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Benefits and limitations of implementing new sustainable technologies in the aviation sector: impacts on the existing system

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Master of Science in Business Administration

Supervisor:
PhD Sofia Kalakou, Assistant Professor,
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BUSINESS
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I dedicate this work to JP, a friend I miss a lot.

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Resumo

O setor da aviação está sob pressão crescente para reduzir o seu impacto ambiental, devido ao aumento das emissões de gases de efeito estufa e à procura por padrões de sustentabilidade. Este estudo investiga a adoção de tecnologias sustentáveis na aviação, como combustíveis de aviação sustentáveis (SAF), aeronaves elétricas e aeronaves movidas a hidrogênio, e examina as suas implicações económicas, ambientais e competitivas. O estudo foi realizado com base na revisão da literatura atual e 11 entrevistas estruturadas com profissionais do setor da aviação, como engenheiros, pilotos e especialistas de operações, bem como de sustentabilidade de diferentes companhias aéreas. As entrevistas consistiram em 14 perguntas abertas, permitindo um exame aprofundado das perspetivas dos participantes sobre despesas operacionais, efeito ambiental e restrições tecnológicas relacionadas com esses desenvolvimentos. Os dados foram analisados qualitativamente, utilizando-se codificação temática com o software MAXQDA, que ajudou a organizar e desvendar tendências nas respostas.

Os resultados sugerem que o SAF é uma solução viável a curto e médio prazo, pois é compatível com a infraestrutura atual, mas os seus preços permanecem elevados. As aeronaves elétricas têm o potencial de reduzir as emissões e a poluição sonora nos voos de curta distância, mas enfrentam limites tecnológicos, particularmente em termos de autonomia da bateria.

Embora as aeronaves movidas a hidrogénio tenham potencial para reduzir drasticamente as emissões de CO2, apresentam dificuldades em termos de infraestruturas e custos operacionais.

O estudo também enfatiza a crescente concorrência entre tecnologias sustentáveis e comboios de alta velocidade em rotas curtas, onde o comboio se mostra mais eficiente em termos de consumo de energia e emissões. Prevê-se que o futuro da aviação sustentável será determinado pela aplicação eficaz destas novas tecnologias, pelo apoio regulamentar e pela capacidade de satisfazer as expectativas dos consumidores, uma vez que todos estes fatores estão a influenciar cada vez mais o equilíbrio entre viabilidade económica e sustentabilidade ambiental.

Palavras-chave: Indústria da Aviação, Companhias Aéreas, Alta Velocidade Ferroviária, Concorrência, Ambiente, Net Zero, Sustentável, Emissão de Gases de Efeito Estufa, Redução de Emissões, Recursos Naturais, Mudança Climática

Sistema de Classificação JEL: L93, O33, Q56

Abstract

The aviation sector is under increasing pressure to reduce its environmental impact, owing to rising greenhouse gas emissions and demand for sustainability standards. This study explores the adoption of sustainable technologies in aviation, such as Sustainable Aviation Fuels (SAF), electric aircraft, and hydrogen-powered aircraft, and examines its economic, environmental, and competitive implications.

The study was carried out using a review of current literature and 11 structured interviews with aviation industry professionals like as engineers, pilots, and operations managers, as well as the sustainability of many airlines. The interviews consisted of 14 open-ended questions, enabling for a thorough examination of participants' perspectives on operational expenses, environmental effect, and technological constraints related with these developments. The data was analysed qualitatively, using thematic coding using MAXQDA software, which helped to organize and uncover trends in the responses.

The findings suggest that SAF is a viable solution in the short and medium term since it is compatible with current infrastructure, but its prices remain high. Electric aircraft have the potential to cut emissions and noise pollution on short-haul flights, but they confront technological limits, particularly in terms of battery autonomy.

While hydrogen-powered aircraft have the potential to drastically reduce CO2 emissions, they offer infrastructural and operating cost difficulties. The study also emphasizes the growing competition between sustainable technologies and high-speed trains (HST) on short routes, where HST prove to be more efficient in terms of energy consumption and emissions. It is stated that the future of sustainable aviation will be determined by the effective application of these novel technology, regulatory backing, and the ability to meet consumer expectations, all of which are increasingly influencing the balance between economic viability and environmental sustainability.

Keywords: Aviation Industry, Airlines, High-speed Rail, Competition, Environment, Net Zero, Sustainable, Greenhouse Gas Emission, Emission Reduction, Natural Resources, Climate Change

JEL Code: L93, O33, Q56

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List of Abbreviations

SAF – Sustainable Aviation Fuel

HST – High-Speed Train

GHG – Greenhouse Gas

CO_2 – Carbon Dioxide

EV – Electric Vehicle

MRO - Maintenance, Repair and Overhaul

LCA – Life Cycle Assessment

NO_X – Nitrogen Oxide

FGEA - First-Generation Electric Aircraft

R&D – Research and Development

1. Introduction

Civil aviation provides an essential transportation network that connects the world and supports global economic growth. However, the aviation industry, one of the most dynamic and rapidly expanding sectors, is currently under unprecedented pressure to incorporate sustainable practices into its operational models. Widely regarded as one of the primary emitters of carbon dioxide (CO2), the sector currently contributes around 2.5% of global CO2 emissions, with projections predicting a 7% increase in developed nations such as the United Kingdom by 2035 (Miu & Miller, 2020; Ritchie Hannah, 2024). To maintain the benefits of aviation while meeting environmental goals, next-generation aircraft must have drastically reduced climate impacts (Adler & Martins, 2023).

Given aviation's enormous impact to climate change and the growing desire for more environmentally friendly alternatives, there is widespread recognition of the critical need to transition to a sustainable operating model. However, the path to aviation decarbonization faces significant hurdles, as short-term technology alternatives such as SAF and electric and hydrogen aircraft are still in development or have limited reach (Yusaf et al., 2024). While other sectors, such as land transportation and power production, are rapidly transitioning to low-carbon solutions, aviation has major technological and operational challenges (Afonso et al., 2023).

Considering these challenges, the pressure on the aviation industry to lessen its environmental impact has grown, especially for short-haul flights, where more sustainable alternatives are becoming increasingly viable. The adoption of high-speed rail (HSR) as an alternative to air travel is gaining more attention. (Avogadro et al., 2021) point out that eliminating domestic flights where rail options are available could significantly cut emissions, with their study indicating a 4.72% reduction in emissions by replacing intra-European flights with rail. Additionally, research by (Dalla Chiara et al., 2017) highlights that HSR is especially efficient for routes under 800 km, as high-speed trains consume less energy per seat-kilometre than airplanes and generate lower CO_2 emissions, making them a more sustainable choice.

In this setting, the incorporation of environmental, social, and governance (ESG) factors has become critical in corporate decision-making and policy formation. Aviation firms must implement technical advancements that connect their operations with sustainability goals, while also maintaining market competitiveness and addressing the growing demand for sustainable air transportation (Baumeister & Onkila, 2017). Given this complexity, it is critical to evaluate not just the financial impact of these new technologies, but also their environmental impact and ability to reconfigure competitiveness with other forms of transportation, such as high-speed trains.

1.1. Objectives and Research Questions

The main goal of this dissertation is to analyse the benefits and limitations of implementing new sustainable technologies in the aviation sector, and how do they impact the existing operational system. To guide the research there are a set of descriptive and explanatory questions that are meant to answer the research problem. The questions are as follows:

- RQ 1: What is the impact of using new technologies (SAF Fuels, electric and hydrogen planes) on costs?
- RQ 2: What is the environmental impact of using these technologies?
- RQ 3: What KPIs should be considered to maintain customer engagement with the use of new technologies in aviation, and how do these technologies impact competition, particularly with high-speed trains?

1.2. Methodology

To answer the research problem there are some objectives that should be met to proper justify the work done. This work is expected to collect information regarding the industry through the study of existent literature, as well as synthesize the best practices, define the main concepts of the sustainability and do interviews with aviation stakeholders. The interviews are an important supplement to the analysis of existing research and synthesis of best practices, providing for a thorough examination of the opinions of key stakeholders in the process of implementing sustainable technologies.

Data was collected via interview formats with the participation of professionals from many fields of aviation, including pilots, engineers, and managers of strategic, operational, and sustainability departments. The data analysis is qualitative, with the goal of gaining thorough insights into the benefits and restrictions of implementing new sustainable technologies in the aviation sector, as well as their impact on current operational systems. Each interview consists of 14 open-ended questions meant to allow for a full study of the participants' perspectives and experiences. To facilitate data processing, interviews are recorded and transcribed.

Data was analysed using qualitative approaches, namely thematic coding of transcribed content. This technique enables the identification of patterns, repeating themes, and significant insights into how new technology adoption may be optimised to maximise sustainability in the aviation sector.

These answers are intended to provide a description of the performance of aviation consider sustainability and market demand. By the end of the dissertation, it is expected to have reached these objectives and be able to make a conclusion regarding the aviation industry reality. The survey results were used to draw conclusions, which are reported in the thesis's conclusions chapter.

1.3. Thesis Structure

The current work is broken into five chapters. The first chapter introduces the problem, motivation, and key objectives of this thesis.

Chapter 2 provides a full review of previous studies on these issues related to aviation industry, sustainability, different modes of transportation and the inclusion of technology in aviation industry. This research will support data analysis methods and survey variables.

Chapter 3 presents a detailed description about the methodology followed in this work, beginning with the description of the survey, including variable selection, survey design, and data analysis methods. Finally, a description of the research context is presented.

In Chapter 4, it is first exhibited the survey results. Then, the estimated discrete choice models are presented and explained. Last, the main results are discussed and compared with literature.

Chapter 5 includes the final conclusions of this study, along with its limitations and suggestions for future work.

2. Literature Review

2.1. Aviation Industry Overview

Increased GHG emissions are a major cause of global warming and are linked to an increase in health issues such as cardiovascular and respiratory. (Aminzadegan et al., 2022). The primary cause of environmental instability, with more extreme and frequent climatic events at the global level, is the increase in the average global surface temperature, which was 1.2 ºC in 2020, more than 0.1 ºC above the pre-industrial period (1850-1900). (Matusiewicz et al., 2023) According to the Paris Agreement, the average global surface temperature should be around 1.5 ºC (IATA, 2021) and according to the World Meteorological Organization, we are approaching this limit and negatively impacting climate change. To address the effects of global warming, reducing emissions to zero is necessary. (World Meteorological Organization, 2022)

About 2.5% of all CO_2 emissions caused by human activity are the responsibility of the aviation industry (Ritchie Hannah, 2024). Considering the economic impact of this industry, it is also one of the sectors with the most impact on environmental changes (Klöwer et al., 2021). In countries with developed economies, such as the UK, aviation accounts for about 7% of CO_2 emissions (Miu & Miller, 2020). It is estimated that this contribution of aviation to the increase in CO_2 emissions will increase until 2035.

In the aviation business, it is predicted that one of the choices to be adopted in this sector is SAF, which accounts for only 17.5%. Alternative new technologies, including electric planes and hydrogen-fuelled aircraft, are being explored, but their implementation is likely to remain restricted. In 2021, IATA has projected a scenario and by 2050, 65% of the decarbonization of aviation will be achieved through the use of SAF, 13% through the use of electric and/or hydrogen-powered aircraft, 19% for carbon offset programs and 3% for improvements in infrastructure and operations (IATA, 2021). Nonetheless, SAF continues to have production challenges, implying that this form of fuel will be difficult to embrace by the entire aviation industry in the near future. Additionally, SAF is currently two to six times more expensive than ordinary aviation fuel. This high cost is a barrier for airlines, who already operate in a market with thin profit margins. The cost differential may discourage airlines from widely adopting SAF, jeopardizing their sustainable ambitions. These constraints, when coupled, create a difficulty of executing SAF due to cost and scalability that may result in less tangible measures than stated. (Goddard & Meier Philip, 2021).

2.2. Environmental effects of air transportation

According to the European Commission's Climate Action - Reducing Emissions from Aviation, on a global scale, aviation contributes roughly 2% of carbon dioxide (CO_2) emissions, with its expansion rate surpassing that of the rail, road, and maritime sectors over recent decades. In the European Union, aviation's direct emissions accounted for between 3.8% and 4% of total GHG emissions in 2022. Within the transportation sector, aviation contributes 13.9% of emissions, positioning it as the second-largest source of GHG emissions, just behind road transport (European Commission, n.d.-b). On top of that, emissions at high altitudes are the main origin of greenhouse effect compared to those released at ground level, with aviation being a major contributor to this impact (Yu et al., 2020).

The importance of designing aircraft with a focus on sustainability is now a top priority for the industry due to growing concerns about the environment and quality of life. To achieve sustainability in the aviation sector, it is essential to adopt a multidisciplinary approach, where various technical fields—such as aerodynamics, propulsion, energy, materials, and structures—work in an integrated manner. The interaction of these disciplines enables the development of innovative and balanced solutions, allowing for the creation of high-performance aircraft that meet market demands without compromising safety, human well-being, and environmental goals (Afonso et al., 2023).

Several strategies have been adopted by the aviation industry to reduce GHG emissions, particularly CO_2. The primary way to improve efficiency and lower carbon emissions in airlines has been through advancements in technological efficiency. The goal of these technologies and practices is to reduce the aviation sector's environmental impact by transitioning to cleaner energy sources and more efficient operations, fostering a more sustainable aviation industry aligned with global emission reduction targets (Z. Wang et al., 2020).

Furthermore, to stabilize GHG emissions from transportation, it is essential to promote behavioural shifts and motivate policymakers to implement rules and guidelines (Aminzadegan et al., 2022).

2.3. Reducing Greenhouse Gas Emissions in Transportation

Lowering GHG emissions in transportation poses a challenge that requires examining numerous factors and dimensions, given the global significance of environmental protection and the swift harm caused by rising emissions across different transportation modes. Van Fan et al. (2018)

indicate that the transportation sector contributes a considerable portion of global emissions, making up approximately 27% of all GHG. GHG emissions from road transportation account for more than 72% of the total in the EU transportation sector, whereas other modes, including air (13.3%), maritime (12.8%), and rail transport (0.5%), contribute a much smaller share (Fan et al., 2018).

Transportation activities adversely affect humans, wildlife, vegetation, and the ecosystem as a whole. Therefore, given this situation, it is crucial to reduce the environmental impacts caused by transportation. Forward-thinking societies should prioritize managing pollution sources, establishing regulations, and crafting preventive policies. Cutting GHG emissions is essential to maintain global warming within a safe threshold of 2°C by 2050 (Aminzadegan et al., 2022). Airplanes also contribute to transportation noise. As discussed by the European Commission, Aviation is a major contributor to noise pollution, affecting communities around airports, particularly with the rise in air traffic over recent years (European Commission, n.d.-a).

This extensive impact highlights the importance of implementing measures to manage and reduce aviation noise to safeguard public health. To reduce the environmental and noise impacts of aviation, it is essential to explore innovative strategies for mitigation.

For routes where other transport modes can provide comparable travel times, shifting from aviation to these alternatives is a practical solution. For instance, in Finland, rail transport stands as the most environmentally friendly form of transportation, producing the least CO_2 emissions. In contrast, short-distance flights contribute substantially more to pollution levels. Based on the route, emissions from short-haul flights are 1.6 to 2.6 times higher than those of a car, 2.3 to 4.5 times greater than those of a bus, and 2.9 to 17.7 times more than those of a train on the same path (Baumeister, 2019). Other literature on the substitution of air travel by high-speed rail presents several compelling findings. Avogadro et al. (2021) support this by discussing policies aimed at banning domestic flights where rail alternatives exist, reinforcing the ecological benefits of such a shift. Their study found that removing intra-European flight routes that could be substituted by rail, with a maximum travel time increase of 20%, would cut emissions by 4.72% (Avogadro et al., 2021). Zhang et al. (2018) and Chen et al. (2019) further elucidate that travel time, costs, and service frequency heavily influence passengers' decisions, with high-speed rail often being more economical and convenient (Chen et al., 2019; Zhang et al., 2018). Dalla Chiara et al. (2017) conclude that replacing short- and medium-distance flights (approximately up to 800 km) with high-speed rail (HSR) is viewed as an approach to lower carbon emissions and promote more sustainable transportation. For journeys under 800 km, high-speed trains use less energy per seat-kilometre than airplanes. Consequently, when comparing equivalent routes, trains emit less CO_2, making them a greener alternative (Dalla Chiara et al., 2017). Finally, Kroes and Savelberg (2019) also identify distance as a key factor, noting that journeys under 800 km are most likely to be replaced by train services. Kroes and Savelberg's analysis estimated that between 1.9 and 3.7 million annual flights could be replaced by high-speed trains by 2030, with the Amsterdam-London route expected to be most impacted. Multiple elements, including the frequency of daily departures, travel convenience, and fare prices, influence the decision between flying and taking the train. These factors determine the practicality of substituting air travel with HSR (Kroes & Savelberg, 2019).

2.4. Environmental impacts of rail transportation

Rail transport is regarded as a more sustainable and eco-friendly choice compared to other transportation modes (Krezo et al., 2014). Rail transport is viewed as an eco-friendly solution for mobility due to its lower emissions and energy usage compared to other transportation methods. However, merely expanding railway infrastructure is insufficient to guarantee sustainability; substantial investments are required to modernize the fleet, enhance auxiliary infrastructure, and develop energy sources with an emphasis on renewables. Moreover, transitioning to electric or hydrogen-fuelled trains can lower emissions, but it is equally important to boost energy efficiency and mitigate the effects on wildlife by adopting measures that safeguard habitats and decrease noise pollution. Consequently, a collaborative strategy that includes manufacturers, experts, and community organizations is essential for achieving a well-rounded and genuinely sustainable advancement of rail transport (Milewicz et al., 2023).

2.5. New Technologies: SAF, Electric Aircraft and Hydrogen

The aircraft fuel system is a significant source of GHG emissions in the commercial aviation sector (Grewe et al., 2021). To cut these emissions further, the aviation sector is investigating alternatives to standard fossil fuels, such as drop-in biofuels that could replace traditional kerosene, along with hydrogen and battery options (Afonso et al., 2023). While promising, these alternatives face considerable obstacles, including technology readiness, safety issues, low economic return, and conflicts with food security and land usage (for example, the use of biomass for biofuels might compete with food production and affect ecosystem services, particularly if poorly managed on a large scale) (Calvin et al., 2021).

2.5.1. Sustainable Aviation Fuel (SAF)

Aviation, a field heavily reliant on fossil fuels (primarily kerosene), is under growing pressure to adopt more sustainable practices due to the substantial environmental impacts of its activities. The European Union (EU) has outlined goals in its Transport White Paper (European Commission, 2011), targeting that by 2050, at least 40% of aviation fuels should be alternative and sustainable (*White Paper 2011 - European Commission*, n.d.). The overarching aim is for the aviation sector to support carbon-neutral growth, meaning that its operations will not add to the net carbon balance in the atmosphere. To reach these objectives, the aviation industry is prioritizing the development and adoption of SAFs. SAFs have the capacity to replace traditional kerosene aiding in the reduction of GHG emissions across the fuel's life cycle. This transition is viewed as essential to achieving a substantial reduction in CO_2 emissions in the sector by 2050, compared to 2005 levels (Staples et al., 2018).

Drop-in biofuels are energy sources derived from biomass (such as forestry by-products, plant oils, and algae) that can seamlessly substitute conventional fuels, such as aviation-grade kerosene. These biofuels can be combined with traditional aviation fuel without requiring major modifications to current infrastructure, like fuel storage tanks and engines. The biomass used for these fuels may be sourced from a range of sustainable materials such as oil plants (Carvalho et al., 2019). SAFs are viewed as an advantageous short-term option because they can be utilized in current aircraft with minimal modifications. This aspect makes SAFs an effective approach to lowering GHG emissions in the immediate future; however, in the long run, it may pose a drawback as it does not fully eliminate emissions. Furthermore, SAFs are considerably more costly than conventional fuels, which raises operational expenses for airlines (Cabrera & Melo de Sousa, 2022).

2.5.2. Electric Aircraft: Perspectives and Challenges

All-electric aircraft, which rely on batteries for power, represent a possible solution for cutting carbon emissions in the aviation industry, particularly on shorter routes. When charged with electricity from renewable sources, these planes produce zero direct CO_2 emissions during flight, making them appealing from an environmental perspective (Schäfer et al., 2019a). However, considerable obstacles remain to making electric aircraft feasible. Key challenges include the low energy density of batteries, which limits their energy storage capacity relative to weight, and their low power density, which affects overall performance (Gray et al., 2021). A study highlighting the specific energy limitations of batteries found that even if a Boeing 737 were fully loaded with batteries, it would only manage to fly for roughly one hour, whereas its range with kerosene is substantially higher (Cinar et al., 2023).

A study by Avogadro et al. (2024) suggests that electric planes with up to 20 seats could replace traditional aircraft on regional routes by 2030-2035, although larger electric planes may be 20% less cost-efficient in the short term. Despite higher upfront costs, reduced fuel and maintenance expenses could make them more affordable over time, with ongoing technological improvements boosting their overall cost-effectiveness (Avogadro & Redondi, 2024). For instance, fuel is one of the largest operational expenses, representing almost a third of an airplane's overall operating expenses (Scheelhaase et al., 2019).

2.5.3. Hydrogen-powered aircraft: the future of aviation?

Hydrogen is recognized as a promising alternative to traditional aviation fuels like kerosene, noted for its cleaner emissions, safety profile, and high energy density, which can reduce direct operating costs and offer favourable environmental and economic impacts (Yilmaz et al., 2012). The utilization of hydrogen as a fuel introduces various design challenges due to its physical properties. Hydrogen needs to be stored as compressed gas or as a cryogenic liquid to optimize energy density, since its volumetric energy density is lower than that of kerosene. While the energy density of hydrogen (energy per unit volume) is roughly four times less than that of kerosene, its energy per unit mass is almost three times higher. This implies that, for an equivalent amount of energy required for a flight, hydrogen is significantly lighter than kerosene. Aircraft powered by hydrogen can employ conventional gas turbines, which are effective and draw upon existing industry expertise, achieving efficiencies of around 40%, necessitating only modifications to the burner design to enhance hydrogen combustion. Conversely, fuel cells provide an alternative propulsion method that can lead to zero-emission aircraft, assuming that water emissions are managed properly. Through these cells, hydrogen is transformed into electricity with efficiencies exceeding 50%. Although hydrogen offers safety benefits by not pooling on the ground, it also has a broader flammability range, requiring stringent safety measures for its use (Adler & Martins, 2023).

For minimal environmental impact, hydrogen production methods vary in sustainability. Green hydrogen, generated from renewable energy, is the most sustainable, emitting no carbon during production and acting as a clean storage option for excess renewable electricity. Blue hydrogen captures or offsets emissions but does not eliminate them entirely, while grey hydrogen relies on fossil fuels, resulting in high emissions. The adoption of hydrogen will depend on policy-driven demand and cost-competitiveness with other decarbonization methods. As infrastructure develops, hydrogen is likely to be used more widely where economic benefits and supportive infrastructure are in place (Berger, 2020).

The implementation of hydrogen-powered aircraft will lead to increased operating expenses. This is mainly attributed to the elevated acquisition and maintenance expenses associated with the required technologies, particularly in terms of hydrogen storage. Nevertheless, lighter tanks designed for liquid hydrogen may assist in lowering the aircraft's fuel consumption. This is essential, as the tank's weight has a direct impact on the aircraft's efficiency. Additionally, the cost of electricity plays a significant role in the unit price of green hydrogen (produced from renewable sources). As the prices of renewable electricity continue to decrease, this could help lower the cost of green hydrogen. Moreover, economies of scale can also play a role in reducing costs (Adler & Martins, 2023).

2.6. Beyond Flight Operations

According to European Commission, Life Cycle Assessment (LCA) is a method used to evaluate the total environmental impact of a product or process, encompassing every phase—from manufacturing, through use, to end-of-life disposal. Unlike approaches that concentrate on a single factor (like carbon emissions), LCA offers a comprehensive perspective by examining multiple impacts, thereby avoiding impact displacement (i.e., addressing one environmental issue while inadvertently creating another) (European Comission, n.d.). The aviation sector's environmental impact is primarily driven by the flight phase, with fuel consumption as the main contributor. As a result, Life Cycle Assessment (LCA) emphasizes this phase due to its large influence, whereas maintenance impacts are relatively minor. It's therefore crucial to foster industry-wide awareness on addressing not only emissions from flights but also environmental effects related to aircraft manufacturing, maintenance, end-of-life disposal, and biofuel use, aiming to mitigate impacts across all stages of the life cycle (Krieg et al., 2012).

Although Keivanpour et al. (2016) already highlighted the need for a comprehensive lifecycle approach integrating maintenance, repair and overhaul (MRO) into aircraft Life Cycle Assessment (LCA), recent work by Rupcic et al. (2023) indicates that research on the impacts of MRO remains limited. This persistent gap underscores the importance of Keivanpour et al.'s recommendation for a more thorough assessment of environmental and economic impacts associated with maintenance, repair, and end-of-life processes such as recycling, landfilling, and reuse (Keivanpour et al., 2017; Rupcic et al., 2023).

With respect to material recycling and reuse in the aviation sector, the expansion of the global fleet and rising environmental awareness have intensified concerns over aircraft reaching end-of-life. Projections suggest that by 2030, around 13,000 commercial, military, and private aircraft will reach the end of their service life, underscoring the urgent need for sustainable solutions. Given the absence of specific regulations for aircraft disposal, coupled with mounting public pressure and the likelihood of future regulation, companies such as Airbus are beginning to investigate recycling and reuse practices. A notable example is Airbus's PAMELA project, which demonstrates these sustainable practices (Ribeiro & De Oliveira Gomes, 2015). The PAMELA project (Process for Advanced Management of End-of-Life Aircraft), initiated by Airbus, exemplifies key efforts to develop sustainable and efficient solutions for aviation waste management. This project aims to create a process that maximizes material reuse and recycling, thereby minimizing the environmental footprint associated with aircraft disposal. Findings from PAMELA revealed that over 85% of an aircraft's total weight can be successfully recovered, either as secondary components for direct reuse in other aircraft or as materials for recycling. This recovery level is notable, as a large portion of aircraft materials—such as aluminium, titanium, and high-performance alloys—are highly valuable and demand considerable energy for initial production. By repurposing these materials, PAMELA not only reduces costs and emissions related to new material production but also significantly cuts down on waste destined for landfills (PAMELA, 2012).

2.7. Passengers' attitudes towards new technologies in aviation

There is a limited amount of research specifically examining consumer views on the adoption of sustainable aviation technologies like SAF, electric aircraft, and hydrogen-powered planes. Most discussions in the literature concentrate on the technological, economic, and environmental aspects of these advancements, with minimal focus on how consumers view or assess these sustainable air travel options. A shift towards digitalization has become prominent in aviation, covering both operational and customer service aspects. This drive to incorporate digital technologies spans areas like air traffic control, aircraft upkeep, and passenger service. With these technologies in place, processes can be automated and optimized, significantly enhancing the passenger journey from booking through to disembarkation (Molchanova, 2020).

The aviation industry is rapidly changing and intensely competitive, compelling airlines to remain current and continually refine their strategic objectives to stay relevant. With digitalization emerging as a global trend, airlines have directed investments toward digital products and services to elevate the passenger experience. The research by Shiwakoti et al. (2022) examined how passengers perceive new technologies and found that understanding passenger needs empowers airlines to craft customer-focused strategies, boosting loyalty and enhancing market competitiveness (Shiwakoti et al., 2022).

2.8. Key Performance Indicators on aviation

The research on air passenger attitudes toward sustainable practices offers valuable insights. Gössling et al. (2009) observed that interest in voluntary carbon offset initiatives is limited, partly due to insufficient awareness and transparency (Gössling et al., 2009). Similarly, Hagmann et al. (2015) found that an airline's eco-friendly image can affect passenger choice, though comfort and price still take precedence (Hagmann et al., 2015). Wittmer and Wegelin (2017) further noted that environmental responsibility enhances brand reputation and customer loyalty, yet price remains a key determinant (Wittmer & Wegelin, 2017). Finally, van Birgelen et al. (2011) demonstrated that the inclination to offset emissions is associated with the perceived urgency of climate change and the significance given to environmentally conscious behavior (van Birgelen et al., 2011). Collectively, these studies indicate that while interest in environmental issues is increasing, there are ongoing challenges in converting this concern into tangible actions, such as carbon offsetting, particularly when additional expenses are involved.

3. Methodology

This section explains the process and techniques used to acquire data for this dissertation. This dissertation's results rely heavily on the methodologies used for conducting and analysing in-depth interviews.

3.1. Research Design

This study investigates the adoption of sustainable technologies in aviation, focusing on the use of SAF fuels, electric, and hydrogen planes. The research intends to understand:

- The impact of using new technologies on costs, including operational and maintenance expenses in aviation.
- The environmental impact of these technologies, analysing their potential to reduce emissions and overall ecological footprint.
- Key performance indicators (KPIs) to maintain customer engagement, exploring how the implementation of these technologies affects customer perception and loyalty.
- Additionally, the study examines how these innovations impact competition, particularly in relation to high-speed trains as alternative modes of transport.

By understanding these factors, the research seeks to provide insights into the economic, environmental, and competitive implications of sustainable aviation technologies. To achieve the objectives of this study, a qualitative research approach will be employed. Interviews with industry experts, aviation engineers, and environmental analysts will provide qualitative insights into the operational, environmental, and competitive effects of these innovations. A qualitative analysis will be conducted using thematic coding of the interviews, which will allow for the identification of patterns and recurring themes. This approach will ensure a holistic understanding of the economic, environmental, and competitive impact of sustainable aviation technologies.

3.2. Data Collection

As mentioned in the previous chapter, understanding the benefits and constraints of introducing new sustainable technologies in the aviation sector and how they affect the present operating system is critical. Analysing and studying these factors not only provides a greater understanding, but also allows the aviation sector to adopt more sustainable methods in the future.

The data analysed in this study was obtained through a qualitative approach, using interviews to gather insights from key experts in the aviation industry. The implementation of new technologies in aviation involves a wide range of areas, including research and development (R&D), production, infrastructure and maintenance, and commercial operations. Each of them has a different business context, objectives, processes, and concerns. Given the diversity of these domains, it was essential to include participants with expertise across different sectors to ensure a comprehensive understanding of the topic. To address these needs, **11**

structured interviews were conducted with professionals such as pilots, engineers, and other management positions from strategy, operations, and sustainability departments. Each interview consisted of **14 open-ended questions**, allowing for an in-depth exploration of the participants' perspectives. This approach ensured that a variety of stakeholders from various areas of the aviation industry were represented in the data collection process. The appendix A presents the interviews structure.

The interviews consisted in the following 3 sections:

- **Section A:** Questions aimed at answering RQ1 and assessing the expenses of implementing and utilizing new technologies such as SAF Fuels, electric, or hydrogen aircraft.
- **Section B:** Questions concerning the environmental impact of employing these technologies allow us to identify the primary impacts and benefits of emerging sustainable aviation technology. This section evaluates factors such as potential CO2 emission reductions, energy usage comparisons, noise pollution impact, and life cycle sustainability.
- **Section C:** Questions designed to elicit customer impressions and preferences, as well as crucial indicators for tracking involvement with sustainable aviation technologies. This helps us to better understand passengers' travel time preferences, the impact of new technology, the most critical variables in selecting sustainable air transport, and the differences between sustainable aviation and high-speed trains.

The interview questions were based on a study by (Thummala & Hiremath, 2022), which addresses green aviation in India and discusses the impact of sustainable technologies such as SAF, contrasting traditional aircraft with more environmentally friendly alternatives. The study looks at the costs of deploying these technologies, their long-term advantages, and the possible reduction in CO2 emissions, which is consistent with the challenges surrounding the cost-benefit and environmental impact of new technology. Wang et al.’s (2024) study "Corporate Social Responsibility’s impact on passenger loyalty and satisfaction in the Chinese airport industry: The moderating role of Green HRM" investigates how sustainable practices affect consumer perception and satisfaction. The study shows that adopting sustainable technologies can improve the passenger experience and promote loyalty, which is directly related to consumer happiness and the choice of sustainable transportation modes such as planes and high-speed trains (C.

Wang et al., 2024). Babuder et al.'s, 2024, study, which examines the impact of emerging sustainable aircraft technologies on the existing operational ecosystem, provides a detailed analysis of how technologies such as SAF fuels, electric propulsion, and hydrogen affect aviation infrastructure and operations. The study investigates the impact of these technologies on airline operations, airport operations, and airport infrastructure. Overall, the documents give a sound foundation for researching topics concerning sustainable technology in aviation, including prices, advantages, environmental impact, and customer views of these developments (Babuder et al., 2024).

To safeguard interviewees and improve information access, verbal agreements were formed to ensure anonymity. Before each interview, participants were informed about the study's aim and verbally agreed to utilize all interview information for the dissertation.

For safety considerations, the interviews were done by video conference between 1st of August 2024 until the 6th of September 2024 with an average duration of approximately 29 minutes and 53 seconds. The interviews began with light conversation to create a relaxed mood. Then, transitions were established by introducing the research topics. All the responses included in this dissertation have been anonymised. All interviews were done using uniformed interview templates (Appendix A). The chosen language was Portuguese; however, two participants preferred to do the interview in English, which eliminated the requirement for translation. To assure the information's integrity, the conversations were audio recorded with the participants' permission. Following the meetings, the interviews in Portuguese were transcribed verbatim and translated into English. Due to the tight time schedule of the interviewees, especially in times of holidays, the length of the interview's ranges from 10:19 minutes to 69:13 minutes. Due to privacy concerns of the interviewees and in order to create more open interviews, the real names of the interviewees will not be disclosed. The table below contains all information, which are allowed to be published in agreement with the interviewees. The number of interviews may not seem high, but the information is in-depth. Since there are no prescribed numbers of interviews needed and the feeling of the writer that after eleven interviews, the level of saturation was reached, it was decided not to conduct any further interviews.

3.3. Method of Analysis

Table 3.1.: Information about the Interviews

Name	Department	Years of Experience	Company	Duration of the Interview	Date of the Interview
Interviewee I	Operations Strategy & Performance	15 years	TAP Air Portugal (TAP) – Airline Company	69:13 minutes	1st of August 2024
Interviewee II	Customer Intelligence	7 years	TAP Air Portugal (TAP) – Airline Company	13:33 minutes	8th of August 2024
Interviewee III	Airline Pilot	5 years	Portugália Airlines (PGA) – Airline Company	28:30 minutes	12th of August 2024
Interviewee IV	Sustainability Consultant	3 years	Airline Company	20:21 minutes	19th of August 2024
Interviewee V	Optimization and Production Engineering	4 years	Airbus – Airline Company	37:13 minutes	21st of August 2024
Interviewee VI	Airline Pilot	12 years	KLM Royal Dutch Airlines – Airline Company	21:37 minutes	22nd of August 2024
Interviewee VII	Sustainability Consultant	3 years	Airline Company	10:19 minutes	25th of August 2024
Interviewee VIII	Group Head of Strategy	25 years	TAP Air Portugal (TAP) – Airline Company	34: 35 minutes	28th of August 2024
Interviewee IX	Airline Pilot	9 years	Airline Company	28:10 minutes	2nd of September 2024
Interviewee X	Operations Strategy	7 years	Airline Company	29:57 minutes	3rd of September 2024
Interviewee XI	Airline Pilot	10 years	Airline Company	35:13 minutes	6th of September 2024

A content analysis was used to categorize a vast volume of non-numerical data and provide detailed insights (Neale, 2016). This content analysis was carried out using the MAXQDA software. MAXQDA is a powerful tool for qualitative and mixed-methods research, allowing researchers to systematically examine textual and multimedia data. The program provides a thorough framework for organizing and coding data, assuring an organized approach to analysis. MAXQDA's interface is user-friendly, with sections dedicated to various types of content and analytical tasks.

The creation of a coding system within MAXQDA is an important stage in the data analysis process since it enables researchers to better categorize and analyse the content. Furthermore, MAXQDA allows for the integration of a variety of data forms, including text, audio, and video, making it ideal for a wide range of research projects.

Appendix B contains the complete coding that was used in the qualitative analysis with their definition and examples. The transcripts were examined several times before beginning with the coding dictionary. The subsequent phase involved identifying repeated codes and related themes. Similar codes were merged and grouped into a single topic. The codes and data were then evaluated to ensure that they were in line with the research topics. Finally, theme names were chosen to convey the subject's fundamental idea. The results of the coding procedure were conceptually reviewed and validated by recognizing themes and responding appropriately to the specified categories.

4. Finding and Discussions

This chapter seeks to uncover and understand the data gathered from the interviews. The following topics are discussed throughout the chapter: the effect of new technology on expenditures, notably operating and maintenance expenses in aviation, the environmental impact of modern technologies, including their ability to cut emissions and the total ecological footprint, Key performance indicators (KPIs) for maintaining customer engagement and investigating how the introduction of these technologies affects customer perception and loyalty. Furthermore, the study investigates how these improvements affect competitiveness, particularly about high-speed trains as alternative modes of transportation.

4.1. The costs associated with using technologies as SAF Fuels, electric and hydrogen planes

When implementing new technologies, it is crucial for businesses to thoroughly analyse the costs associated with each option. Each technology presents unique challenges in terms of operations, infrastructure, and maintenance. To make an informed decision between SAF, electric aircraft, or hydrogen aircraft, a careful economic analysis is necessary, considering both immediate costs and long-term benefits. (**Appendix C**)

The costs associated with using different technologies in sustainable aviation were analysed in three categories: operation, maintenance, and infrastructure. Data analysis from interviews showed the following distributions:

4.1.1. SAF Fuels

The costs associated with the use of SAF have been widely debated due to higher operational expenses, particularly because SAF is more expensive than traditional fossil fuels. This aligns with the study by (Cabrera & Melo de Sousa, 2022)which examines the economic challenges of introducing alternative fuels, such as SAF, into aviation. The study highlights the high production costs and the technological and logistical barriers to implement this technology. The results are consistent with what has been reported in the literature. According to interviewee I: "*in terms of SAF, SAF currently costs about four times more than conventional fuel*" and interviewee VI: "*I think SAF is priced around one and a half to three times higher than regular fossil-based fuels today. So, I know, for example, in my airline that I work for around a third of the total cost of the company is the fuel bill. So, although we try to use as much SAF as we can, it's currently not viable to switch fully to a 100% use of SAF because it's simply too expensive.*".

Nevertheless, according to (Cabrera & Melo de Sousa, 2022) and (Carvalho et al., 2019), SAFs are advantageous since they may be employed in existing aircraft with little or no modification, providing a short-term solution for pollution reduction. Although they are more expensive than traditional fuel, the fact that existing infrastructure does not require considerable alterations helps to keep adaptation costs down. Maintenance has a minor impact because SAF-powered aircraft do not require large structural or technological upgrades. In this regard, the evidence gathered is congruent with what is described in the existing literature. Interviewee VI said, "*A benefit however of using SAF is the fact that it's very similar to regular jet fuels in the way that it's handled and transported and that it's used in the aircraft.*"

4.1.2. Electric Planes

Production costs have been identified as a critical factor for this technology, as research and development costs are high, followed by production and acquisition costs. The cost of infrastructure can be a barrier to implementing this technology, as electrifying fleet requires the creation of new charging infrastructure in airports. Interviewees noted that electric aircraft require less mechanical maintenance due to the lower complexity of electric motors compared to internal combustion engines. This is supported by (Avogadro & Redondi, 2024) which predict that first-generation electric aircraft (FGEA) will have higher ownership costs per seat than conventional planes, but lower fuel and maintenance expenses. In the near future, FGEA are expected to have higher operational costs per seat kilometre, although predicted decreases in aircraft prices, battery replacement, and maintenance costs could improve their cost-effectiveness over time. This point is supported by Interviewee IV said: "*regarding electric planes, I would say there are three main costs: development and acquisition costs. Why? Because electric and hybrid aircraft are still in their early stages of development, and as such, the acquisition costs for electric and hybrid aircraft are currently higher due to limited production scale and the production of batteries. Then we also have operational costs, and it's expected that electric planes will have lower operating costs, as energy production for them is done in a "green" way, making it cheaper compared to aviation fuel.*" and Interviewee VII: "*for electric the initial development costs are much higher, although the energy costs, especially for electric, are not as high. But the initial costs are significantly higher*".

4.1.3. Hydrogen Planes

As stated by (Hoelzen et al., 2022), the viability of hydrogen aircraft hinges on lowering their unit cost (cost per kilogram). However, establishing hydrogen supply systems and modifying aircraft to run on hydrogen fuel will demand significant investments. In an optimistic scenario for hydrogen costs, short- and medium-range hydrogen aircraft may reach operational costs similar to those of kerosene-powered planes. One of the participants (Interviewee V) agreed with the literature and indicated that: "*The issue is that the current hydrogen markets are small, so imagine the ideal situation would be for this liquid hydrogen to be transported—then transported to the airport, and from the airport it would refuel the planes, using the reverse process. If there were abundance, it would end up being super-efficient and both environmentally friendly and cheap; the issue is that currently, there is so little that it ends up being expensive.*".

Regarding maintenance and infrastructure costs, respondents' opinions are consistent with those reported in the literature. (Yusaf et al., 2024) discovered that high production costs and infrastructural requirements are significant barriers to its widespread application in aviation. Several answers point out that, while hydrogen operational costs are promising, particularly in the long run, infrastructure-related expenditures are commonly regarded as exceedingly expensive. Interviewee VII said, "*For hydrogen planes, production and storage are really quite expensive and require specialized infrastructures.", * Interviewee IX *"Regarding hydrogen-powered airplanes, the development and implementation of this technology also involve high upfront costs, including research and development, infrastructure."* and Interviewee X *"As for hydrogen planes, they also have high costs due to design complexity and the need for new maintenance infrastructure."*

This analysis shows that SAF dominates the current market, however hydrogen and electrical technologies are emerging as possible long-term alternatives.

4.2. The cost-benefit trade-off of implementing sustainable technologies in aviation

The cost-benefit analysis of introducing sustainable technology in aviation was based on five key factors: environmental impact (14,58%), costs (47,92%), competitiveness (12,50%), market demand (12,50%), and economies of scale (12,50%). The data acquired through interviews and segmentation allowed us to determine the relative importance of each aspect in evaluating the cost-benefit trade-off. (**Appendix D**)

4.2.1. Costs

Costs were recognized as the primary worry of businesses when adopting sustainable technologies. Respondents emphasized that, despite the potential for long-term operational cost savings from increasing economies of scale, early implementation costs such as infrastructure and new technologies remain very expensive. According to the literature, (Adler & Martins, 2023) and (Yusaf et al., 2024) highlight that the implementation of sustainable technologies such as hydrogen and SAF involves a significant trade-off between the high initial cost and long-term environmental benefits. The respondents' responses were similar. Interviewee I answered "*the benefits are typically financial, but from a carbon emissions perspective. For all the carbon you emit, you have to buy licenses. So, if you emit less, your costs are reduced.*", Interviewee X answering, "*In terms of operational costs, initial investments are high, but over time and with potential government subsidies, part of the initial investments can be offset*" and Interviewee V answering "*Honestly, in terms of SAF, it's very much that. Because now that it is relatively developed and is being implemented, I think Airbus currently uses about 2% to 3%; the idea is to use up to 15%, and they are already conducting test flights within Airbus with 90% to 100% SAF fuel. So, I think in the coming years, imagine, the idea would be that by 2035, this implementation of electric vehicles by the European Union would start, and there would be a phase-out of other fuels. However, I think before that, SAF fuels will need to account for at least 50% of aviation fuels by 2030, mixed with 50% of normal fuel*.".

The data for the cost study of implementing sustainable technology in aviation were divided into many groups. These subcodes indicate the primary areas that contribute to the cost-benefit trade-off and have been divided into the segments shown below:

The "Initial Investment" component stood up as the greatest, accounting for 31.6%. The respondents underlined that the primary initial barrier is the high cost of deploying new technologies, such as the purchase of electric aircraft or the adaption of infrastructure for SAF and hydrogen. The findings align with what is discussed in the literature. For instance, according to (Tiwari et al., 2024), the advancement of hydrogen aircraft and the required infrastructure will demand considerable upfront investments and may take decades to fully develop. Although there is significant momentum in hydrogen research and development, reaching net zero by 2050 is highly improbable without significant early investments. Consequently, both SAF and carbon capture and storage will be essential in closing the gap towards achieving net zero. The responses from the interviewees align with what is described in the literature. Interviewee VI shared that "*I guess the downside to the sustainable innovation within aviation is that things tend to move very slow within the industry. So a lot of research has been done into improving, for example, aerodynamics of the aircraft. However, this can take like tens of years before we see the new technology in our aircraft which is basically because of the very strict certification requirements that they have and that just takes years to* *implement. And also I think a very big factor in this is that the price of aircraft is very high. They can sometimes be several hundred million dollars. And this yeah basically it takes a long time for them to return on the investment and this is going to mean that airlines tend to keep their aircraft in service for at least like 15 to 20 years which effectively means that a large portion of the aircraft that are flying today are produced in the early 2000s and therefore designed in the 90s. So I guess you can imagine that this is pretty old technology flying today and that the modern aircraft, the aircraft that are produced nowadays are way more efficient. But airlines will still tend to keep the older aircraft flying because of the high investment costs"* and Interviewee X "In terms of operational costs, initial investments are high, but over time and with potential government subsidies, part of the initial investments can be offset.".

Fuel consumption was reported in 21.1% of the segments. Fuel efficiency is a major challenge, especially in the context of SAF. Although SAF minimizes CO2 emissions, its costs are still higher than standard fossil fuels. Reducing fuel use, whether by SAF or more efficient technology, is viewed as a long-term strategy to counterbalance high operational expenses. (Tiwari et al., 2024), quoted that in the long run, liquid hydrogen and SAF (which have kerosene-like capabilities) appear to be more enticing possibilities for bridging net-zero gaps for short to long-haul missions.

Regarding regulations, Taxes, and Fees, this aspect was cited in 21.1% of the segments. These types of costs are related with carbon emissions and reaching environmental standards are another important consideration. As more governments enact legislation and taxes to decrease GHG emissions, businesses must factor the costs of these policies into their everyday operations. Cleaner technology can help to reduce some of these expenses, but the cost-benefit analysis is dependent on rapid adaptation to new environmental policies. The literature provides substantial support for this statement. According to (Adler & Martins, 2023), The shift to hydrogen-powered aircraft encounters technical and financial obstacles, including hydrogen storage issues, high expenses for new planes and infrastructure, and the need for affordable renewable hydrogen. Moreover, industry reluctance and narrow profit margins for airlines could slow progress, making government incentives or regulations necessary to encourage more sustainable aircraft. Based on the results, this point is supported by the interviewees, Interviewee I answered "*Some countries may have legislation that favours more sustainable aircraft by lowering costs, taxes, or fees. So, companies with more sustainable planes might also save on airport taxes.*".

Sales are also an issue, accounting for 10.5% of the segments. As customers become more aware of the environment and seek more ecologically friendly transportation options, the transition to sustainable technology has the potential to boost sales. However, this impact is heavily reliant on consumers' willingness to pay a premium for more sustainable alternatives, which is frequently directly tied to company value perceptions and marketing efforts. The introduction of sustainable technology may result in a rise in the cost of airline tickets, since companies might pass on some of the investment expenses to passengers. However, consumer price sensitivity is a consideration that airlines must carefully consider in order to maintain market competitiveness.

This will be reflected on passenger costs with 10.5% of the segments, which is an important factor. A recent study by (Hagmann et al., 2015) found that every second air passenger was willing to pay for a less polluted flight. The prior work primarily used carbon offsets as a tool to quantify air passengers' willingness to pay. Although the results of carbon offsets are debatable, aviation passengers' participation can provide a decent indicator of how eager people are to pay to mitigate climate change. (Wittmer & Wegelin, 2017) criticize carbon offsets for allowing airlines to outsource their environmental responsibilities to flight passengers, who may or may not offset carbon footprints. This uncertainty is sustained by interviewees opinions, Interviewee I "*All airlines that have been publicly talking about this—Lufthansa, for example, which announced about three weeks ago—said they would introduce an environmental surcharge on ticket prices. In other words, they will pass on the sustainability costs to the passenger. So, if SAF is more expensive, the ticket price goes up. It's as straightforward as that. Of course, if everyone does this, it becomes a non-issue—if all airlines raise prices, the market remains the same. But if some airlines raise prices and others don't, then we have a competitiveness problem.*".

4.2.2. Environmental

The environmental dimension ranks second, accounting for 14.58% of the segments. Environmental benefits are widely recognized as one of the primary motivators for the transition to sustainable technologies. The decrease of CO2 emissions and compliance with environmental requirements are essential elements in justifying investment, even if the short-term costs are substantial. The literature supports this view, highlighting that hybrid and electric propulsion, along with SAF, have gained significant attention in recent years as potential solutions to mitigate the climate change impacts of aviation and reduce its dependence on fossil fuels (Afonso et al., 2023). According to (Zaporozhets et al., 2020), technological progress, including advancements in aircraft design, could result in a reduction of up to 25% in GHG emissions by 2050. Furthermore, utilizing SAFs with a lower carbon footprint could lead to a reduction of up to 41% in GHG emissions, playing a key role in reducing aviation's environmental impact. This point is supported by the opinions of interviewees, Interviewee VII answered "*We have environmental benefits, with significant reductions in CO2 emissions, which help mitigate climate change and the current issues of the 21st century. This is really the main advantage. In the long term, with the rise in carbon prices and potential reductions in SAF and hydrogen production costs, the cost-benefit ratio may improve over time*.".

4.2.3. Competitiveness

Competitiveness was noted in 12.50% of the segments (6 out of 48). Competitiveness was highlighted as a strategic benefit. Companies who adopt sustainable technologies early might obtain a competitive advantage in the market by providing more environmentally friendly and innovative solutions than their competitors. However, competitiveness is strongly tied to the ability to absorb initial expenses while maximising advantages in the medium and long term.

4.2.4. Market Demand

Market demand was examined in 12.50% of the segments, or 6 of 48. As consumers become more aware of and prefer sustainable options, the aviation industry will face new demands. Many businesses view the deployment of sustainable technologies as a direct response to shifting client expectations for responsible environmental activities. However, respondents underlined that demand elasticity is determined by competitive prices and market acceptability of technology. A study conducted by (EY, 2023) about SAF, quoted that adoption of new technology is often hindered by its higher cost compared to its predecessor. As technology advances and smart investments are implemented, the cost becomes more affordable. Incentives and policies can significantly influence technology success. The responses obtained from interviewees validate this conclusion, Interviewee IX "*Additionally, companies that adopt these technologies can gain a competitive advantage by meeting the increasing market demand for environmentally responsible practices.".*

4.2.5. Economy of Scale

Finally, economies of scale were acknowledged in 12.50%. Economies of scale are viewed as an important aspect in lowering the long-term costs of implementing new technology. As sustainable technologies become more widely adopted and manufacturing grows, unit operating, and maintenance costs may fall.

In the aviation industry, the cost-benefit trade-off for implementing sustainable technologies is complicated and multidimensional. The initial expenditures are probably the most significant obstacle to implementation, but the environmental and competitive benefits, together with rising market demand, point to a positive long-term future. Furthermore, when economies of scale are solidified, costs are predicted to become more accessible, allowing for a better cost-benefit ratio.

4.3. The potential for CO2 emissions reduction with the use of SAF, electric planes, or hydrogen-powered aircraft

An examination of the data supplied on the potential for CO2 emissions reductions through the usage of SAF, electric aircraft, and hydrogen-powered aircraft indicates an intriguing distribution across the technologies deemed most promising for sustainable aviation.

SAF is viewed as a potential method for reducing emissions in the short to medium term, particularly because it can be deployed on existing aircraft without requiring significant changes to infrastructure or aircraft. This method has the ability to considerably cut CO2 emissions, depending on the raw materials utilized in fuel generation. These findings are consistent with what the literature suggests, since (IATA, 2021) predicts that by 2050, SAF will account for 65% of global aviation decarbonization. One of the interviewers confirmed this viewpoint by stating that (Interviewee IV), "*with SAF, it can reduce CO2 emissions over its lifecycle by up to, I would say, 80% compared to conventional aviation fuel, depending on the raw material and production process, of course. Full adoption of SAF across the aviation industry could lead to significant reductions in aviation's carbon footprint."* and Interviewee X "*SAF can reduce CO2 emissions by up to 80% compared to traditional fossil fuels, depending on the raw material and production process*". Interviewee III also said that "*For electric planes, it will depend on where the factory is and where the electricity is generated. So, depending on the electricity aspect, it can be efficient and save* CO_2*.",* Interviewee VII *"With electric planes, there are zero direct emissions during the flight, but depending on the electricity source used to charge the batteries, there could still be some carbon emissions."*.

However, according to (Adler & Martins, 2023), due to existing technological constraints, particularly in terms of battery energy density, aircraft electrification is limited to short and shorter flights. Despite these restrictions, electrification is regarded as one of the most viable technologies for regional aviation and lowering carbon emissions in short-haul flights. The acquired data confirms the limitation reported in the literature. The interviewee I defended that "*Current aviation fuel is such a great invention because it has such an incredible energy density, that is, kilowatts per kilo, which is extremely hard to achieve with a battery, for example. The amount of battery cells you'd need to store the same energy is much larger than the fuel tank sitting in the wing. So that's the biggest challenge.*" and the interviewee IV also defended that "*Electric planes can potentially achieve zero emissions in operation, assuming the electricity used comes from renewable energy sources. However, current range limitations restrict their impact to short-haul flights*.".

Hydrogen is quoted by (Yilmaz et al., 2012) as one of the most promising long-term alternatives for lowering CO2 emissions. Because hydrogen combustion emits only water vapor, its environmental impact can be significantly decreased when created utilizing renewable energy sources (green hydrogen). However, the infrastructure required to store and distribute hydrogen, as well as aircraft modification, pose technological and economic problems that must still be overcome. Nonetheless, its potential to reduce carbon emissions is well recognized. The viewpoint of the interviewees reinforces the literature. Respondents' responses were similar, with many emphasizing the ability of the technology given to reduce carbon emissions. The interviewee III answered, "*hydrogen could be a bet for the future too, but again, the production cost and storage cost at this stage, I think it's a bit of that*", Interviewee V *"Hydrogen (...) produced from renewable energy and used in the airplane, it's 100%—not 100%, but like 99%. 98%, meaning it's practically zero, zero, zero."* and Interviewee IX *"Hydrogen-powered airplanes can significantly reduce CO2 emissions, especially if the hydrogen is produced from renewable sources.",*

The findings show that reducing CO2 emissions in aircraft will require a combination of technology. SAF provides an instant and short-term option to cut emissions by using existing infrastructure. However, hydrogen-powered aircraft and electric planes are viewed as long-term alternatives capable of delivering significant emission reductions as technology progresses and technical difficulties are met. As a result, the transition to more sustainable aviation will be dependent on the ongoing growth and adoption of these technologies, as well as the establishment of laws and incentives to encourage their widespread application.

4.4. The comparison of energy consumption between electric, hydrogen powered aircraft and traditional aircraft

Hydrogen-powered aircraft have the potential to drastically cut carbon emissions, but energy efficiency remains a key barrier. According to (Adler & Martins, 2023) hydrogen has an energy density per mass nearly three times higher than kerosene, making it lighter for the same amount of energy. However, its volumetric density is much lower, requiring larger tanks for storage. We can find a definite link between the participants' perspectives and what is described in the literature, Interviewee IV said, "*we have hydrogen planes, which, when compared to traditional aircraft, hydrogen has a higher energy density by weight compared to batteries, but it is less dense by volume, meaning it requires larger storage tanks. Therefore, hydrogen planes are expected to be more energy-efficient than traditional aircraft. But the overall efficiency will depend on the hydrogen production process and the aircraft design"* and Interviewee X *"Hydrogen planes have energy efficiency that can be comparable or even superior to traditional planes, especially if hydrogen is used in fuel cells. However, hydrogen storage requires large and heavy tanks, which may affect overall efficiency.*

Electric airplanes convert energy more efficiently than traditional combustion engines, particularly for short-haul flights. However, the energy density of batteries limits the possibility of long-distance flight. Electric aircraft consume substantially less energy than regular aircraft, as long as the energy is generated from renewable sources. The primary difficulty is autonomy and energy storage capacity, as batteries are yet unable to compete with fossil fuels in terms of energy density. According to (Gray et al., 2021), the application of batteries in aviation is more difficult due to the need for more efficient and lightweight energy storage systems, while current battery technology significantly lags behind the specific energy densities of fossil fuels. As stated by one of the research participants Interviewee IV, *"The current energy density of batteries is much lower than aviation fuel, meaning it limits flight range and payload capacity."*.

Although SAF is a viable alternative that makes use of existing infrastructure and planes, its energy usage is comparable to traditional fossil fuels. According to the literature, (Staples et al., 2018) and (Cabrera & Melo de Sousa, 2022) suggest that a sustainable aviation solution is to substitute kerosene with SAF, commonly referred to as drop-in fuel, which necessitates only minimal adjustments to current aircraft. Respondents gave similar responses, with many emphasizing that (Interviewee I), "*In the case of SAF, it's relevant because it consumes exactly the same as fossil fuel in terms of usage—exactly the same as traditional fuel.*" and Interviewee

XI "*Fossil fuels like kerosene have a high energy density in both weight and volume, making them ideal for long distances and large payloads. In this case, energy density is very similar when using SAF.".*

In terms of energy usage, electric aircraft are more efficient for short flights, whereas hydrogen-powered aircraft may be more competitive on long-haul flights, despite the energy challenges associated with hydrogen production and storage. SAF is a viable alternative that has a lesser environmental impact than typical fossil fuels and it does not outperform fossil fuels. Nevertheless, it is vital to remember that the energy efficiency of hydrogen and electricity-powered aircraft is significantly reliant on future advances in infrastructure, batteries, and power generation.

4.5. The impact on noise pollution with the use of new technologies

(Bozigar et al., 2024) have noted that airplane noise can harm health and is associated with various issues, including disrupted sleep, high blood pressure, and heart disease. However, according to (Schäfer et al., 2019b), the introduction of electric and hybrid aircraft has the potential to significantly reduce noise levels, making them a more environmentally friendly alternative to traditional aviation technologies. Electric aircraft can reduce noise, especially during take-off, with an expected 36% decrease in noise contour area relative to the top current-generation short-haul aircraft. This reduction is primarily due to the absence of combustion noise and the lowered fan pressure ratios in electric propulsion systems. The perspectives of the interviewees support this analysis. As we can see through the answers, Interviewee III "*New engines on TAP's airplanes or Airbus, for example, produce 40% to 50% less noise and use the same fuel.",* Interviewee VI "*When looking at the noise that is produced by either electric or electric driven hydrogen aircraft, I think this will be even lower. Seen as the engine that they use; well it hardly produces any noise. At electric cars for example they are also very quiet*.", Interviewee X "*Hydrogen planes can reduce noise pollution, especially if they use fuel cells, which operate quietly*." and Interviewee XI "*Replacing traditional planes with electric and hydrogen planes can significantly reduce noise pollution, especially in areas near airports*".

(Graham et al., 2014) also suggest that a combination of technological advancements in engines and modifications in airport operations could be a viable strategy to reduce noise, CO2, and NOx emissions. The interviewees' answers reinforce this observation: Interviewee I shared that "*There have been significant advancements in recent years regarding the noise emitted by airplane engines. I think that at the level of airports, we will also start to see different* *applications—when I say applications, I mean projects and installations—to absorb noise and suppress it. More and more, this electric mobility will also bring some things that current aviation cannot do, which means it will be possible to have different flight profiles. And these different flight profiles mean that planes will tend to fly higher over noise-critical zones and then descend more aggressively, so to speak. This also means that, even though the plane is emitting more or the same amount of noise, because it is higher, the noise diminishes, so to speak. And that means that for people on the ground, it will seem as if there's less noise.*" and Interviewee VII "*They try and reduce the noise by having better designed acoustic shows around the engine.*".

4.6. The lifecycle sustainability of aircraft powered by more sustainable technologies

The sustainability of the life cycle of aircraft powered by more sustainable technologies encompasses several dimensions, including component durability (lifetime), material recycling and reuse, and the environmental impacts associated with aircraft production and manufacturing. The interviews revealed several concerns that must be addressed, from the production phase to the end of life of the components**. (Appendix E)**

4.6.1. Lifetime

Based on the results, we may deduce that the life expectancy of airplane components is critical, especially as technologies such as electric motors, hydrogen, and SAF. According to Interviewee III, "*The engines of airplanes are very current; they last a long time and are very reliable. They have maintenance schedules, etc. But if we look at the lifespan of the engine, it's about 10, 15, or even 20 years.*". The longevity of current engines is already significant (10 to 20 years), and electric motors are expected to increase this durability even more due to mechanical simplicity, as highlighted by Interviewee VII, "*So all in all I expect for the life cycle of the aircraft itself, I don't think that will change very much. The life cycle of an aircraft is usually determined by a maximum amount of... We call it pressure cycles. So, what that means when the aircraft Takes off we pressurize the aircraft so you can safely breathe inside and then when it lands the aircraft is depressurized again and so this is basically what determines the wear and tear on the fuselage of the aircraft and so the life of an aircraft is usually limited by the pressurization cycles. However, I do think that the life cycle of the engines themselves is going to increase very significantly. As the electric driven engines, well, they only have usually* *one moving component compared to... the jet engines that we use today, even still, they have hundreds of moving components, and they wear over time, and they have to be changed continuously to prevent serious engine damage. So, when you have only one moving part in an electric engine that's going to significantly increase the lifetime of an engine*.". This can provide maintenance benefits such as fewer part changes and lesser wear, extending engine usable life and lowering operating expenses. This concept is supported by the literature, such as (Rahn et al., 2024), which states that while maintenance accounts for only about 1% of the overall environmental impact, it plays a crucial role in aircraft operations. As technologies advance to reduce in-flight emissions, the contribution of maintenance to the environmental footprint is expected to increase, especially for zero-emission aircraft in development. Transparent understanding of the environmental effects of maintenance activities is essential for evaluating innovations and ensuring regulatory compliance and environmental responsibility throughout the aircraft's life cycle.

4.6.2. More Research is needed

The need for additional research is highlighted in 12.12% of segments, underscoring the ambiguity surrounding various developing technologies. Some participants stated that they were unable to submit an answer because they lacked specialized expertise about the subject. As proven by the replies, this emphasizes the significance of continuing to invest in R&D (Research and Development) to guarantee that these technologies remain viable and sustainable in the long run, allowing specialists in the field to develop more solid conclusions in the future. As Interviewee III said "*I believe it is very difficult to answer that today, in my opinion, because there's so much technology being developed in this area to improve battery technology, to make manufacturing more efficient, and at the same time, for them to last longer. I think it's hard to gauge right now*." and Interviewee VIII "*They don't know how they're cracking, how they're bending, how they're going to feel in the net. (…) It's just, you know, you just don't know. So as a result, you basically have to do so much preventative maintenance that it becomes too expensive. Because you don't know what you don't know. So you're just doing everything you can to measure the not know*.".

4.6.3. Production/Manufacturing

One of the most significant issues highlighted is the creation and manufacturing of the components needed for these technologies. The production of batteries and systems includes activities that have a major environmental impact, such as raw material extraction and energy-intensive use. Earlier studies by (Madhavadas et al., 2022) supports this finding, emphasizing that new technologies and processes, like additive manufacturing, deserve further exploration because they can reduce material waste, enhance maintenance efficiency, cut costs, and decrease emissions and resource usage (including energy, materials, and water) compared to conventional manufacturing techniques. This point is supported by the opinions of interviewees. Interviewee I answered "*From a sustainability perspective, pure and simple, I would say that construction... with each new airplane, there have always been concerns about more sustainable construction, so it's normal that there is an improvement, because parts now come on electric trucks instead of diesel trucks on their way to the factory. The factory is powered by a solar plant, all those things.*", Interviewee III "*As for the current airplanes, what I think could improve is that their engines should be built with more sustainable materials*." and Interviewee IV "*electric and hydrogen planes will require new materials and manufacturing processes, particularly for battery systems and hydrogen tanks, which can undoubtedly have significant environmental impacts*.".

4.6.4. Recyclable and Reusable

(Ribeiro & De Oliveira Gomes, 2015), stated that historically, aircraft were either stored or disposed of in landfills, but the aviation sector is now investigating more sustainable options such as recycling and reusing, especially by Airbus. The authors also suggest a procedure for decommissioning, dismantling, and recovering materials, focusing on both environmental and economic sustainability. The (*PAMELA*, 2012) study, funded by Airbus, has shown that more than 85% of airplane materials can be reused or sold for material recovery. Based on the results, it is inferred that the recycling ability of certain airplane components is emerging as a good factor. Through material reuse, this process not only cuts costs and emissions linked to the production of new materials but also significantly minimizes the waste directed to landfills. Interviewees' opinions support this point. Interviewee I shared, "*An airplane today is ninety-something percent recyclable.*", Interviewee XI "*On recycling, sustainable aircraft are designed to be easier to disassemble and recycle at the end of their lifecycle*." and Interviewee VII "*The sustainability of the lifecycle of these new technologies can be better if the materials used are recyclable*".

4.6.5. Non-Reusable/Recyclable

This category, with the greatest percentage (30.30%), demonstrates that certain components are not reusable or recyclable, raising severe worries about the future of more sustainable aircraft. According to the findings of the interviews, the sustainability of the lifecycle of aircraft powered by more sustainable technologies continues to pose significant challenges, particularly in terms of component recycling and reuse, as well as the environmental impact of the manufacturing process. The results of this study align with the data of (Rupcic et al., 2023), who emphasize the challenges in reusing materials like carbon fibres, which are often discarded due to high costs and insufficient market incentives, compounded by the aerospace industry's stringent quality standards. Additionally, there is an absence of infrastructure for the safe storage and recycling of components like hydrogen tanks, which adds complexity and cost to more sustainable technologies, such as hydrogen-powered aircraft. The responses gathered from the interviews confirm this conclusion, since the Interviewee III said "*There are parts of the engine that I believe are nearly impossible to recycle/reuse. There are parts that are made of titanium due to temperature constraints, etc., and I'm not sure how easy it will be to replace that*.", Interviewee IV "*recycling and disposing of batteries and other components at the end of their useful life can also present sustainability challenges, as this process depends heavily on the ability to recycle key components, such as batteries and fuel cells.*" and Interviewee VII "*Electric planes, for example, the batteries could have environmental impacts that aren't as favourable. So, there's a challenge in terms of recycling and the environmental impact that needs to be addressed, but if managed properly, we could achieve greater sustainability over the lifecycle*.".

4.7. Customer feedback on the demand for flights using sustainable fuels, electric aircraft or hydrogen powered aircraft

Several criteria identified in interviews with aviation professionals influence the assessment of demand for flights powered by sustainable fuels, electric, or hydrogen. These factors include difficulties such as market acceptance, price, and sustainability preferences. The data analysis highlights the key problems and priorities of consumers, as studied and interpreted by airline professionals, providing an informed and practical perspective on the application of developing technology in aviation. **(Appendix F)**

The data shows that most of the segments (32.26%) emphasize the need for sustainability as an important aspect in customer evaluation. This suggests that consumers are becoming more concerned about the environmental impact of their travel, and are willing to contemplate flights utilizing sustainable fuels, electric or hydrogen-powered aircraft to lessen their carbon footprint. This data demonstrates a growing trend toward more ecologically friendly air transportation solutions. This fact is supported by the literature through the studies of (Çabuk et al., 2019), which emphasized that airlines need to understand the characteristics and attitudes of eco-conscious passengers to determine their target audience and create segmentation approaches for sustainable marketing. This point is supported by the opinion of one of the interviewees, Interviewee I, "*Large companies want to reduce their emissions, and therefore the fact that we fly and emit less is also useful for them, which starts to influence demand. The IAG group, for example, which owns British Airways, Iberia, and several other airlines, is one of the global groups that has invested the most in purchasing SAF. Their perspective is that they believe it is their mission, so to speak, and their duty to ensure they secure as much SAF as possible because their passengers will choose to fly with them, knowing that they purchase SAF and have a higher likelihood of flying with it.*".

The second most mentioned factor, accounting for 29.03%, is price. While consumers prioritize sustainability, the cost of tickets remains a major concern. This finding is also supported by (Çabuk et al., 2019), whose research revealed that while a significant number of passengers are aware of environmental issues and are willing to adopt eco-friendly behaviours, price continues to be a key factor in their decision-making. They suggest that airlines can increase their appeal to eco-conscious travellers by offering green services at competitive prices, educating passengers about their sustainability efforts, and conducting promotional campaigns to raise awareness. Several interviewees stated that, Interviewee I "*If I have a sense of environmental responsibility and commitment to sustainability that these two companies have, and the prices are similar, it might influence my purchase decision. I would be willing to pay a little more because I know this company heavily invests in sustainability.",* Interviewee II, "*We conducted a survey at the end of 2022 precisely to try to measure the importance of sustainability in purchasing airplane tickets. We found that 27% of our customers with the Miles and Go card believe that sustainability is now more important than it was before, and 65% believe it is as important as it was before. We also know that 50% of our customers are willing to pay more for a more sustainable or eco-conscious trip. Now, of course, the percentage of additional payment varies depending on the country. Most customers, 28%, responded that they are willing to pay up to 5% more. And 16% are willing to pay 5% to 10%*

more. The remaining 6% are willing to pay more than 10%. However, this will change depending on the country. The countries that are willing to pay more are Switzerland and Germany. 32% of Germans are willing to pay 5 to 10% more, and 25% of Swiss are also willing to pay 5 to 10% more for a more sustainable trip" and Interviewee XI, "*The adoption of electric or hydrogen planes could be a very attractive selling point for passengers who prefer direct and more eco-friendly flights, always considering ticket costs.*".

4.7.1 The perception of cost competitiveness and the comparison of travel time between sustainable aviation and high-speed trains.

The analysis of the interviews revealed that cost competitiveness between sustainable aviation and high-speed trains is intrinsically linked to travel distance. All respondents agreed that in countries with well-developed rail infrastructure, high-speed trains present a viable alternative, particularly for short-haul travel. For longer distance journeys, aviation remains the predominant choice, mainly due to its greater time efficiency. The literature strongly supports this claim, with (Dalla Chiara et al., 2017) stating that, when comparing routes, high-speed trains use less energy per seat-km than airplanes on short and medium-haul trips (typically under 800 km). Additionally, (Zhang et al., 2018) highlighted in their research that on short routes (under 500 km), HSR poses significant competition to airlines, leading to a decrease of about 0.8 million passengers annually in South Korea and Taiwan, and 0.3 million in China and Japan. On medium-distance routes (500–1000 km), the influence of HSR is most pronounced in Japan, while in China the effect is less significant. This indicates that in China, competition between various modes of transport remains strong for medium-distance routes. This point is supported by the opinions of interviewees as and Interviewee III "*In terms of travel time, I think the train will be better. Mind you, on these short routes, when I say short, I'm referring to something like Paris-Lyon, which is already a train journey of about 5 hours, 4 hours. I'm talking about TGV; I don't know, a Paris-Lyon trip takes about 3 to 4 hours.*".

One of the crucial elements noted by experts is total travel time, which includes, for flights, activities such as check-in, security checks, transfers, and transportation to/from the airport. Although aircraft have a greater average speed, when the times associated with air travel are added up, the time advantage is generally diminished. High-speed trains, on the other hand, are frequently positioned in urban areas, making them easier to reach and much shorter overall journey times. Furthermore, boarding trains takes less time and is more direct than at airports, resulting in a more efficient and practical travel experience, particularly on short excursions., (Behrens & Pels, 2012) for example, carried out a study on passenger travel patterns between London and Paris, focusing on the competition between HSR and airlines. The research revealed that travel time, frequency, and distance to ports are the key factors influencing passenger decisions. Business passengers are more affected by travel time, while leisure passengers are more influenced by ticket costs. The perspectives of the respondents support this analysis: Interviewee I stated "*My perspective is that for any flight lasting up to about an hour and a bit, the train is competitive. The train is usually competitive, not from a service perspective, but from a complete package perspective. The train departs from the city center, while the airplane leaves from the airport—except in Lisbon, where the airport is conveniently located. In other cases, it's always about a half hour at best, and in some cases, up to an hour, to get to the airport. You arrive at the train station, go up a few stairs, validate your ticket, and usually, 10 to 15 minutes later, you're seated on the train. In contrast, at the airport, you arrive an hour early. These kinds of factors mean that a one-hour flight effectively involves a preparation time of over an hour before you can actually sit on the plane. And normally, when you arrive at your destination, you still have at least half an hour to get to the city center. This means that, generally speaking, a one-hour flight effectively takes about three hours. Given that a plane flies at 800 to 900 km per hour, if you divide that by three, you end up with an average speed of about 300 km per hour that you would need to achieve on a train to cover the same distance in the same amount of time. And 300 km per hour for high-speed trains today is no big deal.*"

The price competitiveness of high-speed trains and sustainable aviation was identified as a significant aspect in the interviewees' analysis. The research by (Gundelfinger-Casar & Coto-Millán, 2017), examines the rivalry between high-speed rail (HSR) and air transportation on domestic routes in Spain. It reveals that air travel demand is affected by factors such as ticket prices, travel time, and income. The expansion of high-speed rail is anticipated to further reduce air traffic, particularly on shorter routes. The study recommends that airports and airlines adjust by considering intermodal solutions, like integrating air and rail services.

Thus, the evidence obtained from the interviews reinforces the literature statements. The Interviewee IX affirmed that "*costs that are reflected in the ticket price, for example.*" and Interviewee VII *"For consumers who are concerned about environmental issues, sustainability can increase their satisfaction. But we must remember that many of our passengers will still prioritize costs and total travel time."*, Other research supports these findings, as noted by (Kroes & Savelberg, 2019), which also emphasized the potential for high-speed trains to substitute short-haul air travel at Amsterdam Airport, indicating that between 1.9 and 3.7 million flights per year could be replaced by 2030, with the Amsterdam-London route experiencing the greatest impact. Factors like the frequency of daily flights, convenience of travel, and cost all play a role in the decision to transition from air travel to HSR. One participant summarized this point of view as follows, Interviewee II, "*We also asked customers whether they would actually switch one form of transport for another. We asked if they would be willing to swap the plane for another mode of transport for short trips. But 79% are not willing to do so. The reason they would not do it would solely be a matter of price. And considering that we do not have a high-speed rail network in Portugal, we don't see that behaviour; that is, that willingness to switch to one... So, I was saying that since we don't have a high-speed rail network, countries like Portugal, Brazil, and the United States would be more inclined to choose the car over the train. Only countries that are already accustomed to using high-speed networks, like France, the UK, Spain, Germany, Switzerland, and Scandinavia, are willing to opt for the train instead of the car if the price justifies it. Sorry, instead of the plane. I think that in terms of travel time, this could be a reason why customers would switch one for the other. If it takes less time, yes. Because what aviation sells is precisely time. What is our biggest advantage compared to other modes of transport? Time. So, if it takes less time and is the same price, I have no doubt they would switch. Now, if the price is higher, even with a shorter travel time, perhaps the customers will analyse whether it is worth it.".*

4.8. The influence of new technologies on customer satisfaction

When incorporating new technologies, various aspects can influence customer satisfaction in the aviation industry, including travel time, pricing, sustainability, comfort, and customer experience. **(Appendix G).** (Fu & Moeckel, 2024) explored the factors influencing the adoption of hybrid-electric aircraft for short-haul flights. Key factors such as travel time, safety, comfort, and environmental impact play a significant role in passenger acceptance, with safety and confidence in the new technology being essential. Increased environmental awareness and trust in the technology can enhance adoption, while concerns about safety and comfort may decrease it. Through the analysis of our results, it is possible to conclude that they are in accordance with what the literature describes. The findings from the interviews show that sustainability one of the most important elements emerged, with mentions in 33.33% of segments. Interviewee I shared "*I think that the sustainability aspect for corporate clients, that is, business clients, is* *what I described earlier. They will be obliged to prefer airlines that offer electric, hybrid, or SAF options over those that use conventional fuels*.". This shows customers' rising concern for environmental responsibility and their willingness to choose more ecologically friendly modes of transportation. Comfort was emphasized in 19.05% of the portions. New technology can dramatically improve the physical experience of flying, whether through quieter aircraft, increased passenger space, or better control of on-board climatic conditions. Comfort is an important component that can boost consumer satisfaction by choosing more sustainable and technologically advanced flights. Interviewee VI shared this perspective "*So airplanes with new technologies are going to be a lot quieter, which is obviously going to increase the comfort of flying.*". Another major component was travelling time, which accounted for 9.52%. Passengers continue to prioritize travel speed and efficiency, and the deployment of technologies that can maintain or reduce overall journey time adds to their happiness. Customer experience, cited in 4.76% of segments, relates to broader aspects of the flight journey, such as ease of booking, customer service, and the incorporation of new digital technology into the travel process. According to one interviewee, Interviewee II, to boost customer satisfaction, technologies must simplify or make people's life easier: "*Anything that makes the customer's life simpler will certainly lead to higher adoption and satisfaction. We see this in all aspects. For example, I can give you an example of a technology that, as it is not necessarily improving the customer experience or making it easier, has lower adoption, which is biometric boarding. If biometric boarding requires the customer to go through an enrolment process that takes a long time or is very difficult, they will probably prefer to go through the normal boarding process instead of using the technology. In other words, technology will always be utilized, and it will generate more customer satisfaction the more it facilitates their lives and the easier it is to use.*".

However, we discovered a common element highlighted by respondents that does not appear in the literature: price. This aspect was identified as a deciding factor in the acceptance of new aircraft, implying that cost competitiveness is an additional criterion to evaluate. The price was noted in 33.33% of cases, indicating a sensitivity to customer costs, as we can confirm through the answer of Interviewee IX "*Customer satisfaction tends to increase with the perception that they are contributing to sustainability without increasing direct costs, i.e., costs that are reflected in the ticket price, for example.*".

4.8.1. The perception of the level of convenience for customers when choosing between sustainable aviation and high-speed rail transport

A variety of factors influence customers' perceived convenience when deciding between sustainable aviation and high-speed rail transit, including comfort, journey duration, pricing, and innovation. The segment analysis illustrates the key problems and aspects that experts identified as important for clients when deciding between these two modes of transportation. **(Appendix G).** Some studies have examined the factors that influence the competitiveness of HSR and its effect on airlines. (Zhang et al., 2018) and (Chen et al., 2019) highlight that travel time, cost, and service frequency are key determinants in passengers' decisions, with high-speed rail often providing a more affordable and convenient option. The most often reported factors were comfort and accessibility, accounting for 29.17%. This reflects the value that customers place on the travel experience, where convenient access to departure places (such as rail stations or airports) and comfort during the journey are critical. High-speed trains frequently provide a more comfortable and accessible travel experience, with less problems connected with operations like check-in and security, giving them a competitive advantage. A study by (Cascetta et al., 2011) examined the effects of the new HSR route between Rome and Naples, focusing on passenger travel patterns and transportation choices. The research revealed that the HSR line greatly enhanced travel behaviour, facilitating easier movement between the two cities and increasing trip frequency. It also emphasized that the HSR link contributed to greater integration of the cities, fostering more economic and social opportunities thanks to improved accessibility. Furthermore, (Pagliara et al., 2012) explain that HSR offers greater comfort for passengers, as they are not required to pass through security checks and can make better use of their time while traveling. HSR stations are typically more accessible than airports, particularly for those who rely on public transportation. The study also revealed that passengers value the comfort and the opportunity to work during their journey, giving HSR an edge over air travel. This is supported by Interviewee VII "*Convenience depends a lot on the distance of the trip and the available transport infrastructure. As I said, for short distances, high-speed trains will be much more convenient than planes, but for longer distances, planes will be much more convenient.*".

Travel time also appears at 29.17%, indicating that the speed with which one may complete the travel is important to many passengers. (Dobruszkes, 2011) studied the competition between high-speed rail (HSR) and air transport in Western Europe and found that the expansion of high-speed rail has led to a decrease in air service availability between certain city pairs, especially when the rail journey offers significant time savings. One of the interviewees agreed with this point and answered Interviewee IV "*In terms of convenience, high-speed trains can be perceived as more convenient for short trips due to less time spent on check-in and boarding,* *as well as central city stations and frequent services. However, there's also the perception of innovation, meaning customers may value the novelty and environmental benefits of sustainable aviation, as we've discussed—there's growing demand for sustainability—but they may be discouraged or inhibited by the higher costs and the potential increase in total travel time. But, to be very honest, at the end of the day, we can say that what will weigh most heavily or have the most impact are the costs because, let's be honest... cost is a universal language for customers*."

The price appears in 20.83% of segments, suggesting that the cost of travel remains a significant issue in client decisions. The schedule frequency was specified in 12.50% of cases. Customers value convenience, which includes the availability of travel options at convenient times. In addition to schedule frequency, punctuality (4.17%) highlights the importance of on-time travel. While high-speed trains are more punctual due to less interference from external causes such as weather, airplanes, including sustainable ones, may be more prone to delays. This is backed by (Pagliara et al., 2012), who emphasized that price and service frequency are the main determinants in choosing between HSR and air travel. HSR's increased frequency and shorter travel times draw more passengers, but improvements in airport check-in and security processes could enhance the competitiveness of air travel. This viewpoint is summarized by the words of one interviewee, who stated, Interviewee II "*It will relate to the factors I mentioned, namely the duration of the trip, the price, and then if the duration of the trip and the price are similar, there will probably be other factors to consider, such as schedules or the proximity of the airport or the train station to where they want to be*.".

Innovation was reported by 4.17% of the segments. Although technological improvement in airplanes is acknowledged, it does not appear to be a key consideration in the selection of convenience. However, breakthrough technologies have the potential to improve customer perception over time.

4.9. The most important factors for customers when choosing a sustainable air transportation mode

Customers' decisions for sustainable air transportation are influenced by a variety of factors, ranging from price to environmental impact. The examination of the interview data suggests that price is the most often mentioned issue, accounting for 41.67% of all mentions. This demonstrates that when selecting a sustainable air transport method, consumers are quite sensitive to ticket prices. Regardless of sustainability improvements, the price issue remains important, and a competitive fare is critical for passengers to choose more ecologically friendly options. **(Appendix H)**. Previous studies support this observation. The research by (Caliao et al., 2023) revealed that the main factors affecting passengers' airline selection are price, flight schedule, punctuality, and the conduct of staff. Although cabin services and safety were also significant, they were of lesser importance. Moreover, promotional fares were a key factor in drawing passengers. One of the interviewees gave a clear illustration, Interviewee II, "*It will primarily be the price because we see from the survey, we conducted that it is the determining factor. Then it will also depend on the distance of the trip, and assuming everything is equal, then it will be the schedules and the distance from the stations or airports to the customer's final destination."* and Interviewee IV *stated that "price is a significant factor, even for passengers who are environmentally conscious."*.

4.9.1. The perception of consumer preferences when deciding between sustainable aviation and high-speed trains as a means of transport

Consumer choices for sustainable aviation versus high-speed trains are influenced by economic, convenience, and environmental performance considerations. The statistics collected demonstrate that passengers prioritize specific factors when deciding which mode of transportation to utilize, namely cost and journey time. **(Appendix H).** (Lohawala & Wen, 2024) found that many passengers opt for air travel over greener alternatives such as trains and buses because of its speed, convenience, and cost-effectiveness, particularly with low-cost airlines. Air travel is often the only viable option for remote locations like Alaska. To promote a shift towards trains and buses for shorter distances, it is essential to improve infrastructure, offer competitive fares, enhance services, and raise public awareness about their advantages. The findings support the viewpoint offered in the literature, with the most frequently mentioned component being cost or price, accounting for 35.71% of all factors. This implies that when choosing between sustainable aviation and high-speed rail, consumers are most concerned with travel costs. Two of the participants offered a realistic example, Interviewee VII, "*I think price will always be a decisive factor for many customers, regardless of whether the option is sustainable or not. Travel time is another crucial factor, especially on short routes. If travel times are too long, customers may choose another mode of transport instead of the train*" and Interviewee VI *"I guess you could say that people when choosing their mode of transport, they will always weigh the convenience against other factors such as, for example, sustainability. So, you could say for a route from Amsterdam to Paris, yeah, both flying and the train are very* *convenient. However, the train is... the more sustainable option, then people are going to choose the train. However, for the route, well, to Copenhagen, for example, as I said, yeah, the plane is just so much more convenient and then I think that people are always going to choose the convenience in this case over sustainability.".*

4.10. The most important Key Performance Indicators (KPIs) for monitoring customer engagement with sustainable technologies

Key Performance Indicators (KPIs) are critical instruments for measuring the performance of any business endeavour, including the use of sustainable technology in the aviation industry. The interviews yielded a few KPIs that businesses may use to evaluate customer involvement and satisfaction with more environmentally friendly air transport systems. **(Appendix I)**

The customer satisfaction rate was the most reported KPI, accounting for 27.50% of all sectors. This emphasizes the need of assessing passenger happiness while implementing sustainable technology such as green-fuel airplanes or emission compensation systems. Customer happiness is a powerful predictor of success and potential future purchases. According to (Hagmann et al., 2015) discovered that an airline's environmentally friendly reputation can influence passenger decisions, although comfort and cost remain the primary factors. The answers from interviewees support this affirmation, Interviewee IV "*customer satisfaction, meaning customer satisfaction scores, surveys, and Net Promoter Scores to measure the perceived benefits of sustainable technologies. Then there are also conversion rates and customer demand. We can measure the demand for sustainable flight options versus traditional alternatives and track conversion rates for customers who choose sustainable options. And, as I mentioned earlier, price sensitivity, meaning how demand fluctuates with price changes for sustainable flights, is a key performance indicator to assess whether higher costs are a barrier to customer adoption or not."*

This statistic, which measures consumer loyalty or the frequency of repeat purchases, was mentioned in 10% of cases. This KPI assesses customers' continued commitment to the organization and its sustainable offers, suggesting long-term involvement. Loyal clients are more inclined to adopt new technologies and drive company growth. This indicator can be evaluated through the Net Promoter Score (NPS), as Interviewee II shared "*Nothing beats asking them directly. So, we will probably conduct some satisfaction surveys, and then we can use the metrics we find most appropriate as KPIs. If we want to measure the likelihood of recommending the airline because it is the most sustainable, we will use the Net Promoter*

Score. If we just want to know customer satisfaction, then it will probably be a Customer Satisfaction Score, a CSAT, which is typically an average. That will depend on what exactly we want to measure: satisfaction, recommendation, or ease of use—how easy it is to use this mode of transport compared to another. In other words, what we will want to measure, the KPI, will reflect more the perception we want to obtain from the customer than just... the fact of being the sustainable direction or anything else. In other words, we will apply existing KPIs to measure this... this specific topic. We use NPS when customers take a trip; we send the NPS survey to find out if they would recommend the airline based on the trip they had. At various touchpoints, we also use Customer Satisfaction surveys; for instance, customers who call our call centre will have a survey, or there will also be a satisfaction question. We can also do this at other touchpoints, such as potentially on flights.”.

The referral fee and ticket cost per person are shown next, both at 12.50%. The cost of a ticket per passenger is an important KPI for determining the financial efficiency of sustainable efforts, as it measures the company's capacity to offer competitive prices while using more environmentally friendly technologies. (Wittmer & Wegelin, 2017) found that air travellers continue to prioritize ticket cost over an airline's environmental commitments.

Market share and adoption rate are equally essential, accounting for 7.50% each. Market share shows the company's ability to capture a large portion of the market with its sustainable solutions, whereas adoption rate reflects the rate at which customers accept new sustainable technology. (Baumeister & Onkila, 2017) examine the possibility of introducing an eco-label in the airline industry to promote behavioural change and mitigate aviation's environmental impact. Based on interviews with 12 industry experts, the study emphasizes the necessity of such a label due to varying environmental performances among airlines. It outlines five essential criteria for a successful eco-label: credibility, comparability, clarity, transparency, and participation. The research underscores the need for a unified global eco-label to prevent confusion and assist both passengers and airlines in making more sustainable decisions.

The emission decrease looks to be 5%, demonstrating the company's environmental commitment, which can influence how customers perceive the value of their sustainable projects. KPIs mentioned by 2.50% of respondents include willingness to pay, sustainable flight sales, participation in emission compensation programs, the number of sustainable flights sold, and the number of miles earned by customers. These indicators can provide extra information on the amount of client acceptance and commitment to the company's sustainability activities.

One of the participants mentioned, Interviewee I “*Willingness to Pay. It’s fundamentally understanding how much the customer is willing to go or pay for this service. And this*

Willingness to Pay, in terms of sustainability, will make a difference here" and Interviewee VII "*The KPIs to monitor customer engagement with sustainable technology will definitely include customer satisfaction, collecting feedback on the experience of these flights, and analysing the price elasticity of sustainable flights—price versus demand. We also need to track repeat purchases from customers who opt for sustainable flights, which gives us an idea of customer loyalty. Additionally, the adoption rate of sustainable flights—understanding the percentage of customers choosing sustainable technologies as more options become available—will help determine whether the use of sustainable technologies is truly influencing consumer behaviour.".*

5. Conclusion

This chapter highlights the research findings and relates them to the research questions posed in the methodology. Indications for future research are also presented, and the study's limitations are acknowledged.

5.1. Research Findings and Discussion

This dissertation provides a realistic and in-depth look at the adoption of sustainable technology in the aviation industry, with an emphasis on new alternatives including SAF, electric aircraft, and hydrogen-powered aircraft. The study attempted to evaluate these technologies' benefits, problems, and competitive consequences, as well as how the industry may adjust to environmental sustainability and regulatory constraints. The primary research questions (RQ1, RQ2, and RQ3) drove the investigation of costs, environmental impact, and competitiveness in the aviation business, particularly competition with high-speed trains (HSR). The study also looked at key performance indicators (KPIs) that should be considered to keep consumers engaged with these technologies, as well as how the industry can secure their effective implementation.

The findings reveal that, while sustainable technologies look promise in the long run, they still face significant obstacles, notably in terms of economic viability. SAF, for example, is a viable alternative to current infrastructure but far more expensive than conventional fuels. Electric airplanes provide a realistic alternative for short-haul flights by decreasing pollution and noise, but their capabilities are restricted by existing battery technology. On the other side, hydrogen-powered aircraft have the potential to eradicate CO2 emissions, but they face significant challenges due to the infrastructure required for deployment and production costs.

In terms of environmental impact, new technologies have the potential to significantly cut GHG emissions as well as other environmental externalities like noise pollution. SAF can lower emissions by up to 80% over their life cycle, while electric and hydrogen-powered aircraft promise nearly zero emissions. However, the adoption of these technologies necessitates a strong infrastructure and renewable energy sources, which now limit their short-term viability.

This dissertation also examined the growing competition between air travel and high-speed rail (HSR), particularly on shorter routes. Rail travel is a more environmentally responsible option, with less energy usage and emissions per passenger. However, airlines continue to have an advantage on long-haul routes, where time efficiency and convenience are crucial competitive criteria. Thus, the sector's future competitiveness will be determined by its ability to strike a balance between convenience, price, and environmental impact.

This dissertation contributes to a practical understanding of the characteristics and problems of applying sustainable technologies in the aviation sector. This report provides a solid foundation for airlines and policymakers to make educated decisions about the future of sustainable aviation by integrating costs, environmental impacts, and competitiveness with alternative means of transportation. The study also emphasizes the necessity of strong legislative backing and a clear consumer engagement strategy in facilitating a smooth transition to more environmentally friendly technologies.

The results and recommendations based on the research questions are as follows:

RQ1: What is the impact of using new technologies (SAF Fuels, electric and hydrogen planes) on costs?

The findings demonstrate that all investigated technologies are still more expensive than conventional fuels and airplanes. SAF, for example, is a short- to medium-term solution, but its exorbitant cost relative to traditional kerosene prevents widespread usage. Despite their enormous long-term potential, electric and hydrogen-powered aircraft confront significant financial and technological difficulties that prevent their immediate implementation.

RQ2: What is the environmental impact of using these technologies?

The environmental impact of emerging technologies is very good. SAF significantly reduces CO2 emissions, and electric and hydrogen-powered aircraft have the ability to virtually eliminate direct GHG emissions. However, the whole environmental advantage is contingent on the development of suitable infrastructure and the utilization of clean energy sources to power these new modes of propulsion.

RQ3: What KPIs should be considered to maintain customer engagement with the use of new technologies in aviation, and how do these technologies impact competition, particularly with high-speed trains?

Consumers' environmental concerns, convenience, trip time, and travel cost are among the key performance indicators mentioned. To keep customers interested, airlines must integrate their sustainability plans with the transparency of their environmental efforts, ensuring that consumers understand the benefits of new technologies in terms of environmental effect. Competition with HSR, particularly over short distances, is becoming increasingly difficult, as trains provide a more sustainable and environmentally friendly answer, particularly in places with well-developed rail lines.

Furthermore, the successful implementation of sustainable technologies in aviation is contingent on a number of factors, including strong regulatory support, economic incentive policies, infrastructure investment, and clear communication with consumers about the environmental benefits of these innovations. Confidence in technology, together with the dedication of industry stakeholders, will be required to overcome the barriers to a more sustainable sector.

5.2. Limitations and Future Research

Although this dissertation has presented in-depth research of the adoption of sustainable technology in the aviation sector, it is vital to acknowledge the study's limits and suggest areas that require additional investigation. The constraints stem from both the methodological methodology and the context of the technologies studied, which influence the breadth of the conclusions. This section discusses the key limits discovered throughout the research and makes suggestions for future research that could increase knowledge and contribute to the evolution of the issue.

5.2.1. Limitations of the Study

1. **Limited interview sample:** The qualitative research was based on 11 interviews with aviation industry specialists, providing valuable but limited insight. Although information saturation has been reached, including more participants or diversifying the profiles interviewed may provide a more thorough picture of the sector's adoption of sustainable technologies.

2. **Focus on Emerging Technologies Still in Development:** Forecasts and data from early-stage projects are highly relied upon when analysing upcoming technologies such as electric and hydrogen-powered aircraft. Given the scarcity of solid evidence on large-scale application of these technologies, financial and environmental implications are speculative and reliant on estimates. This may limit the validity of long-term results, as technologies can advance in unanticipated ways.

3. **Reliance on regulatory incentives and government policies:** The viability of some technologies, such as hydrogen and electric aircraft, is heavily influenced by incentive programs and public infrastructure investments. The study considered this element, but it was unable to investigate in depth the variations in policies in different geographical contexts, which can have a considerable impact on the adoption of these technologies.

4. **Competition with High-Speed Trains (HSR):** While the thesis examined the competition between aviation and high-speed trains (HSR) on short routes, it did not provide a quantitative study of aircraft substitution by trains in specific regions. The lack of more thorough information on the actual substitutability of short and HSR flights restricts the ability to forecast impact in specific regional markets.

5.2.2. Future Research

As there are still various areas that require additional investigation to increase knowledge of the adoption of sustainable technology in aviation, future research should address these gaps and provide new perspectives that complement the findings of this dissertation. The following are some recommended directions for future research:

1. **Comparative Analysis of Geographic Regions:** A future study might examine the adoption of sustainable technology across regions, focusing on differences in environmental policies, infrastructural availability, and market preferences. Case studies from other countries or continents may provide a broader global perspective on the hurdles and enablers to new technology adoption in aviation.

2. **Modal Integration:** Further investigation into the intermodality of aviation and high-speed trains will be beneficial in better understanding how these modes can collaborate rather than compete. Future research could include simulations of scenarios that combine air travel and high-speed rail, considering the total emissions and environmental effect of various transportation combinations.

3. **Consumer Behaviour Analysis:** While the thesis focused on consumer preferences in the eyes of airlines about sustainability, future research might use quantitative approaches to examine the elasticity of demand for sustainable flights in comparison to HSR and other modes of transportation. Large-scale surveys and tests with consumers could provide insights into purchasing behaviour under various price situations and trip times.

4. **Infrastructure and Renewable Energy Development:** Given that many sustainable technologies rely on infrastructure and renewable energy, it would be worthwhile to investigate the role of clean energies in their success. Future research should look into how the increased use of renewable energy sources affects the economic sustainability of electric and hydrogen-powered aircraft.

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Appendix

Appendix A: Interview Questions

1. What are the costs associated with using technologies as SAF Fuels, electric and hydrogen planes?

2. What is the cost-benefit trade-off of implementing sustainable technologies in aviation?

3. What is the potential for CO2 emissions reduction with the use of SAF, electric planes, or hydrogen-powered aircraft?

4. How does the energy consumption of electric/hydrogen planes compare to traditional aircraft?

5. What is the impact on noise pollution with the use of new technologies?

6. What is the lifecycle sustainability of aircraft powered by more sustainable technologies?

7. How do customers evaluate the demand for flights using sustainable fuels, electric aircraft, or hydrogen-powered planes?

7.1. Based on this assessment, how do you perceive the cost competitiveness between sustainable aviation and high-speed trains?

7.2. In terms of travel time, how do flights using sustainable technologies compare to high-speed trains?

8. How can the use of new technologies influence customer satisfaction?

8.1. In your opinion, what is the perceived level of convenience for customers when choosing between sustainable aviation and high-speed train travel?

9. What are the most important factors for customers when choosing a sustainable air transportation mode?

9.1. In your opinion, what are consumers' preferences when deciding between using sustainable aviation and high-speed trains as a mode of transportation?

10. What are the most important Key Performance Indicators (KPIs) for monitoring customer engagement with sustainable technologies?

Appendix B: Coding Dictionary

Question	Code	Subcode	Subcode
1	Costs	SAF	Production/Operations
			Maintenance
			Infrastructure
		Electric	Production/Operations
			Maintenance
			Infrastructure
		Hydrogen	Production/Operations
			Maintenance
			Infrastructure
2	Trade-Off	Economy of Scale	
		Market Demand	
		Competitiveness	
		Costs	Passenger Costs
			Regulations, Taxes and Fees
			Sales
			Operations Gains
			Initial Investment
			Fuel Consumption
		Environmental	
3	CO2 Emissions Reduction	SAF	
		Electric	
		Hydrogen	
4	Energy consumption of electric/hydrogen	Electric	
		Hydrogen	
5	Noise pollution	SAF	
		Electric	
		Hydrogen	Fuel Cells
			Turbine
6	The lifecycle sustainability	Reusable	
		Non Reusable/Non Recyclable	
		Recyclable	
		Production/Manufacturing	
7	The demand for flights using sustainable fuels	Price	
		Demand for Sustainability	
		Travel Time	
7.1	Cost competitiveness		
	High-speed trains		
7.2	Travel time		
8	Customer satisfaction	Price	
		Travel Time	
		Comfort	
		Sustainability	
		Customer Experience	
8.1	Level of convenience	Price	
		Comfort and Accessibility	
		Travel Time	
		Frequency of Schedules	
		Innovation	
		Punctuality	
9	Factors for customers when choosing	Convenience	
		Safety	
		Price	
		Travel Time	
		Travel Experience	
		Flight Frequency	
		Environmental Impact	
		Accessibility	
9.1	Consumers' preferences	Convenience	
		Travel Time	
		Schedules	
		Safety	
		Costs/Prices	
10	Key Performance Indicators (KPIs)	Miles Number	
		Recomendation Rate	
		Customer Satisfaction Rate	
		Adoption Rate	
		Ticket Cost Per Passenger	
		Emissions Reduction	
		Market Share	
		Repeat Purchases/Customer Loyalty	
		Number of sustainable flights sold	
		Net Promoter Scores	
		Offset Programs	
		Sales	
		Willingness to Pay	

Appendix C: Results of Question 1

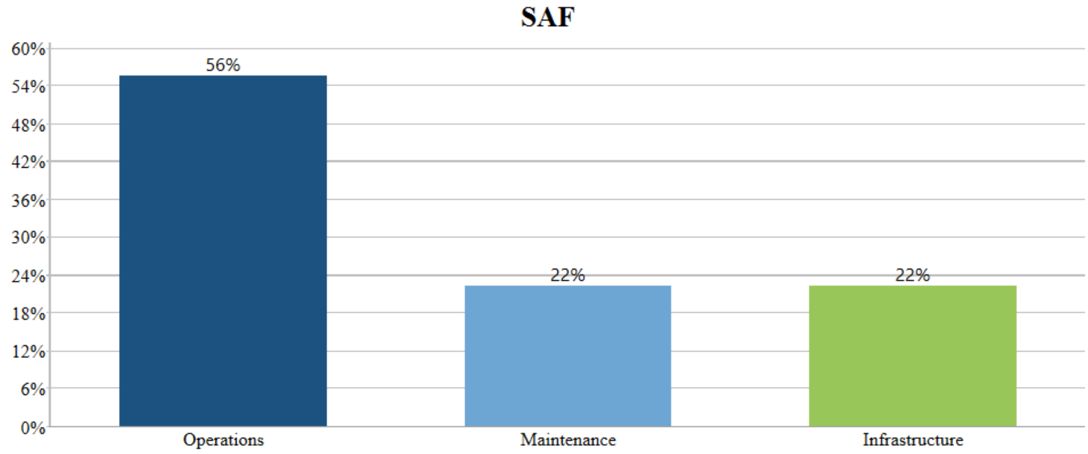

Figure 1 – Costs associated with using technologies as SAF Fuels

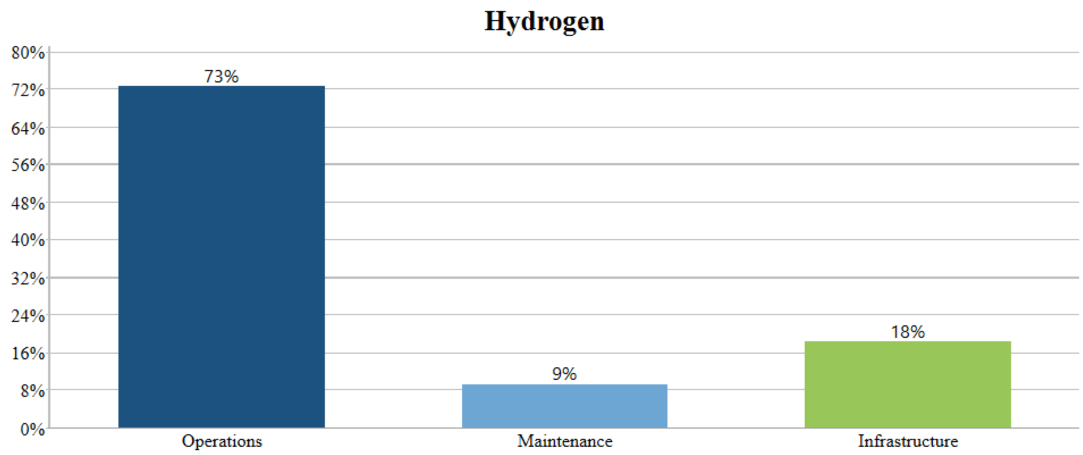

Figure 2 - Costs associated with using technologies as hydrogen planes

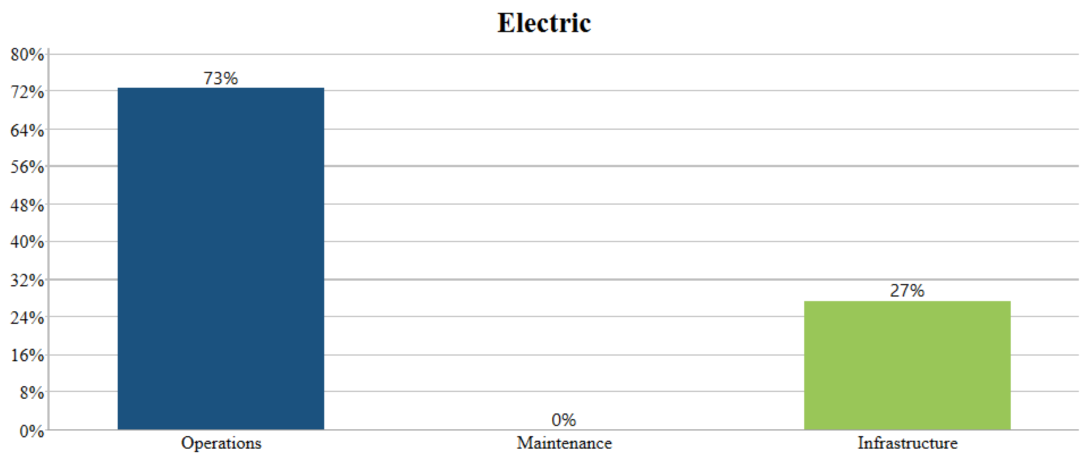

Figure 3 - Costs associated with using technologies as electric

Appendix D: Results of Question 2

Table D.1 – Codes Results

Codes	Segments	%
Environmental	7	14,58
Costs	23	47,92
Competitiveness	6	12,50
Market Demand	6	12,50
Economy of Scale	6	12,50
TOTAL	48	100,00

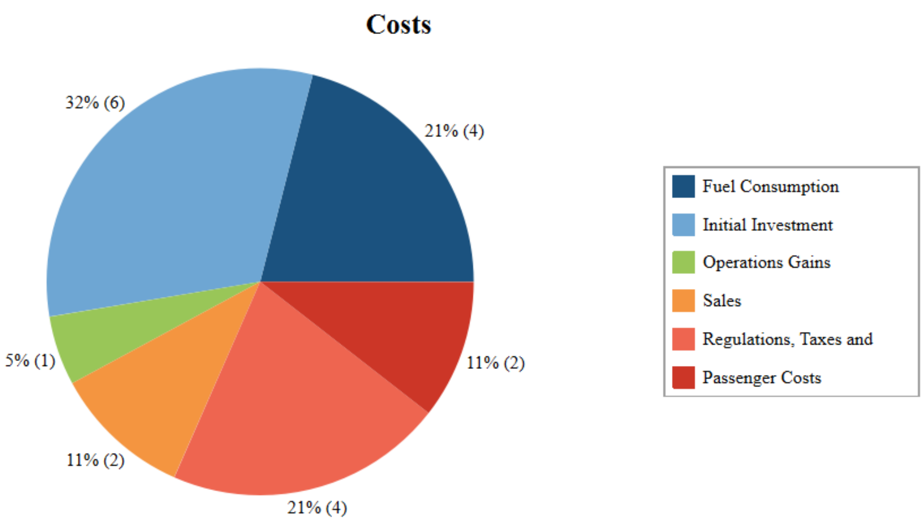

Figure 4 – Subcodes of Cost-Benefit Trade-Off

Appendix E: Results of Question 6

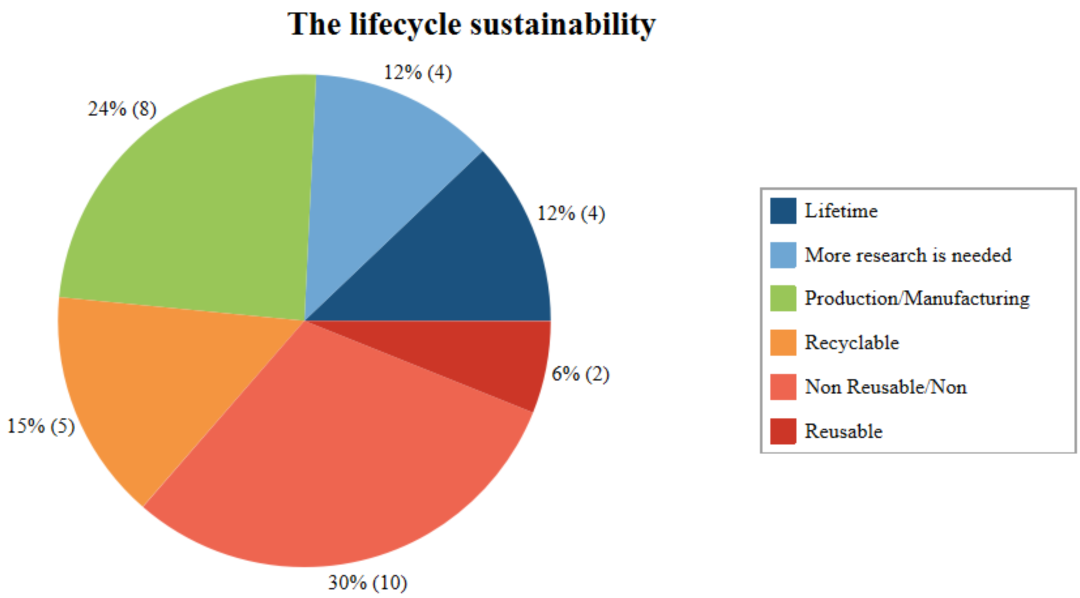

Figure 5 – The lifecycle Sustainability

Appendix F: Results of Question 7

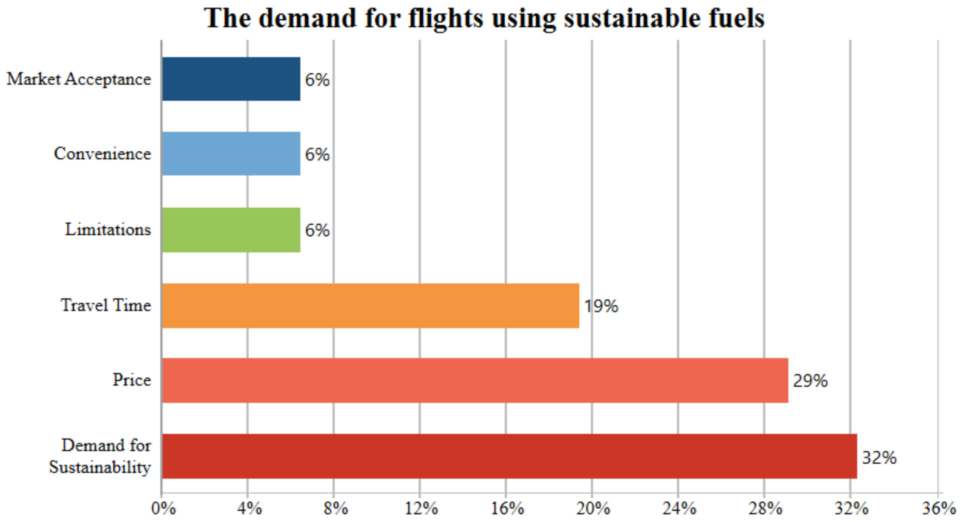

Figure 6 – The demand for flights using sustainable fuels

Appendix G: Results of Question 8

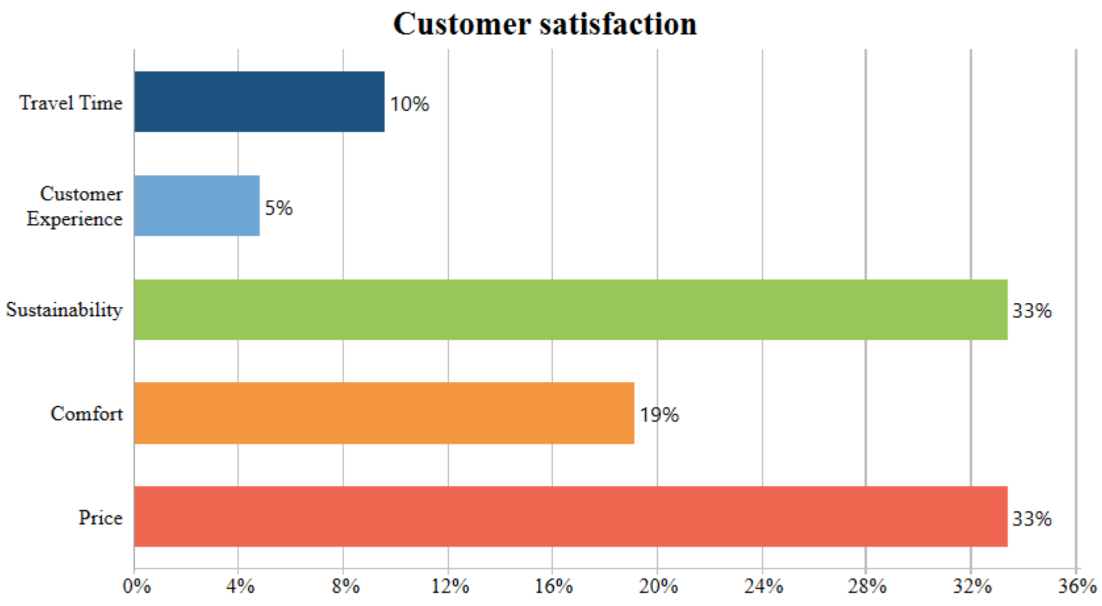

Figure 7 – Customer Satisfaction

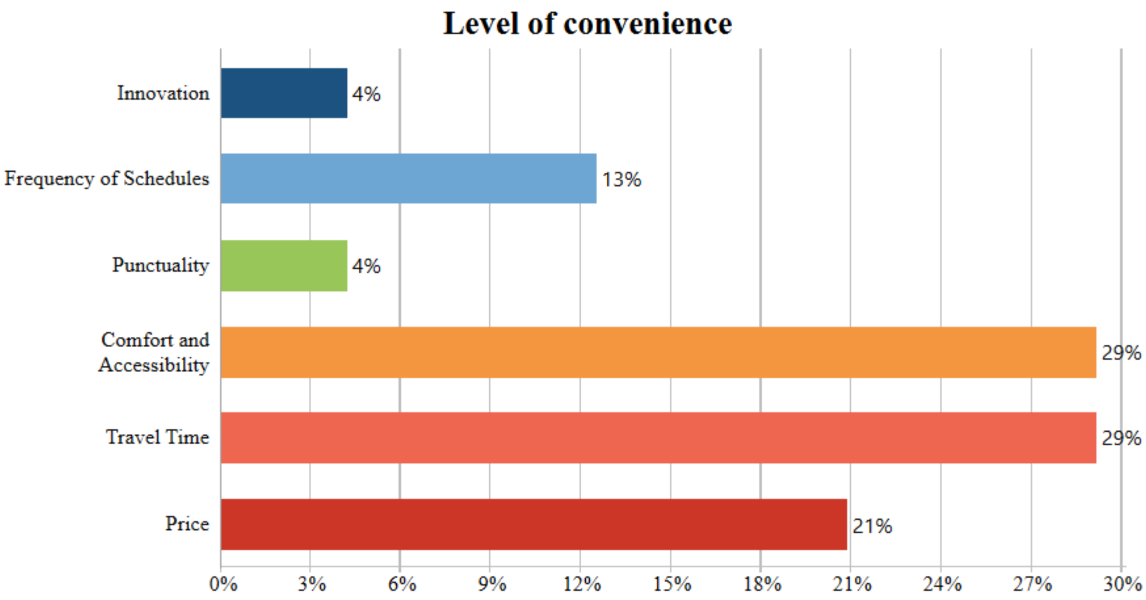

Figure 8 – Level of Consumer Convenience

Appendix H: Results of Question 9

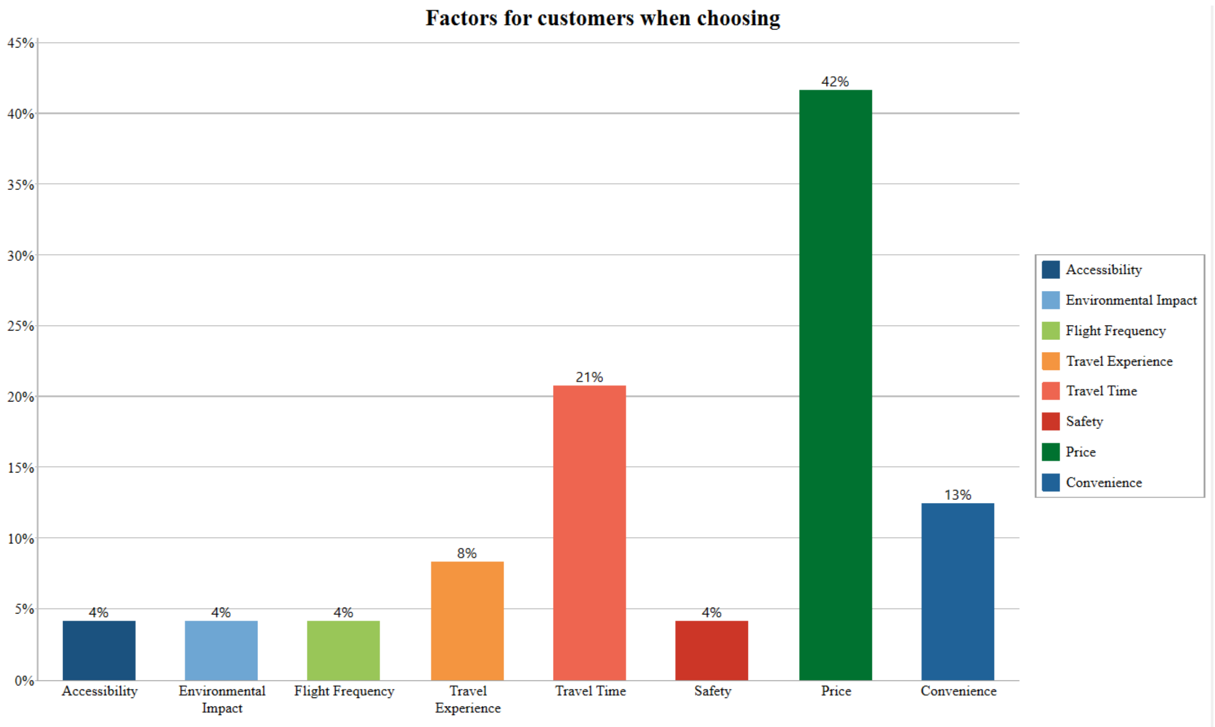

Figure 9 - Customers' decisions for sustainable air transportation

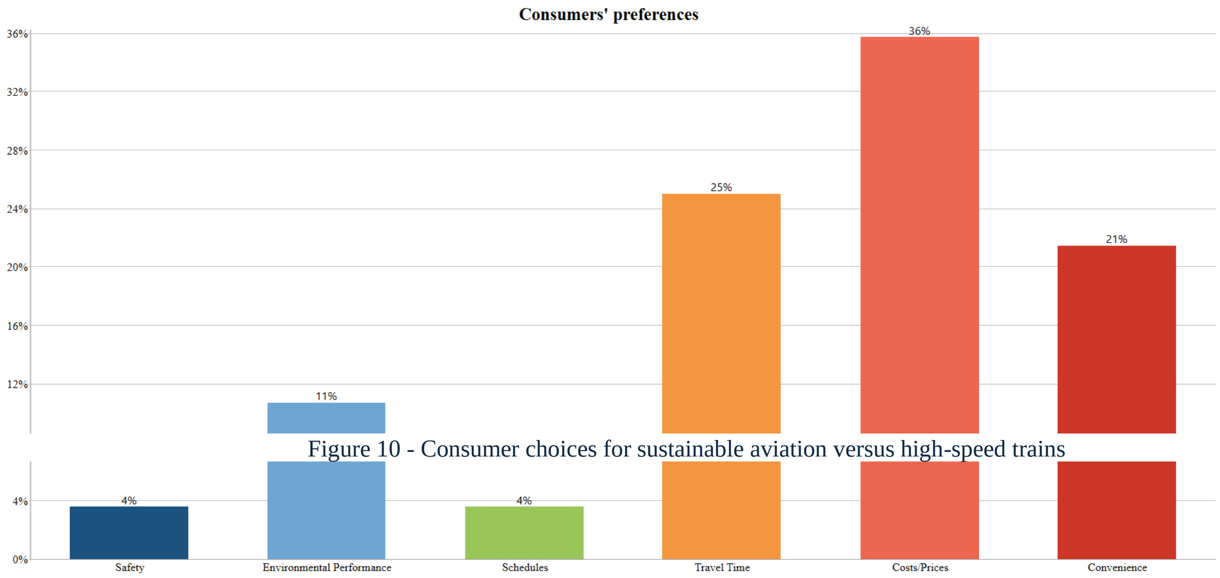

Figure 10 - Consumer choices for sustainable aviation versus high-speed trains

Appendix I: Results of Question 10

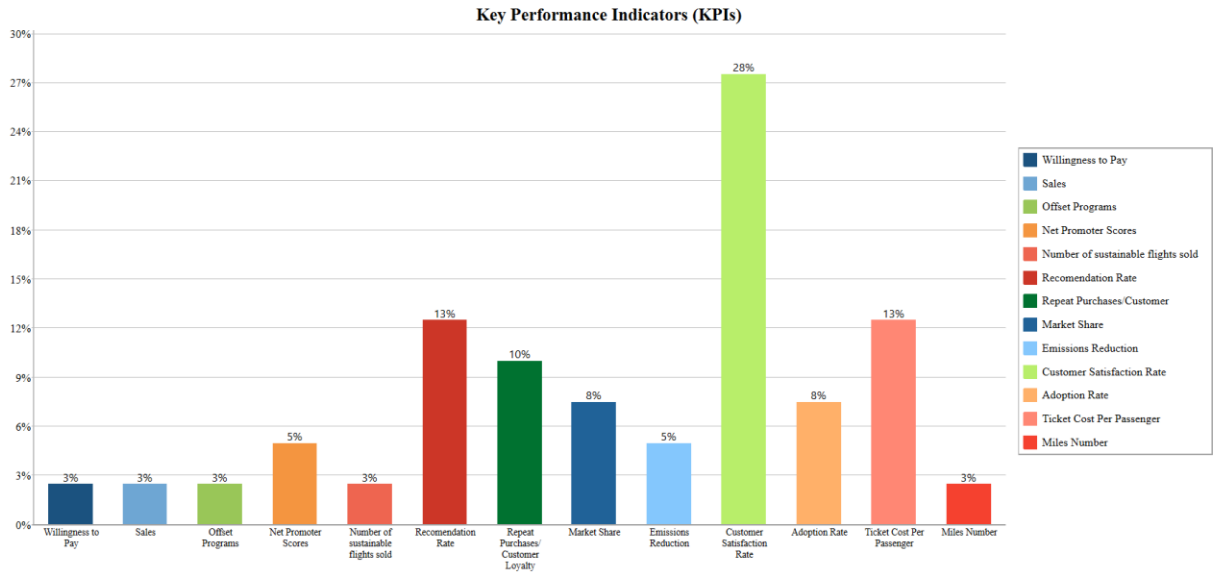

Figure 11 - Key Performance Indicators (KPIs) for monitoring customer engagement with sustainable technologies