Exploring the relevance of ICAO's Sustainable Aviation Fuels framework for the IMO

Authors

Dr Nishatabbas Rehmatulla, UMAS
Dr Pedro Piris-Cabezas, EDF
Domagoj Baresic, UMAS
Marie Fricaudet, UMAS
Dr Carlo Raucci, UMAS
Marie Cabbia Hubatova, EDF
Aoife O'Leary, EDF
Natacha Stamatiou, EDF
Anna Stratton, EDF[1]

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Preface

This report has been written by a team of experts from UMAS and EDF. The report outlines how the IMO can use the work done by ICAO on Sustainable Aviation Fuels as a starting point to guide the development of its own rules on low and zero-emission fuels. It identifies areas where ICAO's approach to Sustainable Aviation Fuels might be relevant to the definition and development of low and zero-carbon fuels for shipping, and the degree of applicability. It also highlights the potential shortcomings in ICAO's methodology, ensuring that the IMO benefits from lessons learnt in the development of the ICAO rules to date.

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[1] In her capacity as a consultant to EDF.

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Contact person

If you require any further information on this report please contact:

Dr Nishatabbas Rehmatulla
UMAS
+44 203 108 5965
14 Upper Woburn Place
London
WC1H 0NN
n.rehmatulla@ucl.ac.uk

Aoife O'Leary
EDF
+447526092615
41 Eastcheap,
London,
EC3M 1DT
aoleary@edf.org

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List of abbreviations

ASTM: American Society for Testing and Materials
CAEP: Committee on Aviation Environmental Protection (ICAO)
CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation
CCS: Carbon Capture and Storage
DLUC: Direct Land Use Change
EEDI: Energy Efficiency Design Index
GHG: Greenhouse Gases
GWP: Global Warming Potential
ICAO: International Civil Aviation Organization
ILUC: Induced Land Use Change
IMO: International Maritime Organization
IPCC: Intergovernmental Panel on Climate Change
ISWG-GHG: Intersessional Working Group on the Reduction of Greenhouse Gas Emissions
LCA: Lifecycle Analysis
LNG: Liquefied Natural Gas
MARPOL: International Convention for the Prevention of Pollution from Ships
MEPC: Marine Environment Protection Committee
MJ: Megajoule
MRV: Monitoring Reporting and Verification
SAF: Sustainable Aviation Fuels
SARPs: Standard and Recommended Practices
SCS: Sustainability Certification Schemes
SEEMP: Ship Energy Efficiency Management Plan
SMR: Steam Methane Reforming
UNFCCC: United Nations Framework Convention on Climate Change

Executive summary

In 2018, the International Maritime Organization (IMO) adopted the Initial Strategy on the reduction of greenhouse gas (GHG) emissions from shipping. This aimed for a minimum reduction in the sector's emissions of 50% compared to 2008 levels by 2050. The Strategy also emphasised the importance of moving to zero emissions as soon as possible in a manner consistent with the Paris Agreement temperature goals.

A natural comparison for the maritime industry is aviation, a sector which accounts for approximately 5% of global anthropogenic GHG emissions and more than 2% of global carbon dioxide (CO_2) emissions.[2] The International Civil Aviation Organization (ICAO) established the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016, with the programme set to operate from 2021 to 2035. The overall aim of the programme is to cap net carbon emissions of international flights at the average of 2019-2020 levels.

Once CORSIA is in operation, airlines operating on covered routes will be able to meet their emission reduction obligations in two ways. One is to invest in emission reductions in other sectors (offsetting). The second is to reduce emissions directly within the sector, for instance through energy efficiency in design and operation or by burning approved Sustainable Aviation Fuels (SAF) that emit less carbon on a lifecycle basis than conventional jet fuels. If using SAF, airlines could still have to purchase offsets but the amount would be smaller, depending on the lifecycle reduction in emissions achieved by the particular SAF used.

As the IMO Initial Strategy strongly encourages the adoption of low and zero-emission fuels, the IMO will need to develop its own framework for evaluating the use of sustainable alternative fuels as a means to meet the GHG targets. While this process took ICAO a considerable period, as a 'second-mover' the IMO is well placed to build upon the existing work done by ICAO on SAF.

This report therefore outlines how the IMO can use that work as a starting point to guide the development of its own rules. It identifies areas where ICAO's approach to SAF might be relevant to the definition and development of low and zero carbon fuels for shipping, and the degree of applicability. It also highlights the potential shortcomings in ICAO's methodology, ensuring that the IMO benefits from lessons learnt in the development of the ICAO rules to date.

The shipping industry has many options available to decarbonise in-sector and should take advantage of those to create a framework which incentivises the uptake of high quality sustainable alternative fuels. This report finds that in the majority of areas examined, ICAO processes offer a sound blueprint for the IMO to follow. However, it also identifies specific instances where the IMO is advised to take a different approach, either reflecting lessons learnt in the development of the ICAO framework, or the innate differences between shipping and aviation. The key findings and recommendations can be summarised as follows:

1. *The IMO must follow the ICAO Sustainable Aviation Fuels framework in including GHG emissions beyond just CO_2*

The ICAO framework and guidelines for SAF require that all GHG emissions, except the non-CO_2 emissions from the aircraft tailpipe, are accounted for. The framework covers full lifecycle CO_2 emissions and other GHG emissions from upstream activities, including nitrous oxide (N_2O) and methane (CH_4), expressed in 100-year global warming potential (GWP_{100}) as carbon dioxide equivalent (CO_2e). Non-CO_2 emissions, which have adverse climate impacts, such as N_2O, water vapour, etc. from aircraft tailpipes were excluded due to uncertainty about their effects and the difficulty in measuring

[2] Lee, David S. et al. "Aviation and global climate change in the 21st century." Atmospheric Environment, vol. 43, 2009, pp. 3520–3537, http://elib.dlr.de/59761/1/lee.pdf.

them. The difficulties in measuring the non-CO2 impacts and effects of aviation do not arise in shipping, therefore all GHG emissions both upstream and on-board the ship must be included in shipping's framework.

By adopting a comprehensive approach, the ICAO framework avoids incentivising a switch to alternative fuels that may have lower CO_2 emissions than a conventional fuel but that overall have a larger climatic impact. The IMO should follow this example and consider emissions of all GHG, with particular attention paid to methane, a growing source of shipping emissions and a potent greenhouse gas[3].

2. *The IMO must follow the ICAO Sustainable Aviation Fuels framework in taking a full lifecycle perspective*

The approach taken by ICAO for SAF requires that direct and indirect emissions are estimated for the full lifecycle of a fuel, from the initial feedstock extraction/production to its final use/combustion in an engine. It protects against an outcome where fossil fuels are replaced by SAF with comparable or even higher lifecycle emissions.

Within the global framework for emissions reductions, both the IMO and ICAO are United Nations bodies responsible for regulating emissions from international sectors that are currently not covered by most countries' National Determined Contributions. The logic of this framework encourages a holistic perspective on emissions, and indeed the IMO's Initial Strategy states clearly that the objective is to contribute to global efforts in fighting climate change.

In order to achieve this, it is important that the IMO takes a whole system objective and looks beyond merely emissions on board. Adopting a lifecycle approach would avoid creating perverse incentives and would ensure the long-term environmental sustainability of marine fuels.

3. *The IMO must consider other time horizons, such as GWP_{20} as a metric for converting non-CO_2 emissions*

The IMO should not simply use GWP_{100} as the default time horizon for transferring emissions of different gases to a common scale but consider other time horizon possibilities to best reflect the climate impact of all gases. When estimating lifecycle emissions of a fuel, ICAO's SAF framework applies GWP_{100} as a metric for converting N_2O and CH_4, expressed as CO_2e. There is a degree of uncertainty over which GWP time horizon is most suited for this purpose, with some studies suggesting a 20-year GWP (GWP_{20}) would be most appropriate. This uncertainty is partly due to the varying impacts of different GHG over different time horizons, and partly due to the need to focus attention on immediate efforts to decarbonise. The choice of emission metric and time horizon depends on the type of application and policy context; hence, no single metric is optimal for all policy goals. Whilst GWP_{100} has been a metric to implement the multiple emissions species in the UNFCCC, the IPCC is clear that there is no scientific basis for selecting 100 years compared with other choices.

The choice of time horizon is particularly important in the shipping sector. The climate impact of fuels varies significantly across different horizons, for example in the case of LNG it more than doubles under GWP_{20} compared to GWP_{100}, due mainly to methane emissions, a powerful short-lived GHG. The IMO should consider the GWP_{20} criteria for eligibility thresholds for alternative fuels and for reporting non-CO_2 emissions, as the shorter timeframe better reflects the urgency of addressing climate change.

[3] This report does not discuss black carbon, as it is outside its scope, but it recognises that it is a significant contributor to shipping's climate impact.

4. *The IMO must follow the ICAO SAF framework that does not automatically allow all biofuels to claim zero CO_2 emissions and build upon the framework to develop guidelines for alternative fuels beyond biofuels*

ICAO has developed a robust framework with default lifecycle emission values for SAF pathways for 16 distinct feedstocks[4]. Each value accounts for the core lifecycle assessment as well as estimated emissions resulting from Induced Land Use Change (ILUC). This approach does not automatically allow all biofuels to claim zero CO_2 combustion emissions, as their lifecycle emissions can in some cases approach or even exceed those of petroleum fuels. ICAO expects new pathways to be developed in the future and outlines criteria for their evaluation[5]. Furthermore, under certain circumstances and feedstocks, ICAO allows innovators to prove actual lifecycle values of new feedstocks if a default value has not yet been developed for their fuel.

ICAO has not yet agreed on default values or methodologies for some types of fuels, such as electrofuels; in the near term, biofuels and fuels made from waste streams are the main potential lower-emission viable fuel option for the aviation sector. It is, however, likely that an appropriate methodology for these fuels would follow the approach used in calculating the indirect effects related to land use change from crop-based biofuels. As alternative shipping fuels are expected to rely heavily on power-to-liquid pathways, a methodology for calculating the indirect emissions of these fuels will need to be developed. All necessary steps should be taken in this process to ensure the data quality of the lifecycle inventories and the method developed to report any uncertainties.

The ICAO methodology assumes that waste, residue and by-product biomass feedstocks have no significant indirect emissions risk. However, the IMO should adopt best practice and so estimate the indirect emissions for each specific pathway.

5. *The IMO must adopt measures to prevent double counting of emission reduction claims*

Double counting occurs when emissions reductions are counted more than once toward a mitigation effort. In aviation, this may happen when aircraft operators report emissions reductions once under CORSIA and once at the national level, or when the host country also claims them for meeting its contribution under the Paris Agreement. CORSIA's eligibility criteria for emissions units require that offset credit programmes take steps to avoid double counting.[6] However, CORSIA's current monitoring, reporting and verification (MRV) framework for SAF claims in the airline's emissions report has two shortcomings that could potentially lead to the possibility of double counting: a time lag of up to three years between fuel purchase and CORSIA reporting, and the possibility that an aircraft operator may report SAF use to a different country than where the SAF was purchased. Both of these shortcomings mean that a country where the SAF originated may be unaware it was used for CORSIA purposes and inadvertently claim it as domestic use under its national inventory. The MRV requirements are meant to address these information gaps but absent further guidance, fuel producers, airlines and countries might not be equipped to avoid double counting.

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[4] ICAO, 2019. CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels. icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions.pdf

[5] ICAO, 2019. CORSIA Supporting Document, CORSIA Eligible Fuels – Life Cycle Assessment Methodology. Available at https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA%20Supporting%20Document_CORSIA%20Eligible%20Fuels_LCA%20Methodology.pdf

[6] ICAO, 2019. CORSIA Emissions Unit Eligibility Criteria. ICAO. Available at https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2009.pdf

When building its framework, the IMO should evaluate the risks for double counting and must put clear safeguards in place to ensure double counting is avoided.

6. *The IMO Member States must adopt procedures to ensure transparency of alternative fuel claims by operators*

ICAO CORSIA's registry does not record the name of the aircraft operators claiming the use of SAF, making it impossible in most cases to know who is claiming the use of SAF for compliance purposes and the associated quality. All claims are anonymised and aggregated in the CORSIA central registry.

For comparison, there is a higher level of transparency in the type of offsets used by airlines to meet their obligations than for emissions reductions from SAF use under CORSIA. In the case of offsets, information on each operator's aircraft and their cancelled CORSIA Eligible Emissions Units for a given compliance period will be publicly available on the registry website. This means that operators who decide to achieve their emission reduction partially through the use of SAF will be subject to a lower level of transparency compared to those who are purely investing in offsets. To ensure full transparency of alternative fuel claims by operators, the IMO should include or request the relevant body to hold a public registry where operators can cancel/retire emissions units from alternative fuels with transparency.

7. *The IMO must follow the ICAO SAF framework in establishing a minimum emission reduction threshold for the eligibility of sustainable fuels, and it should be higher than the one set by ICAO*

Sustainable aviation fuels in the CORSIA framework must meet eligibility criteria in order to be approved, including a 10% minimum reduction threshold in lifecycle GHG emissions compared to average petroleum jet fuel.

To meet the goal set by the IMO's Initial Strategy of at least halving GHG emissions from international shipping by 2050, the minimum reduction threshold for fuels should be considerably higher than 10%, perhaps 50% or even higher (to ensure the goals of the IMO Strategy can be met). This would help direct investment into fuels which offer significant emission reductions, rather than into fuels which offer only marginal emissions reductions.

Lifecycle analysis of GHG emissions associated with a fuel is not perfect; there are margins of error on every final estimate. By allowing for this degree of uncertainty and insisting on a greater minimum reduction, the IMO could ensure that only alternative fuels with significant estimated climate benefits become eligible. This would in turn ensure that real reductions in emissions would be made.

8. *The IMO must include a full range of sustainability criteria for all alternative fuels; if necessary, begin with GHG criteria, followed with the additional sustainability criteria drawn from ICAO*

CORSIA eligible SAF must comply with sustainability criteria. The ICAO framework started with two such criteria (minimum GHG emissions threshold, and carbon stocks),[7] and is currently considering additional ones (water, soil, air, conservation, waste and chemicals, human and labour rights, land use rights and land use, water use rights, local and social development, and food security).[8]

[7] ICAO, 2019. CORSIA Sustainability Criteria for CORSIA Eligible Fuels. Available at https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria.pdf

[8] See ICAO Doc. 10126, CAEP/11 Report (Montreal, 4-15 February 2019).

The IMO must include the full range of sustainability criteria but, if necessary, begin with GHG criteria to allow the industry to understand the types of fuels which will meet the GHG criteria, and to expand to the full range of sustainability criteria before the scheme is established.

In order to produce a framework that can be rapidly put into operation, the IMO should follow ICAO's lead in 'setting out' all relevant sustainability criteria. The full list of ICAO potential sustainability criteria, covering issues such as food security and water use (see Table 2), represents a robust and overarching set of principles. The IMO should draw on this when moving forward.

9. *The IMO must ensure that an appropriate governance structure, including the necessary working groups, is created to ensure proper accounting for lifecycle emissions of fuels on a transparent basis*

A robust sustainability framework needs to be supported by adequate governance structures. Rather than establishing its own full sustainability standard, ICAO relies on third-party standards to define the sustainability indicators used to demonstrate compliance with the sustainability principles and criteria adopted for CORSIA. The IMO could follow this procedure and also use a third party to do this work and potentially even use the same third parties as ICAO.

ICAO's Committee on Aviation Environmental Protection (CAEP), the equivalent of the IMO's Marine Environment Protection Committee (MEPC), oversees ICAO's work on alternative fuels. Within CAEP, the Fuels Task Group addresses technical issues related to aviation fuels, including the setting the default lifecycle emission values for SAF and improving CORSIA's shortcomings (e.g. preventing the risk of double counting and strengthening the sustainability criteria). The IMO would have to ensure that committees like this existed, had adequate capacity to operate fully and got the help of the right experts, which member states could potentially provide (taking into account geography and capacity).

1 Introduction

This report examines how the work done by the International Civil Aviation Organization (ICAO) on Sustainable Aviation Fuels (SAF) could be used in the development of a robust methodology for accounting for the use of low and zero-carbon fuels for the shipping sector by the International Maritime Organization (IMO).

It considers the relevant sections of ICAO's framework that can be built on to ensure an efficient and timely development of the IMO framework. The paper also highlights potential shortcomings in ICAO's methodology, including setting requirements for additional sustainability criteria, guidance for preventing double counting of SAF and enhancing transparency, to ensure that the IMO benefits from the lessons learnt during the development of the ICAO framework.

1.1 ICAO's CORSIA

In 2016, the 191 member states of ICAO adopted a resolution limiting net carbon dioxide (CO_2) emissions of international flights to the average of the years 2019-2020 for the period from 2021 to 2035.

The framework under which this is to be achieved is the Carbon Offsetting and Reduction Scheme for International Aviation, or CORSIA. Since January 1, 2019, all airlines flying on international routes have been required to monitor, report and verify their CO_2 emissions, and from 2021 onwards airlines operating on participating routes will need to comply with the emissions cap, equivalent to average emissions 2019-2020.

Compliance with this cap can be achieved by directly reducing their own emissions, by burning fuels with lower greenhouse gas (GHG) emissions on lifecycle basis than conventional jet fuel, or by investing in emission reductions in other sectors through offsetting. The framework includes a methodology to quantify the climate benefit that each aircraft operator achieves through the use of SAF, so the resulting emissions reductions can be used for CORSIA compliance purposes.

1.1.1 Development timeline of the ICAO SAF framework

The ICAO Committee on Aviation Environmental Protection (CAEP) began work on sustainable alternative fuels in 2013. CAEP is composed of 27 country members and 19 observers (8 countries and 11 organisations). CAEP assists the Council in formulating new policies and adopting new Standards and Recommended Practices (SARPs) related to a number of issues related to aviation's environmental impact.[9] In 2016 the ICAO Assembly adopted CORSIA, including a formal request to develop a methodology for accounting emissions reductions from the use of SAF under CORSIA[10].

These reductions could then be applied by the operator to comply with CORSIA, reducing offsetting requirements under the programme. CAEP has been working on this task since 2014 to complete and improve the full framework of documents and methodologies. In 2018, ICAO's Council approved Annex

[9] ICAO, Committee on Aviation Environmental Protection (CAEP). Available at https://www.icao.int/environmental-protection/Pages/Caep.aspx

[10] ICAO, 2019. CORSIA Supporting Document, CORSIA Eligible Fuels – Life Cycle Assessment Methodology.

16, Volume IV of the Chicago Convention on International Civil Aviation,[11] and in 2019 the ICAO documents on CORSIA-eligible fuels referenced therein.[12]

1.2 IMO Initial Strategy

Maritime transport forms the backbone of international trade and is responsible for around 80% of global trade by volume[13]. Emissions from shipping account for 2.8% of global GHG emissions, a figure equivalent to the emissions of Germany. On a ‘business as usual’ pathway, shipping emissions could increase by 50% to 250% by 2050[14].

For the shipping sector, the IMO serves a function similar to that of ICAO for aviation. The IMO is the UN specialised agency that holds the principal responsibility for the prevention of marine and air pollution by ships, amongst other issues. Under the auspices of the IMO, the main treaty for addressing maritime pollution is the International Convention for the Prevention of Pollution from Ships (the MARPOL Convention). It was originally adopted in 1997 and revised in 2008, with the principal aim of regulating sulphur and nitrogen oxides (SO_x and NO_x) emissions, shipboard incineration, and tankers’ emissions of volatile organic compounds, as well as prohibiting deliberate emissions of ozone depleting substances.

Since the adoption Annex VI of MARPOL, the IMO has been working to address the issue of GHG emissions from ships, examining technical, operational measures and market-based approaches. In 2011, the IMO adopted the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP), followed in 2016 with the adoption of a Data Collection System for the fuel oil consumption of ships. The discussion surrounding GHG emissions at the IMO resulted in the adoption of the 2018 Initial Strategy on GHG emission reduction from ships (also referred to as the ‘Strategy’ or the ‘Initial Strategy’ throughout the text).

The Initial Strategy set a target of at least a 50% reduction in international shipping’s emissions by 2050, relative to 2008 levels. Alongside this, it encouraged the pursuit of efforts to phase out emissions entirely as soon as possible in this century, in a manner consistent with the Paris Agreement temperature goals[15].

The outline in the previous section on the work done through ICAO on CORSIA for international aviation illustrates the importance of learning from what has been done before. By building on existing work, the IMO can streamline the process of adopting a methodology for accounting for emissions of low and zero-carbon marine fuels, in order to meet the goals of the Initial Strategy.

[11] ICAO, 2019. SARPs - Annex 16 Volume IV, Available at https://www.icao.int/environmental-protection/CORSIA/Pages/SARPs-Annex-16-Volume-IV.aspx
[12] ICAO, 2019. CORSIA Eligible Fuels, Available at https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx
[13] UNCTAD, 2018. Review of Maritime Transport, 2018.
[14] IMO, 2015. Third IMO Greenhouse Gas Study 2014
[15] IMO, 2018. Resolution MEPC.302(72), Initial IMO Strategy on reduction of GHG emissions from ships.

2 The ICAO framework and its relevance to the IMO

2.1 Scope of emissions coverage

2.1.1 Overview of lifecycle emissions accounting

The ICAO Framework estimates SAF emissions on a full lifecycle basis. This addresses most direct and indirect GHG emissions associated with the production, processing, transport, and use of the SAF, with the exception of non-CO_2 emissions from the aircraft engine.

By considering total lifecycle emissions, the CORSIA framework does not automatically allow all biofuels to claim zero CO_2 emissions[16] as some other frameworks wrongly do (such as the EU Emissions Trading System). By including indirect emissions, it ensures that SAF use does not inadvertently increase negative impacts such as deforestation that can negate all climate benefits of deploying biofuels.

2.1.2 GHG emissions coverage

The ICAO framework and guidelines for SAF require that all GHG emissions, except the non-CO_2 emissions from the aircraft tailpipe, are accounted for. Non-CO_2 emissions, which have adverse climate impacts, such as Nitrous Oxides (N_2O), water vapour, etc. from aircraft tailpipes were excluded due to uncertainty about their effects and the difficulty in measuring them.

The IMO Initial Strategy discusses 'GHG Emissions from ships', and as such can be considered to refer to all anthropogenic GHG emissions coming from ships rather than to CO_2 emissions alone. The 3rd IMO GHG Study shows that the share of non-CO_2 emissions from shipping, such as methane, has been increasing and the difficulties in measuring the non-CO2 impacts of aviation do not arise in shipping, emphasising the need to include all GHG emissions.

2.1.3 IPCC Guidelines for National GHG Inventories

Earlier policies followed the early Intergovernmental Panel on Climate Change (IPCC) Guidelines for National GHG Emissions Inventories[17], which recommend CO_2 emissions from the combustion of biofuel carbon to be reported separately as an information item but not counted towards national totals. This approach was adopted because, for inventory purposes, net CO_2 emissions from the combustion of carbon of biogenic origin[18] were reported in the Agriculture, Forestry, and Land Use sector. The IPCC has since issued specific guidance clarifying that their approach to inventories does not automatically consider biomass used for energy as "carbon neutral," and drawing attention to the lifecycle approach[19]. The debate around the IPCC guidelines applied originally to biofuel materials only. However, the

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[16] Searchinger et al.2009. Fixing a Critical Climate Accounting Error, Science, Vol. 326, Issue 5952, pp. 527-528, DOI: 10.1126/science.1178797,

[17] The Intergovernmental Panel on Climate Change (IPCC), 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories" Chapter 3: Mobile Combustion. Section 3.2.1.1: Choice of Method.

[18] Net emissions are zero if CO_2 combustion emissions are balanced in the Agriculture, Forestry and Land Use sectors by carbon uptake prior to harvest. If these emissions are not balanced by a carbon removal from the atmosphere, this net emission or removal should, according to 2006 IPCC guidelines be included in the emission and removal estimates for Agriculture, Forestry and Land Use sector through carbon stock change estimates.

[19] IPCC, 2019. Frequently Asked Questions (FAQs) at Q2-10, "According to the IPCC Guidelines CO_2 Emissions from the combustion of biomass are reported as zero in the Energy sector. Do the IPCC Guidelines consider biomass used for energy to be carbon neutral?" (2019), Q and A. Available at https://www.ipcc-nggip.iges.or.jp/faq/faq.html and reproduced in an annex to this paper.

rationale behind the need for emissions reductions to be estimated on a lifecycle basis also applies to fuels based on recycled carbon (from carbon capture) and electrofuels.

The IMO should adopt a similar approach to ICAO, avoiding the mistake made by some schemes that allow users to claim zero CO_2 combustion emissions for biofuels irrespective of lifecycle emissions. It is crucial that the new IMO framework addresses both direct and indirect lifecycle emissions of fuels. There are a number of marine fuels which seem sustainable when considered from the perspective of operational emissions, but which when considered on a lifecycle basis have limited (if any) benefits.

Biofuels such as bio-methanol, for instance, may cause ILUC, while non-carbon alternatives such as hydrogen and ammonia may be produced using fossil fuels without carbon capture and storage (CCS) resulting in lifecycle emissions similar or greater than those of conventional marine fuels. The IMO should follow the ICAO framework in learning from previous policy mistakes, and should incorporate direct and indirect emissions on a full lifecycle basis for alternative fuels.

2.1.4 ICAO lifecycle assessment methodology

ICAO's methodology[20] for assessing the lifecycle emissions of CORSIA eligible fuels breaks emissions down into two main components: core lifecycle value and ILUC. This methodology was developed for use with biofuels, but the overall approach is designed for adaptation to other fuel types as needed. Emission pathways for each SAF are defined based on the feedstock, the conversion process, and the country of production.

Core lifecycle values correspond to the full supply chain of SAF production and use, including processing and transportation. Some fuels, for example produced from waste, residue or by-product feedstocks, have typically low ILUC risk and their core lifecycle value is equivalent to their total lifecycle emissions. However, fuels made from a food or feed crop must add an ILUC to the core lifecycle value to calculate total direct and indirect emissions. This methodology applies a risk-based approach, which assumes food and feed crops are at a high risk of ILUC whereas waste, residue and by-product feedstocks are not.

2.1.5 Accounting for indirect emissions

Accounting for ILUC emissions is particularly important because the production of biofuels can result in the displacement of pasture and agricultural land, previously dedicated to production of food and feed crops. This displaced demand is mainly satisfied through land management practices that intensify production, reduced consumption of food and feed, or by bringing non-agricultural land into production elsewhere. If non-agricultural lands are converted to satisfy displaced demand, biofuel production incurs an ILUC. If the converted land has a high carbon stock, it can lead to significant land use change emissions that have the potential to negate all the emissions reductions achieved from the use of biofuels. In some cases this can result in substantially greater emissions from the biofuel than from a conventional fossil fuel it is intended to replace.

To estimate a fuel's ILUC emissions, two models were used - GTAP-BIO[21] and GLOBIOM[22]. These two models have different structures, land categories, data sets, parameters and emission factors that therefore lead to different results. To determine default ILUC emission standard values, when the difference between the two analyses falls within the tolerance level after harmonisation of the data

[20] ICAO, 2019. CORSIA Methodology for Calculating Actual Life Cycle Emissions Values
[21] Taheripour, F.; Hertel T.W.; Tyner W.E.; Beckman J.F.; Birur D.K. 2008. Biofuels and their By-Products: Global Economic and Environmental Implications. Paper Presented at the 11th GTAP Conference, June 12-14 2008, Helsinki, Finland and at the 2008 American Agricultural Economics Association meeting in Orlando, Florida.
[22] The International Institute for Applied Systems Analysis's Global Biosphere Management Model

and assumptions, the mid-point between the two results is taken as the default value. When this is not the case, the lower of the two model values plus an adjustment factor of 4.45 gCO2e/MJ is taken (which corresponds to half of the tolerance level). The approach of taking the lower ILUC value of the two models has been questioned because the lower value is the result of unduly optimistic estimation of ILUC values in one of the models[23].

Therefore, when estimating a fuel's ILUC emissions, the IMO should take the average of the two model values instead of taking the lower ILUC value. And, as recommended in section 2.6.1., the IMO should also consider adopting a higher minimum reduction threshold to ensure that pathways with significant ILUC risk are not eligible for crediting.

The ICAO methodology assumes that waste, residue and by-product feedstocks have no significant indirect emissions risk. However, the IMO should adopt best practice and so estimate the indirect emissions for each specific pathway.

Overall, the best practice is to exclude fuels with a significant ILUC risk, apply robust sustainability criteria and re-evaluate ILUC values regularly. This is due to the fact that ILUC emissions could change and periodical re-evaluation would allow adjustment based on up-to-date evidence.

2.1.6 Applying accounting rules to the IMO

The IMO Initial Strategy states that, "*robust lifecycle GHG/carbon intensity guidelines for all types of fuels*" should be developed in order to achieve the "*effective uptake of alternative low-carbon and zero-carbon fuels*".[23]

In the LCA approach to emissions accounting, the issue of how to account for upstream emissions is of great importance. Even when operational emissions are low, upstream emissions can significantly change the GHG footprint of a marine fuel. There are significant differences in the lifecycle emissions of fuels depending on the energy feedstock; for instance, the climate impact of hydrogen and ammonia produced from renewable electricity and that produced from natural gas without the use of CCS technologies[24] [25].

Neither the IMO Initial Strategy, nor any IMO regulation, explicitly mentions upstream or operational emissions. However, the Strategy does mention the Paris Agreement and UN Sustainable Development Goals, implying a desire to contribute to lowering global emissions. Without considering upstream emissions, the IMO's decarbonisation efforts would be seriously undermined.

Applying the ICAO approach to the shipping sector would require the IMO to define a set of pathways and corresponding standard values of lifecycle emissions for alternative fuels, which are relevant to reducing GHG emissions of shipping consistently with the Initial Strategy.

Overall, emissions for each ship could be obtained from monitoring fuel consumption and multiplying the fraction of alternative fuels consumed by the corresponding lifecycle emission factor of those fuels, if they are already included in the set of pathways. If not, it would be possible to add new pathways and calculate standard emission values. A pathway would need to be defined by:

- Feedstock/fuel type;
- Fuel processing method;

[23] IMO Initial Strategy, 2018. Available at https://tinyurl.com/yc56fkhl
[24] Gilbert, P.; Walsh, C.; Traut, M.; Kesieme, U.; Pazouki, K.; Murphy, A., 2018. Assessment of full life-cycle air emissions of alternative shipping fuels" Journal of Cleaner Production, Vol. 172, pp 855-866
[25] Lloyd's Register and UMAS, 2019. Zero-emission vessels: Transition Pathways

- Region of origin of the fuel and/or;
- Region of origin of the fuel processing in the case of electrofuels, as the lifecycle emissions are likely to depend on the electricity grid of the region where the electrofuels are produced.

If the new pathway does not result in indirect effects, a streamlined process can be adopted to allow for the adoption of actual values verified by the appropriate body. The following principle, highlighted in CORSIA, also holds for shipping fuels: if a pathway presents variation in lifecycle emissions above a certain threshold, then it needs to be divided into distinct pathways with different characteristics.

Recommendations:

The IMO must follow the ICAO Sustainable Aviation Fuels framework in including GHG emissions beyond just CO_2.

The IMO must follow the ICAO Sustainable Aviation Fuels framework in taking a full lifecycle perspective.

2.2 Emission species

2.2.1 Global warming timeframes

Comparing global warming potential (GWP) of CO_2 to other gases clearly shows that N_2O and methane (CH_4) emissions in particular are significant contributors to climate change alongside CO_2[26].

While the comparison is typically done using GWP_{100}, there is a degree of ambiguity around what time horizon is the most suitable for use. Some sources, such as the International Council on Clean Transportation, suggest that using a 20-year horizon (GWP_{20}) can "better reflect the urgency of reducing GHG"[27]. A submission by Friends of the Earth International *et al.* (MEPC 75/7/10)[28] to 75th meeting of IMO's Marine Environment Protection Committee (MEPC) supports this conclusion, reiterating the point that GWP_{20} better reflects the required urgency of emissions reductions. Other academic work has emphasised the benefit of using GWP_{100}, on the basis that it takes into account longer term impacts of GHG emissions and their climatic effects[29].

The choice of horizon matters because the GWP of a fuel can vary significantly across different measurement windows, depending on the lifetime of the gas emitted. LNG, for instance, is associated with methane emissions not only when burned but through leaks throughout its extraction and supply chain. As a result, its climate impact more than doubles when measured using a GWP_{20} (1 tonne of CH_4 is equivalent to 84 tonnes of CO_2) compared to GWP_{100} (1 tonne of CH_4 is equivalent to 28 tonnes of CO_2)[30].

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[26] Intergovernmental Panel on Climate Change, 2013. Climate Change 2013: The Physical Science Basis.
[27] Pavlenko, P.; Comer, B.; Zhou, Y.; Clark, N.; Rutherford, D., 2020. The climate implications of using LNG as a marine fuel, International Clean Council on Transportation Working Paper 2020-02.
[28] FOEI, Greenpeace International, WWF, Pacific Environment and CSC, 2020. "Proposal to include all greenhouse gases emitted from ships, including methane, in the EEDI" IMO, MEPC 75/7/10.
[29] Balcombe, P.; Speirs, J.,F.; Brandon, N.,P.; Hawkes, A.,D.; (2018). "Methane emissions: choosing the right climate metric and time horizon" Environmental Science: Processes & Impacts, Issue 10. See generally Ocko, I.; Hamburg, S.; Jacob, D.; Keith, D.; Keohane, N.; Oppenheimer, M.; Roy-Mayhew, J.; Schrag, D.; Pacala, S., 2017. Unmask temporal trade-offs in climate policy debates, Science, Vol. 356, Issue 6337, pp. 492-493, DOI: 10.1126/science.aaj2350.
[30] Ibid.

Emission Species	2007	2008	2009	2010	2011	2012
CO_2	884,900	920,900	855,100	771,400	849,500	795,700
CH_4	5,929	6,568	6,323	7,969	9,740	9,742
N_2O	12,152	12,689	11,860	10,615	11,437	10,931
TOTAL	**902,981**	**940,157**	**873,284**	**789,983**	**870,678**	**816,372**
CO_2	98.0%	98.0%	97.9%	97.6%	97.6%	97.5%
CH_4	0.7%	0.7%	0.7%	1.0%	1.1%	1.2%
N_2O	1.3%	1.3%	1.4%	1.3%	1.3%	1.3%
TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 1: GHG CO_2e emissions estimates from international shipping (1,000 tonnes)[31]

Methane emissions from international shipping have increased as a proportion of overall GHG emissions from the sector, nearly doubling over the period between 2007 to 2012, and the Third IMO GHG Study suggests that with the growing use of LNG they are likely to continue to grow their share[32]. While N_2O emissions have maintained a stable proportion of the sector's GHG emissions (~1.3%), they are expected to increase in absolute terms in parallel with CO_2 emissions.

The CORSIA methodology considers only the GWP_{100} horizon. Given the growing share of methane in shipping emissions caused by the increasing uptake of LNG, and the need to take urgent action to combat climate change, the IMO should consider other time horizons for equivalence, such as the GWP_{20}, so that fuels with a particularly negative shorter term climate impact cannot be considered sustainable marine fuels.

Recommendation:

The ICAO framework applies GWP_{100}. The IMO should also consider other time horizons, such as GWP_{20} as metric for converting non-CO_2 emissions as the shorter timeframe better reflects the urgency of addressing climate change.

2.3 Alternative fuels reporting to States

In order to claim SAF reductions under CORSIA, aircraft operators need to make a detailed report to the country in which they are registered and declare that they have not claimed the same reductions under any other GHG schemes. This report is third-party verified.

The claim has to be accompanied by the following documents: fuel purchases and transaction reports, fuel blending records, and sustainability credentials. Third-party verification is required to ensure that the aircraft operator is not claiming the SAF under another mandatory or voluntary scheme, and to guarantee the emissions reduction claims are materially fair, accurate, and consistent with the SARPs. In addition, eligible fuel producers and other economic operators[33] along the supply chain must be certified by an ICAO-approved Sustainability Certification Scheme (SCS). This complementary third-party certification ensures that SAF meet sustainability criteria, designations are correct and there is traceability along the whole supply chain.

[31] CO_2e estimates incorporate climate-carbon feedbacks, the figures here only include operational emissions calculated through 'bottom-up method', as described in the 3rd IMO GHG Study, the data and bottom-up method are available from: IMO, 2015.Third IMO GHG Study 2014

[32] Baresic, D.; Smith, T.; Raucci, C.; Rehmatulla, N.; Narula, N.; and Rojon, I.; 2018. LNG as a marine fuel in the EU: Market, bunkering infrastructure investments and risks in the context of GHG reductions, UMAS, London.

[33] According to *CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes (*Available at https://tinyurl.com/ycgyv3yx), economic operators include feedstock producers, processing facilities, and traders.

For alternative marine fuels, the IMO should develop its own standards and recommended practices. These would guarantee that any fuels produced on land such as hydrogen, ammonia or biofuels are not claimed via any other scheme, and that these reductions are claimed only for the maritime sector.

The IMO could adopt some of the existing eligible fuel standards from CORSIA in order to ensure transparency of reporting and verification of alternative marine fuels. It may even be desirable for ICAO and the IMO to examine the possibility of aligning their approved SCS in the future, which could help to ensure economic operators are subject to consistent standards of review.

Documentation for claims in the maritime sector could be based on the IMO's existing Bunker Delivery Notes and the Data Collection System, in combination with newly developed fuel sustainability credentials. This would operate on the same principles as the ICAO system, using fuel purchases and transaction reports to provide documentary proof of different claims. In addition, independent third-party auditing could be used to avoid double counting of emission reduction claims.

2.4 Preventing double counting

In general, the risk of double counting is related to the potential for emissions reductions to be counted more than once towards a climate change mitigation effort. Double counting could occur in the following ways as defined by ICAO: (1) if more than one unit is issued for the same emissions reduction, referred to as double issuance; (2) if the same unit is used twice, for example in two separate registries, referred to as double use; (3) if the same unit is used by both a buyer and seller, for example the international airline and country of origin of SAF, referred to as double claiming.[34]

The first two categories are addressed with the provisions noted above. However, with regards to double claiming, CORSIA's current MRV framework for SAF could potentially result in double claiming of emissions reductions from SAF towards CORSIA's target and a country's climate efforts. This is an issue ICAO is still examining with respect to the use of SAF in CORSIA, and is directly connected to Articles 4, 6 and 13 of the Paris Agreement. To guard against double counting of the reductions undergirding offset credits, ICAO requires each offset programme to obtain and publish a written attestation from the host country government that it will not count the reductions towards its own mitigation efforts[35].

The risk of double claiming arises from the fact that there is a time lag of up to three years between fuel uptake and CORSIA reporting, and the possibility that an aircraft operator may report SAF use to a different country than where the SAF was purchased. This means that a State where the SAF originated may be unaware it was used for CORSIA purposes and inadvertently claim it domestically. The MRV requirements applicable to SCS are meant to address these information gaps but absent further guidance, fuel producers, airlines and countries might not be fully equipped to avoid double claiming.

The IMO should make sure that reporting rules include safeguards to prevent double claiming of emissions reductions. Specifically, the IMO should not develop a reporting regime that is based around flag states, but rather one that should be administered directly and centrally by the IMO. In developing its rules, the IMO should build on the work done in ICAO and provide states with the necessary information to prevent double claiming.

Recommendation:

[34] ICAO, 2019. CORSIA Emissions Unit Eligibility Criteria.
[35] Ibid; and see ICAO CORSIA Application Form, Appendix A – Supplemental Information, at 3.78-3.713, available for download at https://www.icao.int/environmental-protection/CORSIA/Pages/TAB.aspx

The IMO must adopt measures to prevent double counting of emission reduction claims.

2.4.1 Transparency of alternative fuel claims by operators

Currently, CORSIA does not include a public registry capturing emission reduction claims from individual airlines with transparency. Instead, all claims are anonymised and aggregated in the CORSIA central registry.

For comparison, there is a higher level of transparency in the type of offsets used by airlines to meet their obligations than for emissions reductions from SAF use under CORSIA. In the case of offsets, information on each operator's aircraft and their cancelled CORSIA Eligible Emissions Units for a given compliance period will be publicly available on the registry website. This means that operators who decide to achieve their emission reduction partially through the use of SAF will be subject to a lower level of transparency compared to those who are purely investing in offsets. The IMO must ensure full transparency for all emissions reductions pathways it takes, including on the use of alternative fuels.

Recommendation:

The IMO Member States must adopt procedures to ensure transparency of alternative fuel claims by operators.

2.5 Alternative fuel types

The ICAO approach addresses all SAF, regardless of feedstock or origin, provided that the SAF meet the Sustainability Criteria. Generally, the key fuel types consist of:

1. fuels of biogenic origin (biofuels);
2. fuels derived from hybrid feedstocks with both fossil and biofuel fractions such as municipal solid waste-based fuels;
3. electrofuels (power-to-liquid); and
4. recycled-carbon-based fuels (e.g. off-gases of fossil origin from steelmaking).

ICAO has developed default lifecycle emission values for pathways of 16 distinct sustainable aviation biofuel feedstocks[36]. If a default value for a fuel has not yet been developed, under certain circumstances, ICAO allows innovators to prove its actual lifecycle values.[37]

Further work would be necessary for this methodology to be fully operational for electrofuels and recycled-carbon-based fuels. As a first step, ICAO has focused on existing production pathways, while keeping the door open for additional ones. Pathways conceptually similar to those already considered in the implementation elements of CORSIA SARPs for wastes, residues and by-products can claim the use of an actual lifecycle value, even if ICAO has not yet established a default value.

2.5.1 Biofuels

Under CORSIA, aircraft operators are requested to report all CO_2 emissions from fuel combustion regardless of the fuel[38]. Operators can claim emissions reductions from the use of eligible SAF that

[36] ICAO, 2019. CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels.
[37] ICAO, 2019. CORSIA Methodology for Calculating Actual Life Cycle Emissions Values.
[38] ICAO, 2018. First edition of ICAO CORSIA SARPs Annex 16, Volume IV, Part II, Chapter 2.

meet an agreed standard[39,40] and the actual reductions are assessed on a lifecycle basis and compared with emissions of conventional fuel as a baseline.

As a prerequisite for an aviation fuel being considered a sustainable aviation fuel, it has to meet American Society for Testing Materials (ASTM) certifications under outlined international standards[41]. ASTM has approved alternative fuels up to certain blend restrictions (e.g. 50%) and has now certified six pathways for jet fuel[42].

Within the maritime sector, in the case of biofuels, similar consideration should be given when deciding whether blending restrictions would potentially be necessary. Currently, there are blending restrictions for fatty acid methyl ester(s) (defined in ISO 8216), which are limited to 7%[43]. Marine distillates can also include hydrocarbons from synthetic or renewable sources, similar to the composition of petroleum distillate fuels (ISO/FDIS 8217:2017).

Similar considerations should be made when discussing the use of Hydrogenated Vegetable Oils, synthetic biofuels, and biomass to liquids, with some current academic research showing a wide range of potential blending proportions for different fuels[44].

2.5.2 Electrofuels

To ensure the environmental integrity of electrofuels on a lifecycle basis, electrofuels should only be produced from electricity sourced without generating significant indirect effects. The production of electrofuels is energy intensive. It is therefore necessary to ensure it doesn't cause displacement of renewable energy (both existing and planned) from domestic use, as it would have to be compensated for by the use of fossil fuels or other emitting sources in other sectors and consequently fail to deliver significant emissions reductions, if any.

Electrofuels have not received significant attention from ICAO because this pathway has not yet been certified by ASTM. Accordingly, ICAO has not yet adopted regulation on this matter. Hence, a method to calculate their default indirect effects values would need to be developed by the IMO. For every pathway, the resulting value would need to be added to the core lifecycle value of the fuel to determine eligibility and estimate the total carbon intensity and emissions reductions.

2.5.3 Alternative fuels for shipping

The IMO has not defined alternative fuels for shipping[45]. However, the existing literature provides a diverse range of examples, with many studies stressing the nature of each fuel option (e.g. energy sources used and production processes). Alternative fuels considered in the existing literature can be split in the following categories:

1. Biofuels: fuels derived from biomass or waste streams of biogenic origin.

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[39] ICAO, 2018. First edition of ICAO CORSIA SARPs Annex 16, Volume IV, Part II, Chapter 3.
[40] According to the CORSIA SARPs the scope of the mechanism is Paragraph 6 was extended to cover fossil fuels with lower carbon intensities and now applies to "CORSIA-eligible fuels" , namely (1) sustainable aviation fuels (SAF) and (2) "lower carbon aviation fuels", which are fossil fuels.
[41] ICAO, 2017. Sustainable Aviation Fuels Guide, Available at https://www.icao.int/environmental-protection/knowledge-sharing/Docs/Sustainable%20Aviation%20Fuels%20Guide_vf.pdf
[42] ASTM D7566-19b, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, ASTM International, West Conshohocken, PA, 2019
[43] ISO, 2017. International Standard ISO 8217, Available at https://www.sis.se/api/document/preview/921631/
[44] Paulauskiene, T., Bucas, M., Laukinaite, A. 2019. Alternative fuels for marine applications: Biomethanol-biodiesel-diesel blends, Fuel, Volume 248, 15 July 2019, p. 161-167
[45] IMO Initial Strategy mentions 'alternative low-carbon and zero-carbon fuels

2. Electrofuels: fuels created with the use of electricity. To ensure the low or zero-emissions nature of those fuels, many studies refer to them as the fuels produced from renewable electricity. They are essentially derived from hydrogen produced from electrolysis of water powered by renewable energy. Hydrogen can be used either directly or transformed to produce other fuels. There are currently three types of renewable electrofuels: hydrogen (either in gaseous or liquid form); ammonia; and synthetic hydrocarbons.
3. Fossil-fuel-based: fuels derived from fossil fuels, typically from natural gas. Many studies include LNG as an alternative fuel for shipping, however, its climate benefits are unclear[46]. Other fuels derived from natural gas are the fuels that use hydrogen produced from steam methane reforming (SMR) with CCS. Similarly to electrofuels, natural gas-based fuels are hydrogen (either in gaseous or liquid form), ammonia, and hydrocarbons.

The use of renewable energy for the production of electrofuels is generally assumed to ensure the low/zero-emissions nature of those fuels. However, there is an ongoing debate whether to allow the use of non-renewable energy in a transition period so that the development of electrolysis plants and greater uptake of the technology is incentivised. This approach is risky, as it may prevent the development of renewable plants in the long-term and it could lead to significant increases in emissions on a lifecycle basis compared to conventional fuels.

Synthetic hydrocarbons are fuels that use hydrogen (produced from electrolysis or SMR) and carbon. If CCS is an option, a methodology should be developed providing for additional sustainability criteria and to safeguard against reversals. When considering these fuels, the sourcing of the carbon element is of paramount importance. These fuels need to be carbon-neutral otherwise there is no environmental benefit. If the carbon element comes, for example, from an industrial source, and the processes for capturing the carbon are powered by surplus renewable electricity (see above), then upon combustion the carbon is released again into the atmosphere, negating the environmental benefit. Carbon-neutral fuels would be those that extract CO_2 from the atmosphere using Direct Air Capture powered by surplus renewable energy.

The use of batteries has also been explored. This appears to be relevant only for very small ships due to the constraint on space requirements, as well as the high costs incurred when a large amount of energy needs to be stored on-board[47].

	Low Carbon Alternative Marine Fuels			
Energy Source	**Methanol**	**Gas Oil[48]**	**Hydrogen**	**Ammonia**
Natural Gas with CCS	N/A	N/A	NG-H_2	NG-NH_3
Biomass	Bio-methanol	Bio-gas oil	N/A	N/A
Renewable Electricity	e-methanol	e-gas oil	e-H_2	e-NH_3

[46] Baresic, D.; Smith, T.; Raucci, C.; Rehmatulla, N.; Narula, N.; and Rojon, I.; 2018. LNG as a marine fuel in the EU: Market, bunkering infrastructure investments and risks in the context of GHG reductions, UMAS, London.
[47] Lloyd's Register and UMAS, 2019. Zero-emission vessels: Fuel production cost estimates and assumptions.
[48] Gas Oil refers to fuels which fall within the Marine Gas Oil (MGO) classification, that is fuels that are composed exclusively of distillate components. When referring to Zero GHG fuels, these are fuels that have the same chemical composition as standard MGOs, but are produced through low carbon pathways, in particular from gasification of biomass (i.e. bio-gas oil), or electrolysis in combination with carbon capture (i.e. e-gas oil). These production pathways are described in detail in: LR and UMAS, 2019. Zero-emission vessels: Fuel production cost estimates and assumptions.

Table 2: Main low carbon alternative marine fuels and associated energy feedstocks[49]

Decarbonisation of international shipping will depend on the development and deployment of alternative zero-emission fuels. These not only eliminate operational GHG emissions, but are sustainable with net zero emissions over their entire lifecycle. This in turn means it is necessary to decarbonise the whole production and land-based supply chain of these fuels. Table 2 shows some of the key potential alternative fuels for shipping, with associated energy feedstock. Each of the above fuels can be produced using several energy feedstocks. The main feedstocks are biomass, renewable electricity, and natural gas in combination with CCS (for net zero lifecycle emissions).

The development of infrastructure and production capacities for any of these fuels will require significant investment, especially on land[50]. The IMO should follow ICAO in creating a transparent and streamlined accounting process to ensure that the development of such production facilities and infrastructure does not lead to indirect emissions including ILUC, especially in the case of biomass (i.e. deforestation), through increases in renewable electricity (i.e. hydro, wind or solar plant land requirements), or by promoting an ongoing dependence on natural gas. All of these issues should be taken into account and the ICAO methodology can be used as a starting point to estimate both indirect and direct lifecycle emissions within the IMO. In addition, the IMO should also consider a wider range of issues related to fuels of non-biogenic origin such as hydrogen and ammonia. These might have additional and unique requirements compared to aviation, where most current methodologies have been developed by experience gained through biofuels.

As outlined above, upstream emissions from alternative fuels will greatly depend on their fuel production pathways, in particular those utilising SMR+CCS or relying on electricity. Regarding the former, the IMO should see what relevant steps are necessary to ascertain the efficacy of any CCS technology in viably removing carbon from the atmosphere in the long term. Carbon leakage is a potential risk associated with CCS technologies[51] and the IMO should explore options to take it into account within the LCA. In the case of pathways relying on electricity, LCA is necessary to guarantee that all electricity used for fuel production is GHG neutral (i.e. renewable) and does not cause upstream emissions or displace demand for electricity from other sectors. It is important that any potential competition for these resources with other sectors is identified early in order to be avoided.

Recommendation:

The IMO must follow the ICAO SAF framework that does not automatically allow all biofuels to claim zero CO_2 emissions and build upon the framework to develop guidelines for alternative fuels beyond biofuels.

2.6 Sustainability criteria

A robust set of sustainability criteria together with an operative framework to enforce it are needed to reduce unintended negative consequences of estimating lifecycle emissions reduction. A loose methodology could not only negate the emissions reduction claims but also result in a significant increase in GHG emissions. This increase could be, in some cases, several times greater than emissions of conventional fossil fuels the alternative fuels are meant to displace.

[49] Lloyd's Register and UMAS, 2019. Zero-emission vessels: Transition Pathways.
[50] Krantz et al., 2020. The scale of investment needed to decarbonise shipping.
[51] Deng,H., et al., 2017. Leakage risks of geologic CO_2 storage and the impacts on the global energy system and climate change mitigation, Climatic Change, Volume 144, Issue 2.

To be CORSIA-eligible, SAF must comply with sustainability criteria[52]. ICAO has already adopted two such criteria (minimum GHG emissions reduction threshold of 10% compared to conventional fuel and criteria to prevent land use change of land with high carbon stocks)[53], and is currently considering a number of potential additional criteria[54]. Table 2 provides an overview of the full list of sustainability criteria, recommended by the CAEP in 2017 but never adopted by the ICAO Council.

Theme	**Principle**	**Criteria**
1. Greenhouse Gases (GHG)	Principle: Sustainable alternative jet fuel should generate lower carbon emissions than conventional fuels on a lifecycle basis.	Criterion 1: Sustainable alternative jet fuel shall achieve net greenhouse gas emissions of at least 10% compared to fossil jet fuel on a lifecycle basis.
2. Carbon stock	Principle: Sustainable alternative jet fuel should not be made from biomass obtained from land with high carbon stock.	Criterion 1: Sustainable alternative jet fuel shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forests, wetlands, or peat lands and/or contributors to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.
		Criterion 2: In the event of land use conversion after 1 January 2008, as defined based on IPCC land categories, direct land use charge (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default ILUC value, the DLUC value shall replace the default ILUC value.
3. Water	Principle: Production of sustainable alternative jet fuel should maintain or enhance water quality and availability.	Criterion 1: Operational practices shall be implemented to maintain or enhance water quality.
		Criterion 2: Operational practices shall be implemented to use water efficiently and to avoid the depletion of surface or groundwater resources beyond replenishment capacities.
4. Soil	Principle: Production of sustainable alternative jet fuel should maintain or enhance soil health.	Criterion 1: Agricultural and forestry best management practices for feedstock production or residue collection shall be implemented to maintain or enhance soil health, such as physical, chemical and biological conditions.
5. Air	Principle: Production of sustainable alternative jet fuel should minimize negative effects on air quality.	Criterion 1: Air pollution emissions shall be limited.
6. Conservation	Principle: Production of sustainable alternative jet fuel should maintain or enhance biodiversity, conservation and ecosystem services.	Criterion 1: Sustainable alternative jet fuel shall not be made from biomass obtained from areas that are protected for their biodiversity, conservation value, or ecosystems services, unless evidence is provided that shows the activity does not interfere with the protection purposes.
		Criterion 2: Low invasive-risk feedstock shall be selected for cultivation and appropriate controls shall be adopted with the intention of preventing the uncontrolled spear of cultivated

[52] ICAO, 2019. CORSIA Sustainability Criteria for CORSIA Eligible Fuels
[53] Ibid.
[54] ICAO, 2019. ICAO Doc. 10126, CAEP/11 Report (Montreal, 4-15 February 2019).

		non-native species and modified microorganisms.
		Criterion 3: Operational practices shall be implemented to avoid adverse effects on areas that are protected for their biodiversity, conservation value, or ecosystem services.
7. Waste and Chemicals	Principle: Production of sustainable alternative jet fuel should promote responsible management of waste and use of chemicals.	Criterion 1: Operational practices shall be implemented to ensure that waste arising from production processes as well as chemicals used are stored, handled and disposed of responsibly.
		Criterion 2: Operational practices shall be implemented to limit or reduce pesticide use.
8. Human and labour rights	Principle: Production of sustainable alternative jet fuel should respect human and labour rights.	Criterion 1: Sustainable alternative jet fuel production shall respect human and labour rights.
9. Land use rights and land use	Principle: Production of sustainable alternative jet fuel should respect land rights and land use rights including indigenous and/or customary rights.	Criterion 1: Sustainable alternative jet fuel production shall respect existing land rights and land use rights including indigenous people's rights, both formal and informal.
10. Water use rights	Principle: Production of sustainable alternative jet fuel should respect prior formal or customary water use rights.	Criterion 1: Sustainable alternative jet fuel production shall respect the existing water use rights of local and indigenous communities.
11. Local and social development	Principle: Production of sustainable alternative jet fuel should contribute to social and economic development in regions of poverty.	Criterion 1: Sustainable alternative jet fuel production shall strive to, in regions of poverty, improve the socioeconomic conditions of the communities affected by the operations.
12. Food security	Principle: Production of sustainable alternative jet fuel should promote food security in food insecure regions.	Criterion 1: Sustainable alternative jet fuel production shall, in food insecure regions, strive to enhance the local food security of directly affected stakeholders.

Table 3: Sustainability Themes, Principles, Criteria and guidance recommended by CAEP[55]

2.6.1 Minimum emissions reduction threshold

One of ICAO's approved sustainability criteria for CORSIA Eligible Fuels is that SAF must meet a minimum emissions reduction threshold of 10%, as compared to the lifecycle emissions of conventional fuels[56]. The purpose of the minimum threshold is to safeguard against the uncertainty inherent in calculating SAF lifecycle emissions, so that if the reductions are initially overestimated, SAF are still likely to provide climate benefits compared to a conventional fuel.

The minimum reduction threshold for IMO alternative fuels should aim to be considerably more stringent than 10%. It could be 50% or even more, in order to direct investments to alternative fuels that offer more significant emissions reductions. This would not only drive the sector towards decarbonisation but would also send a strong signal to the industry in terms of their future investment decisions and selection of appropriate technology.

[55] During its 2017 Steering group Meeting. Published in "Committee on Aviation Environmental Protection Report of its Eleventh Meeting, Montreal, 4-15 February 2019 (approved by the Committee on Aviation Environmental Protection and published by decision of the Council)" (ICAO Doc 10126, CAEP/ 11 (2019)).

[56] ICAO, 2019. CORSIA Sustainability Criteria for CORSIA Eligible Fuels.

The IMO could also incorporate additional policy elements that go beyond the ICAO approach by ensuring that the minimum reduction threshold becomes more ambitious over time (i.e. in the form of a fuel standard, or other relevant measure) and gradually increases. However, any method developed should be in line with current SOx/NOx fuel standards and the decarbonisation target of at least 50% reduction in total GHG emissions by 2050 compared to 2008 levels.

Recommendation:

The IMO must follow the ICAO SAF framework in establishing a minimum emissions reduction threshold for the eligibility of sustainable fuels, and it should be higher than the one set by ICAO.

The IMO must include a full range of sustainability criteria for all alternative fuels.

2.7 Governance structures and methodology

2.7.1 ICAO's governance structure and methodology for SAF

A robust sustainability framework needs to be supported by adequate governance structures. Rather than establishing its own full sustainability standard, ICAO relies on third-party standards to define the sustainability indicators used to demonstrate compliance with the sustainability principles and criteria adopted for CORSIA. SCS set requirements for certification bodies, auditors and accreditation bodies, and monitor the effectiveness of its activities and those it is responsible for.

SCS need to meet strict requirements as defined by ICAO, related to documentation, auditing, monitoring and system review, transparency, annual reporting, risk management, stakeholder engagement and complaints. In turn, SCS require fuel producers and any other economic operator along the supply chain to demonstrate and document that it satisfies all CORSIA requirements including that the relevant fuel meets the CORSIA sustainability criteria specified for Eligible Fuels. The compliance of SCS is assessed by SCS Eligibility Group based on the eligibility requirements of CORSIA[57].

Under the CORSIA rules, aircraft operators can either use ICAO approved default lifecycle emissions values[58] or an actual lifecycle value if they can demonstrate it is lower than the default one. At the moment, only aircraft operators willing to use new pathways using waste, residues and by-products are entitled to use the methodology for an actual value, as described in the methodology specified by CORSIA, to the satisfaction of SCS. Reductions achieved through the use of other fuels (including electrofuels) cannot be claimed until a default value has been adopted by the ICAO Council.

For the purpose of estimating actual values, SCS require economic operators along the supply chain to document all relevant data in a Technical Report which is verified by an accredited certification body (certification bodies are hired by SCS to perform audits)[59]. The SCS record detailed information about the calculation of actual values within their system and provide this information to ICAO on request, in line with the CORSIA methodology. This record will be evaluated by CAEP to ensure claims are appropriate and to collect data to inform adoption of default values for new pathways, and refine existing ones.

[57] ICAO, 2019. CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes.
[58] ICAO, CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels. 2019.
[59] SCS require certification bodies to be accredited to ISO standard 17065 by an accreditation body operating in compliance with ISO 17011. SCS require that certification bodies are accredited in accordance with Table 1, Requirement 9." Page 8 in "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes"

New fuels can only be added to the default LCA values if certain criteria set out in the CORSIA methodology are met. These criteria include showing the process has been validated at a commercial scale, and that there is sufficient data on the conversion process, feedstock, and region of interest to perform ILUC modelling (where applicable). Further, the fuel must use a process certified by the ASTM. CAEP will then determine if the criteria have been met for adding a new pathway, carry out the calculation of default LCA values for the pathway, and add it to the Default Values Document.

Importantly, it is not only aircraft operators who can request CAEP to designate a new pathway. ICAO Member States and Observer Organizations can also make such requests.

2.7.2 How can this structure be adapted to the IMO?

Due to the nature of the goals set out in the Initial Strategy, it is important that the IMO streamlines the governance and development of procedures for LCA. The IMO has several relevant working groups that could take forward this work and have already been involved in discussions around GHG emissions from ships. Principally, these are the MEPC and the Intersessional Working Group on Reduction of GHG Emissions from Ships (ISWG-GHG). These groups will likely continue to play major role in guiding research and development with respect to LCA within the IMO.

To translate this process into the IMO, many of the same procedures and bodies developed by ICAO can be used. The ultimate authority in ICAO overseeing this process is the ICAO Council. In the IMO, the Assembly (composed of all IMO Member States) sets the strategic plan for the organisation[60]. The latest strategic plan for 2018-2023 includes responding to climate change and assigns “further development of mechanisms needed to achieve the limitation or reduction of CO_2 emissions from international shipping” to the MEPC.

The MEPC could be considered the IMO equivalent body to the ICAO CAEP, and for several years there have been intersessional greenhouse gas meetings (ISWG-GHG) which could, if put on a more formal footing, form a group advising the MEPC. Such a formal subgroup could then agree and make recommendations for the requirements regarding the IMO’s regulation of alternative fuels. There is an ongoing debate in the IMO about GHG working arrangements and the IMO must resolve this in favour of establishing groups with the appropriate capacity, expertise and authority to do the work as outlined in this report. As the IMO can lean on work already done in ICAO, it should be able to move more quickly than ICAO did, at least with regard to biofuels.

The IMO would need to make sure that the working group gets help of the right experts, which Member States could potentially provide (taking into account geography and capacity). The working group would be in charge of developing a methodology for quantifying the emission reduction benefits of sustainable alternative fuels, similar to the one developed by CAEP for CORSIA.

<u>Recommendation:</u>

The IMO needs to ensure that an appropriate governance structure, including the necessary working groups, is created to ensure proper accounting for lifecycle emissions of fuels on a transparent basis.

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[60] IMO, 2017. Resolution A.1110(30), Agenda item 7, Strategic plan for the organization for the six-year period 2018 to 2023, Available at http://www.imo.org/en/About/strategy/Documents/A%2030-RES.1110.pdf

3 Concluding summary

Aviation and shipping are significant contributors to the global climate crisis. In both industries, there is potential for the use of sustainable alternative fuels to significantly reduce and ultimately eliminate GHG emissions.

In order for this to occur, care must be taken that alternative fuels are truly sustainable on a lifecycle basis, as failure to account for upstream emissions could result in a net increase in global emissions. ICAO has been developing rules around the lifecycle of fuels for a number of years, and the IMO should examine these to identify best practice on a number of issues as set out in this paper.

ICAO's CORSIA framework and approach to sustainable aviation fuels contain specific elements which can be translated into the IMO. However, the elements of CORSIA SAF framework should be adapted with caution; this report has highlighted specific instances where the IMO could benefit from a different approach, whether it's due to the different nature of the two sectors or because of lessons learnt from ICAO's experience. Table 4 summarises the key similarities and differences between the ICAO framework and the current IMO policy and discussions.

	ICAO	**IMO**
Scope of emissions covered	Assessment of GHG emissions on a lifecycle basis, including upstream and indirect emissions such as induced land use change. Minimum threshold to qualify as a SAF is set at a 10% below jet fuel baseline.	Currently in early stages of a discussion on how to account for upstream emissions from fuels, and whether a LCA approach is necessary. Consideration should be given to new and accurate fuel baselines that would better reflect the technological options for the shipping sector that would direct investment in zero-carbon fuels.
Emission species	CO_2, CH_4 and N_2O from upstream activities, and only CO_2 from operational combustion emissions.	The IMO Initial Strategy refers to levels of ambition regarding 'GHG emissions' and as such, the starting point for any accounting methodology should be not just CO_2, but also other emission species, in particular N_2O and CH_4.
Transparent MRV of claims	To claim SAF reductions, the aircraft operator shall (1) report a set of detailed information to its State, and (2) declare that it has not claimed the same reductions under any other GHG schemes. Third-party verification required.	No approach yet developed. However, the IMO could use the existing Bunker Delivery Notes system in combination with newly developed fuel sustainability credentials similarly to the way ICAO uses fuel purchases and transaction reports to provide proof of different claims. There should also be a system enabling economic operators to report to states the claims to avoid double claiming.
Transparent MRV of production	SAF producers and other economic operators involved must be certified by an ICAO-approved Sustainability Certification Scheme.	The IMO discussed the issue of misreporting of upstream emissions in ISWG 6. Experience from ICAO should be taken into account as it has an advanced set of requirements for SCS.
Sustainability criteria	At present, two themes with their corresponding principles and criteria are included to ascertain eligibility of fuels – GHG emissions (10% reduction threshold compared to jet fuel	The IMO Initial Strategy 'Levels of Ambition' and vision give good starting point for discussions of how to define the decarbonisation reduction target/threshold for new fuels. The ICAO carbon stock sustainability

	baseline) and no-go areas for land with high carbon stocks. An additional set of ten themes are being considered by ICAO.	criteria can be applied to begin with, and the full set of themes from ICAO CAEP can be reused at IMO for further consideration.
Alternative fuels	ICAO has developed default lifecycle values for some biofuels pathways. The default values include core lifecycle emissions and induced land use change. The framework includes the possibility to define a new default value if the pathway has not been developed.	The IMO has not developed any clear guidelines for alternative marine fuels, but the IMO Initial Strategy, notes that "global introduction of (...) alternative fuels and/or energy sources" will be needed to decarbonise shipping. The IMO could readily apply developed default core and ILUC values for lifecycle emissions of some biofuels pathways.
Governance and methodology	The Sustainability Certification Schemes define requirements for sustainability certification and accreditation bodies. CORSIA Eligible Fuels producers and economic operators demonstrate and document that CORSIA-eligible fuels meet the CORSIA sustainability criteria.	The MEPC would likely undertake most of the LCA developments under the IMO. For several years there have been intersessional greenhouse gas meetings (ISWG-GHG) and technical working groups which could be tasked with the initial phases of the LCA analysis. In the long-term a separate body may need to be established to monitor and report on the use of alternative fuels. The IMO Data Collection System could be used to streamline the monitoring, reporting and verification.

Table 4: Summary of alternative fuel approaches between ICAO and IMO

The CORSIA SAF framework holds the potential to incentivise the production of truly climate-beneficial fuels. This is because the framework's lifecycle calculation methodologies are comprehensive, any fuel can be added, and because the framework avoids some of the problems that arose with earlier attempts to stimulate the development of alternative fuels. In particular, the IMO could benefit from mirroring the ICAO framework with regards to:

- Accounting for full lifecycle emissions, including both upstream and induced emissions, in order to ensure that any alternative marine fuel provides true environmental benefits.
- Including all emissions species, such as CH_4 and N_2O, in its accounting approach, to ensure that all GHG emissions are taken into account.
- Using the emission reduction threshold developed by ICAO (10%) as a starting point for a similar threshold for alternative marine fuels, but consider one with clearer environmental benefits such as 50%.
- First developing GHG and carbon stock criteria and then gradually moving to other sustainability criteria that have already been developed by ICAO, in order to maximise effectiveness and avoid delays.
- Including third party verification and certification to ensure transparency of emission reduction claims and environmental integrity.
- Addressing concerns surrounding double counting of emissions reduction claims.
- Aiming to develop "default values" for quantifying the carbon benefits of alternative marine fuels through a transparent process.

The transferability of the LCA framework developed by ICAO to the IMO depends on where the system boundary is drawn by the IMO, and consequently on what emissions and associated induced emissions will be counted as being in the remit of the shipping industry. It is important that any approach developed by the IMO does not provide incentives for the use of alternative fuels with high upstream emissions which have no net GHG benefits. It is worth noting that in many instances ICAO accounting was specifically designed with biofuels in mind; when considering power-to-liquid fuels of the sort likely to be used in shipping, specific methodological arrangements and accounting issues that might arise should also be taken into account.

On the question of which GWP time horizon should be used by the IMO, differences in emissions across the two industries mean that the ICAO decision to apply a GWP_{100} is not something that should simply be copied. The IMO should instead consider using GWP_{20} as metric for converting non-CO_2 emissions, as the shorter timeframe better reflects the urgency of addressing climate change.

Within the global framework for emissions reductions, both the IMO and ICAO are United Nations bodies responsible for regulating emissions from international sectors that are currently not covered by most countries' National Determined Contributions. The logic of this framework encourages a holistic perspective on emissions, and indeed the IMO's Initial Strategy states clearly that the objective is to contribute to global efforts in fighting climate change. Following ICAO in its development of the framework for SAF under CORSIA, the IMO should also take steps to develop a framework for the sustainable use of alternative fuels. Under these circumstances, it is important for the IMO to include all GHG emissions within its framework and to take a full lifecycle perspective on fuels.

This paper has set out the positives and negatives of the ICAO approach to building the CORSIA framework for sustainable aviation fuels, and some of the lessons that have been learned in this process. In doing so, it has highlighted current best practice that can serve as a basis for any system the IMO draws up, without which the IMO would have to develop rules from scratch. The CORSIA framework on sustainable aviation fuels provides a solid starting point. However, the shipping industry can do much more on this subject to reflect the level of ambition of the IMO Initial Strategy. It is our hope that this report will assist the IMO in taking on this work at pace.