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Implementation of Sustainable Aviation Fuel

A PESTEL-analysis

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Table of content

List of Figures

Abstract

Global climate changes are one of the greatest global threats affecting society. All sectors, from the largest ventures to the single individual, must aid in addressing and affecting these changes, resulting in a more sustainable and *green* future for the generations to come. Aviation currently stands for approximately 2.5% of global total anthropogenic CO_2-emissions, which is rapidly climbing towards 24% by 2050, not even mentioning NO_x, CO, other non-CO2 effects etc. The industry thereby also faces immense challenges to reach sustainability goals as set out by organizations, unions, and nations throughout the world.

These considerable developments call for radical progresses in technology, innovation and development in all aspects of the industry. This thesis focuses on perhaps the most substantial means of developing the industry – replacing the means of propulsion. This thesis identifies the major component being transitioning to Sustainable Aviation Fuel (SAF) as a replacement to conventional kerosene Jet-A1.

This study will analyze how SAF can reduce aviation's overall emission footprint. This task will be undertaken using the PESTEL-analysis tool as a framework for uncovering barriers and challenges. Through an extensive literature review together with multiple expert interviews from various experts in the field, several conflicts from actors in the field has been identified and solutions presented under the different subparts of the PESTEL-analysis. Finally, an overview on the interaction between the different subparts will be discussed. This study identifies, among others, the lack of international legislation, vast production cost and supply of feedstock as major barriers needing a solution.

It is evident that international cooperation and further political and economic incentives are necessary to drive an industry as complex and governed as aviation towards fulfilling the sustainability ambitions set out.

Foreword

This thesis has been written as a conclusion to the Master of Aviation Science study at University of Tromsø, Norway. The overall subject of this study has concerned transition in the aviation industry towards a more sustainable one, through the implementation of Sustainable Aviation Fuels in the aviation industry. This was a highly desirable topic for the authors due to its nature rooted in aviation and the subject's purpose of making aviation relevant and sustainable for the future to come.

Without the assistance of multiple individuals as well as organizations and ventures, it would never have been possible to complete the studies concerning all aspects of the PESTEL-analysis. We would in this regard like to express our sincere gratitude to Niels, Klaus, Isabelle, Lars, Vibeke, Peter, Alexander, and the Danish Ministries.
Further, we would like to extend great appreciation and a huge thank you to our supervisor, Bright Appiah Adu-Gyamfi and Associate Professor/study program leader, Karina Mesarosova for assisting and replying to various questions and multiple calls of concern.

Finally, a remark as a token of gratitude and appreciation to the friendship and professional companionship of the authors in between. A companionship that over and over again has stood the toll of exhaustive meetings, difficult decisions and suggestions, hourly writing-sessions and brainstorming, often ending up over a beer or five supplied at Hviid's Vinstue or Palæ Bar. It has been great ride so far, we can't wait to our next project.

He who races with time, never wins / Wo pƐ ntƐm aa, wo nnya ntƐm!

1 Introduction

Commercial Air Transport has become an integral part of global connectivity and increasing global revenue, with more than 86,5 billion passengers having flown since the world's inaugural passenger flight in 1918. Furthermore, aviation contributes to approximately 88 million jobs worldwide (ATAG, 2020).

The future for commercial aviation sees prospects of an estimated annual growth rate to the year 2050 of 3.1% annually – a figure representing more than 10 billion passengers by 2050, which implies travelling more than 22 trillion Passenger Revenue Kilometers through the global skies (Inner City Fund, 2021).

A direct consequence of the above-increased globalisation and global wealth is aviation's contribution to direct emissions, primarily from fuel consumption. Aviation has, in total, generated an estimated 2,5% of global CO_2 emissions related to fuel combustion in 2018 alone. This figure has now been estimated to grow more than three-fold between 2000 and 2050 unless direct measures to counteract this increase in emissions are taken (Dahal et al., 2021).

In recent years, significant efforts from the aviation industry have been implemented in order to fulfil the targets as set out by the Paris Agreement limiting global warming to well below 1,5, but at least 1,5 degrees Celsius as compared to pre-industrialisation levels (Gössling & Humpe, 2023; Nations, 2015). Some of the more notable actions taken recently include the design of new conceptual aircraft designs, improving aerodynamic efficiency and the current propulsion systems and revolutionising existing fuel types. To sustain these actions and many more, the Global Carbon Offsetting and Reducing Scheme for International Aviation (CORSIA) has been established to framework the requirements for CO_2 emissions from the civil aviation sector (Dahal et al., 2021).

One of these actions has been the development and slow but gradual implementation of Sustainable Aviation Fuel (SAF). SAF has several significant advantages compared to various other solutions like hydrogen-powered aircraft, electrical fuel cells/batteries etc., one of which is the potential possibility of directly implementing SAF in airliners of today, hence reducing the time-consuming task of developing, testing and approving an entirely new technology (Gössling & Humpe, 2023). Also, SAF emits net-zero emissions due to its sustainable production (Inner City Fund, 2021, pp. 56, 57).

Current challenges with SAF, however, include the minimal availability of raw materials, combined with unreasonable high production costs, which ranges from 15-500% higher than conventional jet fuel, resulting in less incentive from the airliners to implement and enhance its usage, especially in such a minimum-cost driven industry as aviation (Gössling & Humpe, 2023).

The industry, however, has recognised these issues, and extreme measures are currently being taken to overcome the challenges, thereby making SAF much more available than at present. It is, therefore, the firm belief of the authors of this thesis that SAF will be a significant part – if not the most outstanding contributor – in transitioning the aviation industry from a conventional high-emission industry to a highly sustainable one, thereby aiding in underlining the relevance and necessity of its existence in the future to come.

Several approaches to studying aviation sustainability (and all that is encompassed hereunder) have been identified. The Chi-Squared statistical method was used by Amicarelli, Lagioia, Patruno, Grosu, and Bux (2021) in their study on airlines' commitment to green practices, where they analysed whether the commitment depends on their profile (low cost or not, flag carriers or not, years of service, geographical origin) or not. In an attempt to produce a decision-making tool for an airline to use when buying into SAF, Markatos and Pantelakis (2022) applied the methodology of Life Cycle Analysis (LCA) and Life Cycle Costing (LCC). While some have used the qualitative research design to collect data on a case study regarding sustainability in Dubai Airport (Al Sarrah, Ajmal, & Mertzanis, 2021), others take advantage of the SWOT-analysis method (Strengths, Weaknesses, Opportunities and Threats) when conducting studies on sustainability across sectors.

In this thesis, the authors aim to analyse how using a PESTEL analysis can aid in implementing SAF in the aviation industry. This thesis is based on a belief that once SAF has been made more available to the industry, the greatest challenge for the individual airlines will be the implementation process and how to make that process as smooth, convenient, and effective as possible from production to actual burn.

This thesis aims at aiding airlines in that matter in the years to come, thereby contributing with our minor part in aviation's path towards a fully sustainable industry.

1.1 Background and Justification of the Study

As illustrated above, the aviation industry, and transportation in general, is in dynamic growth, with transportation accounting for about 8,23 Gigatons of CO_2 in 2018, with more than 95% originating from fossil fuels. Generally, aviation accounts for approximately 12% of the total Transport Sector emissions but only constitutes approximately 2,8% of the world's total anthropogenic CO_2 emissions (Kroyan, Wojcieszyk, Kaario, & Larmi, 2022).

With the aviation sector being a vital global organ in connecting people and cargo worldwide, it is evident that a further recognition of the need for sustainable practices must be fostered to mitigate environmental degradation. Through redesigns of engines and aerodynamic properties in aeroplane design, the industry has seen an improvement in the energy efficiency of 40% for engine efficiency and a 15% improvement in aerodynamic efficiency between 1959-2000 (J. Lee & Mo, 2011). While the above improvements in energy efficiency may have positive economic benefits, the primary purpose is emission reduction, not cost. Possible sustainable improvements include Electric Propulsion, Hydrogen Propulsion (requiring new aeroplane designs) and Sustainable Aviation Fuels (SAF). While electric aviation and hydrogen propulsion require a significant redesign of the airframe and new infrastructure development, SAF demonstrates great potential in reducing the aviation sector's impact on the environment without the need for rethinking aeroplane design and colossal infrastructure development since the existing infrastructure for jet fuels fits well into the scope of SAF. However, the major challenge for SAF lies in its production. Where conventional jet fuel uses crude oil as a feedstock for the production of kerosene, SAF can be derived from a variety of feedstocks such as woody biomass, vegetable oils and animal fats, agricultural residues and also a combination of water and captured carbon – all depending on the pathway in use (Bauen et al., 2020). However, the high cost of production and scarcity of raw materials limit SAF's large-scale production. These factors require significant regulatory and political incentives to make SAF comparable to jet fuels in terms of cost. This study, therefore, aims to provide a comprehensive overview of SAF, including the benefits, challenges, and potential for its adoption in the aviation industry, by analysing it against the PESTEL framework.

1.2 Problem Statement

The aviation industry plays a significant role in global carbon emissions, and finding sustainable alternatives to traditional jet fuels is crucial for reducing its environmental impact.

Sustainable Aviation Fuel (SAF) offers a promising solution by providing a lower-carbon alternative to reduce aviation's emissions footprint significantly. However, the widespread adoption of SAF faces inherent challenges related to political, economic, sociocultural, technological, environmental, and legal (PESTEL) factors. Understanding and addressing these factors is essential to drive the successful implementation of SAF in the industry.

While the aviation industry recognises the importance of transitioning to sustainable fuel sources, organisations face diverse internal and external influences that impact their decisions and actions regarding SAF adoption. Political factors, such as government policies and regulations, can either facilitate or hinder the adoption of SAF. Economic considerations, such as the availability, cost, and scalability of SAF, as well as market dynamics, play a pivotal role in the feasibility and attractiveness of its implementation. Sociocultural factors, including public perception, consumer demand for sustainable aviation, and stakeholder expectations, shape organisations' attitudes and actions towards SAF adoption. Furthermore, technological advancements, including research and development efforts, infrastructure requirements, and technical feasibility, determine the viability of SAF as a viable alternative to conventional jet fuels. Environmental factors encompass the ecological impact of SAF production, its life cycle emissions, and the potential environmental benefits derived from its adoption. Legal aspects, such as regulatory frameworks, certifications, and compliance requirements, add complexity and influence organisations' ability to embrace SAF.

To provide valuable insights into the barriers, challenges and benefits associated with the implementation of SAF, this study will comprehensively analyse each of the above factors and their interplay. It is hoped that industry stakeholders, policymakers, and decision-makers will be able to compose effective strategies to promote and act upon the implementation of SAF and thereby foster greener aviation.

1.3 Objectives

The primary objective of this study is to make a scholarly contribution to the current body of knowledge regarding SAF production and implementation in the aviation industry, with a particular emphasis on identifying opportunities for reducing emissions associated with aviation. Utilising PESTEL analysis, this study aims to evaluate the challenges and opportunities associated with SAF's production, distribution, usage, and environmental impact within the aviation sector.

Notably, the study seeks to achieve the following sub-objectives by answering the following questions:

1. To what extent is it possible to scale the production of sustainable aviation fuel (SAF) to balance the price gap between conventional jet fuel and SAF, and how can this be achieved?
2. Which SAF production technology is more feasible, Power to Liquids (PtL) or HEFA production, and why?
3. What political and legal incentives are provided by regulatory bodies and political entities to make SAF production and usage more attractive and enable operators to operate at a low economic margin?
4. How does the environmental performance of SAF throughout its life cycle compare to traditional jet fuels, and what factors contribute to any differences?

1.4 Scope of the Study

Exploring the implementation of Sustainable Aviation Fuel (SAF) is paramount for the aviation industry to endure in a more sustainable future. It is, however, a very complex and broad subject matter, and therefore, the main task underlying this study will include the following:

- Present an in-depth analysis of various factors influencing the aviation industry in implementing SAF.
- Conduct a comprehensive literature review to gather existing knowledge on the implementation of SAF.
- Conduct a case study and interview key industry players on the feasibility and challenges of SAF adoption.
- Investigate the challenges and opportunities influencing the adoption of SAF from a PESTEL (Political et al.) perspective.

The overall objective of this thesis is to present an in-depth analysis of various factors influencing the aviation industry in the implementation of SAF. In more detail, the research objectives are to investigate the challenges and opportunities influencing the adoption of SAF from a PESTEL (Political, Economic, Sociocultural, Technological, Environmental and Legal) perspective. Further, the thesis conducts a comprehensive literature review to gather existing knowledge on the implementation of SAF.

1.5 Layout and Presentation of the Thesis

The following is an overview of the structure and organisation of the thesis, including the main chapters and their content:

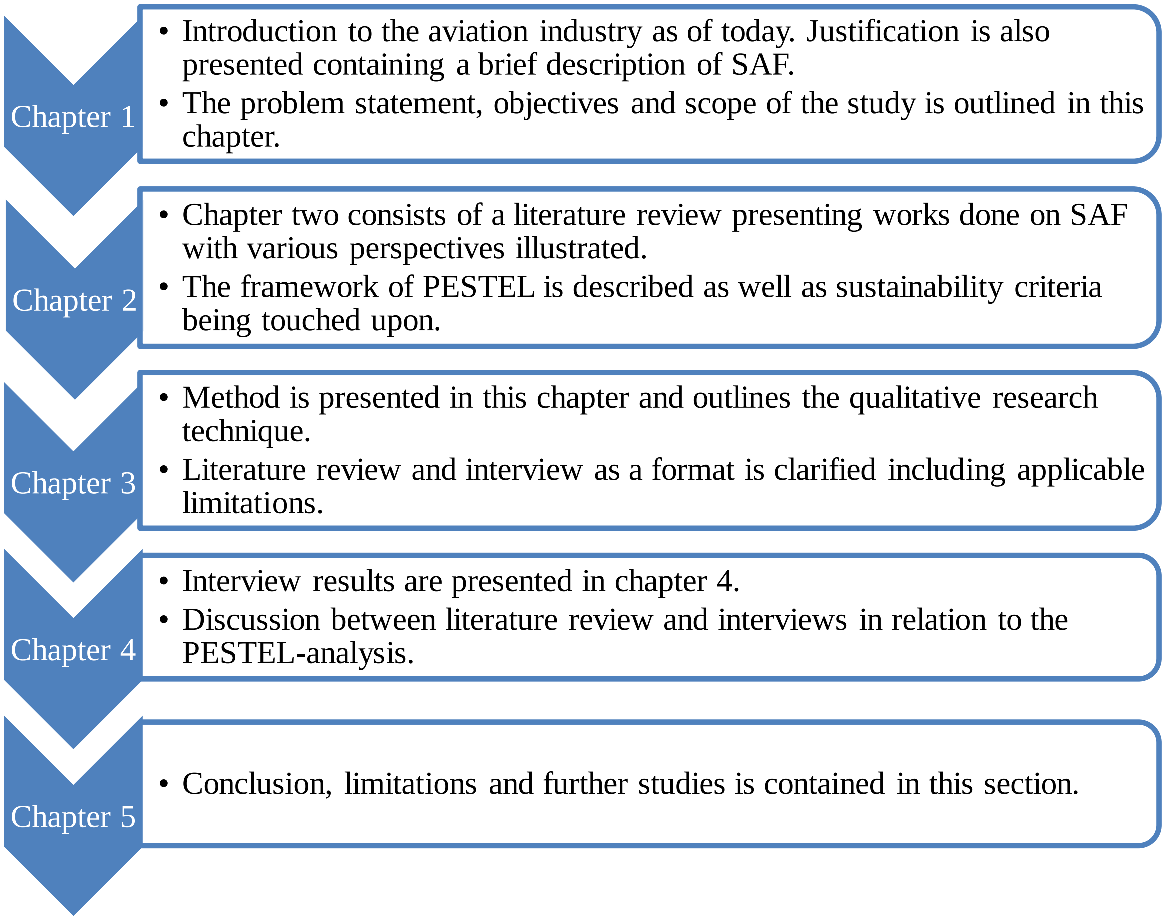

Figure 1: Layout of thesis

2 Literature review

2.1 Introduction to Sustainable Aviation Fuel

If the global society is to comply with the Paris Agreement and close the gap of 1.5 degrees Celsius, a considerable amount of work lies ahead. The aviation industry has already come far – since the early jet age in the 1950s, there has been an 85% improvement in technological efficiency. Since the 1990s, there has been a 55% improvement in operational and technological efficiency (ATAG, 2020). However, there is still a long way to go, and much time, effort and money must be invested in research and development. As mentioned in the introduction, part of this research and development currently being undertaken is the possibilities of hydrogen-powered aircraft, electric aircraft and aircraft powered by fuel cells (Farokhi, 2014).

Challenges with the beforementioned technologies are, among others, the fact that they need entirely new designs with lengthy certification processes (not to mention new infrastructure). These designs will probably be limited to short- and medium-haul sectors, which currently stand for about 27% of the CO_2 emissions, with the remaining 73% from medium- to long-haul sectors (Blanshard, 2021; Farokhi, 2014). This, combined with the slow fleet renewal cycles (commercial planes are typically in service for 25 years or more), is a solid argument for the implementation of drop-in SAF (Wollf & Riefer, 2020). Due to SAF's quality as a drop-in fuel, it is a viable and practical solution today, while electricity, hydrogen etc., have a much longer timespan for operational use. For this reason, the following thesis will be founded on Sustainable Aviation Fuel as the cornerstone of aviation sustainability if the aviation industry is to fulfil its obligations under the Paris Agreement.

The following subchapters will deal with SAF in more detail, among others touching upon the production of SAF, environmental benefits of SAF and barriers/challenges associated with the implementation of SAF. It is worth noting that the authors will not go deeply into detail with biochemical dimensions and properties as this would be well beyond the scope of this thesis.

2.2 Definition and characteristics/properties of SAF

In search of a "drop-in" alternative to conventional jet fuel derived from kerosene and crude oil, scientists started to investigate biofuel or alternative fuel at the beginning of the jet age. This was a concern about supply back then, whereas today's rationale is the environment (Cabrera & de Sousa, 2022). Biofuels and alternative fuels are well-known designations for fuels that do not depend on kerosene and crude oil. While SAF also relies on biological or non-biological feedstock, an extra layer is added compared to biofuel. This extra layer refers to the sustainability aspect, where ICAO (under CORSIA) has identified 19 sustainability criteria that need to be met when dealing with SAF.[1] (ICAO, 2022b). These criteria are established to satisfy the sustainability requirements set up by political entities such as the UN.

Not only the sustainability mentioned above requires a set of tones for the adoption of SAF. So, and possibly to an even greater degree regarding safety and compatibility, does the chemical composition of SAF. For SAF to become an integral part of aviation propulsion, it is paramount to the aviation industry that SAF can fulfil the requirements and possibly add to the value chain as conventional jet fuel is phased out. Holladay, Abdullah, and Heyne (2020) argue that jet fuel has three main requirements: Performance, Operability, and Drop-in.

Performance, in this sense, refers to how the fuel adds value during a flight. Performance properties that the fuel value depends on are specific energy, energy density, emissions, and thermal stability. These can potentially add economic incentives to the end-user – the airlines (Holladay et al., 2020).

The operability perspective ensures that, under testing certification, the fuel in question has a composition that ensures usability under the most severe conditions, such as cold-soaked altitude relight associated with low temperature and low pressure (Holladay et al., 2020).

Lastly, the drop-in refers to substituting conventional jet fuel with SAF without changing the fuel and aircraft infrastructure. With a fully drop-in compatible SAF, one could exchange conventional jet fuel in the storage tanks and fuel lines with SAF and refuel aeroplanes with that same SAF without changing anything between the tank and wake (Holladay et al., 2020). This is a highly desirable trade as the industry will not have to invest in new infrastructure and aeroplane designs and engines.

Regarding the above, it is pretty clear that the industry is searching for a fuel that has comparable properties to conventional jet fuel with a renewable feedstock. Without going into detail about the chemical composition of carbon atoms, it is worth mentioning the amount of

[1] See Appendix 1 for the 19 sustainability criteria under CORSIA.

aromatic content as this is one of the limiting factors for the 50% blending limit, and the literature seems to disagree a fair bit on this matter. Aromatics are a hydrocarbon type naturally found in kerosene-derived jet fuel, and approval specifications demand an aromatic content between 8 and 25%. It is argued that this minimum aromatic content in conventional jet fuel is essential to safe operation, as the aromatics have a sealing effect on O-rings, preventing fuel leaks. On the other hand, too high an aromatic content could lead to erosion on turbine blades and, consequently, engine failure due to the amount of soot produced after ineffective combustion (Doliente et al., 2020; Zhang, Butler, & Yang, 2020). With that said, Holladay et al. (2020) argue that only O-rings and seals previously exposed to aromatics need aromatics to ensure proper swelling. O-rings and seals that have not been exposed to aromatics do not require its content, which is supported by the successful flight of a Boeing 777 with 100% HEFA SAF in one of its engines. From an environmental point of view, reducing the aromatic content is highly sought after as it has been established that aromatic content is the most significant contributor to soot production and particulate matter emissions, which both have a detrimental effect on the environment via bad air quality, forming of contrails and environmental pressure (Holladay et al., 2020). It follows naturally that aromatic content is of utmost importance to consider, especially with respect to the drop-in requirement discussed previously and non-CO_2 emissions.

2.3 Feedstocks and production methods for SAF

As mentioned above, SAF must have the same technical properties as conventional jet fuel, although there is an obvious requirement for SAF to have a lower carbon footprint over its life cycle compared to that conventional jet fuel. There are different pathways to obtaining the requirements set out for SAF, both with respect to feedstocks and production methods.

The literature typically divides feedstocks into 1st, 2nd, 3rd, and 4th generation feedstock. 1st generation feedstock is made from food crops such as palm oil, rapeseed oil, soybean, sugar cane etc. 2nd generation feedstock is made from non-edible raw materials such as grass crops, wood crops, agricultural residues and food/municipal waste (Doliente et al., 2020). Common for both 1st and 2nd generation feedstock is the fact that the feedstock is not considered fully sustainable in the sense that it has the potential to induce pressure on water, food and land resources jeopardising food supply if energy crops become more profitable than food crops (Dodd & Yengin, 2021; Doliente et al., 2020).

3rd and 4th-generation feedstocks are made from microalgae and non-biological feedstocks (CO_2, renewable electricity, and water), respectively, and thereby offer lower environmental and social costs than the 1st and 2nd generation. However, the technology is not ready to support commercial use (as pr. 2021) (Dodd & Yengin, 2021). The microalgae option is of high interest as it has no food value and no land use as such. Microalgae also has a high annual growth rate as well as high carbon fixation capability. It is a feedstock readily convertible with an HEFA-production pathway. Barriers to microalgae will be presented in a later chapter. Non-biological feedstock (water, CO_2, renewable electricity) has the potential to be the most environmentally friendly option of all. It can be utilised via the Power-to-Liquid pathway that uses renewable electricity to produce green hydrogen via the electrolysis of water combined with captured CO_2 (Doliente et al., 2020).

There are quite a few different production methods when it comes to SAF, among others Alcohol-to-Jet (AtJ), Hydroprocessed Fermented Sugars (HFS), Fischer-Tropsch (FT), Hydroprocessed Esters and Fatty Acids (HEFA) and Power-to-Liquid with FT (Bauen, Bitossi, German, Harris, & Leow, 2020). Some of these, including HEFA, FT and PtL FT, have already been certified for production and use under ASTM, each with a different blending limit (Bauen et al., 2020; Chiaramonti, 2019). This section will focus on HEFA and Power-to-Liquid with FT.

The HEFA pathway uses feedstocks such as animal fat, vegetable oils and 3rd generation micro-algal oil. Thereby being a relatively flexible production method as refineries can use different types of feedstocks. In simple terms, the HEFA production method consists of four steps; extraction and refinement, deoxygenation and hydrogenation, cracking and isomerisation, and distillation (Doliente et al., 2020). It is a mature pathway with a Technology Readiness Level of 8 (commercial) that is well-tested and certified under ASTM, and it has already been utilised in commercial aviation with a blending limit of 50%. The HEFA pathway has the highest energy conversion efficiency of all pathways, of 76% (Bauen et al., 2020).

The Power-to-Liquid with FT pathway requires three feedstocks: water, (renewable) electricity and CO_2. Water is used to produce hydrogen via electrolysis. There are different varieties of electrolysers (for example, Solid Oxide Electrolysers and alkaline), each representing a different cost and effectivity. Renewable electricity from solar or wind power may be used for electrolysis to ensure green hydrogen (Bauen et al., 2020). There are different technologies currently being scrutinised with respect to the capturing and utilisation of carbon. Mainly there are two ways this can be done; either by Carbon Capture and Sequestration via Direct Air Capture from the atmosphere or by point-source capturing of carbon, which will have a higher concentration of carbon than Direct Air Capture from the atmosphere (Inner City Fund, 2021). The captured carbon and green hydrogen can then be processed and converted using FT. Power-to-Liquid FT is currently at the demonstration level of the Technology Readiness Scale (TRL 5-6) and is not as mature as the HEFA pathway. However, it has been certified under ASTM as long as the FT synthesis is based on iron or cobalt catalysts with a blending limit of 50% (Bauen et al., 2020).

2.4 Environmental benefits of SAF

The adoption of SAF in aviation presents a vast array of benefits, both economically, socially, and environmentally, and it offers increased potential for energy security (Inner City Fund, 2021). This section will focus on the environmental benefits, which are typically illustrated via a Life Cycle Analysis of SAF compared to that of conventional jet fuel.

Life Cycle Analysis (LCA) is a holistic approach that seeks to explain and account for all direct and indirect emissions from well-to-wake. In other words, an LCA analysis takes into account all steps from extraction (fossil) or harvest (bio), transport, production, refining, distribution, storage and combustion (Wei et al., 2019). One can then argue that an LCA analysis gives a complete picture of the environmental influence caused by aviation, depending on the type of fuel (Farokhi, 2020; Wei et al., 2019).

Life Cycle Analysis can be used to compare different kinds of SAF to conventional jet fuel, and this has been done in several instances. Although there are different approaches when conducting an LCA analysis (consequential and attributional approach), they are both used to measure a fuel's environmental impact over its life cycle and then compared to that of conventional jet fuel. The unit of measurement is grams of carbon equivalent emitted pr. unit of energy. The baseline is defined by ICAO as 89 gCO_2e/MJ (Inner City Fund, 2021).

Figure 2 presents an overview of the carbon reduction potential for selected feedstock pathways for SAF production compared to fossil fuels.

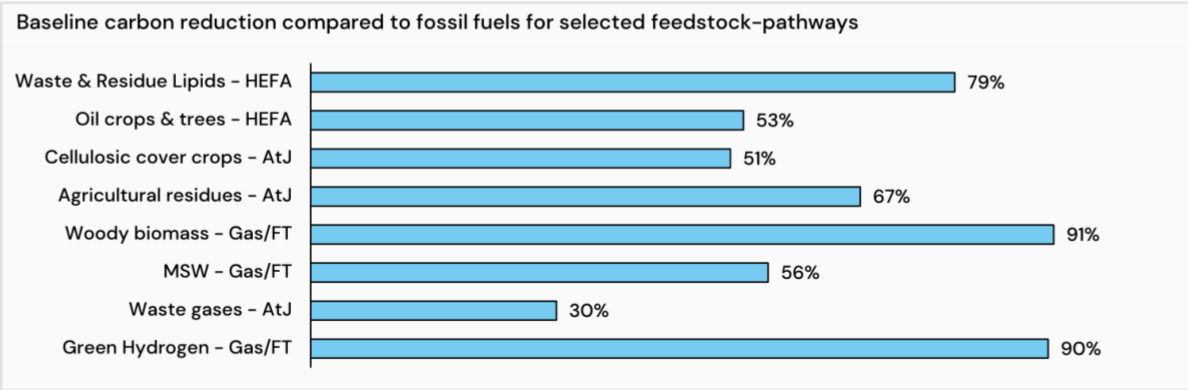

Figure 2: Carbon reduction potential for selected feedstock pathways for SAF production compared to fossil fuels. (ICAO, 2022a; Inner City Fund, 2021, p. 57)

As can be seen from the figure above, the HEFA pathway using oil crops (fx. algae) can potentially reduce carbon emissions by as much as 53%. This number does vary because of different feedstocks being considered – not only algae. The Power-to-Liquid pathway using green hydrogen can potentially decrease carbon emissions by as much as 90%. This has the potential to be further increased with the use of Carbon Capture and Sequestration, which is further supported below.

Another study conducted by Wolff and Riefer (2020, p. 18) is summarised in Figure 3.

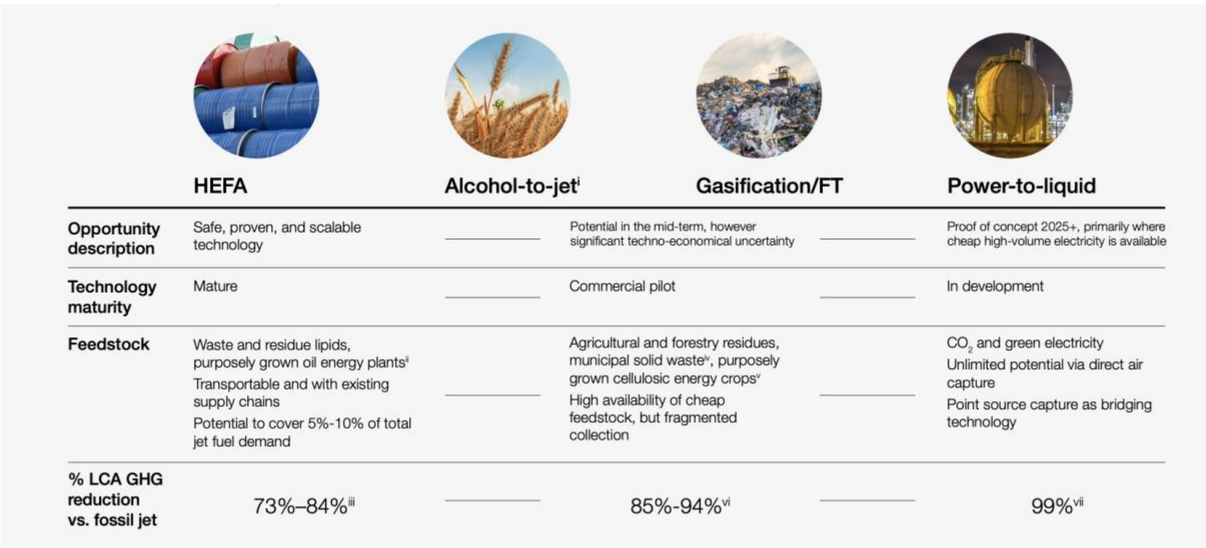

Figure 3: Opportunities and challenges of various SAF production techniques. (Wolff & Riefer, 2020, p. 18)

The 99% reduction in greenhouse gasses for Power-to-Liquid compared to conventional fossil fuel is driven by Direct Air Capture and hydrogen produced only with green electricity (Wolff & Riefer, 2020). The environmental benefits are pretty straightforward when looking at the

Life Cycle Analysis of conventional jet fuel vs both HEFA SAF and Power-to-Liquid, which is why this thesis mainly focuses on these two techniques in relation to the technological pathway of the PESTEL analysis.

It is important to note a premise for these numbers. These SAFs are all considered drop-in fuels, and, for simplicity, they are assumed to have an equal CO_2 emissions factor as conventional jet fuel as they are chemically composed like conventional jet fuel (Blakey, Rye, & Wilson, 2011). With the premise at hand that SAF's are assumed to emit equally as much CO_2 as conventional jet fuel, one can ask oneself where the CO_2 savings come from. Blakey et al. (2011) and Shahriar and Khanal (2022) argue that the emitted CO_2 during combustion will be absorbed by the biomass (or captured in the case of PtL SAF) and thereby creating a net-zero solution reducing the LCA significantly.

Despite the reduction in CO_2 obtained by introducing SAF, there may also be other environmental benefits seen in a potential reduction in non-CO_2 effects. It is estimated that non-CO_2 effects account for more than half of the climate effects and encompass, among others, NOx, SO_2, soot, water vapour and particulate matter (D. Lee et al., 2020) and Avinor (2020) even argues that Aviation Induced Cloudiness (AIC) alone accounts for more than CO_2. Grimme (2022) argue that the chemical composition of SAF can be manipulated to have a small aromatic content and to be free of sulphur particles. This, in turn, can reduce AIC and increase local air quality. Whether the aromatic content can be manipulated as of now will be discussed in a later chapter, as the technology currently in place may not be ready for aromatic-free jet fuel.

2.5 Other benefits of implementing SAF

Aside from the environmental benefits that SAF presents, there are other benefits associated with SAF, such as increased air quality, renewability of energy sources and social factors.

Although there are ongoing discussions about how SAF can contribute to increased air quality around airports when compared to conventional jet fuels, the literature does argue that some SAFs will emit less NOx and SOx particles than conventional jet fuel which, in turn, will increase air quality (Farokhi & Wiley, 2020). To support this, Copenhagen Airport has, together with DLR under the project ALIGHT[2], conducted an experiment with a SAS A320 aircraft flying with 35% SAF 3-4 times a week over a period of 3 weeks to document the benefits that SAF can provide in this relation to air quality around airports (Airport, 2021).

Another benefit of the introduction of SAF is the potential increase in supply stability through the diversification of feedstock sources. This could lead to more stable prices since it is not relying on unstable oil prices and geopolitical instabilities (Yilmaz, 2022). Supply stability will be discussed later, as this point of view may have some adverse effects from a sustainability perspective.

Inner City Fund (2021), in collaboration with Air Transport Action Group (ATAG), argues that the industry will require 5.000-7.000 refineries to sustain the demand for SAF. With that many refineries, they will have to be scattered around the world to be closer to the feedstocks, which in turn will create jobs and increase the energy security and resilience of states all around. In the European Nordic region alone, it is estimated that the production of jet fuel will create between 7 and 11.2 annual full-time employees pr. Million-litre-litre fuel produced (for the production pathways HEFA, FT and AtJ). This equates to between 14.000 and 22.500 additional full-time equivalents in the region, based on a blending level of 37.5% in 2050 of the fuel demand expected in 2050 (Wormslev, 2016). Since the refineries will be scattered around the globe, there is great potential in establishing production plants in rural areas of developing countries. Bole-Rentel, Fischer, Tramberend, and van Velthuizen (2019) identify a potential of 10 to 20 million jobs created in the farming sector of biofuel feedstock in the sub-Saharan region alone. It goes without saying that this would have a significant impact on the economic and social situation of this region.

2.6 Adoption and Use of SAF in the Aviation Industry

There are legal measures and commitments in place in the aviation industry to cut carbon emissions, such as CORSIA (offsetting scheme ensuring net-zero growth), the Paris Agreement and IATA, which has committed to cut emissions with 50% of the 2005 levels by 2050 (Wollf & Riefer, 2020), but how far has the industry come when talking about the actual use of SAF?

[2] ALIGHT is an EU project consisting of various airports, airlines and organisations working on designing and showcasing a future sustainable airport (ALIGHT, 2023).

As of today, both HEFA SAF and Power-to-Liquid FT SAF are certified for use with a maximum of 50% blending (Denmark, 2022; Wollf & Riefer, 2020). Today's engines need certain aromatics, and these are not currently added to Power-to-Liquid FT SAF, at least not at a large scale. However, it would be possible to increase use of Power-to-Liquid FT SAF up to 100% if the industry could add these aromatics to the SAF or by introducing new engines that do not require aromatics for its functioning (Denmark, 2022). SAF was certified in 2011, and by 2020, more than 270.000 flights had taken off with SAF blended to the fuel (ATAG, 2020). This sounds like a large number, however as of today, this only accounts for about 0.05-0.1% of the total consumption and so the need for upscaling of production and certification/legal measures is evident (Bauen et al., 2020; Dodd & Yengin, 2021).

The infrastructure of fuel systems at airports is typically such that the fuel is distributed from storage tanks to the airport via underground fuel lines. The fuel supplier typically has the responsibility for the storage tanks and for the blending of SAF into the storage tanks containing conventional jet fuel. This means that the airport doesn't have a system for conventional fuel and a separate system for SAF (Denmark, 2022). When airports then mandate a certain level of blending, it means that all operating aircraft to those airports will get the same amount of SAF. Oslo Gardermoen is an example of an airport that mandates SAF blending. Currently, they blend 0.5% SAF into conventional jet fuel with consideration to increasing the blending mandate to 30% by 2030 (Wollf & Riefer, 2020).

Further, more tangible examples of the adoption of SAF are included in the next section.

2.7 Case studies of airlines and airports using SAF

There are a lot of facets when looking at the implementation of SAF, some of which will be covered in Chapter 4. The thesis will not go into detail when it comes to energy, airports and their use of SAF, the technicalities of propulsion and such. It will, however, in this subchapter, present where airports and airlines are at the time of writing in relation to the implementation of SAF.

Since SAF was approved for use in commercial aviation in 2009, more than 450.000 flights have been (partially) powered by SAF (IATA), and one of the main stakeholders in the realisation of this number are the airports offering airlines to refuel their aeroplanes with SAF, some even mandate SAF as a blend. Brisbane International Airport, Seattle-Tacoma International Airport and Oslo Airport Gardermoen are all part of an array of airports offering the possibility of refuelling with SAF (Baxter, 2020). Oslo Airport Gardermoen was the first international hub in the world to offer SAF to all airlines refuelling there when the airport integrated the distribution of SAF into their standard fueling facilities in 2016 (Avinor, 2017). From 2020 the Norwegian Government mandated that all flights operating in and out of Norway were to refuel with a blend of 0.5% SAF and conventional Jet Fuel, and further set up a goal that by 2030, that number was to be increased to 30%, equating around 6 million litres of SAF pr. annum (Baxter, 2020).

Since November 2014, when SAS and Norwegian flew on a blend of conventional jet fuel and SAF for the first time out of Oslo Airport Gardermoen (Baxter, 2020), a lot has happened. During Fiscal Year 2021, SAS consumed 1,060 tonnes SAF which corresponds to approximately 0.3% of total fuel consumption (SAS, 2022), whereas during Fiscal Year 2022, SAS used 3,083 tonnes SAF, corresponding to approximately 0.96% of their total fuel consumption (SAS, 2023b). According to the reports, these figures are primarily a result of the Norwegian blending mandate and the Swedish and French reduction mandate. Similarly, Norwegian consumed 1,597 tonnes of SAF during Fiscal Year 2022, corresponding to 0.4% of total jet fuel, and 517 tonnes of SAF in 2021, corresponding to 0.3% of total jet fuel in 2021 (Norwegian, 2023). Again, these figures are a result of the Norwegian blending mandate and the Swedish and French reduction mandate. An essential factor to consider is the fact that the aviation sector struggled greatly during 2021 because of the COVID-19 pandemic, which can have had an effect on the airlines' abilities to attract consumers paying for SAF. Put into perspective, the amount of jet fuel used globally accounts for approximately 0.05% of total jet fuel consumption in 2019 (Eurocontrol, 2021).

As of today, the blending of SAF with conventional jet fuel is limited to 50%, but test flights with 100% SAF (either with both engines running on SAF or one engine with SAF and one engine with conventional jet fuel) have either been planned or executed. Of planned activity, Virgin is planning to fly the first-ever commercial flight from London to New York using one of their Boeing 787 Dreamliners. This is a joint venture between Virgin, Rolls Royce, Boeing and other industry academics, and it is a work in progress aiming to be airborne with 100% SAF during the fall of 2023 (Clarkson, 2022).

Airbus has already completed a series of test flights using different amounts of SAF. As can be seen from a press release dated 29th October 2021, Airbus completed a successful test flight with an Airbus A319neo on the 28th of October 2021. One engine operated on 100%

SAF, whereas the other engine operated on conventional jet fuel. The engines were of the CFM LEAP 1-A series, and the type of SAF used was a HEFA-type based on used cooking oil as well as other fats. The unblended SAF was provided by Total Energies (S. Airbus, Dassault Aviation, Onera, Ministrére Chargé des Transports, Direction Générale de l'Aviation Civile, France Relance, 2021).

On another occasion, Airbus completed a test flight in collaboration with Deutsches Zentrum für Luft- und Raumfahrt (DLR) and Rolls Royce, with one of their double aisle aeroplanes, Airbus A350, powered by Rolls Royce Trent XWB engines. The flight was part of a study called ECLIF3, and early reports show that SAF releases fewer particulates than conventional jet fuel at all tested engine operating conditions, which points to the potential of reducing carbon footprint by introducing SAF. The SAF used was also of the HEFA-type, this time produced by NESTE. Also, positive non-CO_2 effects could be found because the fuel-burning process doesn't release as much particulate matter as conventional jet fuel. So reducing the formation of Aviation Induced Cloudiness (AIC) is a possible positive result of introducing SAF (D. L. R. Airbus, Rolls Royce, 2021).

2.8 Legal measures in implementing SAF

To understand the legal framework encompassing SAF and measures taken (or is intended to be taken), it is imperative to distinguish between complex regulation on the matter and sustainability goals that legal entities wish to accomplish. At first glance, it can be quite a lot to take in with different regulatory entities, but this subchapter will try to narrow down the framework that the airline industry works under. This will be a top-to-bottom approach in that a look will be taken at the technical requirements governing both conventional and alternative jet fuel, then the sustainability policies that ICAO sets out, and finally, zooming down on Europe and the Scandinavian countries.

It is appropriate to look at the regulations governing the technical approvals of aviation fuels. It is, however, not within the scope of this thesis to go into detail with technical specifications or physical and chemical compositions that jet fuel (conventional or alternative) is made up of.

Several organisations and governmental organs are spread around the world to cater for the testing, standardisation, and approval of jet fuel. Among others are ASTM International (formerly the American Society for Testing and Materials) and Def. Stan. (UK Defense

Standardization). To cater for the limitations of this thesis, it is decided to focus on ASTM International, as jet fuels meeting ASTM standards also live up to the standards of Def. Stan (IATA, 2015).

The ASTM specification that governs conventional jet fuel is the ASTM D1655 "Standard Specification for Aviation Turbine Fuel". In aviation terms, fuel certified under ASTM D1655 is commonly known as Jet A or Jet A-1, and it contains a long list of requirements concerning physical and chemical composition as well as density, flashpoint, and aromatic content, to name a few. ASTM D1655 has been modified several times since 1959 when ASTM first issued fuel standards to cover the development the aviation sector has seen with regard to engines and airframes (IATA, 2015). In 2009 ASTM International approved D7566 "Standard Specification or Aviation Turbine Fuel Containing Synthesized Hydrocarbons" – in other words, ASTM International approved a fuel for use by civil aviation that is not derived from kerosene crude. Since then, several pathways have been approved to produce alternative jet fuel. Some of these pathways are the HEFA pathway and the Fischer-Tropsch (FT) pathway. Different pathways and their related feedstock have so far been approved as a blend-in fuel only. The HEFA and FT pathways have been approved with a blend of up to 50% with conventional jet fuel. A simplified blend process is as follows: The pure alternative jet fuel needs first to be approved under ASTM D7566. After showing satisfactory compliance with ASTM D7566, it is blended with conventional jet fuel and then re-tested under ASTM D7566. This blend that is now manufactured and certified under ASTM D7566 also meets the requirement of ASTM D1655 and is now regarded as such – Jet A or Jet A-1 (IATA, 2015).

The reason there is a blending limit may seem obvious to some, in that it must be tested and retested exhaustively to ensure the well-established aviation safety margins. Going a bit more into detail, analysis shows that jet engines need a minimum amount of aromatic content (approximately 8%), which in some alternative jet fuels is not naturally present and therefore needs to be chemically added (a process that is not approved as of now), to ensure that engine fuel seals are functioning properly, thereby limiting the risk of fuel leaks. There is also a maximum amount (approximately 25%) of aromatics, explained by the increased risk of erosion on turbine blades and, consequentially, engine failure (Doliente et al., 2020; Hileman & Stratton, 2014).

An important note when it comes to the ASTM approvals is the fact that the ASTM certification is an approval of the technical properties of jet fuel, their production method, and the feedstock used. This means that sustainability criteria (such as production pathway and feedstock) are not covered within the ASTM approval, meaning that an ASTM D7566 approval does not automatically constitute a sustainable fuel (hence the term "alternative jet fuel" used previously) (IATA, 2015; Martin Porsgaard, 2022). This takes us to the next part: sustainability criteria/policies.

In 2009 the aviation industry committed to work intensely on bringing down its climate impact. Under the leadership of the International Civil Aviation Organization (ICAO), three environmental goals were defined (IATA, 2019):

1. An annual average fuel efficiency improvement of 1.5% from 2009 to 2020. A 2% improvement was averaged in the period 2009-2019.
2. Stabilise net CO2 emissions at 2020 levels with carbon-neutral growth. A global market-based measure is one of the elements that will enable aviation to meet the mid-term goal of carbon-neutral growth from 2020, by complementing technology, sustainable aviation fuels, operational and infrastructure measures.
3. Reduce aviation's net CO2 emissions to half of what they were in 2005 by 2050.

The first goal is relatively short-term, the second goal promises neutral growth from 2020, and the third goal is a long-term goal that the industry can keep track of on the way to 2050. To reach the 2nd and 3rd goal, ICAO introduced Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016. CORSIA is instead a complex system, and therefore, only the main pillars of the scheme will be included in this chapter. CORSIA will be implemented in three phases. The pilot phase and the first phase run from 2021 to 2026, and during these two phases, offsetting requirements will only apply to international flights between two states that have both volunteered to enter the program. The second phase runs from 2027, and from this year, offsetting requirements apply to all international flights (except flights to or from Least Developed Countries, Small Island Developing States and Landlocked Developing Countries, or flights to or from states that represent a small share of international activities) (IATA, 2019).

In short, CORSIA is a carbon offsetting scheme. This means that, in this case, the aviation operators are allowed to emit carbon if they offset their carbon emissions by purchasing "green tickets", which can be from other sectors. In other terms, each operator is required to offset a given percentage of its CO_2 emissions from flights subject to offsetting requirements (IATA, 2019).

The operator will monitor its CO_2 emissions, and these emissions are required to be reported to the appropriate authorities. The amount of reported CO_2 determines the amount of offsetting the operator must do, and the offsetting will take effect when the operator has bought and cancelled an emissions unit. ICAO has identified a list of "Eligible Emissions Units" that the operator can buy in their offsetting agenda. The operator can further claim emission reductions by buying CORSIA Eligible Fuels. CORSIA-eligible fuels include Sustainable Aviation Fuels as well as "lower carbon aviation fuels", which must meet at least a 10% reduction of greenhouse gas emissions based on a life cycle analysis (IATA, 2019). The relationship between the eligible emissions units and the eligible fuels is such that an operator can reduce its required offset by buying eligible fuels – if an operator buys 10% eligible fuel for a sector, then they are only required to offset 90% of the fuel.

The eligible fuels must be approved by an ICAO-approved sustainability certification scheme. As of 2019, CORSIA had approved two Sustainability Certification Schemes, namely the International Sustainability and Carbon Certification (ISCC) and Roundtable on Sustainable Biomaterials (RSB). Both ISCC and RSB have a set of requirements that must be met for a fuel producer to claim that their product is sustainable. Common markers that both ISCC and RSB use to deem a fuel sustainable are, among others, sustainable feedstock availability, direct/indirect land use change (DLUC/ILUC), greenhouse gas emissions, labour/human rights, food security and traceability (IATA, 2019; ISCC; RSB, 2022).

CORSIA has experienced a certain amount of critique as it is not considered the best option to reduce climate impact. Some of the critique includes lack of transparency, lack of participation from crucial markets (China, Russia, India, Brazil) and questionable quality of offsets (among others) (Transport & Environment, 2021).

The EU Emissions Trading Scheme (EU-ETS) is another measure implemented with the purpose of reducing climate impact from several sectors, including aviation. Each airline is given an emissions allowance. If the airline emits less than the allowance, the airline can sell the difference between their allowance and the actual emission, creating a market for emission allowances (Zhang et al., 2020). The effectiveness of this system is widely discussed.

The EU has also published an initiative, “ReFuelEU Aviation", in 2020, with the purpose of promoting a greener aviation future consisting of market-based measures (EU-ETS and CORSIA), improved air traffic management, research on more efficient aircraft design and technology, and increased use of SAF's. The objectives of this initiative are, among others, to impose a blending mandate as well as promote funding mechanisms and technical facilitation and support initiatives (European & Commission, 2020). According to Grimme (2022), this mandate will be applied to airports serving in excess of 1 million passengers or 100.000 tons of cargo, and SAF must therefore be offered at all airports of this size. Instead of the size requirement, the article argues that the mandate should be imposed at airports with proximity to SAF refineries to reduce transport emissions.

The inherent nature of aviation is international, and this fact makes it challenging to determine where the laws and initiatives from international governing authorities are to take effect. Consequently, some national authorities have set up goals and initiatives for the national aviation sector. This includes Denmark, where the Ministry of Transport defined a goal that domestic aviation should be able to be powered by 100% green fuel from 2025 and that from 2030 this is a mandatory requirement (Transportministeriet, 2022). Other national authorities have rolled out plans to accommodate the ICAO 2050 goal, among others, the UK with their Jet Zero plans and the Netherlands.

2.9 Barriers to the adoption of SAF

This section aims to clarify some of the general barriers to the implementation of SAF with focus on HEFA and PtL SAF.

It is evident that the implementation of SAF faces a variety of challenges, but the focus here is related to cost, supply of feedstock, and infrastructure. Each of the barriers will be discussed in the following.

2.9.1 Cost

To be able to assess the economic factor of the implementation of SAF, it is necessary to put into perspective the cost of production of the different types of SAF. Conventional jet fuel has had a price range of 135-1420 USD / tonne for the period of 2001-2021 (Inner City Fund, 2021) and had an average price of approximately 800-900 USD / tonne in 2023.

The cost of HEFA SAF based on oil crops such as algae is expected to be around 1400 USD / tonne SAF in 2025, increasing to approximately 2000 USD / tonne SAF in 2050. There are many variables in the prediction of the cost of SAF, and the expected increase in price of HEFA SAF is explained by an increase in demand. This is, however, strongly dependent on regulatory incentives (Inner City Fund, 2021). Another possible factor in the evolution of the price could be the limited availability of feedstock driving the cost up.

The cost of production of PtL SAF in 2025 is expected to be in excess of 4000 USD / tonne, decreasing over the next 25 years to approximately 1600 USD / tonne in 2050. This trend is expected as a result of decreasing cost of renewable energy, thereby reducing cost for hydrogen production and direct air capture of CO_2/CO (Inner City Fund, 2021). Other factors to affect the cost of PtL SAF in the longer term are the maturity of technology, the cost of renewable electricity, electrolysis, carbon capture, and the FT pathway. These all determine the price of the end product (Bauen et al., 2020; Inner City Fund, 2021).

An important note when presenting price predictions of different types of SAF is the fact that the price will largely depend on the production costs, supply/demand and regulatory incentives. Another layer in the price predictions for SAF is the consideration of other industries demanding their rights to both feedstock and renewable energy in their striving for a greener future.

Considering the price gap between conventional jet fuel and both HEFA and PtL SAF, it is evident that the industry needs economic incentives to overcome this issue. As mentioned previously, CORSIA and EU-ETS have been established as market-based measures where airlines can offset carbon emissions. It is expected that the price of carbon will increase towards 2050, and if this is going to materialise, the relative price of SAF in relation to conventional jet fuel will decrease as a result of fully implemented carbon trade (Inner City Fund, 2021). Another way that governing authorities and regulatory entities can regulate the price gap is by introducing carbon tax on conventional jet fuel, thereby incentivising the production and purchase of SAF (Dahal et al., 2021; Doliente et al., 2020; Scheelhaase, Maertens, & Grimme, 2019).

A common question asked is, then, who is to bear the significantly higher cost of the fuel? The thesis will return to this question in the discussion.

2.9.2 Supply of feedstock

An integral part to consider in the development and implementation of sustainable fuels is, first and foremost, the supply of feedstock, and second, the supply of feedstock by demanding sector and by region. Different sectors are aiming to decarbonise, and guidelines in the distribution and infrastructural system are required to ensure equal distribution between sectors according to demand. The following section will focus on the supply of feedstock for Algae-based HEFA SAF and PtL SAF.

To kick this section off, it is found essential to have a look at the current demand for jet fuel, the expected demand in 2050 and how much of this demand that can be supplied by SAF, according to the availability of feedstock.

According to IATA, the total fuel consumption for system-wide global commercial airlines amounted to approximately 350 Mt in 2019 (Gonzalez-Garay et al., 2022; IATA, 2020), which is equivalent to 1.09 Gt CO_2. These numbers are expected to grow continuously until 2050 to reach approximately 850 Mt jet fuel (Fleming & de Lépinay, 2019). The projected figure considers continuous technology development, improved air traffic management as well as improved infrastructure. This projected fuel demand is, of course, related to a certain degree of uncertainty, resulting in a range from approximately 450 Mt/year to just shy of 1.100 Mt/year.

So how much sustainable aviation fuel can be sustainably produced from the available feedstock for algae-based HEFA SAF and for PtL SAF, respectively?

How much SAF can be produced using algae as a feedstock for HEFA SAF depends on a variety of factors including cultivation method, oil content and scale of production (Prussi, Weindorf, Buffi, López, & Scarlat, 2021). Although there seems to be a lack of actual approximations of the amount of SAF potential, there is in algae-based HEFA; Zhang et al. (2020) gave an estimate of between 1.3 and 11.5 billion gallons (between 3.9 and 34 million tonnes) of SAF. A clear advantage of algae as a feedstock for HEFA SAF is the sustainability aspect in that the cultivation does not infringe on the food market, and at the same time as it has a high growth rate compared to land crops (Prussi et al., 2021).

The supply of feedstock for PtL SAF consists of renewable energy, water and CO_2/CO. The capture of carbon can be obtained via Direct Air Capture or Point Source Capture. Currently, the option of Direct Air Capture is a costly manoeuvre, so the option of Point Source Capture seems more feasible now. With time and maturity, Direct Air Capture technique can replace Point Source Capture since other industries are looking towards more sustainable production, limiting the emissions of carbon. With carbon, water, and renewable electricity as the feedstock for PtL SAF, there is a virtually inexhaustible potential for production of PtL SAF. The primary challenges of PtL SAF are, first and foremost, the cost and, secondly, the availability of renewable electricity as other sectors seek to decarbonise as well. It should be mentioned here that PtL SAF requires less land and water resources than most biological feedstock (Denmark, 2022; Inner City Fund, 2021).

2.9.3 Infrastructural barriers

The infrastructural aspect of implementing SAF presents both opportunities and barriers. It presents opportunities in the sense that it is possible to diversify the production of SAF and thereby construct production facilities close to both feedstock and airports, ultimately offering a potential reduction of transport emissions as part of the LCA analysis (ICAO, 2022a). However, there are also barriers to the infrastructure associated with the drop-in capabilities of SAF. The drop-in capabilities are, at large, a considerable benefit of SAF, as conventional jet fuel can be exchanged with SAF with no changes to fuel and aircraft infrastructure (Holladay et al., 2020). The latter has been catered for in other subchapters as this relates to aromatic content. Other barriers to the infrastructure are found at airports. Most airports use a storage and hydrant fuel system with conventional jet fuel supplied from storage tanks (Moriarty & Kvien, 2021). At airports offering blended fuel, the blending will then take place in the storage tank. If certain airlines, however, order a specific amount of SAF on specific flights, the airport would have to provide this via another infrastructural channel which is not a viable option since this other channel would either be fuel trucks or secondary underground fuel lines, requiring considerable investments. Hence, the airports offering SAF at the moment will offer the same amount of SAF to all aeroplanes wishing to refuel at that airport, and as a solution, Moriarty and Kvien (2021) suggest terminal blending into the pipeline, blending at the airport, blending at the refinery, and greenfield/brownfield site. Different legal barriers are associated with each of these solutions, and it would be beyond the scope of this study to go into detail here.

Figure 4 presents a summary of the barriers and incentives to the adoption of SAF. As can be seen from the figure, governmental incentives are the missing link in the implementation of SAF.

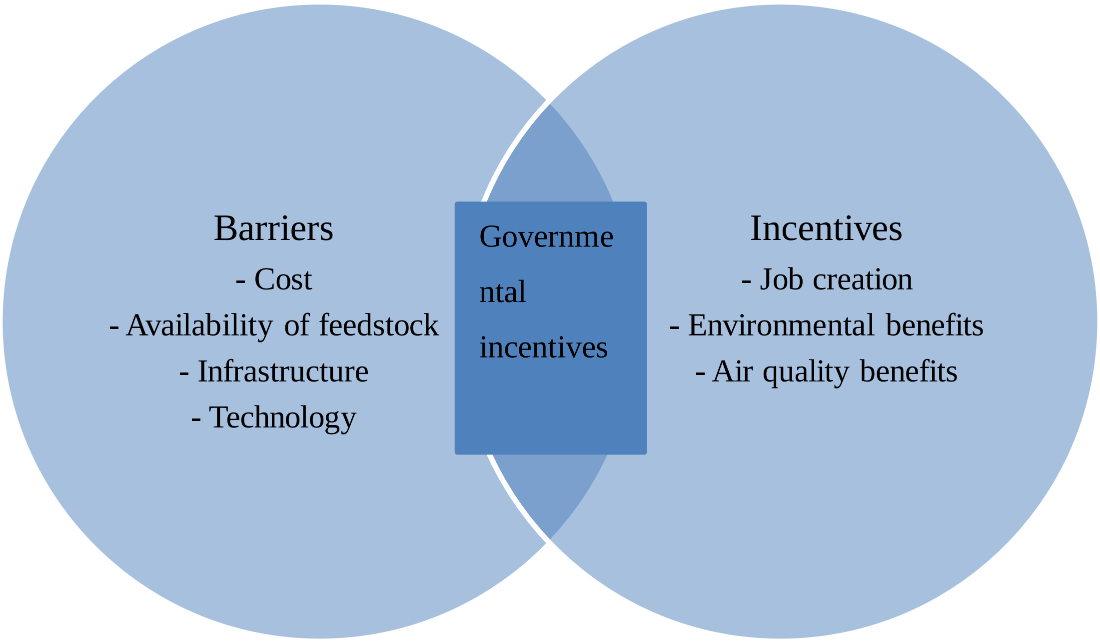

Figure 4: Barriers and incentives of SAF implementation.

2.10 Sustainability

The purpose of this subchapter is to briefly touch upon the sustainability goals laid out by United Nations. The information found in this chapter is all from the UN's official website. The UN Sustainable Development Goals from 2015 were implemented as a global call to ensure the protection of the planet, to end poverty and ensure peace. The focus will be on UN Sustainable Development Goals number 7 (Affordable and Clean Energy), 12 (Responsible Consumption and Production) and 13 (Climate Action). Goal number 7 is divided into 5 goal targets established to ensure that by 2030 energy services will be affordable, reliable, consist of substantially more renewable energy and have an expanded infrastructure reaching out to least developed countries. Goal number 12 (Responsible Consumption and Production) consists of 11 goal targets. They have to do with, among others, the reduction of waste generation through recycling and reuse and management of chemicals and wastes throughout their life cycle to minimise adverse impacts on human health and the environment. By 2030 the sustainable management and efficient use of natural resources should be achieved, as well as a rationalisation of fossil fuel by removing market distortions and, at the same time, minimising the possible adverse effects this could have on developing countries. Goal number 13 (Climate Action) almost speaks for itself in relation to its relevance in this thesis. This goal focuses on strengthening the resilience and adaptive capacity to the changing climate, integrating measures into national policies, strategies and planning and improving institutional capacity on climate change mitigation, adaption and impact reduction (UN).

UN argues on their website that all the different goals are somewhat interrelated, which is also the case for goal number 7, 12 and 13. An example of this is how biofuel is not necessarily a sustainable fuel. This is the case if the energy used for the production of biofuel is not green or if the farmers see a more significant economic incentive in cultivating crops for the fuel market instead of food crops.

2.11 PESTEL Analysis in the Aviation Industry:

2.11.1 Definition and description of the PESTEL framework

The PESTEL analysis in the broad literature is mainly intended to be used in a macro-economic context (Ho, 2014; Whittington, Angwin, Regnér, Johnson, & Scholes, 2021), and as such has, to the knowledge of the authors, not been applied to the implementation of SAF in the aviation industry. This does, from the author's perspective, justify its use in answering the problem statement like the one in hand (Ellis, 2020; Stevenson & Marintseva, 2019).

In the following, a brief description of each subject of the PESTEL analysis will be given.

2.11.1.1 Politics

Politics cover a vast number of various forms of political lobbying and activities involving government interventions. Examples of these are government tax policies affecting social behaviour, environmental laws, and regulations that generally affect the role of the state concerning the given issue (Ho, 2014, p. 6479).

In the case of implementing SAF in the aviation industry, policy frameworks play a crucial role. The development of robust handling criteria and certification schemes is necessary.

2.11.1.2 Economics

Economics includes topics such as interest rates, the effect on income/outcome for a typical organisation, and how an organisation's market is affected by the economic prosperity as a whole (Ho, 2014, pp. 6479-6480). Typically, aviation is a high fixed-cost industry which is fragile to economic fluctuations, and so a challenge lies in the economic viability of airlines to implement SAF.

2.11.1.3 Social

When considering economics in the PESTEL analysis, the social element is capable of influencing the direct nature of demand by assessing demographics, consumer trends, living standards etc. (Ho, 2014, pp. 6479-6480). The social part is further able to shape the character of the organisation within the environment itself.

It is possible to divide the social element of the analysis into four underlying headings.

I. *Demographics,* i.e. ageing populations, create an increased demand for services for the elderly, but with a diminishing supply of labour from the younger generation.
II. *Distribution;* wealth distribution and its influence on various markets.
III. *Geography;* industries and markets are concentrated in certain locations with specific characteristics only for this market.
IV. *Culture;* recent years has shown a dramatic change in cultural attitudes from the customer/consumer of various products and services towards an increased focus on "the sustainable choice".

The above elements often go beyond the organisation itself and towards common backgrounds in terms of geographical origins, business interests and network (Whittington et al., 2021).

2.11.1.4 Technology

Technological factors include the innovations and breakthroughs affecting the development towards implementing SAF. Further, it is necessary to consider the entire supply chain, including the production, storage, transportation, and logistics concerning SAF (Ho, 2014, p. 6479; Thakur, 2021, pp. 3-4).

The technology aspect of implementing SAF entails challenges in the high production cost, availability of feedstock, and investments in infrastructure.

2.11.1.5 Environment

Environmental, or sometimes in the literature ecological, deals specifically with the 'green' issues such as waste, pollution, and climate changes in general. These include all the environmental effects of production, storage, transportation and usage, as well as all future development of the product and whether it continues to be sustainable in the future (Whittington et al., 2021).

2.11.1.6 Legal

Legal cover the legal framework concerning labour, environmental regulation, taxation etc. It will be a focal point in the following to cover environmental regulation, both on a national and international scale, since aviation covers vast geographical areas and has no geographical boundaries as such (Whittington et al., 2021). It is, therefore, also evident in this sense that the legal element of the PESTEL analysis is closely related to the political element previously described.

2.12 Conclusion

The literature review has shown great potential to describe the adoption of SAF in the aviation industry by including benefits and challenges. Although the PESTEL framework has limitations, the possible shortage of essential information in the literature review is attempted to cater for through supplementing with interviews with experts in the field.

3 Methodology

This section aims to present a systematic account of the approach employed to address the research questions of the study. Initially, an overarching overview of the methodology will be provided, outlining the key considerations made throughout the thesis and the specific research methods individually employed. Hence, section 3.1 gives a generic and general overview of the qualitative and quantitative methods, including reasoning behind only utilizing qualitive methodology in this study. Subsection 3.2 encompasses the overall framework and model, and what has been achieved through the methodology used. Subsection chapter 3.2.1 describes in more detail the data-collection methods used in this study, mainly being expert interviews, and the literature review and how these have been conducted. Subsection 3.2.2 employs through different paragraphs various descriptions of the interview and literature review as a method, including their benefits and limitations. A description of the informants who have attended is also included. Finally, a description of a case-study conducted is described. Finalizing with chapter 3.3 follows a description of the PESTEL-analysis as a framework in its relation to the methodology used.

3.1 Qualitative and Quantitative Methods

Two general information-gathering techniques exist; the qualitative method, and the quantitative method (Tjora, 2012). In general terms, the quantitative method focuses primarily on numerical data and vast amounts of respondents, whereas the qualitative method delves deeper into specific, often fewer, topics stressing the context and meaning (Wallwey, 2023). Due to the desire to test various theories and explore topics related to sustainable aviation, as well as the vastness of area covered by the problem statement, it was desired a combination of both primary and secondary data in combination with the qualitative method was necessary. Several scientific researchers however do claim that it is beneficial to use both methodologies listed above in order to understand complex problems, and that a combination of the two would be the ideal solution if resources allow (Tjora, 2012).

Parts of the data presented in this literature review consisted of quantitative, often numerical, data already analyzed and prepared, made ready to use for the reader by other researchers. As this data has not been directly manipulated by the authors during this study, quantitative methodology has not been acknowledged as an active methodology used.

3.2 Framework and model

The underlying research questions and objective has been the foundational basis for the work of this thesis. Due to the high degree of complexity and vastness of the subject defined in the general problem statement, a broad and wide-ranging literature review was initially conducted to establish an informed understanding on historical as well as current developments in innovating, adapting, and implementing SAF in the aviation industry.
Collecting data for the literature review was accomplished through information and relevant data from scientific journals, conference publications, industry publications and several other academic search services within the field.

As an add-on to this literature review, several industrial experts have assisted with decisive and highly valuable data, knowledge and information via various expert interview sessions, industrial collaboration, and on-site visits.

This combination of methods employed to obtain information and knowledge was used since the advantage of the literature review is the ability to systematically collect and synthesize existing research (Baumeister & Leary, 1997; Tranfield, Denyer, & Smart, 2003). If done accurately and thoroughly, this will create a firm foundation for the development and facilitation of various relevant theories regarding the subject, thereby opening up for applicable and relevant research questions to be exploited in more detail through expert interviews (Baumeister & Leary, 1997; Tranfield et al., 2003).

In the following, the various data collection methods employed will be described in more detail, as well as their benefits and limitations.

3.2.1 Data Collection Methods

This study is relying on qualitative data collected from a research design based on a foundation of an extensive literature review supported by various expert interviews with actors in the field.

The literature review has been the basis of the thesis, employing data and results from other researchers to define already known information regarding the problem statement and research questions of this study. Further, the literature review has identified areas where a lack of information exists, thereby opening for relevant further research.

The problem statement and research questions of this thesis has been partly defined because of the identification of relevant areas of further research not already covered in existing literature review.

The expert interviews have mainly been conducted through surveys and actual interviews. These responses have then been used to achieve relevant input and knowledge to answer the problem statement as well as research questions.

3.2.2 Qualitative Studies

To acquire the necessary knowledge and information to answer the problem statement in a satisfactory and meaningful manner, the intention has been to attain thorough and professional contribution through qualitative interviews with professionals in the field. It was found generally beneficial to attempt to find individuals with expertise in different aspects of the PESTEL-analysis as well as the more general challenges associated with implementing SAF in the aviation industry.

3.2.2.1 Primary Data – Interview

The method of the semi-structured qualitative interview was decided to attain the necessary level of detailed information on this specific subject. Another experienced trait of the semi-structured interview is that the interview-method is flexible and allows the conversation to wander into specific subjects found relevant during the interview session (Tjora, 2012).

In preparation of the interview, an interview-guide was prepared. It was attempted to design this guide to facilitate an initial phase with informal questions designed to create a relation between the interviewee and the interviewer(s) (McCracken, 1988). After the initial phase, the interviews entered the reflection phase, which opened up for the core of the interview (Tjora, 2012). As seen from the interview-guide, these questions were minded as open questions, designed to let the interviewee set the tone with only minor inputs and follow-up questions from the interviewer. The questions in the interview guide were generally based on a generically designed guide, with the overall theme being identical but some of the individual questions tailored towards the interviewee's field of expertise.

Only a few questions, like the questions in the interview guide used here, can easily result in an hour of interview or even more, which also was experienced here. Finally, the interviews ended with the conclusion phase, where it was intended to restore the situation to a normal one, end the formal interview and describe and coordinate how the responses and data will be treated afterwards. Finally, it was highly prioritized that all parts had a good experience of a successful interview, and that the atmosphere and relation was well enough for any further questions or comments to be taken by phone or similar in the aftermath (Ryen, 2002; Tjora, 2012). It was attempted to enhance credibility of the information from the respondents through several overlapping questions, thereby enabling cross-checking of responses with individual sources, even though not all the interview guides are completely identical but tailored to the individual's field of competence.

All interviews conducted in person, except the on-site case-study, lasted approximately one hour, whereas the case-study was a four-hour excursion.

In total 8 interviews were conducted in this study, through various forms. Three interviews were conducted as a conversation online through Microsoft Teams Software, four interviews were given, on request by the interviewees, as written questions and replies via e-mail, and one was conducted as an on-site case-study. Participants of the interviews were cautiously selected based on their applicable fields of expertise, and their individual affiliation with the different parts of the PESTEL analysis. All participants received the interview-guide beforehand to prepare and reflect on the questions relevant.

Informants

As described above, informants were selected based on their respective fields of knowledge. It was attempted to cover all six aspects of the PESTEL-analysis through both literature review studies and expert interviews, thereby gaining purpose for different sources of information supporting certain claims made. In an attempt to ensure compliance with GDPR names are not included, only professional titles and company-names.

Several political organs were contacted to give perspectives on the political and legal sides of the PESTEL. Contact was established to the Danish Ministry of Climate, Energy, and Utilities as well as to the Danish Ministry of Transport, office for Railway and Aviation.

Input regarding the environmental subjects came from the non-commercial business organization Green Power Denmark (GPD). GPD is a business organization gathering around 1500 ventures from the value chain surrounding green energy in Denmark, including energy trading companies, refineries, and green electricity storage. As a link between political entities and the industry, it was assumed that they could provide a picture on the relationship between stakeholders.

The infrastructural and technological aspects were attempted covered through contacts within the industry. Primarily contacts were to Copenhagen Airport's Senior Sustainability Officer and the re-refinery, AVISTA Green ApS' CEO as illustrated in the Case Study below.

Furthermore, a highly contributing interview was conducted with the CEO of the company Advanced Surface Plating (ASP). ASP produces electrodes for their mother company, the Norwegian Hydrogen Pro, who's specialty lies in the production of high performing alkaline electrolysers. ASP and Hydrogen Pro has a vital position in the production of green hydrogen, which in turn plays a key role in transforming a variety of sectors, also in the production of sustainable fuels – not only aviation. The purpose of interviewing this individual was, amongst others, to gain additional knowledge on the perspectives of a primary stakeholder in the supply chain of SAF.

Lastly, the airline perspective was achieved through interviews with the Sustainability Project Leader at Scandinavian Airlines, SAS, and the CEO of the Danish Charter and ACMI airline, AirSeven.

The Economical part of the PESTEL-analysis was a focal point in all interviews and discussions.

It was attempted to gain as broad an empirical foundation as possible to sustain specific points-of-view, and thereby not only recruiting informants expected to answer certain questions identical. The replies from all interviewees will be presented and discussed under chapter 4.

Criticism of the Interview – as a format

Points of criticism in the interview format in general has also been experienced during data-collection in this study. It has proven more difficult than expected to establish contact to relevant actors in the field, presumably due to the fact, that this study does not bring any direct economic or social value to an established actor in any direct way, at least in the short term. A further challenge possessed in the interview format is the limited amount of empirical data achieved due to the relatively few informants interviewed. Further, the informant's replies will be biased by culture, relation between the informant and the researcher, the informants relation towards their employer and potentially also through the media the interview is conducted (Tjora, 2012).

The interview as a qualitative research method is often criticized as being subjective due to its dependence on the meaning of the informant, the questions asked, and the researcher's way of shaping the interview. In the literature, this might however also be seen as a strength, since it is the privileged access to the informant's subjective meaning and attitude that is essential to the quality of the method (Kvale & Brinkmann, 2014).

Another source of criticism indicates the interview as a method as not possessing reliability nor validity since the interview is highly dependent on the researcher's guidance and follow-up questions. The term reliable here indicating whether the results can consistently be reproduced if attempted again under the same conditions, whereas validity refers to the actual accuracy of the data collected (Tjora, 2012). If the interview is applied with caution and done with respect to these limitations, the interview can create a strengthening effect since guiding the informant with relevant questions at the right time can ensure actual validity of the responses and sustain already made claims, thereby documenting essential knowledge (Kvale & Brinkmann, 2014).

Due to the above, one could argue that the qualitative research method not necessarily is reliable nor possesses the required validity, unless the researcher has this continuously in the back-of-mind when conducting this type of research.
Conclusively, it is of utmost importance in the aftermath of applicable interviews to assess the reliability and the validity of the information given before making a final judgement on the relevance for the study.

As qualitative studies excel in analyzing the detailed experiences and observations of an individual, often through words and observations, the quantitative research can sustain it by being useful in testing the relation between various observations, potentially even making predictions based on these (Wallwey, 2023).

3.2.2.2 Secondary Data – Literature Review

Initially, this study started with a thorough literature review, which assisted in the overall understanding of the current state of SAF in aviation and to give a deepened level of knowledge in conducting the further research and analysis relevant.

It was found beneficial in the research relevant to this thesis to split the literature review into four phases; 1. Designing the review, 2. Conducting the review, 3. Analysis, and 4. Writing up the review (Snyder, 2019).

Figure 5 shows the actual process conducted during the literature review.

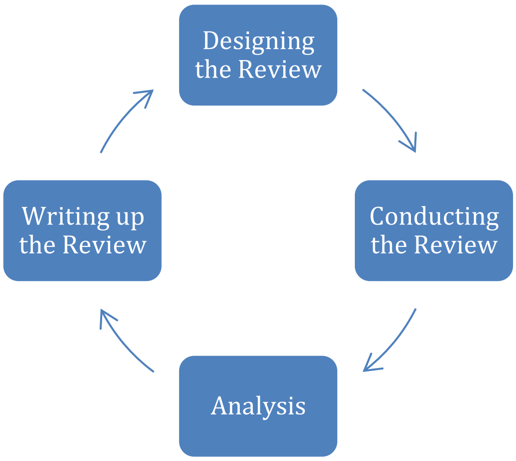

Figure 5: The four pillars of a literature review research process.

Initially, it was needed to establish an answer to the question “why is it important to investigate this matter?”. Since literature review is a comprehensive and time-demanding task, it is of utmost importance that the problem statement has relevance and likelihood of being beneficial to industries, branches, and/or others (Snyder, 2019). It is the authors opinion that the implementation of SAF in the aviation industry per today is of extremely high relevance, an integral part of future transformation of the aviation industry, and further tend to find a gap in the existing literature describing similar research questions.

The second part was conducting the actual review. This part consisted of a vast amount of data search and defining relevant organizations and companies within the industry. This task was modified several times according to newly gained knowledge during the process. The authors decided on focusing primarily on scientific research articles as well as professional reports from both governmental organizations and non-governmental organizations. Further, if possible, it was preferred to find literature giving insight in the subject as well as answering parts of the problem statement and research questions. It has been attempted, where achievable, to find several sources substantiating a certain claim or fact to enhance the credibility of the results.

To the extent possible, it has been attempted to compare information from organizations with opposing interests, although this has proven a very time-demanding task and hence could not be substantiated in all results presented in this thesis.

Finally, it has been one of the focal points in this thesis to focus on recent and up-to-date material due to the extremely fast development SAF is currently undergoing, both technologically and in terms of legal measures. The main foundation of material for the literature review of this thesis is based on the period 2019-2022, though some references inevitably fall outside this span. This decision however had the potential of facilitating confirmation bias. An example of this might be the effect of Aviation Induced Cloudiness, which just recently has been acknowledged as a major cause of concern towards aviation-induced non-CO_2 emissions, thereby gaining a lot of focus in the newest literature and publications, despite the effect is still vastly unknown amongst the industry and experts (Teoh, Schumann, Majumdar, & Stettler, 2020).

After finishing the time-consuming actual literature review, it is time for the third part of the process, the actual analysis of the decided material and data. It was beforehand defined as important to agree on certain rules, parameters and how to perform tasks to avoid any potential differences in sorting relevant data. This would prevent a wrong focus and misinterpretations to achieve a "red line" between the various data, no matter who performed the analysis. It was found especially important due to the main type of material analyzed consisting of fewer hard numbers (though there has certainly been a few), and more of soft values unmeasurable with direct numbers (Snyder, 2019). Hence, the intention has been to achieve a reliable relationship between the authors, the material used, and the audience, creating no significant difference between how material is read, analyzed, or presented.

Finally, phase four and the actual writing of the review here. It has been the intention with the comments during the description of the previous three phases above to describe the actual workflow, to give a trustworthy and transparent description on the collection of the relevant material and of how it has been filtered and analyzed.

Criticism of the Literature Review – as a format

It is important to bear in mind when conducting literature review, that it has certain limitations. Some of these has been described during the four phases above, but worth mentioning is also the high amount of work-load experienced, especially during the search phase. It is easy to stick to the material as one has already spent time on finding and interpreting, even though this might not necessarily be of high relevance. Using online search-tools, as the authors have been using extensively, often results in extreme amounts of material, and potential irrelevant topics, depending on desired search-filters, keywords etc.

This was attempted overcome by agreeing on a certain framework during the review phase as illustrated above, as agreeing on specific search-criteria like specific keywords, publication period, and focal points of relevance in order not to drown in empirical data (Tjora, 2012). Literature reviews further have the potential to lack a direct course to the analysis of the data collected. The conclusions thereby might be open to bias by either the authors of the publications, the readers of the publications, or the authors of the literature review itself. It is also a known source of error that authors may only choose certain literature that supports their already well-known knowledge, which might lead to acceptance of a specific hypothesis – a hypothesis that might prove to be wrong or can lead towards other relevant hypothesis not being investigated (Grant & Booth, 2009).

The intention of describing certain limitations associated with applicable data-collection and research methods is to identify potential pitfalls and sources of false research. With correctly identified restrictions regarding the research method, the scientific researcher has the possibility to be assertive towards these limitations and thereby directing the research in a more correct and applicable direction, with an open mindset.

It is the hope with the literature review in combination with applicable interviews to assist in the creation of a general conceptual model to be used in answering the problem statement. Where interviews often depicts a current view on a certain specific matter, the literature review can support this view in a historical context based on the time the analysis was written (Tjora, 2012). Through correct application of both techniques, a synergy-effect has been achieved, supporting, and elaborating various points of view over a longer timeframe.

3.2.2.3 Case Study

As an integral part of the data-collection method, it was found beneficial to visit an actual site where sustainable fuel would be refined. It was found impossible to find an actual SAF-refinery willing to cooperate in this manner, but instead contact was made to the company AVISTA Green ApS.

AVISTA Green uses many of the same techniques as employed in the production of sustainable aviation fuel, however AVISTA Green is a *re-refinery* processing old used oil and transforming this into high quality base oil ready for re-use, thereby contributing to the global circular economy (AVISTA, 2023b). AVISTA Green with its network of companies is the biggest collector of used oil on the European continent and currently employs 65 full-time employees with a profit after tax in 2021 of approximately 30 million DKK (approximately 4 million Euro) (AVISTA, 2023a; KPMG, 2022).

On June 5th 2023 AVISTA Green's re-refinery in Kalundborg, Denmark was visited, greeted by AVISTA Green CEO. The CEO introduced the plant through a short presentation followed by an interview conducted with reference in the interview-guide. A three-hour tour of the plant followed, showing the entire process from collecting the used oil, filtering, and re-refining it in the factory before finally distributing it internationally. A lot of focus was put on the logistical part as well as the overall challenges associated with governmental support, legal aspects as well as the technological challenges associated with such a complex task as the one at hand. These topics were chosen since they could be applied in a similar context to the challenges faced by a SAF production plant.

3.3 PESTEL-analysis and Methodology

Since the aim of this study has been founded in a thorough understanding of all individual aspects of the PESTEL-analysis, both in a defining and analytical context, as well as how these aspects collectively interact, it was decided to focus on a qualitative literature review in combination with expert interviews as stated in the subsections above. The reasoning behind being an intent to gain valuable background information for the analysis, and through the interviews enhance the opportunity for open questions in the understanding of how the PESTEL-analysis will work as an analysis-framework under the influence of the problem statement.

4 Results and discussion

The following section presents the findings of the survey conducted to explore and analyse the factors influencing the adoption of SAF in the aviation industry. This survey aimed to gather insights from a small sample of eight respondents, representing a diverse group of professionals within the industry. While the sample size is limited, the data collected provides valuable preliminary insights into the perceptions and experiences surrounding SAF adoption.

4.1 Results

The intention of the interviews was to gain knowledge from stakeholders in the field, each representing a different area of expertise. The hope is that the interviewees will shed light on the different elements of the PESTEL-analysis thereby complementing the existing knowledge gained from the literature review. The results from the interviews will be presented in the following, and thereafter the results of the interviews will be discussed against the findings of the literature review under each pillar of the PESTEL-framework.

For an overview of questions asked to the individual interviewees, please look in appendix 2 to 9.

Danish Ministry of Climate, Energy and Utilities

The Danish Ministry of Climate, Energy, and Utilities proclaims that a green domestic route will be established in 2025 and that all domestic traffic will be green in 2030. The primary source of propulsion is expected to be SAF. A passenger-tax of 100DKK (13.5 Euro) will be introduced, and the profits of this tax will be spent on sustainable domestic traffic and the increased societal burden of the elderly population.

The Ministry further claims that SAF is 100% substitutable with conventional jet fuel and focus will be on SAF rather than electric/hydrogen aviation due lack of maturity in technology.

With respect to governmental support, Denmark has provided support of 600 million DKK (80.5 million Euro) to Green Fuels for Denmark (PtL flagship) as part of the Danish contribution to the IPCEI program. Also, a governmental procurement of 1.25 billion DKK (167 million Euro) is announced for production of green hydrogen. However, this is not designated for SAF-production.

Of more international nature, the Ministry mentions a common European blend-in mandate of 2% SAF in 2025, 6% in 2030, 70% in 2050, and a blend-in mandate of PtL SAF from 2030. Also, the EU-ETS quota-system and taxation of jet fuel (ongoing negotiations) is mentioned.

Danish Ministry of Transport, Office for Railway and Aviation

The Ministry does not expect the price of SAF to reach a similar level as conventional jet fuel – not even in the long term. They do imply though, that there is potential to bring down the costs through upscaling of production and increasing supply and technological capabilities.

The Ministry points out how Denmark pushes the international society in two ways to promote SAF. First, by introducing blend-in mandates, secondly, by increasing carbon-taxes or increase price of carbon offsets. The intention is to create an incentive for investments in production facilities.

The Danish government does not plan on facilitating production plants, but indirectly they will support the green aviation transition by assisting the expansion of renewable electricity thereby driving costs down which will enhance the prospects of PtL SAF adoption.

This ministry also points to the passenger-tax of 100DKK but says that what these money will be spent on has not been agreed upon yet. They strongly support international regulation (ICAO and EU) to avoid distortion on the market for carbon-quotas.

CEO of AVISTA Green

For AVISTA Green, a major challenge is the lack of international regulation on renewability and re-use. Political action plans are required to ensure progress in recycling of recyclable materials. This is a complex matter as there are a lot of stakeholders with various interests. An example made by the CEO encompasses how some European countries allow the burning of waste materials suited for renewability, while other countries mandate the recycling of reusable materials. AVISTA Green can thereby exchange their product with waste products from the countries without this mandate. This is done because it makes financial sense – not because of regulation.

Just like with SAF, AVISTA Green is dependent on enough supply of feedstock. The difference between the SAF-section and AVISTA Green is the price gap between conventional material and renewable material, as AVISTA Green's products has an identical price as conventional products.

AVISTA Green expects that the profit made in 2021 will increase a substantial amount, and part of this expectation is attributed to increased focus on sustainability with their customers.

Copenhagen Airport Senior Sustainability Advisor

The fuel infrastructure in Copenhagen Airport is built as a storage- and hydrant-system for receiving, storing, and refueling of Jet-A1. There is from the airport's perspective no challenge in blending Jet-A1 with SAF, as the infrastructure is drop-in capable. The challenge lies in the task of fueling a specific amount of SAF on a specific flight. The refueling system is buried underground and this restricts the beforementioned opportunity, unless the SAF is refueled by truck.

Copenhagen Airport argues that the passenger tax may have the opposite effect than anticipated by the Danish government as it could make more economic sense for airlines to sell less tickets at a higher price, thereby increasing the passenger emissions pr. mileage. Especially domestic traffic will be hit hard with an estimated up to 12% decrease in traffic. Copenhagen Airport further argue, that if the profit of the passenger tax is not solely dedicated to transforming the aviation industry, it will have a marginal effect on climate impact from aviation.

To increase air quality around airports, Copenhagen Airport together with the ALIGHT-project has taken part in a study conducted by DLR. The results of this specific study are yet to be published, while the ALIGHT-project will continue to 2024.

CEO of Advanced Surface Plating

The CEO argues that political entities are already participating and refers to Norway's blending mandate (to be increased to 30% in 2030) and Denmark's goal of green domestic traffic in 2030. According to the CEO, Copenhagen Airport can sell more SAF than they have available, and so they are interested in scoping the landscape for more SAF capacity. A general problem mentioned here, is the lack of green carbon to supply both the aviation and maritime industry. The green carbon will end up in the supply chain of SAF, as the aviation industry will pay a better price than the maritime.

Denmark's goal of green domestic traffic in 2030 is deemed realistic. It does however require investments in SAF facilities and for those investments to materialize, agreements with airlines need to be signed. ASP signed such agreement with DG Fuel in USA to deliver

800MW-capacity electrolysers for SAF-production, as Air France and Delta has communicated reliable interest.

The CEO does believe, that until airplanes can fly safely on aromatic-free jet fuel, the aromatic content can be supplied as waste products from other production facilities. The 1.25 billion DKK allocation by the Danish government will, according to ASP, go to a pool that is not earmarked for production of SAF.

The CEO elaborates on the feasibility of different types of SAF, and states that from an economic point-of-view, the more difficult the converting process, the higher the price. Hydrogen is not expensive and so for PtL the limitation is the technology.

If the industry is willing to accept use of "grey carbon" (carbon captured from the atmosphere) in a transitional phase, the first large scale PtL production facility can be ready in 5 to 10 years. ASP and Hydrogen Pro as actors in the supply chain are ready to scale production to demand. The industry needs to get going even if it means use of grey carbon until the lack of green carbon (biological material and biogas) no longer exists.

In relation to the capital-intensive adoption of SAF, the CEO argues that the passengers are willing to pay for SAF, but maybe not through taxes. They need to know that their money is used for SAF. About CPH's concern about the passenger-tax, he argues that a tax according to load-factor could be induced upon airlines, but stresses that a no-tax situation is possibly the best option as the consumers must take part of the responsibility.

Consultant with Green Power Denmark

The market and the industry are aware that more SAF is needed, and it is also a wish from the aviation sector. The production and the usage must find common ground. The price-gap between conventional and sustainable jet fuel remains a challenge, leading to difficulties in generating contracts between airlines and production companies.

In Denmark focus is on decarbonizing the domestic traffic, but most emissions are international. There is a requirement to reach beyond borders which could be achieved by increasing export of green electricity and hydrogen. This could stimulate the rest of EU to intensify the green transition. With a lack of political focus on international aviation, the risk is that money can be channeled to other sectors.

Political stakeholders are needed in the process of limiting the risks associated with SAF implementation – such as political action on expanding the electricity network. The airlines do ask for SAF but their ability to act on their own is limited.

GPD also mentions the passenger-tax and how this can be a good way to push the green transition, but how the final model (whether the income of the taxes will go back to the sector or not) is still unknown. The Danish Government initially calculated with 13 DKK (1.8 Euro) pr. sold ticket in Denmark to fund the conversion from fossil to sustainable fuel on the market.

With the SAF produced at the production facilities planned in Denmark, EU's entire demand for SAF could be covered by this production. This could increase fuel load carried out of Denmark. There is a need for governing authorities to look at the relationship between supply and demand, and as aviation is international, this should be done by ICAO and the EU.

In relation to the maritime industry, this has an advantage in that methanol is cheaper to produce. However, the aviation industry has an advantage with the drop-in capabilities. On the 2025 domestic route, the SAF will probably be provided via a separate fuel system. Green Power Denmark also mentions the green legitimism and the need for a certificate-system to prove the uplift of SAF, both for the airline and the customer.

GPD suggests a tax on fossil fuel to cater for the current price-gap, however, it may not be enough to cancel it out. On what level the price of SAF ends up will depend on what level the fossil fuel ends – GPD expects it to increase although a level of uncertainty is associated.

The industry should be careful to rely too heavily on governmental support as there are other ways to minimize risk. An important note is the effects of non-CO2. If the research conducted is correct, it is a bad situation, however, this can be used to stimulate the production and consumption of SAF as SAF only holds very little aromatic content – maybe SAF should be used in segments where the climate load is the highest – long-haul.

Sustainability Project Leader, Scandinavian Airlines SAS

SAS is working with the industry to develop next generation electric and hydrogen airplanes, but these technologies will be limited in range. SAF is needed to reduce emissions from long-haul flights. The cost of SAF is the major challenge but as technology matures and supply increases, prices will decrease. The market needs to be stimulated governmental subsidizing of production of SAF like in USA. Great demand of SAF from USA is therefore expected.

SAS sees the US as using a carrot (which will increase supply and demand) whereas the EU uses a stick by requiring a mandate. The latter is not attractive for airlines, but it does create security in production centers and creates a long-term demand ensuring production and lower prices. SAS' hope is that going forward, the issues will be handled on an international scale while the price-gap still remain the main challenge. To reduce the risk of a distorted market, the issues should be handled at a global scale since the industry is international – this is however hard to establish. Some airports uses incentive programs to help airlines (which is appreciated) and this creates an in incentive to uplift SAF at that airport.

SAS is of the belief that carbon taxes should be used to enable the transition, but the money should be brought back to airlines. Taxes usually lowers an airline's revenue, whereas prices are based on willingness to pay. A willingness SAS has seen in their promotion of "SAS Bio"-tickets. The number of sold tickets is in line with expectations, however the leisure segment positively surprised SAS. The revenue is earmarked purchase of SAF and SAS does not earn money on this. They buy the amount of SAF corresponding to the amount of conventional jet fuel. SAS promises that the amount of SAF bought will be uplifted within 12 months of purchase.

The costumer segment in Scandinavia demands sustainable solutions putting SAS under pressure. The transition has to start somewhere, as long as the laws promote the change eluding the possibility of the laws leading to bureaucratic reporting.

SAS continues purchasing and increasing the use of SAF, having established a goal of purchasing an amount of SAF that corresponds to the domestic production in Norway, Sweden, and Denmark by 2030. To reach this, it is of SAS' belief that costumers need to be involved in a greater extent in the long term to cater for the economic burden.

Historically, SAS has been somewhat a "first-mover" in striving for sustainable solutions and they aim to continue being a driving force in sustainable aviation. This has been achieved by working together with other industries (partnerships with Green Fuel for Denmark, Vattenfall, Shell and Lanzatech) to ensure production and supply of SAF in the future. In 2019 SAS deal with American Gevo to buy SAF in the US from 2024 – 2025.

CEO of Airseven

As a charter and ACMI operator, the CEO has not seen great interest in adoption of SAF from the costumers that Airseven serves. The CEO does stress the importance of the drop-in capabilities of SAF, as the industry is a multibillion-dollar industry. The airplanes flying today will serve for another 30 years and this is a fact that lacks attention in the debates. Further, fuel costs account for approximately 20-40% of a ticket price, and so if SAF is to be employed it will increase the ticket prices a fair amount.

Airseven is a relatively small airline and operates with smaller margins compared to the bigger players and so they are forced to "go with the flow". There are potential cost-savings related to the reporting of the use of SAF. Airlines are required to have certificates stating the uplift of SAF to be exempt from paying carbon-tax to EU-ETS. However, the process of acquiring these certificates is very bureaucratic and thus requires resources. A thing that does not come in abundance for airlines. Hence, a tax on conventional jet fuel would be a preferred option.

The industry and the associated stakeholders need to realize, that money earned from taxes imposed on airlines need to put back into Research and Development in the aviation industry. The transition will cost money, but making sustainability bureaucratic will end up producing less sustainability.

4.2 Discussion

One can argue that the political aspect of the solution to emission-free aviation is the foundation on which use of SAF should be built. As described through the literature review and various interviews conducted above, it is evident that the right technology exist, the willingness from all stakeholders in the field exist, and potential solutions to the remaining challenges are at hand – though some might be financially costly and with a lengthy timeframe.

4.2.1 Political environment

The statements given from both the Danish Ministry of Climate, Energy and Utilities as well as the Danish Ministry of Transport, Railways and Aviation describes an explicit ambition of using Sustainable Aviation Fuel as the cornerstone in assisting the green transition of the aviation industry. This is directly in line with various other sources (Holladay et al., 2020;

Wolff & Riefer, 2020), confirming the relevance of SAF as the major contributor before other propulsion-types as electricity or pure hydrogen.

A major barrier identified by many interests (Green Power Denmark, 2023; Inner City Fund, 2021) is identified as the production cost of SAF, and whom to pay for the higher cost of it, either through taxes, economic incentives or carbon offsetting. Even within the current Danish Government, it has not been possible to identify a conclusive potential solution. This illustrated by the Danish Ministry of Climate, Energy and Utilities indicating that a higher tax on the consumer through a passenger-tax should be the primary solution (Danish Ministry of Climate, 2023). At the same time, the Danish Ministry of Transport, Railways and Aviation suggests lowering the production costs through scaling up production, partly via a resemblance of the Refuel EU blend-in initiative and partly the increase of either carbon-taxes or prices of carbon offsets (Danish Ministry of Transport, 2023). The latter Ministry thereby proclaiming an intention to make investors more willing to invest in production facilities, because they would always be able to sell the production materials in the market. This claim is substantiated by the CEO of ASP, describing how Copenhagen Airport already is in a situation where they can sell more SAF than available, also indicating that the passengers are willing to pay extra for SAF, again illustrating the positive willingness and huge potential in the market (Advanced Surface Plating, 2023). This is further supported by SAS as they confirm that the vending of “SAS Bio” tickets is in line with their expectations (SAS, 2023).

Green Power Denmark further indicates a potential dilemma with direct funding in it being needed to start the costly production of SAF, while at the same time the actors in the industry cannot rely too much on governmental support to minimize risk.

Both Danish Ministries interviewed agreed on the implementation of a passenger-tax, though the exact result of how this will be implemented is yet to be decided. What is evident, however, is that the tax will end on approximately 13,5€, and that half of it will be spent on other parts of society than assisting the transitioning to an emission-free aviation sector (Danish Ministry of Climate, 2023; Danish Ministry of Transport, 2023). According to Copenhagen Airport, this passenger tax has the potential to even increase passenger emissions pr. mileage and furthermore even cause a decrease in traffic. It is argued, that if Denmark wants to commit to EU’s “Fit for 55” program as both the Danish Ministry of Climate, Energy and Utilities as well as Copenhagen Airport advocates for, this tax will have a marginal effect on climate impact.

Looking from the perspective of the production-end of the supply-chain, a general trend was identified as the need for political action plans and willing to invest in the industries (AVISTA, 2023b), especially on an international level. An important point made by contributors from the industry to this study is, that they do not expect financial support to their own firms, but insist on funding and political incentives needed in their applicable industries in general(AVISTA, 2023b; Denmark, 2022).

Several political incentives to cater for the long-term perspectives in transitioning to an emission-free aviation sector are currently in place. These incentives include to offset emissions, through buying certain emission-quotas, “green tickets” (IATA, 2019). Offsetting emissions in this way do however come with certain limitations; at this moment, the procedure is not compulsory to all nations nor route-pairings, and it does not offer very good transparency for the governing organs (Transport & Environment, 2021). Further, offsetting schemes like CORSIA could be considered as greenwashing as offsetting does not directly support a solution to the problem, but more of an alternative to such.

Further, general international governing knowledge due the international nature of the industry was identified as a major barrier and concern. This will be described in more detail in chapter 4.2.6, legal environment.

4.2.2 Economic environment

The economic environment in the context of a full-scale implementation of SAF is indisputably one of the biggest challenges. The thesis will try to discuss the economic environment from the point-of-views of the different stakeholders – primarily the supply chain of fuel companies, the airlines, and the political entities.

An important facet of the economic environment is the dynamic nature of both aviation and innovation – this is a field subject to change as technology advances, political incentives evolve and fluctuations in the market occur. Hence the difficulties seen in the literature review in predicting prices – both for SAF and for conventional jet fuel.

The industry is currently in a situation where there are some commercial production facilities when it comes to HEFA SAF, and when it comes to PtL there are links in the supply chain that are ready to upscale their production to meet the demand – when demand arrives (although some links in the production and supply chain need further maturing, such as

Carbon Capture and Point Source). For the links in the supply chain, it seems to be a determinant factor to consolidate sales-contracts with the next link in the chain all the way to the end-user, the airlines (Advanced Surface Plating, 2023). Dodd and Yengin (2021) argue that all three main stakeholders (airlines, fuel companies and policymakers) imply that leadership from airlines is paramount for the integration of SAF, as this would drive a market-pull on a global scale and thereby ensure off-take of SAF. However, zooming in on Scandinavia, there seem to already be a market-pull, a pull the supply of SAF cannot sustain, in that Copenhagen airport can sell more SAF than they have available (Advanced Surface Plating, 2023). The fuel companies want to establish purchasing contracts and argue that they are ready for a market pull, but before such contracts are in place, the upscaling of production is unlikely. Incentives for airlines to commit to these contracts is most probably political engagement in either an economically supportive manner or in the balancing of the price-gap between SAF and conventional jet fuel (Green Power Denmark, 2023). Investments, either/both private or/and political, in the production facilities may be necessary to establish proper conditions for the market, until reaching a state where the market regulates itself (Advanced Surface Plating, 2023). The stakeholders in the supply chain of SAF has a clear advantage over conventional jet fuel in that there are different pathways each requiring different feedstock/resources, and so a diversification of energy facilitation and thereby production is possible, which in turn could lead to pricing stability for SAF products (Yilmaz, 2022). Tax-credits and/or partial funding/economic aid may assist and even encourage SAF producers to start producing without having vending contracts established.

Is does become clear that measures are to be taken to incentivize sustainable fuel producers to start production, but there are many thoughts to consider. Both Green Power Denmark (2023) and Scheelhaase et al. (2019) are of the perception that attention needs to be pointed towards other sectors and not only the aviation sector. The energy sector is of greatest importance to get onboard as vast amounts of electricity is required, especially when it comes to PtL, and the agricultural industry needs to be included when it comes to HEFA SAF. The industry is currently in a situation where there are some commercial production facilities when it comes to HEFA SAF, and when it comes to PtL there are links in the supply chain that are ready to upscale their production to meet the demand – when demand arrives (although some links in the production and supply chain need further maturing, such as Carbon Capture and Point Source). For the links in the supply chain, it seems to be a determinant factor to consolidate sales-contracts with the next link in the chain all the way to the end-user, the airlines (Advanced Surface Plating, 2023).

From an airline perspective, it seems that airlines in general are on the lookout for SAF and purchase opportunities (Advanced Surface Plating, 2023; Green Power Denmark, 2023; SAS, 2023a). Their margins are however very low, especially in the wake of COVID-19, and therefore it is difficult for airlines to commit to capital-intensive obligations like contractual agreements on jet fuel several times the price of conventional. This is exactly one of the challenges that needs to be overcome, and both Green Power Denmark and Advanced Surface Plating argue that a blending mandate and/or black carbon-tax can support the SAF market, balance the price-gap and drive the demand (Advanced Surface Plating, 2023; Green Power Denmark, 2023). Until then the price-gap remains, and it is either going to be the airlines, the consumer, or a combination thereof, who will take the bill – if the supply is there.

For consumers, they need an alternative to conventional jet fuel to be able to relate. If the airline can secure supply of SAF then they can also provide an alternative for the consumers (Advanced Surface Plating, 2023), thereby putting some of the responsibility on the consumers. However, a system of certification must be established first and foremost to ensure green legitimism and second, to extend the required knowledge to the consumers. While being a first mover may have disadvantages for investors as changes in the political/economic framework may occur after the investment has taken place (Scheelhaase et al., 2019), from an airline perspective the first-mover approach could possibly aid in attracting consumers in the ever-so-competitive market, as seen by the high demand on tickets when SAS announced tickets for sale on the first electric flight with SAS in 2028 – the tickets were according to media ripped away. The case for SAF is of course a little different because of the infrastructural limitations and the possibilities of consumers being confused as to the actual uplift of SAF, hence the certificate system as described above (Green Power Denmark, 2023). The certificate system could work as an incentive for airlines to proceed with a first mover approach, although there will still be tough economic decisions to be made. If an airline decides to go on with contractual obligations (fuel hedging) with a supplier, and the relative price of SAF compared to jet fuel decrease, the airline will have lost money. This risk has always been the name of the game for airlines, but with SAF there are possibilities to ensure pricing stability (Yilmaz, 2022). A measure that could intensify the market pull.

Dodd and Yengin (2021) puts forward a point via their interviews with airlines, that a solution to the price-gap could be integrating airlines into the supply-companies of SAF by investing in SAF producers. This does require significant investments and this could be too risky with the limited economic margins that airlines operate with investments (Advanced Surface Plating, 2023; Scheelhaase et al., 2019). An example of this is how SAS has commenced partnerships with other industries (Project Green Fuel for Denmark, Shell and Lanzatech) which in turn will also ensure their supply of SAF in the future (SAS, 2023). Another way that airlines could be integrated into the supply chain, is if they instead of offsetting their carbon emissions, could offset by buying into the technologies that need investments to mature, such as Carbon Capture.

Even though Green Power Denmark argues, that the industry should be careful to rely too heavily on governmental support and policymaking, they, and most other literature, agree that a certain involvement from policymakers and authorities is required to sustain the green transition.

These policymakers have different instruments to apply to make the economic environment more feasible for both sustainable fuel companies and airlines. One such instrument is to manipulate the relative price of SAF by inducing a tax on fossil fuel or introducing a tax-credit on SAF (Dahal et al., 2021; Doliente et al., 2020; Scheelhaase et al., 2019). The relative price is of course dependent on the price of conventional jet fuel, which Green Power Denmark expects to increase within the next 10 to 20 years, although there is quite a bit of uncertainty related. If it is all down to the dynamics of the market, it could also be that the price of conventional jet fuel decreases because of decreased demand when SAF gains "space", however Green Power Denmark as well as the literature expect the price for SAF to decrease as well as a result of maturity of technology an increased availability of green electricity.

Denmark has imposed a passenger-tax on the domestic market. The money earned on this tax is going to both the aviation sector and to the other sectors in Denmark. Copenhagen Airport on the other hand argues, that there is a risk of this tax having the opposite effect because there may be an economic incentive for airlines to reduce their load factor by selling fewer tickets to a higher price (CPH, 2023). This in turn leads to an increase in emissions pr. passenger-kilometer. ASP's CEO replies to this that a tax (model of the tax not further elaborated on) based on load-factor could then be induced upon airlines keeping them from reducing their load factor. There is a risk associated with this as load factors do vary according to season (Advanced Surface Plating, 2023).

Another button to be manipulated by the policymakers is the blending-quota. Some countries (like Norway with the example of Oslo Gardermoen) have already induced blending quotas on all traffic refueling in Oslo Airport Gardermoen, as described in chapter 2. For both PtL and HEFA SAF, the blending limit is 50% and therefore, it is natural to believe that all commercial airplanes are technologically capable of uplifting up to 50% SAF. Inducing an international blending quota would drive the needed investments in SAF production facilities, vending contracts would be signed, and airlines are equally imposed to buying. The price for SAF would initially be higher than expected in the long run, however since there is only talk about a blending quota (such as 5%), the price would still be at acceptable levels (Advanced Surface Plating, 2023; Scheelhaase et al., 2019).

As a concluding remark on this section, this thesis is not aware of an emission-tax imposed on cargo airlines like the passenger-tax, however they do indeed contribute to the overall emission of aviation.

4.2.3 Sociocultural environment

The sociocultural element involves the analysis of potential social, societal, and cultural consequences, in this case with the implementation of SAF. It is of the authors belief, that the requirement for a sustainable transition is generally accepted in the (western) society. Having said that, the pathway towards a sustainable world is far from agreed upon, and it follows that social and societal implications are therefore difficult to assess. In the following, the thesis tries to give an overview of possible social effects of the implementation of SAF, although these estimations may not be accurate as policies and governmental rulings around the world can alter the outcomes presented. It will be primarily from the knowledge gained during the literature review, as the interviewees' views on political, technological, and economic environment took precedence.

The European Commission does perceive it as a likely consequence that the boosting of the SAF market may create additional jobs, especially in the areas of the production and supply of SAF. They do however foresee a possible decrease in employment in the fossil fuel sector (European & Commission, 2020). This is in line with findings from Inner City Fund (2021) arguing that if the global commercial aviation industry is to be supplied with SAF, it will require 5.000 – 7.000 refineries to sustain this demand. Also Wormslev (2016) estimates between 14.000 and 22.500 jobs created in the Nordic region alone, based on a blending level of 37.5% and between 7 and 11.2 annual full time employees pr. million liter fuel (for HEFA, FT and AtJ). Also Bole-Rentel et al. (2019) found a high job-creation potential with establishing SAF facilities the Sub-Saharan region. In other words, there is great potential with respect to job-creation around the world, also in developing regions. What needs to be kept in mind is the sustainability aspect. Job-creation, especially in less developed regions, is an indisputable positive effect. However, the industry needs to do this carefully. First and foremost, regions may become dependent on export of feedstock for SAF, rendering them vulnerable if the market requires shifts in feedstock (Doliente et al., 2020). Secondly, there is a risk that farmers will see greater economic potential in cultivating feedstock for the production of SAF instead of food crops, which may not be in line with UN's Sustainable Development Goals. Having said that, it could also be a positive for individual farmers that they are able to diversify production. A little sidenote is the fact, that algae-production for SAF does not take up any land use (Prussi et al., 2021). PtL also takes up less land and water resources than most biological feedstock leaving the risk of compromising UN's Sustainable Development Goals somewhat out of the picture (Denmark, 2022; Inner City Fund, 2021).

A potential negative effect of the implementation of SAF relates to the high costs associated with SAF. If international authorities would introduce a tax on conventional jet fuel or incorporate a blending quota, if airlines are to bear the cost of implementing SAF without any political incentives/support, they would have to accommodate for increased costs (Scheelhaase et al., 2019). This could lead to higher ticket-prices, which in turn could lead to reduced travel activity and rendering residents in developing countries unable to travel, which again could lead to job losses in the aviation industry.

Looking back at the section where job creation is catered for, maybe the tax money of those specific jobs created could be earmarked to lowering the initial prices for SAF or go into Research and Development in the SAF sector. However, given the inherent characteristic of a tax (as illustrated in the discussion on the Political Environment where the Danish government induces a tax on aviation and uses half the earnings of that tax on other parts of society), it certainly is not a given that taxes imposed on jobs would be earmarked to sustainable transitions.

Of a more cultural nature the interviews conducted in this thesis does show, that passengers are willing to pay for SAF, and so maybe the industry could put more responsibility on the consumer without sacrificing the load-factor onboard.

4.2.4 Technological environment

Even though it is out of the scope of this study to dive deep into the technological and chemical compositions, it is found important in the analysis to highlight the overall technological status of SAF and the challenges it faces in scaling up the production and implementing it in the industry.

In general terms, the technology to produce and distribute SAF exists today, however in a much smaller scale than needed for 100% SAF-usage in the aviation sector (CPH, 2023; Danish Ministry of Climate, 2023). Further, the infrastructure at airports is in place to handle SAF, as the infrastructure already is drop-in capable, however not yet capable of blending a specific amount on a specific flight (CPH, 2023).

The analysis conducted regarding the technology-aspect in this thesis focused on ways to produce SAF in a 100% responsible way, and identified two main-barriers needed to be resolved for the scaling up the production; Firstly, to produce SAF in a socio-cultural responsible manner, and secondly to prevent the formation and further emissions of non-CO_2 effects (Green Power Denmark, 2023; Prussi et al., 2021) The first barrier includes both producing SAF in the most environmentally responsible way, as well as not infringing with other parts of society, food-supply and undesired influences on the economic system.
This study has identified the future overall production of SAF to consist of a supply of feedstock for PtL consisting of renewable energy, water and CO/CO_2, with especially the challenge of availability to cheap renewable electricity in a competitive market, and the process of Carbon Capture as obstacles to be overcome (Advanced Surface Plating, 2023).

Availability to Carbon can be achieved in several ways; Either through “Grey Carbon” via Direct Air Capture or Point Source Capture, the latter being the most energy effective as of now. Alternatively through “Green Carbon” from biological material and biogas, however the supply of feedstock is limited (Advanced Surface Plating, 2023). It is however potentially relevant to employ “Grey Carbon” methods of Carbon Capture to the PtL process in the transitioning period, to accelerate the process and availability to SAF.

The second barrier involves the non-CO_2 effects. This is a relatively newly identified phenomenon, that the industry not yet knows the exact effect of. A potential major part of SAF’s non-CO_2 effect consists of the development of Aviation-Induced Cloudiness, typically created by aromatics and water vapor in both conventional kerosene and SAF (Holladay et al., 2020). These aromatics are crucial in conventional engines’ O-rings and seals already exposed to conventional jet fuel, but they are not a part of SAF from the production (Doliente et al., 2020; Zhang et al., 2020). A manual process of adding aromatics is therefore needed, thus creating undesired atmospheric effects – a certain drawback needing a solution. A potential answer to this is to supply jet-engines with only aromatic-free SAF, since rings and seals in engines already subjected to aromatics will require these in the future, whereas seals and rings not subjected to aromatics do not require its presence (Holladay et al., 2020).

As illustrated above, PtL SAF has in this study been identified as the production-pathway to strive for since it fulfills all sustainability criteria in the production. It is however also clear that PtL is a complex and expensive production method which still have not matured sufficiently. Consequently, the HEFA-pathway should be seen as an alternative in the period of maturing of PtL, since HEFA is a well-known and verified method, fairly cheap at hand.

Since it is a highly complex task to produce SAF, several entities advocate for increased funding or investments if the industry is to fulfill its own laid-out goals by 2030 and onwards (Advanced Surface Plating, 2023; Green Power Denmark, 2023; SAS, 2023a). Advanced Surface Plating has made a huge agreement in the USA regarding delivering electrolysers due to a reliable commitment from Air France and Delta. Another way of achieving the required investments is illustrated from Sustainability Project Leader at SAS who exclaims that in the USA, the production facilities receive a lot of funding, instead of in the European region, there is more of a tendency towards mandating (SAS, 2023a). (Advanced Surface Plating, 2023; Green Power Denmark, 2023; SAS, 2023a).

4.2.5 Environmental environment

As argued in the literature on the possible environmental benefits of the adoption of SAF, there is a lot to gain in terms of reducing the climate impact. With an LCA-approach, ICAO agreed on an emission value of 89 gCO_2e/MJ which potentially can be reduced by more than 50% for HEFA SAF and more than 90% for PtL SAF. These numbers speak for themselves and none of the interviewees have disagreed with the importance of making these potential savings a reality by accelerating the integration of SAF into aviation operations. As such, it has been decided to conclude this section.

It is important to note however, that there seem to be a focus on carbon-reduction in the literature and in fact also with political incentives. Carbon (CO_2 an CO) reduction is inevitably a very important factor in reducing the overall impact of aviation, but it seems imperative that emphasis on non-CO_2 effects is not neglected as these may play an equal to greater role to carbon emissions on the total environmental impact (Green Power Denmark, 2023; D. Lee et al., 2020). The reduction of NOx and SOx is described as a possible potent factor in increasing the air quality around airports and studies on this are currently being undertaken by Copenhagen Airport and DLR (CPH, 2023; Farokhi, 2020). Further, the content of aromatics is of high relevance. This section is therefore continued with aromatic content as a focal point.

The ASTM certification of jet fuels requires 8 – 25% aromatic content to ensure proper sealing in current engines, as described in the literature review. This is the main reason there is a blending limit of 50% depending on feedstock and production pathway. It is suggested that only the engines already exposed to aromatics require its content, whereas new engines would not. Currently, this presents a natural limitation in the blend-in mandate as the industry of course cannot substitute all engines straight away. However, it could be argued that policymakers should reduce the aromatic content interval (Green Power Denmark, 2023). D. Lee et al. (2020) does argue that non-CO_2 effects account for more than half of the climate effects caused by aviation, and this includes the formation of AIC. Aromatics are a key factor in the formation of AIC and as seen in chapter 2, AIC may be the worst component in the climate changes caused by aviation (Avinor, 2020). Green Power Denmark argues that different segments of the aviation sector is responsible for different loads of emissions, both CO_2 and non-CO_2 and further, that the worst segment is long haul.

With long haul being the worst segment of the sector, it could possibly benefit the environment to aim the use of SAF to this segment, ensuring the minimum aromatic content on these flights. It does, however, induce challenges with respect to infrastructural capabilities of airports as this is not currently geared towards a dual fueling system (one for SAF and one for conventional jet fuel) (CPH, 2023).

As it seems that there are quite a few advantages to gain by looking into the aromatic content and by this and the above logic, maybe it could be an idea to investigate the possibilities certification of fuels according to aromatic content instead of blending percentage, after all the blending limit is due to aromatic content. That way the industry could ensure an aromatic content of 8% at all places where blending takes place, instead of up to 25%. The environment would see benefits from this as all airplanes taking off with blended fuel would take off with 8% aromatic content instead of everything in between the specified interval.

Concluding remark on this section; the environment doesn't care which airline employs the use of SAF, which aircraft uplifts SAF, or where the SAF is used, as long as it is employed in the industry.

4.2.6 Legal environment

The legal part of the PESTEL-analysis conducted is closely connected to the political and economic parts earlier described. Means such as passenger tax and mandatory blending mandates. Concerning political incentives in favor of implementing SAF in a much more aggregated manor, all political aspects interviewed agrees on the importance and that SAF is the solution currently at hand (Danish Ministry of Climate, 2023; Danish Ministry of Transport, 2023). Many sources also identify the cost of buying, implementing and using SAF as a major barrier, combined with a sustainable way of producing it (Danish Ministry of Transport, 2023). In order to enforce the implementation and heighten the usage, several legal incentives have been discussed and even implemented on a national level through blend-in-mandates and passenger tax (Baxter, 2020; Danish Ministry of Transport, 2023).

On an international level, several initiatives are currently in place, though there is a definitive lack of direct international law-making, especially in aviation. Several participants interviewed during this study identified the lack of international governing legislation as a major issue and a matter needed to be resolved on the way to an emission free industry (AVISTA, 2023a; Green Power Denmark, 2023; Scheelhaase et al., 2019). Many agreements have been made regarding emissions internationally, i. e the Paris Agreement and EU's *Fit for* 55, but they lack a more ambitious and direct focus on the aviation sector. As an example, Denmark as a nation alone will be able to supply all of Europe's Sustainable Aviation Fuel in 2030 (Green Power Denmark, 2023). Due to the sectors international nature, a legislation governing countries of departure and destination will assist in more actors participating in the SAF-transformation as well as reducing the risk of distorting forces in the market in favor of wealthier countries, as described under the Sociocultural element (Green Power Denmark, 2023). Contrary, many political intentions on the matter has been agreed upon, though these are not compulsory and binding declarations. This illustrated by the EU Emissions Trading Scheme, where airlines emitting less than the allowed amount can sell their quota's to airlines requiring more quota's (Zhang et al., 2020) and the *ReFuel EU Aviation*, both however being labeled as initiatives with no or minor binding parts.

Analyzing the technical aspects of the legislation, however, is a much traditional aviation well-known matter of multiple testing and extensive approval. Several organizations and organs throughout the world are employed with this, like the previously mentioned ASTM International and Def. Stan (IATA, 2015). It is not the scope of this thesis to go in detail with the chemical or technological details of production, but to outline the general trends and overall legislations.

Legal entities governing the technological side of SAF often do only consider exactly that; the technical aspects. ASTM-authorization does thereby only regard the technical properties of the product, the method used in production and the feedstock used in the production, but not if the end-product qualifies as a sustainable solution (IATA, 2015; Martin Porsgaard, 2022).

It is interesting to note, that the technological legislation and requirements in regards of production and especially blending in SAF as a drop-in fuel are hugely agreed upon internationally, contrary to the requirements previously described on mandatory amounts to be blended in etc. As an example, it has been internationally agreed upon to allow up to a maximum of 50% blend-in with HEFA and FT production methods (IATA, 2015). In the future, a compulsory blend-in quota will be implemented, as for instance the Danish report "Grøn Luftfart for Alle" suggests. A huge question of debate lies in the fact whether this can be agreed upon internationally, and whether it will be the producers, distributors or airlines such a legislation will directly affect (Scheelhaase et al., 2019; Transportministeriet, 2022).

Having this in mind, it is interesting to note that the Danish government has proclaimed, a 100% emission free domestic route shall be in place by 2025 impeccably illustrating the conflicts existing between legal requirements, political statements, and intentions. The goal of a 100% emission free domestic route seems overly ambitious given the fact that SAF most probably will not be certified for 100% use by 2025. The first tickets for an electric flight with SAS (in 2028) have just recently been put for sale, and, to the extent of the authors' knowledge, no hydrogen airplanes are or will be in production by 2025.

4.3 Interaction between PESTEL-components

In the above subsections, only a fraction of an inexhaustible list of parameters to be analyzed are described. Thereby, also a fundamentally unlimited number of connections between the different components exist, both of verifying and opposing nature.

Virtually all available sources agree that political willingness is a paramount element in the successful transformation of the aviation industry to a sustainable one. This does however not come without certain dilemmas. As an example, currently the approved legal blend-in limitation of maximum 50% SAF in conventional Jet-fuel does not conform to the political ambitions as laid out previously.
Closely related to this dilemma is the challenge of high production cost and willingness to fund in the market. A general European political perspective favors increased taxes to fund the increased fuel cost, whereas the industry supports stimulating the dynamics in the market. USA on the contrary has put a higher focus on stimulating the market and not requiring a mandate for implementation. The advantage of the European approach is the assurance of available SAF being utilized whereas in the USA, the advantage is better incentives in the industry, resulting in a higher supply. It has yet to be concluded, which approach will be the most beneficial, as the implementation of SAF in both continents still is in its early stages. However, as both airlines interviewed in this thesis points out, a bureaucratic approach is certainly not the way forward.

Passengers are willing to pay the price for SAF as seen by the interview with both SAS and Advanced Surface Plating, although AirSeven has a different take albeit this may be attributed to the difference in market segments that SAS and AirSeven operates in. The passengers are by SAS promised, that the SAF will be used within 12 months of purchase as the infrastructure does not allow for airlines to ensure their passengers that bought SAF will be uplifted on their flight. Seen from an environmental perspective this is in itself not an issue as long as the SAF is used, however it may just push the problems forward in that if the supply is lacking behind the need, the airlines cannot sell the SAF that their customers demand. Placing the cost on the customer, whether from an airline perspective in financing SAF-usage or from a government tax, it is imperative that the income from this fee is used in the industry and in sustaining a further sustainable transition. It is hardly viable to place an extra cost on an industry as income-critical as aviation, with customers as cost-aware as is the tendency, and then channeling the revenue to other parts of society. Staying on the subject of tax, it is disputable if the tax is even the best option going forward. The level of involvement from governmental entities is debated as too little may hinder the green development of the industry because of high costs, and too much may limit the stakeholders in their field of expertise.

In strict relation to the United Nations sustainability goals, it is imperative not to sacrifice a sociocultural dimension to benefit environmentally, when implementing a political ambition. To satisfy the UN goals, stakeholders must be aware of the relationship between the various UN goals and their potential consequences. Hence, an effort made on producing SAF in one part of the globe, to the benefit of the environment, shall not impose negative consequences on certain populations, especially in relation to the least developed countries. In other words, the establishment of green energy production facilities must ensure proper working conditions and feedstock may not be taken from one consumer to another in the pursuit of sustainability. This is especially the case in relation to HEFA-production as this has the potential to take feedstock from certain societies in its production of SAF.

It is of great importance that careful consideration is exercised in establishing the infrastructural network of SAF. The blending quota as outlined by the EU has the potential to provide economic incentives to airlines to uptake as much SAF as possible. Airlines finding an economic incentive to uptake SAF at airports with higher availability may result in tankering extra fuel which implies higher weight, leading to increased fuel burn and a higher environmental burden. Thus, the environment can benefit from policymakers establishing a proper infrastructural system for SAF, keeping in mind that it is a private market that needs stimulation from within.

The aromatic content in jet fuel fall somewhere in between the legal and technological landscape. Reducing the aromatic content has great potential for the betterment of the environment but the technological advancement needs to reach a state where current engines can operate without aromatics, or the interval of 8% to 25% aromatic content should be reduced.

There is a mismatch between the political ambitions and the technology. For example, the Danish government’s ambition of an emission-free domestic flight in 2025 when the industry has not even got the technical capability as of yet. The Ministry of Climate, Energy, and Utilities also claims, that SAF is fully substitutable with conventional jet fuel, however the literature review shows that this is not entirely true in that there is a requirement for aromatic content in current engines.

What has given food for thought is the general tendency for both policymakers and literary scholars focusing on the known effect of carbon (CO_2 and CO). What researchers now identify is the impact of non-CO_2 effects, which may have a greater environmental influence, although limited research is done in the field. It is the impression of the authors that not mentioning the non-CO_2 effects results in a distorted focus.

5 Conclusion

There is no doubt to the benefits the adoption of SAF has for the environment. Through the application of the PESTEL-analysis certain challenges, both isolated and in interrelation, have been identified. First and foremost, the greatest challenge that needs to be overcome, is the economical burden associated with implementing Sustainable Aviation Fuel. No conclusive solution has in this thesis been identified when it comes to financing the transition, however, it is evident that a collaboration between airlines and political organs/lawmakers will be required to find common ground.

In relation to the above it has also been found imperative that international legislation, commonality, and uniformity is required to avoid distortion in the market. A challenge that is essential to overcome in this regard, is the potential of bureaucracy when many participants with different interests are to find mutual understanding.

Currently, the cost of producing HEFA SAF is substantially lower than PtL. However, PtL has in this thesis been identified as the future solution due to the inexhaustibility of feedstocks used in production. Until technology has reached a state of maturity where PtL is economically feasible, HEFA SAF could be used as a transitional propulsion.

On a positive note, a general commonality of all parts involved, also passengers, is that finding a sustainable solution entails the adoption of SAF.

5.1 Limitations and future work

Limitations to this thesis have also been acknowledged. The PESTEL-analysis provides an understanding of the problem at hand in a wider context; however, the collection of data is time-consuming and complex. As such, it does not provide a comprehensive examination of the factors.

As this thesis aims to present a view on the implementation of SAF from an airline perspective the primary focus has been on a review of literature with support from interviews with stakeholders in the industry. In that connection it has been natural to look for previous applications of the PESTEL-analysis in relation to SAF, however this has not been possible to find. As there are many stakeholders – such as airlines, fuel companies, governments/authorities, production units, farmers etc. – this thesis however did find the PESTEL application an appropriate instrument to present a good overview of the challenges and benefits associated with the adoption of SAF, since various perspectives and their interrelation are integral to the PESTEL-analysis. Implementation of SAF is a very complex topic due the inherent nature of aviation. A vast array of stakeholders, national and international regulatory agencies, limited economic margins as well as conflicting environmental goals certainly does not make this topic less complex. There will be factors affecting the adoption of SAF that is not governed in the PESTEL-analysis, however it is still considered to embrace a wide range of external components.

This thesis creates an overview of external factors influencing the implementation of SAF, enabling readers to delve into elements of the PESTEL with the potential for further studies in each of the elements of the PESTEL, possibly making use of quantitative or mixed methodology.

A relevant further study could include an analysis of the transition phase from HEFA to PtL SAF, possibly looking into the development in technology and how this could this to new approaches following the leading-edge principle.

Although the maritime industry faces different challenges than aviation and generally operate with higher margins, it is of high relevance to compare and exchange experience gained during the green transition. In relation hereto is the limitation of green carbon and how delegation of this according to industry is required.

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6 Appendix

6.1 Appendix 1: CORSIA Sustainability Criteria (ICAO, 2022b)

CORSIA SUSTAINABILITY CRITERIA APPLICABLE FOR BATCHES OF CORSIA SUSTAINABLE AVIATION FUEL PRODUCED BY A CERTIFIED FUEL PRODUCER ON OR AFTER 1 JANUARY 2024:

Theme	**Principle**	**Criteria**
1. Greenhouse Gases (GHG)	Principle: CORSIA SAF should generate lower carbon emissions on a life cycle basis.	Criterion 1.1: CORSIA SAF will achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
2. Carbon stock	Principle: CORSIA SAF should not be made from biomass obtained from land/aquatic systems with high biogenic carbon stock.	Criterion 2.1: CORSIA SAF will not be made from biomass that is either obtained/extracted from land or aquatic ecosystems converted after 1 January 2008 that was primary forest, wetlands, peat lands, coral reefs, kelp forests, seagrass meadows, estuaries, tidal salt marshes or mangrove forests or contributes to degradation of the carbon stock in primary forests, wetlands, peat lands, coral reefs, kelp forests, seagrass meadows, estuaries, tidal salt marshes or mangrove forests as these systems all have high carbon stocks.
		Criterion 2.2: In the event of land use conversion after 1 January 2008, as defined based on the Intergovernmental Panel on Climate Change (IPCC) land categories, direct land use change (DLUC) emissions will be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value will replace the default ILUC value.
3. Greenhouse gas Emissions Reduction Permanence	Principle: Emissions reductions attributed to CORSIA SAF should be permanent.	Criterion 3.1: Operational practices will be implemented to monitor, mitigate and compensate any material incidence of non- permanence resulting from carbon capture and sequestration (CCS) activities.
4. Water	Principle: Production of CORSIA SAF should maintain or enhance water quality and availability.	Criterion 4.1: Operational practices will be implemented to maintain or enhance water quality.
		Criterion 4.2: Operational practices will be implemented to use water efficiently and to avoid the depletion of surface or groundwater resources beyond replenishment capacities.

-3-

ICAO document — CORSIA Sustainability Criteria for CORSIA Eligible Fuels

5. Soil	Principle: Production of CORSIA SAF should maintain or enhance soil health.	Criterion 5.1: Agricultural and forestry best management practices for feedstock production or residue collection will be implemented to maintain or enhance soil health, such as physical, chemical and biological conditions.
6. Air	Principle: Production of CORSIA SAF should minimize negative effects on air quality.	Criterion 6.1: Air pollution emissions will be limited.
7. Conservation	Principle: Production of CORSIA SAF should maintain biodiversity, conservation value, and ecosystem services.	Criterion 7.1: CORSIA SAF will not be made from biomass obtained from areas that, due to their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area, unless evidence is provided that shows the activity does not interfere with the protection purposes.
		Criterion 7.2: Low invasive-risk feedstock will be selected for cultivation and appropriate controls will be adopted with the intention of preventing the uncontrolled spread of cultivated alien species and modified microorganisms
		Criterion 7.3: Operational practices will be implemented to avoid adverse effects on areas that, due their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area.
8. Waste and Chemicals	Principle: Production of CORSIA SAF should promote responsible management of waste and use of chemicals.	Criterion 8.1: Operational practices will be implemented to ensure that waste arising from production processes as well as chemicals used are stored, handled, and disposed of responsibly.
		Criterion 8.2: Responsible and science-based operational practices will be implemented to limit or reduce pesticide use.
		Criterion 8.3: Operational practices will be implemented to prevent, minimize, and mitigate any damage from unintentional release of fossil resources, fuel products, and/or other chemicals.

9. Seismic and Vibrational Not applicable

10. Human and labour rights	Principle: Production of CORSIA SAF should respect human and labour rights.	Criterion 10.1: CORSIA SAF production will respect human and labour rights.

11. Land use rights and land use	Principle: Production of CORSIA SAF should respect land rights and land use rights including indigenous and/or customary rights.	Criterion 11.1: CORSIA SAF production will respect existing land rights and land use rights including indigenous peoples' rights, both formal and informal.
12. Water use rights	Principle: Production of CORSIA SAF should respect prior formal or customary water use rights.	Criterion 12.1: CORSIA SAF production will respect the existing water use rights of local and indigenous communities.
13. Local and social development	Principle: CORSIA contribute economic regions of poverty. Production of SAF should contribute to social development in regions of poverty.	Criterion 13.1: CORSIA SAF production will strive to, in regions of poverty, improve the socioeconomic conditions of the communities affected by the operation.
14. Food security	Principle: Production of CORSIA SAF should promote food security in food insecure regions.	Criterion 14.1: CORSIA SAF production will, in food insecure regions, strive to enhance the local food security of directly affected stakeholders.

6.2 Appendix 2: Interviewee #1, Danish Ministry of Climate, Energy and Utilities, May 25th 2023

Through Ministry Attorney

Opening question:

- Explain about your background and its relevance to the overall subject (industry, experience etc.)

Main Question:

- Do you see the use of Sustainable Aviation Fuel (SAF) in the solution to reducing aviation's overall emission footprint?

Follow-up questions:

- How do you see the political challenges in lowering the costs of SAF to a level equal to conventional JetA1 fuel? And; How is this achievable?
- What incitements are currently given from political organizations in order to make SAF-production more attractive, thereby helping the operators to lower the costs?
- What technological challenges does the Ministry identify regarding starting a SAF-production in Denmark?
- In regards to the latest political *Luftfartsudspil* (a future Aviation Presentation), a passenger-emission tax has been introduced. Inform about your considerations regarding the optimum fee, how the tax-money should be invested etc.?
- How is your thoughts on an international cooperation regarding an international aviation-emission-law? Will it be beneficial or too complex for nations to come together?

Concluding Questions:

- Do you have anything to add, or anything you find relevant which we have not yet covered?

6.3 Appendix 3: Interviewee #2, Danish Ministry of Transport, June 7th 2023

Through Ministry Attorney

Opening question:

- Explain about your background and its relevance to the overall subject (industry, experience etc.)

Main Question:

- Do you see the use of Sustainable Aviation Fuel (SAF) in the solution to reducing aviation's overall emission footprint?

Follow-up questions:

- How do you see the political challenges in lowering the costs of SAF to a level equal to conventional JetA1 fuel? And; How is this achievable?

- What incitements are currently given from political organizations in order to make SAF-production more attractive, thereby helping the operators to lower the costs?

- What technological challenges does the Ministry identify regarding starting a SAF-production in Denmark?

- In regards to the latest political *Luftfartsudspil* (a future Aviation Presentation), a passenger-emission tax has been introduced. Inform about your considerations regarding the optimum fee, how the tax-money should be invested etc.?

- How is your thoughts on an international cooperation regarding an international aviation-emission-law? Will it be beneficial or too complex for nations to come together?

Concluding Questions:

- Do you have anything to add, or anything you find relevant which we have not yet covered?

6.4 Appendix 4: Interviewee #3, Copenhagen Airport (CPH), May 15th 2023

Through CPH Senior Sustainability Advisor

Opening question:

- Explain about your background and its relevance to the overall subject (industry, experience etc.)

Main Question:

- Do you see the use of Sustainable Aviation Fuel (SAF) in the solution to reducing aviation's overall emission footprint?

Follow-up questions:

- How do you as an airport identify technological challenges regarding the infrastructure in the airport (supply from storage to the aircraft) concerning a SAF-production in Denmark?

- How is it possible in practical terms to blend in a specific percentage SAF on a certain flight, and not having a general blend for all departures?

- In regards to the latest political *Luftfartsudspil* (a future Aviation Presentation), a passenger-emission tax has been introduced. Please inform about your considerations regarding the optimum fee, how the tax-money should be invested etc.?

- CPH is invested in the project *ALIGHT* and has in this projected conducted analysis regarding other effects of using SAF (noise, other emissions etc.). Are you aware of any preliminary results of this study or other relevant information from *ALIGHT?*

Concluding Questions:

- Do you have anything to add, or anything you find relevant which we have not yet covered?

6.5 Appendix 5: Interviewee #4, Green Power Denmark, 29th March 2023

Through GPD Consultant

Opening question:

- Explain about your background and its relevance to the overall subject (industry, experience etc.)

Main Question:

- Do you see the use of Sustainable Aviation Fuel (SAF) in the solution to reducing aviation's overall emission footprint?

Follow-up questions:

- Is the industry 'on path' in relation to the sustainability goals from the Danish Government?
- How is your impression of the current status of SAF/PtX production in the industry?
- How do you see the challenges concerning infrastructure concerning SAF-production sites to the aircraft?
- Is it possible to draw any parallels to other industries (shipping, trucks etc.), in Green Power Denmark's collection of branches?
- In regards to the latest political *Luftfartsudspil* (a future Aviation Presentation), a passenger-emission tax has been introduced. Inform about your considerations regarding the optimum fee, how the tax-money should be invested etc.?

Concluding Questions:

- Do you have anything to add, or anything you find relevant which we have not yet covered?

6.6 Appendix 6: Interviewee #5, Advanced Surface Plating, 21st June 2023

Through ASP CEO

Opening question:

- Explain about your background and its relevance to the overall subject (industry, experience etc.)

Main Question:

- Do you see the use of Sustainable Aviation Fuel (SAF) in the solution to reducing aviation's overall emission footprint?

Follow-up questions:

- Is the industry 'on path' in relation to the sustainability goals from the Danish Government?
- How is your impression on the political support and willingness in transforming to a more sustainable industry, in general?
- Is it possible for the aircraft of today to safely on aromatic-free SAF?
- Can you elaborate on the positive/negative sides concerning PtL, AtJ and HEGA SAF?
- Is it possible for SAF to supply the entire aviation industry solely with green carbon? Why/why not?
- What is your take on financing the transition? Governmental support, passenger tax etc.?

Concluding Questions:

- Do you have anything to add, or anything you find relevant which we have not yet covered?

6.7 Appendix 7: Interviewee #6, AVISTA Green, 5th June 2023
Through AVISTA Green CEO

Opening question:

- Explain about your background and its relevance to the overall subject (industry, experience etc.)

Main Question:

- Do you see the use of Sustainable Aviation Fuel (SAF) in the solution to reducing aviation's overall emission footprint?

Follow-up questions:

- What are the major legal and political obstacles AVISTA Green faces in the industry?
- How is AVISTA Greens supply of feedstock? International/national? Sufficient amounts?
- How is your impression on the political support and willingness in transforming to a more sustainable industry, in general?
- Does AVISTA Green consider governmental support or economic incentives as a part of transitioning to a sustainable industry, in general?

Concluding Questions:

- Do you have anything to add, or anything you find relevant which we have not yet covered?

6.8 Appendix 8: Interviewee #7, Scandinavian Airlines System, 26th June 2023

Through SAS Sustainability Project Leader

Opening question:

- Explain about your background and its relevance to the overall subject (industry, experience etc.)

Main Question:

- Do you see the use of Sustainable Aviation Fuel (SAF) in the solution to reducing aviation's overall emission footprint?

Follow-up questions:

- How do you see the challenges in lowering the costs of SAF to a level equal to conventional Jet-A1 fuel? And; How is this achievable

- What incentives are currently given from political stakeholders to make SAF-production more attractive, thereby helping both production plants and airlines to lower the financial burden?

- In Denmark the introduction of passenger-tax has recently been agreed upon by the government. In Sweden a passenger-tax has been in place for a few years. Please inform about your considerations regarding the optimum tax-fee, how the tax-money should be invested etc.? And do you see any challenges with a passenger tax? Eg. Airlines' economic incentive to sell less tickets at a higher price.

- How are your thoughts on an international cooperation regarding an international aviation-emission-law? Will it be beneficial or too complex for nations to come together?

- In FY 2022, SAS consumed approximately 3.000 tonnes of SAF. Does SAS have a higher goal for 2023, and how does SAS ensure consistent and reliable supply of SAF?

- How do you asses the economic feasibility of integrating SAF into SAS' operation?

- Do you foresee any specific challenges or opportunities related to the technological integration of SAF into existing aircraft and infrastructure?

Concluding Questions:

- Do you have anything to add, or anything you find relevant which we have not yet covered

6.9 Appendix 9: Interviewee #8, AirSeven A/S, 28th June 2023

Through CEO of AirSeven A/S

Opening question:

- Explain about your background and its relevance to the overall subject (industry, experience etc.)

Main Question:

- Do you see the use of Sustainable Aviation Fuel (SAF) in the solution to reducing aviation's overall emission footprint?

Follow-up questions:

- How do you see the customer-demand for sustainable air travel?

- What solution(s) do you see in transforming the aviation industry to a sustainable one?

- Do you from an airline perspective see any possibilities or limitations in the fact, current aircraft are expected to have a lifetime of 30 years+? Regarding future propulsiontypes, engines etc.?

- How do you see the funding of the costly transition to a "green" aviation industry?

Concluding Questions:

- Do you have anything to add, or anything you find relevant which we have not yet covered?