



Refinery integration, scale-up and certification
for aviation and marine biofuels production

D6.2: Sustainability indicators



Project: REFOLUTION

Refinery integration, scale-up and certification for aviation and marine biofuels production

GA no.: 101096780

Sustainability indicators

Call identifier	HORIZON-CL5-2022-D3-01		
Deliverable ID	D6.2		
Deliverable name	Sustainability indicators		
Work Package (WP)	WP6		
Task	T6.2		
Lead beneficiary	VTT		
Contributors	Inka-Mari Sarvola, Lotta Hepo-oja, Silvia Forin, Hanna Pihkola		
Dissemination level	Public		
Due date	31.12.2024		
Date of final version	20.12.2024		
Document approval	Duncan Akporiaye	20.12.2024	

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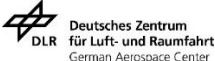
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Funded by
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Funded by the European Union (Grant n°.101096780). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

PROJECT PARTNERS

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BEN	OMV DOWNSTREAM GMBH	
BEN	GRACE GMBH	
BEN	BTG – B.T.G. BIOMASS TECHNOLOGY GROUP BV	
BEN	BTL – B.T.G. BIOLIQUIDS B.V.	
BEN	CNRS – CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	
BEN	DLR – DEUTSCHES ZENTRUM FÜR LUFT – UND RAUMFAHRT EV	
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BEN	ETA - ENERGIA, TRASPORTI, AGRICOLTURA SRL	
BEN	CEPSA/Moeve – COMPANIA ESPANOLA DE PETROLEOS SA	
BEN	RUG – RIJKSUNIVERSITEIT GRONINGEN	
BEN	BTG nExT – B.T.G. ADVANCED BIOFUEL COMPANY B.V	
BEN	NESTE OYJ	

ABBREVIATIONS

ABBREVIATION	DEFINITION
CH ₄	methane
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CO ₂	carbon dioxide
CSRD	Corporate Sustainability Reporting Directive
DNSH	Do No Significant Harm criteria
EUDR	EU Regulation on deforestation-free products
EU ETS	EU Emission trading system
GHG	greenhouse gas emission
ICAO	International Civil Aviation Organization
ILUC	indirect land use change
IMO	International Maritime Organization
LULUCF	land use, land-use change and forestry
NO _x	nitrogen oxides
nvPM	non-volatile particulate matter
N ₂ O	nitrogen dioxide

OPS	onshore power supply
RED	Renewable Energy Directives
RFNBO	renewable fuels of non-biological origin
RSB	Roundtable on Sustainable Biomaterials
SAF	sustainable aviation fuel
UNFCCC	United Nations' Climate Change Conference
UN SDG	United Nations' Sustainable development goals

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Executive summary

This deliverable provides a sustainability assessment framework to quantify and evaluate the environmental impacts of the biofuel technologies developed in the REFOLUTION project in relation to fossil technologies. It considers the existing, foreseen and proposed requirements of the European Climate and Energy Package related to maritime and aviation fuels, and the on-going standardization activities related to co-processing, as part of transition to fully biobased fuels. The goal of this deliverable is to identify the most relevant and suitable sustainability indicators to be used to analyse the environmental performance of the REFOLUTION technologies in Task 6.2 Sustainability indicators and approaches.

The sustainability assessment framework and sustainability indicators used in the REFOLUTION project are selected applying two methods. First, primary literature analysis was conducted on EU legislative texts and on marine and aviation sector specific guidelines concerned with the standardization of sustainability assessments of fuels and co-processing of biofuel to identify the sustainability aspects that are relevant to legislation. Second, structured qualitative interviews were carried out with selected experts from consortium partners to include stakeholder expertise and views in the indicators' selection.

As a results of primary literature analysis and qualitative interviews with consortium partners, greenhouse gas emissions, water usage and carbon efficiency emerged as the most important sustainability indicators for REFOLUTION biofuels. In addition, the sourcing criteria for the forestry and agricultural residues used as a biomass for REFOLUTION were emphasized. As REFOLUTION fuel solutions are produced from forestry and agricultural residues that are non-suitable for wood technology or food industry use, the biodiversity risk assessments demanded by EU green directives and sector specific guidelines are not effective. However, it is good practice to verify the origin of biomaterials in order to avoid risks for carbon stocks, biodiversity and endangered species.

Description of the deliverable content and purpose

The purpose of this deliverable is to identify the most relevant and suitable sustainability indicators to assess the environmental performance of the REFOLUTION technologies. All pillars of sustainable development, namely the environmental, economic and social ones, will be taken into account. A sustainability assessment framework is compiled taking into account present and upcoming requirements of the European Climate and Energy Package related to maritime and aviation fuels, sector specific guidelines related to maritime and aviation bio-based fuels, general sustainability frameworks for bio-based fuels, and the expertise of REFOLUTION project partners.

Deviation from objectives

There is no deviation from the initial objectives.

Introduction

The European Commission's vision of "A Clean Planet for All" [1] communicated in 2020, was followed by target setting processes and policy initiatives that aimed at defining the environmental boundaries of economic activities in more detail. According to the Sustainable and Smart Mobility Strategy [2], the EU aims at reducing their transport related GHG emissions by 90% by 2050. In addition to targets for road transport and climate neutral cities, steps to get there include the increase of short sea shipping and low- or zero-emissions alternatives for the aviation sector. Advanced biofuels appear as an essential solution for reaching the European objectives for tackling climate change.

This deliverable contributes to the sustainability assessment of the novel technologies for the production of biofuels for aviation and maritime transport. Its objective is to identify the most relevant and suitable sustainability indicators to be used to analyse the environmental performance of the technologies.

The REFOLUTION project directly relates to the societal objective of improving the environmental quality while ensuring mobility for people and goods, while taking into account previous work carried out at the sectoral level (maritime and aviation sector) and the considerations and observations of the project partners, which have a broad expertise and practical insights in this field. The environmental criteria to evaluate the technological solutions developed within the project are therefore derived from supranational regulations existing at the EU level, guidelines from sectoral associations and interviews with selected project partners.

1. Methodology

To account for the legislative and sectoral framework of maritime and aviation fuel sustainability and include the expertise of project partners in the selection of indicators, different methods are used. First, primary literature analysis is conducted on EU legislative texts (mainly included in the European Climate and Energy Package) to identify the environmental focus areas and requirements set for maritime and aviation fuels. Primary literature analysis is carried out also on sector specific guidelines concerned with the standardization of sustainability assessments of aviation and maritime fuels and co-processing of biofuel, if available. As sources, literature by standard setting bodies such as the International Civil Aviation Organization (ICAO), responsible for the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), and the International Maritime Organization (IMO), were identified. The second method used consists of structured qualitative interviews that were carried out with selected experts from consortium partners.

1.1. Existing regulations and guidelines

EU Regulations and sector guidelines concerning the sustainability of biofuels were identified. They differ in coverage, some applying to all fuels and others being specific for aviation or marine fuels. The regulations and standards considered in this document are summarized in Table I.

Table I - Regulations and standards considered in the report, with specification of focus area and status.

Name	Focus	Status
EU/2023/2405 ReFuelEU Aviation [3]	Aviation, SAF	Obligations starting in 2025
EU/2023/1805 FuelEU Maritime [4]	Marine, emissions and energy intensity	Obligations starting in 2025
EU 2018/2001 Renewable Energy Directive RED II [5]	Renewable energy, emissions, (I)LUC	In force
EU 2019/807 Delegated Regulation of RED II [6]	Bioenergy, ILUC	In force
EU 2022/996 Implementing Regulation with ref. to RED II [7]	Emissions, (I)LUC	In force
EU 2023/2413 Renewable Energy Directive RED III [8]	Renewable energy, emissions, (I)LUC	In force
EU 2023/1115 Deforestation Regulation EUDR [9]	(I)LUC	In force, extension to biofuels possible after 2025
EU 2020/852 EU Taxonomy [10]	Climate mitigation and adaptation, emissions, water, biodiversity	In force
EU 2021/2139 Delegated Regulation of EU Taxonomy [11]	Adaptation and mitigation	In force
EU 2023/959 EU ETS [12]	Emissions	In force
EU 2023/957 MRV [13]	Emissions	In force
CORSIA Sustainability Criteria for CORSIA Eligible Fuels [14]	Aviation, SAF	In force
CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels [15]	Aviation, SAF	In force
CORSIA Methodology for Calculating Actual Life Cycle Emissions Values [16]	Aviation, SAF	In force
2023 IMO strategy on reduction of GHG emissions from ships [17]	Marine fuel emissions	In force
Guidelines on life cycle GHG intensity of marine fuels (LCA guidelines) [18]	Marine fuel emissions	In force

1.2. Interviews

To gather insight from REFOLUTION partners, interviews were set up with representatives from the following project partners: OMV, Neste, SINTEF, BTG, Grace and CEP SA. Sustainability themes were discussed around the following three questions:

1. What are the most relevant regulations and/or standards from sustainability perspective regarding REFOLUTION biofuel solutions? (environmental, social, economic and/or governance-related sustainability)
2. What are the most interesting and valued sustainability indicators to cover in addition to GHG emissions?
3. What is the status of LCA data availability? (mass flows, energy consumptions, sourcing data of raw materials, expected outcomes on markets etc., public data or not)

Interview results are summarized in results section 3.3.

2. Results

This chapter illustrates the main aspects of the reviewed regulations and guidelines and summarizes the interviews conducted with project partners.

2.1. Regulations

In the following, the context and content of the regulations displayed in Table 2 are summarized, with a particular focus on the sustainability requirements for aviation and marine fuels. The findings are intended to support the selection of the set of sustainability indicators to be applied to the innovative technologies developed in the REFOLUTION project.

The identified regulations can be categorized in two groups, the first one including Directives specific to the aviation and maritime sector (ReFuelEU Aviation and FuelEU Maritime), and the second one having a sector-agnostic scope (the Renewable Energy Directives RED II and RED III, the EU Deforestation Regulation, the EU ETS and EU Taxonomy).

The FuelEU Maritime Directive [4] is dedicated to Renewable and Low-Carbon Fuels in Maritime Transport. Its aim is to reduce the fuels' energy intensity (reference value of 91.16 gCO₂eq/MJ) progressively between 2025 (-2%) and 2050 (-80%). Besides CO₂ emissions, also CH₄ and N₂O are covered by the Directive. The market development of renewable fuels of non-biological origin (RFNBO) is particularly supported. Also, from 2030 on, ships moored at a port must use onshore power supply (OPS) at berths. Annex II defines default values to be used for the tank-to wake emissions calculation. If no suitable default value is found, the emissions can be measured by laboratory testing or direct emissions measurements, with reference to RED [5], [8].

The EU ReFuel Aviation Directive [3] aims at boosting the production, supply and uptake of sustainable aviation fuels (SAF) in order to decarbonize air transport in accordance with the EU's 2020 Sustainable and Smart Mobility Strategy [19]. The directive defines SAF as "aviation fuels that comprise liquid, drop-in fuels, fully fungible with conventional aviation fuels and compatible with existing aircraft engines" and foresees a progressive increase of the compulsory minimum share of SAF for aircraft operators, from 2% in 2025 to 70% in 2050. By the beginning of 2025, the European Union Aviation Safety Agency is expected to provide values to estimate the carbon footprint and CO₂ efficiency per kilometer by aircraft type and fuel used. Regarding the consideration of sustainability aspects, the motivation and legislative scope of ReFuelEU Aviation explicitly include only GHG emissions. However, if biofuels are used, their origin needs to be made explicit and the biofuels are required to comply with the sustainability and lifecycle emissions criteria mentioned in RED II, whereby biofuels produced from food and feed crops are not eligible for the SAF share due to land use change concerns. Instead, biofuels from food and feed origin are considered to have the same emission factor as the least favourable fossil fuel pathway of that type of fuel and do not contribute to the (calculated) decarbonization of fuel, as determined by the Delegated Regulation 2019/807 [6]. Moreover, the contribution of fuels from food and feed crops to the energy consumption of Member States should be reduced from 2024 on and reach 0% by 2030 at latest.

In general, the Renewable Energy Directives (RED) set the legal framework for developing renewable energy in the EU. After leading to national 2020 targets for renewable energy in its first version in 2009, RED II and RED III updated the EU-level target for 2030 to 32% and 42.5% respectively [5], [8].

RED III (2023) acknowledges the relevance of biofuel use also in maritime transport and aviation and that biofuels may bring about land-use-change risks such as biodiversity loss and endangering food security, the latter exacerbated by the war in Ukraine. Particular attention is paid to deforestation, especially to the annual expansion of global production area in high carbon stocks, protection of biodiverse and carbon-rich habitats such as primary and old-growth forests, highly biodiverse forest, grassland peatlands and heathlands.

RED III is an update of the broad legal framework represented by RED II. Introduced in 2019, RED II addresses among others the use of renewable energy in the transport sector, setting the minimum goal of a 14% share for each member state by 2030. It also sets sustainability criteria for biofuels, bioliquids and biomass fuels produced from forest biomass. Among others, it should be reported if the country in which the forest biomass was harvested ensures through legislation and monitoring that the harvested forest can regenerate, no biomass from nature protection areas is used, the harvesting activities do not damage the soil quality and biodiversity, and the long-term production capacity of the forest is not impaired. In order to be accounted as renewable energy source, biofuels, bioliquids and biomass fuels need to fulfil additional criteria, e.g., the country of origin of the forest biomass must be part of the Paris Agreement and include changes in carbon stock caused by biomass harvest in the climate targets submitted to UNFCCC or provide evidence that LULUCF emissions do not exceed removals. Additionally, RED II provides equations for the calculation of the GHG emissions through production and use of biomass fuels, typical and default values for GHG emissions by different biomass fuel production systems (Annex VI), and introduces a privilege for certain advanced biofuels, whose contribution towards the minimum share of biofuels may be considered to be twice their energy content. This privilege can be claimed also for the biomass fraction of wastes and residues from forestry and forest-based industries, non-food cellulosic material and ligno-cellulosic material except saw logs and veneer logs (Annex IX). As a complement, the Implementing Regulation EU 2022/996 provides requirements for the certification of biofuels considering also land-use change aspects and, in Annex IX, standard CO₂, CH₄ and N₂O emission values for energy carriers.

RED II is supplemented by the delegated regulation EU 2019/807 [6] which sets criteria for determining ILUC risk and for awarding the low ILUC-risk certification, including the average annual expansion of the global production area of a specific feedstock, the characteristics of the land into which the expansion took place (e.g., land with high-carbon stock or degraded land, small holders).

The same sustainability area is also addressed by the recent EU Regulation on deforestation-free products (EUDR) [9], which forbids to place on or export from the EU market goods like cattle, cocoa, coffee, oil palm, rubber, soy and wood unless these are deforestation-free and comply with land use rights, environmental protection, forest management, human and labour rights and the rights of indigenous people. The Regulation foresees an impact assessment by 30. June 2025, which should consider the extension of the scope of the regulation to biofuels.

According to the EU Taxonomy [10] and its Delegated Regulation EU 2021/2139 [11], the manufacture of biogas and biofuels for use in transport meets the substantial contribution criteria in for climate mitigation as

long as compliant with RED II, and the DNSH criteria for climate adaptation, pollution prevention circular economy and biodiversity contributed to climate mitigation.

The climate focus of EU legislation linked to aviation and maritime fuels can be found also in the EU ETS [12]. The maritime sector is fully integrated in the EU ETS since 2024. The permits are entirely sold via regular auctions, covering CO₂ emissions from ships with a gross tonnage above 5000 Gt. For routes between ports of one or two EU Member states, the emissions are accounted entirely, from/to an EU port to/from a non-EU port 50% of emissions are accounted for. From 2026 onwards the EU ETS will account also for CH₄ and N₂O emissions, and an extension of the scope to ships below 5000 Gt but not below 400 Gt is planned by end of 2024 according to Rec. 9 EU MRV amendment. As aviation is concerned, free allocations will be phased out by 2024, the cap will be decreased annually and non-CO₂ effects such as NO_x and PMs [20], so far not directly tackled by dedicated policies, will be first monitored, reported and verified (by 2024) and later, if necessary, included in the EU ETS.

To sum up, the main regulations in place at EU level regarding biofuels in general and their use in the maritime and aviation sectors in particular, have a strong focus on CO₂ emissions. Progressively, also relevant non-CO₂ emission like N₂O and CH₄ for the maritime sector and NO_x and nvPM for aviation, are being monitored and limited as well. Also, since RED II released in 2018, issues related to direct land use change, deforestation, indirect land use change, and the use of food and feed crops have been paid increasing attention, also in the wake of the EU Biodiversity Strategy for 2030 [21] and given the availability of renewable fuels of non-biological origin (RFNBOs). In the most recent legislative initiatives, also social criteria such as land use rights, human and labor rights and the rights of indigenous people gain an increasingly important role, following the attention dedicated to the social dimension of sustainability e.g. by the Corporate Sustainability Reporting Directive (CSRD) [22] and the EU Due Diligence Directive [23].

2.2. Existing guidelines and frameworks

The International Civil Aviation Organization (ICAO), responsible for the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), has set sustainability criteria [14], a methodology for calculation of life cycle emissions [16], and default values [15] to assess the sustainability of aviation fuels. These guidelines consider only greenhouse gas (GHG) emissions and set sustainability criteria for the biomass source. Similarly as in RED III [8], the biomass used for SAF is considered sustainable if it is not obtained from land or aquatic system with high biogenic carbon stock, such as primary forest, peat land or kelp forest. In addition, the methodology states that if the direct land use change (DLUC) emissions calculated according to the guidelines created by the Intergovernmental Panel on Climate Change (IPCC) exceed the default indirect land change (ILUC) value given in the CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuel document, the DLUC value shall be used.

On marine fuels, the International Maritime Organisation IMO has issued general GHG emission reduction targets in the 2023 IMO strategy on reduction of GHG emissions from ships [17]. The first Guidelines on life cycle GHG intensity of marine fuels (LCA guidelines) [18], published in 2023, considers GHG emissions, sustainable sourcing of biomass, and sustainable water usage as relevant environmental aspects in relation to marine biofuels. Biomass is considered sustainable if it is not sourced from land with high carbon stock such as primary forest, wetland or peatland, the production does not occur on land converted from high carbon stock or legally protected land after 1st of January 2008, and its cultivation minimizes indirect land-use change.

Also soil health has to be considered and only low invasive-risk feedstock can be selected for cultivation. Water usage is considered sustainable if it maintains or enhances water quality and availability in the marine fuel production area.

The Roundtable on Sustainable Biomaterials (RSB) has published a Sustainability framework [24]. The framework considers social, legal, environmental and management practices in the production of biobased materials, including biofuels. The greenhouse gas emission principle states that greenhouse gas emissions have to be calculated according to RSB's own, RED's, CORSIA's or other RSB approved methodology and show a minimum of 65% emission savings compared to the corresponding fossil baseline. This applies for materials produced in installations that started operations from 1 January 2021. Further criteria regard the material's origin: woody biomass can be sourced only from forestry harvesting residues, forestry processing by-products and residues, end-of-life forestry materials, alien invasive plants and short rotation wood crops and coppices. Further sustainability aspects taken into account by the framework are human and labour rights, water, air pollution, and use of technology, inputs, and management of waste. The other principles have no such clearly formatted indicators and threshold values as greenhouse gas and material's origin principles have.

On a broader scale, sustainability aspects and indicators applicable to biofuels can be found in the United Nations Sustainable Development Goals (UN SDG) framework. Especially goals 7. Ensure access to affordable, reliable, sustainable and modern energy for all, 13. Take urgent action to combat climate change and its impacts and 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss related to biofuels. Biofuel production aligns well with SDG's indicators 7.1.2 Proportion of population with primary reliance on clean fuels and technology and 7.2.1 Renewable energy share in the total final energy consumption. Regarding SDG 13, biofuels fit well with indicator 13.2.2 Total greenhouse gas emissions per year. The biodiversity and non-degradation demand from legislation and sector specific guidelines align with indicators under SDG 15. considering sustainably use of biodiversity and ecosystems both terrestrial and inland freshwater systems.

To sum up, sector specific guidelines and other frameworks reviewed mostly focus on CO₂ emissions and protecting biodiversity at the source of biomass. Under biodiversity protection, preventing direct and indirect land-use change and soil health are considered. Within sector specific guidelines, sustainability aspects outside environmental are not considered. However, more general frameworks consider also social and economic sustainability dimensions.

2.3. Interviews

Interviews were conducted to gain insights into what project partners see as relevant sustainability aspects for future research during the REFOLUTION project. The following partners were interviewed between May and September 2024: OMV, Neste, SINTEF, BTG, Grace and CEPISA. The interviews were recorded. All together six interviews were conducted, and they took on average 30 minutes apiece.

All relevant partners from product development point of view were interviewed. The chosen partners don't represent all value chain actors which might have an impact on the quality of answers and result to some aspects being not included.

Table 2. Interviews conducted in task 6.2 to gain REFOLUTION partners sustainability insights.

Organization	Interviewed person(s)	Date
OMV	Senior expert - innovation and technology	16.5.2024
Neste	- R&D program manager - Marine fuel expert - Aviation fuel expert	22.5.2024
SINTEF	- Mechanical, chemical and process engineer - Project engineer – biofuel production	24.5.2024
BTG	Chemical engineer	24.5.2024
Grace	R&D scientist/market development specialist	7.6.2024
CEPSA	- Researcher – products and application Oil & Bio - Innovation & technology development engineer - Senior scientist - Biomass valorization & Plastic conversion	25.9.2024

Sustainability themes were discussed around the following three questions:

1. What are the most relevant regulations and/or standards from sustainability perspective regarding REFOLUTION biofuel solutions? (environmental, social, economic and/or governance-related sustainability)
2. What are the most interesting and valued sustainability indicators to cover in addition to GHG emissions?
3. What is the status of LCA data availability? (mass flows, energy consumptions, sourcing data of raw materials, expected outcomes on markets etc., public data or not)

2.3.1. Interview findings

Most relevant questions and standards

Several sustainability regulations or standards relevant to REFOLUTION biofuels were mentioned in the interviews. They are listed in

Table 3 and divided between aviation and marine based on their applicability.

Table 3. Most relevant regulations and standards for aviation and marine sector according to interviews.

	Both aviation and marine	Aviation only	Marine only
ASTM standards	x		
Biofuel sustainability standards	x		
CBAM	x		
CORSIA guidelines		x	
EU ETS	x		
Feedstock quality standards	x		
FuelEU Maritime (2025)			x
IMO guidelines			x
LCA standards	x		
Low carbon fuels standards	x		
RED II and III	x		
ReFuelEU Aviation (2025)		x	
Renewable fuel standards	x		

The interviewees remarked that current regulations specify chemicals, not function, e.g. certain amounts of aromatics are allowed but that is because the current production methods produce them so regulation is needed. There is also a divide between marine and aviation fuels: for aviation, security and safety are always the top interest. In the marine sector, there is more flexibility. Additionally, long term stability and blending with other fuels is seen as important.

The regulatory landscape is seen as diverse. On one hand there are EU-level regulations but on the other hand, national regulations of EU member states are not harmonized. One issue is also the lack of global regulations. For example, the carbon trading scheme EU-ETS is good, but it should be followed globally to drive investment decisions. There seems to also be a lack of longevity pathways for industries. Market demand would increase development activities for low carbon fuels, but regulations are needed to enable them to enter the markets. One other point regarding current regulations is that they mostly consider only global warming potential and land use change risk assessments, disregarding many potentially important environmental impacts.

The regulatory landscape was further discussed in parts 2.1 and 2.2 of this deliverable.

Most interesting and valuable sustainability indicators

Partners were asked about interesting sustainability indicators so it would be possible to better gear the future research of this task towards topics that are of interest to the project. In addition to GHG emissions, the following environmental impacts were mentioned:

- particulate matter
- water use
- biodiversity
- land-use efficiency and impacts to arable land
- energy consumption
- CO₂ efficiency related to carbon footprint
- biogenic carbon and its movement to valuable fuel and not to other fractions

Particulate matter was seen as an important factor when transportation is considered as fossil diesel is known to emit small particulates when combusted. It could be assumed that the new REFOLUTION biofuels would cause less particulate matter emissions during use. Water use impacts during the whole life cycle are important to consider, as water scarcity, coupled with temperature increases, strongly affects southern Europe.

Biodiversity impacts and land use efficiency are key topics for REFOLUTION as the main raw material for these new biofuels is biomass and farming biomass needs arable land. The energy demand of fuel manufacturing should also be considered. If the refining process is very energy intensive, it means great amounts of energy need to be readily available. And, for the new biofuels to be truly sustainable, they need to be produced using renewable energy which is not always available in such large quantities. The CO₂ efficiency and tracking of biogenic carbon were also indicated as potentially interesting topics as carbon as a feedstock can be used in many sectors but it is often regarded as waste.

LCA data availability

One aim of work package 6 is to conduct a life cycle assessment (LCA) study on the newly developed biofuels. For this reason, the status of LCA data availability was asked. To make a reliable assessment, primary data should be used. This means i.e. information about mass flows, energy consumption and sourcing of raw material. Here the most important players are the partners in charge of lab, pilot and demo scale production.

The consensus was that data would be available on some parts of the production chain (catalysts, upgrading, refinery). It was also noted that should no primary data be available, partners would be willing to comment on any assumptions made in the LCA. In general, it was concluded that public data, i.e. from literature, should be available for fuel production.

3. Environmental sustainability assessment framework

Based on the screening of regulations and frameworks and the interviews presented in the Results section, we recommend assessing greenhouse gas emissions, water usage and carbon efficiency in sustainability assessment of REFOLUTION biofuels. Full LCA should be conducted on REFOLUTION biofuels to capture the carbon and water footprint of the fuel. In the LCA method, guidance from RED and CORSIA's guidelines are to be followed. However, as a new co-feeding technology is developed, no default emissions factors might be available. In the scope of sustainability assessment, representative estimates and literature values are to be used. However, direct emission measurements are recommended to technical teams of REFOLUTION project.

In addition, sourcing criteria for the forestry and agricultural residues used as a biomass for REFOLUTION biofuel has to be established. As REFOLUTION fuel solutions aim to be produced from forestry and agricultural residues that are non-suitable for wood technology or food industry use, the biodiversity risk assessments demanded by RED III and ReFuel Aviation directive are not effective. However, it is a good practice to confirm that the wood where forestry residues are coming from, or the agricultural residues are not sourced from areas causing risks for carbon stocks, biodiversity and endangered species. The aspects of other sustainability dimensions such as economic or social sustainability are not covered by the existing framework, since they are beyond the scope of the REFOLUTION project.

Conclusion

This deliverable aims to identify the most relevant and suitable sustainability indicators to be used in analysing the environmental performance of the REFOLUTION technologies. The most relevant and suitable indicators were searched via primary literature review on existing, proposed, and anticipated EU legislation, aviation and marine specific sector life cycle impact assessment guidelines and via interviewing REFOLUTION consortium partners.

The sustainability indicators referred in legislation and guidelines are mostly greenhouse gas emissions and land-use change in all forms and regarding biodiversity. These came out as relevant also in the interviews where it was stated that biodiversity impacts and land use efficiency are key topics for REFOLUTION. Most guidelines require a use of default values for impacts. However, legislation will always be behind technological development and like in the case of REFOLUTION fuel, there are no default values for the chosen production pathway. The correct test measurement of emissions requires facilities from the technical side of REFOLUTION project. Before the test results, LCA can utilize representative estimates and literature values.

The interviews conclude that current regulations specify mostly chemicals, not function, e.g. certain amounts of aromatics are allowed as the current production methods produce them so regulating is needed. There is also a divide between marine and aviation fuels in legislation and the landscape is diverse: EU-level, national level, but global regulations are lacking. The interviews pointed to a lack of longevity pathways for industries. Market demand would increase development activities for low carbon fuels, but regulations are needed to enable market entry. Current regulation is seen focusing mostly on global warming potential and land use change risk assessments, disregarding many potentially important environmental impacts.

Based on the primary literature review and interviews, greenhouse gas emissions, water usage and carbon efficiency were identified as the most relevant and suitable sustainability indicators of REFOLUTION biofuels. Additionally, in the sourcing of biomaterial used in REFOLUTION biofuel production it must be ensured, that no risks for carbon stocks, biodiversity and endangered species arise. As the REFOLUTION project continues, the environmental sustainability assessment framework utilized in this project might be refined from the version outlined in this deliverable.

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