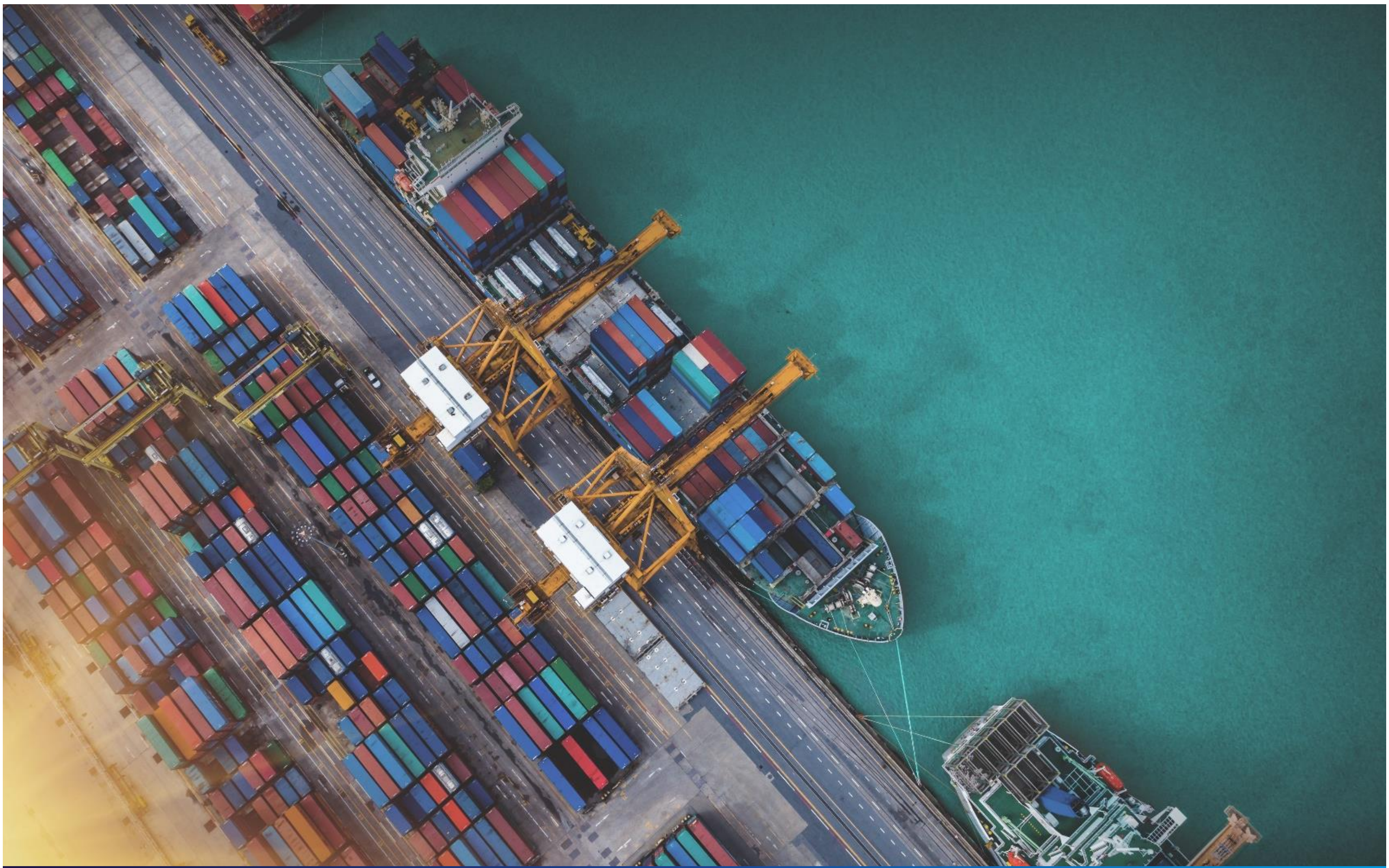

REVIEW OF EXISTING PRACTICES ON MARINE FUEL SUSTAINABILITY ASPECTS/ CERTIFICATION AND THIRD-PARTY VERIFICATION ISSUES

Final Report

Report for: International Maritime Organization (IMO)

Future Fuels and Technology Project

Ricardo ref. ED18601 Issue: 3 25/01/2024

Customer:
International Maritime Organization

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Ricardo reference:
ED18601

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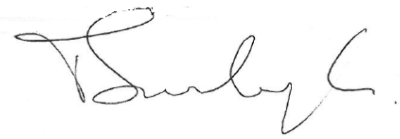

Date:
25th January 2024

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Disclaimer: The analysis and recommendations in this study are the sole responsibility of the authors of this study. The study presents exploratory work that is scientific and policy neutral. It does not prejudge any future policy developments at IMO and does not constitute IMO's views on the development of its Lifecycle Assessment (LCA) framework.

FOREWORD

In September 2022, IMO launched the ***"Future Fuels and Technology for Low- and Zero-Carbon Shipping Project (FFT Project)"*** to support regulatory decision-making held in the Marine Environment Protection Committee (MEPC) by providing technical analysis and easy access to the latest information. This project is funded by the Voyage Together Trust Fund of the Republic of Korea and implemented by the Secretariat.

Following the adoption of resolution MEPC.376(80) on *Guidelines on life cycle GHG intensity of marine fuels (LCA Guidelines),* MEPC 80 identified further inter-sessional work on the IMO life cycle GHG intensity assessment (LCA) framework.

As part of this further intersessional work, MEPC 80 requested the Secretariat to undertake a review of existing practices on sustainability aspects/certification and third-party verification issues so that the Committee can develop further relevant guidance for certification schemes/standards.

To that end, the FFT Project conducted this Study on the ***"Review of existing practices on sustainability aspects/certification and third-party verification issues".***

Draft findings of this review study were submitted to the Expert Workshop on the life cycle GHG intensity of marine fuels (GHG-EW 4, 14-15 December 2023), as document GHG-EW 4/2 (Secretariat), and presented during the Expert Workshop by Ricardo to support the Committee in developing further relevant guidance for certification schemes/standards (MEPC 80/17, paragraph 7.31).

As requested by GHG-EW 4, written comments/feedback from experts on the draft report (GHG-EW 4) were addressed in this final report and will be submitted to IMO ISWG-GHG 16.

What is the key message from the series of studies under the FFT Project?

Achieving a more ambitious decarbonization pathway than business as usual is feasible with a strengthened level of ambition. However, a clear signal of demand is needed to enable sufficient availability of candidate fuels, as concluded in the previous study (MEPC80/INF.10).[1]

In this context, the 2023 IMO GHG Strategy has defined a clear pathway to net-zero emissions, providing a clear signal to the maritime industry as well as energy producers which is expected to drive a considerable uptake of zero and near-zero marine fuels.

A robust framework must be in place to ensure the sustainability credentials of fuels across different feedstock/production pathways are properly assessed and certified, ultimately contributing to achieving net-zero well-to-wake GHG emissions.

For further information or to discuss the study, please contact: futurefuels@imo.org and matthew.moss@ricardo.com

The latest information on the uptake and supply of zero and near-zero marine fuels and technologies will be available on the FFT Project Website[2].

[1] https://wwwcdn.imo.org/localresources/en/MediaCentre/WhatsNew/Documents/MEPC80.INF10.pdf

[2] http://futurefules.imo.org

ONE-PAGE ABSTRACT / VISUAL SUMMARY

Sustainability themes/ aspects

In **Section 2** the environmental themes/aspects as presented in the IMO's LCA Guidelines are explored and compared with other sustainability frameworks. An assessment was conducted on how robust the methodologies are to account for different sustainability themes/aspects across a range of potential marine fuels. Methodologies to account for ILUC, as a theme/aspect, were evaluated to be the least robust, whereas on a fuel basis conventional biofuels contained the highest degree of uncertainty.

Regulatory frameworks/standards and certification schemes

Section 3 summarises ten existing regulatory frameworks/standards and certification schemes that can be applied to marine fuels. None of the explored regulatory frameworks/standards or certification schemes cover all marine fuels. Overall, voluntary regulatory frameworks/standards and certification schemes cover a broader range of sustainability themes/aspects with GHG emissions being the most covered theme/aspect.

Application of sustainability themes/aspects

The practical application of sustainability themes/aspects across the regulatory frameworks/standards was explored through five case studies in **Section 4**. The case studies cover a broad range of feedstocks for a variety of marine fuel production pathways. The robustness of how each theme/aspect is accounted for varies across different fuel production pathways and is largely dictated by the feedstock.

Gaps within existing schemes

Following analysis of existing regulatory frameworks/standards and certification schemes gaps and limitations of accounting for different sustainability themes/aspects were evaluated. Key findings were:

- Limited quantitative measurement or thresholds for soil quality, water use and air quality.
- Inconsistency in feedstock classification across schemes.
- Schemes cannot cover shortcomings in the certification process against legislation and standards.

ILUC considerations

To mobilise a risk-based approach to ILUC, definitions of high and low ILUC risk feedstocks need to be developed. This may involve defining a calculation for the expansion of high-carbon stock land and determining an acceptable upper limit of expansion.

To consider a quantitative approach to assessing ILUC, default ILUC values could be developed for specific fuel production pathways. This is likely to be an extensive undertaking and should be conducted transparently and collaboratively with relevant IMO stakeholders.

Further Considerations

The findings from this study highlight work conducted in other sectors to develop sustainability frameworks for zero and near-zero GHG fuels. Where possible, alignment to existing frameworks would prevent duplication of effort and ensure good practice is translated across to the maritime sector.

Short-term considerations could include:

- Further develop default values for specific fuel pathways with a named feedstock and end fuel product.
- Provide guidance on feedstock classification as high/low ILUC risk to reduce uptake of high ILUC fuels.
- Reconsider the development of a quantitative approach to address ILUC in parallel to the qualitative approach.
- Review wording on constraints around feedstock sourcing and fuel production on high-carbon stock land.

Mid-term considerations could include:

- How to correctly account for e-fuels, especially around the use of renewable energy and high water consumption.

EXECUTIVE SUMMARY

This study commissioned by the Secretariat of the International Maritime Organization (IMO) seeks to further understand existing practices, in and out of the maritime sector, that cover sustainability aspects, certification and third-party verification and their applicability to marine fuels. It aims to support regulatory decision-making discussions held in the Marine Environment Protection Committee (MEPC) by providing technical analysis and will inform further development of the IMO's LCA guidelines. It results from the request of MEPC 80 to the IMO Secretariat to undertake a review of existing practices on sustainability aspects/certification and third-party verification issues and to organise an expert workshop on the life cycle GHG intensity of marine fuels. The study is conducted as part of the Future Fuels and Technology Project.

How are sustainability themes/aspects covered by existing regulatory frameworks/standards and certification schemes?

Ten existing regulatory frameworks/standards and certification schemes were analysed for their coverage of the sustainability themes/aspects (Table E2). None of the regulatory frameworks/standards or certification schemes cover all marine fuels; however, there is partial coverage of some marine fuels by some of the schemes. In general, *voluntary* regulatory frameworks/standards and certification schemes address broader ranges of sustainability themes/aspects than mandatory regulatory frameworks.

The sustainability theme/aspect most well-accounted for and covered across the regulatory frameworks/standards and certification schemes assessed is GHG emissions. The methodology for calculating GHG emissions is well documented and defined: estimates can be made via default emission factors or via a calculation of actual values.

What is the uncertainty when accounting for sustainability themes/aspects across marine fuels?

Ricardo assessed how robust existing methodologies are for defining/quantifying the ten sustainability themes/aspects of the LCA Guidelines (resolution MEPC.376(80)) (Table E1). This identified areas of higher uncertainty which may be further explored within future updates to the IMO LCA guidelines.

Conventional biofuels pose the greatest level of uncertainty when calculating the impacts of different sustainability themes/aspects (Table E1). This is largely due to the Indirect Land Use Change (ILUC) impact which is more pronounced than for other fuels. The robustness of the calculation varies across different fuel production pathways which is largely dictated by the feedstock. Ambiguity in classifying some feedstocks leads to further uncertainty in accounting for sustainability themes/aspects. Methodologies to account for ILUC are the least robust due to significant variations in the approach among different schemes: methodologies ranged from qualitative descriptions, quantified calculations to risk-based approaches.

Table E1: Overall rating of uncertainty in accounting for sustainability themes/aspects for different fuel types

Sustainability themes/aspects	E-Fuels	Blue fuels	Conventional biofuels	Advanced biofuels	Electricity
GHG emissions	Low	Low	Low	Low	Low
Carbon Source	Low	Low	Low	Low	Low
Source of Electricity/Energy	Moderate	Moderate	Moderate	Moderate	Moderate
DLUC	Low	Low	Moderate	Moderate	Low
ILUC	Low	Low	High	Moderate	Low
Water	Moderate	Low	Low	Low	Low
Air	Low	Low	Moderate	Moderate	Low
Soil	Low	Low	Moderate	Moderate	Low
Waste and chemicals	Low	Low	Low	Low	Low
Conservation	Low	Low	Moderate	Low	Low

Table E2: Sustainability themes/aspects addressed in each scheme

	Regulatory Frameworks/Standards						Certification schemes		
	Mandatory			Voluntary					
Sustainability themes/aspects	**EU RED**	**California LCFS**	**RenovaBio**	**Bonsucro Production Standard**	**RSPS**	**CORSIA***	**RSB**	**ISCC**	**CertifHy**
GHG	✓	✓	✓	✓	✓	✓	✓	✓	✓
Carbon Source	✓	✓	✓			✓	✓	✓	
Source of Electricity/ Energy	✓	✓	✓				✓	✓	✓
DLUC	✓	✓(**)	✓(**)	✓	✓	✓	✓	✓	
ILUC	✓	✓		✓	✓	✓	✓	✓	
Water				✓	✓	✓	✓	✓	
Air		✓		✓		✓	✓	✓	
Soil	✓	✓		✓	✓	✓	✓	✓	
Waste and chemicals				✓		✓	✓	✓	
Conservation	✓		✓	✓	✓	✓	✓	✓	
Applicable to marine fuels	✓(***)		✓(***)		✓(***)		✓(***)	✓(***)	✓(***)

** CORSIA will become mandatory from 2027 onwards*
*** DLUC is considered within these schemes but not explicitly addressed*
**** Partial coverage: i.e. a selection of marine fuels are covered by this regulatory framework/standard/certification scheme*

Where are the potential areas for further development in the LCA guidelines?

The IMO LCA Guidelines are well aligned on *environmental* topics with other frameworks in the sustainability themes/aspects that are covered. Further work (beyond the scope of this study) could be undertaken to align *social* and *economic* themes/aspects. Further areas of development and a potential course of action is elaborated in Table E3.

Table E3: Summary of report findings with respect to the IMO LCA Guidelines

Category	Main Findings and Gaps	Recommendations
Sustainability Aspects	Default values are only provided for generic fuel pathways and not the full spectrum of pathways. This contrasts with existing regulatory frameworks/standards and certification schemes where a detailed carbon intensity calculation is required.	<u>Short term</u> Further provision of default values for specific fuel pathways, where a pathway refers to a named feedstock and conversion technology. This would bring the LCA Guidelines further in line with the other regulatory frameworks/standards and certification schemes
	Current definitions for high and low ILUC risk are high level especially compared to EU RED definitions.	<u>Short term</u> Develop more robust definitions on the categorisation of feedstocks as high or low ILUC risk. This is important to help limit the use of high ILUC risk fuels.
	Quantitative approaches for addressing ILUC are implemented in existing regulatory frameworks/standards (California LCFS and ICAO CORSIA).	<u>Short term</u> The IMO *could* reconsider adopting a quantitative approach to ILUC as a neutral approach. Noting this approach is *less robust* and that IMO have already progressed with a qualitative approach.
	Other mandatory regulatory frameworks/standards provide constraints around the sourcing of feedstock and production of fuel on high-carbon stock land and converted land. This is included in the IMO LCA Guidelines but the wording could be clearer.	<u>Short-mid term</u> Reviewing the wording around utilisation of high-carbon stock and converted high carbon stock land. This could reduce the risk of high-carbon land being used for feedstock cultivation and fuel production.
	Sustainability criteria for e-fuels are not fully developed.	<u>Mid-long term</u> The IMO could look to add more details around the sustainability criteria for e-fuels to the LCA guidelines. Especially on the criteria renewable electricity and water, due to the high demand from electrolysis.
Sustainability Certification	Existing schemes/standards such as EU RED and CORSIA have worked with certification bodies such as ISCC and RSB to develop accredited certification standards specific to their respective scheme/standard.	<u>Short-mid term</u> The IMO could consider early engagement with certification bodies to commence the further technical work required to develop sustainable marine fuel standards.
Third-party Verification	Third-party verification is an essential practice to maintain the integrity of the LCA guidelines with respect to issues that are not addressed directly by the guidelines such as feedstock fraud.	<u>Short-mid term</u> The IMO could look to develop a list of recognised third-party verification schemes.

CONTENTS

1 INTRODUCTION

1.1 BACKGROUND AND CONTEXT

The International Maritime Organization (IMO) agreed the 2023 IMO Strategy on Reduction of GHG Emissions from Ships at the 80th session of the Marine Environmental Protection Committee (MEPC 80) in July 2023. The 2023 GHG Strategy states that:

> *'the levels of ambition and indicative checkpoints should take into account the well-to-wake GHG emissions of marine fuels as addressed in the Guidelines on lifecycle 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*'.

The Guidelines on Lifecycle GHG intensity of marine fuels (LCA Guidelines) were also adopted at MEPC 80 as Resolution MEPC.376(80)[3]. The LCA guidelines allow for a Well-to-Wake (WtW) calculation, including Well-to-Tank (WtT) and Tank-to-Wake (TtW) emission factors, of total GHG emissions related to the production and use of marine fuels. The LCA Guidelines describe sustainability themes/aspects of the fuels with some suggestions for metrics or indicators to estimate the impacts of the sustainability themes/impacts.

The LCA Guidelines were developed as a standalone instrument and the 2023 GHG Strategy identifies that the development of the basket of candidate mid-term GHG reduction measures should take into account the well-to-wake GHG emissions of marine fuels as addressed in the 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.

The LCA Guidelines aim to account for the GHG emissions from the entire fuel life cycle, from the extraction or cultivation of feedstock, transport of the feedstock, the conversion of feedstock into a fuel product, the transportation of the fuel, bunkering (to this point: WtT), and its ultimate utilisation aboard a ship (as TtW). The calculations with the provided emission factors follow an attributional approach. This approach considers all the processes within the supply chain of fuel or energy carrier pathways, enabling the measurement of each segment's contribution to the overall GHG intensity of the final fuel or energy product employed on a ship.

However, the sustainability of fuels encompasses many other environmental considerations beyond GHG emissions, as noted in the Guidelines. These include air and water quality (used in the production and distribution of fuels), soil quality, land-use change and biodiversity implications (caused by feedstock cultivation), source of carbon and energy/electricity (used in the production of fuels) and larger societal concerns including the use of scarce resources and introducing further imbalance to the water, food energy nexus.

This topic of the wider sustainability considerations of marine fuels has been previously investigated. The 2021 study for the IMO Global Industry Alliance to Support Low Carbon Shipping (Low Carbon GIA), on '*Sustainability criteria and life cycle GHG emission assessment methods and standards for alternative marine fuels*'[4] identified the need to consider additional environmental sustainability criteria for several impact categories. The findings from this study were among the sources used to specify the sustainability considerations in this first version of the LCA Guidelines.

To advance the work on LCA issues, MEPC 80 invited the IMO Secretariat to undertake a review of existing practices on sustainability aspects/certification and third-party verification issues and to organise an expert workshop on the life cycle GHG intensity of marine fuels.

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[3] https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2014.pdf

[4] https://greenvoyage2050.imo.org/wp-content/uploads/2022/01/RicardoED_IMOAlternativeFuels_ReportFinal.pdf

1.2 AIMS AND OBJECTIVES OF THE STUDY

This study, "*Review of existing practices on marine fuel sustainability aspects/ certification and third-party verification issues*"[5] commissioned by the IMO Secretariat will support the IMO in helping the sector achieve the levels of ambition of the 2023 GHG Strategy through considering the wider sustainability impacts of the fuels anticipated to be needed for that transition. It is important that full scrutiny of the sustainability credentials of future marine fuels is known in order to inform decision-making on how to incentivise their uptake. To achieve this, it focuses on improving the understanding of the existing practices concerning sustainability themes/aspects, certification criteria, and issues related to third-party verification. Special attention is given to fuels with a higher degree of GHG-saving risk and uncertainty. This review may serve as a valuable reference point for the development of additional guidance on certification schemes and standards. The study's objectives align with the IMO's commitment to the 2030 Agenda for Sustainable Development and its associated Sustainable Development Goals.

This study has been implemented as a follow-up to the "*Study on the availability and readiness of low- and zero-carbon ship technology and fuels*" (MEPC 80/INF.10)[6]. It is also funded by and is an outcome part of the Future Fuels and Technology Project (the 'FFT Project'), which was launched by the IMO under the auspices of the Voyage Together Trust Fund of the Republic of Korea and implemented by the IMO Secretariat. The FFT Project aims to support regulatory decision-making discussion held in the MEPC by providing technical analysis and easy access to the latest information on alternative marine fuels and technologies.

The initial findings from this study were presented during an Expert Workshop on the Life Cycle GHG Intensity of Marine Fuels (GHG-EW 4) held in December 2023 as document IMO GHG-EW 4/2. Following feedback the study was revised and the final outcomes will be submitted to Intersessional Working Group of Reduction of GHG Emissions from Ships (ISWG-GHG 16).

The analysis and recommendations in this study are the sole responsibility of the authors of this study. The study presents exploratory work that is scientific and policy neutral. It does not prejudge any future policy developments at IMO and does not constitute IMO's views on the development of its Life Cycle Assessment (LCA) framework. The regulatory application of the LCA framework is yet to be defined by the Committee.

In particular, the choice of fuels and fuel production pathways studied does not constitute IMO's views on the eligibility of the considered fuels to comply with existing and upcoming regulations.

1.3 STRUCTURE OF THIS STUDY

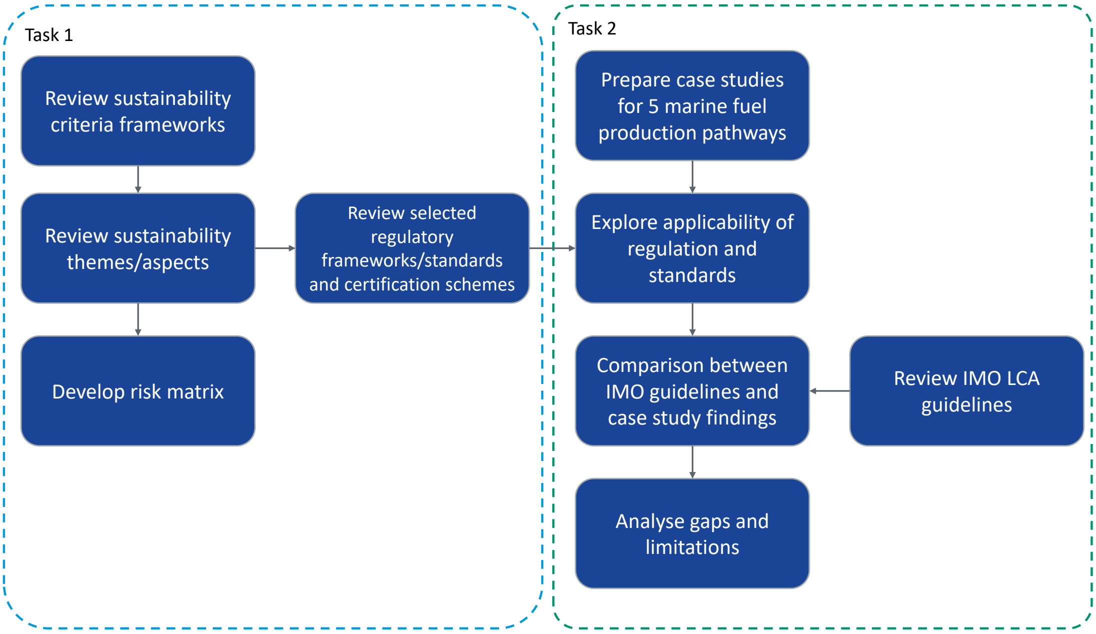
This is the full report of this study. It is a synthesis of the outcomes of the two tasks carried out in this study and follows the logic depicted in Figure 1-1. This report is set out as follows:

- The rest of this introduction sets out the scope of this study and definitions (Section 1.4)
- Section 2 introduces the sustainability themes/aspects. These are then compared against other sustainability criteria frameworks developed for marine fuels, and risks evaluated for the different sustainability themes/aspects for each of the main marine fuel types and production pathways. On this basis, high-risk criteria are identified for marine fuel certification schemes prioritisation.
- A review of existing regulatory frameworks/standards or certification schemes is presented in Section 3. This provides an overview of current frameworks and how they account for different sustainability themes/aspects.
- Section 4 directly follows on from Section 3 and explores a series of practical examples detailing how the sustainability themes/aspects are applied across the different regulatory frameworks within several marine fuel production pathways.
- To finalise this study, Section 5 provides a conclusion as well as providing a recommended course of action for the IMO to consider when updating the LCA guidelines.

[5] https://www.imo.org/en/OurWork/Environment/Pages/Future-Fuels-And-Technology.aspx

[6] https://wwwcdn.imo.org/localresources/en/MediaCentre/WhatsNew/Documents/MEPC80.INF10.pdf

Figure 1-1: Logic of study



1.4 SCOPE AND DEFINITIONS

The LCA Guidelines cover the full range of marine fuels and feedstocks used to produce these fuels. The scope of this study covers zero- and low GHG emission fuels defined on a WtW basis, including biofuels, methanol, ammonia, and hydrogen. These fuels are particularly relevant in the context of the IMO's efforts to address GHG emissions in the maritime sector. The scope and definitions are the same as used in MEPC 80/INF.10. Fuels are defined in Table 1.1. The authors note that standardised, internationally recognised definitions for fuel categories are needed but it falls beyond the scope of this study to define them.

Specifically, for biofuels, the study delves into the practical implementation of a risk-based approach for addressing Indirect Land Use Change (ILUC).[7] This approach aims to assess and mitigate the environmental impact of land use changes associated with biofuel production. It should be recalled that a risk-based approach to ILUC was originally selected by the IMO "*owing to the variability of assumptions underlying the evaluation of indirect effects, quantitative assessment of GHG effects of ILUC is subject to uncertainty, high quantitative variability and to the risk of arbitrary conclusions*".

Table 1.1: Fuel definitions used in this study

Term	Definition
Advanced biofuels	Second/third generation biofuels made from advanced biomass feedstocks (e.g. waste, algae) that do not compete with food/feed for land use.
Conventional biofuels	First generation (1G) biofuels made from conventional biomass feedstocks (e.g. food and feed crops). The use of this feedstock for fuels may compete with food/feed for land use.
E-fuels or RFNBOs	E-fuels or electrofuels are based on hydrogen produced by electrolysis primarily using renewable and nuclear electricity (e.g., e-H_2, e-NH_3, e-methane, e-methanol). These are sometimes referred to as renewable fuels of non-biological origin (RFNBO), green, or synthetic fuels. The carbon content of these fuels can be obtained from either biogenic or captured carbon sources.
Blue fuels	Fuels based on hydrogen made from fossil energy sources with carbon capture and storage (>90% capture rate) across the production process e.g. blue NH_3, blue H_2.
Electricity	From the grid, produced from a mix of fossil and renewable sources, and in the context of marine fuels delivered as shore power.

[7] ILUC refers to the unintended consequences of releasing more carbon dioxide emissions due to a change in the use of existing land

2 REVIEW OF SUSTAINABILITY CRITERIA FOR MARINE FUELS

Overview

This section describes the use of sustainability themes/aspects for marine fuels. Sustainability themes/aspects as listed in the IMO LCA guidelines are used as the main reference for this study. They are described and briefly compared against other sustainability frameworks developed recently for marine fuels. This comparison aims to provide insights into the boundaries and limitations of sustainability themes/aspects defined in the LCA guidelines. Finally, the robustness in methodology in accounting for the different sustainability themes/aspects for each group of marine fuel types and production pathways is assessed. On this basis, themes/aspects with the highest uncertainty are identified for marine fuel certification schemes prioritisation.

Key findings

- The environmental themes/aspects covered in the IMO LCA guidelines comprehensively cover those contained within other frameworks.
- From the literature assessed, Ashrafi et al, 2022 has constructed the most comprehensive framework to account for non-environmental sustainability themes/aspects.
- The methodology for accounting for ILUC is considered the weakest amongst the 10 sustainability themes/aspects because of significant variation in the methodology among different schemes.
- There is the greatest level of uncertainty surrounding conventional biofuels as a marine fuel when considering the sustainability themes/aspects, notably DLUC and ILUC.

2.1 SUSTAINABILITY THEMES/ASPECTS IN THE IMO LCA GUIDELINES

The LCA guidelines have outlined ten sustainability themes/aspects for fuel production that should be assessed to identify the sustainability of marine fuels. Each theme/aspect serves a principle/objective that aims to ensure the sustainability of the fuel and is accompanied by a metric or an indicator to assess the level at which this objective has been achieved. These theme/aspects criteria form a robust framework for evaluating and ensuring the sustainability of marine fuels and are summarised below:

- **Greenhouse Gases** (GHG): aims to mitigate emissions on a lifecycle basis compared to conventional fuels, measured in gCO_2e/MJ for GWP100 and GWP20. [8]
- **Carbon Source**: focuses on identifying whether the fuel's carbon content originates from fossil fuels, recycled carbon, or biogenic sources, emphasising avoidance of fossil energy and preventing double counting.
- **Source of Electricity/Energy:** underscores the necessity of renewable, nuclear, or biogenic sources during fuel production phases.
- **Direct Land Use Change** (DLUC): DLUC focuses on using biomass from low carbon stock lands and avoiding primary forests or protected areas.
- **Indirect Land Use Change** (ILUC): ILUC employs a risk-based approach, distinguishing between low[9] and high ILUC risks[10], aiming to grow feedstock without causing adverse land use alterations.
- **Water:** seeks to enhance water quality and availability during production.
- **Air:** mandates adherence to local, national, and regional air pollution regulations.
- **Soil:** ensures fuel production methods maintain and enhance soil health, incorporating indicators for best management practices and legal compliance.
- **Waste and Chemicals:** prioritises responsible management and measurement metrics for hazardous wastes and industrial chemicals per MJ of fuel produced.
- **Conservation:** aims to maintain or enhance biodiversity, ecosystems, and conservation services, incorporating indicators related to feedstock origin and invasive-risk levels.

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[8] GWP100 and GWP20 refer to the global warming potential over 100 and 20 years respectively.

[9] Low ILUC-risk fuel feedstocks are defined as those mitigating ILUC emissions and that do not come from food or feed crops

[10] High ILUC-risk fuel feedstocks are defined as those produced from food and feed crops and with significant expansion onto high carbon stock land

2.2 COMPARISON WITH OTHER SUSTAINABILITY CRITERIA FRAMEWORKS

As well as the IMO, academic studies and other industry reports have established sustainability criteria frameworks for fuel production both in and out of the maritime sector which this study will draw comparison to a selected few. In this context sustainability frameworks provide a high-level guide for integrating sustainability concepts across a sector and outline key metrics or performance indicators for achieving sustainability practices whereas regulatory frameworks, voluntary standards and certification schemes (as assessed later in this study) provide specific detailed and often enforceable measures to address sustainability issues.

In 2021, the Sustainable Shipping Initiative (SSI) outlined a framework of sustainability principles for the evaluation of zero and low-carbon marine fuels[11]. These principles, developed through a collaborative stakeholder consultation process, emphasise the need to assess the sustainability of marine fuels across their entire lifecycle while considering factors such as cost, availability, and technical feasibility. The primary objective of these principles was to serve as an informed foundation for defining sustainability criteria and engaging with standards and certification organisations to facilitate the creation of universally accepted standards and the development of certification schemes for marine fuels. In total the SSI framework covers 15 fuel-agnostic principles which are detailed in APPENDIX 1.

More recently, Ashrafi et al.[12] developed 18 sustainability themes/aspects, produced through desk research and multi-stakeholder engagement. These criteria also focus on the environmental, economic, and social aspects and have very similar points to the criteria developed in the LCA Guidelines and from the SSI. However, they offer a broader range of criteria, categorizing 18 elements into three different dimensions, economic, environmental and social. One of the main findings of this study is that most stakeholders approve and support the development of a global set of sustainability standards and certification schemes in the context of assessing alternative fuels. These are also detailed in APPENDIX 1.

Within the CORSIA framework, developed by the International Civil Aviation Organization (ICAO) to promote emission reduction in the aviation industry, exists 14 sustainability themes/aspects. 8 of these relate to environmental themes/aspects while a further 6 cover economic and social measures. These are also detailed in APPENDIX 1. Whilst not specific to the maritime sector CORSIA showcases how good practice could be adopted from other sectors to help further the development of marine fuel guidelines.

Based on the above, the stainability themes/aspects specified in the LCA guidelines were compared with other sustainability criteria evaluated by academic studies and industry reports, including social and economic themes/aspects. Table 2.1 provides the comparison of existing maritime sustainability criteria frameworks.

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[11] https://www.sustainableshipping.org/wp-content/uploads/2021/09/Defining-sustainability-criteria-for-marine-fuels.pdf

[12] Ashrafi et al (2022), *Toward and harmonization of sustainability criteria for alternative marine fuels* Available at: https://www.sciencedirect.com/science/article/pii/S2666822X2200003X

Table 2.1: Comparison of maritime related sustainability theme/aspect frameworks

Sustainability theme/aspect framework		IMO LCA Guidelines	SSI	Ashrafi et al	CORSIA
Environmental Criteria	Lifecycle GHG	✓	✓	✓	✓
	Carbon Source	✓	✓		✓
	Source of Electricity/Energy	✓	✓	✓	
	Land Use	✓	✓	✓	✓
	Water	✓	✓		✓
	Air	✓	✓	✓	✓
	Soil	✓			✓
	Waste and chemicals	✓			✓
	Conservation	✓	✓	✓	✓
Economic criteria	Economic well-being		✓		
	Capital expenditures			✓	
	Operational expenditures			✓	
	Fuel cost			✓	
	Opportunity cost			✓	
	Safety-related risk costs			✓	
	Possible regulatory penalty			✓	
Social criteria	Regulatory compliance			✓	
	Social acceptability			✓	
	Ethics and social responsibility		✓	✓	✓
	Public health impact			✓	
	Occupational health and safety		✓	✓	
	Socio-economic development			✓	✓
	Continuous Improvement		✓		
	Food security		✓		✓
	Geological impacts				✓

Having outlined a range of sustainability themes/aspects across a series of different frameworks and dimensions, the remainder of this study prioritises the ten environmental themes/aspects that the Correspondence Group on Marine Fuel Life Cycle GHG Analysis agreed to put more weight on. In that context, the social and economic themes/aspects have not been considered in the scope of this study.

2.3 ROBUSTNESS OF METHODOLOGIES IN ACCOUNTING FOR SUSTAINABILITY THEMES/ASPECTS

This identifies and evaluates uncertainties for the different sustainability criteria and each of the main marine fuel types, represented in an uncertainty matrix with high-level semi-qualitative indications of areas of high uncertainty. Although uncertainty can be quantified it goes beyond the scope of this study to provide a numerical value for the level of uncertainty within each sustainability theme/aspect. The indication combines an assessment of the robustness of the methodology used to define and/or calculate each of the ten sustainability criteria outlined in the LCA Guidelines, and then it is applied to the marine fuel types. The assessment draws on the literature assessment (Sections 2.1 and 2.2) in combination with expert judgement from Ricardo, in line with previous studies. Definition of zero or near-zero marine fuels/energy were also broadly categorised and in line with MEPC 80/INF.10; these are defined in Table 1.1.

Ricardo approached accounting for uncertainty across the different sustainability themes/aspects by first examining the general characteristics of each criterion and exploring where robust methodologies or calculation methods are in place, where variations exist and where known uncertainties are present. Table 2.2 evaluates the robustness of existing methodologies to calculate the effects of each sustainability theme/aspect. It should be emphasised that technological maturity does play a role in how well-defined the methodology is to account for certain fuel types. An example is provided in Section 4.2 – Case Study 5.

The ratings used to evaluate the robustness of the methodologies were:

Strong	The methodology in place is well-defined and standardised and has a clear calculation/approach to follow.
Moderate	The methodology is in place and defined but there exists some uncertainty on data inputs into the methodology leading to some uncertainty.
Weak	The methodology is not well-developed or established. There remains a high-level of variance in the methodology: there is no standardised approach

Table 2.2: Rating the robustness of the methodology for each sustainability theme/aspect (generalised across all fuel types)

Sustainability theme/aspect	Robustness of methodology	Rationale for the rating
GHG emissions	Strong	The quantification of GHG emissions from various fuels and processes is well-established and supported by comprehensive methodologies, emission factors, and scientific research. While there may be variations in emission factors based on specific sources or contexts, the overall understanding of GHG emissions is considered robust and reliable.
Carbon Source	Strong	Determining the carbon source of a fuel is a robust process. Usually, supply chain documentation and verification processes enable a high level of certainty when establishing the source of carbon content.
Source of Electricity/ Energy	Moderate	The methodology to assess the source of electricity used in various processes, such as hydrogen production or direct electricity usage, is generally reliable and consistent. Any uncertainty is introduced from the supply of data from energy suppliers which may vary across regions or between companies depending on the level of transparency available. The extent to which additionality is covered within different schemes is also variable.
DLUC	Moderate	Assessing direct land use change associated with fuel production is typically well-defined and supported by land-use change models and agricultural data. While there may be some variation based on region and specific practices, the overall understanding of direct land use change can be considered to have moderate robustness.
ILUC	Weak	Quantifying indirect land use change, especially in the context of biofuels, is challenging and characterised by high uncertainty. This is due to complex and indirect relationships between land-use changes, market dynamics, and biofuel production. Various models and assumptions are used, leading to considerable uncertainty in the assessment of indirect land use change impacts. As can be gleaned from the analysis in Section 2.3, ILUC assessments vary greatly between schemes from calculation methods to more qualitative approaches.
Water	Moderate	As with electricity sources, the methodology to assess water quality is reliable but the robustness may vary depending on data accuracy, local conditions and the quality of monitoring efforts.
Air	Strong	Air quality monitoring is built upon well-established principles resulting in a strong reliable metric.
Soil	Moderate	As with water, the robustness depends on the availability of soil data and varying methodologies to account for soil quality which may differ across different geographies.
Waste and chemicals	Moderate	The robustness may vary depending on the transparency of data reporting, the accuracy of hazardous waste measurements, and regional variations in waste management practices but the methodology is generally uniform.
Conservation	Moderate	Methodologies to account for conservation may vary across different jurisdictions. Efforts to standardise conservation assessment methodologies are ongoing. However, standards tend to focus on one aspect of conservation such as the protection of biodiversity, ecosystems, and natural habitats.

Table 2.2 shows that GHG, carbon source and air quality were identified as having the greatest level of robustness in their methodologies. GHG emissions perhaps have the most comprehensive methodology in place and impact can be calculated quantitatively using either default values or a calculation of actual values. Carbon source is accounted for through evidenced supply chain documents. Air quality monitoring is an established practice in many geographies and greater certainty around the data collection exists compared to some of the other sustainability themes/aspects. The quality and access to robust data across different geographies introduces the greatest uncertainty for many of the sustainability themes/aspects, particularly for the source of electricity/energy.

The robustness ratings from Table 2.2 were then applied to each of the different fuel types as defined in Table 1.1. Ricardo applied expert judgement per group to determine an overall rating of uncertainty per sustainability theme/aspect considering how well-defined the methodology of accounting for each fuel type is. The rationale for each rating can be found in Table 2.3 and is informed by expert judgement based upon Ricardo's past project for the IMO.[13]

Low uncertainty	There is low uncertainty when accounting for this fuel type as methodologies are in place and straightforward to follow.
Moderate uncertainty	The level of uncertainty is moderate as although the methodologies used to account for the sustainability themes/aspects are in place there may be some uncertainty around data.
High uncertainty	There is a high degree of uncertainty and variability when accounting for sustainability themes/aspects for this fuel type.

Table 2.3: Overall rating of uncertainty in accounting for sustainability themes/aspects for different fuel types

Sustainability themes/aspects	E-Fuels	Blue fuels	Conventional biofuels	Advanced biofuels	Electricity
GHG emissions	Low	Low	Low	Low	Low
Carbon Source	Low	Low	Low	Low	Low
Source of Electricity/Energy	Moderate	Moderate	Moderate	Moderate	Moderate
DLUC	Low	Low	Moderate	Moderate	Low
ILUC	Low	Low	High	Moderate	Low
Water	Moderate	Low	Low	Low	Low
Air	Low	Low	Moderate	Moderate	Low
Soil	Low	Low	Moderate	Moderate	Low
Waste and chemicals	Low	Low	Low	Low	Low
Conservation	Low	Low	Moderate	Low	Low

Examining specific fuel groupings, conventional biofuels are likely to lead to the most uncertainty when accounting for their sustainability credentials. This is driven by the uncertainty in accounting for the effects of ILUC due to the numerous methods used to assess its effects. Indirect land use change has greater variability across different schemes when it comes to assessing its impact. This, compiled with the feedstocks that traditionally go into conventional biofuels, leads to further uncertainty as these feedstocks have often been associated with deforestation and shifting crops away from food production towards energy use. As ILUC, GHG emissions and carbon source are intrinsically linked, any uncertainty in ILUC effects is passed into the

[13] https://greenvoyage2050.imo.org/wp-content/uploads/2022/01/RicardoED_IMOAlternativeFuels_ReportFinal.pdf

GHG calculation methodology also decreasing its reliability (not shown in Table 2.3 as sustainability themes/aspects are assessed independently).

E-fuels and direct electricity exhibit the lowest level of uncertainty. This is due to there being fewer sustainability themes/aspects to consider for these fuel types as the number of inputs/feedstocks to the process is less. Although ILUC and DLUC are applicable to e-fuels (via land required for renewable energy production) the impact was judged to be small compared to other fuel types.

Across all fuel types the source of electricity/energy is rated as moderate as during the production of all fuels electricity and energy is required, the transparency of the source of this varies across different geographies.

3 REVIEW OF EXISTING SUSTAINABILITY PRACTICES WITHIN REGULATORY FRAMEWORKS / STANDARDS OR CERTIFICATION SCHEMES

Overview

This section reviews and examines existing regulatory frameworks/standards or certification schemes that can be applied to zero or low GHG emission fuels, drawing notably on existing practices of other sectors.

Key findings

- Of the regulatory frameworks/standards or certification schemes assessed, none are currently applicable to the full range of marine fuels.
- Voluntary standards and certification schemes address a broader range of sustainability themes/ aspects than the regulatory frameworks explored.
- GHG emission is the most well-accounted for sustainability theme/aspect and is covered across the entire range of schemes assessed.
- Water is the least well-accounted for sustainability theme/aspect as, although it is mentioned in most schemes, the expected increase in water consumption to produce e-fuels is not considered.

This section summarises an assessment of a shortlist[14] of regulatory frameworks/standards or certification schemes.[15] Within the summary a rationale for selection is included which justifies why in the context of this study the chosen scheme was explored. The assessment, based on reviewed literature and compares the depth, comprehensiveness, and robustness with which uncertainty is dealt with. The summary of assessment covers mandatory regulatory frameworks/standards in Section 3.1, voluntary regulatory frameworks/standards in Section 3.2, and certification schemes in Section 3.3. Section 3.4 summarises how the sustainability themes/aspects are covered in the schemes. The shortlisted schemes that have been assessed are in Table 3.1.

Table 3.1: Regulatory frameworks/standards (mandatory and voluntary) and certification schemes assessed in this study

Type		#	Name	Geography	Fuels covered	Sector(s) covered
Regulatory frameworks/ Standards	Mandatory	1	Renewable Energy Directive (RED)	EU + Norway	Biofuels, RFNBOs, RCFs	All sectors
		2	Fuel EU Maritime	EU	All fuel types	Maritime
		3	California Low Carbon Fuel Standard (LCFS)	California	All transport fuels	Road transport
		4	RenovaBio	Brazil	Biofuels (within Brazil)	All sectors
	Voluntary	5	Bonsucro Production Standard	Global	Biofuels (from sugarcane)	All sectors
		6	Responsible Soy Production Standard (RSPS)	Global	Biofuel (from soy)	All sectors
		7	ICAO CORSIA	Global	SAF, LCAF	Aviation
Certification schemes		8	Roundtable on Sustainable Biomaterials (RSB)	Global	Biofuels, SAF	All sectors
		9	ISCC	Global	All fuel types	All sectors
		10	CertifHy	EU	RFNBOs	All sectors

[14] The long list of schemes that were considered for the shortlist are tabulated in APPENDIX 2.

[15] Assessment completed November 2023. As new science and technology develop regulatory frameworks/standards or certification schemes may be updated an example being RED which has received two updates since its introduction in 2009.

The full assessment summarises the most relevant sustainability strategies identified to achieve reductions in lifecycle GHG emission across the spectrum of marine fuels. Within this assessment special consideration is given to sustainability themes/aspects where the uncertainty level is high. This can be found in APPENDIX 3.

3.1 REGULATORY FRAMEWORKS (MANDATORY)

Regulatory frameworks can cover broad overarching policy objectives or specific to focus on key issues. Regulatory frameworks can also include emission reduction targets, carbon pricing mechanisms, and mandates for a minimum share of low/zero carbon fuels in the transportation sector. By imposing legal requirements and financial incentives, regulatory frameworks establish a clear framework for industry stakeholders and encourage the uptake of low/zero carbon fuels.

3.1.1 #1: EU RED

The Renewable Energy Directive (RED II) (EU/2018/2001) sets common principles and rules for renewable energy support schemes, sustainability criteria for biomass and the right to produce and consume renewable energy and to establish renewable energy communities. It also establishes rules to remove barriers, stimulate investments drive cost reductions in renewable energy technologies and empower citizens and businesses to participate in the clean energy transformation.

RED III aims to increase the share of renewable energy in the EU's overall energy consumption to 42.5% total energy consumption by 2030, compared to a target of 32% in RED II. RED III (EU/2023/2413) entered into force on 7th November 2023 and will be legally binding from 21 May 2025. RED III is a revision to REDII

REDII entered into force in 2018 and has been legally binding since June 2021; it was a revision of the original Renewable Energy Directive which came into force in 2009.

Rationale for selection: EU has some of the most stringent sustainability criteria in force and many national legislation are adopted from the RED framework. It includes risk management for ILUC and contains information on how to address a multitude of criteria, feedstocks, and fuels. This legislation also addresses the issue of additionality for renewable electricity used in RFNBO.

3.1.2 #2: Fuel EU Maritime

Fuel EU Maritime[16] is a new legislation which aims to support the decarbonization of the shipping industry. It will enter into force on 1 January 2025, with the goal of increasing the share of renewable and low-carbon fuels in the fuel mix of international maritime transport in the EU. Fuel EU Maritime sets well-to-wake GHG emission intensity requirements on energy used on board ships trading in the EU from 2025. It requires a decrease in GHG intensity of shipping fuels used on vessels over 5000 GT by 2% in 2025 to as much as 80% by 2050. It also mandates the use of shore power for container and cruise ships in certain EU ports from 2030.

To incentivise further uptake of renewable and zero carbon fuels the Fuel EU Maritime legislation also includes a sub-target on RFNBOs, applicable from 2034 onwards, that will be triggered if the natural uptake of such fuels does not reach 1% by 2031.

Rationale for Selection: Expands upon EU RED sustainability criteria and also includes other technologies that apply to the marine sector, such as onshore power.

3.1.3 #3: California Low-Carbon Fuel Standard (LCFS)

The Low Carbon Fuel Standard (LCFS) is one of nine early action measures implemented to initially reduce California's GHG emissions but has now expanded its use across other Western States.[17] The scheme is designed to decrease the carbon intensity of California's transportation fuel pool and provide an increasing range of low-carbon and renewable alternatives. This is done through encouraging the use of cleaner low-carbon transportation fuels and the production of those fuels.

It requires providers of transportation fuels to declare the carbon intensity of their fuel and sets out benchmarks through to 2030, with the overall target of reducing the carbon intensity of transport fuels by 20% by 2030 from a 2010 baseline.

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[16] Regulation (EU) 2023/1805 https://eur-lex.europa.eu/eli/reg/2023/1805/oj

[17] https://thejacobsen.com/news_items/states-considering-lcfs/

Rationale for selection: A more localised legislation that encourages a reduction in the carbon intensity of fuels on a well-to-wheel basis over time. The scheme includes a methodology for indirect land use changes.

3.1.4 #4: RENOVABIO

Brazil's National Biofuel Policy (RenovaBio) aims to (i) comply with the commitments established under the Paris Agreement concerning the United Nations Framework Convention on Climate Change, (ii) contribute to the proper relation between energy efficiency and reduction of greenhouse gas emissions, (iii) promote the production and use of biofuels in the national energy mix and (iv) collaborate predictably for the competitive participation of biofuels in the Brazilian market.

To accomplish its objectives, RenovaBio sets forth certain mechanisms, which include: (i) targets for the reduction of greenhouse gas emissions in the fuel mix, (ii) Decarbonisation Credits, (iii) Biofuel Certification, (iv) mandatory addition of biofuels to fossil fuels, (v) incentives on tax, finances and credits, and (vi) actions under the Paris Agreement.

Rationale for selection: The methodology used in this scheme captures a risk management approach to considering ILUC.

3.2 REGULATORY FRAMEWORKS (VOLUNTARY)

Voluntary standards refer to a set of guidelines, criteria, or specifications that are established by industry stakeholders, organizations, or governments on a voluntary basis. These standards are not legally mandated but are adopted by participants as a means of self-regulation and to demonstrate adherence to certain quality, sustainability, or environmental performance criteria. They serve as a common reference point, simplifying the integration of low/zero carbon fuels into the transport sector while ensuring that these fuels meet the necessary criteria for reducing lifecycle emissions. Standards can also be applied to feedstocks used to produce low/carbon feedstock fuels. Third-party verifiers can be used as independent sources to confirm adherence to standards whether that is for the feedstock or end fuel product.

3.2.1 #5 Bonsucro Production Standard

The Bonsucro production standard is a global framework for sustainable sugarcane production. It is a metric-based tool that enables farmers and millers to improve and certify their practices as sustainable, while also offering buyers assurance when sourcing their sugarcane and derivatives.

The standard contains principles and criteria for achieving sustainable production of sugarcane and all sugarcane-derived products. Its primary purpose is to define a set of principles, criteria, and indicators for the assessment of the performance of operators against economic, social and environmental pillars of sustainability.

Rationale for selection: A scheme focussed on addressing sustainability compliance from the sugar cane industry. It includes a risk-management based approach to ILUC through the use of environmental impact management plans.

3.2.2 #6 Round Table on Responsible Soy Association – Standard for Responsible Soy Production

This Round Table Association is a global multi-stakeholder organization created in 2006 with more than 160 international members of the soy value chain. The main objectives are to promote the production, trade, and use of responsible soy through cooperation with actors in and relevant to the soy value chain i.e. from production to consumption, including producers, suppliers, manufacturers, etc. It sets a standard for responsible soy through a certification scheme that ensures RTRS soy meets its environmental criteria (including a guarantee of third-party verified zero deforestation) but also a wide-reaching set of social and labour requirements.

Rationale for selection: Soy is one of the more contentious feedstocks when it comes to fuel production as there are often concerns about ILUC and deforestation, it is useful to explore how this standards seeks to overcome these issues.

3.2.3 #7 Carbon offsetting and Reduction Scheme for International Aviation (CORSIA)

CORSIA is a global market-based measure, offering a harmonised way to reduce emissions from international aviation, minimising market distortion, while respecting the special circumstances and respective capabilities of ICAO Member States. CORSIA offers a way to offset CO_2 emissions that cannot be reduced through technological improvements, operational improvements, and sustainable aviation fuels with emissions units from the carbon market.

Rationale for selection: An example from the aviation industry where a global LCA framework has been developed for offsetting emissions from flights. The methodology includes an approach to quantify ILUC emissions.

3.3 CERTIFICATION SCHEMES

Certification schemes add a layer of credibility and transparency to the low/zero carbon fuel market. Third-party verifiers can be utilised to check compliance against certification scheme requirements. These schemes, often developed by industry associations or independent third-party organisations, validate the environmental and sustainability credentials of low/zero carbon fuels. Certification can encompass various aspects, including feedstock origins, production processes, and greenhouse gas emissions reductions. By offering a reliable method to verify the environmental benefits of low/zero carbon fuels, certification schemes help build consumer trust and stimulate market demand. In some cases, certification is a requirement to meet regulatory demands. They enable businesses to meet sustainability objectives and comply with environmental regulations, promoting the use of fuels with reduced lifecycle emissions in a responsible and accountable manner.

3.3.1 #8 Roundtable on Sustainable Biomaterials (RSB)

The Roundtable on Sustainable Biomaterials (RSB) standard is a global certification system that promotes the sustainable production and use of biomaterials. It provides a framework for assessing the environmental, social, and economic sustainability of biomaterials throughout their entire supply chain.

The standard sets out general requirements for operations producing, converting, and processing biomass, biofuels, or biomaterials in the RSB certification system. Two types of operators are subject to the sustainability requirements within this standard: (i) Biomass producers such as farmers and plantation or forest managers, and (ii) Industrial operators such as feed-stock processors, intermediary producers, and biofuel or biomaterial producers.

Rationale for Selection: Another scheme that employs a risk management approach to account for ILUC and another certification scheme that is used on a global level (including certification against RED and CORSIA standards).

3.3.2 #9 International Sustainability and Carbon Certification (ISCC)

An international certification system covering a wide range of sustainable feedstocks for renewable fuels, including agricultural and forestry biomass, biogenic wastes and residues, circular materials and renewables. ISCC covers several schemes, including the following: ISCC EU for certification of fuels meeting RED and FQD requirements; ISCC Plus for markets outside the EU and non-transport fuel products; and ISCC CORSIA for certification for SAF to CORSIA standard. ISCC promotes biomass, bio-energy and social sustainability among farmers and processors to respect climate and the environment. ISCC standards cover the entire biomass supply chain from the farm and plantation towards warehouses or logistics points to conversion unions and to the final user.

Rationale for Selection: The most well-known certification scheme on a global level which covers nearly all feedstocks and fuels. This includes dedicated schemes for CORSIA and PLUS (biofuels from outside of Europe).

3.3.3 #10 CertifHY – Guarantees of Origin for Green Hydrogen

CertifHy is a trading standard for renewable hydrogen in the EU. CertifHy has developed quality hydrogen certification schemes across Europe, CertifHy certificates, that will enable consumers to track hydrogen's origin and environmental attributes.

Rationale for Selection: A dedicated scheme for the certification of RFNBOs, given their expected importance as future marine fuels exploring the design of this could provide useful insight for this study.

3.4 SUMMARY OF THE EXISTING REGULATORY FRAMEWORKS/ STANDARDS AND CERTIFICATION SCHEMES

Table 3.2 lists the sustainability themes/aspects addressed in the different schemes assessed. All the sustainability themes/aspects in the IMO LCA guidelines are covered by at least some of the schemes, whereas GHG emissions are covered by all the schemes.

Within the schemes reviewed, only Fuel EU Maritime explicitly addresses fugitive emissions. Fugitive emissions are likely to be a more significant issue in the maritime sector relative to road transport or aviation due to a much higher future uptake of gaseous fuels (e.g. ammonia, LNG etc) in shipping. Fuel EU Maritime is the only maritime focused scheme reviewed, which is why fugitive emissions are accounted for in this scheme – and are not in the others.

Table 3.2: Sustainability themes/aspects addressed in each scheme

	Regulatory Frameworks/Standards						Certification schemes		
	Mandatory			Voluntary					
Sustainability themes/aspects	EU RED	California LCFS	RenovaBio	Bonsucro Production Standard	RSPS	CORSIA*	RSB	ISCC	CertifHy
GHG	✓	✓	✓	✓	✓	✓	✓	✓	✓
Carbon Source	✓	✓	✓			✓	✓	✓	
Source of Electricity/ Energy	✓	✓	✓				✓	✓	✓
DLUC	✓	✓(**)	✓(**)	✓	✓	✓	✓	✓	
ILUC	✓	✓		✓	✓	✓	✓	✓	
Water				✓	✓	✓	✓	✓	
Air		✓		✓		✓	✓	✓	
Soil	✓	✓		✓	✓	✓	✓	✓	
Waste and chemicals				✓		✓	✓	✓	
Conservation	✓		✓	✓	✓	✓	✓	✓	
Applicable to marine fuels	✓(***)		✓(***)		✓(***)		✓(***)	✓(***)	✓(***)

** CORSIA will become mandatory from 2027 onwards*
*** DLUC is considered within these schemes but not explicitly addressed*
**** Partial coverage: i.e. a selection of marine fuels are covered by this regulatory framework/standard/certification scheme*

4 REVIEW OF SUSTAINABILITY THEME/ASPECT METHODOLOGIES

Overview

To explore possible marine fuel sustainability criteria/certification scheme options, five case studies are evaluated to assess how various sustainability themes/aspects are practically applied across four different regulatory frameworks and relevant production standards. This analysis demonstrates how real-world sustainability concerns are addressed by regulatory frameworks and standards and was used to identify any gaps or limitations in the existing schemes. A thorough review of the GHG calculation method used with each regulatory frameworks is presented in Appendix 4 which is then followed by a detailed analysis for each case study in Appendix 5.

Key findings

- Robustness of accounting for the different sustainability themes/aspects varies across different fuel production pathways and can largely be dictated by the feedstock to the process.
- Ambiguity upon the classification of feedstock can lead to errors in calculating the impact of the sustainability themes/aspects.
- Although included in many of the regulatory frameworks, soil and air quality lack a definitive method to account for any impact on them because of fuel production.

4.1 SELECTED CASE STUDIES

The focus of the study is on the applicability of sustainability themes/aspects to marine fuels. The sustainability of a given fuel is primarily dictated by the feedstock used to produce it. Hence for the case studies listed in Table 4.1 a series of illustrative feedstocks were selected that highlight how sustainability themes/aspects are implemented across existing sustainability schemes/standards. The rationale for the selection of each feedstock is given in Table 4.1. Furthermore, as sustainability themes/aspects are assessed on the basis of MJ of fuel (e.g. gCO_2e/MJ), it is necessary to pair each feedstock with an appropriate conversion pathway. Conversion pathways that produce fuels that can be used in maritime applications were selected.

Due to the time limitations of the study, five case studies were assessed. Each case study aims to highlight a specific challenge when designing a sustainability framework as explained in Table 4.1. It would be beneficial to create further case studies, for example examining FAME as a target fuel, gaseous fuels and blue fuels prior to the IMO LCA Guidelines being updated to ensure any challenges around these fuels are accounted for.

Each case study presents a practical application of sustainability themes/aspects for the selected fuel production pathway (i.e. feedstock and conversion pathway pairing). The aim of this analysis is to identify areas of good/common practice across the explored regulatory frameworks/standards, any limitations in the existing methodologies and to highlight areas where improvements could be made.

FuelEU Maritime is not considered further, as the sustainability criteria defined in this legislation is derived from the Renewable Energy Directive (from EU RED). Moreover, certification schemes and voluntary standards are not evaluated here as their role is to aid compliance with the requirements set out in the regulatory frameworks. Additionally, industry production standards, relevant to the feedstock or fuel types, are assessed where relevant – an example being RTRS (Standard for Responsible Soy Production).

Table 4.1 Summary of case studies considered in this report (Full case studies presented in Appendix 5)

Case study	Reason for selection
Case Study 1: Soybeans for HVO production	Soybeans are a crop feedstock and account for 24% of global biodiesel production.[18] It is considered as a feedstock to highlight typical considerations around direct/indirect land use change.
Case Study 2: Palm fatty acid distillate (PFAD) for HVO production	PFAD is included as a feedstock to highlight areas where unclear feedstock categorisation can lead to uncertainty on the sustainability credentials of the finished fuel.
Case Study 3: Used cooking oil for HVO production	Used Cooking Oil (UCO) is a very common "waste" feedstock, however, concerns are often raised around fraudulent production. This uncertainty is not captured in regulatory frameworks so it is included to highlight where uncertainties outside of regulatory frameworks can occur and how they can be addressed.
Case Study 4: Forestry residues for FT-diesel production	Forestry residues are included to highlight considerations around sustainable forestry practices. The sustainability themes/aspects requiring consideration for forestry biomass is often more stringent than for other feedstocks therefore, it is included to explore these extra considerations.
Case Study 5: Renewable electricity and captured carbon for methanol production	Renewable electricity and captured carbon are included as an illustrative example of a renewable fuel of non-biological origin. RFNBOs/e-fuels are likely to play a large role in future marine fuels so it is important to consider how they are currently addressed within the regulatory frameworks/standards.

4.2 FINDINGS FROM THE CASE STUDIES

Case Study 1: Soybeans for HVO production

Across the regulatory frameworks and schemes explored, GHG emissions, DLUC and ILUC risks are quantitively accounted for and default values for carbon intensities are provided. All other criteria are discussed qualitatively; criteria for water, soil and air focus on the application of good practices to minimise pollution. Production standards, outlined in APPENDIX 5, list good agricultural practices for farmers to follow to maintain biodiversity. However, this could be further improved through **quantitative measurement of indicators** and **inclusion of thresholds** for water use and air quality. It should be noted that criteria for electricity/energy source for soybean production are not directly covered by any of the regulatory frameworks or voluntary production standards, although the main impacts of energy use are included through the GHG accounting methodologies.

Case study 2: PFAD for HVO production

Across all regulatory frameworks, the classification of PFAD as a feedstock varies, and in some case is undetermined, leading to **ambiguity on whether some sustainability themes/aspects apply**. Within EU RED, PFAD meets the definition of a residue[19]; in CORSIA it is classed as a by-product; and in California LCFS and RenovaBio the classification is unclear although in the LCFS it was recommended that PFAD was classed as a by-product. GHG emissions are generally well accounted for, despite the uncertainty on feedstock classification. In all cases, no default values exist for HVO production from PFAD, although the actual values can be calculated using the appropriate methodology. Electricity/energy source is not directly addressed in any of the regulatory frameworks however, the energy used during the production of the fuel is indirectly

[18] https://www.fao.org/3/CC0308EN/Biofuels.pdf

[19] Although PFAD meets the RED definition of a residue, it is not explicitly listed in Annex IX of the Directive.

covered through the GHG calculation. Air quality is addressed in two of the four regulatory frameworks, but **inclusion of thresholds or quantitative indicators** would provide greater certainty of their impact.

Case study 3: Used cooking oil for HVO production

The methodology for accounting for GHG emissions is well defined in all regulatory frameworks with default values provided; in LCFS additional default values are provided to account for different production pathways. As UCO is defined as a waste, the ILUC default value is given as zero in regulatory frameworks where it is accounted for, this classification means many of the other sustainability themes/aspects are not applicable. Used cooking oil is an established waste feedstock for HVO production and is thus well understood from a sustainability point of view. Certification schemes to verify the sustainability credentials of the production pathway, from UCO sourcing to end HVO production are numerous, and the main issues regarding the use of used cooking oil for HVO (or other fuel production) lie in the certification processes and not in the regulatory frameworks. An example of failings in the certification process is virgin oils being incorrectly labelled as UCO and entering the European biofuels market where waste feedstocks (such as UCO) are eligible for double the incentives as virgin oils.

Case study 4: Forestry residues for FT-diesel

Although classified as a residue, additional considerations must be taken into account to ensure that any forestry biomass used for fuel production does not lead to adverse effects on the harvested area. Production standards outlined in APPENDIX 5 ensure sustainable forest management practices are upheld, prevent degradation of high carbon stock lands, prevent negative impact on biodiversity and discourage deforestation. In addition to these production standards across all the regulatory frameworks, carbon source and conservation are accompanied by strict requirements on land that can be used for forestry biomass production and are thus well covered. GHG emissions contain a mix of default values or an appropriate methodology to calculate an actual value. Soil quality is not discreetly accounted for; however it is included in relation to the forest management practices and there would be benefit for regulators and certifiers to **introduce metrics or indicators to quantify and monitor soil quality**.

Case study 5: Renewable electricity and captured carbon for methanol production

The sustainability themes/aspects to account for e-fuels such as methanol still being developed and as such for GHG emissions there exists no default value across the regulatory frameworks explored for any production pathway. However, there are methodologies in place to calculate an actual GHG value. The source of carbon has specific requirements across the regulatory frameworks to prevent intentional generation of CO_2 as a feedstock for fuel production. The source of energy/electricity, as the main input to the production process, is included, and there are strict restrictions in the case of the EU RED and LCFS to ensure that only fully renewable electricity is counted when producing e-fuels. Typically, this means that fuels must be produced either using a dedicated electricity source connected to the fuel production facility, or using electricity where conditions on additionality, temporal correlation and geographic correlation are demonstrably met[20].

[20] Delegated regulation on Union methodology for RFNBOs

5 CONCLUSIONS AND RECOMMENDATIONS

Having conducted an extensive examination of sustainability themes/aspects within various frameworks, this study proceeded to present a comprehensive overview of regulatory frameworks, voluntary standards, and certification schemes. Within this overview, the assessment focused on how distinct sustainability themes/aspects are addressed. Subsequently, the findings from this analysis were applied to five specific case studies, offering insights into the practical implementation of sustainability themes/aspects across the examined regulatory frameworks. These case studies were designed to cover diverse marine fuel production processes sourced from a variety of feedstocks. This section encapsulates the key outcomes derived from the comprehensive analysis and subsequently puts forth recommendations for consideration in the further development of the IMO LCA guidelines.

5.1 FINDINGS AND RECOMMENDATIONS OF EXISTING SCHEMES

Soybean for HVO production: In comparison to the IMO LCA guidelines, there are various similarities to the existing sustainability regulatory frameworks/standards assessed; the GHG sustainability theme/aspect is accounted for in a similar manner to that used in RED II, with similarities also lying in the criteria used for land use. However, there are several differences with the areas covered; for example, default values for carbon intensity are only provided here for few specific fuel pathways. No default value is provided for this HVO pathway, the only value provided is for second generation biogenic feedstock (WtT intensity: 14.9 gCO_{2e}/MJ). Additionally, ILUC effects are accounted for using a qualitative risk-based approach, as opposed to quantitative accounting in CORSIA and California LCFS regulatory frameworks. It should however be noted that the IMO LCA guidelines for water usage provide quantitative indicators, as opposed to qualitative discussion per the regulatory frameworks and standards; examples include water use indicators (m^3 /year per MJ or production or yield of feedstock), and freshwater eutrophication indicators (kg eq released to fresh water per kg of feedstock produced). However, no quantitative criteria have been provided for air quality or soil health in the IMO LCA guidelines; meanwhile the RTRS encourages quantification of soil health, e.g. through analysis of organic matter, pH.

PFAD for HVO production: Although no gaps were identified in relation to assessment of the sustainability of PFAD as a feedstock for biofuel production in comparison with the LCA guidelines there are some clear limitations. Specifically, the ambiguity around the categorisation of PFAD as either a residue/by-product or co-product. The absence of explicit guidance on how PFAD should be treated has led to a variety of interpretations, which in turn gives rise to a wide range of values for GHG savings[21].

Used cooking oil for HVO production: Lifecycle impact assessments commonly discount impacts arising during feedstock production due to the waste feedstock classification of UCO. They also neglect potential sustainability impacts from replacing existing UCO uses with virgin vegetable oil due to feedstock competition and do not reflect the risk of feedstock fraud.

Forestry residue for FT-diesel production: EU RED and CORSIA quantitatively account for GHG emissions for FT-diesel, providing default carbon intensities for pathways using forestry residues. California LCFS provides a calculated value only for FT-diesel from municipal solid wastes, therefore a default value is still to be calculated for forestry residues. Compared to the LCA guidelines, there are similarities to the regulatory frameworks discussed here. The GHG methodology is similar to EU RED, however, there are default values only provided for specific fuel pathways. For FT-diesel only two pathways are considered, neither of which includes forestry residues as a feedstock type.

The LCA Guidelines suggest quantitative indicators regarding water quality and availability (i.e. water use indicator, in m^3/year per yield of feedstock), as well as waste management and chemicals use (i.e. tonnes of hazardous wastes generated per MJ of fuel produced and tonnes of industrial chemicals consumed per MJ of fuel produced). Such indicators are however absent in the other regulatory frameworks assessed and only qualitative indicators are included in CORSIA.

Renewable electricity and captured carbon for methanol production: The need to establish a methodology to ensure hydrogen used for renewable electricity comes from renewable sources has not been universally accounted for by all regulatory frameworks considered. Certification measures should be in place

[21] Co-products may also be generated as part of the biofuel production process and can be assigned a share of the overall process emissions. Therefore, co-product generation can also impact the overall GHG emissions of the process.

to verify the electricity source used for electrolysis and ensure they are of renewable origin. Similar considerations are lacking to ensure that the sources of CO_2 for carbon capture are also renewable or sustainable. Biomass through BECCS and BECCU plants can provide some of this renewable CO_2, but the amount of CO_2 available from these sources is limited and has not been considered in the included regulatory frameworks.[22]

The potential for water scarcity associated with renewable hydrogen has not been considered. The production of green hydrogen requires significant amounts of water, and in areas where water is already scarce, this could increase demand further. The question of water demand has been identified as an important issue to be considered in the development of international standards for hydrogen-related projects.[23] While the use of deionised water produced by desalination plants may reduce freshwater demand for this purpose, guidelines will be needed for the removal and disposal of residual chemicals and wastes that may arise from this process.

Both hydrogen production and carbon capture and storage are energy intensive processes. Carbon capture and storage technologies are still highly inefficient from an overall energy perspective and generate their own emissions due to the energy intensive process of capturing and compressing carbon, with additional amounts required for its transportation and storage.[24] These energy intensive processes therefore require large amounts of renewable energy to power them for them to be considered carbon neutral; most carbon capture technologies now use natural gas-powered electricity. The full lifecycle of carbon capture should therefore be considered in regulatory frameworks methodologies if not powered by renewable electricity.

5.2 COMPARISON WITH THE IMO LCA GUIDELINES

Overall, the LCA Guidelines outline a methodology for the calculation of the Well-to-Wake (WtW) emissions related to the production and use of marine fuels. The WtW emissions are calculated as the sum of the Well-to-Tank (WtT) and Tank-to-Wake (TtW) GHG emissions. Note that in neither definition are emissions associated with the construction of infrastructure to produce or distribute the fuels taken into account – this is common across all regulatory frameworks/standards and certification schemes but is included in ISO14040/14044.

The WtT emissions are calculated according to the following equation:

$$GHG_{WtT} = e_{f\,ecu} + e_l + e_p + e_{td} - e_{sca} - e_{ccs}$$

Where:

$e_{f\,ecu}$	Emissions associated with the feedstock extraction/cultivation/acquisition/recovery
e_l	Emissions (annualised emissions (over 20 years) from carbon stock changes caused by direct land-use change)
e_p	Emissions associated with the feedstock processing and/or transformation at source and emissions associated with the conversion of the feedstock to the final fuel product, including electricity generation
e_{td}	Emissions associated with the feedstock transport to conversion plant, and the emissions associated with the finished fuel transport and storage, local delivery, retail storage and bunkering
e_{sca}	Emissions (annualised emission savings (over 20 years) from soil carbon accumulation via improved agricultural management)
e_{ccs}	Emissions credit from carbon capture and storage, that have not already been accounted for in e_p.

The current IMO methodology explicitly accounts for DLUC in the calculation of the WtT emissions which is consistent with EU RED, California LCFS and CORSIA, while RenovaBio does not account for DLUC at all; other than a statement that energetic biomass cannot be used if it is grown on land where removal of native vegetation has not occurred.

The methodology specified proposes to adopt a qualitative risk-based approach to assessing ILUC. This appears consistent with the approach adopted by EU RED, although at present there is limited detail on how,

[22] IRENA and Methanol Institute (2021). *Innovation outlook: Renewable Methanol.* https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Innovation_Renewable_Methanol_2021.pdf

[23] Cremonese, L., Mbungu, G.K., Quitzow, R. (2023) 'The Sustainability of Green Hydrogen: An uncertain proposition', *International Journal of Hydrogen Energy,* 48(51), pp.19422-19436.

[24] Gov.uk. Scoping guidelines on the Environmental Impact Assessment (EIA) of Carbon Capture, Transport and Storage projects. https://assets.publishing.service.gov.uk/media/5a7564f940f0b6360e473c6b/geho0811bucq-e-e.pdf

under the LCA Guidelines, a given feedstock will be assessed as high or low ILUC risk and, more importantly, the impact this would have on a feedstock's eligibility under the LCA Guidelines. California LCFS and CORSIA on the other hand adopt a quantitative approach to assessing ILUC.

Unlike the other approaches to calculating GHG emissions reviewed in this report (presented in Appendix 4), the current LCA Guidelines include a separate calculation of TtW emissions. As well as accounting for emissions from complete combustion of the fuel, this calculation also accounts for fugitive emissions. The consideration of fugitive emissions in particular is unique among the schemes/regulatory frameworks reviewed here (note: FuelEU Maritime, the GHG methodology for which is not reviewed here, also considers fugitive emissions on a mass balance basis). This reflects that these guidelines have been developed specifically for the maritime sector, where gaseous fuels, and therefore fuel slippages (emissions of unburned fuels as GHG), are more common and warrant careful consideration. On the other hand, EU RED and California LCFS were developed predominantly for fuels going to road transport, while CORSIA is exclusively for the aviation sector. Both the road and aviation sectors are much less prone to fuel slip therefore its inclusion is less important.

The LCA Guidelines also provide definitions of feedstock categories, co-products, by-products, wastes and residues. Of note, the LCA Guidelines define a co-product as "*an outcome of a production process, which has economic value and elastic supply*…". This is broadly consistent with the CORSIA definition (although CORSIA specifies the co-product must have "significant" economic value), but different to the EU RED definition (see Appendix 4). As discussed in Section 4.2, this ambiguity in feedstock definitions can create challenges regarding the certification and verification of supply chains. An alternative method, which could help alleviate the ambiguity, is to define the "economic value" with respect to the primary product, mirroring the approaches adopted by the RSB and ISCC. [25]

Like EU RED and CORSIA, the LCA Guidelines provide default values for specified fuel pathways. However, unlike the EU RED and CORSIA approaches, which provide positive lists of eligible feedstocks, the LCA Guidelines adopt broad categorisations of biogenic feedstocks as 1st generation, 2nd generation and 3rd generation, with no definitions of these categories provided at present. Moreover, this means that the default values provided are assumed to be applicable to all "1st generation feedstocks" irrespective of their provenance. Conversely, CORSIA, for example, specifies default values by specific feedstock and also production region – in instances where differences in the overall lifecycle emissions have been identified depending on the provenance of the feedstock.

5.3 FURTHER CONSIDERATIONS

Table 5.1 provides a comparison of the IMO LCA Guidelines against the example fuel pathways used in the case studies of this study.

[25] Xu, H., Lee, U., & Wang, M. (2020). Life-cycle energy use and greenhouse gas emissions of palm fatty acid distillate derived renewable diesel. Renewable and Sustainable Energy Reviews, 134, 110144. https://doi.org/10.1016/J.RSER.2020.110144

Table 5.1: Application of the IMO LCA Guidelines to the five selected case studies and comparison with existing regulation/schemes

Sustainability theme/aspect	1. HVO from soybeans	2. HVO from PFAD	3. HVO from UCO	4. FT-Diesel from forestry residues	5. E-methanol from RE and CO_2
GHG	There is no default value provided for HVO production from first generation feedstocks i.e. soybean oil. Default values are provided under EU RED (46.5 gCO_2e/MJ) and CORSIA (40.4 gCO_2e/MJ), The average reported value under the California LCFS (61.6 gCO_2e/MJ).	It is assumed that the default value of 14.9 gCO_2e/MJ (WtT) HVO from 2nd gen feedstocks is applicable to HVO from PFAD. A default value is provided for an equivalent (HEFA) fuel pathway by CORSIA 20.7 gCO2e/MJ (WtW), but not EU RED. Note, the IMO WtT and CORSIA WtW emissions values can be compared as only non-biogenic CO2 emissions are included in CORSIA TtW calculations i.e. the TtW emissions are 0 for PFAD.	It is assumed that the default value of 14.9 gCO2e/MJ (WtT) HVO from 2nd gen feedstocks is applicable to HVO from UCO. A default value of 15.98 gCO2/MJ (WtW) is provided in EU RED for HVO production from UCO. CORSIA provides a default value of 13.9 gCO2e/MJ (WtW). Note, the IMO WtT and RED/CORSIA WtW emissions values can be compared as only non-biogenic CO2 emissions are included in RED/CORSIA TtW calculations i.e. are 0 for UCO. Certified CI values (including ILUC impacts) developed by CA-GREET model for several UCO to renewable diesel pathways Range between 16.21 – 30.72 gCO2/MJ (average: 22.40).	There is no default value provided for FT-diesel production from second generation feedstocks, which is likely the category under which forestry residues would fall. Default values are provided by both EU RED and CORSIA.	While no default value is currently listed to produce e-methanol in the LCA Guidelines, it is listed as a fuel pathway so we assume will be added in the future. Default values are not provided by any of the other regulatory frameworks/schemes covered. However, a Delegated Act was recently published by the EU containing the methodology for the calculation of RFNBO and RCF GHG emissions.
Carbon Source	Soybeans fall under the biogenic carbon categorisation identified in the LCA Guidelines. However, unlike EU RED, California LCFS, RenovaBio and CORSIA, there are no direct	PFAD meets the IMO definition of a by-product as it has an economic value but inelastic supply. Therefore, land management criteria are not applicable to HVO from PFAD. This is consistent	UCO meets the IMO definition of a waste. Therefore, land management criteria are not applicable to HVO from UCO. This is consistent with the other regulatory	The LCA Guidelines do not provide any specific guidance on the use of forestry residues as a carbon source. While forestry residues meet the definition of a residue across all of the	The LCA Guidelines specify eligible carbon sources, which are in line with those defined by EU RED and California LCFS. However, unlike EU RED, the LCA Guidelines do not specify how double

Sustainability theme/aspect	1. HVO from soybeans	2. HVO from PFAD	3. HVO from UCO	4. FT-Diesel from forestry residues	5. E-methanol from RE and CO_2
	provisions in the LCA Guidelines to ensure that feedstocks are not produced on high carbon stock land.	with the other regulatory frameworks/schemes reviewed here.	frameworks/schemes reviewed here.	schemes/regulatory frameworks reviewed; typically, additional guidance is provided to ensure that they are harvested sustainably.	counting of the carbon will be avoided. EU RED explicitly states that the captured CO_2 cannot have received an emissions credit under other provisions of the law.
Electricity/ energy source	Assessment of the electricity used in the WtT phase of fuel production is broadly in line with the other schemes reviewed.				The LCA Guidelines state that the objective of this criterion is to ensure that electricity/energy used is from renewable, nuclear or biogenic sources, which are additional to current or long standing demand levels, or by using surplus electricity during off-peak hours. However, they do not elaborate how this will be implemented. Due to the nascency of the e-fuel industry, there are no good working examples of how this could be addressed. EU RED is arguably the most advanced regulatory frameworks in this respect.
DLUC	Provisions are in place in the IMO LCA Guidelines to prevent feedstocks containing biomass from high carbon stock land primary forests, wetlands or peat lands. In addition, lands converted from primary forest, forestland, grassland or legally protected land (using 1 Jan 2008 as the cut-off date) cannot be used to produce sustainable marine fuels.				
	Based on the current guidelines it is unclear how DLUC has been accounted for in the calculation of the default values. However, we assume this has been accounted for as it is	PFAD meets the IMO definition of a by-product as it has an economic value but inelastic supply. Therefore, land management criteria are not applicable to HVO from PFAD. This is consistent	UCO meets the IMO definition of a waste. Therefore, land management criteria are not applicable to HVO from UCO. This is consistent with the other regulatory	Forestry residues meet the IMO definition of a residue. Therefore, land management criteria are not applicable. This is consistent with the other regulatory	DLUC is not applicable to e-fuel production.

Sustainability theme/aspect	1. HVO from soybeans	2. HVO from PFAD	3. HVO from UCO	4. FT-Diesel from forestry residues	5. E-methanol from RE and CO_2
	specified in the WtT emissions calculation. For EU RED and CORSIA (i.e. the other methodologies that use default values), detailed supporting documentation that outlines the data and assumptions used in calculating the default values are provided.	with the other regulatory frameworks/schemes reviewed here.	frameworks/schemes reviewed here.	frameworks/schemes reviewed here.	
ILUC	Based on the current LCA Guidelines, it is unclear if soybeans would be classed as a high/low ILUC feedstock. Under EU RED, only palm oil is considered a high ILUC feedstock with soybean oil falling close to the classification thresholds: • Global production area of feedstock increasing by an annual 3%[26] (greater than the 1% criteria). • Soy expansion on high-carbon land estimated at 8% (below the 10% criteria) per the EC assessment, however recent studies show an average of 19% expansion[27].	PFAD meets the IMO definition of a by-product as it has an economic value but inelastic supply. Therefore, land management criteria are not applicable to HVO from PFAD. This is consistent with the other regulatory frameworks/schemes reviewed here.	UCO meets the IMO definition of a waste. Therefore, land management criteria are not applicable to HVO from UCO. This is consistent with the other regulatory frameworks/schemes reviewed here.	Forestry residues meet the IMO definition of a residue. Therefore, land management criteria are not applicable. This is consistent with the other regulatory frameworks/schemes reviewed here.	ILUC is not applicable to e-fuel production.

[26] https://faolex.fao.org/docs/pdf/eur188157.pdf
[27] https://spiral.imperial.ac.uk/bitstream/10044/1/74208/2/ocl190034s%20-%20Strapasson%20et%20al%202019.pdf

Sustainability theme/aspect	1. HVO from soybeans	2. HVO from PFAD	3. HVO from UCO	4. FT-Diesel from forestry residues	5. E-methanol from RE and CO_2
Water	Water quality guidelines are specified in Table 1 of the LCA Guidelines[28]. These requirements are broadly in line with the other regulatory frameworks/schemes reviewed in the case studies.			Although the more general guidelines around water use in fuel production are also applicable to e-fuel production, water is also a feedstock for e-fuel production. No regulatory frameworks or schemes reviewed provide guidance that reflects this.	
Air	Air quality guidelines are specified in Table 1 of the LCA Guidelines. These requirements are broadly in line with those specified by CORSIA. The other regulatory frameworks reviewed do not contain guidelines on air quality.				
Soil	Soil quality guidelines are specified in Table 1 of the LCA Guidelines.[29] These requirements are broadly in line with the other regulatory frameworks/schemes reviewed in the case studies.	PFAD meets the IMO definition of a by-product as it has an economic value but inelastic supply. Therefore, land management criteria are not applicable to HVO from PFAD.	UCO meets the IMO definition of a waste. Therefore, land management criteria are not applicable to HVO from UCO.	The LCA Guidelines stipulate that forestry best management practices for feedstock production or residue collection have been implemented to maintain or enhance soil health, Similar provisions are stated in EU RED and CORSIA.	E-fuel production is not likely to have any impact on soil quality.
Waste and chemicals	Waste and chemical requirements are specified in Table 1 of the LCA Guidelines. These requirements are broadly in line with those provided in CORSIA, which is the only other regulatory frameworks/scheme that provides guidelines on waste and chemicals. CORSIA makes an additional provision to limit or reduce the amount of pesticides used in producing crops.				
Conservation	Conservation requirements are specified in Table 1 of the LCA Guidelines. These requirements are identical to those specified in CORSIA and are broadly in line with the those in EU RED. EU RED makes an additional provision that the feedstock should not be produced on land that was peatland prior to 2008.				

[17,29] RESOLUTION MEPC.376(80): https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2014.pdf

From this comparison, Ricardo have highlighted the areas below for future consideration by the IMO to further develop the LCA guidelines, incorporating good practice from across the range of regulatory frameworks and standards assessed. Where possible, aligning the IMO LCA guidelines with International standards from other sectors ensures a level playing field for the maritime sector.

For sustainability aspects, in recognition of the fact that biofuels are the most commercially developed fuels and therefore more likely to have an immediate impact on the marine fuels market, Ricardo suggest the following priority areas in the **short-term:**

- The provision of default values for specific fuel pathways, where a pathway refers to a named feedstock and conversion technology e.g. HVO from soybean oil, would bring the LCA Guidelines in line with the other regulations/schemes that do not require calculated carbon intensities (i.e. EU RED and CORSIA). The current approach of utilising generic feedstock naming conventions (e.g. HVO from conventional biofuel feedstocks) will likely lead to misrepresentations of lifecycle GHG emissions. Similarly, although default values are not specified by California LCFS or RenovaBio, the methodologies require feedstocks and production regions to be defined.

In the **mid-long term:**

- The treatment of e-fuels within the guidelines could be reflected on. This is an issue common to all the regulatory frameworks/schemes covered and is likely a result of the nascency of the e-fuel industry. Consideration should be given to the criteria around the use of renewable electricity, and the high demand for water for electrolysis.

For sustainability certification and third-party verification issues, the Fuel Lifecycle Label (FLL) is outlined in the LCA Guideline as a possible tool that need to be verified and certified by a third party. It needs international certification schemes/standards to be implemented uniformly to guarantee the quality, reliability and robustness of the IMO framework as a whole and to ensure a level playing field among certification schemes.

ISCC and RSB that were reviewed in this study are renowned international certification schemes/standards that promotes the sustainable production and use of fuels, and both have specific certification solution on the recognition of certification body and accreditation body which were mostly based on ISO/IEC or international standards such as ISO/IEC 17021 and 17065, ISEAL.

5.4 ILUC SPECIFIC CONSIDERATIONS

With regards to ILUC, our understanding of the “risk-based” approach referenced in the IMO guidelines is that it is most similar to the approach adopted by EU RED, where relevant feedstocks can be classed as high or low ILUC risk. Furthermore, the high-level definitions of high and low ILUC risk given in the LCA guidelines are broadly consistent with those in EU RED.

Definitions of high and low ILUC risk are outlined in Commission Delegated Regulation (EU) 2019/807.[30] Following the publication of these definitions, a detailed study was carried out that identified palm oil as the *only* high ILUC risk feedstock. The authors note that although soy is not defined as high ILUC risk it is within 0.5% of the threshold.[31] Assignment of palm oil as high ILUC risk on this basis led Indonesia to lodge a dispute against the EU with the World Trade Organisation.[32]

High ILUC risk feedstocks will be phased out of use in the EU under RED unless they can be certified as low ILUC risk. As part of a wider study on ILUC, draft guidance has been published on the requirements for feedstocks to be certified as low ILUC risk under voluntary schemes.[33] Pending the recommendations of the ILUC study, Commission Delegated Regulation (EU) 2019/807 will be reviewed.[34]

An option for the IMO with regards to operationalising a risk-based approach for ILUC is to **develop the definitions of high and low ILUC risk** given in the LCA guidelines using for example the EU RED framework. For example, the current IMO guidelines define high ILUC risk as resulting in “significant expansion” into high carbon stock land, whereas EU RED defines an equation for calculating expansion and the acceptable

[30] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0807

[31] High ILUC-risk fuels review

[32] WTO | dispute settlement - the disputes - DS593: European Union - Certain measures concerning palm oil and oil palm crop-based biofuels

[33] LOW ILUC-RISK CERTIFICATION – Draft Guidance Handbook

[34] Low ILUC-Risk certification – Presentation

expansion rate as a percentage. Following this definition, we would recommend that the IMO commission a dedicated study to establish the required evidence base to develop and support the required conclusions and identify high ILUC risk feedstocks.

Alternatively, the IMO ***could*** **look to develop a quantitative approach** to assessing ILUC such as those adopted by California LCFS and CORSIA. Noting the IMO have already taken steps to develop a qualitative approach, a quantified approach may also be considered however, there still remains a high-level of uncertainty in a quantified approach as calculated values for ILUC effects can vary greatly across different methodologies for the same feedstock-to-fuel pathway.

It is also possible to have feedstocks certified as low LUC risk under CORSIA.[35] To achieve such certification, it must be demonstrated that the feedstock has been produced as a result of increased yield (i.e. no additional land has been utilised) or through expansion of feedstock production into unused land. Feedstocks that are certified as low ILUC under CORSIA do not have to use the default ILUC value in the LCA calculations.

Within the LCA Guidelines, limitations are placed around sourcing feedstocks from high-carbon stock land which aligns with other regulatory frameworks and schemes to a large extent. **Greater clarity on sourcing feedstock and marine fuel production on high-carbon stock land** could be considered. There is some ambiguity on converted high-carbon stock land and it is currently unclear whether feedstock sourcing from this land is permissible under the IMO LCA Guidelines. The current wording indicated fuel production on such lands is prohibited (provided the land is converted prior to 1st January 2008, pending further guidance to be developed by the Organization) but it is unclear whether feedstocks can be grown on such land.

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[35] ISCC CORSIA – Guidance for Low LUC Risk Certification (iscc-system.org)

5.5 SUMMARY OF FUTURE CONSIDERATIONS

Table 5.2 seeks to conclude the overall findings from this study and set out potential actionable areas for the IMO to consider in respect to further developing the LCA Guidelines.

Table 5.2: Summary of report findings with respect to the IMO LCA Guidelines

Category	Main Findings and Gaps	Recommendations
Sustainability Aspects	Default values are only provided for generic fuel pathways and not the full spectrum of pathways. This contrasts with existing regulatory frameworks/standards and certification schemes where a detailed carbon intensity calculation is required.	Short term Further provision of default values for specific fuel pathways, where a pathway refers to a named feedstock and conversion technology. This would bring the LCA Guidelines further in line with the other regulatory frameworks/standards and certification schemes
	Current definitions for high and low ILUC risk are high level especially compared to EU RED definitions.	Short term Develop more robust definitions on the categorisation of feedstocks as high or low ILUC risk. This is important to help limit the use of high ILUC risk fuels.
	Quantitative approaches for addressing ILUC are implemented in existing regulatory frameworks/standards (California LCFS and ICAO CORSIA).	Short term The IMO *could* reconsider adopting a quantitative approach to ILUC as a neutral approach. Noting this approach is *less robust* and that IMO have already progressed with a qualitative approach.
	Other mandatory regulatory frameworks/standards provide constraints around the sourcing of feedstock and production of fuel on high-carbon stock land and converted land, this is included in the IMO LCA Guidelines but the wording could be clearer.	Short-mid term Reviewing the wording around utilisation of high-carbon stock and converted high carbon stock land. This could reduce the risk of high-carbon land being used for feedstock cultivation and fuel production.
	Sustainability criteria for e-fuels are not fully developed.	Mid-long term The IMO could look to add more details around the sustainability criteria for e-fuels to the LCA guidelines. Especially on the criteria renewable electricity and water, due to the high demand from electrolysis.
Sustainability Certification	Existing schemes/standards such as EU RED and CORSIA have worked with certification bodies such as ISCC and RSB to develop accredited certification standards specific to their respective scheme/standard.	Short-mid term The IMO could consider early engagement with certification bodies to commence the further technical work required to develop sustainable marine fuel standards.
Third-party Verification	Third-party verification is an essential practice to maintain the integrity of the LCA guidelines with respect to issues that are not addressed directly by the guidelines such as feedstock fraud.	Short-mid term The IMO could look to develop a list of recognised third-party verification schemes.

6 GLOSSARY, TABLES OF FIGURES AND TABLES

Abbreviation	Definition
BECCS/ BECCU	Bioenergy with Carbon Capture and Storage/ Bioenergy with Carbon Capture and Utilisation
CCS	Carbon Capture and Sequestration
CO_2	Carbon dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DLUC	Direct Land Use Change
EU	European Union
FFT	Future Fuels and Technology
FQD	Fuel Quality Directive
FT	Fischer-Tropsch
GHG	Greenhouse Gas
GREET	Greenhouse Gases, Regulation Emissions, and Energy Use in Transport
GT	Gross Tonnes
GWP	Global Warning Potential
HEFA	Hydrotreated Esters and Fatty Acids
HVO	Hydrotreated Vegetable Oil
ICAO	International Civil Aviation Organization
ILUC	Indirect Land Use Change
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISCC	International Sustainable Carbon Certificate
ISWG-GHG	Intersessional Working Group on Reduction of GHG Emissions from Ships
LCA	Lifecycle Assessment
LCAF	Low Carbon Aviation Fuel
LCFS	Low Carbon Fuel Standard
LNG	Liquified Natural Gas
LULUCF	Land Use, Land-use Change and Forestry
MEPC	Marine Environment Protection Committee
PFAD	Palm Fatty Acid Distillate
RCF	Recycled Carbon Fuel
RE	Renewable Energy
RED	Renewable Energy Directive
RFNBO	Renewable Fuel of Non-Biological Origin
RSB	Roundtable on Sustainable Biomaterials
RTRS	Round Table on Responsible Soy

Abbreviation	Definition
SAF	Sustainable Aviation Fuel
TTW	Tank-to-Wake
UCO	Used Cooking Oil
WTT	Well-to-Tank
WTW	Well-to-Wake

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7 APPENDICES

APPENDIX 1 ADDITIONAL SUSTAINABILITY THEMES / ASPECTS FRAMEWORKS

SUSTAINABLE SHIPPING INITIATIVE

Criteria relevant to IMO LCA Guidelines

1. *Lifecycle Greenhouse Gas (GHG) emissions* – Zero or close to zero GHG emissions should be produced by sustainable marine fuels aver a well-to-wake (WtW) lifecycle basis, in consistency with the temperature goals as set in the Paris Agreement.
2. *Lifecycle Short-lived Climate Forcers (SLCF) emissions* – One of the main differences between the IMO Sustainability Criteria and the SSI criteria, is that the latter include Short-Lived Climate Forcers (SLCF) emissions. The SLCF emissions (e.g. black carbon, organic carbon, CO, PM2.5, NO_x etc.) are particularly relevant to maritime transport as these are gases that are produced from gas and diesel engines and can stay in the atmosphere for days and months. Similarly, to the previous criterion, zero and low-carbon marine fuels should generate zero or close to zero SLCF emissions.
3. *Air quality* – This criterion ensures that air pollutants (e.g. NO_x, SO_x etc.) will be minimised or eliminated throughout the WtW lifecycle stages of the fuel. This principle/criterion has very similar points to the respective IMO criterion.
4. *Carbon source* – Similarly to the IMO and in the context of minimising carbon throughout the lifecycle of sustainable marine fuels, the SSI outlines that all sources of carbon used in the production of these fuels should be disclosed and that they should not come from fossil origins or come from land with high carbon stock. There is perhaps an **unintentional exclusion of recycled carbon fuels from this definition**.
5. *Electricity/energy source* – In like manner, the primary source of electricity/energy consumed for the production of hydrogen-based zero and low-carbon marine fuels needs to be disclosed. Furthermore, renewable energy sources should be further developed (either in terms of deployment or financing) by the producer, thus including an element of additionality in this criterion.
6. *Water* - Operations in the well-to-tank lifecycle stages of the zero and low carbon marine fuel shall minimise water usage; avoid contamination, pollution and spillage; maintain or enhance the quality, quantity, usage and conservation of water resources; and respect formal or customary water rights.
7. *Sustainable resource use* – A closed-loop approach to resources should be followed throughout the WtW lifecycle stages of sustainable marine fuel.
8. *Land use* – As the IMO has included in the LCA Guidelines, negative land use impacts need to be avoided, and risks related to land use change need to be addressed.

Additional sustainability criteria relevant to economic and social aspects

1. *Ecological impacts* – Operations in the well-to-wake lifecycle stages (including waste management and use of chemicals) of the zero and low carbon marine fuel shall avoid negative impacts on, and shall maintain or enhance biodiversity (including rare, threatened or endangered species and high conservation value habitats), ecosystems, soil, ecosystem services, conservation values
2. *Economic well-being* - Operations in the well-to-tank lifecycle stages of the zero and low carbon marine fuel shall contribute to the economic well-being of local producers, communities and stakeholders where the production of low and zero carbon fuel takes place
3. *Social equity* – Operations in the well-to-tank lifecycle stages of the zero and low carbon marine fuel shall contribute to the social equity of local producers, communities and stakeholders
4. *Social, labour, and human rights* – Operations in the well-to-tank lifecycle stages (including operations in the extractive industries) of the zero and low carbon marine fuel shall not violate labour or human rights of the affected populations, shall promote decent work conditions and workforce well-being, and shall not violate land use rights (through e.g., ensuring Free Prior Informed Consent (FPIC) as recognised in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)).
5. *Food security* - Operations in the well-to-tank lifecycle stages of the zero and low carbon marine fuel shall avoid negative impacts on food security (such as the replacement of staple crops, diversion of exports and local food price increases)

6. *Health, safety, and security* - Health, safety and security risks (including noise, odour and dust) throughout the well-to-wake lifecycle of the zero and low carbon marine fuel shall be addressed by avoidance, mitigation and adaptation through risk assessments, safety management, guidance and training on e.g., accidents, as well as ecological and health impacts of spillage/discharge.
7. *Continuous improvement* - Innovation in the well-to-wake lifecycle stages of the zero and low carbon marine fuel (explicitly including end-of-life treatment and/or disposal of fuel by-products and waste streams, production plants and equipment) shall contribute to the continuous improvement of the fuel's sustainability performance.

STUDY BY ASHRAFI ET AL, "TOWARD A HARMONIZATION OF SUSTAINABILITY CRITERIA FOR ALTERNATIVE MARINE FUELS"[36]

The authors of this study have developed a comprehensive and integrated set of sustainability criteria to evaluate alternative marine fuels. In total, they have initially identified and assessed 58 criteria from the available literature, filtering and grouping them eventually to 18 criteria. These criteria do not include specific descriptions or indexes. A stakeholder consultation task resulted that the development of a global set of sustainability standards and certification schemes is rather important to the maritime industry.

<u>Criteria relevant to IMO LCA Guidelines</u>

1. Economic Dimension
   a. *Capital Expenditures*
   b. *Operational Expenditures*
   c. *Fuel Cost*
   d. *Opportunity Cost*
   e. *Safety-related risk costs*
   f. *Possible regulatory penalty*
2. Environmental Dimension
   a. *Lifecycle GHG*
   b. *Air pollutions*
   c. *Ocean acidification*
   d. *Ecosystem degradation*
   e. *Depletion of natural resources*
   f. *Land use change*
3. Social Dimension
   a. *Regulatory compliance*
   b. *Social acceptability*
   c. *Ethics and social responsibility*
   d. *Public health impact*
   e. *Occupational health and safety*
   f. *Socio-economic development*

CORSIA SUSTAINABILITY CRITERIA FOR CORSIA ELIGIBLE FUELS[37]

<u>Criteria relevant to IMO LCA Guideline</u>

1. *Greenhouse Gases* – CORSIA LCAF should generate lower lifecycle carbon emission and achieve a net 10% reduction compared to the aviation fuel baseline.

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[36] Available at: https://www.sciencedirect.com/science/article/pii/S2666822X2200003X

[37] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2005%20-%20Sustainability%20Criteria%20-%20November%202022.pdf

2. *Carbon Stock* – Fuel should not be made from feedstock obtained from systems with high biogenic carbon stock. If the land has been converted based upon the IPCC land categories DLUC emissions must be calculated. ILUC default values will be used unless DLUC values exceed the default values. In this case the DLUC value should be used.
3. *Greenhouse gas Emission Reduction Permanence* – Emission reduction should be permanent. Operational practices should exist to ensure permanence of CCS activities. Operational and financial measures must be implemented to account for GHG release from the closure of oil and gas wells.
4. *Water* – Production should maintain or enhance water quality or availability this can be achieved through operational practices to prevent adverse effects of quality or quantity of water reserves beyond replenishment capacities.
5. *Soil* – Operational practices should be put in place to ensure soil health is maintained or enhanced.
6. *Air* – Production of CORSIA LCAF should minimise negative effects on air quality through limiting air pollution emissions.
7. *Conservation* – Fuel production should not detriment biodiversity, conservation and ecosystem services. Implemented via practices put in place to protect areas of high biodiversity, prevent spread of invasive species and preserve areas denoted as protected for biodiversity reasons.
8. *Waste and Chemicals* – Any fuel production process should encourage responsible management of waste and chemicals. Operational practices should be implemented to ensure all waste and chemicals are stored, handles and disposed responsibly. Scientific best practice should be deployed to reduce harmful chemical use. Mitigation strategies should be deployed to prevent unintentional release of fossil resources and/or other chemicals.

<u>Additional sustainability criteria relevant to economic and social aspects</u>

1. *Seismic and Vibrational Impacts* – these should be minimised and implemented through operational practices and applicable to surface, sub-surface and underwater activities.
2. *Human and labour rights* – these must be respected.
3. *Land use right and use* – existing rights should be respected whether rights exist formally or informally.
4. *Water use rights* – existing right of local and indigenous communities should be respected.
5. *Local and social development* – production should contribute and benefit communities affected by the operation and strive to improve the socioeconomic status.
6. *Food security* – In regions of food insecurity any fuel production operation should strive to improve the local food security of directly affected stakeholders.

APPENDIX 2 LONG LIST OF SCHEMES CONSIDERED

Table A7.1: Long list of schemes (selected schemes are in bold)

Scheme	Type	Geographical scope	Fuel/impact coverage	Relevance	Rationale for selection
EU RED	**National/Regional Legislation**	**EU**	**Biofuels, RFNBOs**	**ILUC addressed risk management, including guarantee of origin for renewable electricity and eligibility framework for recycled carbon fuels**	**The EU has some of the most stringent sustainability criteria in force and many national legislation are adopted from the RED framework. It includes risk management for ILUC and contains information on how to address a multitude of criteria, feedstocks and fuels. This legislation also addresses the additionality for renewable electricity used in RFNBO.**
Renewable Transport Fuel Obligation	National/Regional Legislation	UK	Biofuels, RFNBOs	Similar to RED but adopted into UK legislation	The RTFO largely aims to comply with RED therefore inclusion in addition to RED would result in duplication.
US EPA Renewable Fuel Standard (RFS) Programme	National/Regional Legislation	US	Biofuels	Uses LCA to regulate fuels, incorporates ILUC GHG emissions in LCA framework	Use developed LCA to assess different production pathways. Less developed than the LCFS.
California Low-Carbon Fuel Standard	**National/Regional Legislation**	**US, California**	**Fuel agnostic (Biofuels, electricity, hydrogen, natural gas, propane)**	**Quantified ILUC impact**	**A more localised legislation that encourages a reduction in the carbon intensity of fuels on a WtW basis over time. A methodology to include indirect land use changes are covered within the scheme.**
RENOVABIO	**National/Regional Legislation**	**Brazil**	**Biofuels**	**ILUC addressed risk management. Captures approach from significant biofuel producer**	**The methodology captures a risk management approach to considering ILUC**

Scheme	Type	Geographical scope	Fuel/impact coverage	Relevance	Rationale for selection
Fuel EU Maritime	**National/Regional Legislation**	**EU**	**Maritime fuels (Biofuels, RFNBOs, RCFs)**	**Linked to RED sustainability criteria but adds onshore power and other technologies**	**Expands upon RED sustainability criteria but branches out to include other technologies that apply to the marine sector, such as onshore power.**
ReFuel aviation	National/Regional Legislation	EU	SAFs, hydrogen	Sets targets for SAF use, and sustainability criteria for feedstocks	More aligned to the aviation sector and inclusion of Fuel EU Maritime is a more logical choice.
EU ETS	National/Regional Legislation	EU	Fuel agnostic	Method of regulating carbon emissions	The sustainability criteria within the EU ETS are linked to RED
EU Taxonomy	National/Regional Legislation	EU	Fuel agnostic (includes natural gas & nuclear energy)	Promotes low ILUC risk biofuels	The EU taxonomy is more focused on financial incentivisation of sustainable economic activities.
US Clean Hydrogen Production Standard	National/Regional Legislation	US	Hydrogen	Quantitative LCA-based hydrogen standard	Built using the GREET model to determine WtW GHG emissions. Possible inclusion.
Canada Clean Fuel Standard	National/Regional Legislation	Canada	Liquid fossil fuels (gasoline, diesel), Low-carbon fuels (Biofuels, hydrogen, RNG, biogas)	Uses a Fuel LCA built into the standard (excludes ILUC)	Follows a similar methodology to the California LCFS however the LCA mode used differs.
UK Low Carbon Hydrogen Standard	National/Regional Legislation	UK	Hydrogen	Hydrogen specific, has emission calculators for different production pathways	Well defined calculation methodology. Possible inclusion.
Standard and Assessment for Low-carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen Energy	National/regional standard	China	Hydrogen	Quantitative LCA-based hydrogen standard	Limited literature information. Built on existing work in Europe so may include duplication.

Scheme	Type	Geographical scope	Fuel/impact coverage	Relevance	Rationale for selection
Australia Guarantee of Origin	National/Regional Legislation	Australia	Hydrogen	Hydrogen specific	Still under consultation at time of writing.
ISO 13065 sustainability criteria	International/ regional standard	Global	Bioenergy	Specifies sustainability criteria, and GHG methodologies (excludes ILUC)	Does not include threshold values and is very broad and geographically agnostic and is used to compared processes at a high-level.
European Standard (EN) 16214 series Sustainability Criteria for biofuel production	International/ regional standard	EU	Biofuels	Specifies sustainability criteria, and GHG methodologies (excludes ILUC)	This group of standards align to RED so doesn't warrant inclusion if RED is included.
Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)	**Voluntary standard**	**Global**	**SAFs, LCAFs**	**Global LCA framework accounts for ILUC GHG emissions**	**An example from the aviation industry is where a global LCA framework has been developed for offsetting emissions from flights. Within the methodology is included an approach to quantify ILUC emissions**
Roundtable on Sustainable Biomaterials (RSB) - Standard	**Certification/ voluntary standard**	**Global**	**Biofuels, RCFs**	**Contains criteria & compliance indicators to minimise ILUC risk**	**Another scheme that employs a management to ILUC and another certification scheme that is used on a global level (including certification against RED and CORSIA standards)**
RSB - CORSIA Certification	Certification	Global	SAFs (from biomass and solid waste)	Contains LCA specifications & quantification of ILUC impacts (specific to SAF)	The certification exists to comply with CORSIA and focus is better placed examining CORSIA directly.
RSB - EU RED Fuel Certification	Certification	EU	Biofuels	Contains sustainability criteria for biofuels, and methodologies on sustainable trade	The certification exists to comply with RED and focus is better placed examining RED directly

Scheme	Type	Geographical scope	Fuel/impact coverage	Relevance	Rationale for selection
International Sustainability and Carbon Certificate (ISCC)	**Certification/ voluntary standard**	**Global**	**All sustainable feedstocks (Biofuels, RFNBOs, RCFs, SAFs)**	**An international certification system covering a wide range of biomass-based fuels.**	**The most well-known certification scheme on a global level which covers nearly all feedstocks and fuels. This includes dedicated schemes for CORSIA and PLUS (biofuels from outside of Europe)**
ISCC EU	Certification	EU	All sustainable feedstocks (Biofuels, RFNBOs, RCFs, SAFs)	Fully compliant with RED and FQD ISCC EU is the most widely used certification scheme for biofuels.	A subset of ISCC focusing on compliance with RED. Although comprehensive inclusion of RED and ISCC (overall) was deemed a better approach.
CertifHy - Guarantees of Origin for Green Hydrogen	**Certification**	**EU**	**Hydrogen**	**Hydrogen specific**	**A dedicated scheme to RFNBOs, given their expected importance as future marine fuels exploring the design of their scheme could be interesting**
Bonsucro Production Standard	**Certification/ voluntary standard**	**Global**	**Sugar cane feedstock**	**Addresses ILUC risks associated with sugar cane feedstock; requires environmental impact management plan in place**	**A scheme focussed on addressing sustainability compliance from the sugar cane industry. Another risk-management approach to ILUC is through the use of environmental impact management plans**
Round Table on Responsible Soy Association – Standard for Responsible Soy Production	**Certification/ voluntary standard**	**Global**	**Soy feedstock**	**Compliance requirements to address ILUC risks associated with soy-based biofuel production**	**Soy is one of the more contentious feedstocks when it comes to fuel production. The inclusion of the compliance requirements from the certification scheme dedicated to soy feedstock fuels feels appropriate to ensure ILUC risks are captured fairly**
TUV Rheinland	Certification/ voluntary standard	Global	All fuels	Covers a broad range of processes and products.	TUV act more as a certification body and there is limited literature information on their voluntary standards.

APPENDIX 3 DETAILED ANALYSIS OF EXISTING REGULATORY FRAMEWORKS, VOLUNTARY STANDARDS AND CERTIFICATION SCHEMES

#1: RENEWABLE ENERGY DIRECTIVE (RED)

Scheme 1 – EU RED	
RED II: Full text[38] RED III: Full text[39]	
General Description	
RED II (Directive EU/2018/2001) was revised and entered into force in 2018 and has been legally binding since June 2021. The directive sets common principles and rules for renewable energy support schemes, sustainability criteria for biomass and the right to produce and consume renewable energy and to establish renewable energy communities. It also establishes rules to remove barriers, stimulate investments drive cost reductions in renewable energy technologies and empower citizens and businesses to participate in the clean energy transformation. RED III (EU/2023/2413) entered into force on 7th November 2023 and will be legally binding from 21 May 2025;[40] it will come into effect within 20 days of this date and be legally binding after 18 months. RED III is a revision to previous renewable energy directives. Within it, a new goal of achieving at least 42.5% total energy consumption by 2030 is outlined, compared to a target of 32% in RED II. The share of renewables required in the transport sector has increased in the RED III from 14% to 29%, or a 14.5% GHG intensity reduction target. Other requirements include new targets for the shift towards RFNBOs in transport, and away from crop biofuels to address the risk of ILUC, through the introduction of a 5.5% target for advanced biofuels and RFNBOs.	
Type of scheme	Regulatory frameworks
Responsible entity	European Commission
Use of scheme	Economic operators, participants whose scope includes either the TASCC Merchanting and/or TASCC Storage modules
Geographic coverage	European Union, Norway[41]
Fuel coverage	Biofuels, Renewable fuels of non-biological origin (RFNBOs), recycled carbon fuels (RCFs)
Sustainability criteria coverage	The policy includes eligibility thresholds for alternative fuels to qualify that are estimated on an LCA basis. GHG emission savings thresholds: • These include a 50%–65% GHG reduction threshold compared to fossil petroleum for biofuels, depending on the date of facility installation. • RED II specifies that advanced biofuels produced from Annex IX feedstocks should meet a 70% GHG emission-saving requirement starting in 2021. For installations that began operation before 2021, the GHG emission savings threshold from the 2020 RED still applies. • RFNBOs, such as electrofuels, and RCFs have a higher GHG reduction threshold of 70% to qualify. • Accounts for GHG emission via LCA calculations, using an energy allocation methodology for allocation of impacts to bioenergy.

[38] https://eur-lex.europa.eu/resource.html?uri=cellar:dbb7eb9c-e575-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF
[39] https://data.consilium.europa.eu/doc/document/PE-36-2023-INIT/en/pdf
[40] https://www.consilium.europa.eu/en/press/press-releases/2023/10/09/renewable-energy-council-adopts-new-rules/
[41] Norway, while not an EU member state, chooses to follow the directives outlined in RED III

	Carbon source sustainability criteria, for feedstock sourced from forest biomass: • Harvesting with legal permits • Protecting areas with high conservation value • Minimizing the impacts of forest harvesting on soil quality and biodiversity • Regenerating cleared forest • Harvesting without exceeding the long-term production capacity of the forest. Criteria for renewable electricity, per Delegated Regulation on Additionality (Article 5):[42] • Electricity counts as renewable if the renewable power plant and the electrolyser are co-located in the same installation or there is a direct connection between them, and electricity from the grid is not used for electrolysis. Moreover, the renewable electricity generator must not have come into operation more than 36 months before the electrolyser. • Electricity taken from the grid may be recognised as fully renewable if it meets the criteria of additionality, geographical correlation, and temporal correlation: • Additionality: Hydrogen producers must make sure that the electricity used for the production of hydrogen is matched by the production of renewable electricity in the same installation, and through a renewables power purchase agreement (PPA)
General Approach	REDIII uses the same GHG calculation methodology as RED II. This methodology allows for calculating the Carbon Intensity (gCO_2e/MJ_{fuel}) for a specific fuel production pathway. Default GHG emission values and calculation rules are provided in Annex V (for liquid biofuels) and Annex VI (for solid and gaseous biomass for power and heat production) of RED II. Economic operators have the option to either use default GHG intensity values provided in RED II or to calculate actual values for their pathway. It calculates GHG emissions from the production and use of biofuels as the total emissions from the extraction of cultivation of raw materials, from carbon stock changes caused by land-use change, from processing, from transport and distribution, and the fuel in use. From this, is subtracted the emission savings from soil carbon accumulation, carbon capture and geological storage, and excess electricity from cogeneration. Several negative emissions can reduce the total GHG emission value. These are, e.g., improved agricultural management methods allowing more carbon to be bound in the soil, excess electricity produced in the biofuel plant, CO_2 that is separated and geologically stored, and CO_2 that is separated and replaced. One example of a feedstock that gives negative CO_2 emissions is manure. There is also a GHG bonus if raw material is cultivated on severely degraded land. The RED II formula includes the direct emissions from land conversion and an option to credit farms for agricultural management practices that increase onsite soil carbon stocks.
Monitoring, reporting and verification	Compliance with criteria can be audited by all voluntary schemes and national schemes that are formally recognised by the European Commission. Interested voluntary schemes may apply for recognition by the commission under the sustainability framework and apply an assessment protocol[43]. An additional template is used for RFNBOs and RCF.[44] All voluntary schemes formally recognised by the EC are also accepted under ISCC EU.

[42] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM%3AC%282023%291087

[43] https://energy.ec.europa.eu/system/files/2022-04/Assessment%20Protocol%20template_REDII_Final%20version%20April%202022_v3.pdf

[44] https://energy.ec.europa.eu/system/files/2023-07/Assessment_Protocol_template_RFNBO.pdf

	Member States shall require economic operators to provide audited information establishing compliance with the harvesting criteria at national or sub-national level,[45] in relation to forestry biomass. To that end, economic operators shall carry out a risk-based assessment which provides accurate, up-to-date, and verifiable evidence of all the following elements: • Country (and sub-national region) of harvest • That the national law ensures the legality of harvesting operations, forest regeneration, and effective protection of areas designated by law, and that forest harvesting is carried out in a way that minimises negative impact on soil quality and biodiversity. • The existence of systems for ensuring the monitoring of implementation and enforcement of the national and sub-national laws • That there is no significant lack of enforcement of the national and/or sub-national laws and regulations

High-risk criteria 1 – ILUC risk

The Directive sets national limits at Member States' 2019 levels for the period 2021 - 2023, which after the 31st of December 2023 will gradually decrease to zero by 2030, for high ILUC-risk biofuels, bioliquids and biomass fuels produced from food or feed crops for which a significant expansion of the production area into land with high carbon stock is observed.

These limits will affect the amount of these fuels that can be counted when calculating the overall national share of renewables and the share of renewables in transport. Therefore, Member States will still be able to import and use fuels affected by the limits, but they will be able to consider them as renewable energy and count them for their renewable targets only up to the limits set in the Directive. The Directive introduces an exemption from these limits for biofuels, bioliquids and biomass fuels certified as low ILUC risk. The contribution of renewable fuels made from non-food feedstocks supplied to the maritime sector will count 1.2 times their energy count towards the 14% transport target, hence leading demand away from land-based crops.

The DA sets out criteria for determining high ILUC-risk feedstocks and certifying low ILUC-risk biofuels.[46] The following conditions apply to high ILUC-risk fuels:

- the global production area of the feedstock has increased annually by more than 1% and 100,000 hectares after 2008.
- more than 10% of such expansion has taken place on land with high carbon stock.

The following criteria apply to certify low ILUC-risk fuels, per Delegated Regulation (EU) 2019/807:[47]

- Feedstock can only be grown on unused land that is not rich in carbon stock
- Use of additional feedstock resulting from measures increasing productivity on the already used land, or from cultivating crops on areas which were previously not used for cultivation of crops (unused lands), provided that a financial barrier has been overcome, or the land was abandoned or severally degraded, or the crop has been cultivated by a small farmer.
- Raw material for biofuel production cannot be taken from primary forests, nature protection areas, highly biodiverse grassland, or land with high carbon stocks such as wetlands and peatlands. If the raw material for biofuel production is forest biomass, RED II defines different criteria to be fulfilled to minimise the risk of using raw material received from an unsustainable production.

High-risk criteria 2 – Renewable electricity/energy source

The Delegated Regulation on Additionality specifies criteria for renewable hydrogen, to avoid a situation where renewable electricity used for hydrogen production is diverted away from other uses, and to minimise GHG life-cycle emissions.

The act specifies that electricity used for hydrogen production is matched by the production of renewable electricity through a PPA, with operators producing renewable electricity. It also specifies that the renewable electricity produced must be matched in the same installation, with the generator coming into operation

[45] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R2448

[46] https://ec.europa.eu/commission/presscorner/detail/en/MEMO_19_1656

[47] Delegated Regulation (EU) 2019/807

within 36 months of the electrolyser, showing that the producers generate renewable electricity corresponding to the amount of hydrogen they claim as renewable.

In addition, the temporal and geographical correlation requirement between electricity consumption and generation helps to ensure additionality. The geographical correlation criteria check that the additional renewables are located in the area of hydrogen production. The temporal correlation criteria check that renewable electricity generation and hydrogen production coincide temporally. This helps minimise the risk of electricity is not produced via renewable sources.

#2: FUEL EU MARITIME LEGISLATION

Scheme 2 – Fuel EU Maritime Legislation	
Full text[48]	
General Description	
Fuel EU Maritime is a regulation which aims to support the decarbonization of the shipping industry. Upon entering into force on 1 January 2025, it will increase the share of renewable and low-carbon fuels in the fuel mix of international maritime transport in the EU. Fuel EU Maritime sets well-to-wake GHG emission intensity requirements on energy used on board ships trading in the EU from 2025; requires a decrease in GHG intensity of shipping fuels used on vessels over 5000 GT by 2% in 2025 to as much as 80% by 2050. It also mandates the use of shore power for container and cruise ships in certain EU ports from 2030. To incentivise the use of renewable and zero carbon fuels on ships over 5000 GT the Fuel EU regulation also includes[49]: a special incentive regime to support the uptake of renewable fuels of non-biological origin (RFNBO) with a high decarbonisation potential; an exclusion of fossil fuels from the regulation's certification process; an obligation for passenger ships and containers to use on-shore power supply for all electricity needs while moored at the quayside in major EU ports as of 2030, with a view to mitigating air pollution in ports, which are often close to densely populated areas; a voluntary pooling mechanism, under which ships will be allowed to pool their compliance balance with one or more other ships, with the pool – as a whole – having to meet the greenhouse gas intensity limits on average; time limited exceptions for the specific treatment of the outermost regions, small islands, and areas economically highly dependent on their connectivity; revenues generated from the regulation's implementation (Fuel EU penalties) should be used for projects in support of the maritime sector's decarbonisation with an enhanced transparency mechanism.	
Type of scheme	Regulatory frameworks
Responsible entity	European Commission
Use of scheme	Ship owners
Geographic coverage	EU, EEA
Fuel coverage	Marine fossil fuels, Biofuels, RFNBOs, RCFs
Sustainability criteria coverage	The FuelEU Maritime regulation seeks to require renewable marine fuels to be compliant with the same sustainability criteria outlined in the RED II, to disincentivise food-based fuels. It applies to the vessel owner as the obligated party, rather than the supplier, and also branches out to include other technologies which apply to the marine sector (e.g. onshore power). It introduces requirements that consider all GHG emissions generated by a given marine fuel (full life cycle), not just those used by the ship. Where biofuels, biogas, renewable fuels of non-biological origin and recycled carbon fuels, as defined in RED, are to be taken into account, the following rules apply:[50] • GHG emission factors of biofuels and biogas that comply with the sustainability and greenhouse gas saving criteria set out in Article 29 of RED (discussed prior in the summary of the RED II scheme) shall be determined according to the methodologies set out in that Directive; • GHG emissions factors of renewable fuels of non-biological origin and recycled carbon fuel that comply with the greenhouse gas emission savings thresholds set out in Article 27(3) of RED shall be determined according to the methodologies set out in that Directive;

[48] https://data.consilium.europa.eu/doc/document/PE-26-2023-INIT/en/pdf

[49] https://www.consilium.europa.eu/en/press/press-releases/2023/07/25/fueleu-maritime-initiative-council-adopts-new-law-to-decarbonise-the-maritime-sector/

[50] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021PC0562

	• biofuels and biogas that do not comply with point (a) or that are produced from food and feed crops shall be considered to have the same emission factors as the least favourable fossil fuel pathway for this type of fuel; • RFNBOs and recycled carbon fuels that do not comply with point (b) shall be considered to have the same emission factors as the least favourable fossil fuel pathway for this type of fuel. GHG emission saving thresholds: • WtW GHG intensity limits on energy used onboard ships trading in the EU from 2025, set as a percentage reduction relative to the fleet average GHG intensity in 2020 (91.16 gCO_2/MJ) • Ships must gradually reduce GHG emissions by cutting the amount of GHG in the energy they use by 2% as of 2025, 6% as of 2030, 14,5% as of 2035, 31% as of 2040, 62% as of 2045 and 80% as of 2050. The regulation also includes requirements for shore-side electricity infrastructure for ships to meet the zero-emission berth requirements (Annex III). A list of eligible zero-emission technologies include: • Fuel cells • On-board electricity storage • On-board electricity production from wind and solar energy
General Approach	Companies shall provide accurate and reliable data on the GHG emission intensity and the sustainability characteristics of biofuels, biogas, renewable fuels of non-biological origin and recycled carbon fuel, verified by a scheme that is recognised by the Commission in accordance with Article 30(5) and (6) of RED. This is performed via the submission of a FuelEU Monitoring Plan. This Regulation establishes the methodology and the formula that should be applied to calculate the yearly average greenhouse gas intensity of the energy used onboard a ship (Annex I). This formula is based on the fuel consumption reported by ships and considers the relevant emission factors of these fuels. The use of substitute sources of energy, such as wind or electricity, is also reflected in the methodology. The GHG calculation formula accounts for fuel emissions, emissions for electricity delivered to the ship, engine fuel slippage and fuel combustion emissions. Default values for WtT GHG factors on fossil fuels should be used (Annex II); for non-fossil fuels, values per Bunker Delivery Notes (BDNs) should be used, where they defer from the default values per Annex II. Companies shall be entitled to divert from the established default values for the tank-to-wake emission factors provided that actual values are certified using laboratory testing or direct emissions measurements.
Monitoring, reporting and verification	Shipping companies are required to submit to the verifier, a FuelEU Monitoring Plan, which sets out the methods for monitoring and reporting the amount of energy (fuel type and consumption) used by ships during voyages and berth. This should include information such as: • Ship's type/name/IMO number/shipowner and information of the shipping company; • Sources of Energy to be used on board while in navigation and at berth; • Procedures for monitoring the fuel consumption of each fuel type; • Procedures for monitoring the WtT and TtW emission factors of energy to be used; • Standards and characteristics of OPS or a zero-emission technology; and • Value of the established total electrical power demand of the ship at berth. The data and information that are recorded for the previous reporting year should be submitted to the verifier as a FuelEU Report for each ship. This should include the following information: • Departure and arrival ports (including date and time); • Amount of fuels used while at berth and at sea; and

	• Amount of electricity supplied to the ship through the OPS Based on the information provided in the FuelEU report, the verifier makes necessary calculations, including the following: • Yearly average GHG intensity of the energy used on board by the ship concerned; • Amount of the yearly energy from the RFNBO used on board by the ship; • GHG emissions for which the GHG intensity limit was achieved or not achieved; • Number of non-compliant port calls for the use of OPS. The Monitoring Plan is assessed for conformity with the requirements before the monitoring period starts and then recorded in the FuelEU database by the verifier. The verifier also identifies potential risks related to the monitoring and reporting process, and potential risks related to the different calculation steps. The verifier shall take into consideration any effective risk control methods applied by the company concerned to reduce levels of uncertainty associated with the accuracy specific to the monitoring methods used. The company concerned shall provide the verifier with any additional information that enables it to carry out the verification procedures, and the verifier may conduct checks during the verification process to determine the reliability of reported data and information.
High-risk criteria 1 – ILUC risk	
Through the inclusion of RED II criteria, FuelEU Maritime is also able to disincentivise the use of high ILUC risk feedstocks.	

#3: CALIFORNIA LOW-CARBON FUEL STANDARD (LCFS)

Scheme 3 – California Low-Carbon Fuel Standard (LCFS)	
Full text[51]	
General Description	
The Low Carbon Fuel Standard (LCFS) is one of nine early action measures implemented to reduce California's GHG emissions. The scheme is designed to decrease the carbon intensity of California's transportation fuel pool and provide an increasing range of low-carbon and renewable alternatives. This is done through encouraging the use of cleaner low-carbon transportation fuels and the production of those fuels. It requires providers of transportation fuels to declare the carbon intensity of their fuel and sets out benchmarks through to 2030, with the overall target of reducing the carbon intensity of transport fuels by 20% by 2030 from a 2010 baseline.	
Type of scheme	Regulatory frameworks
Responsible entity	State of California, Air Resources Board
Use of scheme	California Transportation Fuel Providers
Geographic coverage	California, United States
Fuel coverage	Fossil fuels, Biofuels, Electricity, Hydrogen
Sustainability Criteria Coverage	The standard covers GHG emissions, calculated through a life cycle assessment, including a land use change assessment. [52] • The GHG emissions account for energy inputs and outputs at each stage of the fuel's lifecycle and consider the energy output when the fuel is used in vehicles. This will change the carbon intensity output dependent on the carbon source. • Land use change is considered for various biofuels, with estimates of GHG emission made for various types of land conversions. This analysis considers the following: • Short-term release of GHG emitted from burning and/or decaying cover vegetation. • Slower release of carbon from disturbed soils (below-ground release). • Loss of carbon sequestration capacity of the cleared vegetation. • ILUC: The ILUC emissions value differs for various types of biofuels depending on land use type, irrigation, agricultural practices etc.
General Approach	The Low Carbon Fuel Standard uses a well-to-wheel life-cycle analysis to calculate the carbon intensity (CI) of different transport fuels. To calculate the carbon intensity of each fuel, the GHG emissions from every step of the fuel life cycle are considered. The CIs are calculated using a modified version of the GREET model, termed CA-GREET. The model uses additional inputs from other models, namely, OPGEE and GTAP/AEZ-EF to calculate the emissions from crude oil and land use change. The model can take into consideration the following sustainability metrics: • Energy Use: total energy, fossil energy and renewable energy. • Air Pollutants: VOC, CO, NOx, PM10, PM2.5, and SO_x, estimated separately for total and urban (a subset of the total) emissions. • Greenhouse gases: O_2, CH_4, N_2O, black carbon, and albedo, CO_2e of the five (combined with their global warming potentials). • Water consumption: water supply and demand and water stress impact.

[51] https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf

[52] https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/iluc_assessment/iluc_analysis.pdf

	The CA-GREET model includes the same information as GREET. However, in addition, it allows for specific regional inputs such as electricity mix, local feedstocks and local fuel production rather than US averages as used in GREET.
Monitoring, reporting and verification	The framework and principles of the LCFS verification program are consistent with the verification systems that support California Air Resources Board (CARB)'s cap-and-trade program. The verification program is based on ISO 14064-3 and 14065. • From 2019, verifiers will apply for CARB accreditation and take the required training and exam(s). The list of verification bodies accredited to perform LCFS verification is then made available on the LCFS website. • All entities that submit LCFS data used to calculate GHG emissions and reductions must attest to its accuracy. • Companies are required to submit their fuel data quarterly through California's Electronic Greenhouse Gas reporting tool, which is used to calculate the Carbon Intensity of the fuel.
High risk criteria 1	
The carbon intensity score for biofuels in the LCFS full life cycle analysis includes Indirect Land Use Change for biofuels: including indirect production via intermediate market mechanisms, such as ILUC. • To estimate the ILUC effects from biofuels, the Global Trade Analysis Project (GTAP) is used, where predicted land use change impacts are aggregated by affected land use type (forest and pasture) • Emission factors related to land conversion are considered using the AEZ-EF model. These emission factors provide average values of emissions per unit land area for carbon stores above and below ground as well as the annual amount of carbon sequestered by native vegetation. The amount of "lost sequestration capacity" per unit land area results from the conversion of native vegetation to crops. Additionally, LCFS Land Use Change analysis includes an uncertainty index. This uses the Monte Carlo Simulation (MCS) approach to evaluating uncertainty in ILUC analysis. This model: • Identifies the parameters and parameter groups contributing most of the variance to the resulting ILUC emissions value • Characterises the output distribution for the ILUC emission value for various types of biofuel.	

#4: RENOVABIO

Scheme 4 - RenovaBio	
Full text[53]	
General Description	
Brazil's National Biofuel Policy ("RenovaBio") aims to (i) comply with the commitments established under the Paris Agreement concerning the United Nations Framework Convention on Climate Change, (ii) contribute to the proper relation between energy efficiency and reduction of greenhouse gas emissions, (iii) promote the production and use of biofuels in the national energy mix and (iv) collaborate predictably for the competitive participation of biofuels in the Brazilian market. To accomplish its objectives, RenovaBio sets forth certain mechanisms, which include: (i) targets for the reduction of greenhouse gas emissions in the fuel mix, (ii) Decarbonisation Credits, (iii) Biofuel Certification, (iv) mandatory addition of biofuels to fossil fuels, (v) incentives on tax, finances and credits, and (vi) actions under the Paris Agreement. Regarding certification, the pathways of production of the following biofuels are eligible for the Certificate of Efficient Production of Biofuels: biodiesel; biomethane; alternative fuel synthesised from hydro-processed esters and fatty acids (HEFA); first-generation ethanol fuel produced from sugarcane; first- and second-generation ethanol fuel produced in an integrated plant; second-generation ethanol fuel; first-generation ethanol fuel produced from sugarcane and corn in an integrated plant; first-generation ethanol fuel produced from corn; and imported first-generation ethanol fuel produced from corn.	
Type of scheme	Regulatory frameworks/ voluntary scheme
Responsible entity	Brazilian government
Use of scheme	Economic operators of biofuels
Geographic coverage	Brazil
Fuel coverage	Biofuels
Sustainability Criteria Coverage	The sustainability criteria for biomass include the following: • All certified production must come from an area without deforestation after the date of enactment of the RenovaBio law (December 26, 2017); • The entire area must comply with the Forest Code, through the regularization of the Rural Environmental Registry; and, • The sugar cane and palm production areas should comply with the agroecological zoning of sugarcane and oil palm, as defined by Federal Decrees 6961 and 7172, respectively. The regulatory framework also specifies GHG emissions savings requirements via a decarbonisation target of 620 million tons of CO_2e emissions reduction in the transport sector within 10 years. RenovaBio also incentivises the use of residues as feedstock for biofuels, which are exempt from complying with eligibility criteria, due to its low-LUC risk.
General Approach	RenovaBio uses RenovaCalc as a process-based attributional LCA framework and tool. This is used to quantify direct GHG emissions of biofuels across their entire cycle, including feedstock production, material inputs, feedstock conversion, distribution, and use. The main principle of the LCA methodology is to calculate the CI of biofuels on a consistent gCO_2e/MJ basis and compare it with those from the equivalent fossil fuel.[54] The baseline CI of fossil fuels is based on literature values. The LCA methodology is based on three life-cycle guidelines currently available in Brazil: ISO 14040:2014, ISO 14044:2014, and ISO/TS 14067:2015. The aim is to generate a

[53] https://www.gov.br/anp/pt-br/assuntos/renovabio/arq/law-13576-2017.pdf

[54] https://theicct.org/publication/marine-lca-fuels-apr23/

	biofuel CI value that is subtracted from the fossil fuel CI, resulting in the Energetic-Environmental Biofuel Index (NEEA). The NEEA reflects the individual contribution of each production agent in terms of its mitigation of GHGs compared to the fossil fuel substitute in terms of tonnes of CO_2e. To convert the NEEA, given in gCO_2e/MJ, into CBIO, which is given in tonnes of CO_2e avoided, NEEA is multiplied by the eligible volume of biofuel. Overall, the approach aims to reduce carbon intensity by expanding the use of biofuels and creating a carbon credit market to offset GHG emissions by fossil fuels.
Monitoring, reporting and verification	Participation in the Brazilian Biofuel Policy (RenovaBio) is voluntary for producers and importers of biofuels. RenovaBio relies primarily on accredited verifiers and their own verification procedures. Verification bodies must be accredited with ANP (The Brazilian National Agency for Petroleum, Natural Gas and Biofuels). The list of verification bodies accredited under this Resolution is published and kept updated on the ANP website.[55] Chapter IV sets out further requirements for accreditation of a verification body, which includes the submission of an accreditation request to the National Agency of Petroleum, Natural Gas, and Biofuels. The Certificate of Efficient Production of Biofuels is a document issued exclusively by a verification body as a result of the Biofuel Certification process and that expressly includes the Energy Environmental Efficiency Rating of the primary issuer. This is granted specifically to each biofuel-producing unit. The producer and the importer of biofuel, participants in RenovaBio, are required to provide all information necessary for the calculation of the Energy-Environmental Efficiency Rating, and the eligible fraction of the biofuel volume, included in the phases of generation, treatment, and conversion of biomass into biofuel. Producers must provide specific data each year to prove eligibility in the RenovaBio program, with deadlines for annual monitoring and the requirement to renew certification if the eligible biofuel volume decreases by more than 10%. The use of sustainability certifications can ensure biofuel production occurs on cropland or marginal land and reduce the risk of direct deforestation and emissions from direct land-use change for the land where biomass for biofuels is produced; however, these protections often fail to mitigate the impacts of ILUC.

High-risk criteria 1 – ILUC risk management

The RenovaBio policy uses life cycle GHG accounting to evaluate the climate impacts of fuels and incorporates sustainability criteria (mentioned above) to avoid the use of biofuels directly grown either on high–carbon stock land or in areas tied to deforestation.[56] It also incentivises the use of residues, creating less demand for land.

It should be noted that the GHG accounting does not account for any ILUC emissions. Brazil's government has decided to exclude explicit ILUC emissions accounting from the RenovaBio program because of these emissions' uncertainty and the perception that Brazil's existing land protections are sufficient to mitigate deforestation. However, this is addressed by risk management mechanisms through the eligibility criteria discussed above.

A briefing on the policy sets out the following recommendations on how Brazil's policies could support more sustainable alternative fuels:

- Introduce sub-targets or ILUC factors within RenovaBio to facilitate greater deployment of advanced biofuels. This would allow producers to generate more tradeable decarbonization (CBIO) credits relative to first-generation fuels. Alternatively, a sub-target for advanced fuels—defined as those produced from wastes, residues, or lignocellulosic feedstocks—would provide a separate incentive for advanced biofuels within RenovaBio without substantial changes to its life-cycle analysis methodology. The contribution of high ILUC feedstocks could be excluded or limited by establishing a threshold for deforestation for total production of that feedstock in Brazil, for a producer to generate CBIO credits in the RenovaBio program.

[55] https://www.gov.br/anp/pt-br/
[56] https://theicct.org/sites/default/files/publications/ICCT_Brazil_lowcarbon_fuel_opp_20190726.pdf

- Incorporate sustainability criteria to mitigate indirect land conversion within RenovaBio. This could include eligibility requirements for land conversion for a given feedstock to fall below a threshold for deforestation, which could eliminate risky feedstocks such as oilseeds from being able to generate CBIO credits, thus directing the program support toward feedstocks with better greenhouse gas performance.

#5: BONSUCRO PRODUCTION STANDARD

<table>
<tr><th colspan="2">Scheme 5 – Bonsucro Production Standard</th></tr>
<tr><td colspan="2">Full text[57]</td></tr>
<tr><th colspan="2">General Description</th></tr>
<tr><td colspan="2">The Bonsucro production standard is a global framework for sustainable sugarcane production. It is a metric tool that enables farmers and millers to improve and certify their practices as sustainable, while also offering buyers assurance when sourcing their sugarcane and derivatives.

The standard contains principles and criteria for achieving sustainable production of sugarcane and all sugarcane-derived products. Its primary purpose is to define a set of principles, criteria and indicators, for the assessment of the performance of operators against economic, social and environmental pillars of sustainability.</td></tr>
<tr><td>Type of scheme</td><td>Certification/Voluntary Standard</td></tr>
<tr><td>Responsible entity</td><td>Bonsucro</td></tr>
<tr><td>Use of scheme</td><td>Sugarcane producers</td></tr>
<tr><td>Geographic coverage</td><td>Global</td></tr>
<tr><td>Fuel coverage</td><td>Biofuels (Sugar cane feedstock)</td></tr>
<tr><td>Sustainability Criteria Coverage</td><td>Greenhouse gas emissions, carbon sources and carbon stock are considered under the required Bonsucro Sustainability Management Plan that sets out objectives and targets required to comply with the Bonsucro Production Standard.
Key sustainability objectives:
Impact and efficiency of production and processes while monitoring global emissions. It requires operators to estimate their emissions from agricultural activities and ensure GHG emissions are below the metric threshold.
The management of biodiversity and ecosystem services and maintenance of areas of high conservation value (HCVs).
Operators are required to conduct a land-use change analysis of the unit of certification to determine if land classified as a legally protected natural ecosystem, or as HCV, has been converted to sugarcane.
Implementation of a soil management plan to prevent erosion and improve soil health
Water stewardship plan and pest, disease and weed management plans
Reduction of emissions and effluents and promoting the recycling of waste streams</td></tr>
<tr><td>General Approach</td><td>Bonsucro ‘calculator’ is used to assess sustainability performance measurement. This is a system of indicators that provides information needed to help in controlling, planning, and performance of the economic, environmental, and social activities undertaken by a corporation
Evaluate performance against the Bonsucro Production Standard which is divided into three pillars of sustainability: environmental, social and economic.
Operators can compare their performance with certified operations and seek advice on improving their results
Specific criteria for input, production, and processing efficiencies to enhance sustainability include:</td></tr>
</table>

[57] https://bonsucro.com/wp-content/uploads/SCH_Bonsucro-Production-Standard-V5.2-July-2023-ENG.pdf

	• The operator must conduct a climate risk assessment and ensure that a Climate Change Mitigation and Resilience Plan is in place. As part of this plan, operators must set baseline emissions and absolute reduction targets with a goal of continuous improvement. • Ensuring that GHG emissions per tonne of cane calculated using the Bonsucro calculator are below the metric threshold, including emissions from industrial activities (emissions are field-to-gate). • Development of a Soil Management Plan (SMP) where they identify practices aimed at preventing, mitigating, remedying and reducing soil degradation for each management unit.
Monitoring, reporting and verification	Bonsucro has two standards for certification, one on the production end of the supply chain and one on the trading side. The Production Standard helps farmers and mills measure activity alongside key environmental and social impacts. The chain and custody standard relates to the supply of the product, including feedstock production to consumption. For their production standard, mills and their supplying areas report metric-based performance indicators with the principles of the standard using the 'Bonsucro Calculator'. Performance monitoring of certified producers is conducted using the data reported. This data is then verified by certification bodies, specific to the region mills/suppliers are located in. Certification bodies are required to hold accreditation to ISO IEC Guide 65/EN 45011 (1998) and operate at least one accreditation scheme which is relevant to the sustainability criteria as required by the Bonsucro Production Standard. Additional accreditation against IS_O 14065:_2007 IDT and experience in carrying out audits in conformity with IS_O 14064-3 is recommended but not mandatory. Further, Bonsucro works in collaboration with other third-party certification bodies (e.g., Preferred by Nature, GXQT) to carry out audits and certifications for their members.
High-risk criteria 1 – ILUC Risk Management	
Bonsucro identifies several indicators related to land-use management and analysis as related to the effects of biodiversity loss. This forms part of their fourth principle to "actively manage biodiversity and ecosystem services". • Indicator 4.1.3. requires that operators ensure that no areas of natural ecosystems defined internationally or nationally as legally protected have been converted to agriculture. • Indicator 4.1.4: Land use change analysis is also required for land converted on or after the 1st of January 2021. Minimal levels of conversion are permissible if they are negligible in the context of a given site and if it does not significantly affect the value of natural ecosystems. Additionally, before expansion or new agricultural projects, the operator must conduct a 'Bonsucro Risk Assessment for expansion' • Indicator 4.1.5: operators must ensure that cane expansion is from non-HCV (High Conservation Value) areas following certification. This ensures that HCV areas are protected and maintained by removing the possibility of agricultural expansion into natural ecosystems, such as forests, natural grasslands, wetlands etc. If HCV risk assessments reveal a high risk, a full HCV assessment by an HCVRN-licensed assessor should be conducted.	

#6: STANDARD FOR RESPONSIBLE SOY PRODUCTION

Scheme 6 – Round Table on Responsible Soy (RTRS) - Standard for Responsible Soy Production	
Full text[58]	
General Description	
The Round Table on responsible soy production is a global multi-stakeholder organization created in 2006 with more than 160 international members of the soy value chain. The main objectives are to promote the growth of production, trade, and use of responsible soy through cooperation with actors in and relevant to the soy value chain from production to consumption, including producers, suppliers, manufacturers, etc. It sets a standard for responsible soy through a certification scheme that ensures RTRS soy meets its environmental criteria (including a guarantee of third-party-verified zero deforestation) but also a wide reaching set of social and labour requirements.	
Type of scheme	Certification / Voluntary Standard
Responsible entity	Round Table on Responsible Soy (RTRS)
Use of scheme	Production of soy for human consumption, animal feed, and biofuels
Geographic coverage	Global
Fuel coverage	Biofuels (Soy Feedstock)
Sustainability Criteria Coverage	The standard requires producers to consider emissions, source of electricity, carbon stock and effects on the environment as part of their qualifications. Energy considerations are integrated into their energy and water scarcity considerations, making systems more efficient and irrigation systems more sustainable. Regarding GHG Emissions, producers must make efforts to reduce emissions and increase the sequestrations of GHG. While no formal target is enforced, farms must ensure that the direct fossil fuel use over time is recorded, and the volume per hectare and per unit of product related to soy production is monitored. Producers are required to ensure that the expansion of soy cultivation is responsible, specifically regarding ensuring land is not cleared of native habitat except when in line with an RTRS-approved map and system as per: Indicator 4.4.1 on conservation of High Conservation Value Areas (HCVAs) (see High-Risk Criteria) Agricultural practices must ensure that the quality and supply of surface and groundwater are maintained and avoid the drift of agrochemicals. Additionally, the standard requires products to implement a plan that contains targets for the reduction of potentially harmful phytosanitary products, as part of their good agricultural practice requirements.
General Approach	The standard uses its five main principles and 108 mandatory progressive compliance indicators to determine certification across the entire supply chain. These requirements and procedures are to be complied with by producers and assessed by certification bodies. The main principle of the RTRS methodology is that once a producer is certified they are granted 'RTRS credits', a certification that attests to the responsible conditions of production. One ton of RTRS-certified soy is equivalent to one credit. These credits can then be sold to different organizations
Monitoring, reporting and verification	The unit of certification is the farm on which soy is cultivated and shall be limited by the farm boundaries. This standard has been designed to be used within a voluntary certification system; therefore, those seeking certification are

[58] https://responsiblesoy.org/wp-content/uploads/2023/07/RTRS-Standard-Responsible-Soy-production-1st-DRAFT-4.0.pdf

	committing to transparency concerning the requirements of the standard, including a publicly available summary of the farm's performance. Some indicators of the standard require monitoring. In these cases, a baseline is established at the time of certification, with monitoring and review of trends taking place over time. Monitoring and Evaluation (M&E) System The components of this system involve the following: • Theory of change; describes the mid-and long-term objectives and expected outcomes/impacts from the implementation of RTRS • Impact indicators; used to measure the environmental and socio-economic impact of the implementation • Data collection process; used to feed data into the impact indicators, may be collected by auditors • Impact evaluation and reporting process, RTRS informs constituencies and the larger public about its actual (vs. expected) outcomes and impacts. Certification bodies are responsible for auditing and certifying RTRS standards through qualified RTRS lead auditors. The certification bodies are in turn accredited by National Accreditation bodies. Accreditation bodies must be operating in accordance with the requirements of ISO 17011:2004 to be endorsed by RTRS. • National Accreditation bodies must be: Signatory Members of the International Accreditation Forum, Inc. (IAF), and members of the IAF Multilateral Recognition Arrangement (MLA), having been admitted to the MLA as signatory members in either the QMS (quality management system) MLA or Product MLA category. • International Accreditation Bodies must have full membership of the International Social and Environmental Accreditation and Labelling Alliance (ISEAL).
High-risk criteria 1 – ILUC	
RTRS developed EU Red Compliance Requirements for the supply chain. Part of this scheme will allow soy producers and processors to meet the requirements for supplying soy-based biomass, biofuels and/or bioliquids to European Union member states. This requires producers to address specific requirements on ILUC, greenhouse gas calculations and traceability of their product.[59]	

[59] https://responsiblesoy.org/wp-content/uploads/2022/05/RTRS-EU-RED-Compliance-Procedure-for-the-Supply-Chain-V3.8_ENG-12-4.pdf

#7: CARBON OFFSETTING AND REDUCTION SCHEME FOR INTERNATIONAL AVIATION (CORSIA)

Scheme 7 - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)	
Full text[60]	
General Description	
CORSIA is a global market-based measure, offering a harmonised way to reduce emissions from international aviation, minimising market distortion, while respecting the special circumstances and respective capabilities of ICAO Member States. CORSIA complements the other elements of the basket of measures by offsetting the amount of CO_2 emissions that cannot be reduced through the use of technological improvements, operational improvements, and sustainable aviation fuels with emissions units from the carbon market.	
Type of scheme	Voluntary Standard
Responsible entity	International Civil Aviation Organization (ICAO)
Use of scheme	Airline operators (with annual emissions > 10,000 tonnes of CO_2)
Geographic coverage	Global (125 participating states)
Fuel coverage	Sustainable aviation fuels (SAFs), low carbon aviation fuels (LCAFs)
Sustainability criteria coverage	Sustainability criteria: Land carbon stock, water quality and availability, soil health, air quality, biodiversity conservation, waste and chemicals management, human labour, land use and water use rights, and food security. Specific indicators: • GHG: CORSIA SAF will achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis. • Carbon source: CORSIA SAF will not be made from biomass obtained from land converted after 1 January 2008 that was primary forests, wetlands, or peatlands and/or contributes to the degradation of the carbon stock in primary forests, wetlands, or peatlands as they have high carbon stocks. In the event of land-use conversion after 1 January 2008, as defined based on the Intergovernmental Panel on Climate Change (IPCC) land categories, direct land-use change (DLUC) emissions will be calculated. If DLUC's greenhouse gas emissions exceed the default Indirect land-use change (ILUC) value, the DLUC value will replace the default ILUC value.
General Approach	Applies a process-based attributional LCA approach to account for GHG emissions. The system boundary includes all processes along the fuel production supply chain with significant GHG emissions: feedstock cultivation/collection, feedstock transportation, jet fuel production (conversion), jet fuel transportation, and jet fuel combustion.[61] The CORSIA scheme includes a set of default LCA values for a variety of SAFs and the guidelines to develop LCA values for individual fuel producers based on site-specific data. Direct emissions are estimated primarily using an attributional LCA approach and ILUC emissions are estimated using a consequential approach. The sum of emissions estimated using both methods is compared with the baseline emissions values for petroleum jet fuel. The baseline values are

[60] https://www.icao.int/environmental-protection/CORSIA/Documents/Forms/AllItems.aspx?RootFolder=%2Fenvironmental%2Dprotection%2FCORSIA%2FDocuments%2FCORSIA%5FEligible%5FFuels&FolderCTID=0x0120001E0668FDCEB3914CB43AEE6773BAE9C0&View=%7B2F6075F3%2D7C75%2D4DEA%2D9C62%2D37A41C41848A%7D

[61] European Commission (2023), *Support study on the life-cycle analysis of alternative fuels at International Maritime Organization*, Politecnico di Torino.

	defined in the CORSIA methodology (Annex 16) and are 89 gCO_2e/MJ for jet fuel and 95 gCO_2e/MJ for aviation gasoline. From a methodological standpoint, the SAFs produced from primary and co-product feedstocks, all GHG emissions resulting from the use of energy and chemicals for the cultivation of feedstocks are included in the LCA. For feedstocks categorised as residues, waste, and by-products feedstocks, no upstream emissions burden before collection, recovery, and extraction are included in the LCA of SAFs. Note that the ILUC is only applicable to crops and not to feedstock classes of residues, wastes or by-products.
Monitoring, reporting and verification	CORSIA allows for certification by the International Sustainability and Carbon Certification (ISCC) and the Roundtable on Sustainable Biomaterials (RSB). Sustainability Certification Schemes (SCS) requires bodies to be accredited to ISO standard 17065 by an accreditation body operating in compliance with ISO 17011. • SCS requires that certification bodies conduct assessments of GHG LCA values in line with ISO 14064-3. • SCS requires that certification bodies conduct audits in line with ISO 19011. • The SCS requires that certification bodies being recognised within its CORSIA certification programme, apply the audit objectives to meet CORSIA certification requirements

High-risk criteria 1 – ILUC accounting
Employs a global LCA framework for offsetting emissions from flights; within the methodology is included an approach to quantify ILUC emissions. CORSIA estimates ILUC emissions and complements it with sustainability criteria, to reduce the impact of direct land-use change (e.g. prohibiting the use of lands with high carbon stock). To account for ILUC emissions, CORSIA uses a set of ILUC values which are added to the default core LCA values for various feedstocks. Feedstocks that are specified as 'low risk' for LUC have been assigned with an ILUC value of zero. To use actual values, as opposed to default values, an aeroplane operator must use an eligible sustainability certification scheme.[62]. Aeroplane operators can choose to capture the benefits of utilizing land use change-risk mitigation practices, (e.g., land management practices) to avoid ILUC emissions as part of an accepted fuel sustainability certification process.[63] Such mitigation practices and the requirements for these are discussed in Section 5 of the LCA calculation methodology report.[64]

[62] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2004%20-%20Approved%20SCSs.pdf

[63] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2003%20-%20Eligibility%20Framework%20and%20Requirements%20for%20SCS.pdf

[64] https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions.pdf

#8: ROUNDTABLE ON SUSTAINABLE BIOMATERIALS

Scheme 8 - Roundtable on Sustainable Biomaterials (RSB)	
Full text[65]	
General Description	
The Roundtable on Sustainable Biomaterials (RSB) standard is a global certification system that promotes the sustainable production and use of biomaterials. It provides a framework for assessing the environmental, social, and economic sustainability of biomaterials throughout their entire supply chain. The standard sets out general requirements for operations producing, converting and processing biomass, biofuels or biomaterials in the RSB certification system. Two types of operators are subject to the sustainability requirements within this standard: (i) Biomass producers such as farmers and plantation or forest managers, and (ii) Industrial operators such as feed-stock processors, intermediary producers, biofuel or biomaterial producers.	
Type of scheme	Certification/voluntary standard
Responsible entity	Roundtable on Sustainable Biomaterials Roundtable
Use of scheme	Producers of biomaterials
Geographic coverage	Global
Fuel coverage	Biofuels, SAF
Sustainability criteria coverage	The RSB principles are general tenants of sustainable production which are then supplemented with criteria that describe the conditions to be met. These vary from immediate targets to more long-term progress requirements. These principles and criteria cover the following sustainability criteria: conservation, GHG emissions, soil, water, waste management, and air quality. • Biofuels are required to have on average 50% lower lifecycle greenhouse gas emissions relative to the fossil-fuel baseline (60% for new installations) • Maintaining or enhancing conservation values of local, regional or global importance within the potential or existing area and respecting 'no conversion' areas (e.g., land with high carbon stock such as Wetlands or Peatland) • Soil's physical, chemical and biological conditions should be maintained or enhanced • Implementation of a water management plan including annual monitoring of its effectiveness • Minimization of air pollutant emissions and the phase-out of open-air burning of agricultural residue.
General Approach	Planning, Monitoring and continuous improvement • Context-specific impact assessments to ensure sustainability through the development of effective and efficient implementation, mitigation, monitoring and evaluation plans. Greenhouse gas emissions • GHG emissions methodology considers a lifecycle analysis of the production and consumption of biomaterials. • Various options used to calculate GHG emissions including Biograce, GREET, GHGenius and EU default values.

65 https://rsb.org/wp-content/uploads/2020/06/RSB-STD-01-001_Principles_and_Criteria-DIGITAL.pdf

	• Lifecycle GHG emissions of biofuel calculated by using system boundaries from Well to Wheel, including GHG emissions from land-use change (above and below-ground carbon stock changes).
Monitoring, reporting and verification	RSB has developed specific certification solutions for different contexts Two procedures for RSB standards exist the 'global' and 'EU RED', the main difference being their land conversion requirements for EU trading.. RSB approved auditors review documents and submitted documentation such as GHG calculations and chain of custody procedures. The RSB assurance system comprises: • The RSB accreditation body • Certification bodies • Auditors who are either employed or subcontracted by CBs. RSB uses ASI-Assurance Services International to act as accreditation body and conduct accreditation activities in line with ISO 17011. Compliance is verified by RSB-accredited certification bodies at the level of criteria and minimum/progress requirements. RSB is a member of ISEAL, it therefore follows ISEAL standard-setting code. It also follows ISO/IEC Guide 59:1994 (code of good practice for standardisation) RSB additionally involves stakeholder engagement as part of their monitoring process, including input from local communities, NGOs and other relevant parties who provide feedback and information related to a certified member's performance. The engagement must follow participatory methodologies described in the RSB Impact Assessment Guidelines (RSB-GUI-01-002-01).
High risk criteria 1	
To minimise the occurrence of indirect land use change, the RSB developed an additional module for low ILUC risk biomass. This is an optional requirement that encourages operators to willingly demonstrate that their operations have a low ILUC risk, meaning they are unlikely to cause any displacement of equivalent biomass production to another location. [66] Three approaches: i. Yield increase: demonstrate that additional biomass was produced through an increase in yield compared to a reference date, without any additional land conversion. ii. Unused/degraded land: Operators demonstrate that biomass was produced from land that was not previously cultivated or considered arable. iii. Use of waste/residues: operators demonstrate that the raw material used is derived from existing supply chains and does not require dedicated production	

[66] https://rsb.org/wp-content/uploads/2020/06/RSB-STD-04-001-ver-0.3-RSB-Low-iLUC-Criteria-Indicators.pdf#:~:text=In%20order%20to%20minimise%20the%20occurrence%20of%20indirect,of%20an%20equivalent%20biomass%20production%20to%20another%20location.

#9: INTERNATIONAL SUSTAINABILITY AND CARBON CERTIFICATION (ISCC)

<table>
<tr><th colspan="2">Scheme 9 – International Sustainability and Carbon Certification (ISCC)</th></tr>
<tr><td colspan="2">Full text[67]</td></tr>
<tr><th colspan="2">General Description</th></tr>
<tr><td colspan="2">An international certification system covering a wide range of sustainable feedstocks for renewable fuels, including agricultural and forestry biomass, biogenic wastes and residues, circular materials and renewables. ISCC offers several schemes, including the following: ISCC EU for certification of fuels meeting RED and FQD requirements; ISCC Plus for markets outside the EU and non-transport fuel products; and ISCC CORSIA for certification for sustainable fuels to CORSIA standard. ISCC promotes biomass, bio-energy and social sustainability among farmers and processors to respect climate and the environment. ISCC standards cover the entire biomass supply chain from the farm and plantation towards warehouses or logistics points to conversion unions and to the final user.</td></tr>
<tr><td>Type of scheme</td><td>Sustainability Certification</td></tr>
<tr><td>Responsible entity</td><td>ISCC System</td></tr>
<tr><td>Use of scheme</td><td>Operators of sustainable feedstock operators (e.g., producers, traders)</td></tr>
<tr><td>Geographic coverage</td><td>Global (>120 countries)</td></tr>
<tr><td>Fuel coverage</td><td>Biofuels, RFNBOs, RCFs</td></tr>
<tr><td>Sustainability criteria coverage</td><td>There are six principles set out in ISCC 202,[68] on sustainability requirements for biofuels:
1. Protection of Land with High Biodiversity Value or High Carbon Stock; biomass shall not be produced on land with high biodiversity if areas are converted after January 2008. This principle covers the requirements of RED II.
2. Environmentally Responsible Production to Protect Soil, Water and Air; environmental impact assessments must be undertaken for any new projects associated with intensive agricultural cultivation on uncultivated lands (including semi-natural areas), water-related management, and livestock operations.[69] The assessment must address a project's potential direct and indirect impacts on human populations, fauna and flora, soil, water, air, climate and the landscape, material assets and cultural heritages and interactions among all these factors.
3. Safe Working Conditions
4. Compliance with Human, Labour and Land Rights.
5. Compliance with Laws and International Treaties
6. Good Management Practices and Continuous Improvement
Requirements regarding GHG emission savings in ISCC 205[70] provide the options for stating greenhouse gas (GHG) emission values along the supply chain and provide the methodology, rules and guidelines for calculating and verifying GHG emissions and emission reductions.
Requirements concerning traceability and mass balance include:[71]
• Minimum requirements for the management system of a certified operational unit, and the requirements for documents such as Sustainability Declarations and Self-Declarations for farms/plantations and points of origin. The approach for the group certification of farms/plantations, points of origin and storage facilities are also covered.</td></tr>
</table>

[67] https://www.iscc-system.org/certification/iscc-documents/iscc-system-documents/

[68] https://www.iscc-system.org/wp-content/uploads/2022/05/ISCC_202_Sustainability_Requirements_3.1.pdf

[69] https://www.iisd.org/ssi/wp-content/uploads/2019/09/Biofuels_publications-1.pdf

[70] https://www.iscc-system.org/wp-content/uploads/2022/05/ISCC_EU_205_Greenhouse-Gas-Emissions-v4.0.pdf

[71] https://www.iscc-system.org/wp-content/uploads/2022/05/ISCC_EU_203_Traceability_and_Chain-of-Custody-v4.0.pdf

	• Requirements for the chain of custody methods of physical segregation and mass balance cover the physical handling of materials and the respective bookkeeping, including the mass balance calculation and credit transfer. There are also requirements for allocating sustainability criteria to outgoing batches of material on sustainability declarations.
General Approach	Any actual GHG calculation shall be done following the methodology of ISCC 205. If a fuel production process produces one or more products, the greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content (determined by the lower heating value in the case of co-products other than electricity). When products of a fuel production process are used internally, the (direct and indirect) emission factors used shall reflect the characteristics of the products (i.e. if it is handled as bio-based or fossil-based the product is awarded in the bio-yield calculation, only bio-based products can be regarded as bio-based in the GHG calculation.
Monitoring, reporting and verification	ISCC audits are undertaken by auditors to provide ISCC certification. The various procedures to be complied with under the different schemes are documented here. Certification bodies have to conform to the following criteria to be an approved auditor: • Follow the principles of ISO/IEC 17065 establishing requirements for product certification or ISO/IEC 17021 establishing requirements for management system certification. • CBs must be recognised by a competent national public authority or must be accredited against ISO/IEC 17065 or ISO/IEC 17021 establishing requirements for bodies operating product certification systems. Recognition of certification bodies: • Accreditation must be performed by a national accreditation body which is a member of the International Accreditation Forum (IAF), by the bodies referred to in Article 4 of Regulation (EC) No. 765/2008, by bodies having a bilateral agreement with the European co-operation for Accreditation (EA), or by an accreditation body which complies with ISO/IEC 17011 (this can be demonstrated if the accreditation body is a full member or associate member of ISEAL). Monitoring data requirements include the following: • Basic data - e.g. on farm/plantation, point of origin, chain of custody. • Management system – e.g. whether the system is appropriate to operations, information distributed to relevant parties. • Traceability – the risk of flawed documentation must be evaluated. • Mass balance system/ calculation • GHG emissions and calculation – application of default values, disaggregated default values or actual values.
High-risk criteria 1 – ILUC	
ISCC promotes the use of low ILUC risk fuels, RFNBOs and RCFs, leading the demand away from land-based crops.	

#10: CERTIFHY - GUARANTEES OF ORIGIN FOR GREEN HYDROGEN

Scheme 10 – CertifHy	
Full text[72]	
General Description	
CertifHy is a trading standard for renewable hydrogen in the EU. CertifHy has developed quality hydrogen certification schemes across Europe, CertifHy certificates, that will enable consumers to track hydrogen's origin and environmental attributes.	
Type of scheme	Certification
Responsible entity	CertifHy
Use of scheme	Stakeholders in the Hydrogen supply chain
Geographic coverage	European Union
Fuel coverage	Hydrogen
Sustainability criteria coverage	• The GHG footprint of the hydrogen production batch of a maximum of 12 months is equal to or lower than a specified limit of 36.4 gCO_2e/MJ (based on the lower calorific value) which represents a reduction of 60% compared to the benchmark process (current footprint of 91 gCO_2e/MJ. • The input energy for hydrogen production must be renewable as defined by RED/ RED II;
General Approach	GHG intensity is based on CO_2 emissions of the entire production pathway (well-to-gate), to produce hydrogen. CertifHy develops a dedicated GHG allocation method for each production pathway. Each GO represents 1 MWh of green, grey or renewable hydrogen, and hydrogen from different sources can be mixed. CertifHy uses a book-and-claim approach to the chain of custody because it is thought to reduce management costs and be simpler to implement than the segregated or mass balance approaches. This is in line with the Delegated Regulation on GHG Savings,[73] which establishes a method for calculating the lifecycle GHG emissions savings achieved (as discussed in the RED II scheme above). The methodology defines the total lifecycle emissions from the use of the fuel as the sum of emissions from the supply of inputs, including electricity, processing, transport and distribution, and combusting the fuel in its end use minus any emissions savings from CCS. Emissions from the manufacture of machinery and equipment are not taken into account.
Monitoring, reporting and verification	CertifHy has established a system of electronic certificates, called Guarantee of Origin (CertifHy GO) certificates.[74] These are electronic documents providing proof that a given quantity of hydrogen is produced by a registered production device, with a specific quality and method of production. Auditors, as part of a certification body with a relevant accreditation, ensure that the producers comply with CertifHy scheme requirements. Any accreditation body in Europe – a member of the International Accreditation Forum – is allowed to accredit certification bodies. Auditors must possess technical knowledge (2 years' experience working with hydrogen) and good understanding of the audited activities, sufficient to assess and manage risks. Proficiency in English. Adhere to ISO 19011 and be qualified to carry out external audits.

[72] https://www.certifhy.eu/wp-content/uploads/2022/06/CertifHy_Scheme-Document_V2.0_2022-04-28_endorsed_CLEAN.pdf
[73] https://energy.ec.europa.eu/publications/delegated-regulation-minimum-threshold-ghg-savings-recycled-carbon-fuels-and-annex_en
[74] https://www.certifhy.eu/wp-content/uploads/2022/06/CertifHy_P1.1_CC-Issuing_V2.0_2022-04-28_endorsed_CLEAN.pdf

High-risk criteria 1 – renewable electricity/energy source
CertifHy contains criteria to ensure that input energy for hydrogen production is renewable as defined per RED II. As already specified in the II, electricity counts as renewable if the renewable power plant and the electrolyser are co-located in the same installation or there is a direct connection between them, and electricity from the grid is not used for electrolysis. Moreover, the renewable electricity generator must not have come into operation more than 36 months before the electrolyser. Electricity taken from the grid may be recognised as fully renewable if it meets the criteria of additionality, geographical correlation and temporal correlation. [75] Additionality: Hydrogen producers have to make sure that the electricity used for the production of hydrogen is matched by the production of renewable electricity: • in the same installation, showing that the producers generate renewable electricity corresponding to the amount of hydrogen they claim as renewable; or • through a renewable power purchase agreement (PPA) with operators producing renewable electricity. The installation producing renewable electricity must not have been in operation for more than 36 months before the electrolyser, and it must not have received support in the form of operating aid or investment aid. Geographical correlation: Hydrogen producers have to make sure the additional renewables are located in the area where hydrogen is produced. Temporal correlation: Hydrogen producers must make sure that renewable electricity generation and hydrogen production coincide temporally.

[75] https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/747085/EPRS_BRI(2023)747085_EN.pdf

APPENDIX 4 METHODOLOGIES FOR CALCULATING GHG EMISSIONS UNDER EACH REGULATORY FRAMEWORKS/ SCHEME

Each of the regulatory frameworks/schemes in Table 3.1 has a defined methodology for the calculation of associated greenhouse gas emissions. An overview of these calculations is provided below. The full calculations are presented to allow a transparent comparison between these methodologies and the methodology stated in the IMO LCA Guidelines. Breaking down each methodology provides information on whether the other sustainability themes/aspects have been included directly in the calculation or are considered separately.

RENEWABLE ENERGY DIRECTIVE (RED)

RED sustainability criteria (and those within subsequent Delegated Acts) include a minimum GHG saving requirement for the production and use of biofuels, recycled carbon fuels and renewable fuels of non-biological origin compared to a fossil alternative[76]. The savings required depend on the age of the production facility, with newer plants required to demonstrate higher (65%) GHG savings[76]. While the directive contains default values for common fuels, it also contains a standardised methodology for calculating the carbon intensity of individual fuels.

The carbon intensity of a given fuel on a full lifecycle basis, in units of gCO_2e/MJ fuel, is calculated according to the following equation:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr'}$$

Where:

E	Total emissions from the use of the fuel
e_{ec}	Emissions from the extraction or cultivation of raw materials
e_l	Annualised emissions from carbon stock changes caused by land-use change
e_p	Emissions from processing
e_{td}	Emissions from transport and distribution
e_u	Emissions of fuel in use
e_{sca}	Emission savings from soil carbon accumulation via improved agricultural management
e_{ccs}	Emission savings from CO_2 capture and geological storage
$e_{ccr'}$	Emission savings from CO_2 capture and replacement

Direct land use change is included in the RED GHG emissions calculations, and guidance is provided on how this should be calculated. However, indirect land use change is not explicitly accounted for in these calculations – although it is considered separately in the form of ILUC factors.

Wastes and residues are not allocated any emissions associated with upstream production i.e. cultivation. The GHG calculations are made from the first point of collection and include any other processing steps. Following this assumption, sustainability criteria related to land management are not applicable to wastes and residues.

To generate default values for fuels, assumptions are required regarding production yields, production location, transport distances etc[77]. Furthermore, in the calculation of the default values a 40% conservative factor[78] is added to the calculated typical processing emissions and is intended to incentivise reduction in processing emissions. For the avoidance of doubt, the GHG emissions discussed in this report all include this conservative factor.

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[76] DIRECTIVE (EU) 2018/ 2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 11 December 2018 - on the promotion of the use of energy from renewable sources (europa.eu)

[77] Edwards, R., et al., Definition of input data to assess GHG default emissions from biofuels in EU legislation: Version 1c - July 2017

[78] Conservative factors are included in GHG emission calculations to provide a more cautious approach to emission calculations and to account to uncertainty in the calculation methodology

CALIFORNIA LCFS

Under the California LCFS GHG emissions savings are calculated using the CA-GREET model[79], which is a modified version of the GREET LCA model[80]. These modifications are related to the inclusion of California specific parameters in place of national/ national average inputs used in GREET[81].

Individual fuel producers must apply to have their production pathway certified and a list of carbon intensities of the approved pathways is published online[82]. Producers must provide process specific input data and default values for entire fuel production pathways are not used. Within GREET emissions from ILUC, which are based on the GTAP model[83], are added to the carbon intensity of fuel production. Therefore, ILUC emissions are qualitatively accounted for under the California LCFS.

RENOVABIO

Under RenovaBio, GHG emissions are calculated using the RenovaCalc tool[84]. Biofuel producers are obligated to certify the full lifecycle emissions of their fuel. Conservative default values may be adopted during the certification process and inclusion of actual values is encouraged – although requires approval via a public hearing[85]. In its current format, RenovaBio does not consider any form of land use change in the GHG calculations and instead relies on existing national legislation to prevent direct land use change[86].

CORSIA

CORSIA provides both default values[87] and a methodology[88] for the calculation of actual lifecycle emissions values. Default values are given for a set of "CORSIA Eligible Fuels". Participants in the scheme may also request new default values for conversion processes, feedstocks and/or regions to be added to this list.

The core lifecycle emissions values (gCO_2e/MJ fuel) are calculated according to the following formula:

$$Core\ LCA = e_{fe\_c} + e_{fe\_hc} + e_{fe\_p} + e_{fe\_t} + e_{fefu\_p} + e_{fu\_t} + e_{fu\_c}$$

Where:

e_{fe_c}	Emissions from feedstock cultivation
e_{fe_hc}	Emissions from feedstock harvesting and collection
e_{fe_p}	Emissions from feedstock processing
e_{fe_t}	Emissions from feedstock transportation to processing and fuel production facilities
e_{fefu_p}	Emissions from feedstock-to-fuel conversion processes
e_{fu_t}	Emissions from fuel transportation and distribution
e_{fu_c}	Emissions from fuel combustion in an aircraft engine

In addition to the core LCA value, default "induced" land use change values must also be considered for any feedstocks that are not designated as "low LUC risk"[88]. DLUC is only considered in instances where the calculated DLUC value exceeds the default ILUC value, in which case the DLUC value supersedes the ILUC value.[89]

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[79] https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation

[80] GREET | Argonne National Laboratory (anl.gov)

[81] CA-GREET Life Cycle Model - Life Cycle Associates, LLC

[82] LCFS Pathway Certified Carbon Intensities | California Air Resources Board

[83] Leland, A., Hoekman, S.K., Liu, X., Vivian, 2018. Review of modifications to indirect land use change modeling and resulting carbon intensity values within the California Low Carbon Fuel Standard regulations. J. Clean. Prod. 180, 698–707

[84] RenovaCalc — Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (www.gov.br)

[85] Presentación de PowerPoint (globalbioenergy.org)

[86] Opportunities and risks for continued biofuel expansion in Brazil (theicct.org)

[87] ICAO document 06 - Default Life Cycle Emissions - June 2022.pdf

[88] ICAO document 07 - Methodology for Actual Life Cycle Emissions - June 2022.pdf

[89] Life Cycle Emissions of Sustainable Aviation Fuels (icao.int)

APPENDIX 5 APPLYING THE SUSTAINABILITY THEMES/ASPECTS TO CASE STUDIES

Within this Appendix we apply the 10 sustainability themes/aspects from within the IMO LCA Guidelines to the 5 identified feedstocks and fuel production pathways. Within each of the table's exploration of the sustainability themes/aspects under the four regulatory frameworks/standards explored elsewhere in this study i.e. EU RED, California LCFS, RenovaBio and CORSIA.

CASE STUDY 1: SOYBEANS FOR HVO PRODUCTION

Table A7.2 Application of sustainability themes/aspects to the production of HVO from soybeans

Key

Green	Comprehensive coverage in legislation
Orange	Covered in legislation, but lacking in detail
Red	Missing from legislation
Grey	Not applicable

	EU RED	California LCFS	RenovaBio	CORSIA
GHG	**Total** default value for cultivation, processing, transport, and distribution (based on soybean production in EU27, Argentina/Paraguay, Brazil and the US, and relative import quantities of each, and production of HVO within EU): 46.5 gCO_2e/MJ Split of default values: • **cultivation (e_{ec})**, (including soil N_2O): 22.1 gCO_2e/MJ • **processing (e_p)**, (includes oil extraction): 15.2 gCO_2e/MJ • **transport & distribution (e_{td})**: 9.2 gCO_2e/MJ Emissions of **fuel in use**, **(e_u)**, taken as zero for biomass fuels.	Certified CI values (including ILUC impacts) developed by CA-GREET model for several soybean oil pathways, varying by US fuel producer. Range between 53.86 – 80.81 gCO_2/MJ (average: 61.59)[90]. For comparison with EU RED and CORSIA: removal of the default ILUC value (see below), gives a CI of fuel production in the range 24.8 – 51.7 gCO2/MJ.	Fuel producers must submit documentation of production processes using a provided lifecycle tool (RenovaCalc[91]) to qualify for carbon credits. Spreadsheet is designed for soybean oil, however no default values provided (user input only).	Core LCA value for soybean oil (excluding ILUC value): 40.4 gCO_2e/MJ[92]

[90] https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities
[91] https://www.gov.br/anp/pt-br/assuntos/renovabio/renovacalc
[92] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20June%202022.pdf

	EU RED	California LCFS	RenovaBio	CORSIA
	No default values for the following: • Emission savings from soil carbon accumulation via improved agricultural management, (e_u) • Emission savings from CO_2 capture and geological storage, (e_{ccs}) • Emission savings from CO_2 capture and replacement, $(e_{ccs'})$			
Carbon Source	Requirements per Article 29 on land used for growth: • Fuel should not be from raw material obtained from land with a high biodiversity value • Raw material should not be obtained from land with high-carbon stock • Raw material should not be obtained from land that was peatland in January 2008 Country of crop origin is a Party to the Paris Agreement; has submitted a nationally determined contribution to the UNFCCC; or has laws in place, in accordance with Article 5 of the Paris Agreement;	Only requires the disclosure of emissions due to change in soil carbon stock.	• All certified production must come from an area without deforestation after the date of enactment of the RenovaBio law (December 26, 2017)[93] LUC risk management[94]: • No native vegetation suppression (since November 2018). Zero deforestation in biomass production; • Comply with local environmental legislation (like Brazilian Farm Environmental Registration - CAR); • Comply with agro ecological zoning (if applicable).	• Fuel shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.[95] In the event of land use conversion after 1 January 2008, as defined based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value shall replace the default ILUC value.
Electricity/ energy source	N/A - No electricity requirements provided in the context of crop biofuel production.	N/A - No electricity requirements provided in the context of crop biofuel production.	N/A - No electricity requirements provided in the context of crop biofuel production.	N/A - No electricity requirements provided in the context of crop biofuel production.
DLUC	DLUC accounted for in GHG methodology calculation, as	DLUC accounted for in GHG methodology.	Article 24 of ANP 758/2018 states that biomass grown on land where	In the event of land use conversion after 1 January 2008, as defined

[93] https://www.embrapa.br/busca-de-noticias/-/noticia/33448696/artigo---renovabio-ira-vincular-cbios-a-sustentabilidade-no-uso-da-terra
[94] https://www.embrapa.br/busca-de-noticias/-/noticia/54067756/article-the-science-behind-brazilian-biofuels-policy--renovabio
[95] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2005%20-%20Sustainability%20Criteria%20-%20November%202022.pdf

	EU RED	California LCFS	RenovaBio	CORSIA
	annualised emissions from carbon stock changes caused by land-use change, **(e_l)**. See Annex V Part C (7).		removal of natural vegetation is not eligible under RenovaBio.	based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value shall replace the default ILUC value.
ILUC	Adopts a risk based approach. Soybean oil does not currently meet the EU definition of high ILUC risk therefore its use is not restricted. We note that analysis by the European Commission[96] suggested that soybean oil was relatively close to meeting the high ILUC definition. This indicates that soybean oil could potentially be at risk of being classed as high ILUC[97]. The usage of high ILUC-risk fuels is restricted by national limits from 2021 to 2023, after which these limits will gradually decrease to zero by 2030. Low ILUC risk fuels are exempt from limits on use. To qualify as a low ILUC risk fuel they must meet the following criteria as set out in Delegated Regulation (EU) 2019/807: • Comply with Article 29 criteria, including biodiversity and harvesting requirements for land (e.g. feedstock can only be grown on unused land not rich in carbon stock), and GHG emission saving criteria;	ILUC value used in CI determination, Soy biodiesel: 29.1 gCO_2/MJ[98]	n/a	ILUC LCA values: • USA: 24.5 gCO_2e/MJ • Brazil: 27.0 gCO_2e/MJ • Global: 25.8 gCO_2e/MJ

[96] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0807
[97] Soy, land use change and ILUC-risk – a review (transportenvironment.org)
[98] https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/iluc_assessment/iluc_analysis.pdf

	EU RED	California LCFS	RenovaBio	CORSIA
	• Fuel is produced from additional feedstock obtained through additionality measures per criteria in Article 5, which require that: a financial barrier has been overcome, the land was abandoned or severally degraded, or the crop has been cultivated by a small farmer; • Evidence to identify additional feedstock and substantiate claims is collected and document thoroughly;			
Water	n/a	n/a	n/a	• Operational practices will be implemented to maintain or enhance water quality. • Operational practices will be implemented to use water efficiently and to avoid the depletion of surface or groundwater resources beyond replenishment capacities.
Air	n/a	Provides a collective contribution to the improvement of air quality through the transformation and diversification of the fuel mix and reduction of petroleum dependency.	n/a	• Air pollution emissions will be limited.
Soil	Agricultural feedstock should be produced using practices that are consistent with the protection of soil quality and soil organic carbon.	Not explicitly covered	n/a	Agricultural and forestry best management practices for feedstock production or residue collection will be implemented to maintain or enhance soil health, such as physical, chemical and biological conditions.
Waste and chemicals	n/a	n/a	n/a	• Operational practices will be implemented to ensure that waste arising from production processes as well as chemicals used are

	EU RED	California LCFS	RenovaBio	CORSIA
				stored, handled, and disposed of responsibly. • Responsible and science-based operational practices will be implemented to limit or reduce pesticide use. Operational practices will be implemented to prevent, minimise, and mitigate any damage from unintentional release of fossil resources, fuel products, and/or other chemicals.
Conservation	Requirements per Article 29 on land used for growth: • Fuel should not be from raw material obtained from land with a high biodiversity value • Raw material should not be obtained from land with high-carbon stock • Raw material should not be obtained from land that was peatland in January 2008	n/a	All certified production must come from an area without deforestation after the date of enactment of the RenovaBio law (December 26, 2017).	• CORSIA SAF will not be made from biomass obtained from areas that, due to their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area, unless evidence is provided that shows the activity does not interfere with the protection purposes. • Low invasive-risk feedstock will be selected for cultivation and appropriate controls will be adopted with the intention of preventing the uncontrolled spread of cultivated alien species and modified microorganisms.

Feedstock overview

Production

Soybean seeds can be used to produce soybean oil which is one of the many possible feedstocks to produce Hydrotreated vegetable oil (HVO), a renewable diesel.

Soybeans are grown from seed in the field, like many other field crops, with global production approximately 360 Mt per year[99] and over 60% of that occurring in developing countries. Production of soybean oil involves processing of whole soybeans, either shelled or unshelled. Industrial processing consists of solvent extraction to obtain “crude oil”, which is further refined to produce a pure oil.

As with all oilseed feedstocks soy requires agricultural land to grow. The OECD estimated that on average approximately 130 Mha of land were used for soybean production between 2020-22. As agricultural land is used for production additional considerations need to be accounting for when examining the sustainability themes/aspects of any soy-derived marine fuel.

Uses

Soybeans as a feedstock has various applications: for livestock feed, soybean oil and food for human consumption. Soybean oil can be used in the food industry, for medical uses, and to produce biofuels in the chemical industry.

Risks & certification

Given that soy is grown on agricultural land, the sustainability themes/aspects DLUC and ILUC are more prominent and therefore require extra consideration to account for any soy production diverted towards biofuel production. Certification schemes can allow companies to ensure their supply chain is not linked to the various sustainability risks. Examples include Round Table on Responsible Soy (RTRS), The Certified Responsible Soya (CRS) Standard, and more general schemes covering various feedstocks, such as ISCC EU, REDcert and Biomass Biofuels voluntary scheme.

Industry Production standards

In addition to demonstrating the applicability of sustainability themes/aspects to HVO production from soybean feedstock within existing sustainability regulatory frameworks/standards (EU RED California LCFS, RenovaBio and CORSIA) relevant industry production standards for soybean production were explored. These include the RTRS standard, CRS standard and ProTerra standard. Requirements for each of the sustainability criteria listed under each standard have been discussed below.

RTRS standard[100]

Electricity/energy source - The use of renewable energy (biofuels, biogas, solar and wind energy, etc.) on the farm is encouraged. In the case of renewable energy replacing electricity, the equivalent fossil fuel savings should be quantified (see Principle 4.3.2).

Land use – The following areas must not be cleared or converted from May 2009 onwards: category 1 areas[101] from RTRS maps, or, natural forests, riparian vegetation, natural wetlands, steep slopes and areas designated by law to serve the purpose of native conservation and/or cultural and social protection (see Principle 4: Environmental Responsibility).

Water - Good Agricultural Practices (GAP) must be maintained to ensure quality and supply of surface and ground water is maintained or improved. Examples of specific criteria to demonstrate this include: evidence that any water contamination is reported to local authorities, documented procedures in place for irrigation in line with best practice, location of watercourses are identified and mapped and that natural wetlands are not drained (see Principle 5: Good Agricultural Practices).

Soil – Soil quality is maintained or improved, and erosion is avoided by good management practices. Criteria include: monitoring of soil quality including taking soil fertility samples, implementation of techniques to maintain soil quality and control erosion, implementation of a crop rotation plan (see Principle 5.3).

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[99] https://www.oecd-ilibrary.org/agriculture-and-food/world-oilseed-projections_8cb6adbf-en

[100] https://responsiblesoy.org/wp-content/uploads/2023/03/RTRS-Standard-for-Responsible-Soy-Production-V4.0.pdf

[101] Category 1 Areas: areas critical for biodiversity (hotspots), where stakeholders agree there should be no conversion of native vegetation into responsible soy production. Refer to areas in red on RTRS maps: https://responsiblesoy.org/mapas-rtrs?lang=en

Waste and Chemicals – All application of agrochemicals is documented and handling, storage, collection and disposal of chemical waste and empty containers, is monitored to ensure compliance with good practice. Criteria include: maintain record of use, appropriate disposal of containers, safe transportation of agrochemicals, appropriate use of fertilisers (see Principle 5.5 – 5.7, 5.9).

CRS standard[102]

Land use - Producers must demonstrate their legal rights for the land used to cultivate soybeans. With the CRS standard no farm is allowed to have unresolved land use claims between the farm and other groups, like for example indigenous groups. Criteria include: all land must be owned or rented by the farmer, and that there is no acquisition of land where there is an unresolved land use claim (for this land) by traditional land users under litigation, without the agreement of both parties.

Water - Producers shall implement GAP (see Section 7: Good Agricultural Practices), which entails the use of machinery, the use of seed, as well as the responsible use of agro-chemicals. Criteria for responsible water use include: no aerial application of pesticides in WHO Class Ia, Ib and II within 500m of populated areas or water bodies, there should be no application of pesticides within 30m of any populated areas or water bodies, direct evidence of localised contamination of ground or surface water is reported to, and monitored in collaboration with, local authorities.

Soil – GAP criteria (see Section 7: Good Agricultural Practices) for appropriate soil management include: good practices must be used to minimise diffuse and localised impacts on surface and ground water quality from chemical residues, fertilisers and erosion or other sources; Farmers should enhance the soil by applying crop rotation (minimum of 2 crops); Agrochemicals shall be applied using methods that minimise harm to human health, wildlife, plant biodiversity and water and air quality; An integrated crop management plan should be implemented on the farm.

Conservation - Producers shall take measures to limit potential negative impacts on the land used for soya production and on the biodiversity in the direct surroundings of the production site. This includes zero-deforestation and zero-conversion of important natural landscapes, like, but not limited to the Amazon and Cerrado in Brazil. Criteria include: no land can be converted into farmland after July 24th 2006 for land within the Amazon Biome, areas of natural vegetation (e.g. around water bodies (riparian vegetation and flood plains) and areas sensitive to erosion (steep slopes and hills) must be maintained or restored, and that there are facilities to prevent spills of oil and other pollutants (see Section 5: Environmental responsibility).

ProTerra standard[103]

GHG emissions – Certified organisations should develop an inventory of their greenhouse gas emissions and develop a programme to reduce or compensate emission. Over time, certified organisations shall adopt practices to minimise the use of energy from non-renewable sources and to derive an increasing proportion of their energy from renewable sources such as solar and wind, or from local, recycled materials.

Land use – Areas of native vegetation cannot have been cleared or converted into agricultural areas, or used for industrial or other commercial purposes, after 2008, the following: primary forests (for instance, rainforests), riparian vegetation, wetlands, swamps, floodplains, steep slopes, high above-ground carbon stocks, and others as defined by the High Conservation Values Resource Network. Land use in all cases shall not interfere with the agricultural production systems of neighbours, to allow coexistence of different production systems; Land rights disputes shall be resolved before certified status can be awarded.

Water - Certified organisations shall conserve quantity and quality of existing natural water resources, such as lakes, rivers, artificial lakes, dams, water tables and aquifers around their facilities; - Certified organisations shall not undertake new initiatives that reduce the availability of water for neighbouring communities and farms for drinking and irrigation, or for traditional uses; Certified organisations shall implement best practices for water conservation and avoidance of contamination of surface and groundwater. If irrigating, salinisation and desertification shall be prevented; Any evidence of contamination of ground or surface water shall be reported to the local environmental authority and mitigated based on a plan agreed with such authority if necessary.

Soil - Certified organisations shall define a soil and crop management regime that monitors soil quality, builds soil, enhances fertility and manages pests and diseases; Certified organisations shall evaluate suitability of

[102] https://cefetra-certified-soya-s3-bucket.s3.eu-west-1.amazonaws.com/wp-content/uploads/2021/04/07082553/Certified-Responsible-Soy-Standard-version-4.0.pdf

[103] https://www.proterrafoundation.org/wp-content/uploads/2019/11/ProTerra-Standard-V4.1_EN.pdf

the soil for production of specific crops and to define a soil management regime; Best practices are followed in fertiliser use, based on expert opinion or at least the manufacture's recommendations. Whenever possible producers should reduce the use of chemical fertiliser; Certified organisations shall minimise soil erosion and damage to soil structure caused by wind, water, human activity and presence of farm animals.

Air - Certified organisations shall implement systems and procedures to ensure that concentrations of contaminants emitted through smoke pipes, chimneys, boilers, ovens, incinerators, and electricity generators do not exceed established limits set by local, national or regional law, or by individual authorisations delivered by competent national, regional or local authorities.

Conservation - The area of vegetation should be sufficient to maintain biodiversity and avoid erosion. To the extent possible, large agricultural developments (industrial level), shall support and stimulate the identification and maintenance of valuable biodiversity outside its farmed areas. Certified organisations shall gather wild species or products from their natural habitat only when permitted by law and shall do so only in a manner that assures those species will continue to flourish in their natural habitat along with other species that normally depend on the gathered species. The introduction of invasive species and new pests shall be avoided, and past introductions must be controlled and monitored, and any invasive expansion of these shall be reported to the authorities.

Waste and chemicals - Appropriate management of hazardous wastes and pollutant materials; Certified organisations shall handle, store and dispose of pollutant materials properly, having appropriate facilities to prevent spills. Management of pollutant materials shall at least comply with national laws relevant to the location of the certified operation; If sewage is to be used or otherwise incorporated back into any production system, it must be treated to ensure that liquid that is released back into the environment is safe; Non-hazardous wastes shall be segregated and, where appropriate, recycled or reused. If recycling or reuse is not possible, a legal means of treatment and final disposal shall be employed

CASE STUDY 2: PALM FATTY ACID DISTILLATE (PFAD) FOR HVO PRODUCTION

Table A7.3 Application of sustainability themes/aspects to the production of HVO from palm fatty acid distillate

Key

Green	Comprehensive coverage in legislation
Orange	Covered in legislation, but lacking in detail
Red	Missing from legislation
Grey	Not applicable

	EU RED	California LCFS	RenovaBio	CORSIA
GHG	PFAD is not explicitly named as an eligible feedstock in Annex IX of RED however, it meets the EU definition of a residue. No default value is provided in the RED documentation therefore, the GHG emissions must be calculated by the fuel producer and certified by an approved body. HVO produced from PFAD must meet minimum GHG saving criteria defined by RED[104].	Under the LCFS, a fuel producer must apply to have the fuel certified as compliant with the GHG saving criteria. The carbon intensity is calculated using the CA-GREET model. A taxonomy for feedstock categories (e.g. residue, co-product etc) is not explicitly defined.	Fuel producers must submit documentation of production processes using a provided lifecycle tool (RenovaCalc) to qualify for carbon credits.	HVO is not suitable for use in aircraft therefore is not covered by CORSIA. However, HEFA from PFAD, which is produced by a very similar process to HVO, is listed in the CORSIA documentation as a CORSIA Eligible fuel and a default value (20.7 gCO2e/MJ) is provided[105]. Fuel producers may submit actual GHG emissions values, which must be certified by a CORSIA approved sustainability certification scheme[106].
Carbon Source	Not applicable as PFAD is classed as a residue.	PFAD was recommended to be categorised as a by-product in a report to the administrators of the LCFS[107]. However its current classification in unclear.	Categorisation of PFAD not clear therefore, the applicability of this criterion is unclear.	Not applicable as PFAD is classed as a by-product.
Electricity / energy source	Not applicable in the context of this study as PFAD is used to produce biofuel and is not produced from renewable electricity. Electricity used in feedstock processing/fuel production is directly accounted for in the GHG calculations.	Not applicable in the context of this study as PFAD is used to produce biofuel and is not produced from renewable electricity. Electricity used in feedstock processing/fuel production is directly accounted for in the GHG calculations.	Not applicable in the context of this study as PFAD is used to produce biofuel and is not produced from renewable electricity. Electricity used in feedstock processing/fuel production is directly accounted for in the GHG calculations.	n/a

[104] DIRECTIVE (EU) 2018/ 2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 11 December 2018 - on the promotion of the use of energy from renewable sources (europa.eu)
[105] CORSIA Supporting Document "CORSIA Eligible Fuels_LCA_Methodology" (icao.int)
[106] CORSIA Approved Sustainability Certification Schemes (icao.int)
[107] ICF_LCFS_Biofuel_Categorization_Final_Report_011816 (theicct.org)

	EU RED	California LCFS	RenovaBio	CORSIA
DLUC	Not applicable as PFAD is classed as a residue.	n/a	n/a	Not applicable as PFAD is classed as a by-product.
ILUC	ILUC is not applicable as PFAD is classed as a residue.	n/a	n/a	ILUC LCA Value: 0 gCO_2e/MJ
Water	n/a	n/a	n/a	Not applicable as PFAD is classed as a by-product.
Air	n/a	Provides a collective contribution to the improvement of air quality through the transformation and diversification of the fuel mix and reduction of petroleum dependency.	n/a	Air pollution emissions will be limited.
Soil	Not applicable as PFAD is classed as a residue.	PFAD was recommended to be categorised as a by-product in a report to the administrators of the LCFS[108]. However its current classification in unclear.	n/a	Not applicable as PFAD is classed as a by-product.
Waste and chemicals	n/a	n/a	n/a	Operational practices will be implemented to ensure that waste arising from production processes as well as chemicals used are stored, handled, and disposed of responsibly. Responsible and science-based operational practices will be implemented to limit or reduce pesticide use. Operational practices will be implemented to prevent, minimise, and mitigate any damage from unintentional release of fossil resources, fuel products, and/or other chemicals.
Conservation	Not applicable as PFAD is classed as a residue.	n/a	n/a	Not applicable as PFAD is classed as a by-product.

[108] ICF_LCFS_Biofuel_Categorization_Final_Report_011816 (theicct.org)

Feedstock overview

Palm fatty acid distillate (PFAD) is produced as part of the crude palm oil refining process. Global annual production is approximately 2.5 million tonnes and is concentrated in Indonesia and Malaysia[109]. PFAD mainly consists of free fatty acids and triglycerides, which means it is suitable as a feedstock to produce low carbon fuels such as biodiesel (fatty acid methyl ester i.e. FAME), hydrotreated vegetable oil (HVO) and hydrogenated ester fatty acid (HEFA).

In addition to low carbon fuel production, PFAD is used in animal feed, as a raw material for the oleochemical industry and, less frequently, as a boiler fuel. It is suggested that increased use of PFAD for biofuel production is likely to cause displacement from these markets, that would be met through substitution by palm and soy oil.

PFAD is considered a controversial Low Carbon Fuel (LCF) feedstock because it is produced by the palm industry. Therefore, many of the sustainability concerns most often cited with regards to palm production are arguably applicable to PFAD[109]. For example, palm oil production is considered to cause ILCU and generate significant methane emissions from effluent ponds. However, the impact of this on the sustainability credentials of LCFs produced from PFAD depends on the categorisation of PFAD as either a residue, by-product or co-product in its lifecycle analysis. Upstream emissions are outside of the system boundary when treating PFAD as a residue or by-product, where the GHG calculation starts at the point of collection of the feedstock but are in scope when treating PFAD as a co-product and the GHG calculation starts at the point of feedstock cultivation.

PFAD complies with the RED definition of a residue, as it is "…*a substance that is not the end product that a production process directly seeks to produce. It is not a primary aim of the production process and the process has not been deliberately modified to produce it"*[110]. Despite this, some EU member states (e.g. Netherlands) and the UK explicitly classify PFAD as a co-product in their national biofuels legislation which creates a disparity in the implementation of sustainability/traceability rules and subsequent challenges for certification schemes.

Under CORSIA, PFAD is treated as a by-product because it is a *"secondary product with inelastic supply and economic value"*[110]. Similarly, the *Roundtable on Sustainable Biomaterials* (RSB) classes PFAD as a residue on the basis that its supply is inelastic and its revenue share is less than 5% of the total revenues for all products generated from the same process[110]. However *International Sustainability and Carbon Certification* (ISCC) classify PFAD as a co-product because its market price is over 15% of that of the primary products in a per ton basis[110].

As a result of the lack of agreement on the classification of PFAD as a residue/by-product or co-product, literature estimates of the carbon intensity of HVO production from PFAD can vary between 11.4 – 53.1 gCO_2e/MJ, excluding ILUC[110]. If PFAD is treated as a co-product and consequently is allocated its share of ILUC emissions, estimates of the carbon intensity for HVO production from PFAD vary between 75.2 – 280.1 gCO_2e/MJ.

Industry Production standards

There are no production standards applicable to PFAD.

[109] Malins, C. (2017). Waste Not, Want Not: Understanding the greenhouse gas implications of diverting waste and residual materials to biofuel production. Cerulogy: London, UK.

[110] Xu, H., Lee, U., & Wang, M. (2020). Life-cycle energy use and greenhouse gas emissions of palm fatty acid distillate derived renewable diesel. Renewable and Sustainable Energy Reviews, 134, 110144. https://doi.org/10.1016/J.RSER.2020.110144

CASE STUDY 3: USED COOKING OIL FOR HVO PRODUCTION

Table A7.4 Application of sustainability themes/aspects to the production of HVO from UCO

Key

- Comprehensive coverage in legislation (green)
- Covered in legislation, but lacking in detail (orange)
- Missing from legislation (red)
- Not applicable (grey)

	EU RED	California LCFS	RenovaBio	CORSIA[111]
GHG	**Total** default value for cultivation, processing, transport, and distribution (based on UCO collection in EU27, and production of HVO within EU): 16 gCO_2e/MJ Split of default values: • **cultivation (e_{ec})**: 0 gCO_2e/MJ • **processing (e_p)**: 14.3 gCO_2e/MJ • **transport & distribution (e_{td})**: 1.7 gCO_2e/MJ Emissions of **fuel in use**, **(e_u)**, taken as zero for biomass fuels No default values for the following: • Emission savings from soil carbon accumulation via	Fuel producers must undergo a certification process to qualify for tradeable LCFS credits. The certified carbon intensity varies between UCO pathways[112,113]. Certified CI values (including ILUC impacts) developed by CA-GREET model for several UCO to renewable diesel pathways Range between 16.21 – 30.72 gCO_2/MJ (average: 22.40)	Fuel producers must submit documentation of production processes using a provided lifecycle tool (RenovaCalc) to qualify for carbon credits. UCO only plays a minor role on biodiesel production in Brazil [114,115]	Default lifecycle emission core value: 13.9 gCO_2e/MJ

[111] ICAO (2022) CORSIA default life cycle emissions values for CORSIA Eligible Fuels, https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20June%202022.pdf

[112] CARB (2023) Apply for LCFS pathway, https://ww2.arb.ca.gov/resources/documents/apply-lcfs-fuel-pathway

[113] CARB (2023) LCFS Pathway Certified Carbon Intensities, https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

[114] International Council for Clean Transportation (2019) Opportunities and risks for continued biofuel expansion in Brazil, https://theicct.org/sites/default/files/publications/ICCT_Brazil_lowcarbon_fuel_opp_20190726.pdf

[115] Government of Brazil (2023) RenovaBio, www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/renovabio-1

	EU RED	California LCFS	RenovaBio	CORSIA[111]
	improved agricultural management, (e_u) • Emission savings from CO_2 capture and geological storage, (e_{ccs}) Emission savings from CO_2 capture and replacement, (e_{ccr})			
Carbon Source	Not applicable as UCO is classed as a waste.	Not explicitly covered	Not applicable as UCO is classed as a residue.	Not applicable as UCO is classed as a waste.
Electricity / energy source	Not applicable in the context of this study as UCO is used to produce biofuel and is not produced from renewable electricity. Electricity used in feedstock processing/fuel production is directly accounted for in the GHG calculations.	Not applicable in the context of this study as UCO is used to produce biofuel and is not produced from renewable electricity. Electricity used in feedstock processing/fuel production is directly accounted for in the GHG calculations.	Not applicable in the context of this study as UCO is used to produce biofuel and is not produced from renewable electricity. Electricity used in feedstock processing/fuel production is directly accounted for in the GHG calculations.	n/a
DLUC	Not applicable as UCO is classed as a waste.	n/a	Not applicable as UCO is classed as a residue.	Not applicable as UCO is classed as a waste.
ILUC	Not applicable as UCO is classed as a waste.	n/a	n/a	Default lifecycle emission core value: 0 gCO_2e/MJ
Water	n/a	n/a	Not applicable as UCO is classed as a residue.	Not applicable as UCO is classed as a waste.
Air	n/a	Not mentioned. Provides a collective contribution to the improvement of air quality through the transformation and diversification of the fuel mix and reduction of petroleum dependency.	n/a	Air pollution emissions will be limited.
Soil	Not applicable as UCO is classed as a waste.	Not explicitly covered	Not applicable as UCO is classed as a residue.	Not applicable as UCO is classed as a waste.
Waste and chemicals	n/a	n/a	n/a	Operational practices will be implemented to ensure that waste arising from production processes as well as chemicals used are stored, handled, and disposed of responsibly.

	EU RED	California LCFS	RenovaBio	CORSIA[111]
				Responsible and science-based operational practices will be implemented to limit or reduce pesticide use. Operational practices will be implemented to prevent, minimise, and mitigate any damage from unintentional release of fossil resources, fuel products, and/or other chemicals
Conservation	Not applicable as UCO is classed as a waste.	n/a	Not applicable as UCO is classed as a residue.	Not applicable as UCO is classed as a waste.

Feedstock overview

Used Cooking Oil (UCO) is vegetable oil collected from restaurants and other food processing industries to produce biofuel. These oils may be produced from oil palm, rape seed, sunflower seed, or other lipid energy crops. The environmental impacts of producing the original vegetable oil vary depending on the used feedstock and production processes and are generally not counted towards UCO's lifecycle impacts due to its classification as a waste feedstock. UCO collection rates vary between regions and are generally highest in Europe and North America, while Asia supplies most UCO in absolute terms. Markets with high UCO use in the fuel sector, especially Europe, rely on imports from other regions to meet their demand.[116,117]

The emission intensity of UCO fuels is generally lower than other oleochemical pathways due to the waste feedstock classification. The global warming impacts of UCO fuels concentrate on feedstock transport and fuel production processes. There are no significant lifecycle impacts in other impact categories than global warming potential, and directing UCO to fuel production may prevent environmental harms from unsuitable UCO disposal. [118]

Key challenges in scaling up UCO supply are to mobilise reverse supply chains[119] to access feedstock as well as limitations on theoretical feedstock availability. As UCO is classified as a waste there is only ever a limited quantity available unless waste is intentionally generated. To increase collection rates in country's/markets without formal waste collection and in areas where feedstock sources are not centralised is difficult. Areas where there is high use in many smaller locations present an additional challenge as opposed to collation into a single depot/collection facility as further costs and logistics are required to coordinate such an effort.

Risks and certification

Feedstock competition may arise with other sectors where UCO can replace virgin lipids, for example in chemicals, food processing and animal feed industries. The expansion of UCO-based fuel production may necessitate other sectors such as animal feed production who have previously used UCO, to increasingly rely on virgin lipid feedstocks, such as palm oil. This shift highlights the potential trade-offs between sustainable sourcing and the competition for resources in various industries.

Fraud cases have been reported where virgin vegetable oil was mislabelled as UCO and brought into the market.[120] This fraud risk exists where UCO is more valuable than vegetable oils for example in legislation or frameworks that incentivise biofuel production from waste feedstocks over virgin crops such as the UK RTFO and where certification systems fail to ensure feedstock traceability despite the framework in place to prevent this.

Industry Production standards

UCO is a waste therefore there are no associated production standards.

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[116] CE Delft (2020), Used Cooking Oil (UCO) as biofuel feedstock in the EU, CE Delft, Delft.

[117] IRENA (2021), Reaching Zero with Renewables: Biojet fuels, International Renewable Energy Agency, Abu Dhabi.

[118] Hosseinzadeh-Bandbafha et al.(2022) Environmental life cycle assessment of biodiesel production from waste cooking oil: A systematic review, Renewable and Sustainable Energy Reviews, Volume 161,112411, https://doi.org/10.1016/j.rser.2022.112411.

[119] A reverse supply chain, or reverse logistics, is a system that manages the return, recycling, remanufacturing, and responsible disposal of products and materials, aiming to minimise waste and environmental impact. It involves the flow of goods and information from the point of consumption back to the point of origin or designated recycling facilities.

[120] International Council on Clean Transportation (2022) Setting a lipids fuel cap under the California Low Carbon Fuel Standard, https://theicct.org/wp-content/uploads/2022/08/lipids-cap-ca-lcfs-aug22.pdf.

CASE STUDY 4: FORESTRY RESIDUES FOR FT-DIESEL PRODUCTION

Table A7.5 Application of sustainability themes/aspects to the production of FT-Diesel from forestry residues

Key

- Comprehensive coverage in legislation
- Covered in legislation, but lacking in detail
- Missing from legislation
- Not applicable

	EU RED	California LCFS	RenovaBio	CORSIA
GHG	13.7 gCO_2e/MJ total default value for cultivation, processing, transport and distribution (based on waste wood FT diesel). Split of default values: **Transport & distribution (e_{td}):** 10.3 gCO_2e/MJ **Processing (e_p):** 0.1 gCO_2e/MJ **Cultivation (e_{ec}):** 3.3 gCO_2e/MJ Emissions of **fuel in use**, **(e_u)**, taken as zero for biomass fuels	No default value provided for FT diesel from forestry residues. Certified CI values should be developed using the CA-GREET model, by the US fuel producer. 14.78gCO2e/MJ provided for FT-diesel from municipal solid waste	FT diesel from forestry residue is not currently a covered pathway in RenovaBio. Fuel producers must submit documentation of production processes using a provided lifecycle tool (RenovaCalc[121]) to qualify for carbon credits.	Midpoint value: 8.3 gCO_2e/MJ[122]
Carbon Source	For forest biomass, country of harvest must have laws ensuring the following: legality of harvesting operations; forest regeneration of harvested areas; that areas designated by international or national law or by the relevant competent authority for nature protection purposes are protected; that harvesting is carried out considering	Only requires the disclosure of emissions due to change in soil carbon stock.	• All certified production must come from an area without deforestation after the date of enactment of the RenovaBio law (December 26, 2017)[123] • The entire area must comply with the Forest Code, through the regularization of the Rural Environmental Registry	Fuel shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.[125] In the event of land use conversion after 1 January 2008, as defined

[121] https://www.gov.br/anp/pt-br/assuntos/renovabio/renovacalc
[122] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/CORSIA_Supporting_Document_CORSIA%20Eligible%20Fuels_LCA_Methodology_V5.pdf
[123] https://www.embrapa.br/busca-de-noticias/-/noticia/33448696/artigo---renovabio-ira-vincular-cbios-a-sustentabilidade-no-uso-da-terra
[125] https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2005%20-%20Sustainability%20Criteria%20-%20November%202022.pdf

	EU RED	California LCFS	RenovaBio	CORSIA
	maintenance of soil quality and biodiversity with the aim of minimising negative impacts; and that harvesting maintains or improves the long-term production capacity of the forest		LUC risk management[124]: • No native vegetation suppression (since November 2018). Zero deforestation in biomass production; • Comply local environmental legislation (like Brazilian Farm Environmental Registration - CAR); Comply agro ecological zoning (if applicable).	based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value shall replace the default ILUC value.
Electricity / energy source	Not applicable in the context of this study as FT diesel from forestry residue is a biofuel and is not produced from renewable electricity.	Not applicable in the context of this study as FT diesel from forestry residue is a biofuel and is not produced from renewable electricity.	Not applicable in the context of this study as FT diesel from forestry residue is a biofuel and is not produced from renewable electricity.	n/a
DLUC	Not applicable as forestry residues is classified as residue	n/a	n/a	Not applicable as forestry residues is classified as residue
ILUC	Not applicable as forestry residues is classified as residue	n/a	n/a	Global ILUC LCA Value: 0 gCO_2e/MJ
Water	n/a	n/a	n/a	Operational practices will be implemented to maintain or enhance water quality, to use water efficiently and to avoid the depletion of surface or groundwater resources beyond replenishment capacities.
Air	n/a	Provides a collective contribution to the improvement of air quality through the transformation and diversification of the fuel mix and reduction of petroleum dependency.	n/a	Air pollution emissions will be limited.
Soil	Harvesting is carried out considering maintenance of soil quality and biodiversity, in accordance with sustainable forest management	Not explicitly covered	n/a	Agricultural and forestry best management practices for feedstock production or residue collection will be implemented to maintain or enhance

[124] https://www.embrapa.br/busca-de-noticias/-/noticia/54067756/article-the-science-behind-brazilian-biofuels-policy--renovabio

	EU RED	California LCFS	RenovaBio	CORSIA
	principles, with the aim of preventing any adverse impact.			soil health, such as physical, chemical and biological conditions.
Waste and chemicals	n/a	n/a	n/a	Operational practices will be implemented to ensure that waste arising from production processes as well as chemicals used are stored, handled, and disposed of responsibly. Responsible and science-based operational practices will be implemented to limit or reduce pesticide use.
Conservation	The criteria for feedstock sourced from forest biomass include harvesting with legal permits; protecting areas with high conservation value; minimizing the impacts of forest harvesting on soil quality and biodiversity; regenerating cleared forest; harvesting without exceeding the long-term production capacity of the forest.	n/a	All certified production must come from an area without deforestation after the date of enactment of the RenovaBio law (December 26, 2017).	CORSIA SAF will not be made from biomass obtained from areas that, due to their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area, unless evidence is provided that shows the activity does not interfere with the protection purposes

Feedstock overview

Forestry residues are classified as residual biomass, according to EU RED, and refer to organic material left over from logging and forest management activities. This includes branches, tops, bark and roots, that are often left unused after timber harvesting. The forestry residues are typically collected from logging sites, sawmills and wood processing facilities. The residues are typically chipped, ground, dried or pelletised to make them suitable for gasification.

The availability of this type of feedstock varies depending on regional forestry practices and forest management. The collection and transportation of forestry residues to the production facilities can be logistically challenging and may involve costs. Their availability and quality can also vary seasonally and annually.

Uses

The main competing use of forestry residues is for bioenergy production (heat and power generation), for the production of wood-based products like particle board, fibreboard and paper or left on site to enhance carbon sequestration and soil health. The latter becomes relevant in forest ecosystems that are vulnerable to soil degradation, usually connected with erosive processes due to extensive land-use changes over time.

Risks and certifications

Using forestry residues for biofuel production can be sustainable if is done in a manner that considers long-term carbon sequestration. Removing too many residues from forests without appropriate management practices could affect carbon balance and ecosystem health. Illegal logging and unsustainable harvesting may have negative effects on wildlife habitat, biodiversity, soil health and nutrient recycling, resulting in devastating deforestation.

Forest biomass harvesting guidelines help to ensure the sustainability of forestry residues harvesting aimed for bioenergy production. Certification schemes which ensure that sustainability criteria apply for forestry residues include ISCC EU and RSB EU RED. To meet the requirements of EU certification schemes, residues from forest biomass should meet the following sustainability criteria on national level:

- harvesting operations with legal permits
- protecting areas with high conservation value
- minimizing the impacts of forest harvesting on soil quality and biodiversity
- regenerating cleared forest
- harvesting without exceeding the long-term production capacity of the forest

Additionally, the country of origin of the forestry residues should meet the following land use and land use change and forestry (LULUCF) criteria:

- is a Party to the Paris Agreement; and
- ensures that carbon stock changes resulting from biomass harvest are considered in the context of the country’s specific commitment to mitigate GHG emissions; or
- is bound by law to conserve and enhance carbon stocks and sinks.

Industry Production standards

The production standards concerning forest residues can help ensure that forests are managed sustainably and include guidelines for harvesting practices, reforestation and environmental conservation. Common forest certification standards include the Forest Management Certification[126] from the Forest Stewardship Council (FSC), the Forest Management Standard[127] from the Sustainable Forestry Initiative (SFI) and the Sustainable Forest Management Standard[128] from the Programme for the Endorsement of Forest Certification (PEFC). PEFC is a worldwide organisation promoting sustainable forest management by providing national forest certification schemes.

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[126] https://connect.fsc.org/certification/forest-management-certification

[127] https://forests.org/wp-content/uploads/2022_SFI_StandardsandRules_section2.pdf

[128] https://cdn.pefc.org/pefc.org/media/2019-01/b296ddcb-5f6b-42d8-bc98-5db98f62203e/6c7c212a-c37c-59ee-a2ca-b8c91c8beb93.pdf

PEFC ST 1003:2018 (Sustainable Forest Management – Requirements)[129]

Soil – Management, harvesting and regeneration procedures shall be carried out at a time, and in a way, that does not reduce the productive capacity of the site, for example by avoiding damage to soil and retained stands and trees. Delicate soils and areas prone to erosion, as well as those where operations may result in excessive soil erosion into watercourses, require particular attention and care.

Conservation – The standard mandates the protection of both the quantity and quality of forest resources, as well as the ability of the forest to store and sequester carbon over the medium and long term. This is to be achieved by carefully managing harvesting and growth rates, employing suitable silvicultural practices, and prioritizing techniques that minimise negative impacts on forest resources.

Water – Inappropriate use of chemicals or other harmful substances, as well as unsuitable forest management techniques influencing water quality in a harmful way, shall be avoided. Downstream water balance and water quality shall not be significantly affected by the operations.

Waste and chemicals – the standard requires the strict avoidance of indiscriminate waste disposal on forest land. Non-organic waste and litter must be collected and removed in a manner that is environmentally responsible. Any use of pesticides should be documented and highly toxic pesticides, including WHO Class 1A and 1B, are prohibited.

SCI Forest Management Standard[130]

Land use – Forest conversion or afforestation of ecologically important areas shall be avoided, and forest management plans shall include long-term sustainable harvest levels and measures. Certified Organizations shall ensure that forest management plans include sustainable long-term harvest levels that are consistent with appropriate growth-and-yield models and shall not convert one forest cover type to another without assessing the ecological impacts.

Soil – Soil productivity and soil health shall be protected by good management practices. Indicators include: use of soil maps, processes to identify vulnerable to compaction soils, erosion control measures and designed harvest plans and practices.

Water – The standard requires the protection of water quality and quantity of rivers, streams, lakes, wetlands, and other water bodies. Certified organizations shall meet or exceed all applicable national or local water laws and best management practices, including monitoring of water quality.

Conservation – The conservation of biodiversity shall be maintained or enhanced, at the stand- and landscape-level and across a variety of forest and vegetation cover types. This includes the conservation of plants and animals, aquatic, threatened and endangered species.

Waste and chemicals – The standard mandates the implementation of measures to ensure the long-term productivity and conservation of forest resources through the deployment of integrated pest management strategies, reduced chemical use, soil conservation and protection from damaging agents.

FSC-STD-01-001 V5-3 (Principles and criteria for forest stewardship)[131]

Land use – Certified organizations shall avoid the conversion of natural forest or High Conservation Value areas to plantations or not-forest land use, unless the conversion affects a very limited area, produces secure conservation and social benefits and does not damage or threaten Hight Conservation Values.

Conservation – Endangered and rare species, along with their habitats, shall be protected and proactive measures should be implemented for their viability and survival. Loss of biological diversity shall be avoided through habitat management.

Water – Natural water courses, water bodies, riparian zones and their connectivity shall be protected or restored, to avoid negative impacts on water quality and quantity.

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[129] https://cdn.pefc.org/pefc.org/media/2019-01/b296ddcb-5f6b-42d8-bc98-5db98f62203e/6c7c212a-c37c-59ee-a2ca-b8c91c8beb93.pdf

[130] https://forests.org/wp-content/uploads/2022_SFI_StandardsandRules_section2.pdf

[131] https://connect.fsc.org/document-centre/documents/retrieve/0e2f50a2-bb15-4697-aa39-42d878506bbd?mode=view

Soil – Infrastructure development, transport activities and silviculture shall be managed so that soils are protected and erosion of vulnerable soils and slopes is controlled.

Wastes and chemicals – Certified organizations shall minimise or avoid the use of fertilisers, chemical pesticides and biological control agents. When their use cannot be avoided, the organizations shall prevent, mitigate and/or repair damage to environmental values, including soils and human health. Activities associated with harvesting and extraction of forest products shall be managed in order to reduce merchantable waste and waste materials shall be disposed in an environmentally appropriate manner.

CASE STUDY 5: RENEWABLE ELECTRICITY AND CAPTURED CARBON FOR METHANOL PRODUCTION

Table A7.6 Application of sustainability themes/aspects to the production of methanol from renewable electricity and captured carbon

Key

- Comprehensive coverage in legislation (green)
- Covered in legislation, but lacking in detail (orange)
- Missing from legislation (red)
- Not applicable (grey)

	EU RED	California LCFS	RenovaBio	CORSIA
GHG	E-methanol is not explicitly named, however, guidelines are in place for renewable fuels of non-biological origin, which would include e-methanol. No default value is provided in the RED documentation. The fuel can be considered as fully renewable if the installation producing the renewable liquid and gaseous transport fuel of non-biological origin is in a bidding zone where the average proportion of renewable electricity exceeds 90%. This is outlined in more detail in articles 3 and 4, which can be found here.	No default value provided for e-methanol. A value is included for the feedstock renewable hydrogen: 10.51g CO2e/MJ Includes provisions for fuels produced using Carbon Capture and Sequestration. The amount of net CO_2 sequestered by alternative fuel producers can be used to adjust the carbon intensity of associated fuels.	Not explicitly covered	Not explicitly covered
Carbon Source	Captured CO_2 must meet the following requirements: • The captured CO_2 cannot stem from a fuel that is deliberately burned for producing the CO_2. • The captured CO_2 cannot have received an emissions credit under other provisions of the law (otherwise, this would lead to double counting of GHG emissions)	Types of carbon capture projects eligible under LCFS: Direct air capture and Carbon generated by alternative fuel producers, including: • CO_2 from fermentation during ethanol production • CO_2 streams from production of renewable diesel, renewable gasoline, and alternative jet fuel • CO_2 produced as part of biogas from anaerobic digestion	Not explicitly covered	Not explicitly covered

	EU RED	California LCFS	RenovaBio	CORSIA
		• CO_2 from power plants that produce low-CI electricity supplied for eligible transportation applications such as electric vehicle charging, etc. • CO_2 from hydrogen production using steam methane reforming • CO_2 from production of any other alternative transportation fuel listed in sections 95482(a) of the LCFS legislation		
Electricity / energy source	The electricity demand to produce renewable liquid and gases transport fuels of non-biological origin must be met by renewable electricity, such as green hydrogen produced via electrolysis.	Includes provisions for hydrogen produced from Low-Carbon Electricity, however, only if the hydrogen production facility has a direct, physical connection to the low-carbon electricity source.[132]	Not explicitly covered	n/a
DLUC	Not explicitly covered	n/a	n/a	Not explicitly covered
ILUC	Not explicitly covered	n/a	n/a	Not explicitly covered
Water.	n/a	n/a	n/a	Not explicitly covered
Air	n/a	Not explicitly covered	n/a	Not explicitly covered
Soil	n/a	Not explicitly covered	n/a	Not explicitly covered
Waste and chemicals	n/a	n/a	n/a	n/a
Conservation	Not explicitly covered	n/a	n/a	Not explicitly covered

[132] California Air Resources Board (2023) 'Tier 1 Simplified CI Calculator Instruction Manual: Hydrogen Produced from Steam Methane Reformation or Electrolysis', https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/t1_hydrogen_instruction_manual_v02212023.pdf California Air Resources Board (2023) 'Tier 1 Simplified CI Calculator Instruction Manual: Hydrogen Produced from Steam Methane Reformation or Electrolysis', https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/t1_hydrogen_instruction_manual_v02212023.pdf

Feedstock overview

"e-fuels" are fuels that derive their energy content from renewable electricity. The simplest e-fuel is green hydrogen, which is produced from the electrolysis of water using surplus renewable energy. This hydrogen can then be combined with captured carbon dioxide to produce alcohols (e.g. e-methanol) or hydrocarbons (e.g. e-diesel, e-kerosene etc). In this context, H_2 from renewable electricity and captured CO_2 are the "feedstocks" required to produce e-methanol. Current production of e-methanol is negligible.

Hydrogen

The production of green hydrogen does not have any general geographic restrictions, other than access to sufficient renewable electricity. However, most planned electrolysis capacity is located in Europe and the Asia Pacific region. For example, the IEA expects that by 2030, 32% of global electrolyser capacity will be in Europe[133].

Two key concerns are most frequently raised with regards to the sustainability of green hydrogen. The first is that the use of renewable electricity for hydrogen production can prevent the electricity being used in other sectors in the general energy supply. For this reason, the principal of additionality is often applied to green hydrogen production. This means that renewable electricity used to produce green hydrogen must have been demonstrably generated in addition to what is required for the gird.

More generally, the upscaling of renewable energy generation capacity will require more land to be dedicated to this purpose, presenting potential land use and land cover impacts.

The second concern around green hydrogen production is the demand for large amounts of water for the process. This is compounded by the fact that many regions that are particularly suited to generating large amounts of renewable electricity through photovoltaics are inherently arid – raising concerns around water scarcity brought about by green hydrogen production.

Carbon dioxide

As a feedstock CO_2 is generally divided into three broad categories:

i. **Point source CO_2.** This is CO_2 captured from large point sources such as power plants. While this fossil derived CO_2, its use in e-fuels leads to avoided emissions and a consequent lifecycle GHG benefit, although still net CO_2 emissions. This means that the GHG emission savings of point source CO_2 derived e-methanol will be lower than e-methanol from biogenic or DAC CO_2, consequently, it will be phased out as an eligible feedstock from 2036 in the EU.
ii. **Biogenic CO_2**. This is CO_2 captured from the utilisation of biomass either through combustion (e.g. biofuels or biomass fuels) or through the fermentation/anaerobic digestion. Utilisation of biogenic CO_2 is considered CO_2 neutral.
iii. **Direct air capture (DAC) CO_2.** This is CO_2 obtained from the atmosphere directly through air capture (DAC) or through biomass. Utilisation of DAC CO_2 is considered CO_2 neutral.

Industry Production standards

Existing certification schemes for the use of renewable hydrogen includes CERTIFHY, a scheme that provides electronic certificates that provide proof that a given quantity of hydrogen is produced by a registered production. The certificates grant a tradeable value to renewable hydrogen. The UK has also launched a new certification scheme to verify the sustainability of low carbon hydrogen, but it will not be introduced until 2025.

The GH2 Green Hydrogen Standard

This standard was developed by the Green Hydrogen Organisation (GH2) in May 2022. The standard aims to provide certainty and transparency to investors and stakeholders that Green Hydrogen is made with renewable electricity, and maintains the highest standards on emissions, environmental, social and governance and sustainable development.

This standard requires that production facilities have systems in place that can accurately measure the GHG emission from production periods / shipments. The project must operate at <=1 kg CO_2e per kg H_2 taken as an average over a 12-month period as per the electrolysis production pathway defined by the International Partnership

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[133] Erbach, G. and Svensson, S. (2023) 'EU Rules for Renewable Hydrogen: Delegated regulations on a methodology for renewable fuels of non-biological origin', *European Parliamentary Research Service,* PE 747.085, https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/747085/EPRS_BRI(2023)747085_EN.pdf

for Hydrogen and Fuel Cells in the Economy (IPHE) as outlined in the Working Paper Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen noting the modifications as set out in Policy Note 1[134].

Project operators must also have systems in place to calculate and report on indirect emissions associated with other processes (e.g., water usage and waste disposal), and other emissions associated with the storage, conversion, and delivery of Green Hydrogen and its derivatives.

This standard and certification requires the project operator to demonstrate that Hydrogen produced has been done so through the electrolysis of water with 100% or near 100% renewable energy. It must also carry out an evaluation of the project's utilisation of electricity and the impact on the energy market including, if applicable, network congestion and the impact of their operations on greenhouse gas emissions from the electricity grid. Further, there is an expectation that project operators will identify and implement cost-effective and feasible measures to support the deployment of additional renewable energy projects.

Sets out guidelines for the sustainable management and sanitation of water and addresses risks of reducing water access and the potential for desalination. Project operators must: provide a description of how their project interacts with water and where the water is being sourced from, describe the total water consumption, address how water-related impacts will be considered, and implement a minimum standard for the quality of discharge and how the minimum standards are determined.

The production standard requires that water, noise, and water quality issues relevant to the project implementation are both identified and assessed with the help of experts and that monitoring plans are set into place for this purpose.

The standard recognises the importance of healthy and functional aquatic and terrestrial ecosystems and requires certified projects to ensure that these areas are protected over the long-term, with an on-going process of monitoring and identifying the potential for emerging biodiversity issues.

[134] Green Hydrogen Standard (2023) 'The Global Standard for Green Hydrogen and Green Hydrogen Derivatives including Green Ammonia', p.17 https://gh2.org/sites/default/files/2023-01/GH2_Standard_A5_JAN%202023_1.pdf