What are the key Challenges and Opportunities in scaling up Sustainable Aviation Fuels in the EU? An Analysis of the Aviation and Energy Industry in Europe

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Abstract

The European Union (EU) has agreed on ambitious targets to decarbonize the aviation sector. One main measure to reach this goal is the ramp-up of sustainable aviation fuels that are intended to replace conventional jet fuels over time. In 2050, the EU expects these fuels to account for 70 per cent of the aviation fuel mix.

This thesis conducts a thorough analysis of barriers and opportunities in this scale-up process. The objective is to comprehensively assess key factors such as feedstock availability, economic viability, regulatory landscapes as well as the role of airlines in this transition. The thesis combines existing knowledge from literature with learnings from interviewed industry professionals exhibiting expertise in commercial, technological, strategic, or regulatory areas.

Noteworthy findings reveal a wide range of challenges such as sector competition for feedstock, economic obstacles for power-to-liquid fuels, or an unfavorable investment environment. These factors are likely to lead to higher fuel costs increasing operating costs for airlines that will ultimately raise ticket prices.

On the side of opportunities, high infrastructural compatibility, supporting policy frameworks, emerging technologies as well as the mounting electrification in the road transport sector may support the successful scale-up of sustainable aviation fuels.

The research conclusions underscore the need for collaborative efforts across industries but also globally given the limited regional feedstock availability and disadvantageous conditions to produce power-to-liquid fuels. Furthermore, the policy framework needs to encourage investments and concentrate efforts on the seamless adoption of sustainable aviation fuels.

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Key Words: aviation, decarbonization, sustainable aviation fuels, strategy, sustainability, jet fuel, EU climate targets

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Sumário

A UE estabeleceu metas ambiciosas para descarbonizar o sector da aviação, destacando-se o aumento dos combustíveis sustentáveis, que se destinam a substituir os combustíveis convencionais. Em 2050, espera-se que estes combustíveis representem 70% do uso na aviação.

Esta tese analisa os obstáculos e oportunidades neste processo de aumento de escala, avaliando os principais fatores, como a disponibilidade de matérias-primas, a viabilidade económica, o quadro regulamentar e o papel das companhias aéreas nesta transição. A tese combinou os conhecimentos existentes na literatura com as lições aprendidas com os profissionais entrevistados com experiência em diferentes áreas.

As conclusões revelam vários desafios, como a concorrência setorial pela matéria-prima, os obstáculos económicos aos combustíveis líquidos e um ambiente de investimento desfavorável. É provável que estes fatores conduzam a um aumento dos custos dos combustíveis, o que resultará num aumento dos custos operacionais para as companhias que, consequentemente, aumentarão os preços dos bilhetes.

Nas oportunidades, a elevada compatibilidade das infraestruturas, os quadros políticos de apoio, as tecnologias emergentes e a crescente eletrificação do sector dos transportes rodoviários podem contribuir para o êxito da expansão dos combustíveis sustentáveis na aviação.

As conclusões salientam ainda a necessidade de esforços de colaboração entre as indústrias, mas também a nível mundial, dada a disponibilidade limitada de matérias-primas a nível regional e as condições desvantajosas para a produção de combustíveis líquidos para fins energéticos. Além disso, o quadro político deve incentivar os investimentos e concentrar esforços na adoção sem descontinuidades de combustíveis sustentáveis na aviação.

Título: Quais são os principais desafios e oportunidades para a introdução de combustíveis sustentáveis para a aviação na UE? Uma análise do sector da aviação e da energia na Europa

Palavras-chave: aviação, descarbonização, combustíveis sustentáveis para a aviação, estratégia, sustentabilidade, combustível para jactos, objectivos climáticos da UE

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Abbreviations

A

ASTM ....American Society for Testing and Materials
ATJ-SPK..Alcohol to jet synthetic paraffinic kerosene

C

CapEx.. Capital expenditure
CHJ .... Catalytic hydrothermolysis jet fuel
CO.. Carbon monoxide
CO_2.. Carbon dioxide
CORSIA..Carbon Offsetting and Reduction Scheme for International Aviation

E

EASA .... European Union Aviation Safety Agency
EU… .... European Union
EU ETS .... European Union Emission Trading Scheme

F

FAME .... Fatty acid methyl ester
FOGs .... Fats, oils and grease
FT-SKA .... Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources
FT-SPK .... Fischer–Tropsch hydroprocessed synthesized paraffinic kerosene

G

GHG.. Greenhouse gas

H

HC-HEFA-SPK ....Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids
HEFA-SPK .... Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids
HVO.. Hydrotreated vegetable oil

I

IATA ....International Air Transport Association
ICAO..International Civil Aviation Organization
ICCT ....International Council on Clean Transportation
IRA.. Inflation redution act

M

MoU .... Memorandum of understanding

O

OpEx .... Operating expenditure

P

PtL.. Power-to-Liquid

R

RED...Renewable Energy Directive

S

SAF ....Sustainable Aviation Fuels
SIP..Synthesized iso-paraffins from hydroprocessed fermented sugars

U

UCO .... Used cooking oil

US… .... United States

1. Introduction

1.1 Introduction to topic

Air transport is considered the only method to move goods and passengers worldwide within one day which makes it a crucial connecting piece for different regions and markets. Nevertheless, this convenience results in negative effects on the environment as associated greenhouse gas emissions contribute to global warming. Before the COVID-19 pandemic, global aviation was responsible for roughly 2.5 per cent of the overall carbon emissions (Malina et al., 2022, p. 15).

In 2021, the International Air Transport Association (IATA) made an historical decision by committing to achieve net-zero carbon emissions by 2050 which is aligned with the climate goals set in the Paris Agreement. The IATA, which represents more than 300 airlines from 120 countries, thereby initiated a path of emission reductions that requires strenuous efforts of multiple stakeholders, such as fuel suppliers, governments, aircraft manufacturers, or airlines. A core element of the IATA 2050 strategy is the scale-up of Sustainable Aviation Fuels (SAF) which are expected to abate two-thirds of emissions by then. This measure will be supplemented by further efforts like new propulsion technologies and the usage of carbon capture and storage (IATA, 2023d).

A study by the world bank emphasizes SAF as the most relevant tool to address aviation's decarbonization as new propulsion concepts are hindered by technology constraints and fleet turnover times of more than 20 years. The chemical similarity of SAF to conventional jet fuels enables its usage in existing aircraft engines and fuel systems (Malina et al., 2022, pp. 22–23).

As a result of this high potential, the European Union decided to introduce concrete SAF mandates between 2025 and 2050 as part of their climate targets. The mandates are set to increase to 70 per cent of SAF in relation to total combusted jet fuel by 2050 which shows the significance of this step (Council of the EU, 2023). However, in 2022 the global SAF usage only made up between 0.1 and 0.2 per cent of conventional jet fuel (Early, 2023). Analyzing this substantial gap, the huge extent of the EU's ambition to ramp up SAF becomes apparent.

This thesis will hence shed light on the upscaling of SAF contrasting potential challenges and opportunities during the adoption. These insights are highly valuable for key industry stakeholders such as airlines, governments, fuel suppliers, or customers.

1.2 Research question and objectives

The introduction pointed out a huge disparity between the EU's ambitions for SAF usage and the presently available volumes. Naturally, this raises the question of how the respective SAF scale-up and adoption can and will be facilitated. For this reason, the thesis examines the following research question:

"What are the key Challenges and Opportunities in scaling up Sustainable Aviation Fuels in the EU"

Before delving deeper into respective areas influencing the adoption, the thesis shall provide context for the scale-up including the purpose and major affected stakeholders.

To increase the understanding of the process of the SAF ramp-up and adoption, current technological maturities of SAF production pathways, associated cost factors, and the potential impact on the industry's decarbonization targets shall be analyzed. Furthermore, the corresponding legislative framework will be scrutinized to show potential regulatory incentives or hurdles for the scale-up. The thesis further sheds light on the role of airlines in accelerating the transition by determining their commitments and the economic implications of increased SAF utilization.

The research is focused on the EU but nevertheless intends to reveal global dependencies and potentials for cooperation that may impact the successful scale-up.

2. Theoretical discussion

The theoretical discussion is the literature review depicting contemporary publications concerning the topic. It is complemented by meaningful and current industry-related information published by key stakeholders of the industry.
Firstly, this thesis will provide context for the topic of SAF, examining the current environmental impact of aviation and the associated efforts of governments, associations, and airlines. Subsequently, the reader will be presented with SAF specifications, the legislative landscape, as well as its competitiveness and role in the decarbonization of aviation derived from existing literature.

2.1 Sustainability in the European aviation sector

The EU-27 faced more than a doubling of carbon dioxide emissions in civil aviation between 1995 and 2019 before the emissions significantly decreased during the COVID-19 pandemic from 2020 onwards (Statista, 2023). This reduction, however, is based on the substantial decline in the number of flights (EASA, 2023b) given the pandemic-related travel restrictions (Statista, 2022a). Disregarding this exceptional situation, figure 1 constitutes that emissions have been almost continuously on the rise for roughly thirty years. It contains emissions of all civil flights leaving EU airports.
On the scale of things, the 2019 EU-27 emissions correspond to roughly 16.5 per cent of global commercial aviation emissions (Statista, 2021). In 2017, the EU aviation was responsible for roughly 3.8 per cent of total carbon dioxide (CO_2) emissions in the region which makes it the second most significant polluter in the transportation sector just behind road transport (European Commission, 2022c).

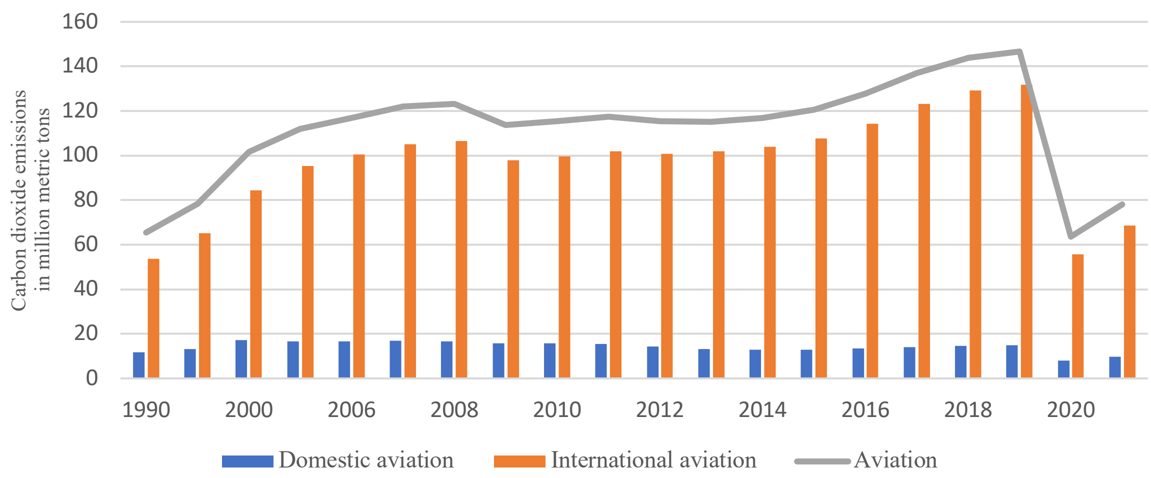

Figure 1: EU-27 civil aviation emissions (1990-2021) (Statista, 2023)

The European Union Aviation Safety Agency emphasizes the enormous impact of long-haul flights accounting for distances of more than 4000 kilometers. While these flights only make up 5.5 per cent of the total EU flights, their attributed emissions reach more than 46 per cent of the aviation emissions in the EU (EASA, 2023b).

In 2021, the IATA announced its commitment to achieving net zero by 2050. About two-thirds of their decarbonization plan could be covered by the usage of sustainable aviation fuels which clearly outlines the importance of the scale-up (IATA, 2021).

The European Union introduced the so-called Fit-for-55 package aiming for a 55 per cent emission reduction by 2030 compared to 1990 which also requires substantial emission cutbacks in the transport sector. As part of the package, the ReFuelEU Aviation initiative acknowledges SAF as one of the key short- and medium-term tools for decarbonizing aviation. It thus aims to address the issue of low supply and high prices of SAF (Council of the EU, 2023).

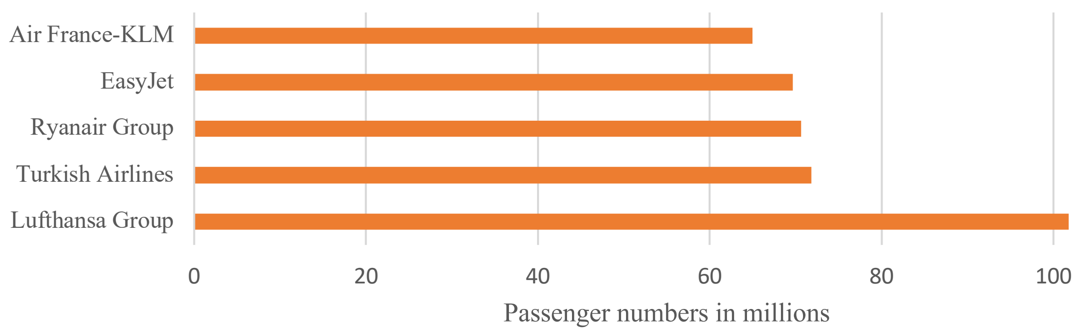

Figure 2: Leading airlines in Europe based on passenger numbers in 2022

European airlines also announce concrete environmental targets and initiatives towards a greener aviation industry as observed among the largest airlines operating in Europe displayed in figure 2.

Before reaching the net-zero target by 2050, the Lufthansa Group wants to reduce its net CO_2 emissions by 50 per cent by 2030 compared to 2019. This target shall be reached by fleet modernization, the improvement of flight operations as well as the adoption of SAF (Lufthansa Group, 2023b). EasyJet intends to bring down its emissions by 78 per cent until 2050 mainly through fleet renewal, the scale-up of SAF as well as a later usage of zero carbon emissions aircraft (easyJet plc, 2023b).

AirFrance-KLM and Ryanair even set out concrete SAF targets aiming for 10 and 12.5 per cent respectively by 2030 (Air France–KLM S.A., 2023b) (Ryanair Group, 2023).

2.2 Introduction to sustainable aviation fuels

2.2.1 Definition and types of SAFs

"A Sustainable Aviation Fuel is a sustainable, non-conventional, alternative to fossil-based jet fuel."

(European Union Aviation Safety Agency, 2023)

The two main types of SAF either refer to SAF as a biofuel or synthetic fuel. The former can be produced via various pathways based on different feedstock sources such as biomass, wastes, or residues. Annex IX in the Renewable Energy Directive (RED) defines the eligible feedstock sources. Synthetic fuels, however, also known as power-to-liquid (PtL) fuels or e-fuels require water, electricity, and CO_2.

SAF is considered a viable option for cutting carbon emissions in existing aircraft without requiring any modifications to the planes. This fuel can reduce lifecycle CO2 emissions by up to 80 per cent in comparison to conventional jet fuel (Airbus, 2022) (European Union Aviation Safety Agency, 2023).

Various recently published journal articles identified seven pathways for producing SAF as well as two supplementary co-processing technologies with different approved blending ratios of up to 50 per cent. All of these pathways are certified under ASTM (American Society for Testing and Materials) guidelines (Shahriar & Khanal, 2022, p. 5) (Afonso et al., 2023, p. 9) (Grimme, 2023, p. 6) which serve as international standards for jet fuels (SkyNRG, 2023). The

D7566-22 specification defines the production of aviation turbine fuel composed of both conventional and synthetic blending components. (ASTM, 2022).

Table 1 provides an overview of main conversion processes, their core feedstocks such as animal fats, algae, or bio-oils as well as their corresponding maximum blending ratio.

Conversion Process	**Approved**	**Possible Feedstocks**	**Maximum Blending Ratio**
Fischer–Tropsch hydroprocessed synthesized paraffinic kerosene (FT-SPK)	2009	Coal, natural gas, biomass	50%
Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids (HEFA-SPK)	2011	Bio-oils, animal fat, recycled oils	50%
Synthesized iso-paraffins from hydroprocessed fermented sugars (SIP)	2014	Biomass used for sugar production	10%
Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources (FT-SKA)	2015	Coal, natural gas, biomass	50%
Alcohol to jet synthetic paraffinic kerosene (ATJ-SPK)	2016	Biomass from ethanol or isobutanol production	50%
Catalytic hydrothermolysis jet fuel (CHJ)	2020	Triglycerides such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil	50%
Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids (HC-HEFA-SPK)	2020	Algae	10%

Table 1: Production pathways SAF
(Afonso et al., 2023, p. 9) (Shahriar & Khanal, 2022, p. 5) (Grimme, 2023, p. 16)

The HEFA-based process is typically performed by the treatment of feedstocks such as animal fats, vegetable oils, or waste grease by means of hydrogen to remove oxygen. Subsequently, the step is followed by isomerization and cracking which leads to the desired fuel specifications (Yilmaz & Atmanli, 2017, pp. 1381–1382).

Fischer-Tropsch fuels are created through a process relying on “syngas” which involves multiple chemical reactions. The sustainable production of syngas can be achieved by using renewable feedstocks like municipal solid waste or forestry residues or by using hydrogen from renewable electricity and combining it with additionally sourced carbon monoxide (CO). The latter approach is essential for the production of PtL (Cabrera & de Sousa, 2022, pp. 8–12).

The production of AtJ fuel involves dehydration, oligomerization, and hydro processing of ethanol or iso-butanol which is typically produced by fermenting biomass feedstock. While these alcohols can originate from various sources, they are commonly derived from the fermentation of starches or sugars sourced by for instance cane or sugar beets. The CHJ is produced through hydrothermal conversion of fatty acid esters and free fatty acids. A combination of processes such as hydrotreating, hydrocracking, and hydro isomerization, along with other standard refinery steps will lead to the CHJ fuels (Afonso et al., 2023, pp. 8–9).

SIPs or Synthesized Iso-Paraffins are synthetic hydrocarbons made from sugar fermentation products such as sugar cane, beet, or processed biomass. At first, enzymes break down biomass to extract sugars before these are biologically converted into a hydrocarbon intermediate that is further processed into fuel (Abrantes et al., 2021, p. 6).

2.2.2 Legislative landscape

This chapter shall broadly mention EU-wide and global schemes and regulations affecting the subsequent usage of SAF.

In 2012, the EU as one of the first institutions introduced the emission trading system (ETS) in an effort to reduce emissions in aviation. This system required polluters to surrender permits equal to their previous year's CO_2 emissions. Such permits can be obtained via annual allocations or bought from other companies. The EU further enforces emission limits by placing caps on the total available permits in the market. However, the ETS only covers intra-EU flights and a large amount of allocations is still granted freely (European Commission, 2022b) (2022a) (Transport & Environment, 2022).

A more global initiative to address CO_2 emissions in aviation was implemented by member states of the International Civil Aviation Organization (ICAO) in 2019. This United Nations agency is responsible for offering technical, legal, and administrative assistance to facilitate cooperation within air transport (ICAO, 2023a).

The organization introduced the so-called Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) which will require airlines to purchase offset credits to compensate for any emissions above a CORSIA baseline set for 2019 emissions. To achieve this target, aircraft operators may reduce their offsetting requirements by means of CORSIA-eligible fuels (ICAO, 2023b) such as SAF. Although the pilot phase started in 2021 and voluntarily involved regions such as the EU or the US, many polluters such as China or India will not join CORSIA before 2027 (EASA, 2023a). The core difference to the ETS scheme can be considered the global scope and the limitation to currently not encourage airlines to save emissions beyond the baseline. Despite the introduction of EU-ETS, the EU aviation emissions experienced a five per cent annual increase between 2013 and 2019 which may be linked to an overallocation of permits consequently leading to cheap ETS credits for the aviation industry.

Additionally, the scheme only covers one-third of the EU aviation emissions because long-haul flights are excluded (European Commission, 2022b) (Transport & Environment, 2022).
As a result, the EU announced a revision of ETS for aviation containing a phasing out of free allowances. Furthermore, an assessment of CORSIA shall be carried out in 2026 with the potential outcome to intensify and extend the scope of EU ETS (European Commission, 2022b). This has been criticized by the IATA who declare this ETS reform as high risk for international consensus on the global scheme CORSIA (IATA, 2023c).
Supplementary to the existing EU-wide and global schemes promoting emission reductions, the EU has unveiled additional regulatory measures to support the concrete scale-up of SAF given its attributed decarbonization potential (Grimme, 2023).
From 2025 onwards, aviation fuel suppliers in the EU will be mandated to include a minimum percentage of SAF in the fuel provided to aircraft operators at EU airports. This requirement will expand to encompass synthetic fuels from 2030. The mandates are set to increase every five years as described in detail in table 2. The sub-target for synthetic fuels (PtL) as a type of SAF is also directed as a percentage of the total jet fuel which means that by 2050 half of the supplied SAF need to be produced by the PtL process (European Parliament, 2023, p. 90) (Council of the EU, 2023).

Year	2025	2030	2035	2040	2045	2050
Total SAF	2%	6%	20%	34%	42%	70%
Sub target synthetic fuels	0%	1.2%	5%	10%	15%	35%

Table 2: EU SAF mandates (European Parliament, 2023, p. 90)

Biofuels originating from food and feed crops are excluded from the regulation. The eligible SAF must comply with the emission-saving criteria set by the Renewable Energy Directive providing the legal framework for the advancement of clean energies in the EU (Council of the EU, 2023) (European Commission, 2023).
The EU proposed minimum fines to be adopted by the member states to ensure compliance with the presented targets. Fuel suppliers shall be penalized by twice the differential of the conventional kerosene price and the SAF price per tonne multiplied by the quantity of SAF needed to meet the target. Aircraft operators on the other side shall be fined by twice the yearly average of the aviation fuel per tonne multiplied by the yearly non-tanked quantity. This mechanism shall enable premiums for SAF producers and incentives for airlines to purchase SAF quantities (NOW GmbH, 2023a).
These SAF targets have a significant impact on the energy and aviation sector in Europe which will be further examined in the following chapters. The research question is derived from the

fact that both the aviation industry, as well as fuel suppliers, are highly encouraged to accomplish the scale-up of SAF.

Furthermore, various regions have plans to increase the adoption of SAF. In the United States (US), there is a target to provide three billion gallons of SAF annually by 2030 as an initial step toward meeting the projected aviation fuel demand of 35 billion gallons by 2050. To facilitate this, the government has introduced measures like tax incentives, production credits, and a SAF subsidy program (Shepardson, 2022). SAF producers can qualify for tax credits of up to 1.75 USD per gallon, with the amount depending on the level of greenhouse gas (GHG) emission reduction achieved (U.S. Department of Energy, 2022).

Beyond that, other regions such as Japan, the United Kingdom, and Canada have expressed their aspirations for SAF through mandated targets. The common goal of all these regions is to achieve a ten per cent SAF share in the aviation fuel mix by 2030 (UK Department for Transport, 2023, p. 6) (Government of Canada, 2022, p. 2) (Nikkei Asia, 2023).

2.2.3 Role of SAF in the decarbonization

The primary rationale for adopting SAF centers on alleviating the environmental consequences of aviation-related emissions (Undavalli et al., 2023, p. 40). Considering the recent trend of the industry's CO_2 emissions, as previously shown in figure 1, this necessity is underscored even more.

Reflecting the increasing number of legislative schemes addressing carbon emissions, it is important to comprehend the potential role SAF can play in mitigating aviation emissions.

The IATA attributes approximately two-thirds of the 2050 net-zero contribution to SAF, as illustrated in figure 4. About 19 per cent may be linked to offsets and carbon capture methods while another 13 per cent shall originate from advancements in new technologies (IATA, 2023d).

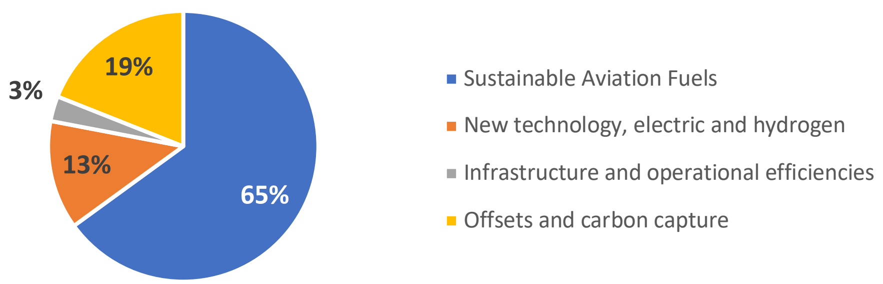

Figure 3: IATA net-zero strategy 2050 (IATA, 2021)

The rather inferior impact coming from these technologies may be justified by the long development and certification timelines as well as the requirement for new infrastructure.

While electric flights are probably limited to short distances, hydrogen-based aircraft would offer the possibility to even power long-haul flights. However, a breakthrough in these technologies is not likely to happen before 2035 while the scale-up of the global fleet could even require another decade (Grimme, 2023, p. 11). Additionally, it must be noted that hydrogen, unlike SAF, cannot be used as a substitute drop-in fuel hence posing new challenges in the quick adoption (Undavalli et al., 2023, p. 26).

These barriers further emphasize the role of SAF in mitigating carbon emissions of aviation. Despite the current blending restrictions of 50 per cent SAF, tests for 100 per cent SAF usage are carried out which is crucial for the achievement of zero-carbon operations (Undavalli et al., 2023, p. 24).

The ultimate SAF emission reduction compared to fossil fuels highly depends on the respective feedstock and conversion process.

An analysis carried out by a researcher at the German Aerospace Center uses default emission values for CORSIA-eligible fuels published by the ICAO. Through the FT process, the potential CO_2 reduction may range between 81 and 103 per cent while the HEFA pathway can achieve up to 83 per cent reduction with the common feedstock used cooking oil (UCO). The AtJ process primarily offers a reduction between 40 and 75 per cent, and SIP provides a reduction of 47 per cent compared to fossil fuels (ICAO, 2022) (Grimme, 2023, p. 3).

The analysis considered lifecycle emissions, encompassing the entire fuel cycle, including feedstock production and transportation, fuel production and distribution as well as the utilization of the final fuel product (US EPA, 2015) (Grimme, 2023, p. 3). Other studies confirm this view, further adding that the emission reduction is mainly achieved via sequestration in fuel production while the SAF fuel combustion itself reaches similar GHG emissions as conventional fuels (Barke et al., 2022, p. 15).

Plants, often building the basis for SAF, absorb CO during photosynthesis which is ultimately during fuel combustion released back into the atmosphere. This process can be considered a closed carbon cycle. As the CO_2 sequestration of crude oil happened millions of years ago, the respective consumption naturally harms the climate (Malina et al., 2022, p. 24).

2.2.4 Economic analysis

An examination of several annual reports of major European airlines, including Lufthansa, AirFrance-KLM, and easyJet, reveals that a substantial portion of operating costs is attributed to fuel expenses. To be more specific, fuel costs represent 23 per cent, 29 per cent, and 26 per cent of their respective operating expenditures, highlighting the significance of this cost component (Lufthansa Group, 2023a, p. 42) (Air France–KLM S.A., 2023a, pp. 296–297) (easyJet plc, 2023a, p. 156). This analysis aligns with figures from Statista, which indicate that fuel costs frequently account for roughly 30 per cent of total expenditures (Statista, 2022b).

In mid-September 2023, the price for conventional jet fuel in Western Europe stands at roughly 0.78 EUR per liter while SAF trades at about 2.28 EUR showing a substantial price difference between the fuels (European Central Bank, 2023) (Aviation Benefits Beyond Borders, 2023) (Perkins, 2023).

In a 2023 study that focused on recent advancements in SAF, minimum jet fuel selling prices for various technologies and feedstocks were extracted from techno-economic studies published after 2015. Among these findings:

The HEFA pathway, using feedstocks like UCOs or vegetable oils, demonstrated the most cost-effective range with potential prices between 0.88 and 1.84 EUR per liter. The FT process when based on biomass, presents the prospect of prices around 1.24 EUR to 3.64 EUR per liter. The PtL fuel option resulted in the highest minimum prices among the examined pathways, ranging from 2.10 to 5.00 EUR per liter. The AtJ process revealed a possible range between 0.90 EUR and 2.75 EUR depending on the usage of advanced feedstocks.

The higher SAF costs are driven by factors such as the scarcity of sustainable feedstocks or the production of hydrogen from renewable sources for PtL.

Additionally, Table 2 provides a breakdown of different cost categories in the production process. It revealed that the FT and Alcohol-to-Jet pathways were primarily influenced by large capital expenditures (CapEx), while HEFA and PtL processes were more dependent on the cost of feedstocks like scarce sustainable oils or hydrogen derived from renewable sources. Operating expenditures (OpEx) showed less significant variations among the different pathways (Detsios et al., 2023, pp. 1–12).

Category	HEFA	FT	AtJ	PtL
CAPEX range (%)	22-40	54-81	45-75	5-20
OPEX range (%)	8-10	12-21	2-14	5-15
Feedstock range (%)	51-69	0-32	20-44	70-85

Table 3: Breakdown of SAF production costs (Detsios et al., 2023, p. 12)

In their findings, the authors mention that the HEFA process produces the only currently commercially viable SAF, whereas the FT and AtJ routes are making progress in commercialization. The PtL faces challenges related to production costs although the literature recognizes potential for cost reductions through more affordable electrolyzers and economies of scale. Lastly, the authors emphasize that carbon-related expenses may play a crucial role in narrowing the cost gap between conventional and alternative fuels in the future (Detsios et al., 2023, p. 13). Presently, existing schemes such as ETS and CORSIA do not close this cost difference (Bullerdiek et al., 2021, p. 3).

2.2.5 Supply chain and infrastructure

The SAF supply chain is categorized into three main stages: upstream, midstream, and downstream. In the upstream phase, core activities encompass feedstock collection, logistics, and initial processing. The midstream stage relates to the conversion of feedstock into SAF, while the downstream segment involves the distribution and ultimate utilization of SAF (Bullerdiek et al., 2021, p. 3).

Core concerns within upstream turn on ensuring availability, determining suitable locations, creating efficient collection methods, and managing costs within the supply chain. Additionally, variables of uncertainty, including factors like seasonal fluctuations, weather conditions, and the physical and chemical characteristics of feedstock need to be reflected (Martinez-Valencia et al., 2021, p. 4).

Besides technical hurdles related to the application of new technologies, the midstream stage faces challenges regarding the feedstock quality that can potentially be influenced by increasing transport distances. Despite this barrier, production facilities need to ensure a certain scale to achieve economic viability (Dragone et al., 2020, p. 2) which may be further supported by the inclusion of co-products (Martinez-Valencia et al., 2021, p. 5).

The literature suggests that drop-in biofuels are compatible with existing fuel infrastructure which would hence allow usage of common transportation methods such as train, barge, pipeline as well as current tanks (Yue et al., 2014, p. 41) (Detsios et al., 2023, p. 9). This is in line with the view of the IATA outlined in their latest net-zero roadmap focused on new fuel infrastructure. Nevertheless, the IATA outlines limitations in infrastructure usage of unblended SAF for which additional tanks or blending infrastructure would be required (IATA, 2023b, pp. 2–5).

To sum up, SAF is distinguished through the high compatibility with existing infrastructure which can be considered more of an existing barrier for long-term SAF alternatives such as hydrogen or electrification in aviation (Detsios et al., 2023, p. 9).

2.2.6 Production constraints and advancements

Until today there are seven approved SAF conversion pathways, however, it must be noted that these technologies vary in maturity. Several studies identified differentiating fuel readiness levels for the different processes, determining the respective progress toward commercialization. While HEFA-SPK is being assessed to be fully commercial given the score of nine out of nine, the remaining pathways vary between the score of five to seven showing room for improvement (Afonso et al., 2023, pp. 8–9) (European Union Aviation Safety Agency, 2022, p. 70) (Detsios et al., 2023, p. 7) (Delbecq et al., 2023, pp. 10–17). The HEFA process can be integrated into existing oil refineries with manageable adaptions. Consequently, the large majority of global volumes are currently produced by this pathway (Cabrera & de Sousa, 2022, p. 8).

Generally, it must be stated that the upscaling of SAF will require vigorous efforts to meet any laid-out targets. The 2022 global SAF production of approximately 300 million liters will need to increase to 449 billion liters according to the net-zero strategy of the IATA (IATA, 2023b) (Undavalli et al., 2023, p. 24). Until now, there has been no production of marketable volumes of PtL SAF (NOW GmbH, 2023b).

Significant limitations to the widespread production of SAF are associated with the availability of feedstock. While estimates vary widely, a potential shortage has been determined that could be counterbalanced by the extended PtL usage which is not relying on biogenic feedstock (Grimme, 2023, p. 6) (Rojas-Michaga et al., 2023, p. 2). Given the competitive landscape in the feedstock market, surged prices are observed such as in cases of UCO or sunflower oil. This trend may be exacerbated further by the fact that other sectors, including the road transportation industry, are depending on similar feedstocks for their products, i.e. biodiesel (Grimme, 2023, p. 6).

A study recently published by the International Council on Clean Transportation (ICCT) examines the sustainable feedstock resources available in the EU. The findings highlight the most significant potential for SAF feedstocks coming from fats, oils, and grease (FOGs), as well as agricultural residues and industrial flue gases. In an optimistic scenario, these abundant feedstocks, when maximally utilized along with additional potential sources, could contribute to producing a SAF amount sufficient to cover up to 5.5 per cent of jet fuel demand by 2030. However, the study clearly stated that realizing this potential would be bound to robust policy support and incentives to redirect volumes initially allocated to the road transport sector.

In a more realistic projection, the study anticipates EU-based feedstocks could cover approximately 1.9 per cent of the 2030 jet fuel demand. The study draws attention to prevailing limitations in the potential contributions of biogenic SAF while emphasizing the necessity for continued policy support to expand the scale of PtL fuels (O'malley et al., 2021, pp. 15–16).

Accordingly, industry experts underscore the need for imports. In 2019, more than half of 2.4 million mt of UCO, known as the main feedstock in the European SAF production, were imported. Other major feedstock producers are the US, Brazil, Indonesia, and China who are all expected to expand their existing feedstock capacity (Malicier, 2022) (IEA, 2022).

Nevertheless, it must be noted that imports carry the risk of fraudulent activities as evidenced by past incidents when importing UCO-based biodiesel (O'malley et al., 2021, p. 3) which reportedly originated from virgin palm oil. The RED incentives for eligibly sustainable feedstock such as UCO led to a high number of doubtful imports from Asian countries. Malaysia for instance was able to export two to three times of UCO per capita compared to the EU, although the country exhibits little UCO collection infrastructure while being a major palm oil producer at the same time (EURACTIV, 2019).

Existing barriers in the PtL pathway, which is not affected by the biogenic feedstock shortage, refer to capital-intensive equipment, substantial need for an increase in renewable electricity production as well as low energy efficiency in the production process (Detsios et al., 2023, p. 7).

The aforementioned challenges in feedstock availability underline the need for further expanding in the variety of feedstocks and the exploring of new production pathways (Undavalli et al., 2023, p. 25).

2.3 Conclusion of the literature review

The literature displays an extensive amount of research on the topic of sustainable aviation fuels. The chapter explored the determining factors comprising barriers and opportunities for a successful upscaling of SAF in the EU.

To provide context for the prospectively mandated usage of SAF, the environmental impact of the aviation industry as well as the decarbonization potential of SAF were comprehensively described.

The author identified feedstock availability and costs as key challenges, especially for biogenic SAF, while PtL fuels are hindered by high production costs, primarily driven by green hydrogen prices. Prevailing regulatory complexities in the EU create uncertainties underlining the need for clear, long-term frameworks. The research detected a certain compatibility with existing infrastructure. Aircraft operators will mainly be affected by higher operating costs as a result of increasing SAF usage which may impact the ticket prices.

3. Methodology

3.1 Type of methodology and objective

This thesis applied qualitative research methodology which is regarded as a well-established mode of inquiry for applied fields such as management (Marshall & Rossman, 2014, p. 1).
Qualitative research stands out through the opportunity to thoroughly explore individuals' experiences utilizing diverse research methods like interviews and focus group discussions (Hennink et al., 2020, p. 10).
Through the conduction of qualitative interviews, this thesis aims to illustrate the understandings as well as experiences of participants (Edwards & Holland, 2013, p. 90) who are considered experts related to the field of the research question. These findings should subsequently be contrasted with the current knowledge gained during the literature review in chapter two.
However, given the many factors involved, such as location, context, or power relations, critics of this methodology question the possibility of replicating qualitative interviews. Furthermore, analyzing the interview transcripts may cause problems if the interviewer tries to interpret the answers in favor of the researcher's point of view (Edwards & Holland, 2013, pp. 91–92).
To avoid the so-called interview bias, the interviewer refrains from showing any kind of reaction to statements made by the interviewees. This also contains facial expressions or visual cues (Qu & Dumay, 2011, p. 248).
The interviews follow a semi-structured approach aiming to cover broad topics while allowing the skilled interviewer to modify elements such as pace and order of questions depending on the course of the conversation. Through potential variations in the interview guide, the interviewer typically tries to elicit the fullest responses from the interviewee (Qu & Dumay, 2011, p. 246).

3.2 Data collection

This thesis collects data through the conduction of qualitative interviews. All conversations are recorded and transcribed before extensive analysis. All participants are fully anonymized within the transcripts. The interviews are conducted online and recorded with the video conferencing software Webex. Each interview had a duration of approximately 15 to 60 minutes. In total six interviews were conducted. One sample of the transcripts is attached to this thesis in the appendix.

All interview experts were required to have a professional connection to the topic of SAF to ensure a relevant contribution to the research question. Table 4 provides an overview of all participants containing their expert ID, the respective roles as well as a brief description of their touchpoints to SAF. The researcher selected relevant international experts working in the EU who are professionally involved with SAF for several years. The varying backgrounds of the experts ensure a holistic analysis of the research question and enable deep insights into the different key factors of the scale-up. As a result, differing experts specialized in commercial, strategic, technological, or legislative areas were interviewed. The author's industry network, the social media site LinkedIn, as well as press departments of relevant companies and associations, were used to identify and approach relevant industry experts.

EXPERT ID	ROLE (INDUSTRY)	RELATIONSHIP TO SAF
E1	Commercial Manager (Energy Industry)	Responsible for negotiating commercial contracts with airlines (conventional jet fuel and SAF)
E2	Senior Analyst (Energy Market Intelligence Company)	Experienced researcher/ analyst in the energy industry for topics such as SAF
E3	Director Energy and Climate Policy (Energy Industry Association)	Involved with the government in all regulations affecting the fuel industry
E4	Head of Biofuels Technology Department (Energy Industry)	Responsible for techno-economic analyses for biofuels including SAF
E5	Business Development Manager Biofuels (Energy Industry)	Responsible for evaluations of market demand of SAF and other biofuels and strategizing supply needs and potential business deals
E6	Head of Climate and Environmental Protection (Aviation Industry Association)	SAF key part of the expert's work given its importance for decarbonization of aviation

Table 4: Interviewed industry experts

Table 5 displays the interview guide prepared prior to the conversations containing 17 questions. These questions encompassed a variety of formats, including open-ended and closed-ended questions, questions necessitating participants to rank items and alternative questions. It was designed to deepen the understanding of existing barriers and opportunities in the scale-up of SAF in the EU. Some questions such as Q6 or Q17 were intentionally held broad to allow the experts to elaborate on their general views. The residual questions were based on pre-identified factors relevant to a successful ramp-up and adoption of SAF. These answers should confirm and complement the findings of the literature review.

QUESTION ID	QUESTION	TYPE OF QUESTION
Q1	Can you briefly elaborate on your current role and how this is related to the topic of Sustainable Aviation Fuels?	Open
Q2	Do you believe the EU SAF targets and subtargets for power to liquid fuels are going to be met? Please answer with yes or no.	Closed
Q3	Can you please explain why you believe the targets will or will not be met?	Open
Q4	What is more relevant for the scale-up, biogenic SAF or Power to liquid based SAF? Please answer with one of the two.	Alternative
Q5	Please explain why you answered this way.	Open
Q6	In your opinion, what are the primary barriers or challenges in scaling up the production and use of SAF in the EU?	Open
Q7	Can you rank these barriers in terms of their significance or impact on the SAF adoption in Europe? (1 = most significant, 5 = least significant) a. Feedstock availability and sourcing b. Production costs c. Regulatory hurdles d. Infrastructure limitations e. Airline commitents	Ranking
Q8	Do you believe there is enough SAF feedstock available in the EU to reach the EU SAF Targts?	Open
Q9	What is mainly driving the current increase in SAF production?	Open
Q10	What roles do airlines play in supporting the scale-up of SAF?	Open
Q11	What SAF production pathways do you consider most relevant and why?	Open
Q12	What advancements or innovations in the SAF production methods do you consider most important for overcoming existing challenges?	Open
Q13	Do you believe the SAF price will ever be able to reach the price levels of conventional jet fuel? Please explain why yes, no.	Open
Q14	Can you comment on the feasibility of integrating SAF into existing infrastructure and distribution networks?	Open

Q15	Do you believe the introduction of SAF mandates and subsidies in other regions such as the US, UK or Japan is supporting or hindering the SAF scale-up in the EU? Please elaborate!	Open
Q16	Are there specific policy changes or incentives that you think could accelerate the SAF adoption?	Open
Q17	Finally, in your expert opinion, what are the key opportunities and strategies that will drive the successful scale-up of SAF?	Open

Table 5: Semi-structured interview guide

3.3 Data analysis

Text data such as interview transcripts can be structured via a codebook allowing subsequent interpretation. Given the concrete research question of this thesis, a structured and closed approach through a priori codebook will be utilized. This method relies on a basic set of codes generated by the conceptual insights of the researcher before reading through the transcripts. Subsequently, this codebook can be modified and utilized as a data management tool containing relevant similar text sections of the transcripts. These sections shall facilitate the interpretation process and confirm or disprove evidence. As a result of the holistic context of the research question, the codebook is based on broad categories derived from the literature review (Crabtree & Miller, 1992, pp. 93–99).

Table 6 represents a simplified version of the codebook to demonstrate the method. The sample text excerpts were identified in the transcripts and assigned to the respective codes. The complete codebook can be found in the appendix.

CATEGORY	DEFINITION (CODE)	TEXT EXCERPT (EXPERT)
BARRIERS	All challenges related to the availability and prices of relevant feedstocks (B-FS)	„the biogenic, there is a certain limit of feedstock we have, there is competition with other sectors, which means that there will be a certain plateau that we did not reach yet. But once that has reached the only scaling is possible with PtL.“ (E3)
	All challenges related to the SAF production cost and availability (B-P)	“At the moment, the most SAF comes from Co-Pro which has a very uncertain and unreliable production scheme because it is very much reliant on what happens in the refinery and if anything happens there, Co-Pro is shut down” (E5)
	All challenges related to the SAF supply chain and infrastructure (B-SC)	“But currently there needs to be, for instance, aromatics in the jet fuel because of at least in older airplanes, various seals require aromatics in the fuel not to dry up. Some talk about legacy fleets or the older planes that still require this and Fischer-Tropsch or HEFA SAF does not contain any aromatics at all. So that is why you need still to blend it 50:50 or more” (E4)

	All challenges related to legislation and SAF mandates (B-L)	„PtL: incredibly long delay in terms of the legal framework, almost two years delay in the delegated acts for green hydrogen, i.e. for the electricity purchase criteria for green hydrogen.“ (E6)
	All challenges related to subsidies and the investment environment (B-IS)	„So I think that in Europe you always say, well, we can invest a half a billion or a billion, but in the end, is that regulation going to be there? This market force is going to be impacting you and you will not be getting a fixed rate, so it gives you less certainty as an investor.“ (E1)
	All challenges related to airlines (B-A)	„they are mostly doing it because they want to greenwash some of their emissions rather than because they think that is the way to go.“ (E2)
	All challenges related to price competitiveness of SAF (B-PC)	„the price of SAF will drop down to conventional jet fuel levels? No, no chance“ (E4)
OPPORTU-NITIES	All opportunities related to the availability and prices of relevant feedstocks (O-FS)	„You can fill a significant portion of that with solid biomass like forest and agri waste and municipal solid waste. But then you are still going to have to have e-SAF on top of that“ (E4)
	All opportunities related to the SAF production cost and availability (O-P)	“So another opportunity for SAF production to incentivize SAF production is for existing HVO units to really go through the designs that they made in the past and see if they can retrofit the distillation unit to actually move some of its volumes away from HVO, from renewable diesel into SAF production. That would keep them flexibility, but of course I mean in the next few years, not like you are going to see a lot of HVO demand destruction because ideally you would like to still see HVO flowing in the road sector for trucks. So that is an opportunity more medium term” (E2)
	All opportunities related to the SAF supply chain and infrastructure (O-SC)	„I think that it is relatively easy as a drop-in fuel. I think that the maximum blend that you can anyway do is 50%. So the European pipeline, the NATO pipeline, CEPS pipeline will also only accept up to 50 % blended SAF..“ (E1)
	All opportunities related to legislation and SAF mandates (O-L)	„You could argue putting in place trade barriers for SAF from other continents, for example. That would probably increase the production of SAF in Europe if you know that cheaply subsidized SAF in the States would not make its way to Europe in any way which I think that they do on soybean derived biodiesel also ready.“ (E1)
	All opportunities related to subsidies and the investment environment (O-IS)	„So I think that in the end, it is good to see that the USA pushed through with the IRA and that it is bringing the competition further ahead and hopefully the EU can collaborate with the US to build upon that then. China has also been expanding a lot its renewables and its legislation to produce a cleaner economy in terms of climate change.“
	All opportunities related to airlines (O-A)	“I do see a strong commitment from the airlines. Lufthansa, for example, has said that they want to halve their CO_2 emissions by 2030. They will achieve this even without their own efforts, so of course the quotas play a role, they have factored them in, but they also have to do something themselves.” (E6)

	All opportunities related to price competitiveness of SAF (O-PC)	„I would say depends how you measure price. If there is a regulation that puts a cost of CO_2 emissions on regular jet fuel, then sure, why not?“ (E1)

Table 6: Simplified Codebook

4. Analysis and results

4.1 Objective and introduction

The chapter analysis and results aims to provide a clear overview of the findings generated by means of the expert interviews conducted. The EU SAF targets have been clearly outlined within the literature review. These ambitions with the goal of contributing to the decarbonization of the aviation sector bear several hurdles that need to be tackled to ensure the ultimate achievement of objectives. On the contrary, this clear positioning entails a wide range of opportunities that can further support the goal attainment.

By reading this chapter, the audience will gain a better understanding of existing barriers and opportunities for the scale-up of SAF within the EU.

The chapter is structured by the coded categories of findings as identified in the literature review and the interviews. The respective analyzed codes are stated in the section headings. Naturally, identified hurdles or opportunities can cause impacts on other categories and are not always independent from each other.

Four out of six experts believe that the EU SAF targets will not be met, while one admitted at least serious doubts about all goals beyond 2030 and the remaining one conceded a 50 per cent chance of success. This underpins the necessity of further analyzing the determining factors of the scale-up.

Question 7 asked for an initial ranking of the significance of several barriers on their importance for the successful scale-up of SAF.

Barriers related to feedstock costs and availability were ranked on average on place 1.6, while production costs and regulation received 2.2 and 2.4 respectively. Infrastructural hurdles and airline commitments were ranked at positions 4.0 and 4.6 which reveals less significance within these categories.

4.2 Feedstock and other raw materials (B-FS, O-FS)

Feedstock availability and respective prices are crucial for the successful scale-up of SAF which is further emphasized by the interviewee's replies in the significance ranking of barriers. Given the strong difference in the production of biogenic SAF and PtL SAF, the hurdles may be different.

Four out of six experts shared their belief that the EU itself does not exhibit sufficient available feedstock while two more did not provide a clear answer but acknowledged the predominant scarcity of feedstock.

Experts 3,4 and 6 further elaborated on the general limited availability of biogenic feedstocks such as oils and fats which could lead to a plateau of supply that has not yet been reached. Experts 1 and 4 reinforce that PtL fuels are required to overcome this barrier and promote further scaling of SAF given different raw material requirements.

Another hurdle referred to by expert 5 is the existing competition for the same feedstocks with other sectors as required for the road and marine to produce Fatty Acid Methyl Ester (FAME) and Hydrotreated Vegetable Oil (HVO). Expert 3 describes the issue of getting accurate estimates of available biogenic feedstock volumes as they vary in factor ten.

Expert 6 additionally mentions EU plans to expand lists of eligible feedstocks within the RED which would, however, still necessitate an effective and practical interpretation of national governments who tend to have an aversion to many biogenic feedstock types. This is further driven by the involvement of NGOs such as Transport and Environment.

If meanwhile, the range of feedstock was widened, this could increase the potential of biogenic SAF as also noted by expert 5. Interviewee 4 sees an unexplored potential in the usage of solid biomass such as forest and agricultural waste or municipal solid waste but does not neglect the necessity of additional PtL fuels on top of that. According to the expert, these fuels could in fact supply 100 per cent of the current jet fuel demand which would then, however, require all renewable electricity available. This unrealistic scenario emphasizes the huge electricity needed to produce these fuels. Expert 5 believes it will take a long time to have a sufficient local supply of renewable energy to use for these purposes in the EU.

Lastly, expert 2 identified redundant feedstocks potentially coming from the current primary off-taker being the transport sector. With the progressing electrification of this sector, feedstocks may be used for the aviation or maritime sector instead.

4.3 SAF Production and availability (B-P, O-P)

Question 4 aims to differentiate the significance of scaling SAF through biogenic routes versus power-to-liquid (PtL) pathways. The industry experts provided resembling answers, stating the short-term importance of biogenic SAF which is nevertheless hindered by the feedstock limited as discussed in the previous chapter. The interviewees conceded the requirement of PtL to reach a bigger scale and ultimately the EU targets.

Naturally, concerns about biogenic feedstock availability limit the actual production potential of SAF as stated by Experts 3, 4, and 5. This particularly relates to biobased SAFs such as HEFA.

Reaching economic viability is an important factor. Experts 1, 2, 4, and 5 emphasized the cheaper production employing the HEFA technology which admittedly is limited by the capacity cap of feedstocks. E1, E2, and E4 highlight economic challenges for PtL SAF given the high production costs strongly driven by the price of green hydrogen.

Technological and operational challenges in SAF production mainly refer to PtL due to the current lack of scaling of the Fischer-Tropsch process and the entailed low energy efficiency as stated by E2 and E3.

Expert 6 worries that the scale-up of SAF will be slowed down due to the risk of early adoption of a technology that is quickly outdated given technological advancements. This leads to a hesitation to invest in production facilities because of the so-called frontrunner disadvantage.

As SAF plants often can switch to HVO production, E4, and E5 mention the risk of market dynamics. Increasing profitability within HVO could divert resources away from SAF production. Expert 5 elaborates on the importance of co-processing in refineries while also emphasizing a certain unreliability of this method given the dependency on stability in refinery operations. Additionally, this expert remains pessimistic on a large amount of SAF supply coming from the US which amplifies the need for localized strategies.

The experts were also able to identify several opportunities in the scale-up of SAF. E4 with expertise in SAF technologies does not believe that this area contains issues that cannot be overcome. While currently almost all volumes are produced by HEFA in Europe and AtJ in the US, the expert expects that more technologies will become relevant shortly. Pathways succeeding in producing SAF utilizing solid biomass will gain a significant advantage given a larger available feedstock pool compared to HEFA.

Expert 2 mentions the potential of retrofitting existing HVO units to SAF production to support the medium-term demand. E5 additionally suggests taking a more global perspective in general. Improvements in predominant trade barriers or regulatory hurdles could facilitate the scale-up. Especially volumes from the Asia-Pacific region could be leveraged to supply the EU. The PtL SAF production could also be more feasible outside Europe in regions with cheaper power or higher solar energy from which volumes ultimately could be imported. To sum up, the expert emphasizes strong confidence in the market's ability to address supply gaps of SAF for mere profit motives.

4.4 Legislation and mandates (B-L, O-L)

The experts elaborated on various obstacles and opportunities related to legislation directly or indirectly impacting the SAF scale-up as well as on the SAF mandates themselves.

Expert 6 raises the issue of mounting complexity in regulations. From the initial simple promotion of renewable fuels, regulations developed into a complex set of barely comprehensible rules including sub-quotas or considerations such as indirect land use change. This creates uncertainty for companies that invest in particular technologies or feedstocks.

Expert 2 adds the difficulty of member states incorporating EU regulations in national law especially if this involves increased prices making it a politically sensitive issue. The imposition of outlined fines for non-compliance with ReFuelEU adds another layer of complexity which complements the argument of Expert 6.

Expert 3 outlines that the introduction of quotas alone may not be sufficient to stimulate investments and further measures or incentives are required to encourage the necessary capital expenditure.

The technology expert E4 sees hurdles in regulatory differences impacting the success of various technologies. While the US promotes the usage of AtJ and its feedstocks, the EU does not display favorable regulatory conditions for this technology. This difference in underlying feedstock eligibility may determine where it is most profitable to produce SAF as emphasized by E4 and E5. The latter expert further sees the risk of insufficient incentives to produce SAF instead of HVO.

E1 and E5 mention the opportunity to set up trade barriers to encourage EU production and prevent the EU from becoming a dumping ground for cheap and subsidized SAF from other regions such as the US.

Generally, E1, E3, and E4 mention the opportunity derived from a clear long-term regulatory scheme that incentivizes the production, blending, and purchasing of SAF to create a level playing field for European airlines. This helps to establish production facilities and achieve scale in the long term. Expert 2 further highlights the need for regulations to make polluters liable for their emissions which is intended by the EU ETS. The scheduled phase-out of free allowances will facilitate the pricing of carbon emissions which can be extended to other greenhouse gases.

4.5 Investment environment (B-IS, O-IS)

This chapter will provide a holistic overview of hurdles and opportunities mentioned for the scale-up of SAF referring to the investment environment including measures such as subsidies. The main barriers potentially preventing the successful SAF scale-up in the EU are depicted by E1 and E2. The investment incentives in the US with the introduction of the Inflation Reduction Act (IRA) and a significant amount of corresponding subsidies suggest a more attractive environment than the EU. E6 describes the nature of capital investment where investors seek the best conditions worldwide.

E3 further outlines the lack of incentives for first movers in the market that are hampered by high costs and long payback periods that are not covered by European regulations. E6 complements the limitations of the European state aid law which restricts subsidies to a ten-year period which implies strong difficulties in amortizing investments in new technologies within such a time frame. The expert notes a reluctance among investors driven by the instability of the regulatory framework which may lead investments to more reliable markets outside the EU. Nowadays almost no industrial plants are built without certain state subsidies which further restrains investment especially based on Annex 9A raw materials where the outcome is even more uncertain than focusing on established feedstocks such as UCO. Additionally, the investment may be further hindered by missing legal framework as witnessed with the delegated acts for green hydrogen required for PtL plants. This can lead to significant delays in investments.

The industry experts mutually shared a rather pessimistic opinion on the investment environment in the EU.

Nevertheless, the introduction of the IRA was also mentioned in a positive context as this may allow future collaboration between the EU and the US to build upon as described by E2.

Expert 3 additionally brought up the opportunity to de-risk investments by mechanisms such as double auction models to provide long-term sales security. This instrument would allow investors to guarantee sales of its products over a longer time frame.

4.6 Supply chain and infrastructure (B-SC, O-SC)

Given the distribution of SAF is still between small and non-existent, the interviews also intended to shed light on potential supply chain or infrastructural limitations. Referring to the results of the ranking of barriers, it may be conjectured that this hurdle is smaller compared to the previous ones outlined.

A huge opportunity for the scale-up of SAF and its positive impact on the decarbonization of aviation occurs since SAF as a drop-in fuel can leverage existing infrastructure. E1 and E6 emphasize that no significant changes to the existing infrastructure are required which also allows for the usage of the European pipeline system with a blending of up to 50 per cent SAF. E4 further outlines the potential to use 100 per cent SAF once a newer aircraft fleet is available explaining that some older aircraft might require engine modifications to accommodate fuels with different properties than conventional jet fuel.

If SAF is produced outside of conventional refineries, this would however require the building of additional infrastructure or the transportation of volumes via ship or train as stated by E6.

One infrastructural challenge potentially hindering the scale-up of SAF is related to competitive advantage. Established players, controlling infrastructure at airports may try to keep away new SAF market entrants which would block their required access to customers. Nevertheless, this may be limited to smaller airports as elaborated by E5.

The commercial expert E1 raises the impracticality of current European regulations requiring physical tracking of SAF molecules. The European pipeline system as an important jet fuel supply route does not offer the possibility to ensure that a certain molecule of SAF ends up at a specific airport. However, claiming molecules of SAF according to European sustainability law requires verifications that molecules went into a specific airport or plane which is simply not feasible with the established system. The expert further elaborates that the currently used book and claim system which does not require physical delivery of the molecules to specific airports may need to be extended. According to the expert, ultimately it does not matter at which airport a certain molecule is used if there is a reliable certification scheme around it.

4.7 Role of airlines and price competitiveness of SAF (B-A, B-PC, O-A, O-PC)

Previous chapters have comprehensively contrasted views on hurdles and opportunities on SAF feedstock, production, legislation, investment environment as well as the topic of infrastructure. The following section shall focus on the role of airlines in the process of ramping up SAF. Question ten concretely asked experts to assess their role and revealed the common understanding that airlines do have the requirement to comply with the EU targets but have a rather limited role in general. Expert 6 assesses them to be “just a fuel customer”.

None of the experts expects the SAF price to become competitive with the pure jet price which indicates how airlines will be impacted by the SAF mandates.

Expert 1 points out that fuel costs make up about 35 per cent of airline operating costs which shows the ultimate need to raise ticket prices as also assumed by E2.
Consequently, this could lead to a competitive disadvantage for EU airlines if they are mandated to use expensive SAF while other airlines may operate in regions without mandates and are hence not subject to SAF usage and associated costs as highlighted by E3 and E5. An example is made by the latter expert for a potential direct flight from the EU to Shanghai compared to a flight with a stopover in Istanbul. While the former flight would be subject to the SAF mandate, the latter would not be, hence this would have a severe impact on competitiveness for associated airlines.
Expert 1 believes that the cost concerns of SAF will make voluntary adoption rather unlikely as airlines would make themselves less competitive. E4 also believes that a voluntary market alone will not sustain SAF production and emphasizes the need for respective mandates.
E1 and E2 further outline that the current SAF small-scale adoption of airlines may be related to greenwashing purposes as that may help with their appearance of being environmentally friendly.
Looking more into opportunities for the successful scale-up, the experts however acknowledge that airlines indeed have been supportive of implementing SAF regulations.
Beyond that, expert 6 mentions the strong commitment from airlines like Lufthansa to reduce their CO_2 emissions strongly and apply pressure to stakeholders to secure SAF. Such measures indeed indicate that there is some kind of indirect leverage on the airline side although this does not mean they would start producing SAF themselves but support the general conditions. Moreover, the expert illustrates the increased signing of Memorandum of Understandings (MoU) by airlines to secure every amount of SAF there is including the willingness to pay high prices. Expert 2 also elaborates on the necessity of deeper cooperation between the airlines and fuel producers to de-risk SAF projects.
A potential "game changer" is highlighted by expert 5 who sees potential for airlines to find a way to monetize SAF as a greener product although it is more expensive. Expert 6 indicates that such measures have not been particularly successful yet as demonstrated with the option of booking SAF for a small surcharge at Lufthansa flights. The expert refers to a conducted survey where passengers declared not wanting to have much to do with how their emissions are compensated for. They would be uncertain about the potential utilized SAF and the respective sustainability. According to the experts, passengers rather opt for a "carefree package" and would even be willing to accept higher prices for that.

5. General discussion

The subsequent chapter shall combine existing literature with the findings derived from the interviews. The author will interpret the results and contain the author's view on the respective consequences. The chapter is structured into key challenges and key opportunities to comprehensively answer the research question.

5.1 Key challenges

As extensively explained in the literature review, the EU intends to significantly ramp up the production and usage of SAF as a major contribution to proclaimed net zero targets in aviation. Both biogenic SAF and PtL SAF are essential to reach their respective goals.

This ambition raises multiple hurdles such as feedstock availability, production costs, and technologies as well as legislative and investment concerns.

The literature review and the interview findings identified the apparent issue in sufficient regional and global volumes of relevant feedstocks to produce biogenic SAF. Although there is no certainty in the exact number of available volumes and new technologies or regulations might even widen the eligible feedstock pool, this hurdle may be further amplified by global competition. Growing SAF ambitions in other regions such as the US or Asia may lead to rising prices for popular feedstocks such as UCO which will ultimately entail increasing SAF prices. This would make the product even less affordable than it is today and result in higher costs for airlines and eventually passengers. Currently, this outcome is very likely given the interviewees do not expect price parity between SAF and jet fuel and the fact that margins in the aviation industry are rather thin hence not allowing a sole bearing of cost increases on the airline side. The interviewees also further pointed out the implied feedstock competition with other sectors such as road transport. To sum up, solving this hurdle can be considered critical as shortages would directly impact the scale-up and hence may jeopardize the EU SAF targets. The EU might need to come up with an additional feedstock strategy.

The industry experts confirmed the literature review in terms of current SAF production. The currently produced volumes are marginal compared to jet fuel which demonstrates the need to significantly increase production. Both literature and expert views confirmed the dependency on feedstock and associated prices to produce biogenic SAF. Expert 1 elaborated on existing limitations to significantly bring down the production costs given the importance of the feedstock component for this type of SAF.

Similar raised issues within the PtL production were reinforced by the experts. This pathway displays lower economic feasibility compared to biogenic SAF as elaborated by the economic analysis in the literature review and several remarks by the experts. There are no commercial plants with relevant scale, which may be justified by high costs of green hydrogen but also uncertainties created through the late provision of proper regulations. These findings revealed the apparent challenge of reaching the EU targets in the short as well as long-term as technological and economic hurdles need to be solved.

However, all experts emphasized the relevance of PtL in the long run which is also in line with the laid-out EU SAF targets.

The literature review outlined the complex EU-wide and global regulatory schemes potentially hampering the scale-up. This was further deepened using the expert interviews revealing the need for long-term clarity in regulations to reduce uncertainty for investments. A potential step back from targets might discourage investors. Beyond that, the interviews conveyed more transparency by elucidating the first-mover disadvantage arising through the risk of quick technological advancements making the first-built SAF plants less competitive. These insights are highly valuable for the EU which could consider encouraging early investments by financial measures such as tax incentives or subsidies.

The introduction of such measures through the IRA in the US might be a threat to the scale-up plans of the EU as capital investments will be directed towards the most attractive environment. Considering the market of jet fuel is global, the EU needs to be conscious of rising dependencies on global feedstock or SAF supply. This could put local suppliers at a disadvantage if potentially not sustainable feedstocks or highly subsidized SAF would make their way in the EU.

The thesis elaborated on the potential risk of lacking logistics infrastructure which was softened by the initial theoretical discussion and further explanations from the experts. However, two additional angles were identified. On the one hand, there is the possibility that conventional fuel suppliers exploit strong market positions and try to restrict airport access for disruptors. The EU needs to prevent such actions to ensure an uncomplex adoption of SAF at airports. On the other hand, the EU legislation aims for physical delivery of a certain SAF percentage at every airport which is, in fact, very challenging given the predominant dependency on pipelines which cannot guarantee the supply of particular green molecules. According to several experts, this necessitates a revision of the legislation. Knowing the primary goal of the EU to encourage SAF usage and respective cutbacks of aviation emissions, the institution should consider removing this hurdle to facilitate the overall SAF utilization without over-regulation. In the end, it would not make a difference for the climate whether SAF is used at airport X or airport Y if there is a reliable scheme tracking the usage and preventing double counting.

As identified in the literature review the airlines only have a limited influence on the successful scale-up of SAF. If there is no sufficient SAF supply in the EU and global markets, airlines are not able to purchase the required volumes to comply with the targets. However, this non-compliance would lead to significant fines not only for fuel suppliers but also for airlines which would financially suffer and be disadvantaged compared to competitors not operating in the EU.

5.2 Key opportunities

Although the successful scale-up of SAF production from less than one per cent to 70 per cent of jet fuel in less than thirty years seems like a nearly impossible undertaking, the literature review, as well as the interviews, revealed several promising factors.

Knowing that the current SAF volumes are almost not noteworthy, it can be derived that the sole existence of a restricted EU ETS scheme was not sufficient to bring up SAF supply and demand to bring down emissions. Considering this and the newly laid-out SAF mandates as well as the adaptation of the EU ETS, the framework condition has changed quite distinctly. It may be argued that the EU has now provided a clearer policy framework that may help support the scale-up.

On top of that, it must be recognized that the aviation industry has recognized the urge for more climate-friendly solutions. This can be inferred from the net zero commitment of the IATA as well as individual aspirations of major airlines such as Lufthansa which may lead to the interpretation that this stakeholder is willing to support the scale-up.

It must be stated that the identified compatibility of SAF with most existing infrastructure such as logistics and tank capacities is a huge advantage. Alternative propulsion technologies such as electric or hydrogen-based airplanes are far from being commercial given a lack of technology, economic viability, and available infrastructure. A commercial breakthrough of these technologies is still years away which may help direct the core focus in decarbonizing aviation towards SAF.

Although the current maximum blending is capped at 50 per cent SAF, it is expected that the future will allow even 100 per cent SAF usage because the technical hurdles are minor as emphasized by certain experts. This improvement combined with newer and more efficient fleets is set to have a large impact on aviation emissions.

The literature review introduced various certified production pathways that show different opportunities depending on the respective regulatory frames. Especially HEFA SAF seems to be a technology with huge potential within the EU as further confirmed through the interviews. Several experts additionally outlined the potential of new and less examined feedstock types such as solid biomass that could expand the scope of SAF production and address possible limitations in feedstock sources.

While the increase of SAF imports naturally entails dependencies as explained in the previous chapter, it can also be leveraged to reach the EU targets, especially for PtL fuels. Given the huge requirement of renewable electricity to produce green hydrogen as a basis for these fuels, other regions simply display location advantages through the vast supply of wind or solar power. Consequently, the EU might need to further clarify its ambitions and a respective scale-up strategy which could involve global cooperation.

Such a strategy could also involve the management of feedstock allocation between different sectors. The faster the road transport sector electrifies, the more feedstock volumes will become available for aviation which may help accelerate the scale-up. This shows that such hurdles often occur on a cross-sectoral level and need respective solution approaches.

The identified limited influence of the airlines on a successful scale-up of SAF may also involve opportunities. Naturally, both fuel suppliers and airlines will want to avoid fines for non-compliance with EU SAF targets. This may enable new ways of cooperation to de-risk investments. Airlines could commit to long-term SAF offtakes as it already happens with some first MoUs being signed. Additionally, they could consider jointly investing in production facilities with SAF suppliers to secure volumes and avoid paying too high SAF premiums on the market.

The conversations with the experts yielded the potential to monetize SAF as a greener product. If customers are willing to pay higher ticket prices for flying more sustainably, airlines in fact could try to profit from the mandated usage of SAF. This however would require a shift in customer preferences.

6. Conclusion

6.1 General conclusion

The thesis aims to comprehensively analyze the challenges and opportunities in scaling up sustainable aviation fuels within the EU. After completing a detailed literature review, the author conducted several interviews with competent industry experts who were able to provide their perspectives on the scale-up. The conducted interviews stand out through a variety of expert profiles which enables valuable insights from different angles. The interview findings have further emphasized the complex nature of predominant hurdles and opportunities for SAF in the EU as outlined through the analysis of economic, technological, and regulatory elements. The introduction highlighted the importance and potential of SAF to achieve the net zero targets of the aviation industry before the determining scale-up factors were presented to the reader.

One of the primary challenges in the scale-up is referring to the limited feedstock availability and costs, especially for biogenic SAF. This hurdle is further amplified by sector competition and uncertainty in the eligibility and technological readiness of various feedstock types. The research particularly highlighted the limited availability of oils and fats and dependencies on respective imports which may pose an additional risk to the security of supply.

Another major challenge is the economic feasibility of PtL fuels which are not produced on a commercial scale yet. However, these fuels display a high importance in meeting the long-term EU SAF targets as further proven within the interviews. As a result of increased production costs for these sustainable jet fuels, growing costs for airlines operating in the EU are expected and will very likely lead to rising ticket prices.

The thesis pointed out the complexity of the European and global regulatory environment that impacts the SAF adoption such as the EU ETS scheme, CORSIA, RED, or the ReFuelEU Aviation initiative. One important finding refers to the necessity for clear and long-term regulatory frameworks that reduce the hurdles of investments and new SAF technologies. Extensive subsidy schemes and more attractive investment environments in other regions such as the US may pull capital investments out of the EU. This would ultimately lead to another dependency on imports and reduced energy security within the EU. If the EU does not impose trade barriers for these SAF volumes, local production could be driven out of the market for economic reasons.

The compatibility with existing infrastructure such as pipelines offers a huge potential for the fast adoption of SAF which however also entails challenges. The medium-term requirement to physically supply SAF volumes to every European airport is not feasible and will lead to further complexities in complying with the mandates.

The thesis additionally identified the potential of overcoming the scarcity of feedstocks by emerging technologies focused on solid biomass as well as potential legislative easements. Beyond that, SAF offers the potential of global trade which means that regions with better location factors may be leveraged as proposed for PtL fuels.

The thesis contributes to the field of SAF by providing a holistic view of currently existing hurdles and opportunities for the scale-up in the EU. The insights are intended to guide industry stakeholders and decision-makers by not focusing on one determining factor but instead taking a broader perspective to address challenges and harness opportunities. These elements may be crucial to achieving the broader goal of sustainable aviation.

Nevertheless, it must be noted that it is not possible to determine a reliable assessment of the success probability for the scale-up. The literature review as well as the expert interviews underpinned rapidly changing framework conditions such as legislation or technology that will highly impact the ramp-up.

The introduction of ReFuelEU Aviation containing concrete SAF mandates, however, can be considered a pivotal change and can be seen as the foundation for arising collaborative efforts.

6.2 Limitations and further research

There are several limitations in the methodology applied which need to be outlined. First, the number of industry experts interviewed is relatively small for reasons of limited availability of experts but also given the extent of this thesis. As SAF is still in its early stages, there are only a few experts who are well-versed in the subject. In addition to that, the experts displayed different backgrounds and occupations. While this diverse expertise conveniently allows to shed light on a variety of angles to SAF, one may also argue that not all experts have similarly sufficient knowledge of all questions mentioned in the interview guide. Experts associated with the aviation industry are underrepresented. However, considering the major concern of mere product availability as identified in the literature review, it is sensible to overweigh experts from the energy industry such as fuel suppliers. Although the two experts from industry associations were able to explain the view of the legislator, it could make sense to add further interviews with policymakers from the EU to increase the understanding of their thinking.

Another limitation is the development of the priori codebook which is based and relying on the understandings of the researcher.

Through the extensive analysis of the research question, the thesis identified additional areas which could benefit from further research. One limitation naturally occurs due to the regional focus on the EU. The thesis showed interconnections in the scale-up with other regions, but this angle would need to be examined further.

There is still a lot of unclarity in the actual availability of feedstock. A comprehensive study on EU and global existing volumes as well as the maximum scale-up potential should be conducted.

This thesis primarily focused on currently existing SAF production pathways and may underrepresent the potential impact of future technologies that are not certified or commercial yet. An analysis of these technologies, their limitations, and potential contributions should be carried out.

Beyond that, the complexity of EU policies and regulations naturally faces the challenge of capturing all the relevant aspects. A reinvestigation of this component could yield better clarity for decision-makers including a concrete quantitative approach implicating financial consequences of non-compliance by considering factors such as SAF prices, fines, or the EU ETS scheme. On top of that, an extensive global and regional supply and demand analysis could be prepared, however, noticing that this will always depend on many fluctuating factors such as feedstock prices, current legislation, or technological advancements.

Both the analysis of economic feasibility and environmental impact assessment for different feedstock types and production technologies are based on various assumptions of researchers and hence display a lack of real observations due to the novelty of this topic. The progressing scale-up will enable more reliable insights on these elements.

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Appendices

Detailed codebook

Category	Code	Code Definition	Expert ID	Text excerpt
Barriers	B-FS	All challenges related to the availability and prices of relevant feedstocks	E1	„lacking feedstock“
			E3	„the biogenic, there is a certain limit of feedstock we have, there is competition with other sectors, which means that there will be a certain plateau that we did not reach yet. But once that has reached the only scaling is possible with PtL.“
			E3	Sees high differences in estimates of available feedstock (factor ten)
			E4	“So, if you look at biofuels, scale-up is fairly limited based on current feedstock like oils and fats… () ...it requires solid biomass feedstocks and then eventually e-fuels. But that is going to be much more expensive”
			E4	Responded with “feedstock availability” as primary challenge in scale-up of SAF
			E4	States there is not enough biological feedstock “For PtL … () … there is enough in theory. If you use all renewable electricity currently available to produce e-SAF, you could probably satisfy even 100% of the jet demand. But of course that is not going to be the case. So the current oil and fat feeds availability is tiny compared to the overall demand going a couple of decades in the future.”
			E5	“when it comes to this particular technology, there is also feedstock and the availability of that. It is in competition with Road and Marine in regards to fame or HVO production”
			E5	“I think power to liquid again is a very good point. The point for Europe is that it is going to take a long time for us to have enough power availability in this region for it to be so abundantly available that we can actually take this step.”
			E6	“In the case of biogenic, I believe that the raw material base is too limited. You have to tackle that. There are also plans to expand the annexes to the Renewable Energies Directive. Even if they are extended, it will depend on how pragmatically they are interpreted. Basically, many governments have a latent to obvious aversion to biogenic raw materials. This is also repeatedly driven by NGOs such as Transport and Environment.”
	B-P	All challenges related to the SAF production technology, cost and availability	E1	think bio SAF going to be the cheaper version, but to meet any type of bigger targets, I think power to liquid SAF will be required.“
			E2	„e-SAF in this case there is just not enough capacity in the pipeline with credible projects and there is just not enough clean hydrogen“
			E2	… „by 2030, actually 2031 because the target for 2030 is actually an average of 2030 through the end of 2031, say 6%. I believe that HEFA SAF will do the heavy lifting and that will probably be met 6%. But I am less hopeful that the 1.2 for renewable fuels of non biological origin, so e-SAF will be met.“
			E2	„the production cost definitely for HEFA SAF is not an issue. The issue is actually the feedstock cost there. But it is definitely an issue for the e-SAF derivatives and hydrogen

				derivatives that we all want to believe that clean hydrogen will cost less than €2 per kilogram or so in the coming years.“
			E2	I believe that Fischer-Tropsch will make sense only in some places where the electricity is extremely cheap and once there is enough knowledge around the operation of electrolyzers and this can actually be a part of the energy system
			E2	„Fischer-Tropsch has been in the market for like 100 years. We know it. It is what it is. The issue is the compounding effects of energy losses which mean higher energy costs of the production of the hydrogen, of finding the source of carbon. Because if it is not a point based carbon capture which again should not be completely encouraged, but there is something to be done there for sure in the next decade and even longer probably. But the director capture is just not an energy efficient method to source the carbon dioxide“
			E3	„HEFA is a matter of feedstock availability. I mean, that's certainly up to the capacities you have. That is very sensible because it is also very cost effective. But then if you want to scale above that, then yes, no chance to get around PtL.“
			E3	„So especially with a Fischer-Tropsch, we see that is actually not yet been successful to scale that on industrial level. So that is key. With methanol, it is more the certification part of it, I believe there the technology is a bit more reliable already.“
			E4	“... the cheaper and more efficient option is biogenic SAF. So until that is exhausted there is not much sense in going to jumping directly to e-SAF”
			E4	„HEFA is the only current one that is actually being done on any significant scale, but we are quite soon reaching the capacity cap on that due to feedstock availability. Then it has to be some solid biomass route.”
			E4	“It is getting the financials right, which means that there needs to be strong enough incentives and then soon would match the production costs. The production costs for all these technologies have been more or less the same for quite some time.”
			E5	„biogenically as well because it is still hard to get the right amount of energy out of solid waste and biogenic feedstock types. However, that could scale-up faster in my view.“
			E5	“The other part of it is not just feedstock availability, it is also demand for fame and HVO. So the majority of plants have this switch, right? They either can decide to produce something else or SAF dependent on how the market is. Because also when you produce SAF you produce less product in relation to how much feedstock you push in than if you produce HVO. So if it is more profitable to keep your production plant at sort of 100% HVO production and buy your SAF from somebody else, they will.”
			E5	“So globally, alcohol-to-Jet is interesting. I think it is going to be a big thing in the US. I think alcohol to Jet in Europe is less relevant. We need more conversion pathways than just HEFA. HEFA is a great pathway, but it is limited in relation to the feedstock availability piece.”
			E5	“So in this sense, they say HEFA will between, I think cost between 2.7 and 1.8 times more than conventional jet fuel. So they do not give absolute numbers, they give how much more it costs in comparison. And HEFA will stay for a long time within the range of very low. So when you talk about competitiveness or the availability to produce a lot, I think

				the two go hand in hand. Scaling up will have something to do with how competitiveness or how competitive it is”
			E5	“I think for us at the moment, the assumption that large volumes of SAF from the US will come to Europe is slightly debunked. As in we do not expect that to happen.”
			E5	“At the moment, the most SAF comes from Co-Pro which has a very uncertain and unreliable production scheme because it is very much reliant on what happens in the refinery and if anything happens there, Co-Pro is shut down”
			E6	“but in this case there is no front-runner advantage, it is generally perceived as a front-runner disadvantage. So if I am the first with my system, it probably will not have the highest efficiency, and it will not be achievable in retrospect. And in ten years' time, when the next system is perhaps already on the market, whether it will not completely displace me because it invests 30 percent less is simply far too uncertain for me”
	B-SC	All challenges related to the SAF supply chain and infrastruc-ture	E1	„The sustainability regulation will need to accept at some point the jet market will not be able to physically ensure that a certain molecule of SAF ends up in the airport. Because then if you put it into the CEPS pipeline, I don't know, it is 10 million tons a year or something that are supplied by that. It is a very important supply route for a lot of airports in Europe. So CEPS cannot ensure that the molecule you put in is the molecule you take out. European Sustainability law says, well, if you want to claim basically the CO2 on that SAF, you basically have to show us that that molecule of SAF went to that airport or went into that plane. And that is not possible in a pipeline or in these CEPS pipeline network.“
			E1	„not really easy to have a separate infrastructure. So basically all what I hear is it is about using existing infrastructure and there cannot be or should not be any differentiation between normal or SAF blends.“
			E2	„there can be some limitations for the blending with tanks because all biofuels have their hurdles in terms of the compatibility with the systems for which right now everything is designed, which is conventional fuels. So wax is created in pipelines and so on can of course become an issue.“
			E3	„but on the short term it (mandates in other regions) can of course depending on how attractive these other measurements are, lead to competition even. When it comes to the limited basically capacities to build production facilities. So starting from electrolyzers or in terms of biofuels just feedstock availability“
			E4	“But currently there needs to be, for instance, aromatics in the jet fuel because of at least in older airplanes, various seals require aromatics in the fuel not to dry up. Some talk about legacy fleets or the older planes that still require this and Fischer-Tropsch or HEFA SAF does not contain any aromatics at all. So that is why you need still to blend it 50 50 or more”
			E5	“I'm sure that some parties will use their competitive advantage. In order to make it difficult for the disruptors in the market to access an airport. How could that specifically smaller ones. Okay. In a historic sense, and my previous role was in Shell. Shell has massive amount of locations and terminals and access to airports that they either have on their own or with a very limited amount of other parties. For Neste

				as a SAF supplier for a long time was very hard to get physically their supply of SAF at the airport because the existing infrastructure and existing players for conventional jets will not make voluntary space for a competitor because that is also their competitive advantage”
	B-L	All challenges related to legislation and SAF mandates	E2	“Then the position and the willingness of member states to transpose into their national laws the regulation as indicated by the EU and they have some liberties there but there is also fines in ReFuelEU that are characterized in the latest regulation. So that is the imposition of the fines and actually delivering the regulation by member states that's I believe the second one it is not an easy task for member states to pass these laws that will increase prices. So it is a politics issue.”
			E3	„basically we see the quota alone is an insufficient instrument to actually get the investments... () .., especially when it comes to the PtL SAF.“
			E4	“I don't think alcohol to jet will have practically any role in Europe because of the regulation, but in the US it will certainly play an important role.“
			E4	Mentions differences in feedstock eligibility between Europe and US
			E5	“So if you want more SAF production for the same amount of feedstock that you push in, there needs to be an incentive higher for SAF than it is for HVO. This is also this coming five year or coming decade conversation that we are having because dependent on the impact of RED III and ETS or RED II and ETS one, the question is really where is it most profitable to be as a supplier and this has a major effect on.”
			E6	„And if you look at how it started and how it is now, it was actually a very simple, we want to have such-and-such a percentage of renewable fuels to a complete jumble of barely comprehensible regulations. How much of one type, how much cultivation of biomass, how much Annex 9b, do we then have sub-quotas again. So this discussion about indirect land use change 2014 2015, if you are a company that has invested heavily in this technology and the first generation, but in the end it is not the plants that are first generation, but the raw material. But the plant is not either, you cannot simply convert it and say we are going to make UCO or something like that“
			E6	„PtL: incredibly long delay in terms of the legal framework, almost two years delay in the delegated acts for green hydrogen, i.e. for the electricity purchase criteria for green hydrogen.“
	B-IS	All challenges related to subsidies and the investment environment	E1	„… through the US. With its Inflation Reduction Act subsidy Scheme. They give any producer 1.50 USD per gallon. You get it as a subsidy, and then you get a couple of other subsidies, basically from the government, where you are relatively sure as a capital owner. So if you want to invest into, say, 500 million or a billion or whatever you want to put into one of these manufacturing sites, you are much more, I think, willing to invest that into the US. Where you say like, well, I know that I will get 1.50USD per gallon on the SAF that I produce.“ „It is a pretty good margin depending on the price that you get. But in general, if you know that you get already 500 or 600 or $700 a ton for your product, that is a pretty good incentive.“
			E1	„So I think that in Europe you always say, well, we can invest a half a billion or a billion, but in the end, is that regulation going to be there? This market force is going to be impacting

				you and you will not be getting a fixed rate, so it gives you less certainty as an investor.“
			E2	„My mind obviously goes to the IRA, which is the largest energy policy ever written down, probably. It is definitely bringing a lot of carrots, a lot more carrots than the EU does for the production of SAF and other, of course, clean energy technologies in the US.“
			E3	When you are on a development curve that is still in the very beginning, the second production facility will be the one that is cheaper than the first. And that means, you are a in disadvantage considering it runs like 15, 20 years before it is written off and that is not covered by current regulation, which means there is not really an incentive to be the first investing in such a big production facility.“
			E3	there needs to be a de-risking of investments so basically make it feasible for private investors to invest in SAF, which is in an unregulated market very difficult because you do not have the perspective on selling the product over a time frame of 10, 15 years. So you need an instrument such as a double auction model with tenders or something where you can make sure an investor has some security about selling products over a long time frame.“
			E4	“SAF and HVO, most biofuels are a global market, but just because there is a SAF mandate in Japan I do not see any reason for the production having to be there locally.” “So what drives where the investments are? Yes, in part it is where the mandates are, but in part it is also where the environment is supporting investments and it relates to feedstock availability and in the future to the availability of renewable electricity, cheap renewable electricity.”
			E6	„I also see that there is a certain reluctance among investors in biogenic fuels in general, because there has been a lot of back and forth in recent years as far as the framework conditions are concerned“
			E6	“So you have already scared off a group of potential investors. I can always point to the largest German biofuel producers, Verbio invests all over the world, but not in Germany, not in Europe. India, in the USA, in Canada. Millions, tens of millions are invested everywhere. But in Germany they say we will not do any more. There are other markets that offer a bit more reliable framework conditions. So if I scare off those who already have a lot of expertise and are in the market, then I have scored an own goal”
			E6	And all the subsidies that are currently available are always limited to ten years by European state aid law. Because that is simply the maximum funding period. But that means that I have to amortize my system in ten years. And, in principle, I also have to have already earned the dismantling and then earned my margin for it to be worthwhile at all. So all this in ten years with such a technology is an impossibility. And that is precisely the reason why we do not have such large investments at the moment.
			E6	“So at the moment it is more of a hindrance, because investors can only spend their money once and they are in a globalized world and capital always goes where the best conditions are, and I have already explained why they are not here.” the Inflation Reduction Act already has a lot of very interesting levers. Yes, so then I can see that both capital and know-how will be withdrawn there, which is logically

				missing here, because I can only invest each euro once, even if it is a dollar
			E6	“But I also see that nowadays you hardly see any industry or there are actually no more industrial plants, start-ups without being subsidized by the state. So here too, I would imagine that especially with Annex 9A raw materials, which are not a sure-fire success like used cooking oil or something like that. In principle, you are the first to do this. For almost all raw materials, so I can also see that there needs to be government support.”
	B-A	All challenges related to airlines	E3	„the ability or willingness to pay is basically non existent and they kind of rely on measurements that make sure that there is competitiveness with non EU airlines in particular.“
			E4	„I do not just believe in a voluntary market being sufficient to sustain proper SAF production. So they have not been opening the floodgates by voluntarily adopting SAF and then also being supportive in the creation of mandates. So I think that is a crucial role.“
			E2	„I think that the main hurdle is actually the cost. It will be more expensive to fly. People do not like things going more expensive”
			E2	„they are mostly doing it because they want to greenwash some of their emissions rather than because they think that is the way to go.“
			E6	„And yes, now I would actually have to say that passengers are also rethinking, but I honestly do not see that on a large scale yet. It is the case for a few people, but overall, the vast majority are not the ones who are now booking Lufthansa SAF, for example, which they can do at any time, it is just a click in the booking process, you do not have to do anything except press this button and pay a few euros on top. But it is not done. And the Greenfaires that have now been mentioned are being better received, but still at a very low level. So I do not think the push will come from the passengers. As our opinion polls show, passengers always say we don't want to bother.Becoming more expensive is okay and it should be included. But we do not want to do anything ourselves and they want to compensate for their flight with SAF. It's already too much for people, then they think oh God, what kind of SAF is that? Is it even sustainable enough? And so on. And then you have to think about it, so to speak, and they do not feel like it and it is just like, I want this all-round carefree package. And in the end I prefer to criticize that it is not sustainable enough.“
	B-PC	All challenges related to price competitive-ness of SAF	E1	„it would triple, quadruple the cost of fuel for this company and for the company which makes up roughly 35% of their cost. So basically, even if you increase it by 20% and you double your fuel cost, you are not competitive anymore. So that's why I think that in the end they will not do it because they would become bankrupt, if they are not able to get it back from their customers. And I do not think anybody will be willing to pay a double airline price for a Lufthansa or for Air France KLM flight knowing that it is green or assuming that it is green or whatever versus flying with Ryanair. Some people will, no doubt, but not big volumes.
			E1	„airlines will not want to pay the high price without making sure that everybody also has to pay that price because otherwise you make yourself very uncompetitive“ → dependancy on mandates

			E2	„if you go back 20 years when there was no ETS and there is essentially no cost of polluting, it is impossible to compete with fossil fuels“
			E3	„ not foreseeable that such a complicated process (SAF) is coming near to where you extract fossil fuel from the ground“
			E4	“if you look at a biomass based SAF, the price of the SAF product needs to be probably higher than is today and if you go to e-SAF, it needs to be significantly higher than it is today.”
			E4	„the price of SAF will drop down to conventional jet fuel levels? No, no chance“
			E5	So if you offer flights to I do not know, Shanghai, and you do that straight from the EU in one go versus going from the EU to, I do not know, Istanbul and then go to China, there is an impact and it can be severe if 70% of your fuel base needs to be SAF, well, by 2050. It has to be, but in Istanbul it does not exactly. It has a massive price impact. So your competitiveness in regards to airlines, in regards to other airlines that have other stopovers, could be massive. Again, we do not know if it plays out like this
Opportuni-ties	O-FS	All opportunities related to the availability and prices of relevant feedstocks	E4	„You can fill a significant portion of that with solid biomass like forest and agri waste and municipal solid waste. But then you are still going to have to have e-SAF on top of that“
			E2	…” And a lot of feedstock will, I believe, become available, particularly because of the speed of electrification of road transport, which is right now where the main demand for biofuels and biofeedstocks lies as transport electrifies … Globally, the increasing shares of battery electric cars and hybrid cars will mean a destruction of biofuel use in cars. And that could drive some feedstocks, some into aviation, though right now mostly hopefully into the maritime sector as well.”
			E5	“You could say, okay, if we widen the amount the types of feedstock that can be used for SAF, sure, you will have a little bit more room to play, but it is limited left, right or center. It cannot solve everything.”
	O-P	All opportunities related to the SAF production technology, cost and availability	E4	“I do not think the issue is technology, to be honest. I think the technology can be solved. It is mostly piece together existing technology.”
			E4	“Anyone who succeeds in making SAF from solid biomass waste will have a huge advantage because you have access to a feedstock pool that is multiples orders of magnitudes bigger than the current SAF feedstock pool for HEFA.” “think that we are kind of on a verge where we start seeing these projects from solid biomass to SAF. Currently everything we are seeing is related to HEFA in Europe and HEFA and alcohol to jet in the US. So alcohol to jet obviously being one biomass route, but I think there will be more profitable biomass routes also possible.”
			E2	“So HEFA SAF is for sure the one right now that will move the needle throughout the remaining years of this decade”
			E2	“So another opportunity for SAF production to incentivize SAF production is for existing HVO units to really go through the designs that they made in the past and see if they can retrofit the distillation unit to actually move some of its volumes away from HVO, from renewable diesel into SAF production. That would keep them flexibility, but of course I mean in the next few years, not like you are going to see a lot of HVO demand destruction because ideally you would like

				to still see HVO flowing in the road sector for trucks. So that is an opportunity more medium term”
			E5	“The SAF supply regulatory hurdles. I think we can add trade barriers to that. Okay, the reason why I am saying that is that there is a high expectance also within this decade that there is going to be a tremendous amount of. SAF supply from APEC, predominantly China and Singapore, to come into the EU markets. I think that is almost more currently in terms of supply than what we can produce here on our own.Then we have a conversation about competitiveness and marginal producers. Where can we produce SAF against the lowest costs in order to compete to what? So this ties into the conversation or the point that I just made. So in the assumption that apex SAF is cheaper on the market and readily available, there is very little incentive for European SAF suppliers to produce anything because it's already there”
			E5	“But I am not too worried about the scale-up of SAF. If there is a gap, if there is a short in the market, there will be supply somewhere, somebody will come up with the supply and the solution space because there is money to be earned. Do not underestimate the power of the market. Like really do not underestimate the power of the market.”
			E5	“So I think power to liquid is an awesome technologically advanced solution to the problem. However, I think from a market perspective it is going to be very hard to get to a point where this works. So this implies that as a European part of the world we might need to go into other parts of the world to come up with very cheap power or very sunny places where there is just a lot of power generation and to make it there and to ship it to Europe.”
	O-SC	All opportunities related to the SAF supply chain and infrastruc- ture	E1	„I think that it is relatively easy as a drop-in fuel. I think that the maximum blend that you can anyway do is 50%. So the European pipeline, the NATO pipeline, CEPS pipeline will also only accept up to 50 % blended SAF..“
			E3	„ not really easy to have a separate infrastructure. So basically all what I hear is it is about using existing infrastructure and there cannot be or should not be any differentiation between normal or SAF blends.“
			E4	().. “because SAF needs to be blended, of course there needs to be some expansion of some kind of blending infrastructure, blending terminals, et cetera, and then clear regulation on how SAF can be transported in pipelines” “eventually we will end up with at least some kinds of SAF not having to be blended, that they can be run 100%”
			E4	Considers 100% SAF feasible with newer fleet: “but I do not think those are impossible to overcome. To tailor the engines, to be able to use a fuel with a slightly different distillation curve than the fossil jet.”
			E5	„Infrastructural limitations are definitely there, I agree with you, but they are relatively easy to solve. So in terms of the percentage of amount of SAF that can go through the pipes is a conversation that needs to happen and a readjustment on the regulation. Access to tankage and blending. Yes, that takes place right now“
			E6	“We are talking about drop-in fuels, nobody is talking about anything else. The infrastructure is exactly the same. And the only thing I need is, if I am not producing in a fossil refinery anyway, i.e. in a conventional refinery, then I will do it somewhere else, then I will transport it by ship or train and then I will have used existing infrastructure.”

	O-L	All opportunities related to legislation and SAF mandates	E1	„You could argue putting in place trade barriers for SAF from other continents, for example. That would probably increase the production of SAF in Europe if you know that cheaply subsidized SAF in the States would not make its way to Europe in any way which I think that they do on soybean derived biodiesel also ready.“
			E1	„So having a very clear regulatory scheme for SAF blending is going to be key. That incentivizes a producer to make a decent margin on producing it, the blender to blend it, and the airline to buy it. So creating a level playing field for airlines also in the end. So, because they are in competition with Emirates or with the North Americans who all buy SAF, I think, on a regular jet quote. So the credit that you as a blender of SAF or producer of SAF in the US get, is an opt in scheme into the transportation sector. So actually it is more the transportation sector paying, I think, for the SAF blended into the airlines. So basically, the European airlines will need a level playing field against the Americans and the Arab airlines, basically. And that you can only do with subsidies and, I don't know, a clear CBAM, carbon border adjustment mechanism or so on incoming flights or something like that. Because otherwise all Europeans will book their flights on American airlines and Emirates. I don't think anybody would then pay triple the price for an Air France or a Lufthansa ticket“
			E2	„because there is not enough regulation in place to make people that are polluting both in terms of climate change, but also in terms of the particulate emissions liable for that pollution. And that is changing just because, and actually not that much because of Refuel EU, which is incentivizing the use of SAF, but rather with the ETS implementation in aviation, which has been going on for a while now. But the phase out of free allowances that is coming in the next few years and in 2026, all of the emissions within the EU will be liable. That should have an impact.“
			E2	„then you have the systems like the ticket system that the Renewable Energy Directive imposes on member states to create in their legislation these biotickets the quota in Germany, the HBEs in Netherlands and so on, that can make the price comparison much more convenient for sustainable aviation fuels. And it will probably do it for HEFA SAF unless the feedstock prices skyrocket.“
			E2	„But I like the legislations that are having the spirit of the legislations, particularly of the EU ETS which is basically putting up price on carbon dioxide emissions and soon enough also on methane and nitrous oxide.“
			E3	it (mandates in other regions) definitely helps to get more production facilities online and to reach scale quicker.“
			E4	“higher mandates and long term mandates are sort of providing security that there will be a market and sort of gives an indication of what the price would be.”
			E4	“.. but also feedstock eligibility. So currently for HEFA, the SAF eligible feedstock is a narrower, it is a smaller pool than what is allowed for HVO, for instance.”
			E5	“I think the realization is that SAF and aviation is not a standalone problem with the standalone solution. It connects to all sorts of other stuff. So policy changes that accelerate SAF adoption might not be in the aviation space, it could be somewhere else. And we have already seen that. I say that

				companies that move their products or transport their products are now looking for the means that emit the lowest CO2 footprint”
			E5	“the EU will put trade barriers up to not to become the dumping ground of cheap US SAF that they make there”
			E5	“So SAF is a percentage of conventional jet fuel. So dependent on how much conventional jet fuel we need, we need a certain amount of SAF which creates an uncertainty. I think that level of uncertainty is unnecessary. So capping it to a certain amount that the market has to absorb or that the airlines or the aviation sector has to absorb could be a factor that incentivizes. So therefore we need X amount of volume. I think when it comes to scaling up SAF technologies on top of HEFA, I think the main credit is how much CO2 reduction can you actually come up with? If that is the goal then it is not about the percentage of volume of SAF that you need but the percentage of CO2 reduction that you are going to create. So moving the market towards a more CO2 focused or reduction focused angle is I think better for the adaptation of some of these other technologies that are sort of the end game for this sector.”
			E5	“There is a very small market right now. I think the additional incentives that, for instance, the Netherlands adopts by using SAF as a tool to create HBE credits allows for more SAF uptake into the market. So that could be a means to incentivize suppliers to build production units.”
	O-IS	All opportunities related to subsidies and investment environment	E2	„So I think that in the end, it is good to see that the USA pushed through with the IRA and that it is bringing the competition further ahead and hopefully the EU can collaborate with the US to build upon that then. China has also been expanding a lot its renewables and its legislation to produce a cleaner economy in terms of climate change.“
	O-A	All opportunities related to airlines	E1	„see value in that basically to portray themselves as green and as being able to offer their customers, again a CO2 friendly flight
			E1	“Airlines already a willing buyer for small volumes”
			E4	„they have been very supportive and that is key in implementing the regulation.“
			E2	“essentially airlines are now obliged to somehow find their way around the lack of sustainable aviation fuels and cooperate with the producers of these fuels to actually deliver them to the market. So it is more of a cooperation thing as it is the case in most new markets that are in which you need the fuel supplier cooperating with, the consumer cooperating with probably also the feedstock provider to essentially de-risk the projects because as we know”
			E5	“One thing what is actually interesting about Airlines in their role is if they find a way to monetize a greener product that is maybe more expensive, but holds sort of all sorts of other benefits that people or companies or cargo trucks are willing to pay for. I think that would be a massive game changer.”
			E6	“I do see a strong commitment from the airlines. Lufthansa, for example, has said that they want to halve their CO2 emissions by 2030. They will achieve this even without their own efforts, so of course the quotas play a role, they have factored them in, but they also have to do something themselves.”
			E6	“They say, for example, that our hub in Leipzig does not have to be there forever. If there is no SAF there permanently, then

				we can also imagine relocating it. And this kind of pressure is already being heard. So in that sense, yes, the airlines do have leverage, even if it does not mean that I am investing and producing SAF myself, but rather that I am pushing the stakeholders to ensure that what happens and both airlines, i.e. Lufthansa and DHL, really do sign every Memorandum of Understandings and try to secure every amount of SAF that exists in the long term. The problem is that there is not that much yet. They also pay very high prices for it.”
	O-PC	All opportunities related to price competitive-ness of SAF	E1	SAF currently entailing very high margins
			E1	„I would say depends how you measure price. If there is a regulation that puts a cost of CO2 emissions on regular jet fuel, then sure, why not?“
			E3	With suffcient carbon price, price competitiveness considered possible
			E3	„you need to leverage financing with the scale. It is impossible to get that from government, so that needs to be some kind of levy towards the consumer. So probably some kind of passenger levy for aviation passengers or some kind of levy on a liter of fuel. And then on the other hand a financing model which basically turns that into 10, 15, 20 year contracts for potential producers.“
			E4	“in that sense“ (with carbon price) “it might drop, but it will not be. So it is the incentives that drives it. So for sure that is going to be the case that it is profitable to produce SAF whether it is because incentives drive down the cost of SAF or there are other incentives incentivizing the production of it“

Interview transcript - expert E2

[00:00:01.690] - Interviewer
Can you briefly elaborate on your current role and how this is related to the topic of SAF?

[00:00:07.890] - Interviewee
So right now I am working as a senior analyst at (company) which is a company based in (Switzerland). (Company) is basically a market intelligence platform in the regulatory environment for mainly biofuels but now also expanded to renewable fuels of non biological origin and the hydrogen derivatives in general recycled carbon fuels for the transport sector. So that is the area of expertise of the company and myself. I have been in various roles in business development and strategy in international energy companies and platforms such as the World Economic Forum working in the energy transition space for the last least seven years.

[00:01:06.050] - Interviewer
Do you believe the EU SAF targets and the sub targets for power to liquid fuels are going to be met? Please answer with yes or no.

[00:01:20.170] - Interviewee
I believe that they will not be met.

[00:01:24.250] - Interviewer
Can you please explain why you believe the targets won't be met?

[00:01:28.190] - Interviewee
Yes. So particularly what entails towards the renewal fuels of non biological origin, so e-SAF in this case there is just not enough capacity in the pipeline with credible projects and there is just not enough clean hydrogen. The way I see it, by 2030, actually 2031 because the target for 2030 is actually an average of 2030 through the end of 2031, say 6%. I believe that HEFA SAF will do the heavy lifting and that will probably be met 6%. But I am less hopeful that the 1.2 for renewable fuels of non biological origin, so e-SAF will be met.

[00:02:29.950] - Interviewer
What is more relevant for the scale-up of SAF? Biogenic SAF or power to liquid based SAF?

[00:02:37.570] - Interviewee
Absolutely biogenic SAF, just because of the quantities available. And the caveat there is that at least regulation in the EU is clearly signaling towards annex nine A feedstocks. So very advanced biofuels from biomass waste streams that do not compete with food and land essentially for their production. I believe that this is of course a major turnaway after the whole palmoil industry fiasco of biofuels in the few years ago. But in the end there is a lot of feedstocks available for biofuels that without of course clearing another Borneo forest can comply with sustainable aviation fuel targets into the future. And a lot of feedstock will, I believe, become available, particularly because of the speed of electrification of road transport, which is right now where the main demand for biofuels and biofeedstocks lies as transport electrifies and we have seen big ice engine cells in 2017. Globally, the increasing shares of battery electric cars and hybrid cars will mean a destruction of biofuel use in cars. And that

could drive some feedstocks, some into aviation, though right now mostly hopefully into the maritime sector as well.

[00:04:39.950] - Interviewer
In your opinion, what are the primary barriers or challenges in scaling up the production and the use of SAF in the EU?

[00:04:59.150] - Interviewee
I think that the main hurdle is actually the cost. It will be more expensive to fly. People do not like things going more expensive. That is quite an easy math. We have seen it and we laughed at it for over a decade now of how cheap it has been. And I am Argentinan. I laughed at how I can take a cheap flight from Barcelona to Amsterdam and pay €10, maybe even less, and the train would cost much more. And that is just because there is not enough regulation in place to make people that are polluting both in terms of climate change, but also in terms of the particulate emissions liable for that pollution. And that is changing just because, and actually not that much because of Refuel EU, which is incentivizing the use of SAF, but rather with the ETS implementation in aviation, which has been going on for a while now. But the phase out of free allowances that is coming in the next few years and in 2026, all of the emissions within the EU will be liable. That should have an impact. And of course, one can only hope that the EU also sees that flights of one or two hours, they do not make any sense when they can be replaced with an efficient train. And the EU has a great infrastructure that just needs to be accelerated into high speed trains. China did it, of course, it is easy to say China did it sometimes because they are amazing at building new infrastructure and they have a lot of less hurdles. But hopefully we can learn a little bit around what they did in terms of increasing the share of high speed train across regions and making this market very well.

[00:07:27.150] - Interviewer
So now I would like to ask you to rank the following barriers in terms of their significance or impact on the SAF adoption in Europe (barriers copied in chat)?

[00:07:52.390] - Interviewee
Can you explain the infrastructure limitations to what are you referring with infrastructure here?

[00:07:57.500] - Interviewer
So I am mainly referring to infrastructure at airports. So blending infrastructure or tank storage units, but also in terms of the feasibility of using existing pipelines, such as the CEPS system.

[00:08:15.310] - Interviewee
So number one is definitely feedstocks, particularly sustainable compliant feedstocks according to EU regulation, as we discussed before, which is very stringent. If other feedstocks were allowed and there is a lot of companies and research institutions trying to develop new technologies to expand on the volume that will be available. They are still early stage. So that is definitely the main hurdle and that is also where I believe most focus is. The production cost definitely for HEFA SAF is not an issue. The issue is actually the feedstock cost there. But it is definitely an issue for the e-SAF derivatives and hydrogen derivatives that we all want to believe that clean hydrogen will cost less than €2 per kilogram or so in the coming years. And that is simply not possible unless somebody is giving away free electrolyzers and there is a bunch of very willing Oompa Loompas working in those electrolyzers and installing all the

Fischer-Tropsch units that will be needed and currently are nowhere to be seen. And the land for that construction is free. So yes, production cost is definitely not one. Regulatory hurdles? Can you clarify regulatory hurdles and what do you mean here?

[00:10:11.620] - Interviewer
I was more referring to what was missing so far in terms of making the SAF adoption possible. So how important is this regulation actually for the SAF adoption? If you say it is all coming from the regulation basically then you would put this on number one for instance.

[00:10:30.010] - Interviewee
No then I would say it is feedstock. Then the position and the willingness of member states to transpose into their national laws the regulation as indicated by the EU and they have some liberties there but there is also fines in ReFuelEU that are characterized in the latest regulation. So that is the imposition of the fines and actually delivering the regulation by member states that's I believe the second one it is not an easy task for member states to pass these laws that will increase prices. So it is a politics issue. I think that the airlines commitments are not relevant. Not too relevant. I mean it is great that they are doing it but to be honest they are mostly doing it because they want to greenwash some of their emissions rather than because they think that is the way to go. So I would say then feedstocks, regulatory hurdles, production cost in the middle if it is for e-SAF it is definitely number one though that is also combined with feedstocks if the hydrogen is a feedstock then the infrastructure limitations there are some but it is honestly not that big of a deal. Airline commitments I would place those in the bottom. I do not see it as too relevant at this stage.

[00:12:29.150] - Interviewer
Do you believe there is enough feedstock available in EU to reach the EU SAF targets?

[00:12:38.450] - Interviewee
I mean right now? Right now absolutely not. Because there is no clean hydrogen so it is impossible.

[00:12:49.350] - Interviewer
What is mainly driving the current increase in the SAF production? I know it is still a really small scale but the total increase was quite significant from 2021 to 2022.

[00:13:08.760] - Interviewee
Again, in the end it is the regulation that imposes fines and actually makes polluters pay. I mean, we have seen it a lot of times when the externality is not visibleized. It is impossible to have a free market that will willingly increase its cost because SAF will always be more costly than conventional fuel. So yes it is about regulation.

[00:13:52.730] - Interviewer
So what roles do airlines play in supporting the scale-up of SAF?

[00:14:05.950] - Interviewer
Aircraft operators, in this case in the EU, are the obligated party by ReFuelEU. Again, because it is the regulatory driven market, the airlines have to cooperate with aviation fuel suppliers who are also liable in the refueling you to meet this target. So essentially airlines are now obliged to somehow find their way around the lack of sustainable aviation fuels and cooperate

with the producers of these fuels to actually deliver them to the market. So it is more of a cooperation thing as it is the case in most new markets that are in which you need the fuel supplier cooperating with, the consumer cooperating with probably also the feedstock provider to essentially de-risk the projects because as we know, it is going to be expensive to produce SAF. It is going to be more expensive than conventional fuels. So the only way to actually de-risk it, is if you have a cooperation between the partners in that value chain. They can all ensure certain profit margin. It is on a level playing field.

[00:15:54.350] - Interviewer
What SAF conversion pathways do you consider most relevant and why? So, thinking about HEFA SAF , Fischer-Tropsch, Alcohol-to-Jet, et cetera.?

[00:16:01.730] - Interviewee
So HEFA SAF is for sure the one right now that will move the needle throughout the remaining years of this decade. I do not know enough of Alcohol-to-Jet to really produce an educated answer on that regard, but just the mere fact that there is so much ethanol production hopefully means that that becomes also a very viable alternative in the future. But it will definitely be more towards the end of this decade and the first few years of the next one. I believe that Fischer-Tropsch will make sense only in some places where the electricity is extremely cheap and once there is enough knowledge around the operation of electrolyzers and this can actually be a part of the energy system. Of course, there is a lot of scenarios in which power to liquids becomes the pervasive mode of fuel in the future. I believe that a much more relevant factor towards decarbonization of aviation fuels in the next 10, 15, even 20 years will be energy efficiency measures such as landing at the right angles, flying at the right speeds and in the right altitudes, reducing the emissions when the plane is in the runway. So airplanes are not designed to move as a car in the runway and they spend a lot of fuel in that space. And I believe that in 10, 15 years when we make up the numbers, we will see that energy efficiency measures, hopefully, if encouraged enough, could at a much lower cost and disturbance to the whole systemic cost, produce probably even more than 30 or 40% of the emissions reductions in the period.

[00:18:52.490] - Interviewer
What advancements or innovations in the SAF production methods do you consider most important for overcoming existing challenges?

[00:19:01.310] - Interviewee
It is definitely around considering that the feedstocks are what are defined right now, so pretty advanced feedstocks. It is about new technologies such as HtL and Alcohol-to-Jet that they become commercialized and that they are scaled up so that they can use biomass that right now is not under consideration because it is not under the scope of HEFA, which is the only method right now moving into SAF, basically. So yes, I believe that those are the two probably best technologies fit for the next few years. I mean, Fischer-Tropsch has been in the market for like 100 years. We know it. It is what it is. The issue is the compounding effects of energy losses which mean higher energy costs of the production of the hydrogen, of finding the source of carbon. Because if it is not a point based carbon capture which again should not be completely encouraged, but there is something to be done there for sure in the next decade and even longer probably. But the director capture is just not an energy efficient method to source the carbon dioxide, the carbon needed for that process to create the e-fuels and the e-SAF in this case.

[00:21:01.890] - Interviewer
Do you believe the SAF price will ever be able to reach the price levels of conventional jet fuel?

[00:21:20.970] - Interviewee
No, they will never do. The only way they will is if you see the associated cost of polluting of the CO2 emissions as part of the conventional fuels price. Maybe at some point with, let us say, I mean right now the EU ETS is at €80 per ton of CO2. Actually not even CO2 equivalent. That translates to about actually, I am not sure for jet fuel, but it should be between 200 and €300 per ton of jet fuel. If that doubles, it starts becoming more appealing. It starts to equalize with the cost of the really cheap biofuels. But those are not the ones that you need for aviation. So it is going to be really difficult. I do not expect that the ETS price, the UA price in the ETS will jump above the 150 threshold in the future. So no, I do not see it possible by itself. Then you have the systems like the ticket system that the Renewable Energy Directive imposes on member states to create in their legislation these biotickets the quota in Germany, the HBEs in Netherlands and so on, that can make the price comparison much more convenient for sustainable aviation fuels. And it will probably do it for HEFA SAF unless the feedstock prices skyrocket.

[00:23:32.050] - Interviewee
But that is the mechanisms that can equalize the price. But if you go back 20 years when there was no ETS and there is essentially no cost of polluting, it is impossible to compete with fossil fuels.

[00:23:55.690] - Interviewer
We have four more questions, and I think this one you slightly covered already. Can you please comment on the possibility of integrating SAF into existing infrastructure and distribution networks?

[00:24:08.430] - Interviewee
So, honestly, I am not familiar with any hurdles. Actually it would be great if I can hear from you from that side because as much as I am aware, of course, there can be some limitations for the blending with tanks because all biofuels have their hurdles in terms of the compatibility with the systems for which right now everything is designed, which is conventional fuels. So wax is created in pipelines and so on can of course become an issue. So that would probably make infrastructure above airline commitments on my list from before. But I am not aware that this is an issue. Very good.

[00:25:14.560] - Interviewer
I actually heard about an indirect hurdle in that direction today in another interview. But I am going to let you know after this interview. Do you believe the introduction of SAF mandates and subsidies in other regions such as the US, UK or Japan is rather supporting or rather hindering the scale-up of SAF in the EU?

[00:25:39.070] - Interviewee
My mind obviously goes to the IRA, which is the largest energy policy ever written down, probably. It is definitely bringing a lot of carrots, a lot more carrots than the EU does for the production of SAF and other, of course, clean energy technologies in the US. A crossroads in which the EU really stands is that we do not have within the continent the best energy clean

energy resource compared to other regions. We have a high cost of labor, usually. We lost essentially the solar market back in the day to China. Right now, the wind industry is performing quite badly and it is aso the region in the world that is implementing the more stringent rules around decarbonization. So it is producing some backlash in EU countries. I think that in the end it is all mostly good competition. It is great that the US has built on IRA. They have to figure out a lot of their stuff too, because then you have some companies that are I will not name them, but they seem just to be milking the subsidies on the US. Trying to milk the subsidies also in the EU to produce a product that is really not compliant with what you would want to have in a decarbonized world. So I think that in the end, it is good to see that the USA pushed through with the IRA and that it is bringing the competition further ahead and hopefully the EU can collaborate with the US to build upon that then. China has also been expanding a lot its renewables and its legislation to produce a cleaner economy in terms of climate change. And of course there is a lot of geopolitical tensions, but those rely more on the way that we see democracies essentially or not in the world than on the strict legislation. So I would say that it is good to see that key regions such as China, US and Europe, which probably encompass like 80 or more percent of greenhouse gas emissions, are raising the bar in their markets and imposing also costs and things like the carbon adjustment mechanism within each other and within the rest of the world. With the rest of the world. What really is an issue is that developing countries is where the emissions are rising the steepest, and the cost of producing, actually delivering new energy projects is highest because they usually have a higher interest rate to a company. So it is more financially difficult to deliver those projects.

[00:30:02.380] - Interviewee
So yes, I do not have a lot of hopes for the COP next week, but hopefully we see some progress on facilitating financial means for decarbonization in the rest of the world, not only in the advanced economies.

[00:30:23.350] - Interviewer
We have two more questions.

[00:30:25.350] - Interviewee
Did I actually answer your question or did I not.

[00:30:30.790] - Interviewer
I think so. Okay, what is your final answer? What I identified was rather supporting from your side.

[00:30:44.530] - Interviewee
Yes, I think that it is supporting for sure. Very good.

[00:30:48.750] - Interviewer
Are there specific policy changes or incentives that you think could accelerate a SAF even more?

[00:31:00.290] - Interviewee
I mean, there definitely are. Which are the right ones? It is difficult to say at this stage. I do think that you made a very clear decision in commitment in the Renewable Energy Directive to incentivize that both biofuels and renewable fuels of non biological origin end up in the

shipping and aviation sector. But then of course member states can decide to change that. It is not clear yet. Can you repeat the question? Sorry, I lost myself.

[00:31:54.280] - Interviewer
The question was, are there specific policy changes or incentives that you think could accelerate the SAF adoption even more? One that would come to my mind right now, which you mentioned already, would be the full implementation of the EU ETS for instance right?

[00:32:10.970] - Interviewee
Absolutely. The ETS is coming for aviation as well. Then there is the Energy Taxation Directive, which is a little bit of a grey area for me at this stage, but that according to how it is written down right now and it would impose a very heavy cost on fossil fuels, maybe even similar to ETS or higher. So yes, all those layers add up. The issue I believe with the EU legislation as it stands right now is that they roll out a lot of different regulations and directives, indications for regulation, but they do not all speak well to each other between the different directives and they are overly complex. So that is great actually for my company that tries to digest this regulation to field producers and shipping companies and so on, but it is just too much, I believe and I hope for in the future a simplification of these right now there's also the creation of this new ETS for both other industries and buildings. I understand why it is separate from the current ETS. You do not want to break what it is already kind of going, but they just stack up legislation on top of each other and it is just too much to deal with.

[00:34:15.890] - Interviewer
So finally, in your expert opinion, what are the key opportunities and strategies that will drive the successful scale-up of SAF? So rather thinking a bit positively here.

[00:34:42.010] - Interviewee
So let me divide for right now, the efforts to develop SAF are being done and it is great, you can see them materializing. Actually, I do not want to go beyond 2030 right now because it is just too early stage to really produce. But I like the legislations that are having the spirit of the legislations, particularly of the EU ETS which is basically putting up price on carbon dioxide emissions and soon enough also on methane and nitrous oxide. I believe that ReFuelEU should actually have been more of a greenhouse gas emission reduction target rather than a SAF increasing target. I think that is an opportunity in terms of for decarbonization but actually not for SAF itself. So another opportunity for SAF production to incentivize SAF production is for existing HVO units to really go through the designs that they made in the past and see if they can retrofit the distillation unit to actually move some of its volumes away from HVO, from renewable diesel into SAF production. That would keep them flexibility, but of course I mean in the next few years, not like you are going to see a lot of HVO demand destruction because ideally you would like to still see HVO flowing in the road sector for trucks. So that is an opportunity more medium term. So, of course, for producers to actually see whether they can shift as the transition evolve, it is not 1 minute stay and the other minute it is night. It is more of a sunset in which you will see a lot of changes within the energy system. And I think that that is an opportunity right off the table to increase SAF production quite dramatically, actually.