The Introduction of Carbon Neutral Propulsion Systems and Sustainable Air Fuels in Aviation

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Abstract

Climate change is forcing the aviation industry to transform towards greater sustainability and lower emissions. The aviation industry accounts for about 2.6% of global greenhouse gas emissions (Grewe et al, 2019). Today's jet engines are based on fossil fuel and are responsible for the largest share of CO_2 emissions in the industry. Therefore, key stakeholders are working on the introduction of carbon neutral propulsion systems (CNPS) and sustainable air fuel (SAF).

The dissertation examines the introduction of CNPS regarding emerging competitive advantages for airlines, manufacturers, and fuel suppliers. The focus is set on battery- and liquid-hydrogen-based propulsion systems as well as SAFs. Semi-structured interviews with industry experts from different disciplines were conducted to answer the research questions. Nearly all interviewees agreed that sustainability is the most important strategic topic among their executives thereby underlining the importance of CNPS. All experts are confident about a large-scale implementation of SAFs in commercial aviation. They were less confident about hydrogen- and not confident about battery-based propulsion.

Mandatory SAF quotas and a limited supply of SAF will likely lead to a SAF price increase. Airlines hedging against that risk now can gain a competitive price advantage. Fuel suppliers coming up with SAF mass production technology can gain a first mover advantage. Manufacturers should focus on hydrogen instead of battery technology; for the short-haul aircraft market, an increased demand can be assumed.

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Keywords: aviation, airline, aircraft manufacturer, jet fuel, sustainability, carbon neutral, hydrogen, battery, sustainable air fuel, competitive advantage, strategy.

Sumário

As alterações climáticas forçam a indústria aeronáutica a maior sustentabilidade e a menores emissões. A indústria da aviação é responsável por cerca de 2,6% das emissões globais de gases com efeito de estufa (Grewe et al, 2019). Os motores a jato atuais usam combustíveis fósseis e são responsáveis pela maior parte das emissões de CO_2 na indústria. Por conseguinte, os principais interessados estudam a introdução de sistemas de propulsão de carbono neutro (CNPS) e de combustível aéreo sustentável (SAF).

A dissertação estuda as vantagens competitivas da introdução do CNPS para as companhias aéreas, fabricantes, e fornecedores de combustível. O foco é colocado nos sistemas de propulsão baseados em baterias e hidrogénio líquido, bem como nos SAF. Realizaram-se entrevistas semiestruturadas com peritos da indústria para responder às questões da investigação. Quase todos os entrevistados concordaram que a sustentabilidade é o tópico estratégico mais importante, sublinhando a importância do CNPS. Os peritos estão confiantes numa implementação em larga escala de SAFs na aviação comercial, masmenos confiantes quanto à propulsão a hidrogénio e não confiantes quanto à propulsão a bateria.

As quotas SAF e uma oferta limitada de SAF conduzirão a um aumento do preço das SAF. As companhias aéreas que se protegerem contra esse risco podem ganhar uma vantagem competitiva de preço. Os fornecedores de combustível que adotem tecnologias de produção em massa de SAF podem ganhar vantagem de antecipação. Os fabricantes devem concentrar-se na tecnologia do hidrogénio; para o mercado das aeronaves de pequeno curso, pode presumir-se um aumento da procura.

Título: A Introdução de Sistemas de Propulsão Carbono Neutro e Combustíveis Aéreos Sustentáveis na Aviação

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Palavras-chave: aviação, companhia aérea, fabricante de aeronaves, combustível para jactos, sustentabilidade, carbono neutro, hidrogénio, bateria, combustível para ar sustentável, vantagem competitiva, estratégia.

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1. Introduction

This dissertation is about the competitive advantages achieved through the use of alternative fuels and carbon neutral propulsion systems in aviation. More specifically, it evaluates how sustainable aviation fuels, hydrogen-based and battery-based aircraft can disrupt and transform the industry towards carbon neutrality.

Aviation accounts for 2.8% of all global CO_2 emission (Grewe et al, 2019). Although that does not seem like much, flying is presently one of the most environmentally harmful activities (Grewe et al, 2019). Only 20% of the entire world population have ever flown on an airplane (Gurdus, 2017). However, as flying is becoming cheaper and middle classes and prosperity around the world rise, flying will be available for more people (Addepalli et al, 2018). For many emerging markets, it may become the sole option for traveling; road and rail infrastructure in many emerging markets is, instead, taking a flight is oftentimes the most convenient solution (Addepalli et al, 2018). Traveling can be considered desirable for growing middle classes in emerging markets, and thus, more and more people will be flying in the near future, according to study results from Addepalli et al. (2018). As a result, the aviation industry will eventually account for significantly more than 2.8% of global CO_2 emissions if the industry does not undergo a sustainability transformation.

One possible solution to reduce CO_2 emissions in the airline industry is to reduce flying overall. Especially in Europe, short-distance flights are viewed critically. Presently, political discussions have proposed eliminating all short-distance flights and switching to road and rail transportation for environmental reasons (Götz, 2021; ZDF, 2021; Berliner Zeitung, 2021). Taking a closer look at the presumed issue suggests that this solution may be just political symbolism.

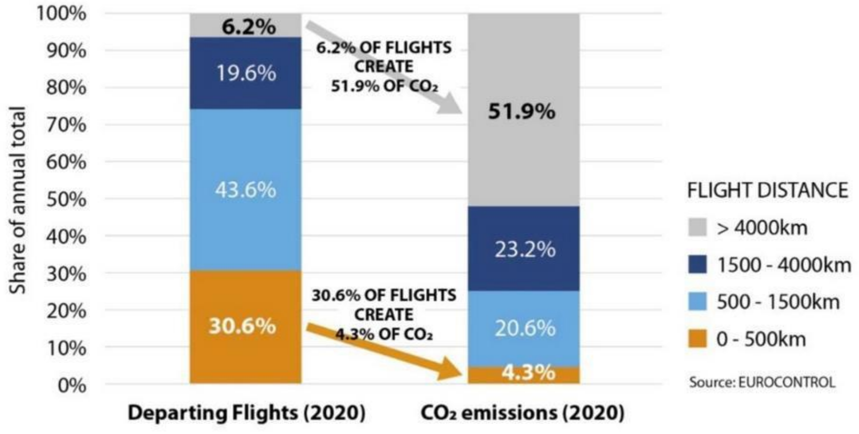


Figure 1: short-distance flights account for just 4.3% of CO_2 emissions. (EUROCONTROL, 2021)

A recent report from Eurocontrol (2021) reveals that short-distance flights make de minimis contributions to the CO_2 airline emissions. Out of the 2.8% global CO_2 emission (Grewe et al, 2019) only 4.3% is emitted by short-distance flights below 500 km distances, while 6.2% of all flights make up for more than half of the CO_2 emissions (Eurocontrol, 2021). Moreover, the CEO of Austrian Airlines said that the airline's short-distance flights are mostly connecting flights. A fact that applies to other airline operations as well. He described the effect of eliminating short-distance flights by giving this example:

> "On a flight from Graz to Vienna, there are hardly any passengers that fly from Graz to Vienna. More than 95% of those passengers connect in Vienna to other flights, for instance, to New York or to Shanghai. If this flight wasn't offered, our passengers do not switch to a train to Vienna, but to another feeder flight, that flies for instance from Graz via Amsterdam to New York or via Frankfurt to Shanghai […] in many cases the passengers would even fly longer detours" (von Hoensbroech, 2021).

While it makes sense to expand efforts to reduce CO_2 emissions, cancelling or reducing flights potentially represents a backstep for modern society. Flights connect people, move freight faster, make travelling hundreds of kilometers a matter of minutes instead of hours. Obviously, continuing with business as usual is not an option and aviation must become more climate neutral as soon as possible. However, there are more rational and viable solutions than banning a certain category of flights. This thesis shows how climate neutral propulsion systems can contribute as a solution and become the core component of transformation towards sustainability in the aviation industry.

1.1.Problem Statement

The Paris climate agreement from 2015, signed by 191 nations and the EU, sets itself the objective of limiting the rise of the average temperatures to below +2°C, preferably below +1,5°C in this century (Glanemann et al., 2020). This requires drastic reductions in emissions along with cutting back on the use of fossil fuels. Stranded assets, meaning natural resources that have been claimed but not used by oil and gas companies because of their carbon footprint, may become a major problem for today's fuel suppliers. This is because it will eventually become too expensive to emit CO_2 by using regular jet fuel. In Europe, the price per CO_2 metric ton is presently at around 60€ and analysts assume further price increases (Flauger et al., 2021). Substitute products less harmful to the environment will become cheaper than regular jet fuel. Therefore, it is no surprise that the aviation industry is conducting intense research on climate neutral technology. The use of fossil fuels in conventional jet engines accounts for the largest share of CO_2 emissions in aviation. Airlines, manufacturers, and fuel suppliers are therefore trying to find new suitable and climate neutral future propulsion systems.

1.2. Academic and Managerial Relevance

Fortunately, there are already promising research approaches. In his article on the topic of elimination of short-distance flights, Austrian CEO von Hoensbroech points out that he sees the future in sustainable aviation fuels (SAFs) rather than within the elimination of flights:

> "We should focus far more on the other 96% of CO_2 emissions in aviation *(Figure 1)*, that can certainly not be replaced by ground transportation […] There is a solution in sight, that can make the entire aviation climate friendly. And this solution is called "Sustainable Aviation Fuels." (von Hoensbroech, 2021).

Sustainable aviation fuel is one of the most popular future technologies. According to Air BP, their "SAF gives an impressive reduction of up to 80% in carbon emissions" (Air BP, 2021). It is equal in quality to standard jet fuel and can be used by all aircrafts in service today that use conventional jet fuel. Thus, it can drop into the existing airport infrastructure and aircraft. Air BP's aviation fuel is either made of algae, non-palm plant oil, animal waste or household waste. The fuel has been successfully tested over the last years in jets of all sizes (Air BP, 2021). Air BP expects that in the future, so-called "power-to-liquid" technology can be used to combine CO_2 from the air with water to produce SAF. The downside of SAF is its production cost. However, Air BP states that "as the technology matures, it will become more efficient and […] less costly for customers." (Air BP, 2021). To broadly establish SAF on a long-term basis, significant investments need to be made in technology research.

SAF is not the only possible solution to lead the industry to carbon neutrality. The design of more efficient aircrafts, smarter operations, and the development of alternative propulsion technologies can contribute as well. The present dissertation will also focus on the latter, being battery-based and hydrogen-based propulsion systems. This new type of aircraft propulsion is fully powered by either electric motors or gas turbines (Airbus, 2021). While SAFs do still emit "recycled" CO_2, electric motors or hydrogen-powered gas turbines are emission free in their use (Airbus, 2021). However, battery-based and hydrogen-based propulsion systems are still subject to research.

1.3. Research questions

The aviation industry is facing an unprecedented transformation. Climate research expects that actors to counteract the climate crisis must decide within this decade; CO_2 emission reductions and cutting on fossil fuels are an integral part of strategies to stop the change in climate (IPCC, 2021). Commercial aviation is one of the industry sectors that rely heavily on the use of fossil fuels and is therefore one of the most important sectors to be transformed. The new opportunities provide airlines and aircraft manufacturers with possibilities for attaining new competitive advantages in this vast and competitive $2.7 trillion industry (Molenaar et al., 2021). This thesis will evaluate the foreseeable future of SAFs and carbon neutral propulsion systems (CNPS) in aviation and resulting competitive advantages for airlines, manufacturers, and fuel suppliers. The research questions examined are:

- **RQ1**: How is the importance of climate neutrality perceived in the aviation industry?
- **RQ2**: How will the introduction of carbon neutral propulsion systems transform the aviation industry?
- **RQ3**: What are the potential competitive advantages for key industry stakeholders that would arise from the introduction of carbon neutral propulsion systems?

2. Literature Review

Competitive advantage in aviation has been achieved by a variety of approaches and strategies; in the past, airlines have used extraordinary service quality and convenience, aircraft safety, cost leadership, or a modified management structure (Al-Romeedy, 2019; Harvey & Turnbull, 2020). Manufacturers and their suppliers meanwhile achieve competitive advantage through technological superiority and product innovation (Mazareanu, 2020; Rutkowski, 2020). The introduction of CNPS could become a new element providing manufacturers, suppliers, and airlines at the same time competitive advantages when used correctly.

2.1. Achieving competitive advantage in aviation

Aviation can be assumed to be a highly competitive industry. Competing airlines serve similar routes and markets, trying to prevail with different strategies (Harvey & Turnbull, 2020). Manufacturers Boeing and Airbus have established a de-facto duopoly; however, they are intense competitors to each other and are being challenged by smaller manufacturers like Embraer and Bombardier in different market niches (Hardiman, 2020; Singh, 2021).

2.1.1. Strategic agility

Rapid changes in the competitive environment due to globalization, innovation, and other factors require companies to adapt quickly (Alavi & Abd-Wahab, 2013). Therefore, companies should review their strategic objectives and policies to respond rapidly and with flexibility to new requirements in their working environment (Al-Romeedy, 2019). Agile organizations are coming up with new and better ways to respond to changes through the development of strategy, technology, human resource structure, and employee training (Zain et al., 2005; Hosein and Yousefi, 2012), a quick meeting of needs, and rapidly entering and exiting alliances alliances (Oyedijo, 2012), as well as offering new services in a timely manner (Shah and Ward, 2003), while taking advantage of opportunities and minimizing risks in an evolving environment (Qin and Nembhard, 2015). According to Al-Romeedy (2019), airlines are no exception. In his case study about Egypt Air, he revealed that the airline has achieved a competitive advantage in the global market through elements such as innovation, service quality, delivery reliability, process flexibility, and cost leadership. His analysis concluded that strategic agility is closely tied to all these elements, with delivery reliability and innovation having the highest impact on competitive advantage. He recommends that airlines should focus on employee training and continuous learning to develop skills, this results in an airline attaining high degrees of innovation, reliability and thus, competitive advantage.

2.1.2. Cost Leadership

Globally, Ryanair is likely one of the most renowned and successful budget airlines. The airline focuses on intra-European routes only, mostly serving second tier airports that are distant from the actual passenger's destination city. In contrast to other airlines that follow the concept of "low cost with care and convenience", Ryanair "refuses to fall for any of this old management bullshit, or MBA rubbish about clichéd concerns for passengers" (Michael O'Leary, CEO of Ryanair, quoted by Kilduff, 2010). Instead, it offers the most basic service to its passengers. Harvey & Turnbull (2020) investigated how the company can be highly profitable. Despite a much lower value-passenger-base, Ryanair is still able to generate profit because while output is homogenous (budget flights), input costs are heterogenous, that is, the airline's marginal costs are much lower than other budget airlines' because of much higher labor productivity and much lower average labor costs (Harvey & Turnbull, 2020). This means fewer aircrew deal with more passengers, and wages, benefits, social payments and taxation are trimmed. The authors consider that Ryanair's total cost advantage, when compared to traditional airlines like British Airways, is close to 60%, principally as a result of their higher labor productivity and significantly lower labor costs for aircrew (Harvey & Turnbull, 2020). Ryanair's competitive advantage is deeply rooted in its strategy for labor and law which 'permits' a traditional configuration of HR management and reinforces the market position of airline's product and its labor market power. The airline has pushed the limits of regulatory ‘spaces of exception’ in their HR structure. For example, it has avoided labor unions that could demand higher basic pay, sick pay, a universal pension scheme, stable crew rosters, predictable working hours, compensation for disruptive schedules etc. Besides its HR structure, Ryanair also achieves competitiveness through tax avoidance (O’Sullivan & Gunnigle, 2009). The Ryanair fleet is mostly registered in Malta and Ireland, which serves as a sort of tax shield for the company (Spero, 2019). The pilots are self-employed, which means they are not taxable in the country in which they work but where they are registered. To save on taxes, Ryanair has obliged its pilots to register in Ireland, which has much lower labor taxes compared to other EU Member States (Harvey & Turnbull, 2020). These tricks and tweaks exploiting the boundaries of law allow Ryanair ultimately to charge minimum prices while still generating 12% margins in 2019 (Harvey & Turnbull, 2020).

2.1.3. Aircraft Safety

A recent paper by Rutkowski (2020) stipulates another competitive advantage, namely aircraft safety. He assumes there are two types of competitive advantages in aviation, a managerial and a technological one. Managerial advantage focuses on airlines and is achieved through good management that leads to airline profitability, allowing it to invest in new innovative aircraft with the latest technology systems. Technological advantage focuses on manufacturers and suppliers; it is achieved by scientific and technical knowledge that yields innovation in products, systems, and other solutions generating competitive advantage. In his paper, Rutkowski (2020) focuses on product innovation in the latest Airbus and Boeing models, the A350 and B787 respectively. Both aircraft allow airlines to operate new long distance and ultra-long-distance flights profitably while offering a high-quality onboard. Product innovations such as a new carbon fiber composite construction, the use of new lightweight materials, and improvement of aerodynamic properties make both aircraft more efficient (see also: 2.1.4 Innovation and Technology). Airlines operating these new aircraft models can tap into new markets or improve the economics on existing routes, which yields competitive advantage. New aircraft can, however, have issues such as battery and engine problems that quickly decrease customer acceptance. The Boeing 787 suffered battery failures shortly after it was introduced, leaving a bad impression on airlines and passengers (Rutkowski, 2020). The A350, which was released shortly after the B787, did not suffer from major issues. It therefore left mostly good impressions on Airbus customers and gave Airbus a competitive edge over Boeing in this market segment during its product launch. Therefore, the author concludes that eliminate early issues with new aircraft by extensive testing is crucial before product launch to achieve satisfactory sales and maintain acceptable levels of safety. When customer acceptance in terms of product safety is achieved, airlines can start to exploit the potential of these aircraft such as reduced operating costs, new routes, increased cruising speed, and better passenger comfort, which can accrue competitive advantages (Rutkowski, 2020).

2.1.4. Innovation in Technology

Modern aircraft are constantly improving and evolving to become more efficient and technologically advanced. The average fuel expenses account for around 23.7% of an airline's total operating expenses (Mazareanu, 2020). Because savings on fuel are significant, it is often cheaper for airlines to buy the latest aircraft from Airbus and Boeing instead of sticking to older models in their fleet (Clark, 2017). According to Clark (2017), a high degree of innovation and research and development expenditure yield competitive advantages for manufacturers because airlines will buy more efficient aircraft. As a result, Clark considers that even seemingly small innovations in weight reduction, flight management computers, or efficiency can change customers' minds about which product to buy or lease (2017). Here are some examples of small and major innovations from the past decade in aviation to which this applies.

- **Brake to vacate system**. Airbus' auto brake system was first introduced with the A380 in 2009 and has since then been incorporated into all of their following models (Kaminski-Morrow, 2019). The system not only prevents runway overruns but also can be set up to brake at the exact distance of a specific turnoff point of the runway after landing. This allows for a very smooth passenger experience and pilots do not need to use the engines to reach their assigned runway turnoff point, saving on fuel.
- **Composite material structure**. Airbus and Boeing are both using composite materials for their A350 and B787 (Singh, 2021). Composites such as carbon fiber are not as heavy and are more robust as standard materials like aluminum, and external factors do not wear and tear them as much. The materials make up 50% of the weight of these two models, a reduction in weight that decreases fuel consumption by 20% and allows for a longer maintenance circle (Singh, 2021).
- **Airbus NEO program**. Airbus equips its latest version of the A320 family with a new set of engines (New Engine Option) from Pratt & Whitney and CFM International (Hardiman, 2020). Together with newly designed wingtips the aircraft delivers 20% fuel reduction compared to the older model.

- **Sharkskin**. Lufthansa wraps its Boeing 777 freighter fleet with a special shark scale-like foil (Lufthansa, 2021). The foil's texture is inspired by marine life to reduce drag and fuel consumption by 1%, saving the equivalent of 48 flights from Frankfurt to Shanghai (Domel et al, 2018).

2.2. Carbon neutral propulsion systems

2.2.1. Battery-based propulsion

A team of Czech researchers has analyzed battery-powered aircraft in general aviation. They focused on the advantages in operational costs and environmental impact when compared to regular fuel-powered aircraft. Their research implicates a bright future for all-electric aircraft in general aviation (Hospodka et al. 2020). However, there are significant limitations to the technology.

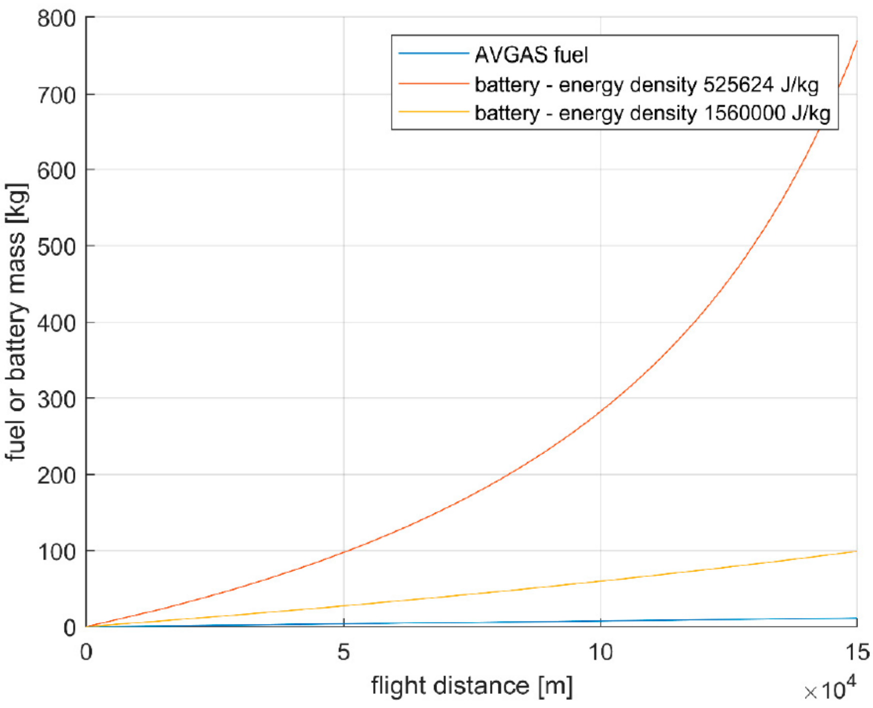


Figure 2: Required mass of batteries increases exponentially with distance (Hospodka et al. 2020)

Their research shows that the energy density required is not yet comparable to AVGAS – the fuel used by small propeller aircraft (figure 2). The required battery mass increases exponentially as flight distance increases. The authors also compared battery performance in lab conditions (yellow line) and their real-life performance (orange line). In both instances, performance was significantly worse than with fuel. The difference in required lithium-ion battery mass increases significantly with increasing flight distances. Future batteries based on lithium-sulfur, graphene, lithium cobalt oxide will most likely achieve today's battery lab performance in real-life, which would still leave a significant gap in fuel vs. battery mass the authors predict. High energy density of fuel is crucial for the economics of airlines for flying distances at a profit. Hospodka et al. (2020) assume that battery research today has been focused on automotive batteries. Accordingly, the energy density of batteries was a focus, while mass and size were not given priority. When considering batteries in aircraft, battery mass and size must be prioritized in addition to its density for a successful use. While small electric propeller aircraft are already licensed and for sale, a breakthrough in battery research is required for implementation in civil aviation (Barzkar & Ghassemi, 2020). Hospodka et al. (2020) are uncertain about battery-based propulsion in commercial aviation.

Cost wise, all-electric aircraft seem to competitive advantages over aircraft with common piston engines. The energy price for electricity is lower than for fuel, and due to the simplicity of electric engines, less maintenance is required (Barzkar & Ghassemi, 2020). According to Hospodka et al. (2020), due to additional fuel consumption caused by the increased mass of the aircraft, the advantage of cheaper electricity is partially neglected. Once again, the energy density of batteries is key for cost effective all-electric aircraft. When analyzing the price of electricity compared to classic jet fuel, “electricity is three times cheaper in comparison and five times for AVGAS” (Barzkar & Ghassemi, 2020). Moreover, policymakers that are tied to the Paris Climate Agreement (Glanemann et al., 2020) can be expected to increase fuel taxation in the upcoming years to incentivize CNPS in aviation, resulting in even more significant cost savings when operating all-electric aircraft (Hospodka et al. 2020).

Environmental impact is perceived as a key element when considering CNPS in aviation. The authors found that the CO_2 emission of electric aircraft are only reduced by 25% when compared to regular aircraft in general aviation. Due to too much fossil fuel associated with the electricity generation and of energy-intensive raw material extraction, the impact on climate is not very significant. Nevertheless, the impact on emissions is positive, “it is obvious that the main benefit of this transition is in lowering emissions endangering health” (Hospodka et al., 2020).

Overall, the authors conclude that “electric aircraft have several benefits in comparison to the piston engine. The direct cost of fuel is significant today and could be even more significant in the future, especially if some adjustment in taxation is made.” Operational limitations are the limited energy density of existing batteries. Further, it is unclear if there are enough resources available for batteries to transform a big portion of the general aviation industry into all-electric aircraft. Both are issues to be solved by future battery research. For the upcoming decade, analysts from Goldman-Sachs (Hallam & Allard, 2021) predict that battery-based "zero-carbon commercial flight is not possible in the near future" and that "evolutionary technologies, offsetting, and sustainable aviation fuels" are the way to go.

2.2.2. Liquid hydrogen-based propulsion

Hydrogen as a source of energy and power has a long history. In aviation, hydrogen was already used in the 20th century to lift the infamous Zeppelins (Robinson, 1973). One of the element's characteristics is that it is lighter than air and generates a natural lift which allows Zeppelins to fly (Boyd, 2015). Another characteristic of hydrogen is its tendency to explode which is a significant risk. In its gaseous state, the element was described as early as 1625 by Johann Baptista van Helmont. The first hydrogen fuel cell was built in 1842 by physicist William Robert Grove (Lubitz & Tumas, 2007). Hydrogen cells are electrochemical cells in which hydrogen and oxygen are converted into electrical energy (US Energy Information Administration, 2021; Jacobson et al, 2005). Fuel cells are key to any hydrogen-based propulsion system. Other than regular batteries, hydrogen fuel cells rely on the continuous supply of hydrogen and oxygen. Oxygen can be retrieved from the air, whereas hydrogen comes from a tank (Jacobson et al, 2005). Outputs next to electricity are water, and a small amount of heat (US Energy Information Administration, 2021; Jacobson et al, 2005). Small hydrogen fuel cells can power phones and computers, whereas large fuel cells can power entire buildings (Jacobson et al, 2005). The fuel cell conversion process does not emit any greenhouse gasses and the materials required exist in abundance (Jacobson et al, 2005). Therefore, it is an attractive and contemporary energy source. However, hydrogen does have disadvantages. In its gaseous state, hydrogen requires lots of volume and massive tanks for storage (Jacobson et al, 2005). As this is impractical in everyday use, hydrogen gets cooled down to -253°C to become a liquid (Petrescu et al., 2020). This is a very energy-intensive process that is negative for sustainability. Further, the extraction and sourcing of hydrogen is energy-intensive as well, according to Jacobson et al (2005), who did research on how hydrogen-based propulsion systems can ultimately provide cleaner air and improve public health. The authors concluded that hydrogen-based propulsion systems are only truly sustainable if the energy required for hydrogen extraction and cooling comes from carbon neutral sources.

According to Khandelwal et al. (2013) the technology can be applied in aviation as well. In aircraft, fuel cells could power two gas turbines that generate enough thrust for taking off and flying short and medium distances (Khandelwal et al., 2013). However, hydrogen fuel cells are expensive, highly explosive, require more space, and need heavy constant cooling (Khandelwal et al., 2013). Not only in the air but also on the ground, new infrastructure is required, the authors concluded. Airports need to build new infrastructure that can handle the requirements of liquid hydrogen fuel and the challenges that come with it (Khandelwal et al., 2013; Petrescu et al., 2020). In addition, the changes in liquid hydrogen-powered aircraft design are significant (Khandelwal et al., 2013). In today's aircraft where design is based on a metal tube, fuel is stored inside the wings. According to Khandelwal et al. (2013) this is not possible for hydrogen aircraft as the shape of the liquid-hydrogen fuel cell must be spherical. Therefore, they suggest that a liquid hydrogen tank must be placed behind the passenger cabin, at the so-called rear pressure bulkhead. Moreover, Khandelwal et al. (2013) point out that a tank would require 18% more space than today's jet fuel tanks to be capable of flying similar distances, as liquid hydrogen has a different energy density compared to jet fuel. This results in less space for passengers and freight, thereby possibly reducing the revenues per seat for hydrogen aircraft, as the authors argue. The Brazilian manufacturer Embraer has moved the aircraft engines to the back for its latest short-distance turboprop model to ready it for the future use of hydrogen technology (Hemmerdinger, 2021). Moving the engines back to the tailplane brings them closer to the hydrogen tank, just as today's engines are mounted below the wings to be close to the jet fuel. Competitor Airbus meanwhile intends to keep the engines on the wings for their hydrogen-powered concept plane (Airbus, 2021). Therefore, Embraer might have a small competitive advantage because their hydrogen-powered aircraft are more efficient and therefore cheaper to operate for airlines.

2.2.3. Sustainable Aviation Fuels

Renewable drop-in kerosene is an attractive option for decarbonization in aviation because it does not require modification of the aircraft, its engines, and the existing refueling infrastructure (Bauen et al., 2020). At present, batteries cannot match the performance of liquid hydrocarbon fuels, which means that in the short and mid-term for short-haul flights – and in the long-term for long haul flights – flying will remain jet-fuel based (Sustainable Aviation, 2020). Today, only small quantities of sustainable air fuels (SAF) are produced, at a significantly higher cost than regular jet fuel. An initiative for promoting SAF in the UK created by major industry players predicts that SAF will be an essential bridging technology to decarbonize the challenging aviation sector until batteries become relevant for civil aviation (Sustainable Aviation, 2020). The initiative underlines the importance of support from policymakers, not only in the UK but worldwide. A report from Goldman-Sachs's analysts (Hallam & Allard, 2021) goes even further and predicts that SAFs "are likely to be more widely adopted in the coming decade". The use of SAF will require governmental financial subsidies to encourage companies and investors in SAF investments (Air BP, 2021). Supported by the right policy, introducing SAF could reduce UK emissions by 32% (Sustainable Aviation, 2020). A model designed by Bauen et al. (2020) further points to the potential of SAF. Their analysis estimates that SAF will contribute to 4-8% of the global aviation fuel use in 2035, and a third of the UK's fuel needs until 2050. The authors assume that technology converting solid and liquid waste as well as industry waste gases will contribute SAF until 2035, while from there carbon capture technologies and algae will take over (Muldoon and Harvey, 2020). During this year's IATA annual meeting (International Air Transport Association), all major airlines agreed on a target to reach net-zero carbon emissions by 2050 (IATA, 2021). 300 airlines are part of this association, covering over 94% of international air transportation (IATA, 2021). This already can be considered a major milestone. However, Chinese airlines have found this too ambitions and sought to push the target year to 2060 (Petchinek, 2021). It is planned that SAF will fuel most of the aviation's global emissions mitigation by then (IATA, 2021). Starting from 2025, their plan foresees that SAF must make up 2% (8 billion liters) of total fuel requirements, in 2050 the SAF share will be around 65% (449 billion liters). However, industry transformation requires large investments and can only be successful through collaborative action. Therefore, governments need to back up the industry as it explores the most promising technology to achieve the goals of the Paris Climate Agreement (Petchenik, 2021).

3. Methodology

There are different approaches in research design and data gathering (Bryman, Bell, & Harley, 2018). This dissertation uses a qualitative research approach to answer the research questions. According to Silverman (2020), the best way to obtain data within a niche in an already specialized industry such as aviation is to interview experts. Insights from in-depth interviews can be understood as the primary source of data. Hill and Rothaermel (2003) suggests that the primary data should be combined with secondary data. The insights from current research reflected in the literature are therefore used as a secondary data source.

3.1. Research Design

To obtain the data, semi-structured interviews with industry experts were conducted to draw relevant findings and implications. This method is aligned with Diefenbach's (2009) understanding of collecting and obtaining data using expert interviews. Moreover, a general industry analysis using the Porter's Five Forces framework (Porter, 1979) provided an overall understanding of the aviation industry landscape. Silverman (2020) suggests interviewing experts from different disciplines within a particular branch of industry to capture as many views as possible from different backgrounds. A wide range of aviation industry experts (see table 2) have been interviewed in order to review the thesis topic from different angles. Interviewees had two predefined requirements: they were only found suitable when exceeding five years of relevant experience in aviation and having a position in management or something equivalent. There were ten participants in total from which ten interviews were used for the analysis. The interviews were conducted via video call and averaged 30 minutes in length. They were recorded with consent and summarized (see appendix). Two interviewees preferred not to be recorded. All interviewees are anonymized.

3.2.Data Collection

The interview questions were set up in a way that they could be answered by every participant, no matter what the professional background. This meant that airline managers were asked the same questions as engineers, aviation consultants, or pilots. No candidate was told beforehand that the aim of the dissertation was to identify new competitive advantages that could arise in the course of the transition to climate neutrality in the industry. This method was used to ensure unbiased answers from the interviewees. According to Diefenbach (2009), semi-structured interviews use structured questions, however, the interviewer can diverge from the interview guide and ask follow-up questions. The interview guide consisted of 12 structured questions (see table 1) that can be classified into one of three categories: yes and no questions, open questions, ranking questions.

It can be assumed that the main driver behind carbon neutral propulsion systems (CNPS) is climate and sustainability requirements. To determine whether the technologies discussed in the literature review are relevant for the aviation industry it was key to research the true significance of sustainability in the industry. The transformation of the industry towards sustainability is connected to significant efforts and investments. Therefore, only if sustainability is of highest priority did it make sense to investigate the competitive advantages of climate-neutral propulsion systems. Hence the first seven questions covered the importance of sustainability in aviation in general. Subsequent questions 8 to 12 were more specific about the introduction of CNPS, subsidization, and competitive environment to answer the research questions.

ID	QUESTION	TYPE
1	Is sustainability the most important strategic topic to the company executives right now?	*Yes/no*
2	When does your company want to achieve climate neutrality?	*Open*
2.1	Do you also want to achieve it for your value chain?	*Yes/no*
3	Are you more satisfied with your company's attitude or actions towards sustainability?	*Attitude/ action*
4	Are economic efficiency and sustainability a contradiction in terms?	*Yes/no*
5	Which three challenges do you face to achieve carbon neutrality in aviation?	*Open*
5.1	How are you tackling them?	*Open*
6	During this year's IATA annual meeting, member airlines agreed on achieving carbon neutrality by 2050. On a scale of 1-5, how realistic is carbon neutrality in aviation?	*Ranking*
7	Which steps is your company undertaking to implement sustainability at the core of its business model?	*Open*
8	On a scale from 1-5, how confident do you feel about large-scale implementation of: 1. SAFs 2. electric propulsion 3. hydrogen propulsion?	*Ranking*
9	How would you rank the importance of these 3 technologies (S, E, and H) to achieve a sustainable aviation industry?	*Ranking*
10	Are SAFs just a bridging technology until hydrogen and electric aircraft become more viable?	*Yes/no*
11	SAFs are an essential tool for achieving carbon neutrality in aviation. However, their success is highly dependent on government subsidies. How must this subsidizing look like to get to a technology breakthrough?	*Open*
12	Do you think that new companies working on these propulsion systems can disrupt long-established players within the aviation value chain? If so, why?	*Yes/no*

Table 1: interview guide

The interview guide was designed in a way that the answers could be used to derive implications for competitive advantages in aviation that are related to the shift to climate neutrality. The data set obtained is analyzed in the subsequent content analysis and discussed.

4. Findings

Table 1 lists the interviewees anonymously and their respective job position. Their answers will be described in detail in the findings part and analyzed in the discussion part.

ID	ROLE	TYPE
EXPERT 1	Executive of a major Austrian airline	Airline Manager
EXPERT 2	Executive of a major Canadian airline	Airline Manager
EXPERT 3	Head of strategy and sustainability of a large European airline	Airline Manager
EXPERT 4	Research engineer for new propulsion systems at a large European aircraft manufacturer	Aircraft Manufacturer
EXPERT 5	Executive at a large European aircraft manufacturer	Aircraft Manufacturer
EXPERT 6	Manager at a large American aircraft manufacturer	Aircraft Manufacturer
EXPERT 7	Pilot (First Officer) at a German airline	Pilot
EXPERT 8	Pilot (Captain) at a Portuguese airline	Pilot
EXPERT 9	Partner for aviation at a renown consulting company	Consultant
EXPERT 10	Manager at a startup in alternative aircraft fuels industry	Fuel Supplier

Table 2: interviewee roles and types

4.1.Industry Analysis using Porter's Five Forces framework

To get a better overall understanding of the aviation industry, Porter's Five Forces framework (Porter, 1979) has been applied to the airline industry. It reveals the airline industry landscape and its competitiveness. Implications for the airline value chain, for example, aircraft manufacturers and fuel suppliers, can be drawn from this.

1. Supplier bargaining power: **high**. Airlines rely on lots of inputs like aircraft, fuel, and labor to function properly.
2. Buyer bargaining power: **high.** Customers have a variety of airlines or substitute products to choose from.
3. Substitution threat: **medium.** The covid pandemic revealed that lots of travelling can be substituted by video calls. Public transportation and private cars are threats on short-distance routes. Policymakers might apply tariffs to incentivize more climate friendly traveling.
4. Entry barriers: **high.** Capital and labor-intensive, regulatory hurdles.

5. Industry competition: **high.** Lots of airlines serving the same markets, routes, and customer groups.

Overall, the industry is highly complex, competitive, and contested. The space for business errors is small and requires sophisticated strategies. In this environment, it is not only desirable but also vital to successfully highlight and exploit a competitive advantage. Nonetheless, airlines and their entire value chains are an important and prestigious economic factor for governments and societies, as they create an abundance of jobs and open up countries for goods and people. Further implications of this analysis in the context of the interview findings will be discussed in the discussion part.

4.2.Description of the interview findings

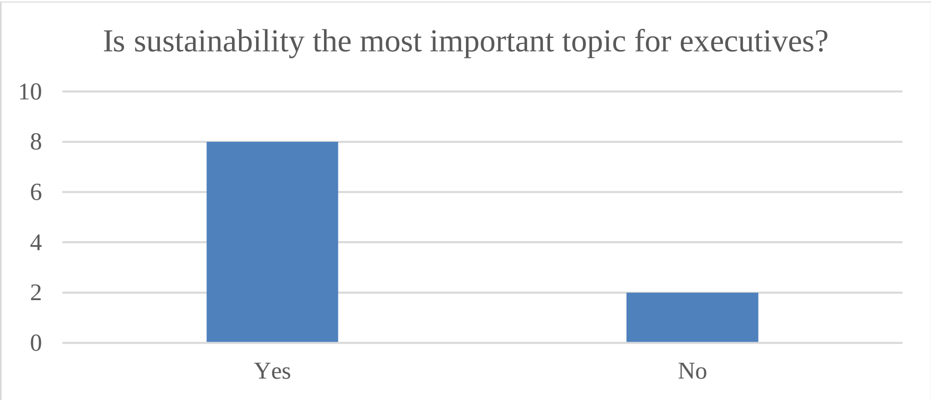
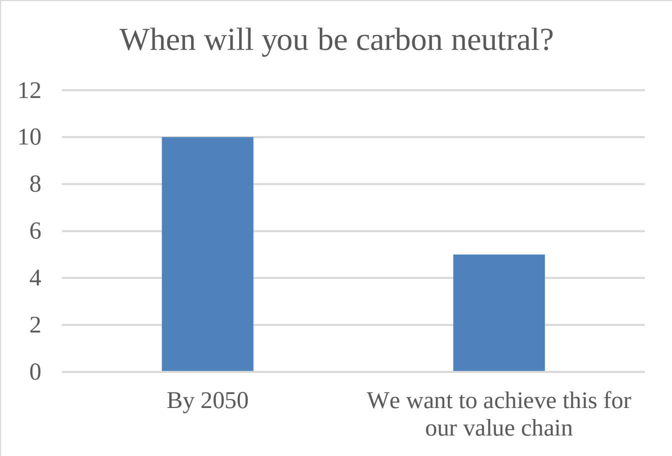


Figure 3: interview question 1

The first question of the interview guide was if sustainability was the most important strategic topic to the company executives at the time of the interview. This was asked in order to measure the present importance of the topic and how seriously the employer is taking sustainability. From this, a better understanding of the strategy behind self-set goals in climate neutrality can be derived. The results are unambiguous, eight participants answered with yes and two with no. The two “no” answers were given by experts 7 and 8, both pilots. This could be because they are not as involved in management as the other participants. Sustainability has replaced digitalization or the impact of the covid pandemic for companies and their executive`s agendas. Moreover, experts answering “yes” said that climate neutrality was the most important component within sustainability.



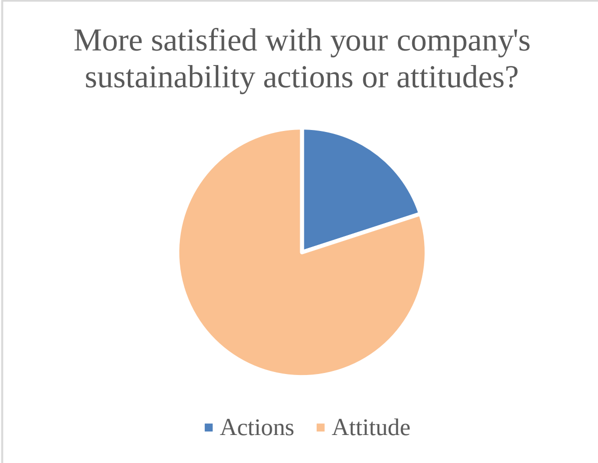


Figure 4: interview questions 2 and 3

Question two (*What is your goal for becoming climate neutral?*) and three (*Are you personally more satisfied with your company's actions or attitude towards sustainability?*) are both concerning climate neutrality goals of the company. Question two focuses on measurable company goals for sustainability while question three refers to the perception of experts towards sustainability within their own companies.

All companies have set goals to become climate neutral in 2050. Expert 9 and 10, the consultant and the startup manager working on SAFs respectively, were asked when their clients wanted to become climate neutral. Five of ten experts said they wanted to achieve climate neutrality for their value chain as well, which is remarkable considering the complex value chain of airlines or aircraft manufacturers. These questions were asked to see if there were misalignments between company goals and the confidence of its employees in achieving them, ultimately researching the relevance of sustainability for the company as a whole.

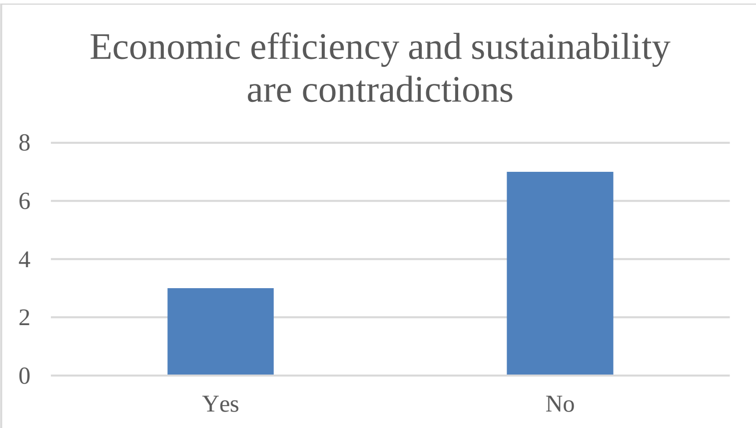


Figure 5: interview question 4

The experts were divided whether economic efficiency and sustainability go together or represent a contradiction for aviation. Although a majority of 7 voted "no", three voted for "yes" in question four. Those voting for “yes” were experts 6 (aircraft manufacturer manager), 7 (pilot) and 9 (consultant). It is remarkable that experts 6 and 9 said yes this is a contradiction, because it is not aligned with their own (clients’) company goals of climate neutrality by 2050 and sustainability is the most important imperative for executives. All “yes” votes justified their answers by saying that the aviation industry as such is too dependent on conventional fuels and that CNPS could lead to climate neutrality. But without subsidies they are permanently too expensive for an industry with traditionally low margins. Therefore, this is against profitability and economic efficiency. However, 7 out of 10 experts did not share these concerns and were rather confident that sustainability and economic efficiency can go together in the aviation industry, although this transformation will require lots of resources.

Question five was an open question: *Which three challenges do you face to achieve carbon neutrality in aviation*? *How are you tackling them*? The top three challenges for sustainable aviation and the introduction of CNPS are affordability, technical hurdles, and industry commitment. As of today, SAFs are three to four times more expensive than regular jet fuels, experts 1 (airline executive) and 10 (SAF production startup) underlined. The production price is too high and needs to be subsidized to be competitive. Liquid hydrogen or battery-based propulsion systems need R&D as there are still concerns about how exactly the industry can benefit from this technology. The extraction of hydrogen is harmful to the environment. Small quantities of green hydrogen are already available, but these are far more expensive alternatives than the current extraction method and thus face the same challenges as SAFs. Industry commitment is the third challenge; interviewees mentioned that the industry’s transformation towards climate neutrality cannot be enforced by single industry players. Governments across the world need to set equal guidelines and incentives for the industry, the experts agreed. Only through regulation can companies be guaranteed long-term planning security and commitments can be enforced.

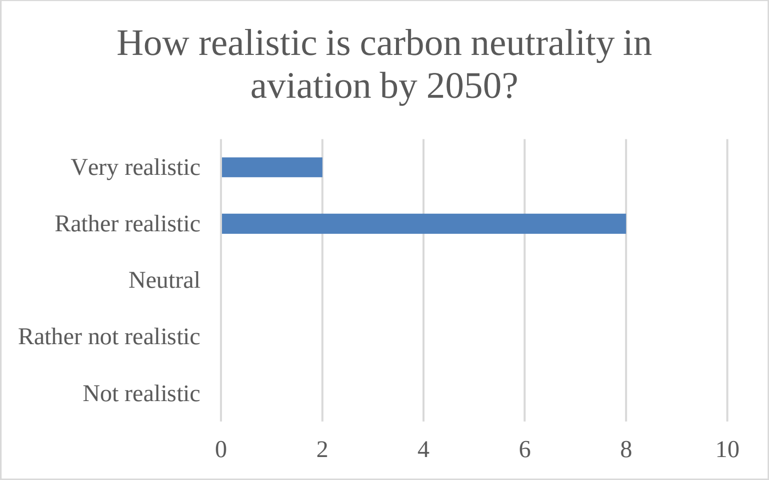


Figure 6: interview question 6

Despite all the concerns about feasibility and whether sustainability and economic efficiency are mutually exclusive, all experts considered it realistic (8) or very realistic that climate neutrality in aviation will be achieved by 2050. As all airlines organized within IATA agreed on this goal in 2021, airline suppliers such as manufacturers are following now. The aircraft manufacturer experts also named 2050 as the target for climate neutrality for their respective companies. Even if that is still 29 years into the future, the airline industry is characterized by very long research and development cycles. This deadline is not that far away by industry standards. Boeing and Airbus both have significant backlogs in orders (Boeing: 5,058 aircraft, Airbus: 6,893 aircraft as of 10/2021) that will be produced within the next decade and in service for around 20 years and not contributing to climate neutrality if not using SAFs (Oestergaard, 2021). This explains why eight out of ten interviewees answered question 7 “rather realistic” instead of “very realistic”. Aircraft with other climate neutral propulsion such as liquid hydrogen-based or battery-powered systems are still in development.

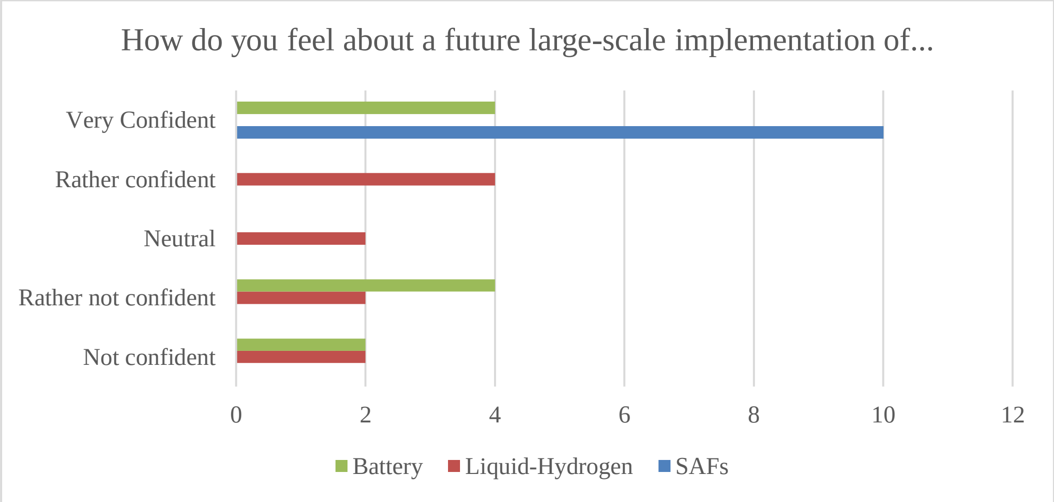


Figure 7: interview question 8

Experts were asked how confident they felt about a large-scale implementation of the three discussed propulsion systems in the future in question 8. All were very confident about sustainable fuels. While experts agreed on SAFs being a short-term solution, they did not agree on whether SAFs are just a bridging technology or would remain for the foreseeable future.

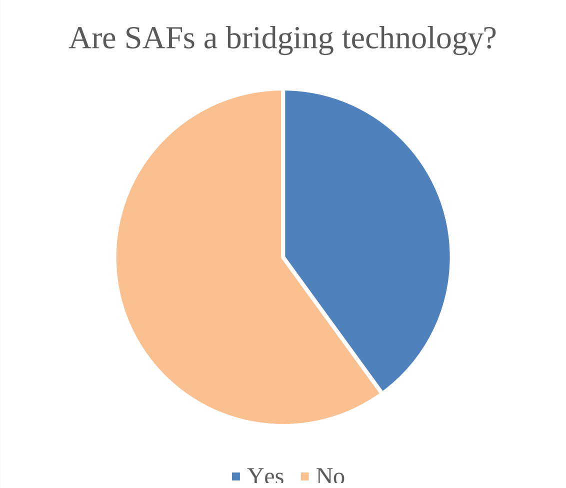


Figure 8: interview question 10

The reasons for an affirmative response were that SAFs do still emit CO_2 in high altitudes and can never be as green relative to the other two technologies. The reasons for no were that SAF is the most convenient solution as it does not require adaptation of current aircraft and is less expensive.

Experts differed in confidence about battery and liquid hydrogen powered aircraft as well. It was notably expert 5 (executive of a European aircraft manufacturer) who was more confident about battery-based technology than hydrogen propulsion technology, although he mentioned only envisaging battery-based aircraft in small planes in general aviation. Expert 5 is in charge of R&D at his company, which is now conducting strong research on hydrogen-based propulsion technology and not battery technology. However, he was only "rather confident" about a large-scale implementation of this technology in aviation.

Expert 3 (head of strategy and sustainability at a large European airline) was even more pessimistic about a large-scale implementation of hydrogen aircraft and answered with "rather not confident", although his employer airline launched a big research hub for liquid hydrogen in aviation just in 2021. His biggest concern, shared by other interviewees as well, was not the technology itself but the airport infrastructure which is not built to serve hydrogen aircraft and requires substantial investments.

Expert 4 (engineer working on hydrogen-propulsion technology at a European aircraft manufacturer) was more confident about a large-scale introduction of his work. Although a great deal of research is still required, he is rather confident about a future with hydrogen short to mid-range aircraft. He rejected battery-powered aircraft, however, saying that power generation for commercial aviation routes must necessarily take place on board.

Being asked about ranking the importance of the three propulsion systems to achieve a sustainable aviation industry (question 9), all experts ranked SAFs clearly first, hydrogen second, batteries third. Manufacturing batteries is an environmentally harmful process; their capacity is not going to increase enough in the foreseeable future to allow for long flights, the experts argued. Further, they assumed that the hydrogen technology will have a wider range of applications in aviation and thus a greater impact on climate neutrality when being implemented on a large scale.

It is evident from the literature that SAFs can only achieve a breakthrough with government subsidies. Therefore, interviewees were asked how optimal SAF subsidies must be structured (question 11). First, there was no consensus among the experts regarding who should pay for the increased costs of SAF. The airline experts argued that all additional SAF costs should be paid by government subsidies, non-airline experts favored passing on some of the increased costs to customers via ticket prices. Airline experts said that under no circumstances should European airlines have significantly higher fuel costs than foreign carriers, otherwise they would be at a major competitive disadvantage. Therefore, they brought up a mandatory SAF quota for all flights leaving Europe. The SAF quota, which has already been discussed and finalized in Europe and the USA, comes with levies which should be earmarked for SAF research. Other ideas of what to subsidize include SAF research funds, airlines that refuel with SAF, financial support for blending SAF quota.

The last question asked the experts whether they expected a long-term disruption of the industry by new market players emerging as a result of industry transformation.

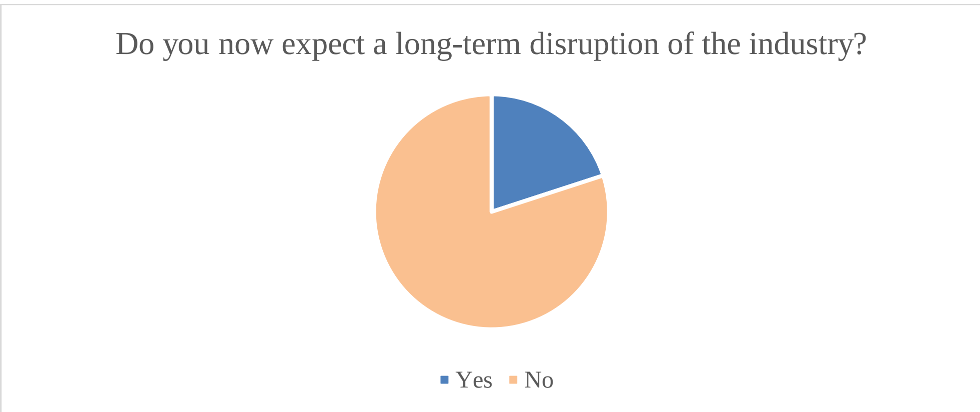


Figure 9: interview question 12

A majority of eight said no, two answered yes. Concerning manufacturers, the Airbus Boeing duopoly is unlikely to be dissolved quickly and is instead expected to continue. The difference in technology between the two competitors is expected to be minor as they use similar suppliers for their aircraft. Expert 5 said employees at the two incumbents are researching the exact same technological things simultaneously and neither Airbus nor Boeing have enough capacity to serve the global jet market by themselves. Expert 6 (manager at an American aircraft manufacturer) said that new short- and medium-haul aircraft cannot be developed quickly enough to become serious competitors. Moreover, neither of the experts considered aircraft manufacturers from Russia or China as serious threats to their business. However, the experts saw an increasingly competitive landscape in the regional jets market, as battery and especially hydrogen propulsion systems are made for typical distances in this segment.

The airline experts justified their “no” answers concerning no likelihood of market disruption differently. Network carrier airlines rely on feeder traffic for their big hubs; therefore, they need planes with enough seat capacity which small future aircraft equipped with hydrogen tanks or batteries do not have. The introduction of SAF will not disrupt or affect the competitiveness of global airlines as long as it is not to their disadvantage to refuel with more expensive SAF instead of regular fuel.

Expert 10 argued that fuel suppliers that can provide significant amounts of SAF could change and disrupt the existing air fuel supplier landscape. Although many companies are doing research on SAF mass production such as carbon capturing and power to liquid technologies no one has yet had a significant breakthrough. Moreover, airlines operating short-distances only might capture competitive advantages in terms of fleet operating costs with a pure battery-based or hydrogen-based fleet as they can benefit from cost advantages over regular regional aircrafts.

5. Interpretation and Discussion

5.1. Sustainability in aviation

Top executives identified sustainability as the most important strategic issue in aviation. The insights derived from questions one to eight of the interview guide have answered **research question 1** sufficiently (*how is the importance of climate neutrality perceived in the aviation industry?*). The importance of sustainability is given high priority by accountable managers. In some companies sustainability is within the responsibilities of the CEO. Expert 3 served as a good indicator for high relevance of sustainability in aviation as well. His strategy department got restructured to become the company’s strategy and sustainability department. Strategy and sustainability are both being integrated. Previous top strategic issues, such as digitization and the Covid-19 pandemic, are still considered weighty but not equally important by industry executives. The importance and urgency of sustainability in aviation has been understood, and the issue is being driven by the top executives in the company. This prepares the ground for a successful transformation of the industry and gives sustainability projects a realistic chance of succeeding. The fact that climate change was seen as the most important component of sustainability automatically directs the focus to CO_2-saving measures in the industry. The burning of fossil fuels-based jet fuel in commercial aviation is responsible for the vast majority of the industry's CO_2 emissions and is therefore the biggest lever. As a result, climate neutral propulsion systems have come into the focus of decision-makers.

The airline industry analysis using Porter's Five Forces revealed that the market is characterized by strong competition. Capturing trends in time is crucial for success. However, sustainability and climate neutrality are not just perceived as trendy topics but rather as a future part of the core business model, giving them higher importance. To maintain competitiveness in an already tight market, companies must act swiftly yet carefully. For airlines, this includes, for example, the procurement of sufficient SAF to meet possible mandatory quotas, for manufacturers investments in hydrogen and battery technology research, and for fuel suppliers this means development of low-cost mass production tools for SAF. With collaborative action, the industry can achieve climate neutrality by 2050 as a set goal. At present, company executives want to achieve so called level 2 climate neutrality, meaning the company itself is climate neutral. However, next steps will be level 3 climate neutrality, which includes the companies' value chains. Half of the interviewees said they are already working towards the level 3 goal. However, they are less satisfied with their actions than with their attitudes towards sustainability. "Actions can only be derived from the right attitude", expert 4 said. Even if this is true, the decision-makers must now take courageous action. The path to climate neutrality in aviation will certainly involve difficult decisions. Therefore, true leadership qualities are required over the next decade to drive industry transformation successfully. It can be derived from the interviews that some experts have not yet accepted that this major shift towards sustainability comes with its downsides and instead they anticipate a largely silent transformation of the industry. All interviewed airline experts pointed out their carbon neutrality strategy relies heavily on the use of SAFs. However as of today, there is barely any SAF available on the global market, production is expensive and only possible at a small scale. Although a breakthrough in this technology might happen within the next years, it is not yet given and therefore a risk to their strategies.

The discrepancy between the experts' attitudes and actions is partly reflected in reality in consumer behavior; consumers themselves often demand sustainable products from companies but then decide at the decisive moment not for the climate but for their wallets. Price sensitivity can be considered, but not always, as the decisive factor. Therefore, it is even more important to clarify whether the higher costs resulting from SAF and other CNPS will later be passed on to the customer or whether they are fully subsidized so as not to be at a competitive disadvantage compared to foreign airlines without mandatory use of CNPS.

5.2. Competitive advantages

The literature and expert interviews show that sustainability and climate neutrality are highly relevant in aviation. From the expert interviews we can deduce that this goes hand in hand with introducing climate-neutral propulsion systems in aviation. The insights gained from the interviews on the three propulsion technologies investigated - SAF, battery and hydrogen - are examined in the following section for competitive advantages and managerial implications for three key industry stakeholders: aircraft manufacturers, airlines and jet fuel suppliers. A sufficient answer to **research question 2** (*how will the introduction of carbon neutral propulsion systems transform the aviation industry?*) and **research question 3** (*What are the potential competitive advantages for key industry stakeholders that would arise from the introduction of carbon neutral propulsion systems?*) is provided.

5.2.1. Competitive advantages for manufacturers

According to the experts, aircraft with **battery-based** propulsion systems are mostly a viable solution for general aviation. They are irrelevant for typical longer commercial routes because of their battery capacity (Hospodka et al. 2020). General aviation aircraft have small production quantities, which is not within the scope of big established manufacturers. Moreover, it is questionable if battery mass production is sustainable because of the environmentally harmful sourcing process of limited resources. There is no competitive advantage for aircraft manufacturers serving airlines in using this technology in the foreseeable future.

Aircraft with **liquid hydrogen-based** propulsion systems meanwhile are considered to become highly relevant. The experts were confident about large-scale implementation of this technology. It allows for short and mid-range flights with enough capacity for passengers and freight on board. As long as the hydrogen is being produced with green electricity these planes are considered to be zero-emission aircraft. Governments might subsidize this type of aircraft to incentivize airlines to purchase and passengers to travel more environmentally friendly. Experts agreed that liquid hydrogen will play a role in a sustainable aviation industry, significant potential lies within the future market. The short and mid distance jet market is dominated by the Boeing and Airbus duopoly; they are likely to keep their dominant position considering all their expertise in the segment. The regional jets market is more competitive and fragmented. Air traffic volume will increase in the future as more aircrafts are required on regional routes; therefore, players in the regional jets market segment such as Embraer, Mitsubishi, Sukhoi, and Bombardier must develop aircraft capable of liquid hydrogen propulsion. Otherwise, Airbus and Boeing can take over market share in this segment with their know-how on liquid hydrogen propulsion systems.

SAF do not hold a lot for manufacturers themselves. The expert interviews revealed that this technology is most promising for a carbon neutral aviation because of its simplicity. Manufacturers with the most fuel-efficient aircraft today are likely to gain a competitive cost advantage because SAFs can be used in today’s planes but they are expensive. Price sensitive airlines will optimize their fleet focusing on fuel efficiency to avoid increased fuel costs.

5.2.2. Competitive advantage for airlines

According to the literature and expert interviews, **battery-based** aircraft are only relevant for airlines that serve a route network with only short-range flights. For airlines that do not fulfill this criterion it is irrelevant to consider battery-powered aircraft. Airlines operating a battery-based aircraft fleet on very short-distances can establish a competitive cost advantage as according to Hospodka et al. (2020) maintenance and energy cost for this type of aircraft is lower than for regular aircraft.

Aircraft operating with **liquid hydrogen** can be beneficial for airlines that operate on short and mid distance routes. Zero-emission aircraft might be subject to government subsidizing. Once hydrogen sourcing becomes fully green and available in enough capacity, these airlines can establish a competitive cost advantage due to low operating and purchasing cost of hydrogen aircraft.

Sustainable air fuel is presently a rare resource. However, SAF quotas will unavoidably come. Low supply will meet a high demand resulting in SAF price increase until technology allows for cheaper SAF mass production. Therefore, hedging SAF now to can yield a temporary competitive cost advantage for those airlines that are confronted with a mandatory SAF quota in the future. Using a higher share of SAF than required by legislation can also yield a competitive advantage: investors who invest with sustainability in mind could thus become aware of airlines that are implementing climate-neutral measures more excessively than others. A high ESG company score (Environment, Social, Governance) can influence an airlines valuation positively and provide additional financial resources resulting into a financial competitive advantage.

5.2.3. Competitive advantage for fuel suppliers

The increasing demand for **SAFs** and **liquid hydrogen** in aviation can benefit fuel suppliers. Players that manage to supply SAF and liquid hydrogen in large quantities at a reasonable price can benefit through a first mover advantage and establish themselves within this market niche.

However, a breakthrough in technology is required to lower the presently high production cost. The expert interviews indicated that SAFs might eventually substitute regular jet fuel, therefore, there is potential for new market entrants to disrupt established fuel suppliers when providing a SAF mass production technology first. Power-to-liquid systems that provide fuel by mixing CO_2 with water are considered to be the most promising approach.

6. Conclusion

This chapter consists of a conclusion, limitations, and further research recommendations.

6.1. General Conclusion

The global aviation industry is facing its biggest transformation in decades. The transformation is very complex and highly dependent on all players connected to the industry's value chain. Key stakeholders will determine to a large extent how quickly the transformation occurs. New business models, products, processes, competencies and technologies are required to succeed. The experts surveyed assumed that they will have to adapt their core business model, at least in part, in order to survive in a sustainable economy. Companies in the industry must set concrete, measurable, and easily understandable goals. The path to the ultimate industry goal of climate neutrality by 2050 must be further defined with equally clear intermediate targets, so that manager convenience does not win out after first initial successes. However, the plan toward climate neutrality must remain flexible; there are still too many imponderables on the horizon. To ensure success, companies in this sector should not only rely on top-down communication but also on governance that strengthens sustainability. In other words, the role of executives as sustainability drivers must be transformed into a powerful governance mechanism that is present in every area of the company. Sustainability must be lived by the company as a whole and not only by individuals at the top.

The upside is promising. Aircraft manufacturers can enhance their existing product portfolio with new innovations, and airlines can tap into new target groups with these products. This is particularly true for the three propulsion technologies investigated based on green liquid hydrogen, batteries, and SAFs. Battery-based aircraft in general aviation have a competitive cost advantage over existing aircraft in the sector. Sustainable air fuels are expected to replace existing fuel solutions, as a possible bridging technology for short- and mid-distance flights and permanent solution for long distance flights. Aircraft based on liquid hydrogen propulsion technology have the potential to substitute SAFs on short- and medium distance flights once the technology has matured.

6.2. Limitations

The present thesis contributes to the field of study; however, it comes with limitations that must be mentioned in order to contextualize the results.

First, the sample size of ten interviewees is low, experts from fuel suppliers were underrepresented. Eight out of ten experts are from Europe, experts from other regions with possibly different mindsets about climate neutrality in aviation are understated. The identified competitive advantages apply primarily to the European market and those with similar market conditions. Two interviewees were pilots who were naturally less familiar with complex airline business strategies. Pilots are primarily involved in an airline's business operations which may result in skewed interview responses.

Second, the field of study is futuristic, at least for battery-powered and liquid hydrogen-powered aircraft. There are no commercial licenses for these type aircraft yet, hypothetical future technology topics may cause biased interviewee assumptions and answers. Other climate neutral propulsion systems than the three proposed were not considered in the dissertation because there is not enough advanced research on them.

Third, it is a topic that requires a certain level of technological industry knowledge about propulsion systems in aviation. The applied interviewee requirement of 5 years industry experience and manager position or equivalent might not be sufficient to give qualified answers to questions demanding expertise.

Fourth, all interviews were conducted remotely because of the Covid-19 pandemic. Online interviews may lead to different responses and outcomes compared to in-person interviews.

6.3. Further research

The present dissertation focuses only on commercial aviation; however military aviation must not be excluded from this technology as military operations do also account for CO_2 emissions in aviation. Climate neutrality might become a priority in this sector as well with governments increasingly imposing sustainability regulations. Moreover, the three discussed propulsion systems can yield tactical competitive advantages for military aircraft. Battery-powered aircraft have reduced inflight noise emissions, the different design requirements in liquid hydrogen and battery-based aircraft open up alternative possibilities in aircraft shape. However, military aircraft have different propulsion requirements than commercial jets, to give recommendations on the use of CNPS in this sector, further research must be conducted.

Urban air mobility vehicles may benefit differently from the three propulsion systems than commercial jet liners. Further research must be conducted to identify common use cases with commercial aviation in order to make recommendations.

Performing a quantitative analysis on the introduction of CNPS in aviation would yield further insights into the industry transformation. Data on the use of SAF could identify a more accurate CO_2 saving potential of the three discussed technologies which could contribute to more precise climate models.

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Appendix

RQ1: How is the importance of climate neutrality perceived in the aviation industry?
RQ2: How will the introduction of carbon neutral propulsion systems transform the aviation industry?
RQ3: What are the potential competitive advantages for key industry stakeholders that would arise from the introduction of carbon neutral propulsion systems?

Appendix 1: research questions for reference

ID	QUESTION	TYPE
1	Is sustainability the most important strategic topic to the company executives right now?	*Yes/no*
2	When does your company want to achieve climate neutrality?	*Open*
2.1	Do you also want to achieve it for your value chain?	*Yes/no*
3	Are you more satisfied with your company's attitude or actions towards sustainability?	*Attitude/ action*
4	Are economic efficiency and sustainability a contradiction in terms?	*Yes/no*
5	Which 3 challenges are you facing to achieve carbon neutrality in aviation?	*Open*
5.1	How are you tackling them?	*Open*
6	During this year's IATA annual meeting, member airlines agreed on achieving carbon neutrality by 2050. On a scale of 1-5, how realistic is carbon neutrality in aviation?	*Ranking*
7	Which steps is your company undertaking to implement sustainability at the core of its business model?	*Open*
8	On a scale from 1-5, how confident do you feel about large-scale implementation of: 1. SAFs 2. electric propulsion 3. hydrogen propulsion?	*Ranking*
9	How would you rank the importance of these 3 technologies (S, E, and H) to achieve a sustainable aviation industry?	*Ranking*
10	Are SAFs just a bridging technology until hydrogen and electric aircraft become more viable?	*Yes/no*
11	SAFs are an essential tool for achieving carbon neutrality in aviation. However, their success is highly dependent on government subsidies. How must this subsidizing look like to get to a technology breakthrough?	*Open*

12	Do you think that new companies working on these propulsion systems can disrupt long-established players within the aviation value chain? If yes, why?	*Yes/no*

Appendix 2: interview guide for reference

ID	**ROLE**	**TYPE**
EXPERT 1	Executive of a major Austrian airline	Airline Manager
EXPERT 2	Executive of a major Canadian airline	Airline Manager
EXPERT 3	Head of strategy and sustainability of a large European airline	Airline Manager
EXPERT 4	Research engineer for new propulsion systems at a large European aircraft manufacturer	Aircraft Manufacturer
EXPERT 5	Executive at a large European aircraft manufacturer	Aircraft Manufacturer
EXPERT 6	Manager at a large American aircraft manufacturer	Aircraft Manufacturer
EXPERT 7	Pilot (First Officer) at a German airline	Pilot
EXPERT 8	Pilot (Captain) at a Portuguese airline	Pilot
EXPERT 9	Partner for aviation at a renown consulting company	Consultant
EXPERT 10	Manager at a startup in alternative aircraft fuels industry	Fuel Supplier

Appendix 3: interviewee roles and types for reference

Expert n°1	
Sustainability most important topic?	Yes, apart from the covid-19 pandemic sustainability is the most important strategic topic. The airline industry must be transformed
When climate neutral? Your value chain as well?	Cut 50% of emissions by 2030 by new aircraft, optimized operations such as flights paths and ground handling. We want to be a role model in climate neutrality in aviation. Climate neutral by 2050 as agreed in IATA annual meeting 2021. We want to achieve this for our value chain as well
Attitude or actions towards sustainability?	Actions. Satisfied with both, we are already doing a lot. From 2025 on, we want every aircraft within our fleet to fly partially with SAF
Do sustainability and economic efficiency contradict?	No. reducing CO_2 emissions does not contradict with being a competitive airline and thus nit with being profitable in what we do.
3 Challenges in sustainability in aviation?	1. affordability of new propulsion technology, 2. Research is still in the process, 3. political regulation is insufficient.
Carbon neutral realistic?	Yes, 5 out of 5. Very confident, SAFs will show us a way into climate neutrality. SAFs as solution are very obvious for aviation
How implement sustainability in your BM?	Holistic approach. We take both air and ground (office, energy efficiencies in launches, operations, flight route optimization, less food waste on board, fly greener initiative (plastic is recycled into oil), aircraft weight reduction)
Large scale implementation of S, E, H?	Feeling very confident about SAFs (5), not so much about battery and hydrogen technology as research is still being conducted. These solutions are still quite far away and have not yet proven themselves. SAFs however have been tested and used experimentally quite often by now.
Importance of S, E, H?	SAFs are the most important factor for achieving climate neutrality. The other technologies cannot compensate for today's air traffic to the same extent. S, H, E
SAF bridging technology?	Yes. They are short- and midterm the only viable solution for the industry.
How to subsidize SAFs?	SAF is 3-4 times as expensive as conventional kerosene. Subsidies should be used for research funds, subsidies for airlines that refuel with SAF, blending quotas. European airlines should not be disadvantaged by the higher costs compared to foreign airlines.
New entrant disruption?	Hydrogen is only possible in small aircraft; batteries are not viable at all. New competition will emerge in the production of SAF, new suppliers for SAF and new companies in this area could change the existing supplier landscape.

Appendix 4: interview expert nº1 (own development)

Expert n°2	
Sustainability most important topic?	Yes. The Canadian government supports sustainability in economic businesses. Moreover, we as a company want to contribute to a more sustainable world and show that aviation can be part of this world.
When climate neutral? Your value chain as well?	As in IATA agreement this year we agreed upon 2050. Airlines from Asia were not keen to sign this agreement and favored climate neutrality until 2060. We want to achieve this for our value chain in the foreseeable future as well.
Attitude or actions towards sustainability?	Attitude over action, we must do more in our industry. I have the feeling that most airline executives developed the right mindset by now.
Do sustainability and economic efficiency contradict?	No, they go together. Our industry was not built with sustainability in mind, this is why some may see a contradiction here. However, with existing solutions and future technology an economic efficient and sustainable aviation industry can be achieved. Nevertheless, a major transformation is required which is already happening today.
3 Challenges in sustainability in aviation?	1. Availability of SAF, 2. cost of SAF, 3. Availability of alternative carbon neutral propulsion systems
Carbon neutral realistic?	Yes, I am 5 out of 5 confident that we can reach the goal. It is necessary.
How implement sustainability in your BM?	The most direct and tangible control that we can implement to mitigate our carbon footprint is to operate our fleet and ground infrastructure as efficiently and safely as possible. Therefore, we choose a variety of measures to lower our fleet’s emissions. In addition, we established green initiatives for our buildings and ground-support equipment and use carbon offset methods.
Large scale implementation of S, E, H?	SAF very confident (5), hydrogen-based and battery based commercial aircraft both 1 out of 5 in confidence. Our fleet serves mid to long range distance flights, SAFs are the only option for us that makes sense.
Importance of S, E, H?	1. SAF, 2, hydrogen, 3. Battery
SAF bridging technology?	No. SAF is the only solution for climate neutrality in the aviation industry that has been tested successfully and can be implemented into the system.
How to subsidize SAFs?	Airlines should not have a competitive disadvantage when using environmentally friendly technology.
New entrant disruption?	Yes. I believe there are upside opportunities in every major industry transformation. The duopoly of Airbus and Boeing is unlikely to be disrupted by a change in aircraft propulsion, however I do believe that the market for regional jets will see different suppliers from today in the future.

Appendix 5: interview expert nº2 (own development)

Expert n°3	
Sustainability most important topic?	Yes. One of the most important in the strategy. Covid is no longer quite as important, repaying financial aid to the state as the most important topic overall.
When climate neutral? Your value chain as well?	2050 net zero for the entire airline group. The largest share of CO_2 emissions is mainly due to the aircraft in their use, 65% CO_2 emissions of the entire group. Want to achieve this for the value chain as well.
Attitude or actions towards sustainability?	Attitude is the be-all and end-all. For actions we are dependent on our suppliers.
Do sustainability and economic efficiency contradict?	No. We have to reconcile the two. Old aircraft are already depreciated, so they generate a higher profit. This allows us to pay leasing rates for the A350. Fleet decisions are very important. Margins are becoming increasingly difficult to predict, probably lower overall. In addition, we have to pay back the aid money for covid over the next 10 years.
3 Challenges in sustainability in aviation?	1. Industry wide agreement which solution to support the most, 2. Lack of experience, 3. Regulations and guidelines on the extent of CNPS
Carbon neutral realistic?	Yes, it is feasible, climate change leaves us no other choice, there is no other way. 4 out of 5
How implement sustainability in your BM?	new technologies, mainly new aircraft. SAFs have a lot of potential but development is also very slow. Sustainable in our infrastructure, in single European sky for harmonized air corridors (route optimization). Operational efficiency
Large scale implementation of S, E, H?	For SAF 5 (from 2025 there will be quotas), battery 3 (only on the short haul), hydrogen 2 (infrastructure, rather hybrid technology, a320 demonstrator for beta testing in with hydrogen for experiments parked in Hamburg).
Importance of S, E, H?	S, H, E
SAF bridging technology?	No, not a bridging technology. Using power to liquid technology in SAFs would then be a cycle of CO_2.
How to subsidize SAFs?	SAF quota for all flights leaving Europe. SAF quota comes with levies, these levies should be earmarked for SAF research. Pass on price to customers is rather not so good, but no firm opinion on this so far. In the end, not everything is passed on to customers, but a little bit is.
New entrant disruption?	Airbus and Boeing will not be broken quickly as a duopoly and will continue to exist. Even small hydrogen and battery-based aircraft cannot be developed quickly enough to be a serious competitor. As a network carrier, one is dependent on feeder traffic to the hubs, one needs mass capacity in the aircraft, which the aircraft with the new technology do not have.

Appendix 6: interview expert nº3 (own development)

Expert n°4	
Sustainability most important topic?	Yes. In research, the budget for our sustainable future products is the biggest among all research topics.
When climate neutral? Your value chain as well?	The company wants to be climate neutral in manufacturing and operations by 2050. The value chain is complex, no information from the management about it.
Attitude or actions towards sustainability?	Actions. Attitude is already there, the actions from today are leading the industry into the future. These actions are promising to me.
Do sustainability and economic efficiency contradict?	No. They can go hand in hand, there are many companies and other industries out there that have shown the way.
3 Challenges in sustainability in aviation?	1. we rely on a complex value chain for manufacturing aircraft it is not easy to track each supplier's efforts in sustainability to reach level 3 carbon neutrality, 2. Long certification cycle for new CNPS technology, 3. SAF production capacities
Carbon neutral realistic?	100% SAF powered engines are possible in 2-4 years. However, there are lots of difficulties in production. Today, 50% SAF quota is possible, however, only 2-3% are actually used.
How implement sustainability in your BM?	We conduct research on the engine level mostly. The certification very long process, SAF production is the bottleneck.
Large scale implementation of S, E, H?	Very confident about SAF implementation. We are also looking into other technology to reduce carbon emission even more.
Importance of S, E, H?	SAF first, it is easy to certify. 2nd could be hydrogen, lots of research to be done. Engine power must be produced onboard, batteries not feasible.
SAF bridging technology?	Yes. SAF is just a bridging technology, hydrogen has many challenges like cooling and explosives but is overall more climate friendly. However, production of hydrogen is not green, challenges in production.
How to subsidize SAFs?	The price of SAF is x4-6 more expensive than regular fuel. Maybe passenger going to pay for that, maybe governments compensate. This is not the core of our business as a manufacturer. However, sustainability is no issue in China and other large markets, resulting in a competitive disadvantage for airlines when they use SAFs. The pressure for airlines to use clean propulsion must also come from the people and not only from governments.
New entrant disruption?	Everyone is working on climate neutral propulsion, the differences between competitors are and will be very small. After all, established manufacturers have the same suppliers for their aircraft. We are competitive also in the future for new technology. For small aircraft clean propulsion technology is already here, for large aircraft, we need 10 or more years for certification.

Appendix 7: interview expert n°4 (own development)

Expert n°5	
Sustainability most important topic?	Yes, clearly.
When climate neutral? Your value chain as well?	In 2050 we want to achieve climate neutrality on a level 1 and 2 bases. *(This does not include the value chain and only speaks of the company itself).*
Attitude or actions towards sustainability?	Attitude. The right attitude must be there only then actions can follow.
Do sustainability and economic efficiency contradict?	No. There is, however, an interfering period where we need to come to an alignment with our business models; government policies must act as guidelines and set boundaries for the markets.
3 Challenges in sustainability in aviation?	1. Certification processes for new CNPS systems are new, licensing our next generation aircraft can take longer than usual because we lack experience, 2. Availability of SAF and its cost, 3. Hydrogen production is not green
Carbon neutral realistic?	I am 4 out of 5 confident that we can achieve climate neutrality in aviation by 2050.
How implement sustainability in your BM?	It requires a holistic approach. Mindset and attitude first which we already achieved, actions second. Our decision making must be done with sustainability in our mind. So far, we have developed a Zero-E platform, we took measures in sustainable manufacturing, offices, materials used, life cycle products. All of them are already implemented.
Large scale implementation of S, E, H?	SAF 5 (target 20% SAF quota in aircraft), batteries 5, but only for small aircraft/urban air mobility, hydrogen 4 that we can make it, the operation in the aviation environment still in the making and must be carried on by airports in terms of infrastructure.
Importance of S, E, H?	SAF, hydrogen, batteries last.
SAF bridging technology?	No. Need SAFs for foreseeable future. Hydrogen production is also expensive and may never undercut SAFs.
How to subsidize SAFs?	Governments must ensure price equality for regular fuel and SAF. There are many different ways, cannot answer.
New entrant disruption?	No, not at all. It cannot just be us; our American counterpart needs to do research as well! Most of the new entrants are not targeting big aircraft that we produce; they are no competitors to us.

Appendix 8: interview expert nº5 (own development)

Expert n°6	
Sustainability most important topic?	Sustainability is an integral part to our company. It is one of the most important topics for us, alongside with aircraft safety and quality assurance presently.
When climate neutral? Your value chain as well?	2050. We had a set goal to reduce emissions by 50% compared to 2005 until 2050, however we redefined our sustainability strategy this year.
Attitude or actions towards sustainability?	Actions. We understood the issue long ago, our aircraft have become increasingly fuel efficient over time, our US facilities use 100% green energy, we are conducting research on zero-emission aircraft. Recently, one of our jets at United Airlines successfully flew with 50% SAF on a regular flight, the highest share of SAF ever used. Successful projects like this confirm our sustainability attitude and give us the right to be proud of our actions.
Do sustainability and economic efficiency contradict?	No. We are being sustainable today already, it is a matter of the sustainability extent that eventually may harm profitability for a limited period of time.
3 Challenges in sustainability in aviation?	1. Align the industry on sustainability standards, 2. Availability of carbon neutral propulsion systems, 3. Covid did already cost a lot of money, research budget is limited
Carbon neutral realistic?	Yes. I believe that SAFs will play a major role here. The pressure on automotive and oil and gas industry has unlocked a wave of new research, the solutions can be transferred to the aviation industry such we did it with as SAFs. However, there is no one-size-fits-all solution. The covid crisis hit the industry hard, budgets for research are limited unfortunately.
How implement sustainability in your BM?	Sustainability focuses on our people, products, services, technologies, and operations. Our new planes are 15-25% more efficient than their previous version. Technology innovation is the most important leaver for us to achieve climate neutrality in time of our set goals. Moreover, our airplanes are designed with sustainability in mind and are 90% recyclable when being disassembled. 3D printing uses less raw materials and is therefore environmentally beneficial. Carbon offsetting and green energy for our facilities must be mentioned as well.
Large scale implementation of S, E, H?	Very confident about SAF (5), also doing research on hydrogen (4) and batteries (2).
Importance of S, E, H?	SAF 1st, hydrogen 2nd, battery 3rd.
SAF bridging technology?	No. They will play an integral part over the next 20-30 years in decarbonizing the industry, there is no follow-up technology in sight for routes longer than 500km.
How to subsidize SAFs?	Cannot answer, airlines, fuel suppliers and governments must come together and propose a solution.
New entrant disruption?	No. Our company is doing similar research to our competitors around the world. It is unlikely that one of them comes up with something totally different than we do.

Appendix 9: interview expert nº6 (own development)

Expert n°7	
Sustainability most important topic?	No, I do not think so.
When climate neutral? Your value chain as well?	By 2050, we are part of a large airline group that has defined this goal.
Attitude or actions towards sustainability?	-
Do sustainability and economic efficiency contradict?	Yes. The two cancel out each other in aviation, otherwise we would already see counterexample in the industry.
3 Challenges in sustainability in aviation?	1. SAF is expensive and not available at every airport. 2. Who should pay for sustainability? 3. Sustainability is a problem in Europe and America, however, if the rest of the world does not consider the issue equally important, we have competitive disadvantage in pricing in an already low-margin business
Carbon neutral realistic?	4 out of 5 confident.
How implement sustainability in your BM?	I can only speak from an operational level. We try to reduce fuel burning overall. I order to do so, we reach optimal climb speed more often, lower cost index per flight (*the balance between right speed and right fuel consumption)* or we are advised to shut down one engine during taxi after landing whenever we can.
Large scale implementation of S, E, H?	Confident from 1-5: SAF 5, battery 2, hydrogen 4.
Importance of S, E, H?	SAF, hydrogen, battery.
SAF bridging technology?	No, SAFs are here to stay, especially for our long range-flights.
How to subsidize SAFs?	-
New entrant disruption?	-

Appendix 10: interview expert nº7 (own development)

Expert n°8	
Sustainability most important topic?	No. Our airline is struggling with the impact of the covid crisis. Our business model is based on charter flights. due to the pandemic, we had and still have a massive drop in flights. The most important issue for our management is to somehow get through this crisis and leave as little as possible behind. Sustainable flying is more important for the big 5 in Europe (*IAG, Air France-KLM, Lufthansa, EasyJet, Ryanair)* than for us.
When climate neutral? Your value chain as well?	We have been an IATA member for over 10 years now and we are committed to the climate-neutral target in 2050. I do not know about similar plans for our value chain. Our owner (*German Charter Airline*) oversees the strategy here.
Attitude or actions towards sustainability?	Neither but if I had to choose it is attitude. We are a small company with limited capabilities for meaningful investments in sustainability. The topic is of low priority presently as far as I know. However, our commitment for the IATA 2050 target lies within supporting European SAF quotas.
Do sustainability and economic efficiency contradict?	Rather yes, but unsure. I do personally think our (parent) company has not been pressured enough yet to consider sustainability as major field of action.
3 Challenges in sustainability in aviation?	1. Honest commitment and deriving meaningful actions from the right attitude
Carbon neutral realistic?	The industry can do it, rather yes. It will require big airlines to guide the way to climate neutrality, their best practice could then be used by smaller airlines.
How implement sustainability in your BM?	Covid left us mostly grounded, the savings in emissions by that are the biggest contribution we have done so far. In flight, we are trying to fly as energy efficient as possible if we do not have time pressure. The use of SAFs will be another contribution from ourselves as well as further flight path optimization and route planning.
Large scale implementation of S, E, H?	SAF yes (5), battery 2, more confident about hydrogen here (4).
Importance of S, E, H?	SAF, hydrogen, battery.
SAF bridging technology?	No, I think SAFs are a very convenient solution for the industry transformation as they do not require major infrastructure changes and are therefore comparably cheap. SAF will be increasingly used and eventually eliminate regular jet fuel – at least in the western world.
How to subsidize SAFs?	In a way that it is as cheap as regular fuel. However, as a charter airline we serve customers that are typically less price sensitive, share of the price increase of SAF could be transferred to customers.
New entrant disruption?	Cannot say.

Appendix 11: interview expert nº8 (own development)

Expert n°9	
Sustainability most important topic?	Yes. Our clients in aviation have reset their strategies moving sustainability into the focus. Although we expect covid to have an impact on the day-to-day business for quite some time, aiming for the sustainability transformation requires more attention. The industry transformation will accompany our clients far beyond the covid crisis.
When climate neutral? Your value chain as well?	Our clients are largely aligning with the 2050 climate neutrality goal. It is now important to set interim goals to measure progress and hold the management accountable for the next 30 years. Around 50% want to reach level 3 climate neutrality (→*value chain included).*
Attitude or actions towards sustainability?	Attitude. There are still decision makers in the industry pursuing a "sustainability as a nice to have" mindset, hindering companies on taking necessary actions. However, bespoken personnel must adapt their mindset to allow companies for actions. It is not enough if top management has the right mindset, it must be transferred to the entire company so that decisions are made with sustainability in mind.
Do sustainability and economic efficiency contradict?	No, I don't think so. We are just taking the wrong measures for accountable management and decision makers so that it might seem like that.
3 Challenges in sustainability in aviation?	1. Technology availability, 2. How can governments support the industry transformation most effectively? 3. How can we ensure worldwide sustainability standards in order to let the industry play after the same rules globally?
Carbon neutral realistic?	Our clients are part of a complex industry that relies on others to become climate neutral. Even if an airline for example wants to become climate neutral tomorrow, the planes for that must still be produced by someone else, who is itself relying on hundreds of suppliers. Airline customers must demand it, governments must set the regulatory frame.
How implement sustainability in your BM?	Those who do not see it just as marketing have established chief sustainability officers or given sustainability in the hands of a board member. However, options are limited for airlines as they rely on their suppliers for getting closer to climate neutrality.
Large scale implementation of S, E, H?	SAFs very confident (5), battery 2, hydrogen 4. Hydrogen will still take a long time to establish itself on the market, research is just starting.
Importance of S, E, H?	SAF, hydrogen, then battery.
SAF bridging technology?	No. There is no other technology in sight that allows airlines to operate mid to long-distance flights and stay profitable and competitive at the same time.
How to subsidize SAFs?	Governments must find a way to ensure the industry on their transformation journey. Therefore, provide SAF subsidies until they can be produced at a competitive price in reasonable quantities. Fuel suppliers can benefit from the government subsidizing, just like electric car manufacturers benefit from them as well.
New entrant disruption?	Yes, for SAFs and short distance aircraft based on liquid-hydrogen with 60-80 seta capacities.

Appendix 12: interview expert nº9 (own development)

Expert n°10	
Sustainability most important topic?	Yes. We are a producer of SAF, all our clients have identified sustainability as future core to their business model. Our funding is largely based on the importance of sustainability.
When climate neutral? Your value chain as well?	Our airline customers want to become climate neutral in 2050. We are using green electricity only for our production processes and facilities and are climate neutral already. As we are part of an airline's value chain, we are already contributing to possible level 3 climate neutrality plans.
Attitude or actions towards sustainability?	Actions. Our entire business model and its operations are based on the foundation of sustainability. We are producing SAF to transform the aviation industry, our product is considered to be the main driver behind a successful transformation. The demand of airlines is already beyond our capacities although jet fuel is significantly cheaper, we are conducting heavy research on enhancing production capacities.
Do sustainability and economic efficiency contradict?	No. I strongly believe in a working sustainable world. We can achieve prices of SAF comparably to the ones of regular jet fuel once we hit a critical mass. Economics of scale do also apply to sustainably products, as well as their profitability.
3 Challenges in sustainability in aviation?	1. SAF production capacity is too low to serve the market, industry solution required 2. Mindset of key industry stakeholders is insufficient or lacks actions, 3. Need regulations beyond countries on a global scale
Carbon neutral realistic?	Yes. We are transforming the industry towards sustainability already; we would not have started our company if we would not believe in a realistic chance of aviation becoming carbon neutral.
How implement sustainability in your BM?	I am going to answer this on behalf of our clients. Airlines should see SAF as a cheap and viable option in making their jets climate neutral. Other than hydrogen or battery technology, this technology does already exist and is ready to use. Besides higher cost, there is no reason to not use SAF today. However, jets are not the only environmentally harmful assets of airlines. Buildings and waste are two factors that must be considered for sustainability as well, and SAFs are obviously no solution to that. Overall, airlines must use a holistic approach to implement a variety of sustainability measures company wide. Therefore, it is important to dedicate a person accountable for sustainability in the company and measure sustainability impact regularly.
Large scale implementation of S, E, H?	SAF yes (5), hydrogen (4), battery (2).
Importance of S, E, H?	1. SAF, 2. hydrogen, 3. battery.
SAF bridging technology?	No. We consider our SAF as a long-term solution and to be implemented largely into the industry globally in the near future. SAFs are the cheapest method for airlines to become significantly more climate friendly in a short time.
How to subsidize SAFs?	The purchasing cost of SAF is high, however we experience that our clients care more about the environmental impact than its price. This reflects a changed attitude of the public and company management. If the airline and passengers accept temporary higher ticket prices due to SAF increase no subsidizing is required at all.
New entrant disruption?	I can only speak for the fuel supplier sector, in this case, we are the best example. We are already competing successfully with traditional big oil in SAF production and have signed purchase agreements with airlines. The sustainability transformation brings lots of opportunities for new business to thrive.

Appendix 13: interview expert nº10 (own development)