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WORKING DOCUMENT

From:	General Secretariat of the Council
To:	Delegations
Subject:	Draft submission by Member States and the Commission to the International Maritime Organization's 15th Intersessional Working Group on Reduction of GHG Emissions from Ships on the levels of ambition in the Revised IMO Strategy on reduction of GHG emissions from ships • Presidency compromise

In view of the Shipping Working Party meeting on 11 May 2023, delegations will find attached a Presidency compromise proposal.

Changes compared to the previous document are indicated in **bold underline** (new text) and ~~strikethrough~~ (deleted text).

General scrutiny reservation: all delegations.

Deadline for transmission to IMO: **12 May 2023**.

ANNEX

INTERSESSIONAL MEETING OF THE WORKING GROUP ON REDUCTION OF GHG EMISSIONS FROM SHIPS
15th session
Agenda item ~~XX~~**2**

ISWG-GHG 15/~~xx~~**2**/xx
~~Document date, i.e. 1 January~~**12 May** 2023
ENGLISH ONLY

Pre-session public release: ☒

FURTHER CONSIDERATION ~~OF CONCRETE PROPOSALS ON THE REVISIONOF THE INITIAL STRATEGY, AND INITIATION OF THE DEVELOPMENT OF A~~ AND FINALIZATION OF THE DEVELOPMENT OF THE DRAFT REVISED IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS

Specification of the levels of ambition in the Revised IMO Strategy on reduction of GHG emissions from ships

Submitted by Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands (Kingdom of the), Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the European Commission

SUMMARY

Executive summary:	This document specifies elements to concur with the strengthening of the level of ambition in order to revise the Initial IMO Strategy on reduction of GHG emissions from ships and adopt the revised strategy by/at MEPC 80. It includes further developments based on a literature review of several published decarbonization studies, all of which contain scenarios leading to phasing out GHG emissions from international shipping by 2050 in line with a 1.5 °C aligned pathway.
Strategic direction, if applicable:	3
Output:	3.2
Action to be taken:	Paragraph 22
Related documents:	Resolution MEPC.304(72); MEPC 77/16 and MEPC 77/7/22, MEPC 78/7, MEPC 78/7/2, MEPC 78/7/6, MEPC 78/7/14, MEPC 78/7/18, MEPC 78/7/20, MEPC 78/7/24, MEPC 78/7/27, **MEPC 80/INF.10** and C127/4(a)ISWG-GHG 13/3/1, ISWG-GHG 14/2, ISWG GHG 14/WP.2

Background

1 In 2018, the Organization adopted the Initial IMO Strategy on reduction of greenhouse gas emissions from ships (the 'Initial IMO Strategy') (MEPC.304(72)). The Initial Strategy specified the initiation of its revision at MEPC 77, with the revision ("Revised Strategy") to be adopted at MEPC 80.

2 MEPC 77 initiated the review of the Initial IMO Strategy and recognized the need to strengthen the ambition of the Initial Strategy during its revision process. This was reaffirmed at MEPC 78.

3 MEPC 79 reaffirmed its commitment to adopt a revised IMO GHG Strategy in all its elements, including with a strengthened level of ambition by MEPC 80. It was agreed that further developments should be raised during ISWG-GHG 14 and 15 to finalize the draft Revised Strategy in that timeframe.

4 At ISWG GHG 14 WP2/rev.1 has been considered. It was concluded that this document would form the basis for further negotiations at the next session. The basis document consist of several proposals under section 3 on the levels of ambition which are still open for further consideration, such as the intermediate checkpoints for 2030 and 2040 and the final reduction target.

5 The submitters of this document have previously submitted documents ISWG-GHG 13/3/1 (Austria et al.) and ISWG GHG 14/2 (Austria et al.), which identified elements for consideration in the Revised strategy. In ISWG GHG 13/3/1 proposals were made for the ambition of the checkpoints for 2030 and 2040 in line with 1.5 °C temperature goal without specifying the exact reduction values for the 2030 and 2040 checkpoints.

6 This document specifies elements to concur with the strengthening of the level of ambition. It includes further developments based on a literature review by CE Delft of several published decarbonization studies, all of which contain scenarios leading to phasing out GHG emissions from international shipping on a GHG life cycle basis by 2050 with a 1.5 °C aligned pathway. The full report is annexed to this document.

Context and further rationale and feasibility

7 In the synthesis report of the International Panel for Climate Change (IPCC) published on 20 March 2023 it is mentioned that: "Urgent climate action can secure a liveable future for all: Emissions should be decreasing by now and will need to be cut by almost half by 2030, if warming is to be limited to 1.5°C." Furthermore, in the IPCC AR6, WG3, Technical summary it is written that "In some cases, notably with respect to aviation and shipping, sectoral agreements have adopted climate mitigation goals that fall far short of what would be required to achieve the long-term temperature goal of the Paris Agreement".

8 The availability of fuels with low and zero life cycle emissions will be a determining factor when aligning the IMO's climate mitigation goal with the temperature goal of the Paris Agreement. Therefore, at MEPC 79, the Secretariat was tasked to initiate a fuel/technology availability study with the aim to provide information for ISWG-GHG 15 on the readiness and availability of low- and zero-carbon ship technology and marine fuels towards 2050. **This study was carried out by Ricardo and DNV and a summary report**[1] **can be found in document MEPC 80/INF.10.** ~~During the presentation organized at ISWG-GHG 14, preliminary results were presented by the members of the consortium (Ricardo and DNV), which are tasked to execute the study.~~ According to ~~the presenters~~ **this study**, also targets with deep GHG reductions in 2030, 2040 and 2050 appear to be achievable. The ~~consortium~~ **study** also stated that:

- Achieving a more ambitious decarbonization pathway than ~~BAU~~ **business as usual** is not limited by commercial readiness of alternative fuels and technologies, nor infrastructure and shipyard readiness.
- Current forecasts of readiness ~~would accelerate if increased demand is agreed~~ **found that technology development isn't to be seen as a barrier for roll-out of fuels and technology**.
- A clear signal of demand is needed to enable sufficient supply of candidate fuels.
- A clear **policy** signal ~~of demand~~ **to transition the sector to a more ambitious decarbonization pathway is** needed very soon to enable meeting interim targets of the decarbonization scenarios.
- The higher cost of candidate fuels ~~than~~ **compared to** conventional fuels is not a barrier to deployment if the demand signal is clear.

9 As stated by many organizations representing industries during ISWG 14, there is a clear willingness and ambition of the industry recognizing the urgency to decarbonize shipping and strengthening the targets, including adding intermediate checkpoints. Industry members reiterate calls for clarity and unambiguous signals regarding the transition, to allow them to take informed investment decisions. The levels of ambition of the revised GHG Strategy will provide guidance as to the level of stringency required from the policy measures and send a signal to the industry regarding the rate of technology change and uptake rate of zero- and near-zero GHG fuels that they should set their business strategy for. As recalled by many organizations, including WSC, ICS, CSC, Euromot, the industry call for this clarity is acknowledged in several submissions and interventions.

10 These reports and positions mentioned in para 7 to 9, coming from researchers, experts and industry stakeholders, concur on and emphasize the importance to define and set intermediate checkpoints in order to stay on track for the 1.5 °C aligned pathway. In light of the above, the co-sponsors are of the opinion that this submission and its concrete proposals, is supportive of our discussions to strengthen the levels of ambition.

Literature review

11 Several maritime decarbonization scenario studies published over the last couple of years analyze how international shipping can decarbonize by 2050. These studies typically discuss which fuels have the potential of leading decarbonization, and several concentrate on the question of availability of low- and zero-GHG fuels.

12 To assist in the analysis of how to come to effective 1.5 °C aligned intermediate checkpoints, hereby attach a comparative analysis of maritime decarbonization scenario studies. The comparison focusses on the emission reductions modelled for 2030 and 2040.

[1] The full final report of the study is available at https://futurefuels.imo.org

13 This submission presents in annex 2 the literature review conducted by CE Delft of several published decarbonization studies, which contain scenarios leading to phasing out GHG emissions from international shipping by 2050 with a 1.5 °C aligned pathway and required GHG emission reductions by 2030 and 2040.

14 The emission reductions required for a 1.5 °C aligned pathway in 2030 relative to 2008 range from 0 to 57% in the various studies, with an arithmetic mean of 29%. For 2040, significantly higher reduction rates ranging from 54 to 100% are presented, with an arithmetic mean of 83%. Note that pathways with lower reductions in 2030 have higher reductions by 2040 and vice versa. All studies concur in concluding that significant emissions reductions must be achieved by 2030 in order for the sector to stay on a 1.5 °C aligned pathway, as otherwise emission reductions needed to occur between 2030 and 2040 would be unrealistically steep. This confirms the need to adopt and implement the mid-term policy measures as soon as possible, and in any case well before 2030.

15 All studies claim to present 1.5 °C aligned emission pathways. The projections are based on different assumptions: from the pace of the fleet transition to the availability of low- and zero-GHG fuels, as well as on the availability of capital, bunkering infrastructure, and policies. All but one decarbonization scenario project full decarbonization.

16 Several decarbonization scenario studies provide information on the share of renewable fuels or the types of fuel used by 2030. All pathways with remaining positive emissions in 2040 require an uptake of renewable fuels of at least 9% by 2030.

Proposed Levels of Ambition

17 As already reaffirmed at MEPC 78, the revised strategy should strengthen the level of ambition. In addition to that, the co-sponsors propose to establish intermediate checkpoints to measure progress towards the 2050 level of ambition and facilitate the timely adoption of corrective action on the measures as appropriate in case the reduction pathway in fact is not met. The co-sponsors advocate for levels of ambition, consistent with the Paris agreement temperature goal of 1.5 °C and take into account current projections on feasibility and uptake of low- and zero-GHG fuels and energy saving technologies in the sector. The levels of ambition should be expressed in terms of life cycle emissions of all significant greenhouse gases – including CO_2, methane, and nitrous oxide – in order to avoid displacing GHG emissions from shipping to other sectors, and to accurately reflect the full impact of the fuels on the climate. The GHG reduction from the value chain**, including final combustion/oxidation** of shipping fuels must be achieved without recurring to out of value chain offsets[2].

18 The co-sponsors propose to include ambitious checkpoints, namely that the GHG emissions should start declining in absolute terms as soon as possible to be reduced by at least 29% by 2030 and by at least 83% by 2040 compared to 2008. Intermediate checkpoints for 2030 and 2040 are essential to ensure that we are on the right track and to assess the effectiveness of measures. Furthermore, they will provide a clear direction to steer the shipping sector with the necessary speed further clarity to the shipping sector as to the speed at which it is expected to decarbonize.

[2] I.e. it must not be allowed to use credits of emission reductions from outside the value chain of fuels used by international shipping (which net zero emission reduction implies).

19 Furthermore, the co-sponsors propose to phase out life cycle GHG emissions from international shipping by 2050 at the latest. In other words, reduction of GHG emissions from the value chain of fuels for shipping should attain 100% at the latest in 2050[3].

20 The co-sponsors propose to use 3.1ter as proposed in annex 1 to this document, as it clarifies the exact meaning of the exclusion of out-of-sector offsetting, and how it should be understood in the context of the LCA guidelines being developed by the Organization and that the emission reduction is within the shipping energy system boundaries, avoiding shifting emissions to other sectors.

21 Finally, the co-sponsors propose to include a checkpoint to reach at least 10% of the energy used by the international fleet coming from fuels and/or energy sources with zero or near-zero emissions on a life cycle assessment (LCA) basis (well-to-wake analysis) by 2030. The objective of this checkpoint is to stimulate the uptake of new fuels by specifying a minimum amount of early adoption of new fuel that could constitute a tipping point, allowing subsequent rapid scaling and further use in the 2030's.

Action requested of the Working Group

22 The Group is invited to consider the information presented in paragraphs 11 to 16 and the proposals in paragraphs 17 to 21, as well as in annex 1 containing proposals for 3.1 ter, fuel indicator for 2030, checkpoints for 2030 and 2040 and the level of ambition for 2050 for further deliberation and discussion at this session.

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[3] This goal does not entail a complete ban on emissions. However, any emissions generated e.g. at the combustion phase would need to be 100% compensated by GHG *absorption* during other phases, and notably the production phase. For example,, it would be acceptable that a ship emits GHG from use of methanol provided that these emissions are counterbalanced in other parts of the value chain, such as during the production of the fuels.

Annex 1

ISWG-GHG 14/WP.1

3.1 ter The levels of ambition should represent the well-to-wake GHG emissions of marine fuels as addressed in the Guidelines on life cycle GHG intensity of marine fuels (LCA guidelines) developed by the Organization with the overall objective of reducing GHG emissions within the boundaries of the energy system of international shipping and preventing a shift of emissions to other sectors.

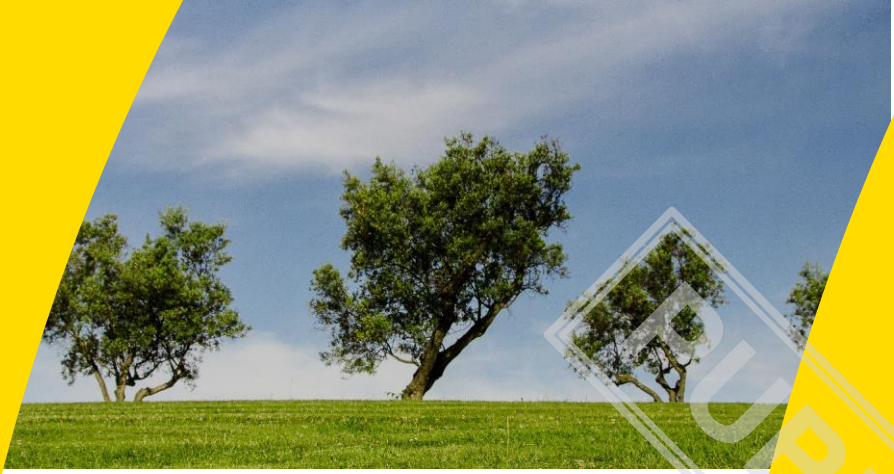
3.1qrt Levels of ambition directing the 2023 IMO GHG Strategy are as follows:

.**3** ***uptake of zero or near zero GHG emissions fuels*** **and/or energy sources**
To ensure that zero or near-zero GHG emissions fuels represent at least 10% of the energy used by international shipping by 2030;

.4 ***ensuring progress towards phasing out GHG emissions from international shipping through intermediate checkpoints***
To reduce the total annual GHG emissions from international shipping by at least 29% by 2030 and by at least 83% by 2040, compared to 2008;

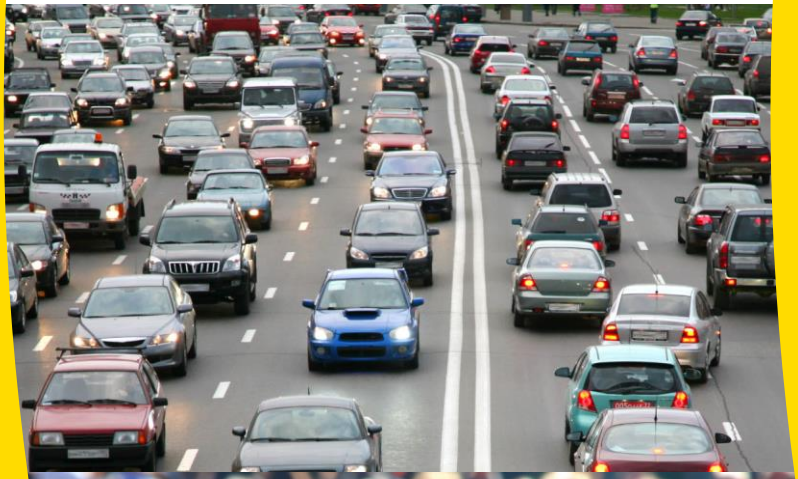
.5 ***GHG emissions from international shipping***
To peak GHG emissions from international shipping as soon as possible whilst phasing them out by 2050 at the latest on a pathway of GHG emission reductions consistent with the Paris Agreement temperature goals and the aim to limit global temperature rise to 1.5°C above pre-industrial levels.

Annex 2



Maritime decarbonisation scenarios

A comparative review



CE Delft
Committed to the Environment

Maritime decarbonisation scenarios

A comparative review

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Committed to the Environment

Through its independent research and consultancy work CE Delft is helping build a sustainable world. In the fields of energy, transport and resources our expertise is leading-edge. With our wealth of know-how on technologies, policies and economic issues we support government agencies, NGOs and industries in pursuit of structural change. For 40 years now, the skills and enthusiasm of CE Delft's staff have been devoted to achieving this mission.

1. Introduction

In 2018, the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) adopted the Initial IMO Strategy on reduction of GHG emissions from ships (IMO, 2018). This Initial Strategy is to be revised in 2023 and MEPC 80, scheduled for July 2023, should adopt a Revised Strategy.

Several Member States and Observer Organisations to the MEPC have submitted proposals on the revision of the Strategy. The Initial Strategy contains Levels of Ambition for 2030 and 2050 on the fleet carbon intensity and for 2050 on absolute GHG emissions of international shipping. Proposals have been made to include 'intermediate targets': Levels of Ambition for 2030 and 2040. Some delegations have proposed specific targets (e.g. a 50% reduction in GHG emissions by 2040, relative to 2008), while others have proposed to set intermediate targets, but have not made concrete proposals.

At the same time, a number of maritime decarbonisation scenario studies have been published which analyse how international shipping can decarbonise by 2050. These studies typically analyse which fuel transitions could result in decarbonisation, and several studies also analyse the availability of low- and zero-GHG fuels in more detail.

This paper presents a comparative analysis of maritime decarbonisation scenario studies. The comparison focusses on the emission reductions modelled for 2030 and 2040, as well as on the fuel mix which helps achieve those reductions. This overview can serve as an input for the consideration of intermediate targets.

2. Studies included in the analysis

This study has compared eight different decarbonisation scenarios for the shipping sector:

The 'Maritime Decarbonization Strategy 2022' by the Maersk McKinney Møller Center for Zero Carbon Shipping contains a 1.5 °C aligned emissions pathway and an overview of fuels which can enable such a pathway (Maersk McKinney Møller Center for Zero Carbon Shipping, 2022). A more detailed study with a different emission pathway (not 1.5 °C aligned) has been published in 2021 (Maersk McKinney Møller Center for Zero Carbon Shipping, 2021).

The Danish Technical University (DTU) coordinated a project called 'Electro fuels for long-range maritime transport' (in short: Mar-e fuel) which contains a series of scenarios for the decarbonisation of maritime transport by 2050 (Hendriksen et al., 2021). While not derived from an analysis of the budget available to keep the average global temperature increase to 1.5 °C above preindustrial levels, the pathway is a linear reduction from BAU 2025 levels to zero by 2050, with a 30% reduction by 2030 and a 65% reduction by 2040, both compared to 2008 levels.

UMAS, UCL and E4Tech developed 1.5 °C aligned pathways which the UK submitted to MEPC 79 (Smith, Galbraith, et al., 2022).

IRENA developed scenarios for the decarbonisation of the shipping sector (IRENA, 2021). Their 1.5 °C aligned scenario does not result in full decarbonisation by 2050 but a reduction by 80% relative to 2008 levels.

WWF, UMAS, UCL and the Smart Freight Centre have developed 1.5 °C aligned pathways which WWF submitted to MEPC 79 (Bonello et al., 2022).

UCL and Tyndall Centre for Climate Change Research have developed three linear emission reduction pathways which differ in the year in which emissions start to decrease: 2022, 2025 and 2030 (Smith, Baresic, et al., 2022).

Three researchers from the Tyndall Centre for Climate Change Research have developed three 1.5 °C aligned scenarios for shipping (Bullock et al., 2022). Similar to Smith, Baresic, et al., (2022), they have varied the date of implementation of emission reduction measures.

3. Required GHG emission reductions by 2030 and 2040

This section presents the GHG emission reductions by 2030, 2040 and 2050 from the different decarbonisation scenario studies. All studies claim to present 1.5 °C aligned emission pathways and the emission reductions presented in this section represent what is necessary for shipping to be aligned with such a pathway according to their authors.

Note that not all scenarios project a full decarbonisation of the shipping sector by 2050. The reason is that there are two different ways for alignment:

1. The total GHG budget to keep the temperature increase blow 1.5 °C above pre-industrial levels with a certain degree of certainty is derived from the IPCC Sixth Assessment reports or from the Special Report on 1.5 °C (IPCC, 2018). This budget is divided over sectors, for example on the basis of their share in current emissions. The thus derived carbon budget for the shipping sector is divided over time within certain constraints, such as full decarbonisation in a certain year or a specific shape of the curve. The size of the carbon budget depends on the share of the total budget assigned to shipping and the chance to keep the global temperature increase below 1.5 °C. Maersk McKinney Møller Center for Zero Carbon Shipping, (2022); Smith, Galbraith, et al., (2022); Bonello et al., (2022); Smith, Baresic, et al., (2022); and Bullock et al., (2022) follow this approach.
2. The mitigation pathways modelled by Integrated Assessment Models for the IPCC Sixth Assessment WGIII Report are used as a basis (IPCC, 2021). These pathways often fully decarbonise by 2050, but as they consider the entire economy, the emissions of some sectors are balanced by negative emissions in other sectors. In these pathways, the transport sector typically still has emissions in 2050. The size of the carbon budget for shipping in these pathways depends on the share of emissions of the transport sector allocated to shipping as well as the chance to keep the global temperature increase below 1.5 °C. IRENA, (2021) follows this approach.

Error! Reference source not found. presents an overview of the emission pathways in the decarbonisation scenario studies which have been reviewed.

Table 1 - 1.5 °C aligned GHG emission pathways for shipping in reviewed decarbonisation scenario studies

Study	2030 GHG emissions (reduction relative to 2008)	2040 GHG emissions (reduction relative to 2008)	2050 GHG emissions (reduction relative to 2008)
Maersk McKinney Møller Center for Zero Carbon Shipping, (2022)	365 Mt CO_2e 54%[4]	105 Mt CO_2e 87%	0 Mt CO_2e 100%
Maersk McKinney Møller Center for Zero Carbon Shipping, (2021)* all levers activated	580 Mt CO_2e 27%	290 Mt CO_2e 63%	58 Mt CO_2e 93%
Maersk McKinney Møller Center for Zero Carbon Shipping, (2021)* ammonia not safe as fuel	700 Mt CO_2e 12%	525 Mt CO_2e 34%	173 Mt CO_2e 78%
Hendriksen et al., (2021)*	555 Mt CO_2e 30%	280 Mt CO_2e 65%	0 Mt CO_2e 100%
Smith, Galbraith, et al., (2022), scenario A	595 Mt CO_2e 25%	87 Mt CO_2e 89%	0 Mt CO_2e 100%
Smith, Galbraith, et al., (2022), scenario B	390 Mt CO_2e 51%	160 Mt CO_2e 80%	0 Mt CO_2e 100%

[4] Maersk McKinney Møller Center for Zero Carbon Shipping, (2022) state that by 2030, a 45% reduction in GHG emissions is required relative to 2010 in order to be aligned with a 1.5 ºC pathway. Because 2010 emissions of international shipping were 84% of 2008 emissions (Smith et al., 2014), this is equivalent to a 54% reduction relative to 2008.

Study	2030 GHG emissions (reduction relative to 2008)	2040 GHG emissions (reduction relative to 2008)	2050 GHG emissions (reduction relative to 2008)
Smith, Galbraith, et al., (2022), scenario C	745 Mt CO_2e 6%	40 Mt CO_2e 95%	0 Mt CO_2e 100%
Bonello et al., (2022) linear scenario	340 Mt CO_2e 57%	200 Mt CO_2e 75%	0 Mt CO_2e 100%
Bonello et al., (2022) s-curve scenario	475 Mt CO_2e 40%	40 Mt CO_2e 95%	0 Mt CO_2e 100%
IRENA, (2021)	575 Mt CO_2e 27%[5]	365 Mt CO_2e 54%	150 Mt CO_2e 81%
Smith, Baresic, et al., (2022), start 2022	555 Mt CO_2e 29%	220 Mt CO_2e 72%	0 Mt CO_2e 100%
Smith, Baresic, et al., (2022), start 2025	590 Mt CO_2e 26%	140 Mt CO_2e 83%	0 Mt CO_2e 100%
Smith, Baresic, et al., (2022), start 2030	794 Mt CO_2e 0%	0 Mt CO_2e 100%	0 Mt CO_2e 100%
Bullock et al., (2022) immediate action	520 Mt CO_2e 34%	240 Mt CO_2e 70%	0 Mt CO_2e 100%
Bullock et al., (2022) medium delay	620 Mt CO_2e 22%	160 Mt CO_2e 80%	0 Mt CO_2e 100%
Bullock et al., (2022) long delay	750 Mt CO_2e 6%	40 Mt CO_2e 95%	0 Mt CO_2e 100%

Note: All emissions reductions have been expressed relative to 2008 emissions of international shipping, which amounted to 794.1 million tonnes CO_2e. All absolute emissions have been recalculated to apply to international shipping, and rounded to multiples of 5 million tonnes.

* Not 1.5 °C aligned.

As shown in **Error! Reference source not found.**, the emission reductions required for a 1.5 °C aligned pathway in 2030 relative to 2008 range from 0 to 57% in the various studies, with an arithmetic mean of 29% and a median value of 28%. In most cases, the lower values are found in scenarios in which emission reductions start just before or by 2030, and these scenarios have much higher reduction rates for 2040. The only exception is IRENA, (2021), which has a reduction of 27% by 2030, relative to 2008. As mentioned above, this study uses a different method to derive a 1.5 °C aligned pathway.

For 2040, **Error! Reference source not found.** shows significantly higher reduction rates ranging from 54 to 100%, with an arithmetic mean and median of 83%. The higher values are typically in pathways that project emissions to remain more or less constant until 2030 and start reducing emissions from that year.

By 2050, all but one decarbonisation scenario project full decarbonisation. The only exception is IRENA, (2021), which uses a different method to derive a 1.5 °C aligned pathway.

Based on this overview, it is clear that a delay of the implementation of decarbonisation measures to 2030 or beyond would be incompatible with any definition of a 1.5 °C aligned pathway, unless unrealistically steep emission reductions occur between 2030 and 2040. A smooth pathway would require that GHG emissions by 2030 are reduced by at least 25% relative to 2008, and by 55-95% by 2040.

4. Feasibility considerations in the decarbonisation studies

The feasibility of the decarbonisation pathways depends on the pace of the fleet transition, the availability of low- and zero-GHG fuels, as well as on the availability of capital, bunkering infrastructure, and policies.

[5] The emission reduction by 2030 in IRENA, (2021) are 22% relative to 2018. According to Faber et al., (2020), GHG emissions of international maritime shipping in 2018 amounted to 755 million tonnes CO_2e, which amounts to 95% of 2008 emissions.

Several of the studies analyse the fleet transition (Maersk McKinney Møller Center for Zero Carbon Shipping, 2022), Hendriksen et al., (2021), (Smith, Galbraith, et al., 2022), and (IRENA, 2021). All these studies assume a 25 to 30 year lifetime of ships. Although not explicit in every study, it appears that most assume that from the time that a technology is available to use low- or zero-GHG fuels, most (or all) new ships will be equipped with that technology.

Apart from the transition of new ships, various studies consider retrofitting technologies to existing ships to increase the pace of the fleet transition. The model used by Smith, Galbraith, et al., (2022) allows for retrofits and sometimes double retrofits of both energy efficiency technologies and of fuel technologies. In contrast, the model used by Maersk McKinney Møller Center for Zero Carbon Shipping, (2021) allows for retrofitting of energy efficiency technologies only. This may be one of the reasons why the emission reductions by 2030 as modelled by Smith, Galbraith, et al., (2022) are much higher than those in Maersk McKinney Møller Center for Zero Carbon Shipping, (2021) (the latter study is not 1.5 °C aligned).

The supply of low- and zero-GHG fuels for the shipping sector depends on the increase in the production of these fuels, the increase in production of inputs to their production processes (renewable electricity, renewable CO_2, fresh water, et cetera), as well as on competition with other sectors for these fuels and the production inputs. Several studies have assessed fuel availability, taking some or all of these factors into account.

IRENA, (2021) is the only surveyed study which uses a model that includes the global energy system and all other energy using and GHG emitting sectors.[6]

Bonello et al., (2022) focus on the shipping sector and assume that there are no physical constraints in the production of e-fuels. Consequently, the supply to the shipping sector depends entirely on the availability of capital, a timely start of the production, and the demand by the shipping sector, which in their model is driven by policies. Their conclusion is that all pathways are feasible if policies are sufficiently stringent.

Smith, Galbraith, et al., (2022) also focus on the shipping sector and compare the demand for low- and zero-GHG fuels from the shipping sector with the supply projection under the assumption that the production capacity of fuels would be ramped up with the highest pace historically recorded. They find that the supply of green ammonia may be able to keep up with increasing demand by the shipping sector, and that biofuel demand from the shipping sector constitutes just a few percent of global sustainable supply. They assume that shipping will have access to all produced ammonia if policies are sufficiently stringent. The study does not consider supply of inputs to the production of green ammonia, such as renewable electricity and fresh water, nor the competition with other sectors for those inputs.

Hendriksen et al., (2021) take demand from all sectors for both fuels and inputs in the production processes into account. Their pathways are not aligned with a 1.5 °C target, and they find that when there is much demand for biomass from other sectors than shipping, their pathway cannot be achieved for lack of low- and zero-GHG fuels.

In conclusion, the feasibility of the decarbonisation scenarios has been analysed in a number of different ways. The most comprehensive ones, i.e. that analyses that take demand from all sectors into account, either do not fully decarbonise by 2050, or are not on a 1.5 °C aligned pathway. Other studies conclude that the stringency of policies is the most important driver. In other words: if the shipping sector has the highest willingness to pay for low- and zero-GHG fuels, and if ammonia can be used as a ship fuel, and if ships retrofit their engines, shipping will be able to stay on a 1.5 °C decarbonisation pathway with full decarbonisation by 2050.

5. Fuel mix

Several decarbonisation scenario studies provide information on the share of renewable fuel used by 2030 or the types of fuel. These are summarised in **Error! Reference source not found.**. The shares range from 3 to 52%. The lowest share relates to a pathway that has a rapid and almost complete decarbonisation

[6] Or it constraints its shipping model with output on fuel availability from a model that encompasses the global energy and fuel system as well as manufacturing.

between 2030 and 2040. All pathways that are more gradual require an uptake of renewable fuels of at least 9% by 2030.

Some decarbonisation studies project that most renewable fuels by 2030 will be e-fuels (mainly e-ammonia) while others project a mix between e-fuels and biofuels.

Table 2 - Share of renewable fuels in the reviewed decarbonisation studies, 2030 (energy based)

	Share of renewable fuels	Types of renewable fuels	Share of blue fuels	Share of fossil fuels
Maersk McKinney Møller Center for Zero Carbon Shipping, (2022)	52%	Not specified	Not specified	48%
Hendriksen et al., (2021)	50%	Biomethanol, bio-diesel, biogas, e-methanol, e-ammonia	0%	50%
Smith, Galbraith, et al., (2022), scenario A	9%	Mainly ammonia Small fractions of biofuels and electricity	0%	91%
Smith, Galbraith, et al., (2022), scenario B	39%	Mainly ammonia Small fractions of biofuels and electricity	0%	61%
Smith, Galbraith, et al., (2022), scenario C	3%	Ammonia, biofuels and electricity	0%	97%
Bonello et al., (2022) both scenarios	20%	Biofuels and e-fuels	10%	70%
IRENA, (2021)	14%	Advanced biofuels and e-ammonia	0%	86%

6. Carbon intensity

Several decarbonisation scenario studies provide information in the development of the GHG intensity in 2030 and 2040. Careful interpretation is required because some studies report operational carbon intensity (e.g. EEOI) while others report supply-based carbon intensity (AER), and one study reports both. In the current policy framework, the
supply-based metric is more important because the CII is a supply-based metric.

As **Error! Reference source not found.** shows, CII improvements for a 1.5 °C aligned pathway vary from 27 to 60% by 2030, relative to 2008. Note that the 27% improvement corresponds to a pathway that sees a very rapid decarbonisation between 2030 and 2040. More gradual pathways require a CII improvement of at least 42% by 2030, relative to 2008.

Table 3 - Fleet GHG intensity pathways in reviewed decarbonisation scenario studies

Study	2030 GHG intensity reduction	2040 GHG intensity reduction
Smith, Galbraith, et al., (2022), scenario A	42%† 49%*	93%† 94%*
Smith, Galbraith, et al., (2022), scenario B	62%† 66%*	87%† 89%*
Smith, Galbraith, et al., (2022), scenario C	27%† 35%*	97%† 97%*
Bonello et al., (2022) linear scenario	74%*	83%*

Study	2030 GHG intensity reduction	2040 GHG intensity reduction
Bonello et al., (2022) s-curve scenario	65%*	89%*
IRENA, (2021)	53%*	75%
Smith, Baresic, et al., (2022), start 2022	60%†	96%†
Smith, Baresic, et al., (2022), start 2025	55%†	91%†
Smith, Baresic, et al., (2022), start 2030	41%†	100%†

Note: All GHG intensity reductions have been expressed relative to 2008 GHG intensity of international shipping.

* EEOI-based.

† AER-based.

References

Bonello, J.-M., Parker, S., Smith, T., Smith, D., Lewis, A. & Villasana, F. R., 2022. *Science-based Target Setting for the Maritime Transport Sector - Version 1.0,* s.l.: The Science Based Targets initiative.

Bullock, S., Mason, J. & Larkin, A., 2022. The urgent case for stronger climate targets for international shipping. *Climate Policy,* 22, 301-309.

Faber, J., Kleijn, A., Hanayama, S., Zhang, S., Pereda, P., Comer, B., Hauerhof, E., Loeff, W. S. v. d., Smith, T., Zhang, Y., et al., 2020. *Fourth IMO Greenhouse Gas Study,* London: IMO.

Hendriksen, P. V., Sørensen, T. A. & Münster, M., 2021. *MarE-Fuel: Sustainable Maritime Fuels: Executive Summary Report,* Kongens Lyngby: Technical University of Denmark.

IMO, 2018. *Initial IMO Strategy on Reduction of GHG Emissions from Ships (Resolution MEPC.304(72)), paragraph 3.1.3,* London: International Maritime Organization (IMO).

IPCC, 2018. *Global Warming of 1.5°C. : An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty,* Geneva: World Meteorological Organization.

IPCC, 2021. *Working Group III contribution to the Sixth Assessment Report : Technical Summary*: Intergovernmental Panel on Climate Change (IPCC).

IRENA, 2021. *A pathway to decarbonise the shipping sector by 2050,* Abu Dhabi: International Renewable Energy Agency (IRENA).

Maersk McKinney Møller Center for Zero Carbon Shipping, 2021. *Industry transition strategy,* Copenhagen: Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping.

Maersk McKinney Møller Center for Zero Carbon Shipping, 2022. *Maritime Decarbonization Strategy 2022: A decade of change,* Copenhagen: Maersk McKinney Møller Center for Zero Carbon Shipping.

Smith, T., Baresic, D., Dávila, A. S., Taylor, J., Bullock, S., Jones, C. & Larkin, A., 2022. *Maritime Review: A review of existing evidence on maritime emissions reduction pathways, in support of the UK government contributions to the revision of the IMO's Initial Strategy for GHG Reduction (MEPC 79/INF.30),* London: International Maritime Organization.

Smith, T., Galbraith, C., Perico, C. V., Taylor, J., Fuente, S. S. d. l., Thorne, C., O'Keeffe, E., Kapur, A., Howes, J., Roberts, L., et al., 2022. *International Maritime Decarbonisation Transitions - The costs and impacts of different pathways for international shipping to achieve alignment to the 1.5°C temperature goal - Main Report,* London: Department for Transport (DfT), UK.

Smith, T., Jalkanen, J., Anderson, B., Corbett, J., Faber, J., Hanayama, S., O'Keeffe, E., Parker, S., Johansson, L., Aldous, L., et al., 2014. *Third IMO GHG Study 2014: Executive Summary and Final Report,* London, IMO.