BL2F

Transforming Black Liquor to Biofuel

Research and Innovation Action

H2020-LC-SC3-2019-NZE-RES-CC

Identification of major trends in future biofuel demand

WP6 - Task 6.2

30/09/2021

Lead Beneficiary: LGI

Authors: Adéola Jaiyeola, Mathilde Legay, Luc Berman

@BL2F_EU **www.bl2f.eu** **BL2F_EU**

Disclaimer

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement n°884111.

Document Information

Grant agreement	884111
Project title	Black Liquor to Fuel by Efficient Hydrothermal Application integrated to Pulp Mill
Project acronym	BL2F
Project coordinator	Prof. Dr Tero Joronen
Project duration	1st April 2020 – 30th November 2023 (36 Months)
Related work package	WP 6 – Market Potential and exploitation
Related task(s)	Task 6-2: Identification of major trends in future biofuels demand
Lead organisation	LGI
Contributing partner(s)	SINTEF-ER, Valmet, Neste
Due date	31.08.2021
Submission date	31.08.2021
Dissemination level	Public

History

Date	Version	Submitted by	Reviewed by
17/12/20	Skeleton	Mathilde Legay	Lamiaa Biaz
07/02/20	Advanced Skeleton	Mathilde Legay	Luc Berman
12/07/21	V1	Adéola Jaiyeola	Mathilde Legay
04/08/21	V2	Adéola Jaiyeola	Lamiaa Biaz
18/08/21	V3	Adéola Jaiyeola	Tero Joronen
01/09/21	V3	Adéola Jaiyeola	Fanni Mylläri
16/09/21	V3	Adéola Jaiyeola	Juha Lehtonen

Contents

Executive Summary

This deliverable presents an analysis of major trends and factors that will influence the demand for biofuels in aviation and shipping by 2040 in Europe.

The methodology for the preparation of the study is based on a PESTEL analysis (Political, Economic, Societal, Technological, Environmental, and Legal), which constitutes a framework of macro-environmental factors. It is carried out with the inputs of nineteen professionals whose expertise is related to biofuels in aviation or shipping and/or to the pulp and paper industry and who were interviewed or participated in a dedicated workshop. All factors potentially impacting the future biofuel demand are analysed in terms of intensity, probability, and proximity in date.

The study reveals that the following factors will have a major impact on the biofuel demand by 2040:

On a long medium-term (2030/2040):

- Policies promoting biofuels in aviation and shipping
- High cost competitiveness of fossil fuels

On a shorter-term (before 2025/2030):

- Cost competitiveness of imported biofuels
- Health crisis

Moreover, the study highlights that the demand for biofuels in Europe will be mostly driven by political decisions to promote the demand for biofuels and low carbon energies in transportation including aviation and shipping. The Green Deal ambitious objective to make Europe the world's first climate-neutral continent by 2050 indeed plays a major role in this quest for decarbonisation. The regulatory framework also influences other aspects such as the cost competitiveness of fossil fuels and biofuels, the mobilisation of sustainable feedstock for biofuels, the investments in targeted R&D efforts and the citizens' perspective on biofuels. The majority of the scenarios which were investigated, either resulted in an increased biofuel demand or a minorly affected demand. Among the factors that could negatively impact the future biofuel demand (e.g., Political crisis, Global warming, Uncertainties about the availability of sustainable biomass, Health crisis), policy decisions remain the most decisive to influence the biofuel demand and it is in the best interests of the decarbonisation objectives to promote them.

Advanced biofuels are however still far from being used on a large scale and have a significant expansion margin ahead of them. Among several options, they will contribute to the reduction of carbon emissions in the transportation sector and will most likely be a medium-term solution to address aviation's emissions. By 2040, the biofuel demand is expected to rise inevitably, encouraged by ambitious objectives set by policymakers and none of the investigated factors is expected to alter or reverse this growth.

List of Figures

List of Tables

Abbreviation & Acronyms

Acronym	Description
ASTM	American Society for Testing and Materials
BL2F	Black Liquor to Fuel
CEPI	Confederation of European Paper Industries
CO_2	Carbon dioxide
CSR	Corporate Societal Responsibility
DME	Dimethyl Ether
EU	European Union
EU-28	Corresponds to all countries that belonged to the European Union between 2013 and 2020
EU ETS	European Union Emissions Trading System
GHG	Greenhouse Gas
GMF	Global Market Forecast
HFO	Hydrofluoroolefin
HVO	Hydrogenated Vegetable Oil
IATA	International Air Transport Association
ILUC	Indirect Land Use Change
IMO	International Maritime Organisation
LNG	Liquefied Natural Gas
LT	Long Term
MARPOL	Marine Pollution
NGO	Non-Governmental Organisation
PESTEL	Political Economic Societal Technological Environmental Legal
RED II	Renewable Energy Directive II

RPK	Revenue Passenger Kilometre
SO_x	Sulphur Oxides
ST	Short Term
T&E	Transport & Environment
TAU	Tampere University
TRL	Technology Readiness Level
UCO	Used Cooking Oil
UN	United Nations
WP	Work Package

Keywords

PESTEL, biofuel demand, aviation, shipping, advanced biofuels, black liquor

Glossary

Acronym	Description
Biofuels	Fuels produced from biological raw materials. Four generations of biofuels are distinguished: • First-generation biofuels are crop-based biofuels as they are commonly derived from food plants, such as biodiesel from oilseed rape and bioethanol from sugar. • Second-generation biofuels are produced from lignocellulose materials derived from whole or parts of plants and trees that are not used for human consumption. These include all biofuels derived from wood and include black liquor-based fuels, lignocellulosic bioethanol and synthetic diesel produced using gasification or the Fischer-Tropsch process. • Third-generation biofuels are those derived from aquatic biomass. • Fourth-generation biofuels, so-called "electro fuels", include the use of renewable electricity and carbon dioxide as feedstock (Sandquist, 2017). Advanced Biofuels, as defined by the European Technology and Innovation Platform, are those "(1) produced from lignocellulosic

	feedstocks (i.e. agricultural and forestry residues, e.g. wheat straw/corn stover/bagasse, wood-based biomass), non-food crops (i.e. grasses, miscanthus, algae), or industrial waste and residue streams, (2) having low CO_2 emission or high GHG reduction, and (3) reaching zero or low Indirect Land Use Change impact."(ETIP Bioenergy, 2021).
Black Liquor	A black liquid residue produced by the pulping of wood during the papermaking process. Black liquor is highly concentrated in lignin and cooking salt, it can be used as feedstock for the production of biofuels.
Cellulosic Biomass	Cellulosic biomass refers to any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood wastes and residues, plants (including aquatic plants), grasses, residues fibres, and animal wastes, municipal wastes, and other waste materials (N.W.Y.Ho, 2011). Lignocellulosic biomass refers to plant biomass that is composed of cellulose, hemicellulose, and lignin. It is the most abundant renewable feedstock (Xumeng Ge, 2018).
Decarbonisation	Decarbonisation is the reduction of carbon dioxide emissions through the use of low carbon power sources, achieving a lower output of greenhouse gases into the atmosphere (TWI Global, n.d.).
Drop-in biofuels	Liquid bio-hydrocarbons that are functionally equivalent to petroleum fuels and are fully compatible with existing petroleum infrastructure (van Dyk, Su, McMillan, Saddler, 2019).
E-fuels	Electro fuels or e-fuels are an emerging class of carbon-neutral drop-in replacement fuels that are made by storing electrical energy from renewable sources in the chemical bonds of liquid or gas fuels. They are a sustainable solution for aviation, maritime and road transport (Siegemund, 2017).
Feedstock	Any renewable, biological material that can be used directly as a fuel or converted to another form of fuel or energy product.
Forest Biomass	Forest biomass includes all parts of the tree, not only the trunk but also the bark, the branches, the needles, or leaves, and even the roots (Government of Canada, 2020).
Hydrogen fuel	Hydrogen is a clean fuel that, when consumed in a fuel cell, produces only water (US Office of Energy Efficiency and Renewable energy, n.d.).
Power-to-Liquid fuels	The Power to Liquid concept is based on the conversion of renewable energy to liquid fuels and chemicals such as methanol, oxymethylene ether ammonia, and Fischer-Tropsch products (Hadrich, Salem, n.d.).

Sustainable aviation fuel	Sustainable Aviation Fuel is a clean substitute for fossil jet fuels and is produced from sustainable resources (SkyNRG, n.d.).

1 Introduction

In 2019, European Commission president Ursula von der Leyen unveiled the Green Deal, an ambitious roadmap of €1,000 billion of investments over 10 years that aims to make Europe the world's first climate-neutral continent by 2050 (European Commission, 2019). The transport sector is expected to play an important role in achieving the carbon neutrality objective. In 2017, transportation accounted for 27% of the EU emissions, representing one of the fastest-growing GHG sources since 1990 (European Environment Agency, 2019). Reversing this trend is as essential as it is complex, and all the levers of action must be mobilised.

Biofuels strive to contribute to the decarbonisation of long-distance transportation and reduce fossil fuels dependence. The biofuel industry is still developing, as the biofuel consumption for transport increased by 6.8% between 2018 and 2019 in the EU-28 (EurObservER, 2020). In the EU, the RED II supports the production and development of renewables, which includes advanced biofuels. In the transportation sector especially, the EU objective is to reach 14% renewable energy by 2030 (European Commission, 2021b).

The technology developed in the BL2F project is expected to convert black liquor into advanced biofuels for the shipping and aviation industries. The process could produce more than 50 billion litres of sustainable advanced biofuels by 2050, meeting the EU demand for advanced biofuels for aviation and shipping. The BL2F solution is expected to reach TRL9 and be operational on the market around 2030. By 2040, the biofuel demand will continue to evolve based on several elements related to EU and national regulations, cost competitiveness of biofuels, societal evolutions, technological availability, and environmental influences. This study will therefore explore the major trends and factors that will impact the demand for biofuels for aviation and shipping by 2040 in Europe.

2 Methodology

- **Description of factors impacting future biofuels demand**

The PESTEL analysis methodology was used in this research to identify the main trends for future biofuels demand. *PESTEL* stands for Political, Economic, Social, Technological, Environmental, and Legal. The PESTEL analysis constitutes a framework of macro-environmental factors described in **Figure 1**.

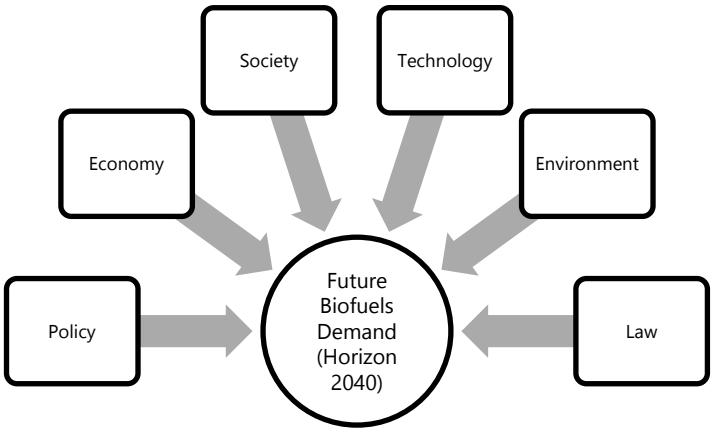

Figure 1. Factors impacting future biofuels demand

- **Political and legal factors** are referring to the factors affecting the degree to which the government intervenes in the economy or on the market.
- **Economic factors** include the state of macroeconomic health (economic growth of the sector, consumer confidence among others) that creates underlying trends in consumption levels.
- **Societal factors** include the evolution of the population and its characteristics (demography, age pyramid, new socio-cultural behaviours, environmental awareness) generating, among other things, new purchasing behaviours and sources of opportunities.
- **Technological factors** include technological innovations that weaken or strengthen the technical leadership of the players involved. They can determine barriers to entry, minimum efficient production level and influence outsourcing decisions. Furthermore, technological shifts can affect costs, quality, and lead to innovation.
- **Environmental factors** include environmental aspects such as global warming, availability of sustainable resources, that physically restrict access to some markets.

A preliminary PESTEL analysis was conducted through desk research, which enabled the identification of multidimensional factors potentially impacting future biofuels demand. An assessment grid was constructed including all identified factors (Appendix 1). To have an exhaustive overview and an evaluation of each factor's potential influence, LGI gathered the insights of cross-disciplinary experts, who reviewed each factor and complemented them. The following figure illustrates the impact assessment methodology that was carried out:

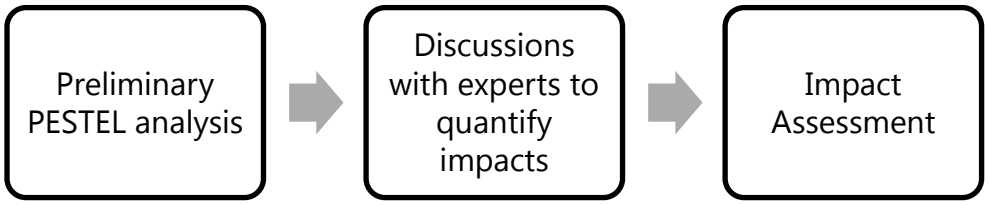

Figure 2. Impact assessment methodology

- **Discussions with experts**

As described in Figure 3, LGI selected experts from all along the value chain to have a holistic view of the future biofuels demand. Experts from different sectors, such as the pulp industry, technology providers, oil refinery, distributors & engine suppliers were interviewed from October 2020 to January 2021.

The BL2F technology will enable the pulp industry to value Black Liquor into advanced biofuels, thanks to a novel Integrated Hydrothermal Liquefaction (IHTL) process. Black Liquor, a side stream from the pulp industry, will first be transformed into HTL-oil and then into a fuel intermediate by technology providers. The fuel intermediate will then be converted by oil refiners into drop-in fuels for aviation and shipping, suitable for use by distributors and engine suppliers.

Companies within the consortium, such as The Navigator Company, Valmet, Ranido, Neste, and entities part of the Industry advisory board of the BL2F project, such as Avinor and Cepi, participated in discussions. Other external stakeholders, such as Concawe and FuelsEurope (oil refiners), Safran and DNV (distributor & engine supplier) were also interviewed.

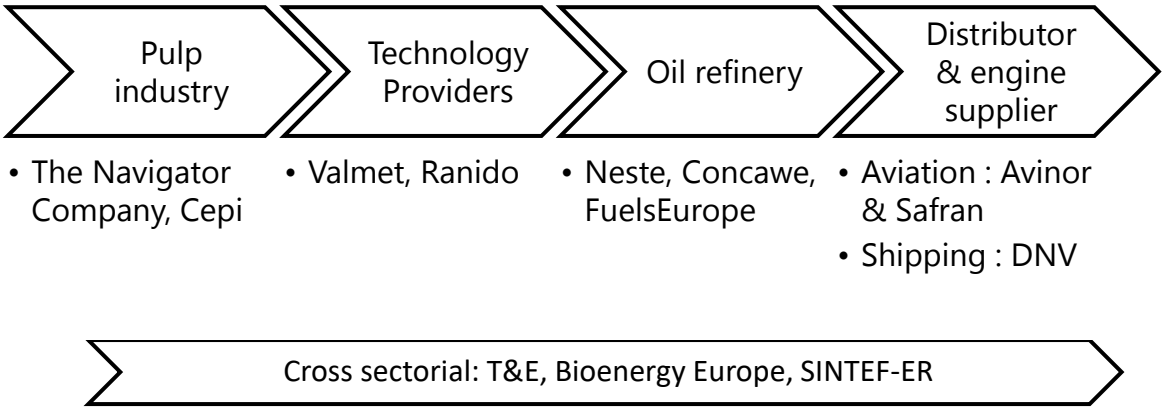

Figure 3. Interviewed organisations along the value chain of advanced biofuels produced from black liquor feedstocks

Discussions were carried out with representatives from different expertise (a total of 19 representatives with expertise in biofuels) aiming at bringing out the most relevant macro-environmental factors. Table 1 below lists the names of participating experts and their area(s) of expertise.

Table 1 List of interviewed experts

Name of the Expert	Position	Company	Area of expertise	Date of interview
Arvid Løken	Senior adviser in the Carbon Reduction Programme	Avinor	Environmental & technological	4/12/2020
Nicolas Jeuland	Prospective manager Aviation environmental impact assessment and low carbon fuels	Safran	Environmental & Technological	23/11/2020
Aino Vettenranta & Joakim Autio	Specialist in Chemical Modelling & Researcher	Valmet	Technological, economic & Political	16/11/2020 and 27/11/2020
Cristina Mestre	Biofuel manager	T&E	Political	30/11/2020
Giulia Cancian	Policy Director	Bioenergy Europe	Political & Legal	6/11/2020
Anselm Eisentraut	Head of Market Intelligence, Strategy	Neste	Economic	12/11/2020
Judit Sandquist	Research Scientist	SINTEF-ER	Technological	3/11/2020
Alexandre Gaspar[1]	Industrial scale-up & New Business Development	The Navigator Company	Technological & Economic	11/01
Christos Chryssakis	Business Development Manager	DNV	Economic, technological	08/01/2021
Damien Valdenaire & Marta Yugo	Science Executives	Concawe	Technological & Economic	08/01/2021

[1] Exchanges were carried out by e-mail and during a workshop

Name of the Expert	Position	Company	Area of expertise	Date of interview
Daniel Leuckx	Policy Executive	Fuels Europe	Political & Economic	08/01/2021
Jori Ringman	General Director	Cepi	Environmental	11/01/2021
Jussi Orhanen	Business Development Manager	Valmet	Economic, Technological	11/01/2021
Pavel Kukula	Managing Director	Ranido	Technological	11/01/2021
Juha-Erkki Nieminen	Head of Business Development, Lignocellulosics	Neste	Technological	11/01/2021
Mikko Uusitalo	Material Technology Manager	Valmet	Technological	11/01/2021
Tero Joronen	New technology/ Industry Professor	TAU	Technological, economic	11/01/2021

During the discussions, LGI asked the experts to name the most important factors and events that would have an impact on future biofuels demand. Following this open question, LGI asked the experts to rate their impacts on future biofuel demand in the assessment grid developed by LGI (Appendix 1.)
LGI conducted one-hour interviews with twelve experts, and six members from BL2F Advisory Board participated in a dedicated workshop organised by LGI. One expert (The Navigator Company) was willing to quantify the factors by e-mail and also participated in the workshop.

- **Impact assessment of factors**

LGI asked experts of the field to evaluate each factor on the following criteria:

- **Intensity of the consequences** on the market, if they occur, rated from 1 (very weak) to 4 (very strong).
- **Probability to occur**, rated from 1 (very unlikely) and 4 (very likely).
- **Term (or Time horizon),** rated from 1 (long term, by 2040) to 4 (short term, by 2021-2022).

After calculating the average of experts' answers, an impact index was produced by multiplying the three criteria, according to the following formula:

$$Impact\ Index = Intensity\ X\ Probability\ X\ Term$$

- **Representation of results**

The results are represented graphically to assist in the analysis and decision making. The graphics are in the form of one or more bubble charts, as illustrated in **Figure 4**. On the ordinate is represented the probability of occurrence, on the abscissa the intensity of the consequences of the factor, and the size of the bubbles represents the intensity of the impact of the factor. The colour of the bubbles indicates the proximity in time (red and orange for the short term and yellow and green for the longer-term).

(colour code Red=short term <Orange<Yellow<Green=long term)

(size code Small=Low impact of the factor <Medium<Large=High impact of the factor)

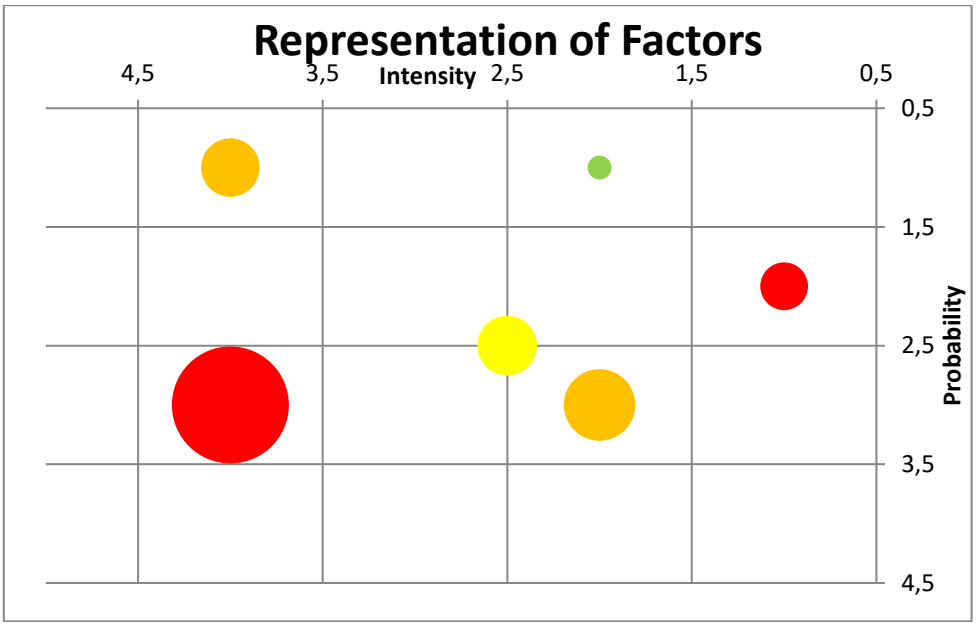

Figure 4. Representation of the results

- **Interpretation of results**

To interpret the results of the analysis, priority is given to the factors with a rate closer to 4, meaning proximity in time, high intensity, and a high probability (**Figure 5**). Prioritization is then made in terms of probability of occurrence, intensity, proximity in time and overall impact. Factors with an overall impact index superior to 30 are considered as having a major influence on the future biofuel demand and considered priority.

Figure 5 explains how LGI prioritises macro-environmental factors to be considered in making strategic decisions, the highest priority is given to the bubbles that have both high intensity and probability (located most far from the origin) and are large in size. The big red bubble at the bottom left has the highest impact index and is then logically the first macro-environmental factor to be taken into account.

(colour code Red=short term <Orange<Yellow<Green=long term)

(size code Small=Low impact of the factor <Medium<Large=High impact of the factor)

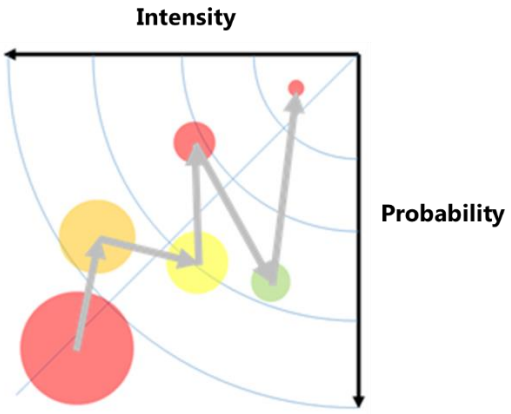

Figure 5. Interpretation of the results

In this illustration, the size of the bubbles represents the intensity of the impact of the factor (small for limited impact, big for high impact) and their colour indicates the proximity in time (red and orange for short term and yellow and green for longer-term). Since the overall impact index, the probability of occurrence and the intensity of the impact of the large red bubble are much higher than any other bubble, priority is given to the factor represented by the red bubble.

- **Market Potential**

The representation of factors and elaboration of scenarios of the demand for biofuels in 2040 will be analysed for their market potential in the deliverable D6.3 Market potential (M26).

3 Analysis of factors influencing the demand for biofuels by 2040

3.1 Political and legal factors affecting future biofuel demand

3.1.1 Main results

Representation of the assessed factors

Policy will be the most decisive factor in the evolution of biofuel demand in the next 20 years (See Figure 6 below). Seven political factors and two legal factors were identified and analysed. The interviews and analysis concluded that the two political factors with the highest impact are the following: *Policies promoting biofuels in aviation and shipping* and *Policies supporting biofuels in road and rail transportation.*

Table 2 Political and legal factors impacting future biofuel demand

	Political and Legal factors	Term	Impact Index
P1	Policies promoting biofuels in aviation and shipping	2.8	36
P2	Policies supporting biofuels in road and rail transportation	2.8	20
P3	Policies diminishing EU ETS quota in aviation and shipping	2.7	18
P4	Policies promoting low-carbon energies	2.3	17
P5	Consolidation of the shipping industry in terms of policies	2.2	13
P6	Policies promoting domestic and local energy production	1.6	6
P7	Political crisis	2.0	5
L1	Policies making certifications easier in shipping	2.0	14
L2	Policies making certifications easier in aviation	1.5	13

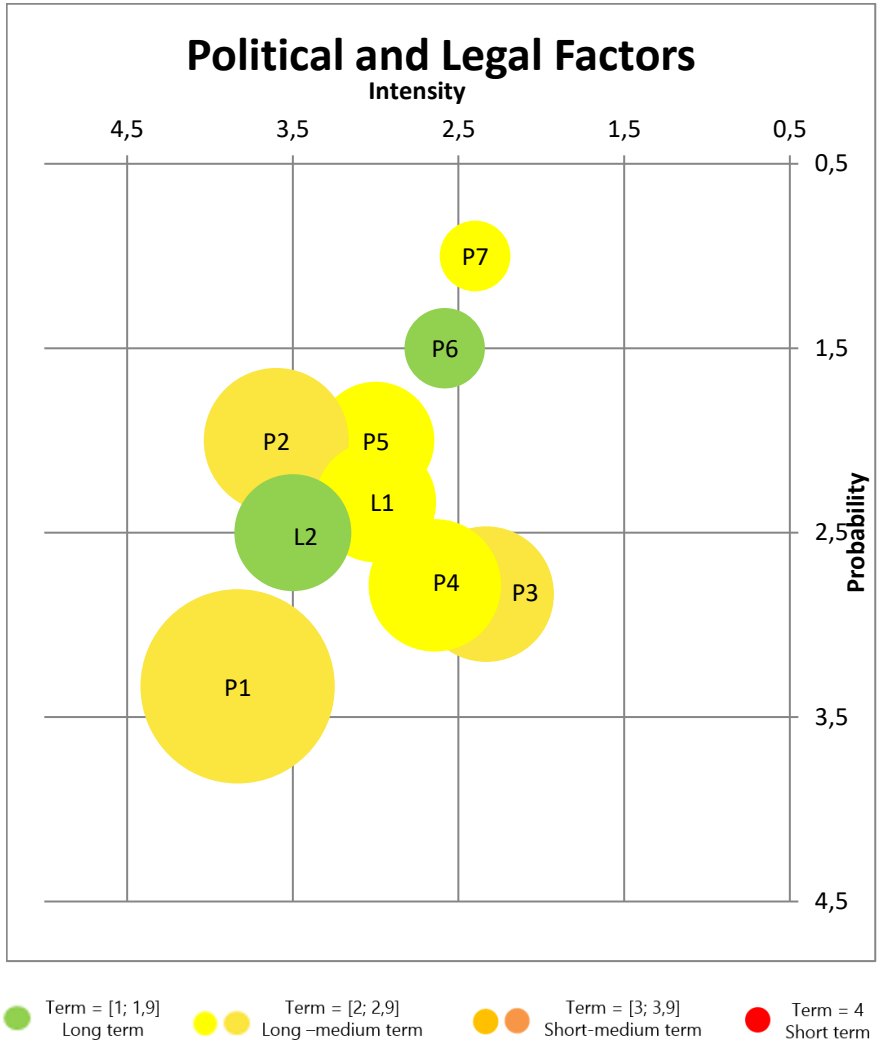

Figure 6. Representation of political and legal factors

3.1.2 Description and analysis of political & legal factors

In 2020, sustainable aviation fuels only represented 0.05% of total jet fuel consumption (European Commission, 2020c). The European Union (EU) is the main body prescribing policies in the aviation sector in Europe. On a legal side, the American Society for Testing and Materials (ASTM) has an important role in defining the technical standards in the aviation industry at the global level. In the shipping industry, policies are shaped by the International Maritime Organization (IMO), which is also under strong pressure from the EU. As EU directives must be implemented through national legislation, EU countries are expected to take their measures and use a variety of policy instruments to meet the objectives imposed by the EU directives. Twelve political and legal factors were studied with the inputs of Avinor, Valmet, Neste, Bioenergy, T&E, DNV, CONCAWE, FuelsEurope, Safran experts and the BL2F Members.

The following section describes major types of policy and legal decisions and events that may influence the future biofuel demand in the next 20 years.

Policies promoting biofuels in aviation and shipping

An increasing number of policies promoting biofuels and advanced biofuels in aviation and shipping are expected at both European and national scales, driven by European directives such as the Indirect Land Use Change Directive and the RED II (Legay, Jaiyeola, Berman, 2020). For example, RED II includes a sub-target for advanced biofuels in aviation and shipping, which must meet a minimum of 3.5% by 2030, and will be double-counted towards this target (European Commission, 2016). All advanced biofuels must meet the sustainability criteria, and their feedstock is present in Annexe IX of the RED II (Appendix 2). Several European countries, like Denmark, Finland, and Germany, have started to implement advanced biofuel mandates in aviation and shipping in the last few years. This trend is expected to be pursued and the minimum obligation of advanced biofuel in current national mandates is expected to increase over the years. Moreover, the impact assessment from the 2030 Climate Target Plan highlights biofuels as one of the main agents for decarbonisation of road transport, aviation, and shipping: "*Some hard to abate sub-sectors, notably aviation, will also require the development of advanced biofuels and sustainable alternative low or zero-carbon fuels and gases. The decarbonisation of road, maritime and air transport requires advanced biofuels that need to be produced at scale after 2030.*" Additionally, this scenario implies increasing investments and financial support to research and development in advanced biofuels (European Commission, 2021a).

The analysis revealed that this factor will be one of the most impactful, having a strong influence on the future biofuel demand in aviation and shipping (3.8) and a high probability (3.3), on a medium-term (2.8).

The push of policies towards biofuels and advanced biofuels will be key to driving the biofuel demand in the next 20 years. According to Bioenergy Europe expert, biofuels are needed for the decarbonisation of the transportation sector and attract great interest to both the aviation and shipping industries. However, biofuels are one out of multiple solutions to decarbonize

these industries, and will most likely be a medium-term solution for aviation (G. Cancian, personal communication, 2020; C. Mestre, personal communication, 2020; Vettenranta, Autio, personal communication, 2020). In the long term, electrification and hydrogen appear to be more promising solutions for transportation and aviation due to a stronger policy push of these alternatives along with their expected considerable technological developments to reach carbon neutrality (A. Løken, personal communication, 2020; C. Mestre, personal communication, 2020; Vettenranta, Autio, personal communication, 2020). Biofuels are still far from implementation at a large scale and have a large growth margin in front of them as the vast majority of transportation is currently powered by fossil fuels. Indeed, in 2019, the use of advanced biofuels made from agricultural, forestry and municipal waste is estimated at 0.2% of the energy use in transport in the EU (Flach, Lieberz, Bolla, 2019). For now, biofuels are only produced at a limited scale and their production quantity will not be sufficient in the short term to compete with fossil fuel production, and to cover the market for aviation and shipping, highlighting the need for complementary alternative fuels (J. Sandquist, personal communication, 2020). Bioenergy is moreover often left out of major documents, undermining investments in the bioenergy sector (J. Sandquist, personal communication, 2020).

While the RED II and other policies promoting biofuels are long term, several policy reforms have occurred in the past to come back on previous decisions or to lower the stringency level of a decree, increasing the uncertainty of ongoing investments and potentially disrupting the expected long term occurrence of this factor (C. Mestre, personal communication, 2020).

It is also important to highlight that stricter policies promoting the use of biofuels will not trigger an immediate demand boost. The market players will resort to compliance at minimum cost, meaning that they will meet the minimum biofuel amount required to limit the compliance costs. As the regulations become gradually stricter, the use of biofuels will increase with time, but price shall remain the major determinant factor of selection for a fuel (C. Chryssakis, personal communication, 2021).

Policies supporting biofuels in road and rail transportation

The BL2F policy analysis highlighted the majority of policies promoting biofuels in the transportation sector targeted road and railroad transportation in the first place (Legay, Jaiyeola, Berman, 2020).

This factor is the second highest in terms of impact index (20). The impact of this factor on future biofuel demand for aviation and shipping was difficult to assess for most experts as different scenarios may arise from this factor:

On one side, the increased adoption of biofuels in other transportation sectors may be a first step towards driving the promotion of biofuels in aviation and shipping. For instance, a considerable demand for biofuels from the automotive industry might help increase the overall biofuel production, which could make them available for all sectors including aviation and shipping (C. Chryssakis, personal communication, 2021).

On the other side, the road sector may be prioritised insofar as it is the predominant transportation sector in terms of demand, and the limited fuel availability may make competition arise between sectors, limiting the biofuel supply in aviation and shipping. DNV

expert makes the hypothesis that even in this scenario, the shipping industry shall be able to take advantage of high demand in road transportation since the maritime industry is a minor fuel consumer compared to other sectors (C. Chryssakis, personal communication, 2021). In the short term, aviation and maritime may not be prioritised over road, but in the longer term, policies could help the resources to be shared in a more balanced manner (A. Løken, personal communication, 2020).

However, electrification seems to be the preferred decarbonisation solution of light road transportation in the EU over sustainable fuels, as most climate scenarios rely on the electrification of vehicles and the switch to biofuel for maritime and air transport (Mirova, 2019).

For the SAFRAN expert, a priority allocation of liquid fuel to non-substitutable uses, typically maritime and air transport, is essential and a holistic approach to global climate mitigation across sectors is needed (N. Jeuland, personal communication, 2020).

Policies diminishing EU ETS quota in aviation and shipping

The European Union Emissions Trading Scheme (EU ETS) is the main instrument used to record and cap GHG emissions in the region across every industry to enable trading of corresponding allowances (European Commission, n.d.-a). Aviation is included in the EU ETS "cap and trade"' system, and a proposal from the European Parliament was approved in 2020 to also include shipping starting 2022 (European Parliament, 2020). The CO_2 quota of both sectors is therefore expected to diminish by 2040.

The analysis revealed that this factor will have a limited intensity on the future biofuel demand (2.3). The biofuel mandates will have a stronger impact on the biofuel demand than the EU ETS. With the current prices, airlines may favour buying quotas to resort to compliance at minimum cost (A. Løken, personal communication, 2020).

Policies promoting low-carbon energies

The impact assessment from the 2030 Climate Target Plan stipulates that the share of renewable energy in the transport sector shall increase through further development and deployment of electric vehicles, advanced biofuels and other renewable and low carbon fuels *as part of a holistic and integrated approach* (Malpas, Sbraga, 2020). Several promising alternative energies are currently under development with the aim of decarbonizing transportation at a large scale. Among these alternatives are biofuels, but also hydrogen, power to liquid fuels, electricity, e-fuels and multiple other renewables or sustainable fuels. According to the interviewed experts, these sources of energy may be pushed more than biofuels in the future (G. Cancian, personal communication, 2020; N. Jeuland, personal communication, 2020; A. Løken, personal communication, 2020; Vettenranta, Autio, personal communication, 2020). For instance, hydrogen is expected to have tremendous potential for aviation in the longer term. The EU Hydrogen Strategy, unveiled by the European Commission in July 2020 aims at boosting clean hydrogen production in Europe and pinpoints hydrogen as an investment priority to foster economic growth and resilience (European Commission, 2020). In 2020, Airbus announced its ambition to develop, by 2035, the "ZEROe concept aircraft", the world's first zero-emission commercial aircraft powered by hydrogen (Airbus, 2020). Additionally, national

policies and local-level actions to support electric vehicle deployment emerge across European countries (IEA, 2020).

In shipping, many types of sustainable drop-in fuels are already available on the market or being tested at limited scales, such as hydrogenated vegetable oil (HVO), used cooking oil (UCO), liquefied natural gas (LNG) or dimethyl ether (DME). Biodiesel, biogas, biomethanol, methanol, hydrogen and ammonia are also options that may grow in the future (C. Chryssakis, personal communication, 2021). Moreover, electrification of short-haul marine transport (ferries, harbour tugs and other harbour vessels etc.) has already started (FinFerries, 2017). Multiple complementary solutions will be developed and scaled up in line with fulfilling the GHG reduction objectives and reducing dependence on fossil energy sources.

GHG emissions may also be reduced through more restrictive measures, including higher carbon tax rates in countries where the carbon tax is in place, or the introduction of more stringent measures against fossil energy sources. An improved account for emissions in aviation and shipping may also result in policies supporting the use of low carbon alternatives for these sectors.

This factor has an overall impact index of 17. The analysis suggests that policies promoting low carbon energies will profit the biofuel demand along with the other low carbon energies. The probability and intensity of the future biofuel demand are however limited (2.6 and 2.8 respectively) and shall occur in the medium-long term (2.3).

Many different solutions are needed for decarbonisation in the next 20 years (G. Cancian, personal communication, 2020; Vettenranta, Autio, personal communication, 2020). Therefore, there might not be competition between different low-carbon energy sources or technologies (N. Jeuland, personal communication, 2020). In the medium- long term, there shall be enough space for all low carbon solutions depending on availability and adequacy (G. Cancian, personal communication, 2020). As mentioned earlier, the impact of this factor on the future biofuel demand for aviation will most likely be medium-term as electrification and hydrogen may be more promising long-term solutions and more intensely promoted at the political level. Avinor expert mentioned the "zero-emission" character of hydrogen and electric aircraft: *If a zero-emission society is the objective, then biofuels is not the way to go* (A. Løken, personal communication, 2020). There are indeed limitations on biofuel availability and capacity to be developed sustainably. In the shipping industry, the replacement of a fleet is a very slow process, justifying a high scale transition that will be seen in the long term (C. Chryssakis, personal communication, 2021).

However, policies promoting low carbon energies will not necessarily drive up the demand for biofuels because the sustainability classification will most likely shift by 2040, meaning that not all types of biofuels might be considered as "low carbon energy". Political decisions will refine the definition of low carbon energy and regulate the classification of black-liquor based fuels and forest-based fuels (Vettenranta, Autio, personal communication, 2020). While this redefinition would be detrimental to first-generation biofuels, it may drive the demand for black-liquor based fuels or forest-based fuels including the BL2F technology.

Consolidation of the shipping industry in terms of policies

The shipping sector is more fragmented than the aviation sector in terms of policies: More policies are implemented for the aviation sector, while shipping mostly operates through less formalised initiatives and local regulations (Legay, Jaiyeola, Berman, 2020). The hypothesis is that a consolidation of the policies in the shipping industry would drive more biofuel mandates in shipping at a national or European scale.

This factor is estimated to have a relatively strong intensity on the future biofuel demand (3), for an overall weak impact index (13). A consolidation of the policies in the shipping industry would contribute to increasing the future biofuel demand in shipping in the short term, but it will most likely occur in the longer term. (C. Chryssakis, personal communication, 2021)

Policies promoting domestic and local energy production

EU nations are highly dependent on fossil fuel imports, and biofuel imports from outside the EU to meet their energy needs. In 2018, almost two-thirds of the extra-EU's crude oil imports came from Russia (30 %), Iraq (9 %) and Saudi Arabia, Norway, Kazakhstan, and Nigeria (7 % each). A similar analysis shows that almost three-quarters of the EU's imports of natural gas came from Russia (40 %), Norway (18 %) and Algeria (11 %), while almost three-quarters of solid fuel (mostly coal) imports originated from Russia (42 %), the United States (18 %) and Colombia (13 %) (European Commission DG Energy, 2018).

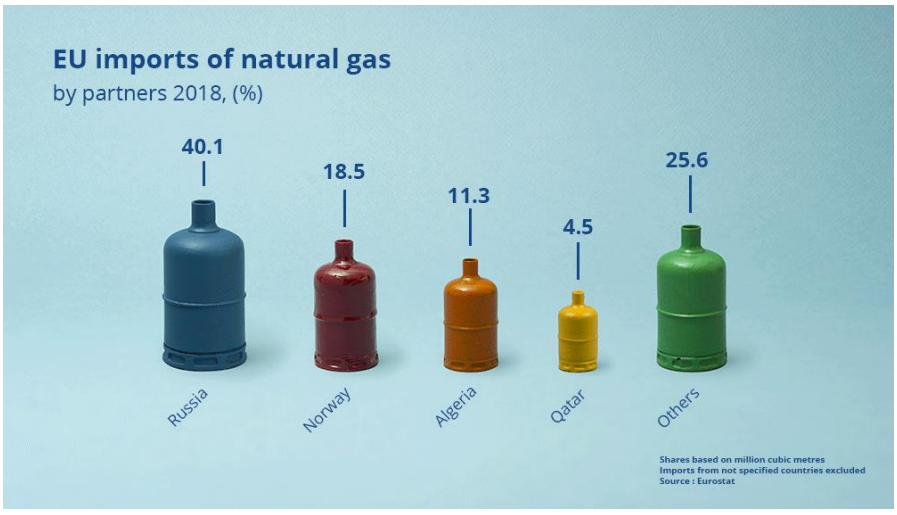

Figure 7. EU imports of natural gas, Eurostat, 2018

The introduction of policies restricting the import of any feedstock would most likely be tied to stricter environmental legislation. Currently, two main initiatives could lead to higher environmental sustainability requirements: the revision of the Renewable Energy Directive in 2021, and the policy debates on third countries deforestation that started in 2018 (G. Cancian, personal communication, 2020).

This factor has a very limited impact index on the future biofuel demand (6). The probability of occurrence is very low, and it will not have any significant impact on future biofuel demand. The feedstock availability is indeed insufficient to rely exclusively on domestic biomass to address European transportation needs (C. Mestre, personal communication, 2020). In some

European countries, including Norway for instance, the impact index would be higher due to their higher domestic biomass availability (A. Løken, personal communication, 2020).

Political crisis

A political crisis is a broad multifaceted scenario, which may consist of a conflict at the global, European, or national level. Depending on the nature, intensity, and geographical location, such a crisis may have several direct or indirect repercussions on the biofuel demand.

This factor's impact index is low (5), due to the difficulty of assessing the multiple possible outcomes of a political crisis on the biofuel demand. The general assumption is that a political crisis will hurt the biofuel demand and affect the demand the time the crisis lasts (C. Mestre, personal communication, 2020). In the eventuality of a crisis affecting the oil industry, the search for substitutes will be accelerated, possibly increasing biofuel production and demand (A. Løken, personal communication, 2020).

Policies making certifications' standards easier to meet in aviation

Aviation fuel certification is a very complex and expensive process. This process is managed by the ASTM in the United States and is mandatory for the whole aviation industry (N. Jeuland, personal communication, 2020; Valdenaire, Yugo, Leuckx, personal communication, 2021).

Less stringent certification standards could be implemented for biofuels, and eventually push towards 100% of biofuels in aircraft, instead of 50%. If the long-term objective is to reach fossil-fuel-free aviation, high percentages need to be targeted (A. Løken, personal communication, 2020). This 50% biofuel incorporation limit was originally intended to ensure fuel compatibility with the aircraft. Targeting 100% is possible and depends on technology choices. Manufacturers will have to ensure that future generations of aircraft are much more versatile in terms of fuel use, to allow the use of up to 100% paraffinic fuels and functioning properly with all fuels (N. Jeuland, personal communication, 2020). According to SINTEF-ER and Avinor experts, this factor will strongly drive the future demand for aviation biofuels (3.5), but it will be in the long term (1.5).

Policies making certifications' standards easier to meet in shipping

While there is currently no official biofuel certifications in shipping, the IMO may eventually implement standards in the future (C. Chryssakis, personal communication, 2021).

With an impact index of 14, this factor is estimated to have a relatively strong influence on future biofuel demand (3). Such policies would be game-changing for the future biofuel demand and drive the growth of biofuel demand in shipping, yet in the long-medium term (C. Chryssakis, personal communication, 2021).

3.2 Economic factors affecting future biofuel demand

3.2.1 Main results

Representation of the assessed factors

Five economic factors were identified and analysed. The economic factors with the highest impact are the following: *High cost competitiveness of fossil fuels* and *Cost competitiveness of imported biofuels*.

Table 3 Economic factors impacting future biofuel demand

	Economic Factors	Term	Impact index
EC1	High cost competitiveness of fossil fuels	2.8	35
EC2	Cost competitiveness of imported biofuels	3.3	32
EC3	Increased demand for aviation and shipping	2.6	19
EC4	Transition of the pulp and paper industry into biorefineries	1.7	6
EC5	Resource competition of black liquor between biofuels and other products	1.9	5

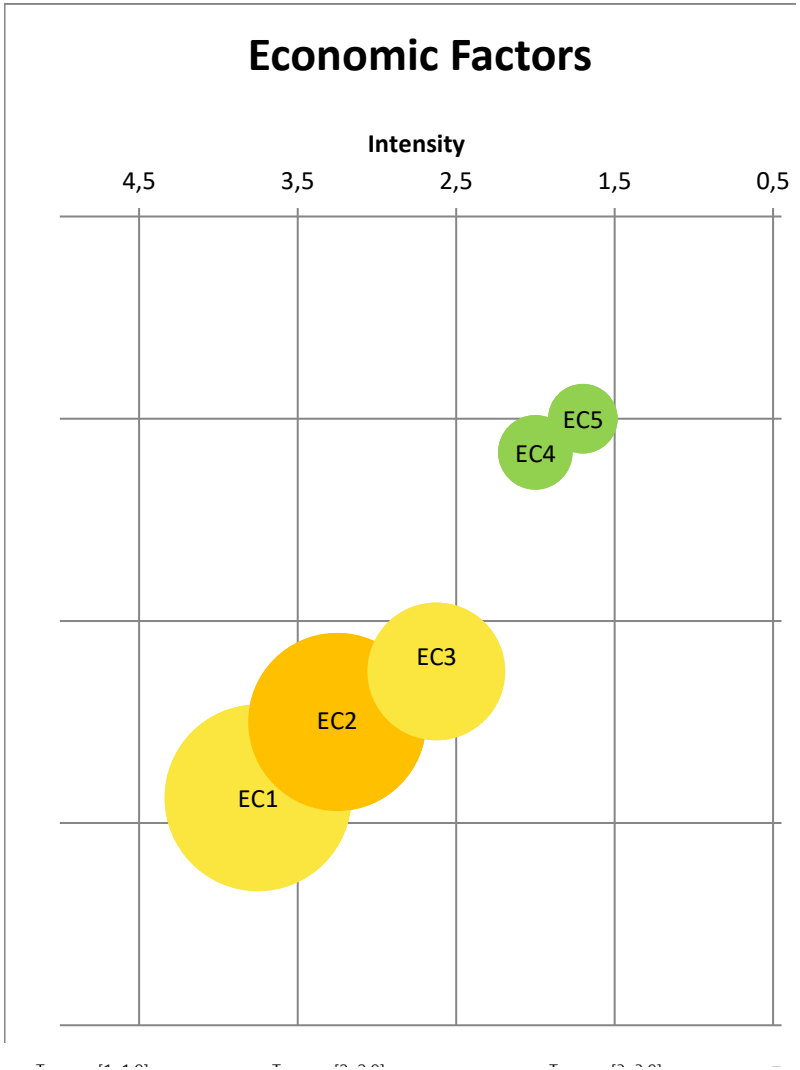

Figure 8 Representation of economic factors

3.2.2 Description and analysis of economic factors

The following section describes key economic factors or events that may influence the future biofuel demand between now and 2040. Five economic factors were studied with the inputs of FuelsEurope, Valmet, Neste and DNV experts.

High cost competitiveness of fossil fuels

While fossil fuels represented 93% of final energy consumption in EU transport in 2017, low-emission and renewable solutions accounted for only 5% despite record volumes availability ('EU Transportation Sector Still Overly Dependent on Fossil Fuels', 2019). Among other causes is the economic cost of fossil fuels which remains more competitive than other energy sources, including biofuels (Festel et al., 2014). It is estimated that an oil price below US$80 per barrel will deem the second-generation biofuel uncompetitive price-wise with the fossil fuel market for the next 30 years (Achinas et al., 2019; International Renewable Energy Agency., 2016). The lower carbon footprint cannot be a decisive factor alone for the aviation and shipping sectors, as long as the cost gap between fossil fuels and alternative fuels remains so important (Valdenaire, Yugo, Leuckx, personal communication, 2021). For market players, cost remains the major determinant factor of selection for a fuel. Without strong policy interventions or solutions to make biofuels more affordable, fossil fuels will continue to be favoured by the targeted industries as a major source of energy and demand for biofuel risks remaining at low level.

The analysis reveals that this factor will be the most impactful on the economic side with an impact index of 35. It will have a very strong influence on the future biofuel demand in aviation and shipping (3.8) with a high probability (3.4), on a medium-term (2.8). The availability of fossil fuels in considerable amounts justifies their high cost competitiveness over biofuels no matter what. In 2020, while the global oil production amounted to 88.4 million barrels per day, (N.Sönnichsen, Oil production worldwide from 1998 to 2020, 2021) global biofuel production levels reached 1,677 thousand barrels of oil equivalent per day. (N.Sönnichsen, Biofuel production worldwide from 2000 to 2020, 2021). Moreover, according to BP's 2020 Statistical Review of World Energy, more than 84% of global primary energy consumption was still produced by the burning of fossil fuels in 2019, and biofuels only represented a tiny part (0.7%) in comparison, as illustrated in the figure below.

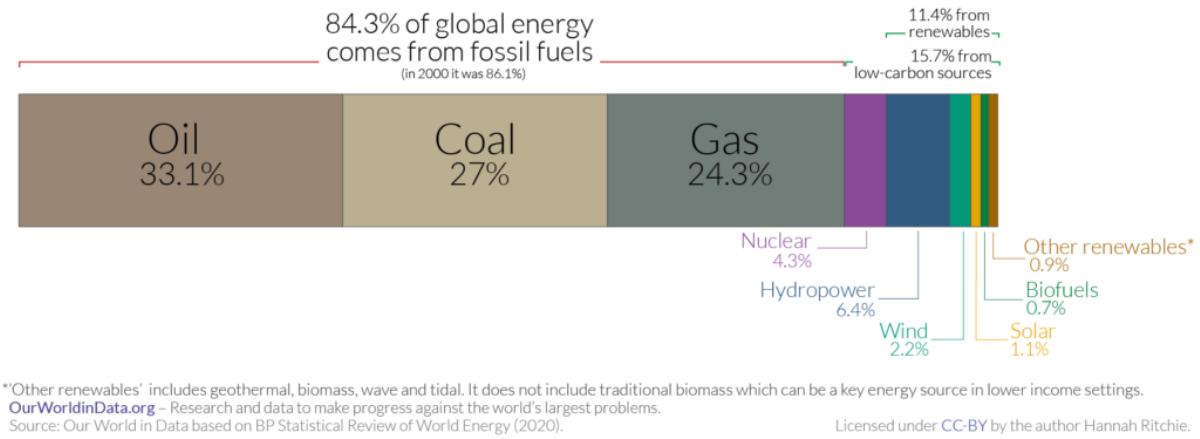

Figure 9. Global energy mix 2020, Energy for Humanity 2020

According to SINTEF-ER experts, policy interventions in the next 20 years will not be sufficient for biofuels to compete with fossil fuels. Indeed, although the share of renewable and sustainable fuels will increase over time, fossil fuels will remain competitive no matter what (J. Sandquist, personal communication, 2020). The figure below illustrates a scenario of the evolution of the global energy demand mix between 2000 and 2040, highlighting that the demand for oil, natural gas, and coal remains superior to other renewables, electricity or wind and solar energy by 2040.

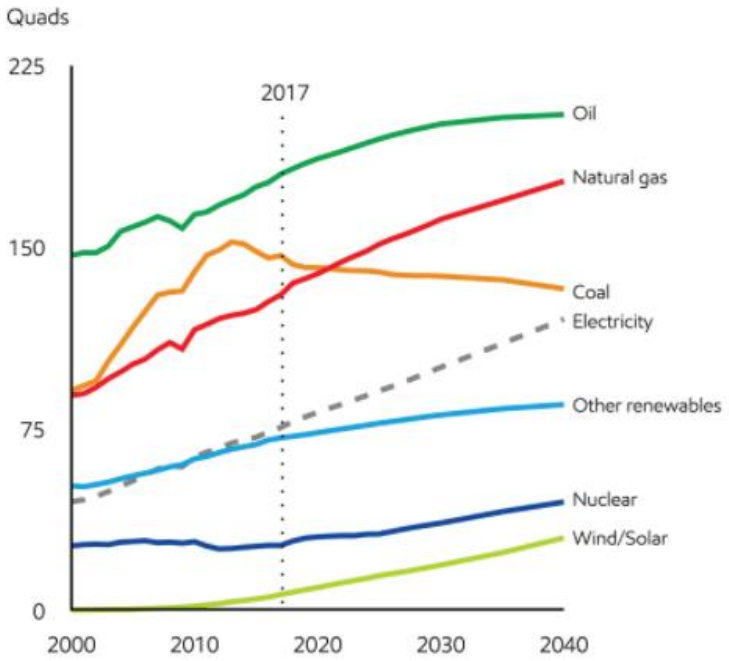

Figure 10. Global energy demand mix evolution, ExxonMobil 2019

These numbers illustrate the major gap between oil and biofuel production in the last years and highlights the considerable availability of fossil fuel in comparison to biofuels, partly justifying their higher cost competitiveness. However, it is important to highlight that this is one scenario among many others. Depending on the energy mix future scenarios renewable energy is sometimes projected to outcompete fossil energy sources by 2040 (McKinsey, 2020; Total Energies, 2020).

Cost competitiveness of imported biofuels

The cost competitiveness of advanced biofuels partly depends on the degree of proximity of the feedstocks to the market (A. Eisentraut, personal communication, 2020). Indeed, lignocellulosic biofuels from Europe and elsewhere may be equally competitive based on the feedstock location and the market location. However, the cost competitiveness of first-generation biofuels imported from Asian countries, including palm oil, has been a driver for the biofuel demand in the last years. Indonesia, Malaysia, and Thailand are indeed major sources of EU palm oil imports, accounting for a combined share of 74% of total EU imports of palm oil products from third countries in 2017 (Copenhagen Economics, 2018). As palm oil is criticised for its high CO_2 emissions and unsustainable production process, the NGO BiofuelWatch warned in 2017, that "*any significant uptake of aviation biofuels would almost certainly require large-scale palm oil use*", due to their high availability and affordable costs (BiofuelWatch, 2017).

This factor will have a strong impact on the future biofuel demand, with an impact index of 32, the influence will be strong (3.3), quite likely to have an incidence on biofuel demand (3) and in the short-medium term. Some nuances are brought up by Neste expert, who states that the demand is not driven by feedstock availability and imports of feedstock, but by the regulatory framework (A. Eisentraut, personal communication, 2020). For instance, the phase-out of palm oil from transport fuel adopted by the EU in 2018 announces a drop in the demand for food-based fuel. The ILUC directive also limits the contribution of biofuel feedstocks causing indirect land-use change (Muzi, 2018).

Increased demand for aviation and shipping

Pre-Covid-19 crisis projections on aviation and shipping expected flows to maintain sustained growth (Chiambaretto, 2019; Fleming & Ziegler, 2016; United Nations Conference On Trade and Development, 2020). Air traffic was expected to double every 15 years (Schulz, 2018) with an annual growth of 4% to 5%, while observers expected shipping to increase between 3% and 4% in the next five years (United Nations Conference On Trade and Development, 2020). However, these trends must be taken caution considering the impact of the COVID-19 pandemic which reduced global exchanges and travels, and reduced economic growth in 2020 and part of 2021, impacting both aviation and shipping traffic. As illustrated in Figure 11 below, Covid-19 has caused a 60% decline in world air passenger traffic between 2019 and 2020.

IATA estimates that global passenger traffic (RPKs) will not return to pre-

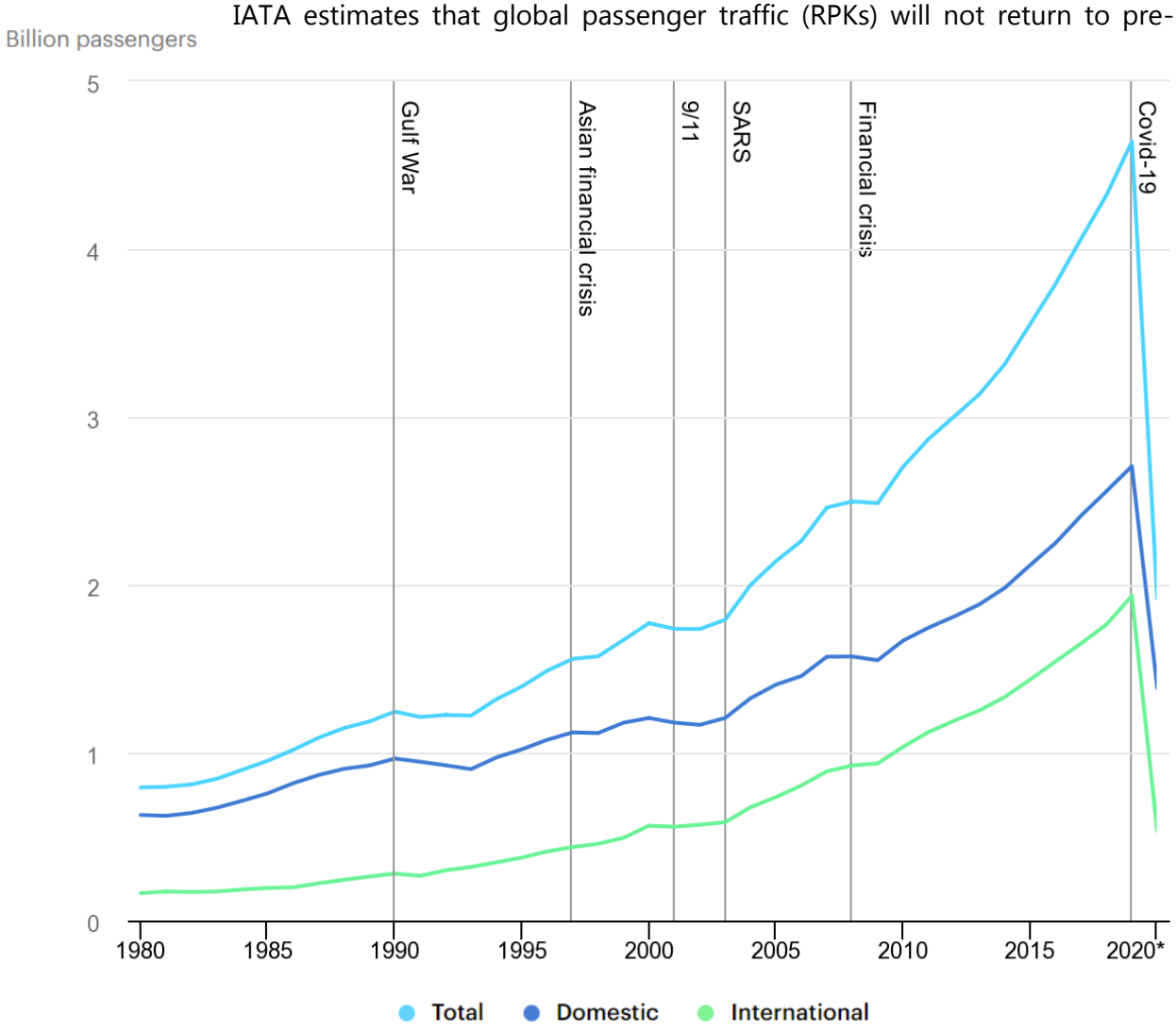

Figure 11. World air passenger traffic evolution, 1980-2020 (ICAO, 2020)

COVID-19 levels until 2024, a year later than previously projected (IATA, 2020). The growth of air traffic will however be pursued, fed by two main contributing factors. Bolstered by international trade and travelling agreements, the first contributor to higher demands for aviation and shipping is the global economic growth which leads to an increase in goods exchanges via planes and shipping containers and which allows for more people to travel by aeroplane. The second contributor is the increase of the world's population which increases

demand for goods and travel.[2] As demand for aviation and shipping is expected to increase, so is the demand for the energy used to power these sectors. As such, gross demand for biofuels can benefit from growing aviation and shipping sectors along with the implementation of stricter environmental requirements on the two industries (J. Sandquist, personal communication, 2020).

This factor discloses an impact index of 19 and will have a limited influence on the future biofuel demand because the amount of biofuel that will be available by 2040 will not be sufficient to address the increasing traffic in aviation and maritime.

Transition of the pulp and paper industry into biorefineries

In 2015, for the first time, worldwide demand for graphic paper has seen a decline. However, the global paper and paperboard industry has pursued its growth despite a drop in this segment. The paper and forest-products industry is willing to adapt to the evolutions of the market involving considerable changes in the industry's structure and market segments (Berg & Lingqvist, 2019). In this industry, diversification of activities is possible, and biorefineries are relevant options. Biorefineries can produce different kinds of products at the same time and shall be able to produce both biochemicals and biofuels. Producing both would be a huge benefit for biorefineries to reduce the production cost of biofuels and maximise the resource efficiency, as the side streams produced by a refinery producing biochemicals can be turned into biofuels (Vettenranta, Autio, personal communication, 2020).

With an impact index of 6, this factor will have a low impact on the future biofuel demand. The transition of the pulp paper industry into biorefineries won't have a significant impact on biofuel demand. Even in case of a decline in pulp production, black liquor production won't be affected (A. Eisentraut, personal communication, 2020). It would be more profitable for biorefineries to adapt to be able to produce many types of products e.g., biochemicals, biofuels and pulp (Vettenranta, Autio, personal communication, 2020).

Resource competition of black liquor between biofuels and other products

Biomass is an organic matter that can be used as a source of energy and converted into liquid biofuels to meet transportation fuel needs. However, biomass is also used in a wide variety of other areas, such as food, heat and electricity production, material, and resources in the industrial sector and particularly in the wood, paper, and chemical industry. More specifically, the energy released from burning black liquor derivatives can be used for transport but also electricity production (Darmawan et al., 2017) or applications in high added-value biochemicals (Gillet et al., 2017; Smolarski, 2012; Yu & Kim, 2020). As a result, there can be competition between these end-uses which could impact the supply of black liquor for transport biofuel production. Policies have a role in defining the priority use of biomass depending on the sectors (EIA US Energy Information Administration, 2020).

The analysis reveals an impact index of 5, meaning that it will have a low impact on future biofuel demand. While biomass will be a more and more scarce resource, its use is divided among different fractions: While the high-quality biomass can be used for construction

[2] see *Rising Population* in the Societal factors

materials, the lower quality biomass is an excellent option for biofuels and cannot be used for other purposes. There is therefore no direct competition with biofuels and other uses (A. Løken, personal communication, 2020; J. Sandquist, personal communication, 2020). Indeed, black-liquor based biofuels use sustainable residues of black liquor and do not directly compete with products using black liquor (BL2F Industrial Advisory Board, personal communication, 2021). Biochemical production may even support biofuel production, meaning that they don't have conflicting goals. The availability of biomass for biofuels may even increase if a strong push is made towards the maximisation of the output (Vettenranta, Autio, personal communication, 2020).

Moreover, it is expected to have black liquor prioritised for biofuel production rather than electricity. Electricity is a less attractive market for black liquor, as the increase of renewable supply is making electricity cheaper, making the electricity market more competitive (A. Eisentraut, personal communication, 2020; Vettenranta, Autio, personal communication, 2020).

Finally, the stronger regulatory framework is more advantageous for biofuels applications rather than raw material applications (A. Eisentraut, personal communication, 2020).

3.3 Societal factors affecting future biofuel demand

3.3.1 Main results

Representation of the assessed factors

While six factors are lifted, the societal dimension is not the most impactful on the future biofuel demand. One factor stands out as the most impactful *Health crisis* followed by *Increased demand for non-crop-based biofuels* and a *Rising population*.

Table 4 Societal factors impacting future biofuel demand

	Societal factors	Term	Impact index
S1	Health crisis	3.5	37
S2	Increased demand for non-crop-based biofuels	2.7	24
S3	Rising population	2.0	21
S4	Local population opposed to the pulp mills activities	2.5	15
S5	Progress of environmental awareness in society	2.3	14
S6	Commercial aviation industry loses in popularity	2.0	5

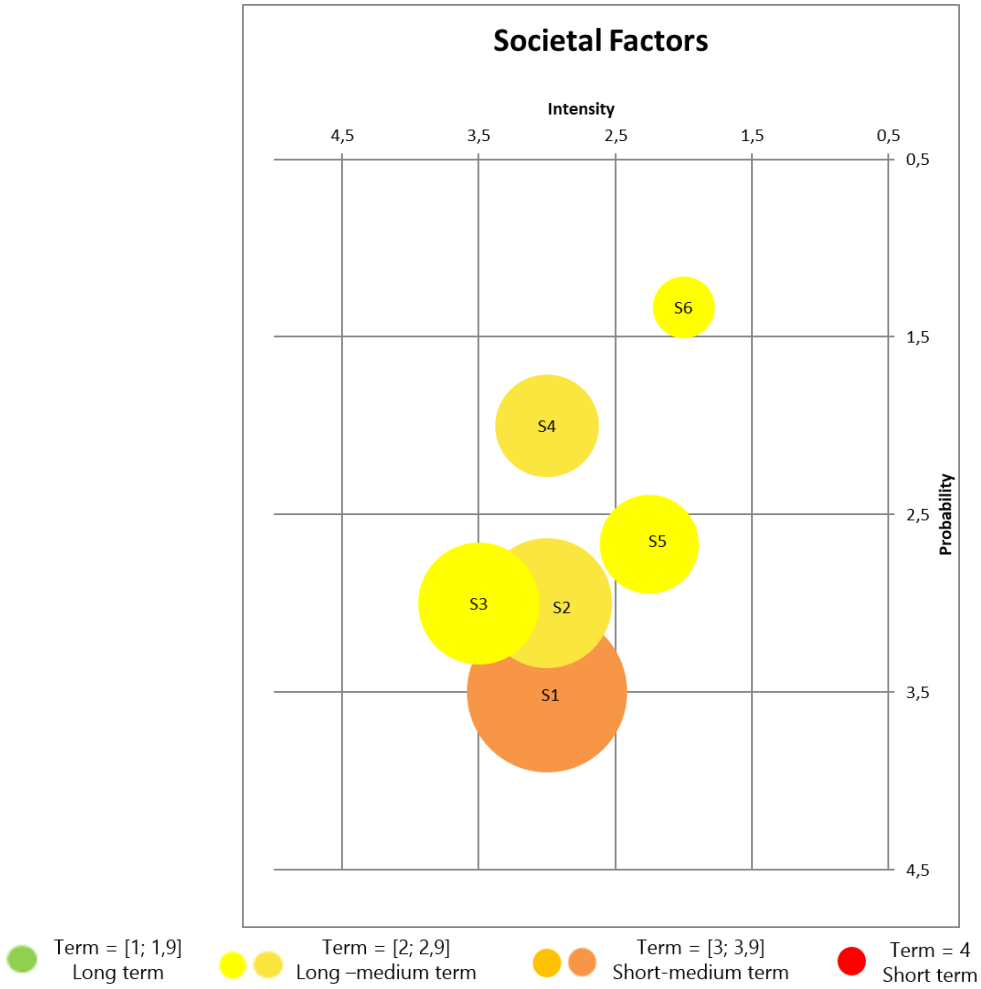

Figure 12. Representation of societal factors

3.3.2 Description and analysis of societal factors

Through the discussions with Valmet, SINTEF-ER, Neste, CONCAWE, FuelsEurope, Avinor and T&E, six societal factors were studied. The following section describes factors and events coming from the general public and society in general, that may impact the future biofuel demand until 2040.

Health Crisis

The Covid-19 crisis, which led to a societal, economic, and political crisis, was taken as a concrete example to illustrate this factor. The global pandemic drove acute political decisions at national levels to respond to an unpredictable threat, having a high impact on the economy, including the transportation sectors, and society, impacting citizens' mobility.

With an impact index of 37, this factor is one of the most impactful, strongly influencing the future biofuel demand in the short term (3.5). This crisis drove lower demand for aviation and shipping, decreasing the demand for biofuel in these sectors (C. Mestre, personal communication, 2020). Covid-19 however has a limited impact on long term energy demand, as it rebounds quickly post-crisis (McKinsey, 2020). According to estimates from Metabiota, a company that tracks infectious disease risks and outbreaks, there is a 47% to 57% chance that the world will experience another pandemic or epidemic that kills at least as many people as COVID-19 in the next 25 years (Cheney, 2021).

Increased demand for non-crop-based biofuels

First-generation biofuels are currently subject to controversies due to their relations with food supply as a significant amount of the feedstock consists of of agricultural products also used in food production, for example, corn, wheat, cane, soybean, rapeseed, and sugar beet. Moreover, the production of such biofuel feedstock competes directly for land with other food crops such as coffee beans or rice. The expansion of first-generation biofuel production has a significant impact on the world's agricultural market and food security. Accused by the UN and NGOs of pushing up food prices, and causing global food shortage, they are expected to be phased out for the benefit of non-crop-based biofuels. Indeed, second-generation feedstock, which includes lignocellulosic biomass and waste oil, increasingly supports the co-existence of biofuel and food production. According to the impact assessment of the 2030 Climate target plan, the European Commission is willing to shift away from biofuels relying on food and feed crops to advanced biofuels produced from woody energy crops in the next 20 years (European Commission, 2020).

This factor will have a strong influence on the future biofuel demand, with an impact index of 24. The phase-out of crop-based biofuels is highly probable and will have a positive impact on non-food based biofuels, including the BL2F technology (A. Eisentraut, personal communication, 2020; A. Løken, personal communication, 2020). Moreover, it will contribute to improving the public opinion for biofuels, since people may have a more favourable opinion for non-crop-based biofuels over palm oil fuels or food-based biofuels.

Rising population

The global population is expected to reach 9 billion by 2040 (PopulationPyramid, n.d.). The growing population implies a rising energy demand and growing demand for aviation and shipping, therefore an expanded demand for aviation and shipping fuel.

This factor will have a strong influence on the future biofuel demand (3.5), with a high probability (3) of occurrence in the medium-long term. As the population increases, more land area will be needed to address the growing fuel demand. As stated in the political dimension, biofuels will be a medium-term than a long-term solution. The amount of biofuel that will be available by 2040 will however not be sufficient to address the needs of this growing population.

Local population opposed to the pulp mills activities

Any industrial project or infrastructure development should take into account the Corporate Social Responsibility (CSR) and external stakeholders directly impacted by the project or company activities. The local population may encounter water scarcity, noise exposure, visual pollution, or inconvenient smells. Any negative externality may create opposition from the local populations against pulp mills activities, and threaten the production of biofuels, and extensively biofuel demand.

With an average intensity rate of 3.5, this factor may have a strong influence at a small scale, but not on the overall biofuel demand. More specifically, such a factor may have a strong impact on the development of the BL2F technology. CSR concerns will need to be addressed during the scale-up of the project to minimize potential risks.

Progress of environmental awareness in society

Environmental awareness consists in understanding the importance of protecting the environment and sustainably managing our planet's resources and ecosystems. This awareness has recently picked a momentum at a larger scale and has the potential to steer public opinion and policy-making in favour of the sustainable energy transition in Europe (European Social Survey, 2018). As consumers will seek to become better informed in their decisions, companies offering alternative transportation modes or low carbon transport may benefit from these societal changes. The acceptance of biofuels in the public space is also a key factor for the development of advanced biofuels and increasing demand.

While there is a general agreement that alternative fuels can help decrease dependency on fossil fuels, public knowledge is however limited regarding the specific implications of the alternative energy sources. The term "biofuel" may suffer from a negative image because it includes crop-based biofuels and palm oil, which have a demonstrated negative impact on the environment as well as food and water security. Advanced biofuels may be confused with these "traditional" biofuels. On the other hand, the increased protection of forest areas may be a barrier to the development of wood-based biofuels, which may have a negative public opinion because of its assumed link with deforestation. Lack of public information is one of the factors that has limited the market growth and acceptance of alternative fuels. Indeed, public attention is mostly towards electric vehicles, which are often seen by society as the best way to reach transport decarbonisation (A. Eisentraut, personal communication, 2020). However, this also

means that public perceptions regarding these energy sources may be susceptible to change based on several factors, including shifts in knowledge levels and changes in media use patterns (Cacciatore, Scheufele, Shaw, 2012).

In the shipping industry, customer pressure, quite well aligned with the IMO regulations, are contributing to the shift of shipping market players towards more sustainable fuels. Major banks financing shipping, and charterers are introducing their sustainability requirements for new ships (C. Chryssakis, personal communication, 2021).

This factor will however have a limited overall impact on the future biofuel demand (14), insofar as the biofuel demand is not citizen-driven (C. Mestre, personal communication, 2020). As consumers, citizens do not have decision power and have very limited knowledge when it comes to fuels used for aviation or shipping. The biofuel could be partly passenger or company-driven if passengers and companies are allowed to pay the extra cost for biofuels. Some airlines such as Scandinavian Airlines offer this opportunity to all passengers buying tickets on their website (A. Løken, personal communication, 2020).

Commercial aviation industry loses in popularity

As an increasing number of people are becoming more conscious of the environmental impact of their activities and mobility, public debates on the emissions of air traffic have led to the development of flight shaming, or "flygskam," encouraging citizens to decrease their flight travels. The airline industry also recognized the movement as a threat (BBC News, 2019).

Other factors may impede the development of the aviation industry, beyond the sustainability aspect. Travellers may favour other ways of travelling or avoid resorting to aircraft for their leisure travels due to a multiplication of terrorist attacks or other events detrimental to the aviation industry.

This factor is considered to have a low probability of occurrence and therefore a low impact on the future biofuel demand, with an impact index of 5.

3.4 Technological factors affecting future biofuel demand

3.4.1 Main results

In the scenario that result from our research, it was found that the *Development of other sources of energy for aviation* had a higher impact on future biofuels demand, before the *Development of other sources of energy for shipping,* and the *Development of other means of transportation than aviation and shipping*.

Table 5 Technological factors impacting future biofuels demand

Code	Factor (qualitative)	Term	Impact Index
T1	Development of other sources of energy for aviation	1.5	10
T2	Development of other sources of energy for shipping	1.5	8
T3	Development of other means of transportation than aviation and shipping	1.8	6

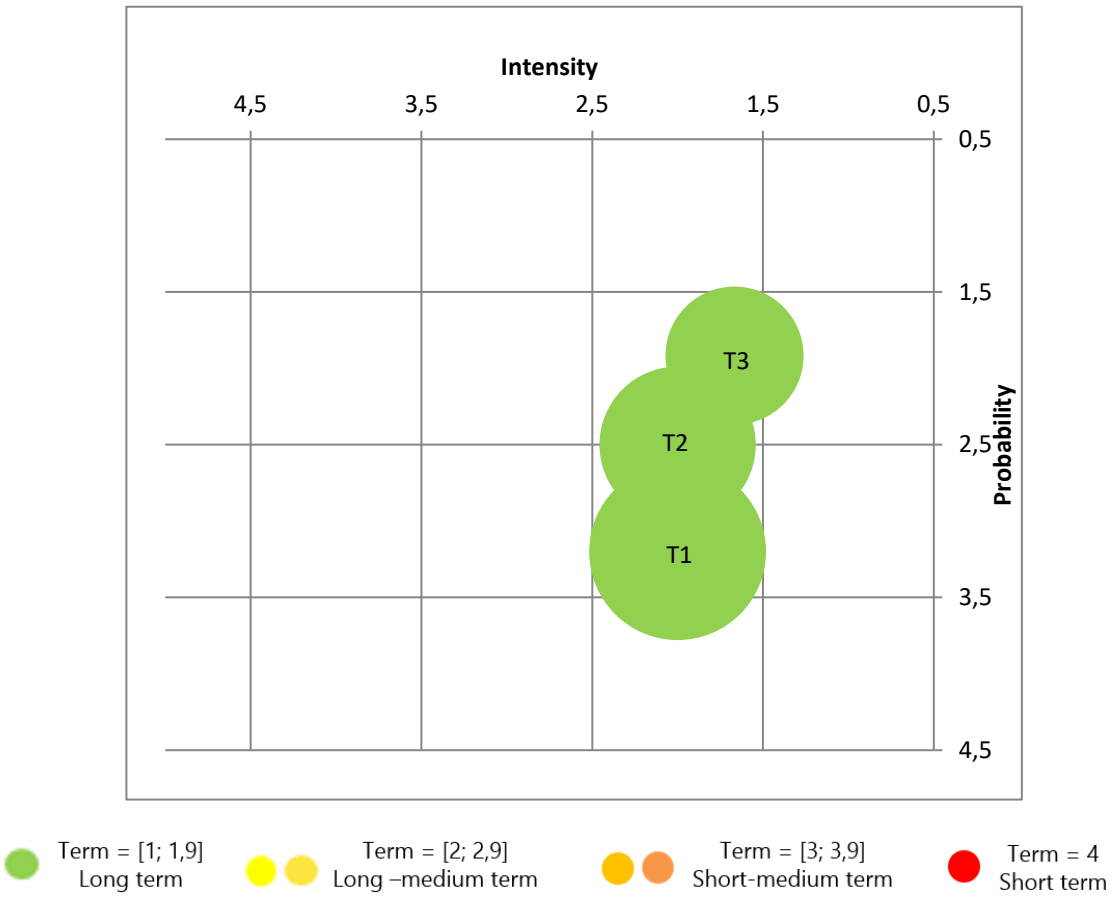

Figure 13. Representation of technological factors

3.4.2 Description and analysis of technological factors

The five following technological factors impacting future biofuels demand in aviation and shipping were studied with actors from the value chain of the advanced biofuels production: Valmet, Neste, Concawe, DNV, Safran, SINTEF-ER, Avinor, The Navigator Company, and Ranido. The following section describes each factor and its impact on the future biofuels demand.

Development of other sources of energy in shipping

The shipping industry has been testing and using multiple alternatives to reduce its CO_2 emissions.[3] Biofuels, also served as drop-in fuels, would allow decarbonisation to happen on the current boat infrastructures. Other low-carbon solutions would require changing the current fleets, such as the development of hydrogen batteries, fuel cells and batteries, system propulsion and ammonia (C. Chryssakis, personal communication, 2021).

This factor is considered to have a very low impact on the future biofuel demand, with an impact index of 8. All low-carbon solutions will be leveraged for decarbonisation, including the deployment of biofuels for shipping. While the development of alternative sources of energy for shipping will help reduce the overall fossil fuel demand, they will not necessarily affect the biofuel demand (C. Chryssakis, personal communication, 2021).

A shift of energy sources in maritime shall happen in the long term (1.5). The infrastructure of the vessels is a major factor at stake: The lifetime of a modern vessel is between 15 and 30 years. While some changes can be done to the machinery on board after the ship is designed, these modifications remain expensive and rare, unless a strong reason justifies it (C. Chryssakis, personal communication, 2021). Fleet replacement is a very slow process, therefore drop-in fuels could be the first candidates for maritime decarbonisation. Moreover, as biofuel penetration is currently low in maritime, the demand for biofuel shall increase significantly in the next years despite other measures and events (Valdenaire, Yugo, Leuckx, personal communication, 2021). The major factors which will influence the future biofuel demand are not related to technology, but rather to regulations and price, as compliance at minimum cost will come into play (C. Chryssakis, personal communication, 2021).

Development of other means of transportation than aviation and shipping

Some observers expect the European demand for rail to increase over the next decade with airlines and inland waterways predicted to be the main losing parties of such trends (Morgan, 2020; SCI Verkehr, 2019). Rail is indeed benefitting from a recent regain of political willingness and interest, viewing railway as a viable sustainable solution for transport. This is manifesting in discourses, national and European plans, but also in actions with reinvestment into network and reforms to make the mode more cost competitive. In the event of a sustained gradual shift towards more rail transportation (powered by electricity), the hypothesis is that the growth of the demand for biofuels in aviation and shipping might be limited to the decrease of these two sectors' expansion. This change of consuming habits could impact the volume demand of fuels and consequently biofuels in aviation.

The low impact index of this factor (10), is justified for two main reasons:

[3] see the Factor *Policies promoting low-carbon energies* in Political/Legal

First, the development of railroad transportation for long distance travel has been limited in the last decade, and a significant change is not expected to happen by 2040 (A. Eisentraut, personal communication, 2020).
Second, the development of other transportations means than aviation could potentially impact negatively the demand for aviation in the short term but at very weak intensity (N. Jeuland, personal communication, 2020). Indeed, almost 80% of aviation CO_2 emissions come from a long-haul flight of more than 1500km (Eurocontrol, 2021). Since a shift in transportation from aviation to railroad could be expected for short-distance flights only (less than 1500 km), a minor part of aviation CO_2 emissions will be impacted and therefore influence very weakly the demand for aviation biofuels.

Development of other sources of energy in aviation

Current aircraft rely on kerosene, which is known for having a high carbon footprint. Some sustainable aviation fuels are entering the market, as policies set up new mandates.[4] Currently, the development of new generations of aircraft aims at reducing the consumption of fossil fuels. Biofuels and hydrogen can help accompany decarbonisation. Biofuels also referred to as Sustainable Aviation Fuels in the aviation industry, can be blended in with fossil fuels, and work on current aircrafts. Hydrogen also referred to as "zero net emissions", can reduce the carbon footprint of the aviation industry (A. Løken, personal communication, 2020). Hydrogen-powered aviation might develop, through novel aircrafts and aero-engines (N. Jeuland, personal communication, 2020). These solutions promote the path towards decarbonisation of aviation, which might drive the demand for sustainable aviation fuels. Other upcoming solutions will also play a part in the decarbonisation of aviation and shipping such as e-fuels, and Power-to-Liquid fuels (A. Eisentraut, personal communication, 2020; N. Jeuland, personal communication, 2020; A. Løken, personal communication, 2020; J. Sandquist, personal communication, 2020).

This factor is however expected to have an extremely low impact on the future biofuel demand (6).
The low intensity is justified since all these solutions previously mentioned will still be at the early development stage and available in small amounts in 2040, having no significant impact on biofuels, which availability will still be limited in quantity (N. Jeuland, personal communication, 2020).

3.5 Environmental factors affecting future biofuel demand

3.5.1 Main environmental factors

Among the investigated environmental factors, *Uncertainties about the availability of biomass for pulp & advanced biofuels production, Non-CO_2 effects of aviation and Global warming generating new challenges* are perceived as having a impact on future biofuels demand. The repercussions are expected in the long/medium-term.

[4] see Factor "Policies promoting biofuels in aviation and shipping" in Political/Legal

Table 6 Environmental factors impacting future biofuel demand

Code	Factor	Term	Impact Index
EN1	Uncertainties about the availability of biomass (forests) for pulp & advanced biofuels production	2.8	26
EN2	Non-CO_2 Effects of aviation	2.0	24
EN3	Global warming generating new challenges	2.4	23
EN4	Impacts on Biodiversity	2.3	17
EN5	High level of SOx emissions for shipping	3.1	3.9

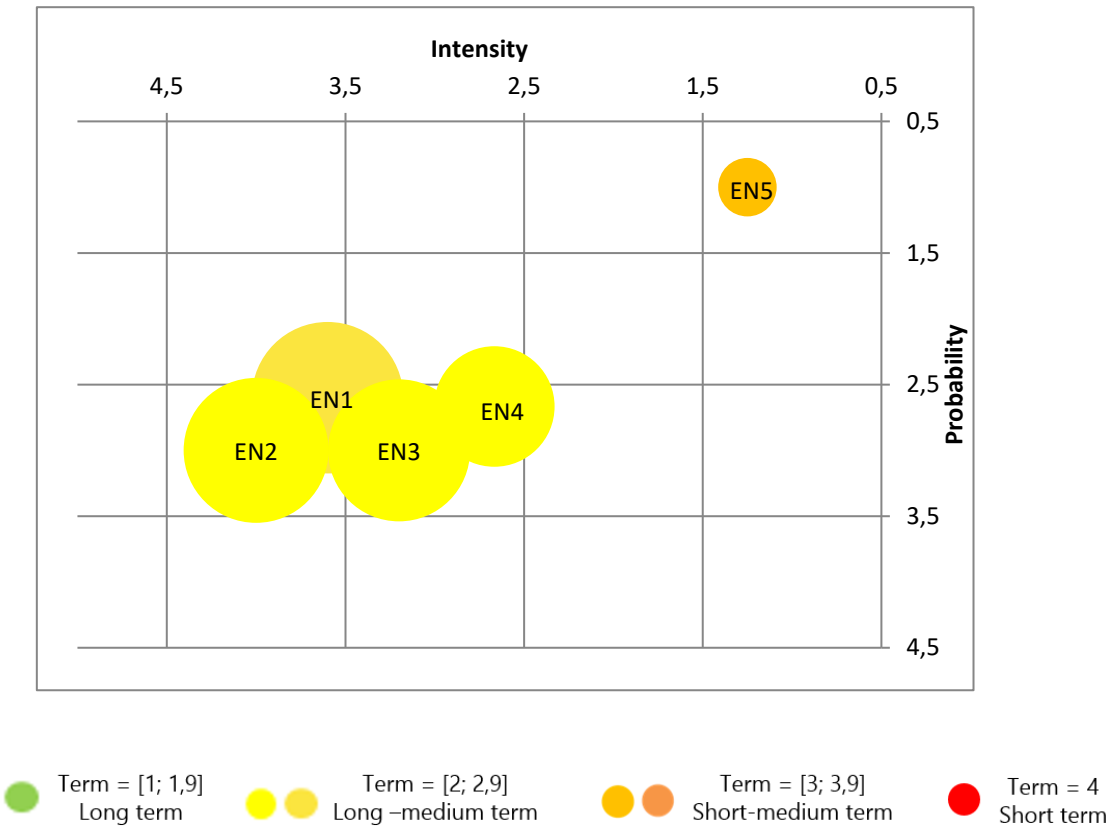

Figure 14. Representation of environmental Factors

3.5.2 Description and analysis of environmental factors

Through the discussions with Valmet, Bioenergy Europe, T&E, and Safran, the following five environmental factors were studied as having an impact on future biofuels demand.

Global warming generating new challenges

Global CO_2 emissions continue to rise worldwide. As highlighted in Figure 15, the aviation industry's direct emissions represent about 3% of the EU's total greenhouse gas emissions and more than 2% of global emission, whereas shipping represents around 3% of the EU's GHG emissions, (ATAG Air Transport Action Group, 2020) and about 3% of global greenhouse gas emissions (Gordon-Harper, 2020).

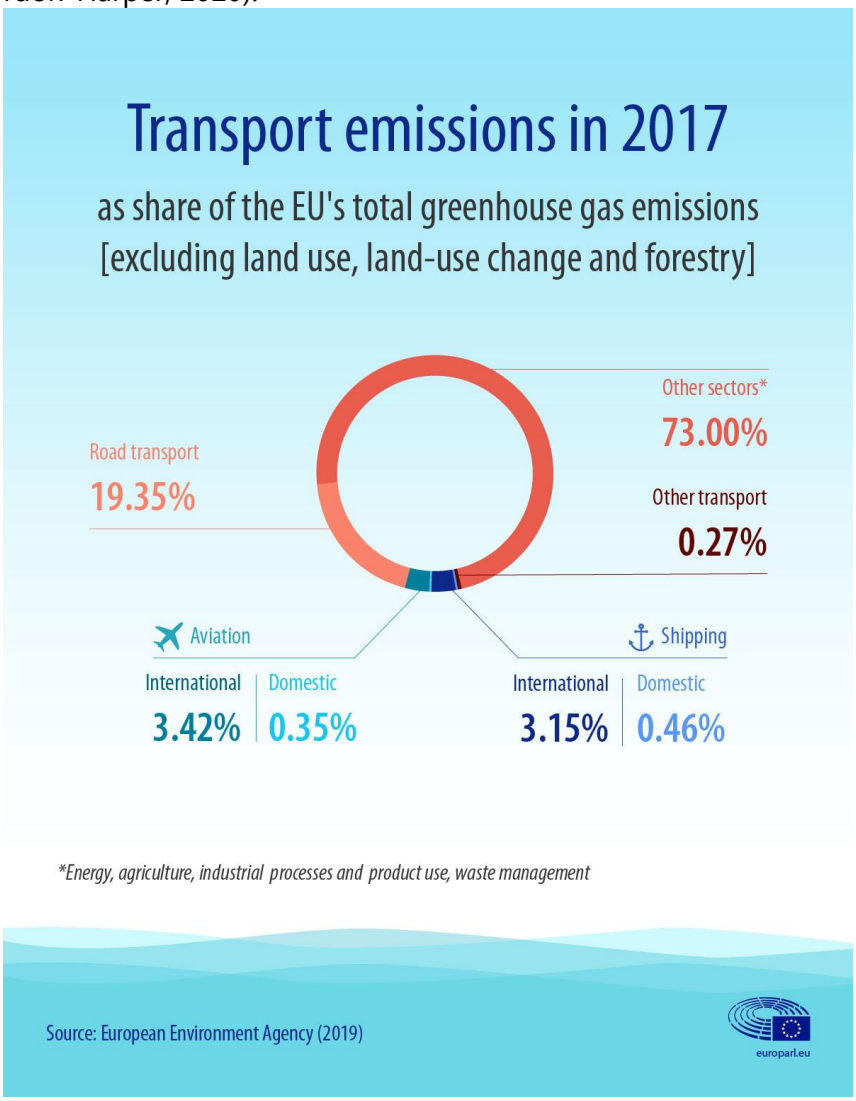

Figure 15. Transport emissions in 2017, European Environment Agency 2019

Aviation CO_2 emissions are rapidly growing: if no action is taken, the UN International Civil Aviation Organisation (ICAO) foresees a 300% growth from 2020 to 2050 (European Commission, 2016). In this context, the need for low-carbon fuels in aviation and shipping appears key to tackle climate change, and several technologies are foreseen, as seen in 3.4 Technological factors affecting future biofuel demand. Biofuels with lower life cycle assessments than fossil fuels will enable the decarbonisation of aviation and shipping. Black

Liquor valorisation into biofuels, as promised by the BL2F technology, could have a much lower carbon footprint compared to kerosene.

Shipping CO_2 emissions could increase between 50% and 25% by 2050, according to the IMO. The IMO has committed to halving the total emissions (reference 2008) by 2050 as seen in part 3.4 Technological factors affecting future biofuel demand, biofuels could be a decarbonisation enabler for the shipping industry.

This factor has an impact index of 23. With rates of respectively 3.2 and 3, the intensity and probability of impact of this factor are strong. The occurrence is medium-term (2.4), because the impact of climate change will last forever, and the impacts are already perceived today (A. Eisentraut, personal communication, 2020; C. Mestre, personal communication, 2020).

Uncertainties about the availability of sustainable biomass for advanced biofuels production

Biomass is a widely available renewable source of energy: the organic materials used to produce biomass are infinite, as they include waste, wood, manure and so on (McFarland, 2017). Residues and co-products from the forest and agriculture industry are also considered as feedstocks. Biomass can be exploited for various uses, such as heat, electricity, and transport.

In 2020, world sustainable biomass availability was projected to be 2,500 Mtoe/y by IRENA, and about 6000 Mtoe/y by 2050, as highlighted in Figure 16 (IRENA International Renewable energy agency, 2016). However, some stakeholders, such as ICCT, set the limit of low-carbon biomass to be supplied for energy by 2050 around 2,150 Mtoe/y (Pavlenko, Malins El Takriti, Searle, 2016).

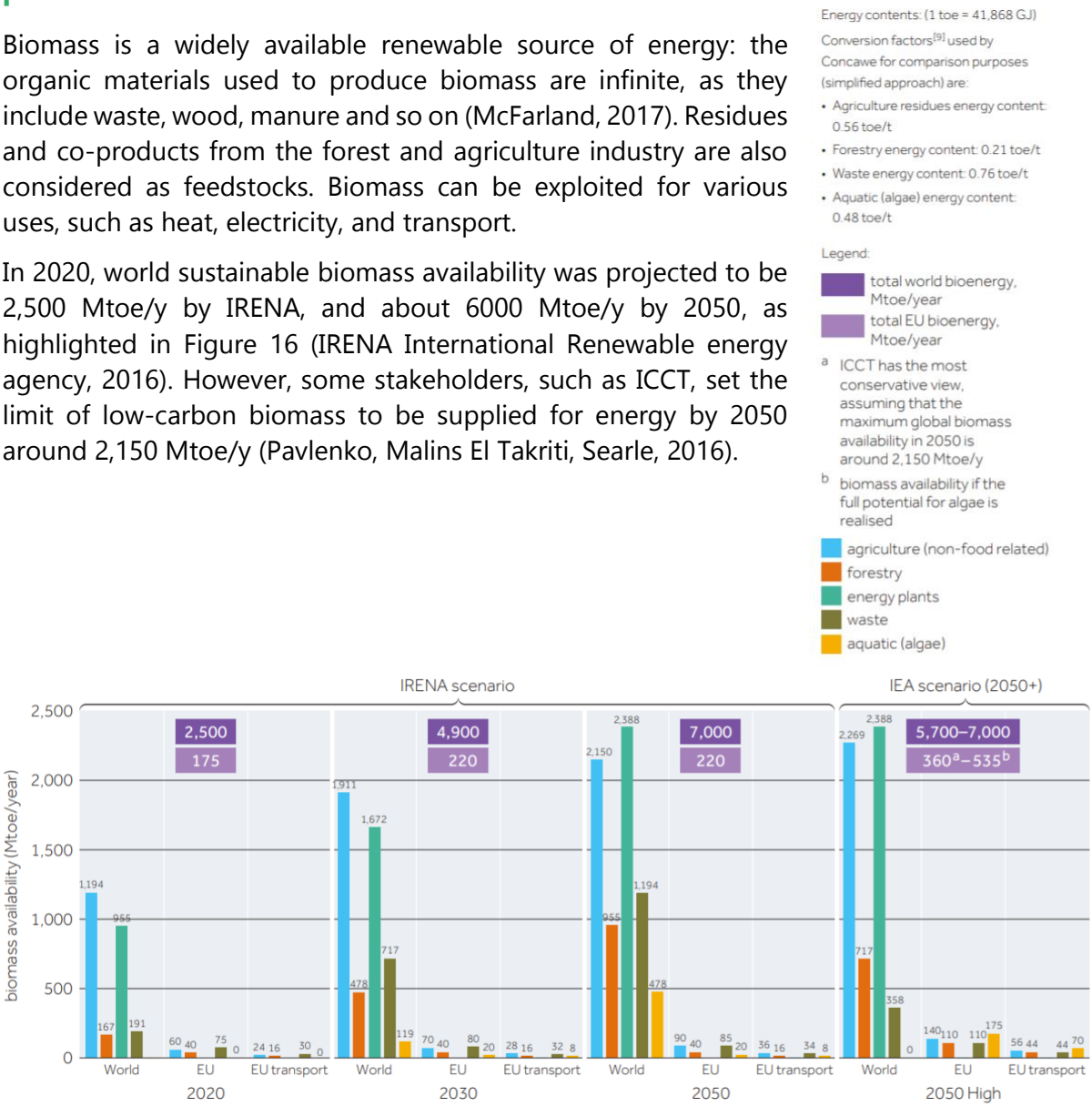

Figure 16. World maximum biomass availability, 2020-2050 (CONCAWE, 2019)

To support the EU climate and energy targets, all advanced biofuels must meet the sustainability criteria required by the 2018 Renewable Energy Directive (European Commission, 2021) and have their feedstock (black liquor, waste etc.) appearing in the annexe IX of RED II (Appendix 2).

If feedstocks meeting internationally recognised sustainability criteria are used, significant volumes of biofuels may be produced. However, the problem might not be the availability of the feedstock, but its mobilisation (N. Jeuland, personal communication, 2020). As cellulosic biomass is available on a renewable basis, its availability is sufficient to address the market needs, but uncertainties remain on the ability to mobilise and exploit biomass. In the shipping industry, biomass availability is already limited (C. Chryssakis, personal communication, 2021), which represents a risk as actors may substitute sustainable feedstock that is difficult to mobilise with other materials that might be unsustainable (C. Mestre, personal communication, 2020). The key is strong political support of the sector to allow an optimised mobilisation of the resources (N. Jeuland, personal communication, 2020).

With an overall impact index of 26, it is the highest impact environmental factor. Biofuels demand might decrease if there are no available and sustainable feedstocks (J. Sandquist, personal communication, 2020). Its intensity will be high (3.6), while the probability will be limited (2.6), with a medium-term occurrence (2.8).

Non-CO_2 effects for aviation

Other environmental impacts in aviation will have influenced the selection of the source of energy of the future, e.g., the non-CO_2 impacts, encompassing the emissions from the aircraft such as NO_x, soot particles, oxidised sulphur species, and water vapour (European Commission, n.d.-b). Non-CO_2 effects lead to global warming and could even be more impactful than direct CO_2 impacts, the greenhouse gas emissions (N. Jeuland, personal communication, 2020).

More research is yet to come on the different non-CO_2 impacts and the trade-offs between them. Scientists indicate that the use of advanced biofuels or Power-to-liquid fuels will reduce soot particulate emissions (European Commission, n.d.-b). Possible upcoming policies targeting aviation's full climate impact will be crucial to selecting the next technology.

This factor was only rated by one expert (Nicolas Jeuland, Safran), with an impact index of 24, high intensity and probability (respectively 4 and 3), and a medium-term occurrence.

Impacts on biodiversity

Biodiversity is affected by the production of certain biofuels, which could cause challenges when it comes to their adoption in shipping and aviation. Biodiversity has been impacted by the first generation of biofuels. Crop-based biofuels have been causing Indirect Land Use Change: the conversion of natural lands occurred to produce biofuels (C. Mestre, personal communication, 2020). Moreover, the use of fertilizers and pesticides damages the ecosystems, threatening some species while leading to the development of invasive species.

Concerns become more important regarding the production of monocultures of wood to produce second-generation biofuels (C. Mestre, personal communication, 2020). However, industrial experts highlight the fact that residues will be used for this technology. As a result,

biofuels demand is expected to increase if impacts on biodiversity are handled carefully for all biofuel types. This factor has an overall impact index of 16.6. The probability and influence on the future biofuel demand are limited (2.7 and 2.7 respectively) and shall occur in the medium-long term (2.3).

High level of SO_x emissions for shipping

The demand for biofuels in the shipping industry could be highly dependent on the desulfurization of the industry. Since January 2020, the IMO seeks a reduction of the global sulphur cap of fuels from 3.5% to 0.5% in the revised MARPOL Annex VI (International Maritime Organization, 2020). Among possible solutions to decrease SO_x emissions, all types of biofuels could replace heavy fuel oil as they respect the 0.5% sulphur cap. As a result, CO_2 emissions from ships are expected to shift, depending on existing technologies lowering sulphur content. Scrubbers are the most economical solution however, as they consume significant energy, CO_2 emissions are 2% higher than systems without scrubbers. Another solution consists in using low-sulphur fossil fuels (marine diesel oil, marine gas oil and desulfurized HFO) which emit equivalent CO_2 or shift towards natural gas which allow reducing CO_2 emissions by 20%. In the future, all types of biofuels could replace heavy fuel oil as they respect this 0.5% sulphur cap and are less carbon-intense (Den Boer, Hoen, 2015).

This factor has a very low impact on the future biofuel demand (3.9 impact index), as biofuels only represent a small part of the shipping industries' emissions (C. Chryssakis, personal communication, 2021; C. Mestre, personal communication, 2020).

3.6 Factors without impact on future biofuel demand

The study allowed the identification of three factors that were found to have no impact on the future biofuel demand. Due to their irrelevance, the following factors were dismissed:

***Relocation of industries on European territories**:* Following the Covid-19 crisis, some countries, including France have considered the relocation of industrial activities on their national territory, formerly offshored abroad (d'Abbundo, 2020).

Urban exodus: The urban exodus is the process of "escaping" the city to move to the countryside. This phenomenon has been on the rise especially during the Covid-19 crisis, yet it is too short term to determine whether the phenomenon is temporary or permanent (Steinkopf-Frank, 2020).

Need for cleaner fuels for higher health standards: Air pollution poses a major threat to health, killing an estimated 4.2 million people worldwide every year, as a result of exposure to outdoor air pollution. (World Health Organization, 2020). The major outdoor pollution sources include residential energy for cooking and heating, vehicles, power generation, agriculture/waste incineration, and industry. This statement enhances the need to improve air quality by developing cleaner energy and cleaner fuels at a high scale. However, experts confirm that no link exists between better health and biofuels (Valdenaire, Yugo, Leuckx, personal communication, 2021).

4 Main results and Conclusion

4.1 Main results in a multidimensional approach

This study demonstrates that all dimensions Political, Economic, Societal, Technological, Environmental and Legal, are closely interacting with each other and impacting systemically the current and future biofuel demand. Many of the investigated factors are indeed influenced by several dimensions simultaneously. The policy dimension remains the most dominant, as it plays a hegemonic role in each dimension of the PESTEL analysis.

Between 2020 and 2040, policymakers are expected to keep promoting biofuels and low carbon energies at the EU and national level, measures that will profit the future biofuel demand, along with the demand for other low carbon fuels and technologies. Technological advancements are indeed expected in the fields of electrification, alternative energies, and low-carbon fuels for transportation in the medium term, yet they won't be widespread without adequate policy support. At a time where fossil fuels represent, a major part of energy consumption in EU transport and the most cost-competitive option, it is a necessity for policymakers to promote several different solutions to reach decarbonisation.

For market players in the transportation sector, striving for lower CO_2 emissions is however not a decisive criterion. Cost competitiveness remains the major determinant factor of selection for fuel, and as long as the cost gap between fossil fuels and biofuels remains so significant, compliance at minimum cost will be resorted to despite policies becoming more stringent against fossil fuels. Policy interventions are needed to strongly influence the economic dimension and provide incentives to promote the cost competitiveness of biofuels. By 2040, fossil fuels shall however remain more cost-competitive than biofuels due to their availability in considerable amounts compared to biofuels and other low carbon energies.

The regulatory framework also has a role in defining the priority use of biomass by adopting a holistic approach to global climate mitigation across sectors. Moreover, strong political support is expected to allow an optimised mobilisation of sustainable raw material resources, not solely dependent on environmental availability.

Beyond their strong influence on the future biofuel demand, policies will also influence the societal perception of biofuels.

Finally, the Covid-19 crisis has affected the political, economic, societal, and technological dimensions simultaneously, driving a lower demand for aviation and shipping and decreasing the demand for biofuel in these sectors. As the impact of the crisis is expected to be short term, it shall not have major repercussions until 2040.

4.2 Conclusion

The PESTEL analysis allowed the identification of four main factors with an impact index superior to 30. The following factors will have a major impact on the biofuel demand by 2040:

- Policies promoting biofuels in aviation and shipping
- High cost competitiveness of fossil fuels
- Cost competitiveness of imported biofuels
- Health crisis

Table 7 Major factors impacting future biofuel demand

Code	Factor	Impact Index
S1	Health crisis	37
P1	Policies promoting biofuels in aviation and shipping	36
EC1	High cost competitiveness of fossil fuels	35
EC2	Cost competitiveness of imported biofuels	32

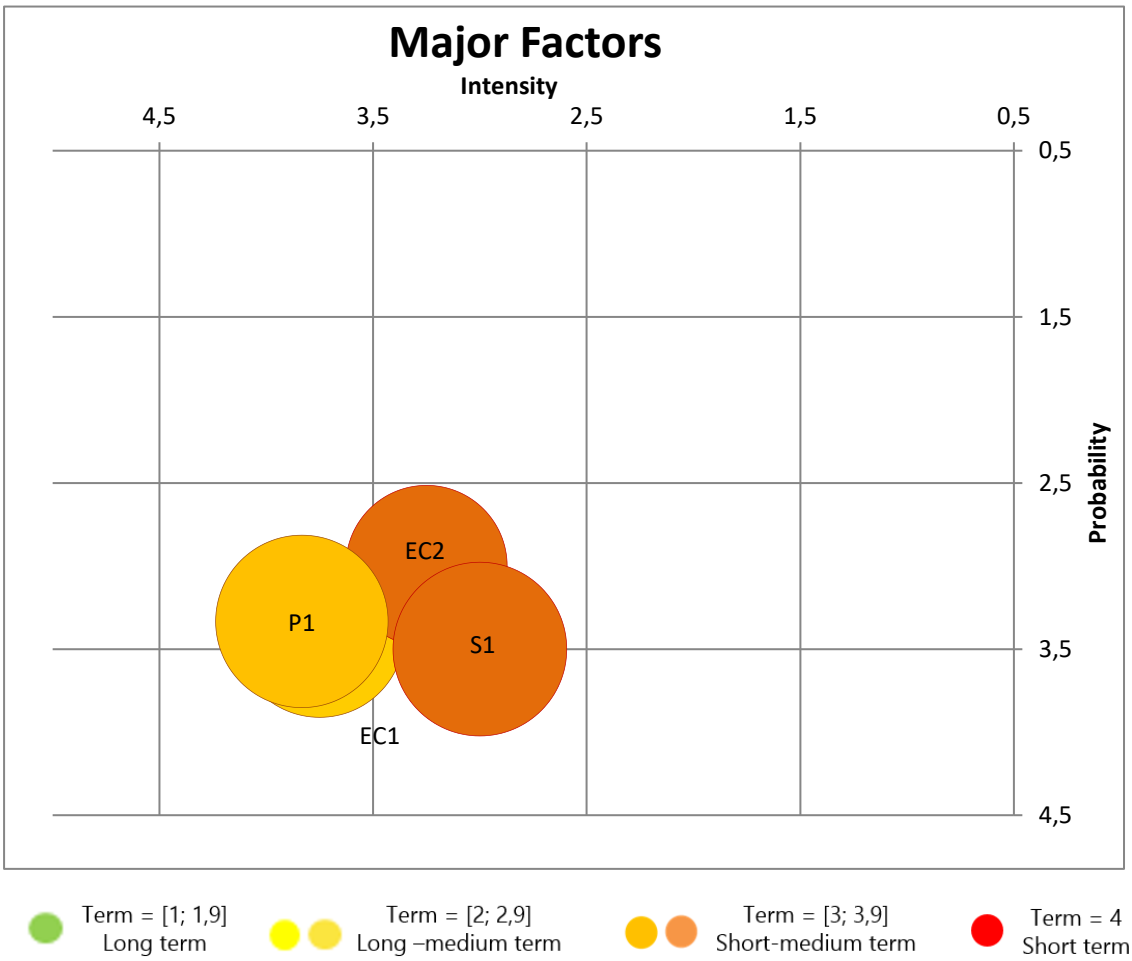

Figure 17. Representation of major factors impacting future biofuel demand

In the next 20 years, the regulatory framework will be the most decisive factor in the evolution of biofuel demand. The demand for biofuels in Europe will mostly be driven by political decisions to promote the demand for biofuels and low carbon energies in transportation, including aviation and shipping, to reach climate-neutrality in the EU by 2050. Although some economic and societal factors also stood out in the study, policy decisions remain relevant in all dimensions. By 2040, due to their high cost competitiveness, one scenario stated that fossil fuels may remain dominant despite the increased share of renewable and sustainable fuels in the transportation mix. As cost is a major factor of selection for market players, fossil fuels may continue to be favoured by the targeted industries, hence the importance of policy interventions to provide strong incentives for market players to diminish their fossil fuel consumption. Biofuels imported from non-EU countries may remain dominant due to their higher cost competitiveness.

The Covid-19 crisis strongly influenced the future biofuel demand in the short term, as it drove lower demand for biofuels due to a decreased demand for aviation and shipping. Repercussions are however not expected in the long term, yet the recurrence of a similar crisis remains existent.

Technological, societal, and environmental factors shall not be the most determinant for the future biofuel demand. Similarly, biofuel demand will not be directly affected by environmental events such as climate change, or feedstock availability, but by the political decisions which will result from these events. Society wise, the biofuel demand is not citizen-driven as citizens do not have decision power and have very limited knowledge when it comes to fuels used for aviation or shipping. Finally, there won't be significant technological evolutions that will disrupt the market by 2040 and impact the future biofuel demand.

The majority of the scenarios which were investigated, either resulted in an increased biofuel demand or a minorly affected demand. Among the factors that could potentially negatively impact the future biofuel demand (e.g., Political crisis, Global warming, Uncertainties about the availability of sustainable biomass, Health crisis), policy decisions remain the most decisive to influence the biofuel demand and it is in the best interests of the decarbonisation objectives to promote them.

Because biofuels are currently produced in limited amounts compared to fossil fuels, which will still dominate the great majority of transportation by 2040, biofuels are still far from being used on a broad scale and have a significant expansion margin ahead of them. Biofuels are one of several options for reducing carbon emissions in the transportation sector, and they will be a medium-term solution for aviation. As a fundamental shift of energies in maritime and aviation will happen in the long term, drop-in fuels could be the first candidates for decarbonisation. By 2040, the biofuel demand is expected to rise inevitably, encouraged by ambitious objectives set by policymakers and none of the evaluated factors is expected to alter or be detrimental to this growth.

5 References

Achinas, S., Horjus, J., Achinas, V., & Euvering, G. J. W. (2019). A PESTLE Analysis of Biofuels Energy Industry in Europe. *Sustainability*, *11*(5981).

Airbus. (2020). *Airbus reveals new zero-emission concept aircraft*. https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-new-zeroemission-concept-aircraft.html

ATAG Air Transport Action Group. (2020). *Facts and Figures*. https://www.atag.org/facts-figures.html

BBC News. (2019). *'Flight shame' could halve growth in air traffic*. https://www.bbc.com/news/business-49890057

Berg, P., & Lingqvist, O. (2019, August 7). Pulp, paper, and packaging in the next decade: Transformational change. *McKinsey & Company*. https://www.mckinsey.com/industries/paper-forest-products-and-packaging/our-insights/pulp-paper-and-packaging-in-the-next-decade-transformational-change

BP British Petroleum. (2020). *Statistical Review of World Energy 69th Edition*. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

Cacciatore, Scheufele, Shaw. (2012). *Public attitudes toward biofuels. Effects of knowledge, political partisanship, and media use*.

Cancian, G. (2020). *Interview with expert from Bioenergy Europe to share expertise on future biofuel demand* [Personal communication].

Cheney, C. (2021). How might probability inform policy on pandemics? Metabiota has ideas. *Devex*. https://www.devex.com/news/how-might-probability-inform-policy-on-pandemics-metabiota-has-ideas-100427

Chiambaretto, P. (2019, May 8). *Trafic aérien mondial, une croissance fulgurante pas prête de s'arrêter*. The Conversation. http://theconversation.com/trafic-aerien-mondial-une-croissance-fulgurante-pas-prete-de-sarreter-116107

Chryssakis, C. (2021). *Interview with expert from DNV GL to share expertise on future biofuel demand* [Personal communication].

CONCAWE. (2019). *A look into the maximum potential availability and demand for low-carbon feedstocks/fuels in Europe (2020–2050)*. https://www.concawe.eu/wp-content/uploads/Feedstocks-1.pdf

Copenhagen Economics. (2018). *EU Imports of palm oil from Indonesia, Malaysia, and Thailand*. https://www.copenhageneconomics.com/dyn/resources/Publication/publicationPDF/8/448/1528720336/eu-imports-of-palm-oil-16may2018.pdf

D'Abbundo, A. (2020). La France s'engage dans la relocalisation. *La Croix*.

Darmawan, A., Hardi, F., Yoshikawa, K., Aziz, M., & Tokimatsu, K. (2017). *Electricity production from black liquor: A novel integrated system*. *142*, 23–28. https://doi.org/10.1016/j.egypro.2017.12.005

Den Boer, Hoen. (2015). Scrubbers—An economic and ecological assessment. *Delft*.

EIA US Energy Information Administration. (2020). *Biomass explained*. https://www.eia.gov/energyexplained/biomass/

Eisentraut, A. (2020). *Interview with expert from NESTE to share expertise on future biofuel demand* [Personal communication].

Ernsting, A. (2017). *Aviation biofuels: How ICAO and industry plans for sustainable alternative aviation fuels' could lead to planes flying on palm oil*. BiofuelWatch. http://www.biofuelwatch.org.uk/wp-content/uploads/Aviation-biofuels-report.pdf

ETIP Bioenergy. (2021). *Advanced Bioenergy in Europe*. https://www.etipbioenergy.eu/advanced-biofuels-overview#sustainable

EU transportation sector still overly dependent on fossil fuels. (2019, July 12). *Bioenergy International*. https://bioenergyinternational.com/markets-finance/eu-transport-still-overly-dependant-on-fossil-fuels

EurObservER. (2020). *Biofuels Barometer*.

Eurocontrol. (2021). *Data Snapshot #4 on CO_2 emissions by flight distance*. https://www.eurocontrol.int/publication/eurocontrol-data-snapshot-co2-emissions-flight-distance

European Commission. (n.d.-a). *Reducing emissions from aviation*. https://ec.europa.eu/clima/policies/transport/aviation_en

European Commission. (n.d.-b). *REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL - Updated analysis of the non-CO2 climate impacts of aviation and potential policy measures pursuant to EU Emissions Trading System Directive Article 30(4)*.

European Commission. (2016a). *Commission welcomes landmark international agreement to curb aviation emissions*. https://ec.europa.eu/commission/presscorner/detail/en/IP_16_3326

European Commission. (2016b). *Renewable Energy – Recast to 2030 (RED II)*. https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii

European Commission. (2019). *2050 long-term strategy*. https://ec.europa.eu/clima/policies/strategies/2050_en

European Commission. (2020a). *A Hydrogen Strategy for a climate neutral Europe*.

European Commission. (2020b). *COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT*.

European Commission. (2020c). *Sustainable aviation fuels – ReFuelEU Aviation*. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12303-Sustainable-aviation-fuels-ReFuelEU-Aviation_en

European Commission. (2021a). *Proposal for a regulation of the European parliament and of the council on ensuring a level playing field for sustainable air transport*.

European Commission. (2021b). *Renewable energy directive*. https://ec.europa.eu/energy/topics/renewable-energy/directive-targets-and-rules/renewable-energy-directive_en

European Commission. (2021c). *Renewable Energy Directive – guidance on the sustainability criteria for forest biomass used in energy production Draft Act*. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12943-Directive-sur-les-energies-renouvelables-orientations-sur-les-criteres-de-durabilite-applicables-a-la-biomasse-forestiere-utilisee-dans-la-production-d%E2%80%99energie_fr

European Commission DG Energy. (2018). *From where do we import energy and how dependent are we?* https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-2c.html

European Environment Agency. (2019). *Greenhouse gas emissions from transport in Europe*. https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-12

European Parliament. (2020). *Parliament says shipping industry must contribute to climate neutrality*.

European Social Survey. (2018). *Public Perceptions on Climate Change and Energy in Europe and Russia*.

ExxonMobil. (2019a). *Energy demand: Three drivers*. https://www.exxonmobil.be/en-be/Energy-and-environment/Looking-forward/Outlook-for-Energy/Energy-demand#Electricityandpowergeneration

ExxonMobil. (2019b). *Outlook for Energy: A perspective to 2040*. https://corporate.exxonmobil.com/Energy-and-innovation/outlook-for-energy/Outlook-for-Energy-A-perspective-to-2040#ExxonMobilsupportstheParisAgreement

Festel, G., Würmseher, M., Rammer, C., Boles, E., & Bellof, M. (2014). Modelling production cost scenarios for biofuels and fossil fuels in Europe. *Journal of Cleaner Production*, *66*, 242–253. https://doi.org/10.1016/j.jclepro.2013.10.038

FinFerries. (2017). *Electrifying Finnish ferry service*. finferries.fi/media/elektra-technical-data.pdf

Flach, Lieberz, Bolla. (2019). *EU-28 Biofuels Annual 2019* (No. NL9022).

Fleming, G. G., & Ziegler, U. (2016). *Environmental Trends in Aviation to 2050* (p. 7). International Civil Aviation Organization (ICAO).

Ge, Chang, Zhang, Cui, Luo, Hu, Qin, Li. (2018). *Chapter Five—Conversion of Lignocellulosic Biomass Into Platform Chemicals for Biobased Polyurethane Application*.

Gillet, S., Aguedo, M., Petitjean, L., Morais, A. R. C., Lopes, A. M. da C., Łukasik, R. M., & Anastas, P. T. (2017). Lignin transformations for high value applications: Towards targeted modifications using green chemistry. *Green Chemistry*, *19*(18), 4200–4233. https://doi.org/10.1039/C7GC01479A

Government of Canada. (2020). *Forest Bioenergy*. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/forest-industry-trade/forest-bioeconomy-bioenergy-biop/forest-bioenergy/13325

Hadrich, Salem. (n.d.). *Power-to-Liquids*. https://www.ise.fraunhofer.de/en/business-areas/hydrogen-technologies-and-electrical-energy-storage/thermochemical-processes/power-to-liquids.html

Ho, Ladisch, Sedlak, Mosier, Casey. (2011). *Biofuels from Cellulosic Feedstocks*.

IATA. (2020). *Traffic recovery slower than expected*. https://airlines.iata.org/analysis/traffic-recovery-slower-than-expected

IEA. (2020). *Policies database*. https://www.iea.org/policies

International Civil Aviation Organization. (2020). *World air passenger traffic evolution, 1980-2020*. https://www.iea.org/data-and-statistics/charts/world-air-passenger-traffic-evolution-1980-2020

International Maritime Organization. (2020). *Prevention of Air Pollution from Ships*. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx

International Renewable Energy Agency. (2016). *Innovation Outlook: Advanced Liquid Biofuels*. International Renewable Energy Agency.

IRENA International Renewable energy agency. (2016). *Innovation Outlook. Advanced Liquid Biofuels*. https://www.irena.org/publications/2016/Oct/Innovation-Outlook-Advanced-Liquid-Biofuels

Jeuland, N. (2020). *Interview with expert from SAFRAN to share expertise on future biofuel demand* [Personal communication].

Kovács, Z. (2019). *The end of the fossil fuel car is on the EU agenda*. https://www.transportenvironment.org/news/end-fossil-fuel-car-eu-agenda

Legay, Jaiyeola, Berman. (2020). *BL2F Policy Mapping and Stakeholder Assessment*. https://www.bl2f.eu/wp-content/uploads/2021/06/BL2F-D6.1-Policy-and-stakeholder-assessment-30092020-Jaiyeola-Berman-Legay.pdf

Løken, A. (2020). *Interview with expert from Avinor to share expertise on future biofuel demand* [Personal communication].

Malpas, Sbraga. (2020). *Inclusion of shipping in the EU Emissions Trading System: Current landscape, perspective, and potential impact*. https://www.lexology.com/library/detail.aspx?g=c60523cf-2eeb-412b-9b8d-c16366d44ac4

McFarland, K. (2017). *Biomass advantages and disadvantages*. https://www.syntechbioenergy.com/blog/biomass-advantages-disadvantages

McKinsey. (2020). *McKinsey Energy Insights Global Energy Perspective 2021*.

Mestre, C. (2020). *Interview with expert from T&E to share expertise on future biofuel demand* [Personal communication].

Mirova. (2019). *The Electrification of Transportation*. https://www.mirova.com/sites/default/files/2019-12/ElectrificationTransports2019.pdf

Morgan, S. (2020, April 15). Planes vs trains: High-speed rail set for coronavirus dividend. *Www.Euractiv.Com*. https://www.euractiv.com/section/railways/news/planes-vs-trains-high-speed-rail-set-for-coronavirus-dividend/

Muzi, N. (2018). *EU Parliament orders Commission to execute the phase-out of palm oil in diesel*. https://www.transportenvironment.org/press/eu-parliament-orders-commission-execute-phase-out-palm-oil-diesel

Pavlenko, Malins El Takriti, Searle, N., Sammy, Chris, Stephanie. (2016). *Beyond the Biofrontier: Balancing Competing Uses for the Biomass Resource.* ICCT The International Council on Clean Transportation. https://theicct.org/publications/beyond-biofrontier-balancing-competing-uses-biomass-resource

PopulationPyramid. (N.d.). *Population Pyramid 2040*. https://www.populationpyramid.net/world/2040/

Ringman-Beck, Orhanen, Kukula, Nieminen, Uusitalo, Joronen. (2021). *Workshops discussions with experts from CEPI, Valmet, RANIDO, Neste and TAU* [Personal communication].

Sandquist, J. (2017). All you need to know about biofuels. *SINTEF Blog*. https://blog.sintef.com/sintefenergy/bioenergy/all-you-need-to-know-about-biofuels/

Sandquist, J. (2020). *Interview with expert from SINTEF-ER to share expertise on future biofuel demand* [Personal communication].

Schulz, E. (2018). *Global Networks, Global Citizens*. Airbus.

SCI Verkehr. (2019). *European Rail Freight Transport Market 2019*. https://www.sci.de/fileadmin/user_upload/MC_Studien_Flyer/Flyer_MC_European_Rail_Freight_Transport_Market_2019_de.pdf

Siegemund, S. (2017). *The potential of electricity-based fuels for low-emission transport in the EU*.

SkyNRG. (n.d.). *Sustainable Aviation Fuel*. https://skynrg.com/sustainable-aviation-fuel/saf/

Smolarski, N. (2012). *High-Value Opportunities for Lignin: Unlocking its Potential*. Frost & Sullivan. https://www.greenmaterials.fr/wp-content/uploads/2013/01/High-value-Opportunities-for-Lignin-Unlocking-its-Potential-Market-Insights.pdf

Sönnichsen, N. (2021a). *Biofuel production worldwide from 2000 to 2020*. https://www.statista.com/statistics/274163/global-biofuel-production-in-oil-equivalent/

Sönnichsen, N. (2021b). *Oil production worldwide from 1998 to 2020*. https://www.statista.com/statistics/265203/global-oil-production-since-in-barrels-per-day/

Steinkopf-Frank, H. (2020). Urban Exodus? First Signs Of A Move Out Of The World's Cities. *Worldcrunch*. https://worldcrunch.com/coronavirus/urban-exodus-first-signs-of-a-move-out-of-the-world39s-cities

Total Energies. (2020). *Total Energy Outlook 2020*. https://totalenergies.com/sites/g/files/nytnzq121/files/documents/2020-09/total-energy-outlook-presentation-29-september-2020.pdf

TWI Global. (n.d.). *What is decarbonisation ?* https://www.twi-global.com/technical-knowledge/faqs/what-is-decarbonisation

United Nations Conference On Trade and Development. (2020). *Review of Maritime Transport 2019*. United Nations.

US Office of Energy Efficiency and Renewable energy. (n.d.). *Hydrogen Fuel Basics*. https://www.energy.gov/eere/fuelcells/hydrogen-fuel-basics

Valdenaire, Yugo, Leuckx. (2021). *Interview with experts from Concawe and Fuels Europe to share expertise on future biofuel demand* [Personal communication].

van Dyk, Su, McMillan, Saddler, S., Jianping, James, Jack. (2019). *'DROP-IN' BIOFUELS: The key role that co-processing will play in its production*. IEA Energy. https://www.ieabioenergy.com/wp-content/uploads/2019/09/Task-39-Drop-in-Biofuels-Full-Report-January-2019.pdf

Vettenranta, Autio. (2020). *Interview with experts from VALMET to share expertise on future biofuel demand* [Personal communication].

World Health Organization. (2020). *Air Pollution*. https://www.who.int/health-topics/air-pollution#tab=tab_1

Yu, O., & Kim, K. H. (2020). Lignin to Materials: A Focused Review on Recent Novel Lignin Applications. *Applied Sciences*, *10*(4626).

6 Appendix

Appendix 1: PESTEL template shared with experts during interviews

Dimensions	*Factor*	*Intensity* (1 = weak / 4 strong)	*Probability* (1 = weak / 4 = Strong)	*Term* (1 = LT / 4 = ST)	Impact Index
Political	Policies promoting biofuels in aviation and shipping				
	Policies promoting low-carbon energies				
	Policies diminishing EU ETS quota in aviation and shipping				
	Policies supporting biofuels in road and railroad transportation				
	Consolidation of the shipping industry in terms of policies				
	Policies promoting domestic and local energy production				
	Political crisis				
Economic	Higher demand for aviation and shipping				
	Transition of the pulp and paper industry into biorefineries				
	Resource competition of black liquor between biofuels and other products				
	High cost competitivity of fossil fuels				
	Cost competitivity of imported biofuels				
Societal	Higher demand for non-crop-based biofuels				
	Local population opposed to the pulp mills activities				
	Rising population				
	Need for cleaner fuels for higher health standards				
	Progress of environmental awareness in society				
	Commercial aviation loses in popularity				
	Health crisis				
Technological	Development of other means of transportation than aviation and shipping				
	Development of other sources of energy for aviation				
	Development of other sources of energy for shipping				
Environmental	Global warming generating new challenges				
	Uncertainties about the availability of sustainable biomass for advanced biofuels production				
	High level of SOx emissions for shipping				
	Non-CO2 effects (aviation)				
	Impacts on Biodiversity				
Legal	Policies making certifications' standards easier to meet in aviation				
	Policies making certifications' standards easier to meet in shipping				

Appendix 2: ANNEX IX of RED II Part A.

"Feedstocks and fuels, the contribution of which towards the target referred to in the first subparagraph of Article 3(4) **shall be considered to be twice their energy content**:

a) Algae if cultivated on land in ponds or photobioreactors.

b) Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC.

c) Bio-waste as defined in Article 3(4) of Directive 2008/98/EC from private households subject to separate collection as defined in Article 3(11) of that Directive.

d) Biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro-food and fish and aquaculture industry, and excluding feedstocks listed in part B of this Annex.

e) Straw.

f) Animal manure and sewage sludge.

g) Palm oil mill effluent and empty palm fruit bunches.

h) Tall oil pitch.

i) Crude glycerine.

j) Bagasse. 85

k) Grape marks and wine lees.

l) Nut shells.

m) Husks.

n) Cobs cleaned of kernels of corn.

o) **Biomass fraction of wastes and residues from forestry and forest-based industries, i.e., bark, branches, pre- commercial thinnings, leaves, needles, treetops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin, and tall oil.**

p) Other non-food cellulosic material as defined in point (s) of the second paragraph of Article 2.

q) Other ligno-cellulosic material as defined in point (r) of the second paragraph of Article 2 except saw logs and veneer logs.

r) Renewable liquid and gaseous transport fuels of non-biological origin.

s) Carbon capture and utilisation for transport purposes, if the energy source is renewable in accordance with point (a) of the second paragraph of Article 2.

t) Bacteria, if the energy source is renewable in accordance with point (a) of the second paragraph of Article 2."