the drawbacks of biofuels is in purposely planting crops such as palm oil in order to be turned into biofuels, particularly in developing countries where it may compete with food crops and is one of the major causes of deforestation, and it is difficult to reliably document this sourcing. The other main drawback is that there is already high demand from other sectors (e.g., road transport) and we cannot produce enough of it, so it can never be a serious replacement for the total demand. Even in Maersk's own press release announcing the maiden voyage of their 16,000 TEU methanol-enabled container ship, they state: "Maersk has secured sufficient green methanol to cover the vessel's maiden voyage and continues to work diligently on 2024-25 sourcing solutions for its methanol-enabled vessel fleet" (Maersk, 2023). Thus, there is the danger that if we switch to many methanol ships, they are likely to have to use e-methanol (Lloyd's List, 2023) or simply continue using conventional fossil fuel oil (as they are all dual-fuel vessels).

Carbon neutral e-fuels also have the advantage of being drop-in fuels that can be used in existing engines as they are simply synthetic versions of existing fossil fuels. The main drawback with all e-fuels, as mentioned, is that they require (green) electricity as a feedstock. Moreover, the cost of capturing carbon from the atmosphere is very high. There is also a real problem with inefficiency, as much of the energy is lost translating electrical energy to other fuels and there is an implicit danger of double counting of carbon reduction emissions from the capture and use, which must be strictly monitored. According to Lindstad et al. (2023), from a full lifecycle perspective, to produce 1kWh of propulsion even from green electricity to a battery-powered vehicle requires an input of 1.5kWh of energy, due to losses in transportation and battery usage. When converting that electrical energy into the leading e-fuels, large amounts of energy are lost, meaning that to produce 1kWh of propulsion of the vessel, the amount of energy put in is 4.2 kWh for e-ammonia, 5.0 kWh for e-hydrogen, 5.9-6.5 kWh for e-methanol and 6.3-7.1 kWh for e-diesel. Such a high rate of inefficiency questions whether, in a world where energy is scarce, so much can be utilised in converting to e-fuels. The authors calculate the total annual energy demand of shipping as around 5.3 exajoules (EJ). If this were to be provided with e-hydrogen, with an efficiency ratio of only 1:5, it implies that five times this amount of green electricity would need to be produced solely to decarbonise the shipping industry. As a result of this calculation, Lindstad et al. (2023) speculate that, since there will most likely not be enough green electricity to produce this amount of fuel in the decades to come, it is more likely to be directed to sectors where the losses are not so high, e.g., using the electricity directly in battery-powered road transport and domestic uses, with shipping continuing to use fossil fuels until around 2070.

Table 2 shows the current world fleet and order book for zero-carbon and carbon-neutral vessels (thus fossil fuels such as LNG are not shown). The first thing to note is the different types of engine. A single-fuel engine obviously uses just that fuel, which can include "drop-in" fuels, for example, using e-diesel as well as regular diesel in a diesel engine. A dual-fuel vessel is designed to be able to burn more than one type of fuel in its engine. This is the most common way of using LNG at the moment and can provide reliability and flexibility. The third type is called "ready," for example, ammonia-ready. This means that they use conventional fuel oil (usually diesel) but can use a small amount of ammonia mixed in. The engine components have been upgraded and modified to be able to deal with the corrosiveness of ammonia and with future full conversion in mind. The table shows that decarbonised fuels are barely evident among either existing or ordered vessels. Only two hydrogen vessels exist with three on order. All methanol ships are dual fuel. There is a clear trend towards "ready" vessels which may never use any of these fuels or may not use green versions. There is also a clear trend towards ammonia and methanol.

Table 2 Current fleet and orderbook for zero-carbon and carbon-neutral vessels

Single fuel, dual-fuel or "ready"	Fuel	Vessels in operation	Percentage of world fleet	Vessels on order	Percentage of order book
Single	Hydrogen	2	0.0002	3	0.07
	Biofuel	62	0.059	5	0.11
Dual fuel	Conventional/ hydrogen	3	0.003	0	0
	Conventional/ methanol	23	0.022	62	1.38
	Methanol/ biofuel	0	0	2	0.04
Ready	Hydrogen ready	3	0.003	6	0.13
	Ammonia ready	22	0.021	131	2.91
	Methanol ready	0	0	34	0.75
Total		115	0.1082	243	5.39

Source: adapted from the analysis of data from the Clarkson's shipping register by from Tomos et al. (2024). Note: while both methanol and LNG can be used either in their fossil fuel or carbon neutral (biofuel or e-fuel) variants, only methanol is included here as all methanol ships are intended to be fuelled by the carbon neutral option. All current LNG ships are fuelled exclusively by fossil fuel and they will not use any carbon neutral version until at least 2040 (see policy discussion) therefore in this paper LNG is not considered a genuine alternative fuel.

It should also be borne in mind that vessel engines can be retrofitted, thus not all alternatively fuelled vessels in future will be newbuilds. The Global Maritime Forum (2021) proposed a 2050 scenario where approximately half of zero emission vessels would be newbuilds and half retrofits of existing vessels. According to Lagemann et al. (2023): "From a shipowner perspective, both methanol and LNG appear to be relatively robust initial power system choices for a broad range of emission reduction ambitions. Both power systems enable low-cost fuel switches to bio- or electro-fuels, while LNG potentially also enables low-cost retrofits to, e.g., ammonia. These findings coincide with the current orderbook indicating that LNG and lately methanol engines are preferred options by shipowners."

4 The danger of lock-in to fossil fuels

There is a significant danger that the proposed fuel options encourage lock-in to existing fossil fuels, due to three reasons: drop-in use of e-fuels, the use of dual-fuel engines and the production of zero carbon fuels from fossil sources.

The reliance on the availability of drop-in e-fuels makes it more likely that the industry will carry on longer with fossil fuel engines because they can just use e- versions, or they can just say that they will switch to e-versions as they are available and cost competitive. This is what is happening with the EU's proposed ban on the sale of new ICE trucks from 2035, which has now been relaxed to allow such vehicles to be sold as long as they only use e-fuels in the engines. This will delay adaptation as we will continue to produce the same engines, and when (as is likely) sufficient quantities of the e-versions of these fuels are not available (or are not cost competitive), we will continue burning fossil fuels (unless it is prevented through policy).

The second driver of lock-in to fossil fuels is the use of dual fuel ships. The majority of existing LNG ships, for example, are actually dual fuel, which means they can use fuel oil when LNG is not available (see Lindtsad et al., 2021 for more details on e-fuels and dual fuel engines). Despite a slow increase in LNG ships in contrast to the hype during the last two decades (Monios & Fedi, 2023), and the World Bank (Englert et al., 2021) recently suggesting that the potential for LNG as an alternative fuel has peaked, popularity of LNG is suddenly growing. 941 vessels (0.89%) of the world fleet are currently dual-fuel LNG/conventional, with 871 on order, comprising 19.00% of the order book (Tomos et al., 2024). This change is due both to the Russian invasion of Ukraine leading to gas-importing countries needing to diversify their supply from around the world (many of the LNG-fuelled ships are actually LNG carriers), and to recent tightening of regulations around carbon intensity, which can easily be met by switching to LNG (see discussion in policy section). As shown in Table 2, all methanol ships on order are dual fuel or methanol ready; none are 100% methanol only. The dual fuel option makes the transition smoother, for example a dual fuel ship could be able to use either methanol or diesel, begin with the latter and then simply increase its use of the former as it becomes available. The problem here is that it also means that the vessel can simply continue to use fossil fuels forever if the new fuels do not become available in sufficient quantity or suitable price.

Finally, another danger even of preparing for green-electricity-derived hydrogen and ammonia, is that they are currently mostly produced from fossil fuels (so-called blue or grey as opposed to green). Thus, if we switch the fleet to engines that can use hydrogen or ammonia, this could incentivise continued production of such fuels since the green versions produced from electricity will not likely be available in sufficient quantities or at attractive prices. As such, we would only swap the current fossil fuels for new fuels produced (less efficiently) from fossil fuel.

5 The role of policy

Given the operational challenges and high prices of alternative fuels, the only serious driver of decarbonisation is direct policy action to create a level playing field. While domestic transport falls under each nation's decarbonisation responsibility and targets, the fact that the majority of shipping is international means that it was agreed at the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 to retain the responsibility for decarbonisation of these emissions outside of individual country accounts and within the remit of the IMO. In the past, the IMO's role has been more about safety and security; however, since the adoption of the International Convention for the Prevention of Pollution from Ships (MARPOL, agreed in 1973, entering into force in 1983), commencing with annexes on sea pollution and waste, until the addition of Annex VI on air pollution (agreed in 1997, entering into force in 2005), some progress has been made on SOx, NOx and PM, but decarbonisation policy proceeds very slowly.

Until 2023, the IMO goal was only 50% reduction on 2008 levels (the peak year) by 2050, but since July 2023 this target was upgraded to "reach net-zero by or around, i.e., close to 2050, mindful of different national circumstances." While "net-zero" sounds less stringent than real zero, the fact that the targets will be assessed on a full well-to-wake basis should ensure that fossil-produced fuels (e.g., blue and grey as opposed to green) will not allow shipowners to evade attention. The strategy includes intermediate goals of "20% striving for 30% by 2030, and 70% striving for 80% by 2040, compared to 2008." Given that shipping emissions remain around 10% below the peak year of 2008, the aim of 20% reduction by 2030 means only about a 10% reduction, but this would nevertheless be substantial given that current predictions expect future emissions to continue rising. Another intermediate goal is for "Low-carbon and zero-carbon fuels/energy source uptake for international shipping to be at least 5%, striving for 10%, by 2030", similar to the EU's new regulation discussed below. In addition to alternative fuels, the IMO continues to focus on efficiency improvements, aiming for: "A reduction in CO_2 emissions per transport work (carbon intensity) by 2030 to be at least 40% as an average across international shipping compared to 2008 levels." While many commentators welcomed the official net-zero target, many organisations remained critical that the target is too weak and lacks measures to achieve it (Schuler, 2023).

The current policy measures to reduce carbon emissions that have been adopted at the IMO relate to efficiency. In 2011, the IMO introduced the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), and since 2023 it is required that all ships calculate their Energy Efficiency Existing Ship Index (EEXI) and report their annual operational carbon intensity indicator (CII). The danger of focusing on the efficiency of individual vessels is that there is no link with overall reduction of emissions across the sector, as demand and total transport work increase. Research shows that shipping emissions have continued to rise as vessel efficiency increased (Monios & Wilmsmeier, 2022).

Over the years, other measures have been proposed by member states at the IMO. A policy of shipping speed limits was proposed by France at the IMO Marine Environment Protection Committee (MEPC) 74 in May 2019, with support from countries such as Greece but opposition from the UK meant it was ultimately rejected (Psaraftis, 2019b). Market-based measures (MBMs), primarily either a carbon tax or an emission trading scheme (ETS) have been proposed and debated during many years but have never been adopted (Psaraftis, 2012; Monios & Ng, 2021). The process started with a formal request for submissions at MEPC 59 (July 2009) until discussions were formally suspended at MEPC 65 in May 2013. They returned to the table at MEPC 76 in June 2021 but were again postponed pending further work and analysis outside the MEPC.

Research shows the pros and cons of both a carbon tax and an ETS (Psaraftis, 2019a; Lagouvardou et al., 2020). A carbon tax is much simpler than an ETS, although it would be politically difficult to set a high price and difficult to manage at a global level in terms of collecting and distributing the revenues, and the unknown price would not allow any certain achievement of carbon reductions, as the increased cost may simply be absorbed and have no influence on action. While in theory the ETS is better because the amount of carbon emitted can be fixed and the price left to fluctuate according to the market, it comes with administrative complexity and potential offsetting (if it is allowed) rather than reduction of shipping emissions.

The challenges at the IMO are well known, being a forum for decision making between 174 member states, some of which have more concern than others for their shipping fleets or for their economic reliance on shipping. Some large developing countries, namely China, Brazil and India, oppose several initiatives, as they believe that their economies would be unfairly disadvantaged by increased maritime costs as a result of regulation. They justify their position according to the principle of “Common But Differentiated Responsibilities (CBDR)” enshrined in the UNFCCC which, however, conflicts with the IMO policy of “no more favourable treatment” (Psarafatis & Kontovas, 2020; Monios & Ng, 2020).

Many member states are represented at the IMO by industry, thus the preferred solutions at the IMO tend to be technical (Bach & Hansen, 2023) and those that do not disrupt current practice rather than forceful policy changes (e.g., focusing on increasing efficiency rather than forcing the change of fuels or banning of fossil fuels). There is frequently a gap between the environmental policies of a country towards domestic decarbonisation, and what their representatives lobby for behind closed doors at the IMO, given that they have little incentive to push for decarbonisation of a sector that lies outside their own nationally-determined contributions. Monios and Fedi (2023) argue that countries play a dual role in maritime policymaking; first, as agents of the IMO (and the same applies at the EU) which must implement their directives and regulations, and second, as principals who determine the policies and measures adopted by these international bodies. While it is important to identify the inability of a primarily technical organisation such as the IMO to set stringent environmental regulations and policies, attention must also be paid to the role of the member states who lobby against their agreement, delay their implementation or later refuse to ratify them or neglect to transpose them into national law or enforce them.

Lack of action at the IMO does not preclude individual countries or blocs from taking their own action. The EU has often implemented policies which were later adopted at the IMO level (e.g., regulations on double hulls to prevent oil spills, Port State Control to inspect old vessels and SOx limits at EU ports). The EU’s carbon ambitions, known as the “Fit for 55” package, are stated as follows: “In September 2020, the Commission adopted a proposal to cut greenhouse gas emissions by at least 55% by 2030 and put the EU on a responsible path to becoming climate neutral by 2050. To achieve climate neutrality, a 90% reduction in transport emissions is needed by 2050” (European Commission, 2021b). The two key pieces of legislation adopted by the European Commission are the inclusion of maritime transport in the ETS and the 2023 Fuel EU regulation.

The EU ETS has existed since 2003, but since 1 January 2024, maritime transport has been included. The ETS will include 100% of CO_2 emissions from ships sailing between EU ports, and 50% of emissions between EU and non-EU ports. Methane (CH_4) and Nitrous Oxide (N_20) will be added from 2026. The amount of these emissions needing to be covered by ETS permits will be phased in gradually: 40% of 2024 emissions, 70% of 2025 emissions and 100% of 2026 emissions (European Commission, 2024). Shipping lines are already charging levies for this, e.g., CMA CGM charges €25 per TEU for the Asia to North European route, noting that this rate is based on the current (early 2024)

EU carbon price of €80 per tonne of CO_2. There will be issues of leakage and thus opportunities for neighbouring countries; for example, ships coming from Asia to Europe could tranship their containers at a nearby non-EU port (e.g., in Turkey), thus drastically shortening their non-EU to EU port journey for which 50% of emissions must be accounted. All regional carbon policies face such risks, which over time could perhaps be addressed by use of a Carbon Border Adjustment Mechanism (CBAM).

Another important recent EU policy is the Fuel EU regulation. This regulation aims "to increase consistent use of renewable and low-carbon fuels and substitute sources of energy in maritime transport across the Union, in line with the objective of reaching Union-wide climate neutrality at the latest by 2050, while ensuring the smooth operation of maritime transport, creating regulatory certainty for the uptake of renewable and low-carbon fuels and sustainable technologies and avoiding distortions in the internal market" (European Parliament, 2023). Like the ETS, this regulation covers 100% of emissions between EU ports, 50% of emissions between an EU and non-EU port,[4] and also includes emissions while at berth (moreover, the regulation mandates that passenger ships and container ships use onshore power supply while berthed at major EU ports from 2030). The specific limits on well-to-wake GHG intensity of the fuel used by ships (measured in gram of CO2eq per MJ of fuel), will be scaled up over time, from a reduction on 2020 levels of 2% in 2025 to 80% in 2050.[5]

The advantage of this policy is that it cannot be met simply by increasing efficiency or reducing fuel use through slow steaming. The carbon intensity of the actual fuel used must be reduced. This can be done either by adding drop-in fuels to the existing fuel mix, or by using a lower carbon fuel in a dual fuel engine for part of the time such that the overall mix of fuel used in a year meets the reduced target. An additional measure to accelerate uptake of zero-carbon fuels is that, until 2033, the carbon intensity value of renewable fuels of non-biological origin (RFNBO, i.e., e-fuels), will be halved. Another interesting part of the regulation is that it allows the voluntary pooling of emissions between a group of ships, whereby the pool would need to meet the GHG limits on average rather than individually. Research shows, however, that the first three limits can be met by fossil gas such as LNG, thus it is not until 2040 that genuinely renewable fuels would need to start being used, which runs the risk of delaying transition and locking in fossil fuels (Christodolou & Cullinane, 2022; Transport and Environment, 2022). Transport and Environment (2022) argue that the policy should not be technology

[4] Both the ETS and the Fuel EU regulation cover vessels above the size of 5,000 gross tonnes, which is around 55% of all ships but around 90% of total shipping emissions.
[5] Note that the initial proposed regulation in 2021 was strengthened by the time of the final adoption in 2023.

neutral and should specify fixed percentages of renewable fuels required in order to avoid lock-in and start the transition sooner.

6 Conclusion

The maritime industry does not genuinely expect to be net zero by 2050. The IMO aim was only 50% until recently, and a recent survey of industry stakeholder expectations for the fuel mix in 2050 reveals an expectation that the main fuels (around 50%) will be conventional fuel oil, green ammonia and bio-diesel, with the rest made up of blue ammonia, LNG, e-methanol, bio-methanol, bio-LNG and e-LNG (McKinsey, 2023). A narrative has taken hold characterising shipping as "harder-to-abate", and analysis of availability of green electricity suggests that shipping (if it continues with a similar level of demand) will continue to use primarily fossil fuels until around 2070 (Lindstad et al., 2023). It is impossible to avoid the conclusion that the maritime industry is not serious about decarbonisation. Only very few authors have raised the possibility that the total volume of shipping will need to reduce in a world where green energy is scarce and expensive (De Beukelaer, 2022; Monios & Wilmsmeier, 2022, Van Leeuwen & Monios, 2022).

There is, as yet, no trend towards solely renewable powered vessels. All the vessels that can use green fuels are either dual fuel or green fuel "ready", meaning both could potentially continue using only fossil fuels forever or mixed with a tiny amount of extremely inefficiently produced carbon neutral e-fuels. These trends raise a serious danger of lock-in to fossil fuel. The Fuel EU regulation is a start, but will not bite until 2040 at the earliest. Some authors have proposed banning the use of fossil fuel in shipping by 2050 (Van Leeuwen and Monios, 2022), which would set a fixed deadline and reduce incentives for continued investments in fossil fuels and help to avoid lock-in. In addition, no credible forecast suggests that we will have sufficient green energy to produce the zero carbon or carbon neutral fuel for the current level of shipping.

It is not realistic to expect individual shipowners to invest in green ships if their competitors are free to continue using fossil fuels. Moreover, it is not simply a matter of identifying the best method of decarbonisation in an ideal scenario; our choices will be shaped by the urgent timeline and the scarcity of green electricity as the main feedstock for alternative fuels. Therefore, the following policy steps could be considered for the decarbonisation of shipping by 2050:

- **Efficiency improvements** such as engine and hull designs are already part of IMO policy, and industry will continue to adopt such measures in order to save fuel. This is an essential beginning, but these savings will be overtaken by growth of demand.
- **Slow steaming** is one of the best options we have, to easily and quickly reduce 10-30% of emissions. Therefore, despite its shortcomings, policy makers could achieve an easy win by mandating speed limits.
- It is time for the industry to get serious about **wind assistance** which is the only genuinely green propulsion option. It can save 20+% in existing large ships and we should also incentivise fully wind-powered smaller vessels. Policy makers need to mandate the use of wind assistance and do everything possible to expand its use to the entire fleet.
- **We cannot lock in fossil fuels** by lack of action that allows shipowners to keep using them and intend to keep doing so. Therefore, we should consider banning fossil fuels by 2050 to send a strong signal that there is no point avoiding renewables. Policy makers should implement an aggressive timetable to phase them out, which will reward early movers.
- **Technology neutral policies are attractive in the short term but will fail in the long term.** Ammonia is toxic and produces too much N_2O which is a powerful GHG, biofuels don't scale, drop-in e-fuels are inefficient and will be unaffordable due to scarce green electricity that is better used for producing hydrogen. While it is possible that the problems with ammonia may be solved in future, it is a highly risky strategy given that 2050 is only 25 years away. Therefore, while it has its drawbacks, hydrogen is the only serious alternative fuel. The existing Fuel EU policy is a promising start but it could be adapted to mandate hydrogen rather than the current version which is technology neutral.
- Hydrogen production will be limited due to a lack of green electricity supply and competition from other sectors, so we must recognise that hydrogen will be scarce and expensive. Therefore, we must **be prepared to ship a lot less**. It is time to accept the new reality of energy scarcity instead of talking about delaying decarbonisation to 2070.

It is clear that strong policy action is the only way to accelerate the decarbonisation of maritime transport as part of a net zero economy. This means some policy direction (e.g., mandating use of wind assistance plus focusing on hydrogen) as well as direct action by governments (massive scaling up of green electricity and hydrogen production). In either case, a reduction of international shipping is inevitable in a net zero economy. Are policy makers and industry ready to accept it?

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