ECONOMIC IMPACT OF SAF ON AIRLINES' BUSINESS SUSTAINABILITY:

SeCA – Economic Comparative Analysis of LCC and FSC, Current Landscape and Future Trends

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Final work to obtain the Master of Science degree in

Air Transport Operations

July 2025

FINAL VERSION

ISEC LISBOA | INSTITUTO SUPERIOR DE EDUCAÇÃO E CIÊNCIAS

Escola de Gestão, Engenharia e Aeronáutica

Examinations for obtaining the Master's Degree in Air Transport Operations

Outputs: Economic Impact of SAF on Airline Business Sustainability: Comparative Analysis between LCCs and FSCs in the Current Landscape and the Future Trends; SAF Economic Impact on Aircraft Operations: Case Study LCC vs FSC (to be considered to best student paper award); SAF Economic Impact on Aircraft Operations: Case Study SATA Azores Airlines (to be considered to best student paper award); Towards Sustainable Aviation: Assessing Airport’s Progress Towards Net Zero Emissions by 2050

ECONOMIC IMPACT OF SAF ON AIRLINES' BUSINESS SUSTAINABILITY

SeCA – Economic Comparative Analysis of LCC and FSC, Current Landscape and Future Trends

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July 2025

ACKNOWLEDGEMENTS

Reaching the end of this journey would not have been possible without the support, encouragement, and guidance of many people to whom I would like to express my heartfelt gratitude.

First and foremost, I would like to thank Professor Maria Baltazar, my Dissertation supervisor, for her continuous support, valuable insights, and constructive feedback throughout this process. Her dedication and availability were instrumental in helping me shape this work, and I am truly grateful for the knowledge and confidence I gained under her guidance.

I am also deeply thankful to ISEC Lisboa, not only for the academic foundation it provided, but also for fostering an environment that encourages critical thinking, exploration, and professional development. The experience of studying at this institution has been a formative and enriching chapter in my life over the last five years, including my Bachelor's years.

To my family, who have always believed in me, your love, patience, and constant support were the pillars that sustained me throughout this demanding journey. And to my friends, thank you for being there, cheering me on, listening when I needed to vent, and reminding me to take breaks when I forgot how to do so.

To my manager and my team, thank you for the trust, understanding, and encouragement offered along the way. Your support was crucial during moments of challenge and doubt, and I deeply appreciate the motivation you provided as I balanced professional responsibilities with academic goals.

I would also like to express my gratitude to everyone who contributed, directly or indirectly, to the completion of this Dissertation through conversations, advice, or encouragement. Every gesture, no matter how small, had a meaningful impact.

As someone once said, *“For some, the sky is the limit. For us, it is our home.”* This phrase resonates deeply with the journey I’ve undertaken — one grounded in passion for aviation, yet always reaching higher.

Thanks Everyone!

RESUMO

Este estudo analisa as implicações económicas da incorporação de SAF nas operações diárias de companhias aéreas comerciais, em particular até ao limite legalmente permitido de mistura nos depósitos de combustível das aeronaves. A investigação surge da crescente necessidade de alinhar as atividades do setor da aviação com os objetivos globais de sustentabilidade, bem como da intensificação da pressão exercida por reguladores, partes interessadas e consumidores no sentido da adoção de práticas ambientalmente mais responsáveis.

Apesar dos contínuos avanços tecnológicos na eficiência aeroespacial e nos mecanismos de mitigação de emissões, o SAF mantém ainda um papel marginal na aviação comercial global, essencialmente devido à sua disponibilidade limitada e ao seu custo unitário superior por litro, quando comparado com o CAF. Embora o SAF permita reduzir as emissões de CO_2 até 80%, o seu elevado custo de produção — impulsionado por cadeias de abastecimento restritas, infraestruturas de produção pouco desenvolvidas e economias de escala ainda incipientes — torna a sua adoção economicamente inviável no atual contexto de mercado, particularmente quando comparado com os combustíveis fósseis tradicionais utilizados na aviação.

Para quantificar este impacte económico e explorar possíveis mecanismos de compensação, foi desenvolvido e aplicado o Modelo SeCA (SAF em Companhias Aéreas), uma estrutura original concebida pelo autor. Este modelo está estruturado em duas fases: uma avaliação económica quantitativa, suportada por dados, do impacte da utilização de SAF, seguida da implementação de três soluções de reequilíbrio de receitas, concebidas para restaurar o Resultado Líquido a um ponto de neutralidade. A metodologia baseia-se em dados empíricos extraídos dos relatórios financeiros das companhias aéreas analisadas, aplica fórmulas de transformação de custos de combustível e realiza modelações de impacte com base em margens operacionais, volumes de passageiros e estratégias tarifárias.

O Modelo SeCA foi aplicado à Ryanair e à Emirates — duas operadoras com modelos de negócio fundamentalmente distintos. Estes dois estudos de caso foram selecionados com o objetivo de captar a heterogeneidade económica do mercado global da aviação

comercial, oferecendo um contraste valioso entre os modelos LCC e FSC quando expostos aos custos associados ao SAF.

A análise considerou diversas variantes de SAF, cada uma com diferentes preços por litro (€/L) e rotas tecnológicas de produção, de forma a simular uma gama realista de encargos de combustível sob um cenário de mistura de 50% de SAF, em conformidade com os limites regulamentares atuais. Os resultados do Modelo SeCA demonstraram que, para todas as variantes de SAF — com exceção do SAF-B [N] no caso da Ryanair — ambas as operadoras registaram uma deterioração significativa no Resultado Líquido, em virtude do aumento dos custos de combustível. Importa destacar que o cenário SAF-B [N] foi o único em que uma companhia aérea atingiu o ponto de equilíbrio, devido exclusivamente ao preço altamente competitivo por litro desta variante de SAF, inferior ao custo médio de aquisição de combustível convencional pela Ryanair. No entanto, no caso da Emirates, mesmo este cenário mais favorável resultou em prejuízo operacional, dada a sua menor base de custo por litro de combustível convencional, reforçando assim a conclusão de que a adoção do SAF carece, neste momento, de paridade económica com o CAF.

Após a quantificação do impacte económico, o modelo testou as três estratégias de mitigação propostas: Solução +PAX (aumento do número de passageiros pagantes mantendo constante a tarifa média), Solução +FARE (aumento da tarifa média mantendo o volume de passageiros constante), e Solução Ótima (equilíbrio híbrido entre as duas abordagens anteriores). Recorreu-se à abordagem CVM para medir empiricamente a WTP dos passageiros por aumentos tarifários justificados pela contribuição ambiental associada à utilização de SAF. Os resultados demonstraram que, em ambos os casos estudados, os níveis observados de WTP — ainda que reveladores de uma crescente consciência ambiental — permaneceram insuficientes para sustentar, do ponto de vista económico, a Solução +FARE. A elasticidade-preço da procura, particularmente no segmento sensível ao preço da Ryanair, agravou ainda mais a inviabilidade de ajustes tarifários como solução isolada.

Em conclusão, a aplicação do Modelo SeCA à Ryanair e à Emirates confirma a atual inviabilidade económica da utilização de SAF tanto nos paradigmas de LCC como nos de FSC, nas condições de mercado vigentes. O estudo reforça a necessidade urgente de mecanismos de apoio político de larga escala, da estabilização dos preços do SAF e de uma

otimização estratégica das frotas, de forma a mitigar os custos decorrentes das exigências de sustentabilidade. Adicionalmente, a investigação evidencia a diversidade setorial na sensibilidade às variações nos custos de combustível, com companhias de baixo custo, como a Ryanair, potencialmente mais aptas a beneficiar, em menor prazo, de futuras reduções nos custos do SAF, ao passo que FSC's, como a Emirates, poderão necessitar de transformações estruturais mais profundas ou de ajustamentos regulatórios para manter a rentabilidade sob regimes sustentáveis de combustível.

Palavras-chave

Alterações Climáticas, Sustainable Aviation Fuel, Sustentabilidade Empresarial, Custos com os Combustíveis, Willingness-to-Pay

ABSTRACT

This study examines the economic implications of incorporating SAF into the daily operations of commercial airlines, particularly up to the legally permitted blend ratio in aircraft fuel tanks. The research emerges from the growing imperative to align aviation activities with global sustainability objectives and the mounting pressure from regulators, stakeholders, and consumers to adopt more environmentally responsible practices.

Despite ongoing advancements in aerospace efficiency and emissions abatement technologies, SAF continues to play a marginal role in global commercial aviation due to its limited availability and higher cost per litre compared to CAF. Although SAF can reduce CO_2 emissions by up to 80%, the high unit cost associated with its production—driven by constrained supply chains, immature production infrastructure, and limited economies of scale—renders its adoption economically unfeasible under current market conditions, particularly when compared to legacy jet fuels.

To quantify this economic impact and explore viable offsetting mechanisms, the SeCA Model—an original framework developed by the author—was employed. This model is structured around a two-phase assessment: a data-driven economic impact evaluation of operating with SAF, followed by the implementation of three revenue-rebalancing solutions designed to restore the Net Result to a neutral state. The methodology leverages empirical data from the subject airlines' financial reports, applies fuel-cost transformation formulas, and performs impact modelling based on operational margins, passenger volumes, and pricing strategies.

The SeCA Model was applied to Ryanair and Emirates—two fundamentally distinct carriers. These two case studies were selected to capture the economic heterogeneity of the global commercial aviation market, offering a valuable contrast between low-cost and full-service business models when exposed to SAF-related costs.

The analysis considered several SAF variants, each with distinct €/L pricing and production pathways, to simulate a realistic range of fuel cost burdens under a 50% SAF blend scenario, consistent with current regulatory limits. Results from the SeCA Model revealed that, across all SAF types, except for SAF-B [N] in Ryanair’s case, both carriers experienced a marked deterioration in Net Result due to increased fuel expenses. Notably, SAF-B [N] was the only scenario where an airline achieved break-even performance, attributed solely to this SAF variant's highly competitive €/L pricing, which undercut Ryanair's average conventional fuel procurement cost. For Emirates, however, even this most economically favourable SAF scenario resulted in negative profitability due to its lower baseline fuel cost per litre, thereby reinforcing the notion that SAF adoption currently lacks economic parity with CAF.

Following this impact determination, the model tested three proposed mitigation strategies: Solution +PAX (increasing the number of revenue passengers at a constant average fare), Solution +FARE (raising the average fare with a static passenger volume base), and Optimal Solution (a hybrid equilibrium between the two strategies). The CVM approach was employed to empirically measure passengers' WTP for fare increases under the premise of contributing to environmental sustainability via SAF usage. Findings demonstrated that, in both case studies, the observed WTP levels—though indicative of a growing environmental awareness—remained insufficient to support Solution +FARE economically. The price elasticity of demand, particularly in Ryanair's cost-sensitive market segment, further exacerbated the impracticality of fare adjustments as a standalone solution.

In conclusion, the application of the SeCA Model to Ryanair and Emirates confirms the current economic infeasibility of SAF in both low-cost and full-service paradigms under present market conditions. It reinforces the urgent need for large-scale policy support mechanisms, SAF price stabilisation, and strategic fleet optimisation to offset sustainability-related costs. Moreover, the research highlights the sectoral diversity in sensitivity to fuel cost shifts, with LCCs, such as Ryanair, potentially benefiting more rapidly from future reductions in SAF costs. At the same time, FSCs, such as Emirates, may require deeper structural transformations or regulatory adjustments to maintain profitability under sustainable fuel regimes.

KEYWORDS

Climate Change, Sustainable Aviation Fuel, Business Sustainability, Fuel Costs, Willingness-to-Pay

Resumo Alargado

Introdução

O setor da aviação civil tem assumido, ao longo das últimas décadas, um papel fulcral na conectividade global, no comércio internacional e no crescimento económico. Contudo, esta relevância crescente tem vindo a ser acompanhada por um escrutínio cada vez mais apertado no que respeita às suas externalidades ambientais. Entre as diversas soluções que procuram mitigar o impacte ambiental da aviação, o SAF destaca-se como uma alternativa promissora ao CAF, apresentando o potencial de reduzir até 80% das emissões de CO2 ao longo do seu ciclo de vida (International Air Transport Association, 2021b).

Apesar da sua sustentabilidade ambiental comprovada, o SAF permanece economicamente inviável para a maioria das companhias aéreas, principalmente devido ao seu elevado custo unitário e à limitação da oferta global. É neste contexto que esta Dissertação se insere, propondo-se a analisar o impacte económico da operação com SAF sobre dois modelos de negócio distintos: as LCC, representadas pela Ryanair, e as FSC, representadas pela Emirates.

Enquadramento da Dissertação

A presente Dissertação propõe-se a avaliar a viabilidade económica da incorporação do SAF nas operações comerciais regulares das companhias aéreas. Para tal, o autor desenvolveu o modelo SeCA — "SAF em Companhias Aéreas" —, concebido como uma estrutura analítica de base quantitativa, com o objetivo de estimar o impacte económico do uso do SAF e de testar soluções mitigadoras que possam devolver os resultados líquidos das companhias a um ponto de equilíbrio.

A escolha das companhias Ryanair e Emirates como objeto de estudo prende-se com a sua representatividade nos extremos opostos do espectro operacional: a primeira simboliza uma operação de elevada eficiência e baixos custos, enquanto a segunda opera num modelo orientado para a experiência do passageiro e serviços diferenciados. Esta dicotomia permite aferir de que forma o modelo de negócio influencia a absorção do impacte económico associado ao uso de SAF.

DESCRIÇÃO DO PROBLEMA E OBJETIVOS

A problemática central que motivou esta Dissertação prende-se com o paradoxo entre a urgência da descarbonização do setor da aviação e a atual inviabilidade económica da adoção em larga escala de combustíveis sustentáveis como o SAF. O SAF é apontado por entidades como a International Civil Aviation Organization (2022b) como uma das principais vias para atingir a neutralidade carbónica até 2050. Contudo, enfrenta entraves estruturais: é significativamente mais caro do que o CAF, a sua produção é escassa, e as cadeias logísticas e de abastecimento ainda estão em fase embrionária.

Esta dissonância entre a necessidade ambiental e a realidade económica levanta uma questão crítica para o futuro da aviação: como é que as companhias aéreas, com diferentes modelos de negócio, poderão incorporar o SAF nas suas operações sem comprometer a sustentabilidade financeira? É precisamente com base nesta interrogação que se formula a seguinte pergunta de partida:

Qual é o impacte económico da operação com SAF para uma LCC e uma FSC, no contexto atual e em cenários futuros?

A resposta a esta pergunta é orientada por cinco hipóteses de trabalho, definidas como segue:

- H1: Atualmente, o uso de SAF não é economicamente viável para companhias aéreas, independentemente do modelo de negócio.
- H2: No futuro, o SAF tornar-se-á significativamente mais viável do ponto de vista económico.
- H3: O impacte económico do SAF difere entre LCCs e FSCs.
- H4: Algumas soluções e incentivos mitigam ou anulam o impacto económico da adoção de SAF.
- H5: A dimensão social da sustentabilidade ambiental pode ser um fator de compensação económica relevante.

Com base nestas hipóteses, estabelecem-se os seguintes objetivos de investigação:

- Analisar, com base empírica, o impacte económico direto da utilização de SAF em companhias com modelos de negócio distintos;

- Testar cenários de mitigação económica baseados em estratégias operacionais realistas, tais como aumento da base de passageiros, reajuste tarifário ou combinação de ambos;
- Avaliar o grau de aceitação por parte dos passageiros no que respeita à possibilidade de pagar mais por voos com menor pegada carbónica, aferindo a sua WTP;
- Desenvolver e validar um modelo analítico — o modelo SeCA — aplicável à análise económico-operacional da adoção de SAF na aviação comercial.

Esta abordagem procura, assim, não apenas quantificar impactes, mas também propor caminhos concretos de transição energética no setor, ancorados na realidade económica das companhias e na perceção social dos consumidores.

ARGUMENTO

A metodologia adotada na presente investigação baseia-se numa abordagem exploratória de base quantitativa, estruturada através da construção e aplicação do modelo SeCA. Este modelo é composto por duas fases distintas: numa primeira etapa procede-se à avaliação do impacte económico direto da utilização de SAF, baseada em dados empíricos provenientes de relatórios financeiros e indicadores operacionais das companhias Ryanair e Emirates. Numa segunda etapa, exploram-se cenários de compensação económica através da implementação de três soluções alternativas, desenhadas para restaurar a neutralidade do resultado líquido das operadoras.

As soluções de compensação analisadas foram:

1. Solução +PAX: aumento do número de passageiros, mantendo a tarifa constante;
2. Solução +FARE: aumento da tarifa média, mantendo constante o número de passageiros;
3. Solução Ótima: combinação ponderada entre as duas anteriores, visando o reequilíbrio do resultado líquido.

A componente comportamental foi também integrada na análise, através da aplicação de um inquérito estruturado com base no método CVM, o qual permitiu aferir a disposição dos passageiros para pagar tarifas acrescidas motivadas por razões ambientais. Esta variável revelou-se especialmente relevante na avaliação da viabilidade da Solução +FARE e da Solução Ótima.

PRINCIPAIS CONTRIBUIÇÕES

Do ponto de vista científico, esta Dissertação contribui para o avanço do conhecimento através da criação de um modelo económico original — o SeCA —, que permite estudar a viabilidade da utilização de combustíveis alternativos em contexto real, integrando múltiplas dimensões (económica, operacional e comportamental). Para além disso, a sua aplicação empírica a duas companhias com perfis antagónicos reforça o valor prático da investigação e potencia a replicabilidade do modelo a outros contextos.

Em termos estratégicos, o estudo fornece evidência objetiva para apoiar a formulação de políticas públicas orientadas para a transição energética na aviação, sublinhando a necessidade de estímulos económicos e regulamentares para mitigar o impacte do SAF no desempenho financeiro das operadoras.

PRINCIPAIS CONCLUSÕES

A aplicação do modelo SeCA demonstrou que, à exceção do cenário SAF-B [N] na Ryanair, todas as simulações resultaram numa degradação significativa do resultado líquido das companhias. Esta exceção ficou a dever-se ao facto de, nesse caso específico, o preço por litro do SAF ser inferior ao custo médio do CAF pago pela Ryanair. Ainda assim, mesmo neste cenário, a Emirates registou prejuízos operacionais, confirmando uma menor resiliência à incorporação de SAF, em virtude da sua estrutura de custos baseados num combustível convencional mais económico.

As soluções de compensação testadas revelaram que a Solução +FARE se mostrou, na maioria dos casos, inviável, tendo em conta os baixos níveis de WTP verificados entre os passageiros, sobretudo nos segmentos de mercado mais sensíveis ao preço, como o da Ryanair. A Solução +PAX apresentou maior viabilidade, embora dependa da disponibilidade de capacidade operacional e da existência de procura adicional. Por fim, a Solução Ótima revelou-se conceptualmente equilibrada, mas com exigências operacionais e logísticas que podem dificultam a sua aplicação direta.

Estas conclusões permitem testar as hipóteses propostas, confirmando a inviabilidade económica atual da adoção de SAF e evidenciando a necessidade de soluções complementares para tornar viável a sua implementação no setor aéreo.

Perspetivas de Investigação Futura

Esta dissertação abre caminho a múltiplos desenvolvimentos futuros. Desde logo, a replicação do modelo SeCA a um leque mais amplo de companhias aéreas, incluindo operadoras regionais e intercontinentais, permitiria avaliar a robustez dos resultados em diferentes contextos operacionais. Paralelamente, a integração de variáveis não-operacionais — como custos associados a taxas aeroportuárias, regimes fiscais ou manutenção — poderia enriquecer a análise e oferecer uma perspetiva mais holística.

Outra linha promissora reside na utilização de modelos dinâmicos que simulem cenários futuros com base em projeções de evolução do preço do SAF, desenvolvimento tecnológico ou alteração nas regulamentações internacionais. A complementaridade entre a análise económica e a LCA permitiria, por sua vez, conjugar métricas de desempenho financeiro com métricas ambientais, ampliando a relevância estratégica da investigação.

Por fim, uma investigação mais aprofundada sobre os perfis sociodemográficos e comportamentais dos passageiros com maior propensão a pagar por viagens sustentáveis poderá revelar-se essencial para definir políticas tarifárias diferenciadas e estratégias de marketing orientadas para a sustentabilidade.

A transição ecológica no setor da aviação exige, mais do que intenções, um compromisso profundo com soluções economicamente viáveis, ambientalmente sustentáveis e socialmente aceitáveis. Esta dissertação pretende ser um contributo nesse sentido.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

Abbreviations and Acronyms

AAF – Alternative Aviation Fuel

APAC – Asia/Pacific

ASK – Available Seat Kilometre

AwA – Airline-within-Airline

B – Billion

B.C. – Before Christ

CAF – Conventional Aviation Fuel

CAGR – Compound Annual Growth Rate

CASA – Central and South America

CFS – Clean Fuel Standards

CO_2 - Carbon Dioxide

CORSIA – Carbon Offsetting and Reduction Scheme for International Aviation

EEA – European Emission Allowance

EU ETS – European Union Emission Trading Scheme

EV – Electric Vehicle

FSC – Full-Service Carriers

GHG – Greenhouse Gases

HEFA – Hydroprocessed Esters and Fatty Acids

HWTP – Hypothetical Willingness-to-Pay

IATA – International Air Transport Association

ICAO – International Civil Aviation Organisation

IPO – Input-process-output

ISEC – Instituto Superior de Educação e Ciências

K – Thousand

LCAF – Lower Carbon Aviation Fuel

LCC – Low-Cost Carriers

LCCA – Life-cycle Cost Analysis

LCFS – Low Carbon Fuel Standards

LF – Load Factor

M – Million

MEA – Middle East and Africa

MRO – Maintenance, Repair, and Overhaul

NA – North America

NGO – Non-Governmental Organisation

OPEC – Organisation of the Petroleum Exporting Countries

P&L – Profit and Loss

PAX – Passengers

PFC – Perfluorinated Compound

PLF – Passenger Load Factor

R&D – Research and Development

RD&D – Research, Development, and Demonstration

RPK – Revenue Passenger Kilometres

RWTP – Real Willingness-to-Pay

SAF – Sustainable Aviation Fuel

SARS – Severe Acute Respiratory Syndrome

SDGs – Sustainable Development Goals

SIP – Synthetised Iso-Paraffins

TAT – Turnaround Time

TRL – Technology Readiness Level

US – United States

VFR – Visiting Friends and Relatives

YoY – Year-over-Year

WOCE – Wings of Change Europe

WTP – Willingness-to-Pay

1. INTRODUCTION

1.1. GENERAL

The phenomenon of flight has fascinated and challenged humankind since the earliest times. Evidence of this can be traced back to around 400 B.C., when Greek mythology recounted the legend of Icarus and his father, Daedalus, who, accordingly to the tale, decided to craft wings from bird feathers held together with wax to escape from an island where King Minos had imprisoned them.

Following a chronological perspective, several milestones further illustrate humanity's pursuit of flight. Leonardo da Vinci, for instance, conceived visionary designs such as the ornithopter[1] alongside other well-known aeronautical concepts. Later, in 1783, the Montgolfier brothers revolutionised aviation by constructing and successfully testing the first manned hot-air balloon. The Wright brothers' monumental achievement in 1903, when they engineered and flew the first heavier-than-air aircraft, further cemented aviation's progress. Additionally, the rapid advancements in aviation during World War I were of great significance.

From a more patriotic perspective, it is also worth highlighting the remarkable feat accomplished by two Portuguese aviators, who, on March 30, 1922, took off near the Belém Palace in Lisbon and, after several stops and technical challenges, successfully landed in Rio de Janeiro, Brazil, on June 17. This historic journey marked the first-ever aerial crossing of the South Atlantic.

Like the First World War, the Second World War spurred extraordinary advancements in aviation, leading to the historic breaking of the sound barrier in 1947 and the maiden flight of the renowned Comet in 1949. From that point onward, aeronautical and aerospace development has been nothing short of remarkable. Today, the aviation industry encompasses a vast array of aircraft models, produced by multiple manufacturers, a multitude of airlines and airport infrastructures, a workforce of

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[1] Ornithopter – a mechanical designed to derive its chief support and propulsion from flapping wings (Merriam-Webster, 2025).

countless professionals, and millions of passengers transported across the globe each year.

Environmental protection has not always been considered, let alone prioritised, in the design of an organisation's business model. However, in today's world, the adoption of measures to mitigate environmental impact has become imperative for both individuals and organisations alike. Day after day, numerous events highlight the continuous environmental degradation caused by human activity on multiple levels.

As is characteristic of the aviation sector, technological advancement and a forward-looking vision remain the key drivers for its development. When combining aviation with environmental sustainability, it is possible – and indeed necessary - to recognise and commend the industry's efforts to move towards a greener and more sustainable future. These advancements occur across various dimensions; however, they remain insufficient to fully meet the ambitious goal set by numerous entities: achieving carbon neutrality by 2050. One of the main enablers of this goal is Sustainable Aviation Fuel (SAF), as emphasised by the International Air Transport Association's (IATA) General Director, William Walsh, at the Wings of Change Europe (WOCE) event (International Air Transport Association, 2024b).

SAF is defined as an Alternative Aviation Fuel (AAF) derived from the processing of renewable materials or waste-based feedstocks that meet specific established criteria (International Civil Aviation Organization, 2022b). While SAF is undoubtedly an environmentally sustainable alternative, it remains economically unviable, especially when compared to Conventional Aviation Fuel (CAF), due to its significantly higher acquisition cost for airlines. This elevated acquisition cost stems from an imbalance between limited supply and increasing demand.

1.2. SCOPE

As part of the Master's Degree in Air Transport Operations, this Dissertation emerges as research related to the economic impact of operating with SAF up to the legally accepted percentage levels in the aircraft's fuel tanks.

The research focuses on the aviation sector, especially in analysing the economic implications for an airline that chooses to adopt a greener fuel policy by incorporating SAF in its day-to-day operations.

Nowadays, the need to minimise the environmental impact of the aviation sector is indisputable. However, if the economic burden of transitioning to more environmentally sustainable practices proves too significant, industry players may feel discouraged from pursuing the "greening" of the sector. Among other challenges, this transition could lead to reduced operating margins, ultimately affecting the profitability and competitiveness within the aviation industry.

1.3. MOTIVATION

Aviation has historically been a pioneer in developing new solutions, typically striving for greater safety and efficiency. However, when it comes to the fuel used to power the aircraft, the industry lags behind other modes of transportation.

In the road transport sector, hybrid and electric vehicles are becoming increasingly common, with projections indicating that their market share will continue to grow Year-over-Year (YoY) (International Energy Agency, 2024). This shift is driven not only by legal restrictions but also by the inherent advantages of these vehicles, both environmentally and economically, for their owners. As a result, traditional petrol and diesel-powered vehicles, both derived from petroleum, which is a highly polluting and non-renewable resource, are gradually losing ground to Electric Vehicles (EVs) (Olayode et al., 2024). Meanwhile, in the railway sector, hydrogen-powered trains have already been deployed, with some experts considering this solution the most sustainable in the long term for the aviation sector as well (World Economic Forum, 2024).

Currently, although not a perfect long-term solution, there is one fuel that industry stakeholders have recognised as the most sustainable for both short-term and medium-term transitions, which is SAF. SAF is significantly less polluting than CAF and is produced from renewable resources, making it even more environmentally friendly (International Civil Aviation Organisation, 2022b). However, SAF has a major drawback in comparison with CAF that lies in its high acquisition cost (Shahriar & Khanal, 2022). Due to its limited production capacity relative to the scale of the aviation industry, SAF remains considerably more expensive than CAF.

These costs present airlines with a dilemma. On the one hand, adopting a greener fuel policy would demonstrate their corporate social responsibility and serve as a differentiating factor in the market. However, the economic burden of SAF makes this approach economically unfeasible, potentially threatening an airline’s economic sustainability. On the other hand, continuing to use conventional aviation fuels – despite their harmful environmental impact – poses fewer economic risks, making it easier for airlines to fulfil their ultimate goal: generating positive economic returns and meeting shareholders' expectations.

Beyond fuel costs, several factors influence the overall economic impact of transitioning to SAF. These include airport fees, passengers’ Willingness-to-Pay (WTP) for greener travel, the portion of SAF used in the aircrafts fuel tanks, the business model of the airlines themselves so if they follow a Low-Cost Carrier (LCC) approach where the operating margins are quite low, or if the airline follows a Full-Service Carrier perspective where the customer experience is prioritized, and other operational considerations that should be taken into account.

By carefully assessing these variables, it becomes possible to estimate the approximate cost of transitioning to a less polluting and more sustainable fuel alternative.

1.4. OBJECT AND OBJECTIVES

This Dissertation aims to assess the economic impact of an airline operating with a more environmentally sustainable fuel, namely SAF. Given the current state of SAF production, where supply remains significantly lower than demand, the economic burden on airlines is expected to be very substantial. Due to the principles of supply and demand, this imbalance results in a considerably higher selling price for SAF compared to CAF. This paradox, where the positive environmental benefits of SAF are countered by its potential to undermine an airline’s economic sustainability, highlights the urgent need for incentives and strategic solutions to mitigate the expected economic impact.

However, the outlook is not entirely bleak. While urgent action is required to ensure a sustainable future for the planet, various incentives – some of which are quite ambitious

– have already been implemented to facilitate this transition. These incentives primarily focus on supporting the Research and Development (R&D) of SAF production, which, if successful, could lead to larger and more optimised production, ultimately reducing acquisition costs for airlines. Additionally, some initiatives provide airlines with economic support or significant tax reductions to encourage the adoption of SAF.

The starting question of this research is: What is the economic impact of operating with SAF on an LCC and an FSC, both today and in the future?

The hypotheses proposed for this research are:

- H1: Nowadays, the use of SAF is not economically viable for airlines despite their business model.
- H2: In the future, SAF will become significantly more economically viable for both LCCs and FSCs.
- H3: The economic impact of SAF usage differs between LCCs and FSCs.
- H4: Some potential solutions and incentives mitigate, and could even offset the economic impact of operating with SAF, making it a more economically sustainable solution for airlines.
- H5: The social dimension of environmental sustainability can be a main driver in alleviating some of the economic challenges associated with SAF.

The primary objective of this research is to evaluate the economic impact of using SAF on the operations of both an LCC and an FSC in current and future contexts. The secondary objectives include:

- Determine the current and future operating costs associated with SAF.
- Assess the economic impact expected for an LCC and an FSC operating with SAF within the legally accepted terms.
- Evaluate whether the passengers' WTP vary and enables the airlines to offset the economic impact.
- Determine ways to reduce or eliminate the economic impact of operating with SAF.

While preliminary estimates suggest that operating with SAF is currently not economically viable, this research emphasises the importance of forward-thinking solutions. The goal is to identify ways to make SAF economically viable for airlines. The researcher anticipates that the proposed solutions within the chosen model will help to eliminate or at least mitigate the expected economic concerns regarding the impact of SAF adoption.

1.5. METHODOLOGY

This Dissertation is based on an exploratory research philosophy, as the topic of environmental sustainability has gained relevance in aviation management, particularly for airline operators. The research adopts a broad approach, enabling an in-depth analysis of SAF implementation in airlines and its impact on operational efficiency.

The research methodology relies on the analysis of journal articles, published reports by experts in the field of aviation, studies from international committees, and experiences from global airlines. Additionally, projects, news, academic research, and practical applications related to the use of SAF in air transport will be considered as valid sources of information.

This Dissertation follows a hypothetico-deductive approach, which is appropriate when the available knowledge is insufficient to explain a phenomenon fully. In this case, a set of hypotheses has been formulated and will be tested for validation or refutation. As these hypotheses undergo different tests and analyses, the understanding of the economic impact of SAF in aviation is strengthened. However, it is essential to note that even well-supported hypotheses may be rejected by new evidence and future testing, as both the aviation sector and the environmental sustainability variable are highly dynamic.

A hybrid questionnaire will be conducted, containing both open-ended and closed-ended questions, to analyse whether passengers' WTP changes when they are aware that their choices can contribute to a greener and more sustainable future, as well as the development of environmental sustainability within the aviation sector itself. This factor may be crucial in mitigating the potential economic impact on airlines.

Key Performance Indicators (KPI's) will be used to create analysis scenarios based on case studies, allowing for a realistic assessment of the economic impact of SAF adoption. The data will be organised and interpreted through graphs, tables, references, and other visual formats, making the information accessible, objective, and easy to understand for readers.

With this approach, the research aims not only to measure the economic impact of using SAF for two different business models but also to propose strategies that make the adoption of SAF economically viable for airlines.

1.6. WORK STRUCTURE

Chapter 1 sets the stage by providing an overview of the overall context in which the research project is situated. It begins by delineating the scope and focus of the investigation, clearly articulating the central problem that motivates the research. Subsequently, it outlines the starting question, the proposed hypothesis, and the specific objectives to be achieved and presents the methodological approach selected to address the identified problem. Furthermore, the chapter provides an overview of the Dissertation's organisation, offering a roadmap to guide the reader through the subsequent chapters. This foundational chapter ensures the alignment of the research rationale with its intended contributions to the academic and operational understanding of sustainable aviation practices.

Chapter 2 presents a comprehensive and systematic review of the existing literature relevant to the Dissertation's thematic focus. The review is structured into seven subchapters, with the first and final sections dedicated to the framing and concluding of the Literature exploration, respectively. The intermediate subchapters (from the second to the sixth) delve into individual thematic axes, each corresponding to a specific keyword central to the research.

Chapter 3 presents the research methodology adopted for the empirical investigation. In the initial section, the methodological approach is described in detail, including the research design, data collection methods, and analytical procedures employed. The second section introduces the SeCA model—SAF em Companhias Aéreas—developed specifically for this study. This model is designed to quantify the economic impact of SAF integration within the daily operations of commercial airlines. Grounded in the theoretical insights gathered in Chapter 2, the SeCA model operationalises key variables and constructs to simulate real-world scenarios and support evidence-based decision-making.

In Chapter 4, the SeCA model is applied to two airlines for empirical validation. On one hand, the model is applied to Ryanair, the LCC considered for the research. On the other hand, it has been tested to Emirates, representing FSC business model. Each application involves a series of detailed calculations, supported by contextual data and assumptions. The resulting outputs are critically analysed to assess the economic implications of SAF usage and to evaluate the model's robustness and applicability across different operational contexts.

Chapter 5 presents the conclusions of the Dissertation. It synthesises the main findings and highlights the theoretical and practical implications of the study. Special attention is given to the contributions made to the field of sustainable aviation, particularly in the areas of economic modelling and decision-support tools. Additionally, this chapter outlines several key recommendations for future research, identifying areas where further investigation is warranted. It also acknowledges the methodological and practical limitations encountered during the study, offering a transparent account of the study's boundaries and constraints.

2. LITERATURE REVIEW

2.1. INTRODUCTION

The global aviation sector, a cornerstone of international mobility and economic development, is increasingly scrutinised for its environmental externalities, particularly its contribution to Greenhouse Gas (GHG) emissions and climate change. Within this context, the literature surrounding climate change mitigation, sustainable fuel alternatives, economic viability, and consumer behaviour becomes indispensable for shaping a robust understanding of the operational challenges and opportunities airlines face in transitioning to more sustainable models. The present Literature Review synthesises interdisciplinary perspectives—ranging from climatological sciences and policy frameworks to aviation-specific sustainability pathways and consumer-centric economic modelling—to build the theoretical foundation for assessing the economic impact of SAF across two contrasting airline business models: Low-Cost Carriers and Full-Service Carriers.

The chapter begins by anchoring the discourse in the global challenge of climate change, as defined by the United Nations (1992, 2025), highlighting the anthropogenic forces driving planetary warming through key activities such as power generation, deforestation, manufacturing, and aviation. Particular attention is given to the disproportionate contributions of high-income nations and industries—such as the air transport sector—and the systemic consequences this has on planetary health, biodiversity, food security, and socio-political stability. The severity of these consequences, quantified in recent reports by institutions such as the Intergovernmental Panel on Climate Change (2022), National Aeronautics and Space Administration (2025), and the European Environment Agency (2020), positions the aviation sector at a crossroads between economic expansion and environmental accountability.

The review then transitions into the conceptualisation and regulatory architecture of SAF. Drawing heavily on frameworks such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (International Civil Aviation Organization, 2018) and the American Society for Testing and Materials (2022) D7566 standard, the section explores the lifecycle sustainability metrics, technical compliance requirements, feedstock classifications, and conversion technologies essential for SAF certification. Notable is the distinction between pre-2024 and post-2024 sustainability criteria, which reflect an increasingly rigorous global push toward holistic environmental integrity across the SAF supply chain. The discussion further delves into the economic and logistical barriers to SAF scalability, including high production costs, distribution inefficiencies, and regional disparities in fuel pricing, thereby contextualising the policy interventions proposed by entities such as the RefuelEU (European Union, 2020b) and the World Economic Forum (2020, 2021). Supply-side and demand-side policy levers are examined as critical enablers in achieving market parity between SAF and CAF.

In alignment with the economic scope of this Dissertation, the Literature on fuel cost structures is then explored. Here, scholarly works by Hansen (2010, 2013), Hamdan et al. (2020), and others highlight the significant impact of fuel expenses on shaping airline profitability and strategic fleet optimisation. The variability of fuel cost representativeness across different airline models and geographical zones further sets the stage for comparative empirical analysis.

Lastly, the review presents the theoretical and methodological underpinnings of WTP, a central construct for evaluating consumer acceptance of price adjustments associated with the adoption of SAF. Both Hypothetical WTP (HWTP) and Real WTP (RWTP) are analysed through the lens of empirical studies, experimental auction models, direct and indirect survey techniques, and the Contingent Valuation Method (CVM). This analytical lens is crucial, as airlines may only shift towards SAF usage if the end-consumer demonstrates sufficient elasticity in WTP to accommodate elevated operating costs without eroding demand.

Collectively, this chapter integrates scientific, regulatory, economic, and behavioural scholarship to lay a comprehensive foundation for analysing the viability and scalability of SAF across diverse airline business models. This synthesis not only informs the subsequent empirical framework but also contributes to the evolving academic discourse on aviation sustainability and the economics of energy transition.

2.2. CLIMATE CHANGE

The United Nations (1992) define "Climate change" in the United Nations Framework Convention on Climate Change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods". This "Climate change" can stem from various sources and have catastrophic consequences for the planet and, consequently, for humanity, as highlighted by the United Nations (2025). The United Nations (2025) identifies seven main drivers for these sources that should be considered, as shown in Figure 1.

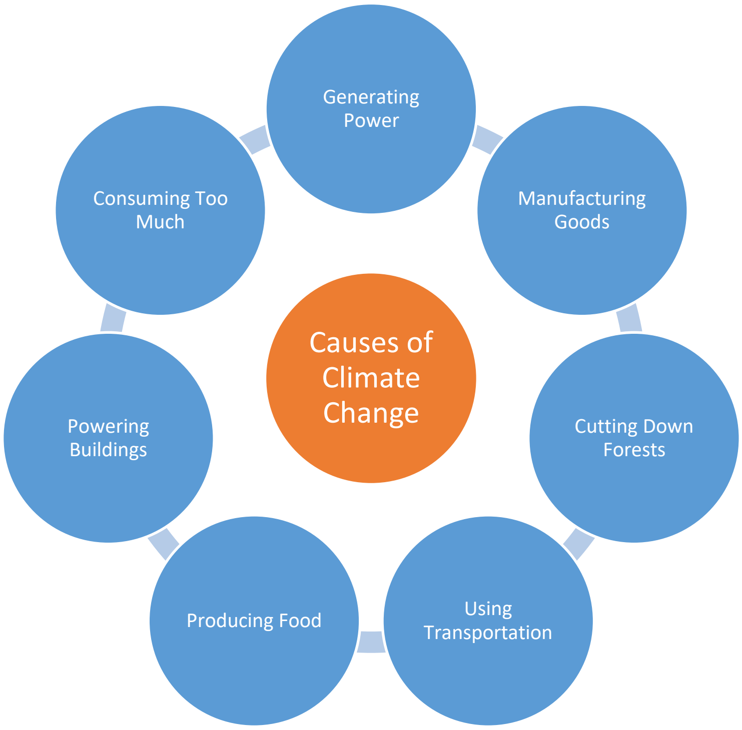

Figure 1 - Causes of Climate Change
Source – (United Nations, 2025)

Examining the "Generating Power" driver, the burning of fossil fuels for electricity and heat is a significant source of global emissions, releasing carbon dioxide and nitrous oxide that trap heat (Amponsah et al., 2014). Over a quarter of the world's electricity comes from renewable sources, such as wind and solar, which produce minimal to no greenhouse gases or pollutants. However, they still account for just about 30.3% in 2023, compared to the expected 45.6% in 2030, as shown in Figure 2.

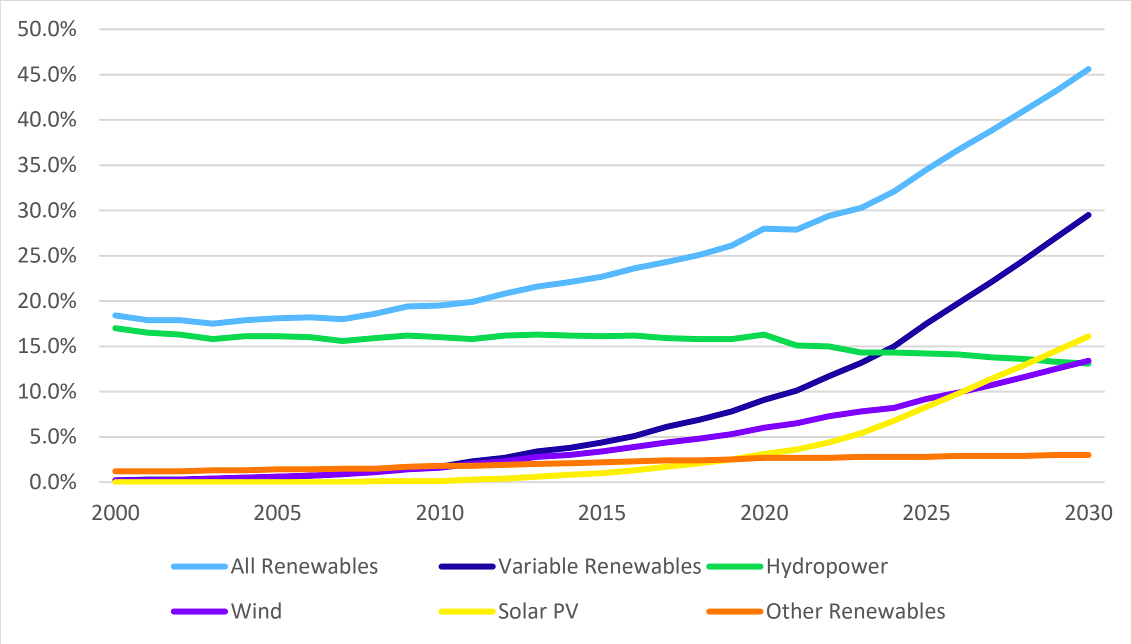

Figure 2 - Share of renewable electricity by technology, 2000 – 2030
Source – (International Energy Agency, 2023)

In the "Manufacturing Goods" driver, industry is a major source of emissions, primarily from the burning of fossil fuels to generate energy for producing goods such as cement, steel, plastics, and electronics (Devasahayam et al., 2019). Mining, construction, and industrial processes also release GHGs, mainly because the machines used in these activities often run on coal, oil, or gas, and some materials, such as plastics, are derived from fossil fuels (Moomaw, 1996).

Deforestation, driven by agriculture, pasture creation, and other factors, contributes to climate change by releasing stored carbon when trees are cut (Nunes et al., 2020). Approximately 10 million hectares of forest are lost annually (Climate Impact Partners, 2024), which is problematic because forests naturally absorb carbon dioxide, and their destruction hampers the planet's ability to mitigate emissions. Deforestation and land-use changes account for approximately 22% of global greenhouse gas emissions (United States Environmental Protection Agency, 2019).

Transportation, which is largely dependent on fossil fuels, is a significant source of greenhouse gases, particularly carbon dioxide (United States Environmental Protection Agency, 2025). Road vehicles contribute the most, burning petroleum-based fuels such as gasoline, while emissions from ships and aviation are also rising (International Energy Agency, 2022d).

Food production generates greenhouse gases, such as carbon dioxide and methane, through deforestation, livestock digestion, fertiliser use, and energy consumption in farming and fishing (Ghosh et al., 2020). Packaging and distribution also contribute significantly to emissions, making the food industry a substantial driver of climate change (Crippa et al., 2021).

Residential and commercial buildings consume over half of the world's electricity, relying on coal, oil, and gas for heating and cooling, which generates significant emissions (Cao et al., 2016; International Energy Agency, 2025).

Daily activities, from energy use at home to transportation, food consumption, and waste disposal, contribute to greenhouse gas emissions. Consumer goods, including clothing, electronics, and plastics, also play a significant role in the economy. Private households are a significant source of emissions, with their lifestyles having a substantial impact on the planet. Notably, the wealthiest 1% generate more emissions than the poorest 50% combined (OXFAM International, 2020).

Each cause of climate change leads to its own set of consequences, which are diverse and complex. These consequences have far-reaching impacts, affecting not only the environment but also human societies. Understanding these effects is crucial for addressing the challenges posed by climate change and for developing effective strategies to mitigate its risks. As a result, the United Nations (2025) has outlined several consequences driven by climate change, as shown in Table 1.

Table 1 - Consequences of Climate Change
Source – (United Nations, 2025)

Consequences	Description
Hotter Temperatures	Rising greenhouse gases have driven record-high temperatures, with the 2011-2020 decade being the warmest on record. Heatwaves, illnesses, and wildfires intensify, while the Arctic warms at twice the global average rate.
More Severe Storms	Warmer temperatures increase evaporation, intensifying storms, rainfall, and flooding. Warming oceans fuel stronger cyclones, hurricanes, and typhoons, leading to destruction, loss of life, and economic damage.
Increased Drought	Climate change exacerbates water scarcity, droughts, sandstorms, and desertification, resulting in reduced farmland and threatened water access.
A warming, rising ocean	The ocean absorbs heat and carbon dioxide from global warming, resulting in rising sea levels and increased acidity that threaten marine life and coral reefs.
Loss of Species	Climate change increases extinction risks, with species disappearing approximately 1,000 times faster than they did in the past. One million species may go extinct soon, driven by fires, extreme weather, and pests. Some may adapt, but many will not survive.

Consequences	Description
Not Enough Food	Climate change exacerbates hunger and malnutrition, posing risks to crops, livestock, and marine resources. Arctic disruptions and heat stress exacerbate food supply issues.
More Health Risks	Climate change poses a significant health threat, leading to pollution, disease, extreme weather events, displacement, and food insecurity. It leads to around 13 million deaths annually, spreads diseases, and strains healthcare systems.
Poverty and Displacement	Climate change exacerbates poverty, as floods, heat, and water scarcity harm livelihoods. Between 2010 and 2019, 23.1 million people were displaced annually, mostly from vulnerable countries.

Analysing the "Hotter Temperatures" variable and referring to Figure 3, it becomes evident that global temperatures have been consistently rising year after year. The concern is particularly significant because, in recent years, this upward trend has been accompanied by even higher temperature anomalies. In this context, the term "Anomaly" refers to the deviation of the average global temperature of each specific year from the long-term average global temperature, highlighting how much the current year's temperature differs from the typical or expected global temperature based on historical data. This increasing anomaly reflects a clear and concerning trend of accelerated global warming, which ultimately results in a more accelerated de-icing of the poles (Duncan, 2024).

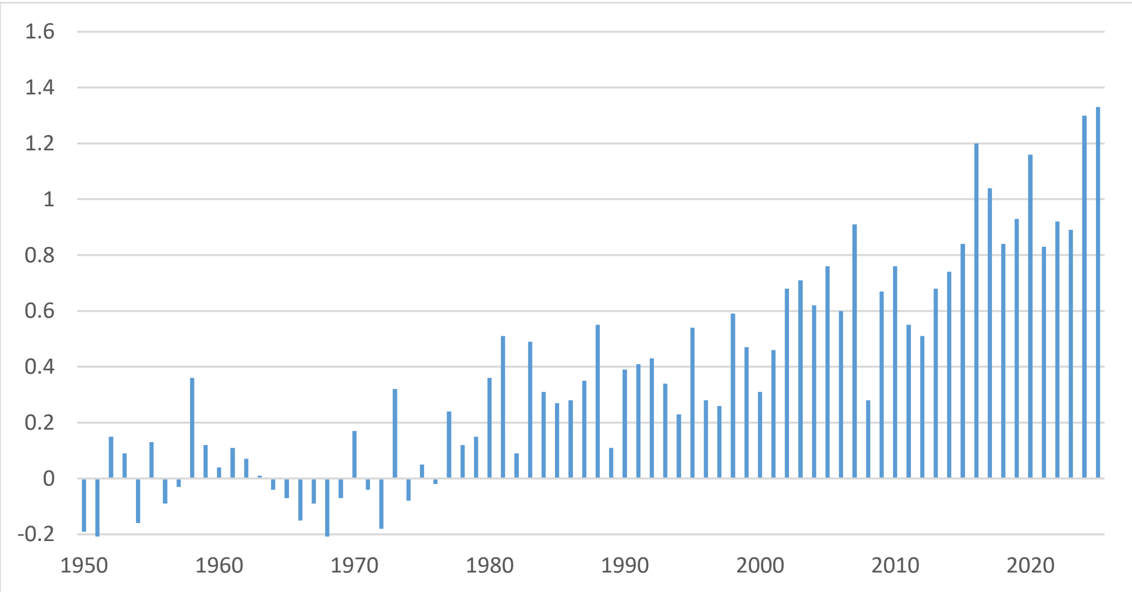

Figure 3 - Average Temperature Anomaly (1950-2025)
Source – (National Centres for Environmental Information, 2025)

According to the United Nations (2025), one of the most significant consequences of climate change is the increasing intensity and frequency of severe storms. The National Aeronautics and Space Administration (2025) further highlights that the occurrence and severity of extreme weather events, such as wildfires, droughts, tropical cyclones, heavy precipitation events, floods, and high tide floods, have been rising YoY at an unprecedented rate. This continuous increase in extreme weather events poses serious risks to ecosystems, infrastructure, and human livelihoods (European Environment Agency, 2020). The warming atmosphere leads to greater evaporation rates, which intensify rainfall, while rising ocean temperatures fuel stronger hurricanes and typhoons (Environmental Defence Fund, 2025).

The increasing severity of droughts, exacerbated by climate change, poses profound challenges to water availability, ecosystem integrity, and agricultural productivity. Elevated temperatures accelerate evapotranspiration, depleting soil moisture, while shifts in precipitation patterns disrupt replenishment cycles (Dai, 2013; Intergovernmental Panel on Climate Change, 2022). In the Mediterranean region, projections indicate an increase in drought frequency and intensity, which augments the risk of desertification and threatens food production systems (European Union, 2022). Globally, the spatial extent of drought-prone areas has expanded, resulting in corresponding losses in crop yields that can amount to billions of dollars in annual economic damage (Roudier et al., 2011). This phenomenon directly compromises rural livelihoods and food security, particularly in agrarian economies, and has been empirically linked to increased child stunting rates where early-life exposure to drought occurs (World Bank, 2023). Without robust adaptation strategies—such as drought-resilient cropping systems, green-water management, and integrated groundwater governance—vulnerability to socioeconomic shocks escalates significantly (United Nations, 2022).

Accelerating sea-level rise and ocean warming represent a dual-faceted threat to coastal communities and marine ecosystems. Thermal expansion and cryospheric melt are projected to increase global mean sea levels by 0.6 to 1.1 meters by 2100 under a high-emissions scenario, significantly increasing coastal inundation risks for more than 300 million people, particularly in deltaic and small island regions (Intergovernmental Panel on Climate Change, 2021). Ocean warming also contributes to ocean acidification, which weakens the structures of coral reefs and diminishes biodiversity. These systems support critical ecosystem services—including coastal protection, fisheries, and carbon sequestration—that, if disrupted, could result in annual economic losses exceeding USD 10 billion in some regions (Gattuso et al., 2015; Hoegh-Guldberg et al., 2008).

Biodiversity loss is accelerating, with an estimated one million species at risk of extinction due to climate perturbations and habitat degradation (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2020). Climate-driven phenomena—such as altered rainfall regimes, temperature stress, and shifts in phenology—undermine ecosystem resilience and disrupt key mutualisms (e.g., pollinator-plant interactions), compromising both terrestrial and aquatic biodiversity (Urban, 2015). The loss of keystone species further cascades through food webs, diminishing ecological stability and reducing carbon sink capacities.

Agricultural systems are especially vulnerable to climate variability. Elevated temperatures increase crop evapotranspiration demands, while reduced snowmelt and altered rain patterns limit freshwater irrigation (Lobell et al., 2011). Climate stress has already reduced global agricultural productivity by approximately 21%, resulting in 30–35% losses in warmer, lower-latitude regions (Challinor et al., 2014; Ortiz-Bobea et al., 2021). Regions heavily dependent on glacier- and snowpack-derived water, such as South Asia and the Andes, face increased food insecurity due to glacier retreat and shifting hydrological cycles.

The public health domain is also facing escalating pressures from climate dynamics. Rising temperatures and intensifying extreme weather events are expanding the geographic range of vector-borne diseases, such as dengue, malaria, and Zika, as well as waterborne diseases like cholera and typhoid (Gaythorpe et al., 2020; Githeko et al., 2000). Heatwaves and degraded air quality exacerbate respiratory and cardiovascular conditions, resulting in an annual excess mortality of 13 million deaths (Githeko et al., 2000). Climate displacement and famine cycles disproportionately affect marginalised populations, often triggering conflict and compounding socioeconomic instability (United Nations High Commissioner for Refugees, 2020).

Finally, rising poverty and forced displacement have emerged as significant consequences tied to climate stressors. It is estimated that climate-related events forced approximately 23.1 million people into internal displacement annually between 2010 and 2019, largely due to floods, storms, and droughts (Internal Displacement

Monitoring Centre, 2020, 2021). These dynamics exacerbate food insecurity and educational disparities, particularly among women and children born into climate-stressed conditions—a population cohort that experiences long-term reductions in income, health, and educational attainment (International Fund for Agricultural Development et al., 2022; Montez & Hayward, 2011). The intergenerational transmission of poverty becomes entrenched in contexts where climate-induced resource shortages compound household vulnerability (United Nations Development Programme, 2022).

Due to the escalating impacts of climate change and the persistent rise in GHG's emissions, numerous international organisations and governing bodies have taken proactive measures to implement comprehensive strategies aimed at safeguarding the future of the planet and ensuring the long-term sustainability of human civilisation (Intergovernmental Panel on Climate Change, 2022). These initiatives focus on short-term, medium-term, and long-term objectives, addressing critical areas such as emissions reduction, the promotion of renewable energy sources, sustainable development practices, and climate adaptation policies (Umeh et al., 2024). By fostering global cooperation and enforcing regulatory frameworks, these strategies seek to mitigate environmental degradation, enhance resilience to climate-related disasters, and promote a transition towards a low-carbon economy (Javid & Shahid, 2025).

2.3. SUSTAINABLE AVIATION FUEL (SAF)

The International Civil Aviation Organisation (2022) outlines that SAF falls under the category of an AAF, derived from the transformation of renewable resources or waste-based materials. Although there are numerous definitions for SAF, these definitions consistently emphasise one key aspect: that SAF is considered sustainable throughout its entire life cycle, from the sourcing of raw materials to its combustion in the aircraft's engines. The Carbon Offsetting and Reduction Scheme for International Aviation, developed by the International Civil Aviation Organisation (2021), lists the sustainability criteria that a given fuel should comply with to be considered as SAF. To initially encourage SAF production and later enforce stricter sustainability standards, the ICAO established two key "Principles" that must be met for SAF produced before January 1st, 2024, and fourteen additional "Principles" that must be complied with for SAF produced after this date.

Before January 1, 2024, for a given fuel to be considered as SAF, it must comply with the Principles Outlined in Table 2.

Table 2 - CORSIA Sustainability Principles for Fuel Before January 1st, 2024
Source – (International Civil Aviation Organisation, 2021)

Theme	Principle
1. Greenhouse Gases	CORSIA eligible fuel should generate lower carbon emissions on a lifecycle basis.
2. Carbon Stock	CORSIA eligible fuel should not be made from biomass obtained from land with high carbon stock.

After January 1st, 2024, for a given fuel to be considered as SAF, it must comply with the Principles Outlined in Table 3.

Table 3 - CORSIA Sustainability Principles for Fuel After January 1st, 2024
Source - (International Civil Aviation Organisation, 2021)

Theme	Principle
1. Greenhouse Gases	CORSIA SAF is expected to generate lower carbon emissions on a life-cycle basis.
2. Carbon Stock	CORSIA SAF should not be made from biomass obtained from land/aquatic systems with high biogenic carbon stock.
3. Greenhouse Gas Emissions Reduction Permanence	Emissions reductions attributed to CORSIA SAF should be permanent.
4. Water	The production of CORSIA SAF is expected to maintain or enhance water quality and availability.
5. Soil	The production of CORSIA SAF is expected to maintain or enhance soil health.
6. Air	The production of CORSIA SAF is expected to minimise negative effects on air quality.
7. Conservation	Production of CORSIA SAF should maintain biodiversity, conservation value, and ecosystem services.
8. Waste and Chemicals	The production of CORSIA SAF should promote the responsible management of waste and the use of chemicals.
9. Seismic and Vibrational Impacts	Not applicable.
10. Human and Labour Rights	Production of CORSIA SAF should respect human and labour rights.
11. Land use rights and land use	Production of CORSIA SAF should respect land rights and land use rights, including indigenous and/or customary rights.
12. Water use rights	Production of CORSIA SAF should respect prior formal or customary water use rights.
13. Local and social development	The production of CORSIA SAF is expected to contribute to social and economic development in regions of poverty.
14. Food security	The production of CORSIA SAF is expected to promote food security in food-insecure regions.

The criteria associated with each "Principle" for SAF production before January 1st, 2024, is detailed in Table A1. The criteria applicable after this date is listed in Table A 2.

The European Civil Aviation Conference (2023) analyses these 14 principles and defends that they can be divided into three schemes:

- Carbon-reduction: Greenhouse Gases, Carbon Stock, and Greenhouse Gas Emissions Reduction Permanence.
- Environmental: Water, Soil, Air, Conservation, Waste and Chemicals, and Seismic and Vibrational Impacts.
- Socio-Economic: Human and Labour rights, Land use rights and land use, Water use rights, Local and social development, and Food security.

After January 1st, 2024, the same CORSIA manual also introduces a new fuel certification called Lower Carbon Aviation Fuel (LCAF) (International Civil Aviation Organization, 2019b). For a fuel to be certified as LCAF, it must meet the "Principles" and corresponding criteria outlined in Table A 3. LCAF can complement SAF by contributing to a minimum 10% reduction in aviation GHG lifecycle emissions (International Civil Aviation Organisation, 2022a). While industry leaders consider SAF as the primary fuel solution for the short, medium, and long term, ICAO also recognises the LCAF's potential to significantly reduce emissions in the aviation sector (International Civil Aviation Organization, 2022a). LCAF incorporates technological measures to reduce the lifecycle carbon intensity of aviation kerosene, as shown and explained in Table 4.

All the criteria previously mentioned, for both SAF and LCAF, are designed to ensure that the production of these fuels actively contributes to lowering aviation's carbon footprint without compromising other sustainability dimensions, such as human labour rights, among others.

In addition to these sustainability requirements, SAF must comply with technical standards to ensure safe and efficient aircraft performance. These technical requirements are detailed in the ASTM D7566 (American Society for Testing and Materials, 2022), a specification designed to regulate alternative aviation fuels. Meeting these standards is essential to guarantee that SAF can seamlessly replace or blend with CAF without compromising engine performance, fuel system integrity, or overall flight safety. For example, biodiesel, despite being a renewable energy source, cannot be used as an AAF due to its lower energy density and higher freezing point, which could severely impact aircraft performance in colder temperatures (Roberts, 2011).

Table 4 - LCAF Technologies
Source – (International Civil Aviation Organisation, 2022a)

Technology	How it works
Energy Conservation	Reducing energy consumption is one of the most cost-effective ways to cut GHG emissions, with oil and gas companies achieving this through energy-efficient plant designs, advanced controls, improved reservoir modelling, innovative extraction methods, and enhanced equipment monitoring.
Methane Emissions Reduction through Flare Management and Gas Recovery	Methane, a major component of natural gas and a potent GHG, requires targeted reduction efforts. Oil and gas companies can reduce methane emissions by upgrading equipment, enhancing leak detection, and implementing new production techniques. To reduce flaring emissions, flare gas recovery systems can capture, treat, and recycle gas; however, their cost-effectiveness varies depending on site conditions.
Venting Control	Process vents release gases into the atmosphere, either continuously or through pressure relief valves. Modifying processes or recycling materials is the most effective way to achieve emission control. If not feasible, vapour recovery or destruction systems can be used. Gas emissions from oil storage, loading, and unloading can also be reduced with Vapour Recovery Units and ‘closed hatch’ practices.
Fugitive Emissions Detection	Refineries have numerous piping components that can leak small amounts of hydrocarbons, collectively becoming a major source of emissions. In comparison, traditional leak detection requires labour-intensive 'sniffing' devices; newer technologies, such as optical gas imaging and satellite imagery, offer faster and more efficient detection.
Carbon Capture and Storage	Carbon Capture and Storage (CCS) involves capturing CO_2 from fossil fuel production and storing it deep underground in geological formations. Refineries can capture CO_2 from processes such as catalytic cracking and hydrogen generation; however, further technological development is needed to reduce costs.
Renewable Electricity	Oil and gas facilities can utilise renewable energy sources, such as solar panels or offshore wind power, to reduce their reliance on fossil fuels. Some facilities also purchase renewable energy through agreements, and offshore platforms may connect to shore-side electricity to replace their use of natural gas.
Blue and Green Hydrogen	Hydrogen is used in refining to remove impurities, such as sulfur. It is typically produced through the steam reforming of natural gas, but lower carbon-intensity hydrogen, known as "blue hydrogen," can also be made by capturing carbon emissions. "Green hydrogen" is produced using renewable electricity to split water, offering a cleaner alternative to reduce GHG emissions in fossil fuel production.

Currently, a range of feedstocks can be converted into SAF, as specified in the CORSIA guidelines from the International Civil Aviation Organization (2025). These feedstocks can be classified as (International Civil Aviation Organization, 2025):

- Primary and co-products: the main products of a production process. These products have significant economic value and an elastic supply.
- By-products: secondary products with inelastic supply and economic value.
- Wastes: materials with inelastic supply and no economic value. A waste is any substance or object which the holder discards or intends to discard or is required

to discard. Raw materials or substances that have been intentionally modified or contaminated to meet this definition are not covered by this definition.

- Residues: secondary materials with inelastic supply and little economic value.

Some examples of feedstocks currently used to be converted into SAF and already classified are illustrated in Table 5.

Table 5 - Positive list of materials classified as Residues, Wastes, By-products or Co-products
Source – (International Civil Aviation Organisation, 2019)

Category	Feedstock
Residues	Bagasse, cobs, stover, husks, manure, nut shells, stalks, straw, bark, branches, cutter shavings, leaves, needles, pre-commercial thinning, slash, treetops, crude glycerine, cobs, forestry processing residues, empty palm fruit bunches, palm oil mill effluent, sewage sludge, crude tall oil, tall oil pitch, wheat starch slurry.
Wastes	Municipal solid waste, used cooking oil, waste gases.
By-products	Palm fatty acid distillate, beef tallow, technical corn oil, non-standard coconuts, poultry fat, lard fat, mixed animals' fat.
Co-products	Molasses.

These feedstocks are then processed and tested to produce SAF. Depending on the given feedstock, the conversion process may vary. The conversion process can be defined as a type of technology used to convert a feedstock into aviation fuel (International Civil Aviation Organisation, 2024a). For SAF, the International Civil Aviation Organisation (2024a) has identified the conversion methods presented in Table 6 under the CORSIA framework.

Table 6 - SAF conversion methods
Source – (International Civil Aviation Organisation, 2024a)

Short Name	Conversion process specification	Description
Gasification FT	ASTM D7566 Annexe A1 (Fischer-Tropsch), or equivalent specification	Fischer-Tropsch hydroprocessed synthesised paraffinic kerosene from gasification of feedstocks such as biomass and coal
CO_2 FT	ASTM D7566 Annexe A1 (Fischer-Tropsch), or equivalent specification	Fischer-Tropsch hydroprocessed synthesised paraffinic kerosene with the use of CO_2 as a feedstock
HEFA	ASTM D7566 Annexe A2 (HEFA), or equivalent specification	Synthesised paraffinic kerosene from hydroprocessed esters and fatty acids
SIP	ASTM D7566 Annexe A3 (SIP), or equivalent specification	Synthesised iso-paraffins from hydroprocessed fermented sugars
FT-SKA	ASTM D7566 Annexe A4 (FT-SKA), or equivalent specification	Synthesised kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources
ATJ-SPK from ethanol	ASTM D7566 Annexe A5 (ATJ-SPK), or equivalent specification	Alcohol to jet synthetic paraffinic kerosene, from the use of ethanol as input
ATJ-SPK from isobutanol	ASTM D7566 Annexe A5 (ATJ-SPK), or equivalent specification	Alcohol to jet synthetic paraffinic kerosene, from the use of isobutanol as input
ATJ-SPK from isobutene	ASTM D7566 Annexe A5 (ATJ-SPK), or equivalent specification	Alcohol to jet synthetic paraffinic kerosene, from the use of isobutene as input
CHJ	ASTM D7566 Annexe A6 (CHJ), or equivalent specification	Catalytic hydro thermolysis jet fuel
HC-HEFA-SPK	ASTM D7566 Annexe A7 (HC-HEFASPK), or equivalent specification	Synthesised paraffinic kerosene from hydrocarbon-hydro processed esters and fatty acids
ATJ-SKA	ASTM D7566 Annexe A8 (ATJ-SKA), or equivalent specification	Synthetic Paraffinic Kerosene with Aromatics with the use of C2-C5 alcohols from biomass as inputs
Co-processing Esters and Fatty Acids	ASTM D1655 Annex A1, or equivalent specification	Co-processing of Esters and Fatty Acids in a traditional petroleum refinery
Coprocessing of Fischer-Tropsch hydrocarbons	ASTM D1655 Annexe A1 - co-processing of Fischer-Tropsch hydrocarbons, or equivalent specification	Co-processing of Fischer-Tropsch hydrocarbons in a traditional petroleum refinery
Coprocessing HEFA	ASTM D1655 Annexe A1 - co-processing of HEFA, or equivalent specification	Co-processing of hydro-processed esters and fatty acids in a traditional petroleum refinery

In addition to these conversion methods, Zhang et al. (2020) emphasise the need for continued investment in and discovery of additional conversion methods over time. Zhang et al. (2020) also concluded from their analysis, which discussed SAF's opportunities and challenges, that lignin-derived SAF may be the most economically viable in the long term, primarily due to its lower production cost compared to other SAF types.

Shahriar & Khanal (2022) examined the strengths, weaknesses, and suggested improvements for each main conversion method, resulting in Table 7.

Table 7 - Strengths, Weaknesses, and Improvement suggestion for SAF Conversion Methods
Source – (Shahriar & Khanal, 2022)

Conversion method	**Characteristics**		**Improvement suggestions**
	Strengths	**Weaknesses**	
FT	Lower MJSP compared to ATJ; no hydrogen is required during the production process, and the raw material used affects the food supply.	Lower energy density than HEFA, high capital investment.	Selecting a biomass gasification unit for syngas production should be based on the biomass feedstock.
HEFA	Low sulphur content, low GHG emissions, high energy density.	High production costs for an H_2 unit, relatively high raw material costs, and limited availability of sustainable oil.	Upgrading existing oil facilities to accommodate an HEFA plant can provide access to hydrogen at the production site, thereby enhancing the overall efficiency of the facility.
SIP	Low GHG emissions produce high-quality biochemicals.	Low blending capacity with other fuels (10%), low energy consumption at low fermentation temperatures.	Producing SAF and biochemicals together can be more profitable due to the high value of biochemicals.
ATJ	Better thermal efficiency and carbon utilisation than FT, with municipal waste and industrial gases as potential feedstocks.	Time-consuming process with reduced yield.	Instead of converting all biomass into SAF, selling some by-products can be more profitable.

Compared to CAF, SAF can reduce CO_2 emissions by up to 80%, depending on the type of material used for conversion and the distribution method employed until it reaches the airport (International Air Transport Association, 2021b).

Another significant advantage of SAF is that no technical modifications are required for the aircraft currently in operation to replace traditional fuel with SAF (BP, 2022). Even though the aviation industry players are actively working towards enabling SAF to be used as 100% of the fuel in aircraft tanks (U.S. Department of Energy, 2025)– as demonstrated, for example, by the test flights conducted by Airbus and Boeing (Airbus, 2023; Boeing, 2023) – the reality is that the allowable percentage of SAF blended in aircraft fuel tanks still depends on the feedstock used and, consequently, the conversion method applied, but is capped at a maximum of 50% (International Civil Aviation Organization, 2022b). This maximum limitation varies depending on the type of SAF used (SkyNRG, 2025).

The Airports Council International & Aerospace Technology Institute (2022) created a world map illustrating the current SAF producers, as well as those planning to enter the market. The map also highlights the main type of SAF that each producer will manufacture and their planned production capacity. From this map, it can be observed that there are currently four SAF-focused producers (producers that only produce SAF): World Energy, Total, Neste, and Atmosfair. Among these, three are based in Europe, while World Energy is the sole SAF-focused producer in North America, and notably, the one with the highest production capacity. The map also indicates that 57 additional SAF production facilities are planned for the coming years, marking a significant step forward in expanding the availability of this sustainable fuel.

The blending of SAF with CAF can be carried out at a fuel terminal, refinery, or directly at the airport (Johnson et al., 2023). Each of these locations has its own specific set of characteristics, presenting distinct advantages, disadvantages, and limitations (Airports Council International & Aerospace Technology Institute, 2022), as outlined in Table 8.

Table 8 - Considerations for Fuel Blending
Source – (Airports Council International & Aerospace Technology Institute, 2022)

	Advantages	Disadvantages	Limitations
Fuel Terminal	• Larger volumes can be blended compared to airport facilities. • Experience in handling biofuels; • Existing infrastructure for fuel loading and unloading (no need for changes to the airport infrastructure); • Full focus on fuel operations; • Multiple airports can be supplied from the same terminal. • Some terminals have prior experience in fuel blending.	• Requires a specific means of supplying infrastructure to the airport.	• Limited in space and capacity to accommodate the expected SAF demand by 2050; • Efficient supply control system for airports.
Refinery	• Experience in handling hydrocarbons, including biofuels; • Expertise in managing jet fuel; • Flexible transportation infrastructure (pipelines, railways, etc.).	• Only suited for large quantities of fuel.	• Optimised for large quantities of fuel, making it unlikely to mix with small amounts. • Infrastructure is generally farther from airports, potentially requiring more transportation resources.
Airport	• Fewer transport trucks required; • Reduced transportation costs; • Enhances SAF visibility and presence at airports.	• Requires airport infrastructure capable of receiving, storing, and blending the fuel; • Fuel certification must be conducted at the airport. • Potential for ground traffic congestion.	• Trucks are required if the transport of 100% SAF is not authorised via pipelines (current situation), limiting transport volumes. • Storage capacity is lower compared to other infrastructures. • Regulations for on-site mixing are demanding; • Lack of a legal framework for the transport of 100% SAF in some countries.

The SAF transportation method also becomes a relevant variable that primarily influences its sale price (Airports Council International & Aerospace Technology Institute, 2022). Therefore, Table 9 identifies the advantages and disadvantages of each transportation method.

Table 9 - SAF Transportation Methods
Source – (Airports Council International & Aerospace Technology Institute, 2022)

	Advantages	**Disadvantages**
Truck	• Flexible and resilient. • Does not require a large infrastructure for loading and unloading.	• Suitable only for small quantities. • As SAF demand grows, it may become insufficient to meet the need.
Rail	• Suitable for large fuel volumes.	• Requires railways from SAF refineries to the mixing location. • Not very flexible if supplying multiple mixing locations.
Ship	• Large quantities of fuel can be transported.	• Many airports lack maritime ports for unloading. • Significant infrastructure development is required. • Only producers with ports can use this transportation method.
Pipelines	• Low operational cost. • Existing infrastructure can serve multiple airports.	• 100% SAF is still not allowed to be transported in pipelines that also carry other products. • High investment if the infrastructure does not yet have a pipeline.

The World Economic Forum (2021) has developed a well-structured framework in its "Clean Skies for Tomorrow" report, presenting its vision of the regulatory landscape required to scale the SAF market and meet the needs of the aviation sector, as illustrated in Figure 4.

Regarding the "Feedstock Sustainability", which serves as the foundation for all subsequent measures, the World Economic Forum (2021) emphasises that "a set of policies that ignores this principle risks both nullifying the positive environmental effects expected from producing SAF and economically undermining the value chain for it". In the short term, as the industry scales, policy frameworks must pragmatically balance feedstock availability with sustainability while maintaining flexibility to adapt to advancements in technology and feedstock supply. To illustrate this, the World Economic Forum (2020) has developed Figure 5, which provides an overview of potential feedstocks for SAF production.

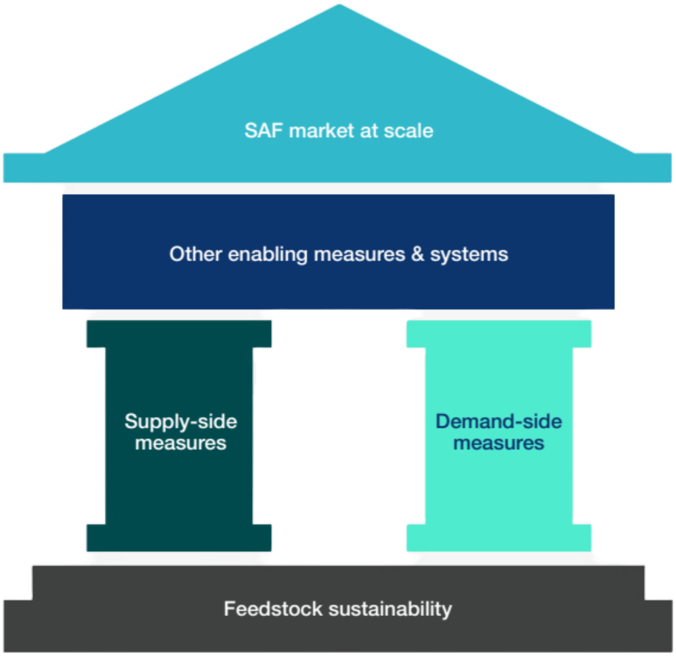

Figure 4 - Overview of Regulatory Framework for a SAF Market at Scale
Source – (World Economic Forum, 2021)

Feedstock type	Feedstock category	Feedstock[vi]	Substantial GHG savings potential[vii]	Low sustainability concerns[viii]
1st gen / crop-based	Edible oil crops	Palm	✗	✗
		Soybean	✗	✗
		Other (incl. sunflower, rapeseed/canola)	✗	✗
	Edible sugars	Sugar cane	(✓)	✗
		Maize	✗	✗
		Other	✗	✗
Advanced and waste	Waste and residue lipids[ii]	Used cooking oil (industrial or private sources)	✓	✓
		Animal waste fat (tallow)	✓	(✓)
		Other (incl. tall oil, technical corn oil, fish oil, POME, PFAD)	✓	(✓)
	Purposely grown energy plants – Oil trees on degraded land	Jatropha, pongamia	✓	(✓)
	Purposely grown energy plants – Rotational cover crops – Oil cover crops	Camelina, carinata, pennycress	✓	(✓)
	Purposely grown energy plants – Rotational cover crops – Cellulosic cover crops	Miscanthus, switchgrass, reed cannarygrass	✓	(✓)
	Agricultural residues	Rice straw	✓	✓
		Sugar cane bagasse	✓	✓
		Other (incl. corn stover, cereal residues)	✓	✓
	Forestry residues[iii]		✓	✓
	Wood-processing waste[iv]		✓	✓
	Municipal solid waste[v]		✓	✓
Recycled carbon	Reusable plastic waste		✗	✓
	Industrial waste gas	CO_2 from point source capture (CCS)	✓	✓
		Other (e.g. flue gas from steel production)	✓	✓
Non-biomass based[i]	CO_2 from direct air capture (DAC)		✓	✓

| Focus of analysis ✓ Satisfied (✓) Potentially satisfied[ix] ✗ Not satisfied

i. Adjustment of RED II category "Renewable fuel of non-biological origin"; **ii.** Some not included in RED II definition of advanced (e.g., used cooking oil, animal waste fat), while others are (e.g., tall oil, POME); **iii.** Leftovers from logging operations, including leaves, lops, tops, damaged or unwanted stem wood; **iv.** By-products and co-products of industrial wood-processing operations, including sawmill slabs, saw dust, wood chip; **v.** May contain up to 20% non-reusable plastics; typically inefficient to separate organics and plastic; **vi.** Algae not assessed due to limited feasibility; **vii.** In line with RSB: >60% based on LCA,; **viii.** Mainly related to food security and land use change; **ix.** Depending on local circumstances

Figure 5 - Overview of Potential Feedstocks for the Production of SAFs
Source – (World Economic Forum, 2020)

From bottom up in Figure 4, under "Supply-side Measures to Support SAF Deployment", this section of the Clean Skies for Tomorrow toolkit explores policies aimed at expanding the sustainable supply of SAF by increasing production capacity and feedstock availability.

The International Air Transport Association (2024a) has already examined this topic and identified three short-term measures to address the supply-side challenges of SAF; these measures are:

- “Increased co-processing: Existing refineries can be used to co-process up to 5% of approved renewable feedstocks alongside the crude oil streams. This solution can be implemented quickly and requires minimal material investments. It should urgently be expanded by allowing a greater amount of renewable feedstock to be co-processed. By 2050, co-processing could save $347 billion in capital expenditures, as more than 260 renewable fuel plants would not need to be built.
- Diversify SAF production: There are 11 certified pathways to produce SAF, but the HEFA method is expected to account for around 80% of production over the next five years. SAF volumes could be boosted by increasing investments to scale up production through other certified pathways, particularly ATJ and FT, which utilise biological and agricultural waste and residues.
- Create a global SAF accounting framework: It is essential to have a registry that allows airlines to benefit from the environmental attributes of their SAF purchases and to claim these against their obligations in a transparent manner that prevents double-counting. Such a registry is necessary for achieving a global SAF market where all airlines can buy SAF, and all SAF producers can sell their fuel to airlines.”

The World Economic Forum (2021) has developed Table 10, which outlines a series of supply-side measures along with their corresponding supporting policies.

Table 10 - Supply-side measures and their supporting policies
Source – (World Economic Forum, 2021)

Goal	**Grow SAF supply**				
	Increase SAF production capacity.			**Increase sustainable feedstock availability.**	
	Bring new SAF pathways to market.		**Support SAF capacity scale-up**		
Pathways	Fund and promote RD&D	De-risk first-of-a-kind SAF production plants	Support the scale-up of higher TRL SAF pathways	Prioritise feedstock for SAF & optimise fuel plant production slates	Stimulate sustainable feedstock production and processing
Policy options	Establish dedicated innovation funds or financing options to support early-stage SAF production pathways at lower technology readiness levels.	Establish contract-for-difference schemes to reduce the price gap between SAF and conventional jet fuels based on the life-cycle assessment of GHG emissions.	Provide a combination of upfront capital grants and low-interest loans for the construction and operation of SAF production facilities to attract private investment.	Support the development of non-bio-based decarbonization options in competing sectors to incentivise the redirection of feedstocks and national renewable fuel production for aviation.	Grant tax exemptions for SAF, focusing on the regional location of production and the provenance of the feedstock, while ensuring strict adherence to sustainability criteria.
	Create knowledge hubs and innovation centres to accelerate SAF development	Establish a government-backed price floor to support SAF provision during the early stages of deployment	Apply SAF-like policies to the low-carbon by-products resulting from SAF production to enhance the economics of SAF projects	Gradually phase out mandates and subsidies for non-aviation renewable fuel use to incentivise the redirection of feedstocks and national renewable fuel production for aviation as other sectors electrify	Invest in comprehensive municipal waste collection infrastructure at scale and establish a separate collection of organic waste to increase biomass supply
	-	Provide a combination of up-front capital grants, low-interest loans and favourable tax treatment for the building and running of first-of-a-kind plants.	Create mechanisms to limit the volatility of SAF feedstock prices for production routes, such as HEFA, where it represents the largest share of production costs.	Fund and promote RD&D to enhance the production processes – increase conversion yields and lower manufacturing costs – of SAF pathways already at high commercial readiness levels	Facilitate access to public credit and training for SAF bio-feedstock producers to incentivise planting of new sustainable crops, e.g. cover crops on degraded lands.
	-	-	Establish contract-for-difference schemes to reduce the price gap between SAF and conventional jet fuels based on the life cycle assessment of GHG emissions.	-	Exempt from taxation is the income obtained from sustainable crops used as SAF feedstock

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Under "Demand-side measures", this section explores policy instruments designed to increase SAF adoption by offering options that stimulate voluntary, mandatory, and market-based demand. In this regard, the International Civil Aviation Organisation (2024b) has proposed four key measures aimed at addressing and stimulating demand for the SAF market.

The first measure is to mandate Renewable Energy Volume Requirements in the Fuel Supply, which can be achieved by creating "an obligation for fuel providers to progressively increase the volume of SAF blended into the existing fuel supply on a multi-year schedule. This approach incentivises the production of more SAF and other fuels that meet renewable energy definitions, which may include life-cycle greenhouse gas emissions reduction requirements".

The second measure is to mandate a Reduction in the Carbon Intensity of the Fuel Supply, which can be accomplished by "requiring fuel providers to reduce the carbon intensity (life-cycle greenhouse gas emissions intensity) of the transportation fuel supply over a multi-year schedule. This measure encourages the production of SAF and other low-emission fuels. Policies such as the Low Carbon Fuel Standard (LCFS) and Clean Fuel Standard (CFS) can be used to target and regulate the carbon intensity of a region's fuel supply.

The third measure is to mandate a Reduction in the Carbon Intensity of the Fuel Uptake by Aircraft Operators, which can be implemented by "obligating airlines to lower the carbon intensity of their operations through the fuel they purchase over a multi-year period. This requirement fosters competition among fuel producers, encouraging them to adopt the most efficient technology to produce SAF. As a result, airlines will be able to assess and select the most cost-effective and sustainable fuel options".

The fourth measure is to create a Requirement for End Users to support SAF Use, which can be achieved by implementing "a system where air transport users contribute to SAF adoption based on their fuel consumption, in line with the 'user pays' principle. This measure ensures transparency for consumers and maintains a level playing field, as costs are distributed according to flight length and class of travel. Additionally, it provides a financially sustainable, long-term approach to generating SAF demand, with costs being absorbed by the aviation system. However, this measure does not necessarily impose a mandatory requirement”.

The World Economic Forum (2021) outlined a series of potential measures in its Clean Skies for Tomorrow toolkit to stimulate demand in the SAF market. These measures are comprehensively listed in Table 11.

Table 11 - Demand-side Measures and their Supporting Policies
Source – (World Economic Forum, 2021)

Goal	Stimulate SAF demand				
	Mandatory mechanisms	Market-based mechanisms			Voluntary mechanisms
		Reduce the SAF price for users.		Increase the price of SAF alternatives.	
Pathways	Stimulate demand for SAF through a SAF blending mandate	Direct subsidies for SAF	Indirect subsidies for SAF	Increase the cost of CAF	Include SAF in public procurement
Policy Options	Establish a SAF blending mandate with blending levels increasing progressively over time.	Provide direct tax incentives for SAF off-takers, producers or blenders to reduce the cost differential between SAF and conventional jet fuel.	Apply a dedicated SAF levy on flights to finance SAF acquisition, with possible variation accounting for distance and blending targets.	Introduce a domestic carbon price or cap-and-trade mechanism, potentially aviation-specific, to price in the social and environmental costs of fossil fuel emissions.	Impose a minimum SAF public procurement quantity for government flights and commercial flights by government employees.
	-	-	Exempt or credit SAF under existing carbon pricing or cap-and-trade systems	Gradually decrease existing subsidies and indirect tax incentives on conventional jet fuel to reduce cost disparities with SAF.	-
	-	-	Incorporate a SAF multiplier for use in existing cap-and-trade systems	Introduce a minimum tax on conventional jet fuel used for domestic flights	-
	-	-	Authorise the use of SAF in public incentive programmes to improve air quality	-	-
	-	-	Redistribute existing air ticket levies to favour SAF-powered flights.	-	-

After analysing the two foundational "pillars", the next step is to implement measures and systems that facilitate the scaling of SAF. This area focuses on mechanisms designed to bridge and enhance the effectiveness of both supply and demand-side measures by mitigating scaling barriers and fostering trade. In alignment with this approach, the World Economic Forum (2021) has provided further insights on this subject, building on the principles outlined in the Clean Skies for Tomorrow toolkit, as shown in Table 12.

Table 12 - Enabling measures and their supporting policies
Source – (World Economic Forum, 2021)

Goal	**Enable the SAF supply and demand connection**			
	Stimulate SAF trade			
Pathways	Create a marketplace for SAF	Ease SAF-related imports and exports	Facilitate and harmonise SAF certification	Other measures
Policy Options	Establish and recognise an existing environmental attribute ownership system (B+C) to facilitate the trade of SAF certificates and credits.	Reduce import barriers on SAF-related products if national production is not feasible or is insufficient to meet domestic demand.	Adopt clear and globally recognised feedstock sustainability standards	Support existing SAF production technologies and international capacity building for emerging markets to promote SAF adoption globally
	Adhere to a global accounting mechanism using chain of custody systems, such as B+C, and work to harmonise global standards.	Reduce export tariffs on renewable feedstocks or SAF surplus after meeting national obligations.	Establish a technical adviser to assist producers in obtaining industry fuel qualifications while also prioritising SAF certification within national regulatory agencies to reduce market lead-time	Establish a dedicated governmental entity for SAF or a similar cross-departmental body to support and monitor its development and commercial deployment.
	-	-	-	Establish climate performance labelling for airlines, aircraft and airports to support customers in making sustainable decisions and to develop green lead markets.

One of the primary barriers to the widespread adoption of SAF is its elevated purchase cost, which consequently renders CAF significantly more competitive in economic terms (Pechstein et al., 2020). To overcome this challenge, governments and regulatory authorities must develop and implement incentives and policies that enhance the attractiveness of SAF compared to CAF (International Air Transport Association, 2018). Despite the existence of some mechanisms designed to promote the production and consumption of SAF, L. Zhang et al. (2020) argue that these measures remain insufficient to enable the full-scale development and market penetration of SAF.

Among the various incentives currently in place, the European Union Emissions Trading Scheme (EU ETS) emerges as particularly noteworthy. This scheme offers financial incentives to aircraft operators that demonstrate higher levels of sustainability, contingent upon compliance with the sustainability criteria and emissions thresholds outlined in the RED/REDII Directives (European Union, 2008). An additional legislative instrument of relevance is the Sustainable Aviation Fuel Act (The House Of Representatives, 2021), which seeks to introduce a tax credit mechanism per gallon of SAF, calibrated according to the emissions profile associated with the respective fuel. Furthermore, the CORSIA endeavours to support the overarching objective of achieving net-zero greenhouse gas emissions within the aviation industry (International Civil Aviation Organization, 2018).

A closer examination of the EU ETS reveals that it is characterised as “a cornerstone of the European Union’s policy to combat climate change and a key tool for reducing greenhouse gas emissions cost-effectively, being the world’s first major carbon market” (European Union, 2023a). Between 2005 and 2019, this mechanism contributed to a reported 35% reduction in emissions within the EU region. The EU ETS operates across all Member States of the European Union, in addition to Iceland, Liechtenstein, and Norway, and imposes emission caps on approximately 10000 installations spanning the energy sector, manufacturing industries, and airlines operating within the covered jurisdictions – collectively accounting for around 40% of Europe’s greenhouse gas emissions (European Union, 2023a).

The operational structure of the EU ETS is based upon the “cap and trade” principle, whereby a “cap” – a fixed maximum limit – is imposed on the total volume of greenhouse gas emissions permitted. This “cap” is designed to decrease progressively over time. Each participating entity is required to hold a sufficient quantity of European Emission Allowances (EEAs) to correspond to its verified annual emissions of GHGs. These allowances may either be allocated free of charge or purchased through the market (Appunn & Wettengel, 2023). Due to the limited quantity of allowances, a market dynamic is established in which companies can trade allowances among themselves (European Union, 2023a). Entities failing to surrender a sufficient number of allowances to match their emissions levels are subject to financial penalties (European Union, 2023a).

Specifically, the EU ETS aims to mitigate CO_2 emissions from sources such as oil refineries, iron and steel production facilities, and commercial aviation activities within the European Economic Area. It also aims to curtail emissions of N2O originating from the production processes of nitric, adipic, glyoxylic, and glyoxal acids, as well as Perfluorinated Compounds (PFCs) resulting from aluminium production (European Union, 2023a) Although the system encompasses all enterprises within the energy, industrial, and aviation sectors, certain exceptions apply. In some sectors, only installations exceeding a specific size threshold are subject to compliance obligations. Moreover, smaller installations may be exempted if national governments implement equivalent emissions-reduction measures. Concerning aviation, it should be noted that, up to and including December 31, 2023, the EU ETS exclusively applied to flights operating within the European Economic Area (European Union, 2023a).

On July 14, 2021, the European Union adopted a comprehensive set of legislative proposals aimed at ensuring adherence to its overarching goal of achieving climate neutrality by 2050, with an interim objective of reducing net greenhouse gas emissions by at least 55% by 2030 relative to 1990 baseline levels (European Union, 2023a).

In the specific context of aviation, the EU ETS is structured around three primary objectives (European Union, 2023a):

- To contribute towards the European Green Deal objective of reducing aviation sector emissions by 90% compared to 1990 levels by 2050;
- To facilitate the implementation of the CORSIA mechanism established by the ICAO;
- To guarantee equal treatment of airlines operating on identical routes, irrespective of whether they are European or non-European carriers.

Furthermore, from 2027 onwards, it is stipulated that airlines must obtain emissions allowances exclusively through auctioning processes, thereby fostering increased operational efficiency and encouraging more sustainable planning practices (European Union, 2023a). Although the EU ETS does not directly promote the utilisation of SAF, it indirectly stimulates efforts to reduce greenhouse gas emissions within the aviation sector, wherein the deployment of SAF constitutes a critical strategy.

In addition to the EU ETS, another important European initiative is the ReFuelEU Aviation. This policy initiative arises from the recognition that “to decrease its emissions significantly, the aviation sector must reduce its current reliance on fossil fuels and increasingly depend on SAF over the coming years, (…) as new technologies like electric or hydrogen-powered aircraft are not expected to be mature enough to play a major role in commercial aviation within the next few decades” (European Union, 2020b). It further acknowledges the substantial economic barriers linked to SAF, particularly its elevated production costs, which translate into higher market prices (European Union, 2020b).

The principal aim of the ReFuelEU Aviation is to minimise the environmental impact of aviation activities and to facilitate the achievement of the European Union’s climate targets by simultaneously bolstering both the supply and demand for SAF (European Union, 2020b). Among the measures foreseen are:

- The establishment of a SAF blending market.
- The revision of the renewable energy directive multiplier.
- The creation of a central auctioning mechanism.
- The establishment of a dedicated financing mechanism;
- The prioritisation of specific SAF types.
- The promotion of voluntary agreements.
- The implementation of technical support activities; and
- The development of mechanisms for monitoring SAF implementation data.

The SAF blending mandate requires that a minimum proportion of SAF be supplied to ot utilised by airlines.

The revision of the renewable energy directive multiplier entails adjustments to the current multiplier value of 1.2, potentially resulting in a 20% decrease in SAF production volumes.

Through the central auctioning mechanism, SAF producers will be invited by a centralised authority to submit bids for supplying predetermined quantities of SAF to the aviation market over specified periods, with the selection being based on the lowest offered prices.

The financing mechanism will empower the European Union to direct financial resources towards supporting the deployment of SAF production infrastructure within the Union, thereby helping to bridge the existing cost gap and encouraging a gradual transition towards SAF adoption by the aviation industry.

The prioritisation of specific SAF types acknowledges the scarcity of certain raw materials crucial for sustainable fuel production, necessitating a strategic allocation towards transportation modes where emissions reductions are deemed most urgent.

To foster voluntary agreements, the European Union will establish a collaborative platform to facilitate negotiations between SAF producers and airline operators, offering guidance and best practices for stakeholders throughout the negotiation process.

Leveraging its extensive technical expertise, the European Union also intends to provide technical assistance to SAF producers and to facilitate the establishment of collaborative networks between airline companies and producers, aiming to advance SAF-related innovations.

By implementing robust monitoring systems for SAF, the European Union will be able to collect, analyse, and leverage data to track and enhance key performance indicators associated with the deployment of sustainable fuels.

With these measures, significant impacts are expected at three essential levels (European Union, 2020a):

At the economic level, it is anticipated that there will be growth and investment in SAF production, an increase in the sector’s competitiveness, a strengthening of Europe’s regional competitiveness, greater innovation and research, and progress towards what the European Union defines as an Energy Union. The increase in SAF production and acceptance is expected to attract important investments, particularly in the development of production and distribution capacities. However, since SAF is currently more expensive than CAF, the decision to purchase SAF necessarily reduces the operating margins of airlines, thus negatively affecting their competitiveness in the air transport market. Therefore, the impact of this initiative should first be carefully assessed within the European industry and then compared with initiatives in other regions of the world. With an ambitious policy to boost SAF production and uptake, the European Union has the opportunity to become a global leader in the sustainable and innovative aviation fuel market. By fostering SAF production within Europe, the European Union also reinforces its broader goal of achieving carbon neutrality by 2050.

At a Social Level, it is expected that the development of the SAF market will create new jobs, particularly in the production and distribution sectors. However, there may be negative effects on employment linked to the production of traditional fossil fuels, as a gradual replacement of CAF by SAF is anticipated.

At the Environmental Level, it is expected that a significant deployment of SAF in the aviation sector will result in a major reduction in greenhouse gas emissions. Each operation conducted using SAF can emit up to 80% less CO_2 compared to the same operation using CAF. Furthermore, any policy measures aimed at boosting aviation sustainability by promoting the SAF market must pay special attention to the overall environmental integrity of SAF production. The production of SAF from biogenic sources may also contribute to and incentivise more effective waste management within the European Union.

2.4. BUSINESS SUSTAINABILITY

Business Sustainability is divided into three domains: environmental, economic, and social, which must interact continuously to ensure the company's sustainability (Júnior et al., 2019). Social sustainability encompasses, among other variables, working conditions, cultural diversity programs, and the relationship between the company and its employees (Landin Neto, 2016; Pires Aguiar et al., 2016). Environmental sustainability involves decision-making aimed at reducing the environmental impact that may be caused, directly or indirectly, by the company's activities in the short, medium and long term (Fonseca, 2015; Luiz Da Silva et al., 2012). Economic sustainability focuses on the company's pursuit of achieving consecutive positive net results, ideally (Fernandes et al., 2018).

Another possible definition of "Business Sustainability" is provided by Coral (2002), citing Sachs (1993), who advocates for a 5-dimensional approach:

- "Social sustainability: means achieving equity in the distribution of income for the inhabitants of the planet.
- Environmental sustainability: using renewable natural resources and limiting the use of non-renewable resources.
- Economic sustainability: reducing social and environmental costs.
- Spatial sustainability: achieving a balanced configuration between rural and urban populations.
- Cultural sustainability: ensuring the continuity of traditions and the diversity of people."

Coral (2002) also created a model of corporate sustainability similar to that of Júnior et al. (2019), which is presented in Figure 6.

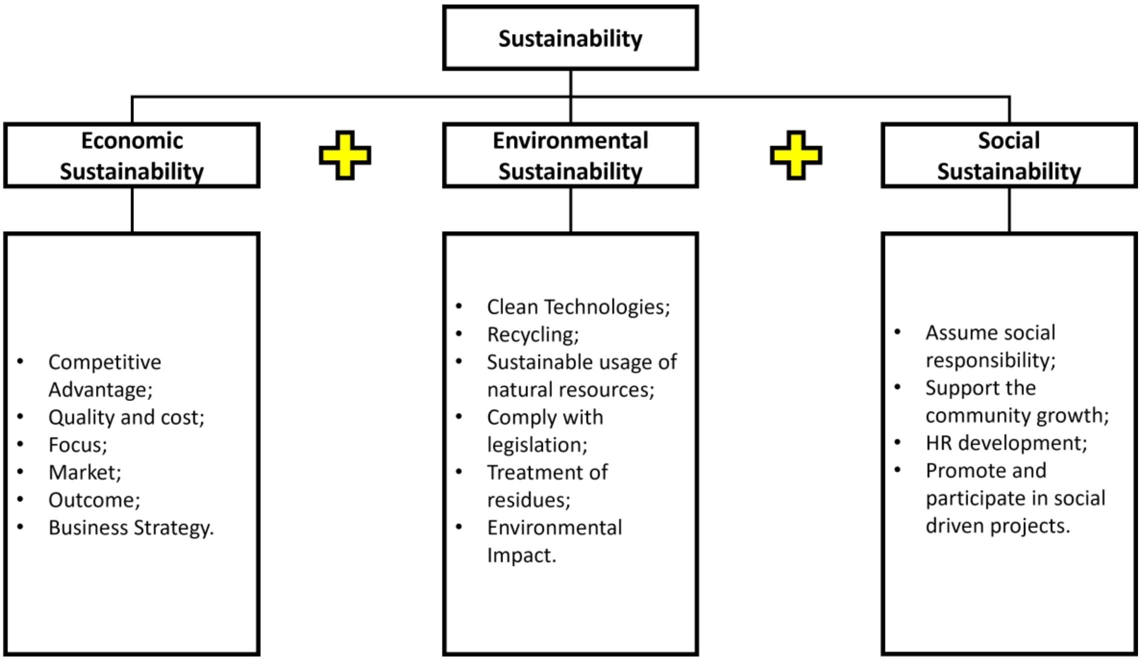

Figure 6 - Business Sustainability
Source – (Coral, 2002)

Business sustainability in the aviation sector encapsulates the strategic integration of environmental, economic, and social considerations into long-term corporate decision-making and operational frameworks. As outlined by Júnior et al. (2019), true sustainability emerges not from isolated interventions but from the systemic interaction of these three domains. This triadic structure—often referred to as the Triple Bottom Line (Elkington & Rowlands, 1999)—requires airlines to concurrently pursue ecological responsibility, financial resilience, and social equity.

At the environmental level, sustainability involves deliberate action to mitigate the environmental footprint of airline operations, particularly by reducing greenhouse gas emissions, noise pollution, and reliance on non-renewable resources. In aviation, the transition toward SAF is a cornerstone of this environmental strategy. Environmental sustainability also encompasses broader ecosystem protection measures, including the responsible use of biogenic feedstocks to prevent biodiversity loss and maintain ecological integrity (International Energy Agency, 2021).

At the economic level, sustainable business models in aviation aim to maintain profitability while reducing externalities. Economic sustainability requires airlines to adapt to volatile fuel markets, invest in fuel-efficient fleets, and explore new revenue streams such as ancillary services and carbon offset programs. The integration of SAF into commercial operations presents a challenge in this regard, as its current market price is significantly higher than that of CAF, sometimes by a factor of 2 to 5 (Hamdan et al., 2022). As such, incorporating SAF may compress airline operating margins, threatening competitiveness, especially in price-sensitive market segments, such as those of low-cost carriers. However, this challenge is counterbalanced by the long-term economic rationale of reduced regulatory risks, potential tax credits, and hedging against fossil fuel volatility (European Union, 2023b; European Union Aviation Safety Agency, 2023). In addition, economic sustainability implies internalising the environmental costs of emissions, enabling a transition from short-term cost-cutting to long-term value creation.

From the social perspective, sustainable aviation considers the well-being of multiple stakeholders, including employees, passengers, supply chain actors, and local communities. Social sustainability, according to Landin Neto (2016) and Pires Aguiar et al. (2016), is reflected in fair labour practices, inclusive hiring policies, and engagement with communities impacted by airport and flight operations. In the SAF context, the growth of biofuel supply chains—particularly in rural areas—could generate employment and contribute to social cohesion. Nonetheless, a just transition must also address potential job displacements in the fossil fuel industry and ensure workforce retraining, as recommended by the International Labour Organization (2021). Moreover, passenger acceptance of SAF-linked ticket surcharges is also a social dimension, explored through WTP surveys, which assess consumers' support for environmental initiatives based on transparency and perceived corporate responsibility (Rice et al., 2019).

Coral's (2002) five-dimensional model of sustainability adds further richness to this framework. Beyond the conventional three pillars, it includes spatial sustainability—advocating for balanced development between urban and rural regions—and cultural sustainability, which highlights the need for inclusive, diverse, and contextually sensitive strategies that honour local traditions and knowledge systems. In airline operations, spatial sustainability might relate to airport location decisions and the accessibility of air services in underserved regions. In contrast, cultural sustainability could inform corporate governance and customer engagement strategies in global markets.

Additionally, Achkar et al. (2005) propose a four-level model that includes the political dimension, reflecting the importance of governance, regulatory frameworks, and institutional stability. In aviation, this is especially relevant given the sector's exposure to international policy regimes, such as the EU ETS, ICAO guidelines, and national decarbonisation roadmaps (European Union, 2023b; República Portuguesa, 2019). Political sustainability entails long-term consistency in these frameworks to provide predictability for investment in SAF infrastructure and sustainable technologies.

In strategic terms, business sustainability is not a static goal but a dynamic capacity that enables airlines to anticipate, respond to, and shape environmental and market transformations, this includes aligning with Sustainable Development Goals (SDGs)—especially SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action)—while building resilience into core business processes (United Nations, 2025b).

In summary, business sustainability in aviation must evolve from traditional compliance-based approaches to integrated, forward-looking strategies that balance short-term operational performance with long-term environmental stewardship, economic resilience, and social legitimacy. As airlines navigate a post-pandemic recovery marked by heightened environmental awareness, regulatory tightening, and shifting consumer expectations, embedding sustainability into the business's DNA becomes both a competitive imperative and a moral responsibility.

2.5. FUEL COSTS

Fuel costs are typically one of the top two largest expenses to an airline's operational costs (Sibdari et al., 2018). As airlines continually strive to enhance their operational margins by minimising operational costs, fuel expenses play a pivotal role in the equation (Hamdan et al., 2022).

Ryerson & Hansen (2010) evaluated three types of aircraft: narrow-body, regional jets, and turboprops. They determined the minimum fleet cost and later concluded that an optimised fleet is highly sensitive to both fuel costs and passenger costs. In a later study, Ryerson & Hansen (2013) found that significant reductions in fuel costs are largely driven by upgauging[2] and the adoption of more advanced technologies. Consequently, investment in modern, fuel-efficient aircraft, such as the Airbus A320neo and Boeing 787 Dreamliner, is often justified by their superior fuel burn rates per seat-kilometre. These strategic capital expenditures not only reduce operating costs but also contribute to emissions compliance and sustainability goals.

To better understand the significance of fuel costs, Figure 7 was created, which illustrates the representativeness of fuel costs relative to operational costs through a simple division. For this analysis, the top 10 airlines with the highest revenue in 2024 were selected according to Aviation A2Z (2025).

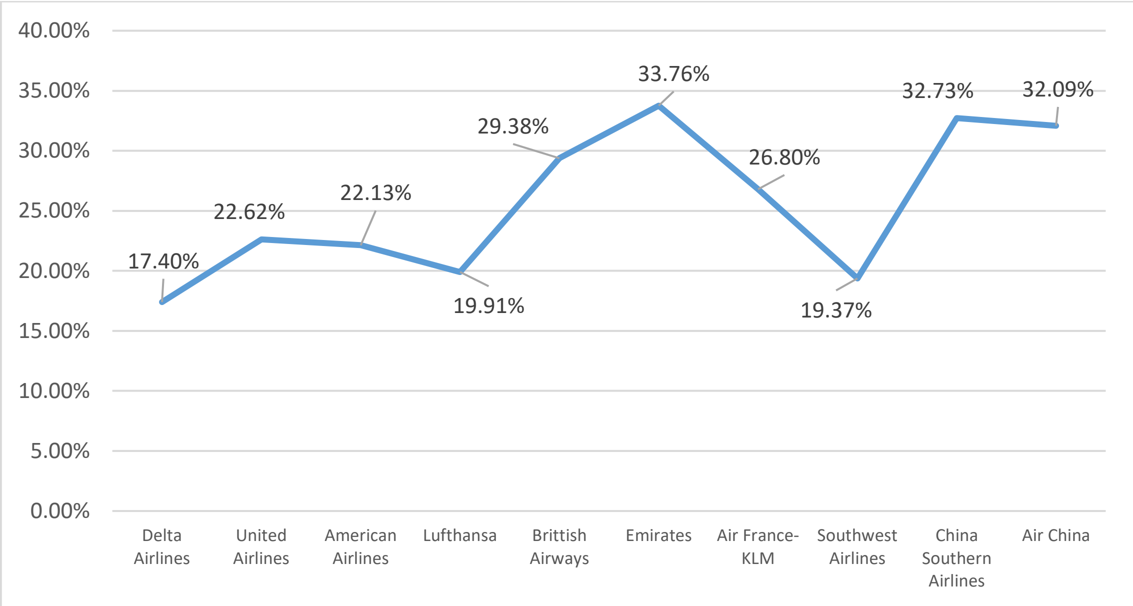

Figure 7 - Fuel Costs Representativeness in Operational Expenses
Source – Own Elaboration (Based in the Annual Reports (Air China, 2024; AirFrance-KLM, 2024; American Airlines, 2024; China Southern Airlines, 2024; Delta Airlines, 2024a; Emirates, 2024; IAG Group, 2024; Lufthansa, 2024; Southwest Airlines, 2024; United Airlines, 2024))

This category of expense exhibits extreme sensitivity to global energy price volatility, geopolitical instability, supply-demand imbalances, and carbon pricing mechanisms. Accordingly, fuel costs exert a direct and often volatile influence on an airline's profitability, pricing strategy, and long-term competitiveness.

[2] Upgauging: the practice of airlines increasing the capacity of a flight, either by adding more seats to an existing aircraft or by replacing a smaller aircraft with a larger one (SATAIR, 2024).

Historically, aviation fuel pricing has been benchmarked against the Brent crude oil market, with airlines purchasing Jet A or Jet A-1 fuel. Due to the capital-intensive and fuel-reliant nature of commercial aviation, the cost of jet fuel has become a central component in airlines' financial forecasting and risk exposure. According to the International Air Transport Association (2022), global airline fuel expenditure reached over $222 billion in 2022, representing approximately 30% of total airline costs, a notable increase from the pandemic-induced low of $92 billion in 2020.

In response to the volatility of jet fuel prices, airlines frequently engage in fuel hedging—a financial risk management tool that stabilises future fuel expenditures. This mechanism involves contractual arrangements, such as options and swaps, which enable airlines to lock in fuel prices for future periods. However, hedging itself introduces complex financial risks. The failure of these instruments to accurately forecast future fuel price trends can lead to significant losses, as seen in several airline cases during the 2008 global recession and the 2020 COVID-19 pandemic (Morrell & Swan, 2006).

Beyond economic risk management, fuel costs also influence the design of airline business models. For instance, LCC optimises cost structures through standardised narrow-body fleets, high seat density configurations, and rapid aircraft turnaround strategies, achieving favourable fuel efficiency per revenue passenger. In contrast, FSCs, which operate long-haul wide-body fleets, face inherently higher fuel burn rates per flight segment, albeit partially offset by premium yield strategies and cargo belly revenue.

Another critical dimension of fuel cost analysis lies in the transition to SAF. Despite SAF's promise to reduce lifecycle greenhouse gas emissions, its production cost remains substantially higher than that of CAF (European Civil Aviation Conference, 2023). Consequently, the adoption of SAF imposes upward pressure on fuel cost structures, threatening the cost competitiveness of airlines, particularly those operating in price-sensitive markets.

Further academic studies support these conclusions. For example, Brueckner et al. (2024) found that fuel cost escalation directly correlates with fare adjustments, particularly on competitive routes. In contrast, there are authors who argue that fuel surcharges often fail to compensate for fuel inflation due to fare elasticity limits fully.

From an environmental policy perspective, the cost of fuel—especially when internalising the social cost of carbon—becomes a tool for behavioural change. Governments have proposed fuel taxes, emissions-based slot allocation, and SAF blending mandates, all of which are poised to further entrench fuel costs as a core strategic variable in airline management.

2.6. WILLINGNESS-TO-PAY (WTP)

By definition, Willingness-to-Pay refers to the maximum amount a customer is willing to pay for a particular product or service (Hanemann, 1994). Early discussions highlight a distinction between HWTP and RWTP, where the key difference lies in the method of assessment: HWTP is determined through questionnaires in various formats, while RWTP is established through the customer's actual purchase of a product (Miller et al., 2011).

Völckner (2006) proposes a measurement method using a closed-ended question format, where predefined response options help determine the price that a customer is willing to pay for a given service. Other authors suggest a mixed approach that combines closed-ended and open-ended questions, allowing respondents to justify or even advise on their chosen price, thereby improving the researcher's understanding (Wertenbroch & Skiera, 2002).

Breidert et al. (2006) developed Figure 8, which outlines the various methods for measuring WTP:

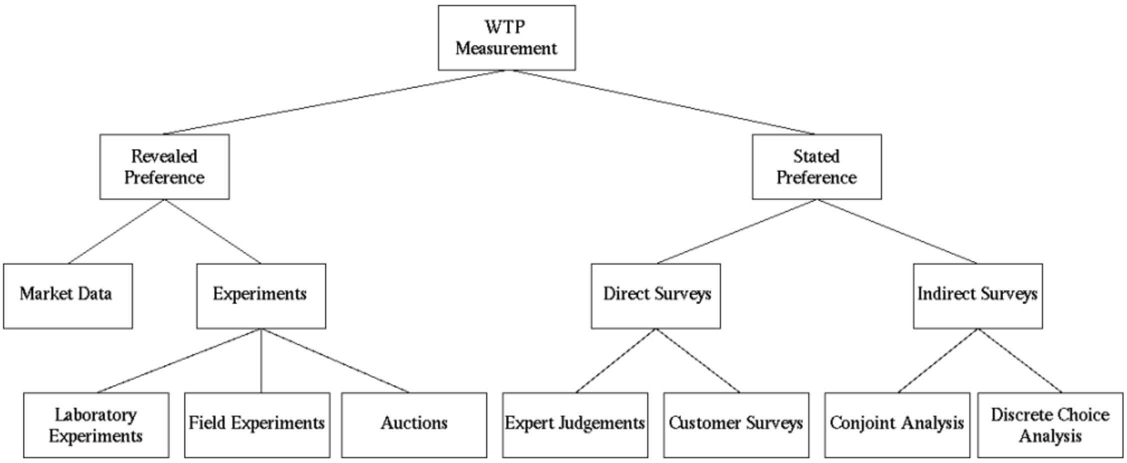

Figure 8 - WTP Measurement Methods
Source – (Breidert et al., 2006)

Market data analysis is employed to estimate price-response functions. The main challenge with this approach is the assumption that past demand can be used to predict future demand, which is not always accurate. This limitation led Sattler & Nitschke (2003) to deem this method unfeasible.

Additional insights into this data analysis method can be found in the research by Kamakura & Russel (1993) and Leeflang & Wittink (1992).

Experiments can be categorised into laboratory experiments, field experiments, and auctions (Malhotra & Birks, 2004).

In laboratory experiments, consumer purchasing behaviour is assessed using the Assessor Method, developed by Silk & Urban (1978). In this method, participants are given a specific amount of money and instructed to spend it within a defined product scope. By analysing their purchasing decisions, it becomes possible to determine their preferences and purchasing rationality. However, a key limitation of this method is that participants may exhibit more rational behaviour than they would in real-world scenarios, which can introduce discrepancies between experimental choices and actual purchasing behaviour (Nassim & Dodge, 1995).

In field experiments, consumers may or may not be aware that they are participating in a study. Here, prices are frequently adjusted to assess consumer responses and purchasing behaviour (Gaul et al., 1996). Compared to laboratory experiments, field experiments are generally more costly and time-consuming for businesses (Nagle & Holden, 1995).

Auctions have also been explored as a method to determine consumers' WTP. Wertenbroch & Skiera (2002) concluded that Vickrey Auctions are particularly effective in this regard. In Vickrey Auctions, participants submit sealed bids without knowing the values offered by the other bidders. The highest bidder wins the auction but pays the price of the second-highest bid (Vickrey, 1961).

In addition to the Vickrey method, other auction methods have been proposed and studied, including those by Abrams, (1964), Chernev (2003), and Spann et al. (2004).

Direct surveys allow researchers to collect respondents' statements regarding their price preferences. These can be conducted in two ways: by interviewing either specialists or potential customers (Breidert et al., 2006).

Specialist interviews primarily focus on commercial managers or marketing managers, as these professionals are not only directly involved in the market but also maintain closer connections with customers. This proximity enables them to understand the competitive market structure better and involve customer needs, key factors influencing WTP (Nassim & Dodge, 1995).

The earliest customer interviews aimed at determining WTP were conducted by Stoetzel (1954), who believed that these interviews could effectively establish both the minimum and maximum acceptable prices for a given product. Later, Marbeau (1987) formulated two key questions that align with Stoetzel's (1954) concept:

- "Above what price would you not purchase the product, either because you cannot afford it or because you believe it is not worth the price?".
- "Below what price would you not purchase the product because you would suspect its quality?".

This method has been widely analysed, with various studies highlighting its advantages, disadvantages, and limitations (Abrams, 1964; Gabor et al., 1970; Stout, 1969).

In contrast, indirect surveys focus on gauging customer responses to predetermined prices rather than directly asking respondents to state their fair prices (Brown et al., 1996). This method aims to assess whether a customer would purchase a product based on a predefined price (Marbeau, 1987).

Cameron and James (1987) identified two prominent methods within indirect surveys: conjoint analysis and discrete choice analysis.

Conjoint analysis is a method used to measure individuals' preferences for different product attributes in an experimental setting. In this method, the individual is presented with a series of product profiles that vary in attributes, and then ranks these profiles from most to least valuable in their opinion, enabling the possibility of determining which product has a higher or lower WTP (Carrol & Green, 1995). Further research on this methodology has been conducted by Green and Srinivasan (1978) and Gustaffsson et al. (1990).

In the discrete choice analysis, respondents choose between several product profiles (Ben-Akiva & Lerman, 2018; McFadden, 1980, 1986). The main differences between this method and the previous one lie in the underlying estimation technique (Louviere et al., 2000).

To compare these methods, Breidert et al. (2006) created Table 13, which compares seven key elements.

WTP for green initiatives has been investigated in various contexts, including product packaging (Singh & Pandey, 2018), species protection for endangered animals (Lew, 2015), and ancillary products sold in the aviation industry (Hinnen et al., 2015). Regarding the aviation sector, Shaari et al. (2020) studied whether including emission fees in fares would impact the Malaysian passengers' WTP.

Table 13 - Comparative evaluation of competing methods for measuring willingness-to-pay
Source – (Breidert et al., 2006)

	Market Data	Experiments	Direct Surveys	Indirect Surveys	
				Conjoint Analysis	Discrete Choice Analysis (CBC)
Cost effective	+/-	--	++	+	+
Time efficient	+/-	--	++	+	+
Flexibility to include new price/product combinations	--	++	+/-	++	++
Validity of estimations	++	+/-	--	+	+
Real purchase behaviour	++	+/-	--	--	--
Observed choice behaviour	++	+	--	--	+
Individual-level estimations	+/-	+/-	++	++	+

+ (++) = (strong) advantage
- (--) = (strong) disadvantage
+/- = no clear advantage or disadvantage (depending on data-collection and/or estimation method)

Studies also suggest that even passengers who are currently unwilling to pay higher prices may have a greater WTP in the future (Cliffe, 2014; Gössling et al., 2009). Hinnen et al. (2015) concluded that 20% of Swiss passengers are willing to pay more for products if they are assured of the sector's "greening".

To assess passengers' WTP for measures aimed at reducing GHG emissions, some researchers have used the CVM (Brouwer et al., 2008; Jou & Chen, 2015; Rahim & Shaari, 2017).

The Contingent Valuation Method is widely used in cost-benefit analysis for environmental protection measures (Burness et al., 1986; Mitchell & Carson, 1989). The primary criticisms of this method pertain to the reliability and validity of the results. The term "validity" refers to the accuracy of the results, while "reliability" refers to the consistency and reproducibility of the findings (Kealy et al., 1990).

Venkatachalam (2004) conducted a more generalised investigation of this CVM method.

In CVM, respondents are typically asked about a general topic — for example, how they believe aviation emissions might affect human life and the environment. Following this, a series of potential price impacts is presented, and respondents answer "yes" or "no" to indicate whether they would be willing to pay those amounts. Additionally, demographic questions may be included to obtain even more specific results (Shaari et al., 2020).

2.7. CONCLUSION

This Literature Review has methodically traversed the interdisciplinary terrain required to understand the complex interplay between climate change, airline fuel strategies, economic sustainability, and consumer behaviour in the context of transitioning towards SAF. Beginning with a comprehensive overview of the multifactorial causes and consequences of climate change, it becomes clear that the aviation sector’s decarbonization is not just a regulatory imperative but a planetary necessity. As demonstrated through authoritative sources such as the United Nations (2025), the Intergovernmental Panel on Climate Change (2022), and the European Union (2023b), the adverse environmental and socio-economic impacts of persistent GHG emissions demand immediate and scalable mitigation efforts, of which SAF emerges as a pivotal solution.

The review of SAF highlights its dual role as both a technological innovation and a regulatory construct. SAF's lifecycle advantages, compatibility with current aircraft infrastructure, and capacity for significant CO_2 reductions (up to 80%) position it as the most viable alternative to CAF in the foreseeable future. However, the discussion also surfaces critical impediments—namely, the economic infeasibility of large-scale SAF deployment under current market conditions, the fragmented regulatory landscape, and the lack of harmonised global standards. The analysis of the CORSIA (International Civil Aviation Organization, 2018) framework, the (American Society for Testing and Materials, 2022) D7566 specification, and the European Union (2020b) initiatives such as ReFuelEU illustrates the intricate nexus of technical certification, environmental governance, and strategic policymaking required to legitimize and institutionalize SAF adoption.

Moreover, the review of SAF feedstocks and conversion pathways underscores the heterogeneity of technological readiness levels, economic performance, and environmental externalities associated with each method. Insights from scholars such as L. Zhang et al. (2020) and Shahriar & Khanal (2022) provide a nuanced understanding of the strengths, weaknesses, and innovation potentials embedded within various SAF production technologies, this is further complemented by a discussion on blending logistics and distribution methods, where the Literature points to a critical role for infrastructure modernization and supply chain reconfiguration to minimize end-user fuel costs.

In parallel, the economic implications for airline operators—particularly in terms of fuel cost representativeness and margin sensitivity—are thoroughly explored. The Literature suggests that while larger FSCs may benefit from hedging, economies of scale, and diversified revenue models, LCCs operate within narrow cost margins, making any increase in fuel prices especially consequential. This dichotomy informs the comparative framework adopted in this Dissertation and serves as a conceptual precursor for evaluating the financial viability of SAF within each model.

Finally, the review of Willingness-to-Pay Literature, including both hypothetical and real preference approaches, offers critical insight into the behavioural elasticity of aviation consumers. The use of CVM and discrete choice modelling establishes a robust methodological pathway for empirically testing the acceptability of SAF-induced fare premiums. Given that consumer buy-in is a precondition for the commercial success of any sustainability initiative, the theoretical exploration of WTP becomes a cornerstone of both this Literature Review and the broader research inquiry.

In sum, this chapter has integrated environmental science, regulatory analysis, fuel economics, and behavioural research to construct a multidimensional framework for assessing the economic impact of SAF on airline business sustainability. This holistic foundation is essential not only for the empirical analysis that follows but also for informing stakeholders—ranging from policymakers and airline executives to sustainability advocates—on the systemic prerequisites for a viable and equitable energy transition in the aviation sector.

3. METHODOLOGY AND DATA

3.1. INTRODUCTION

Considering the increasing pressure on the aviation industry to align with global decarbonization goals and adopt sustainable practices, this chapter delineates the methodological framework employed to quantify the economic impact of SAF integration in commercial airlines. The analysis is structured around the SeCA model—SAF em Companhias Aéreas—a purpose-built analytical framework developed to simulate and evaluate the financial repercussions of incorporating SAF up to the legally permissible blend ratios within aircraft fuel tanks. The overarching goal of this methodology is not merely to assess the direct cost implications, but to offer a robust, decision-oriented model that can inform strategic airline management within both Full-Service Carriers and Low-Cost Carriers.

The methodology adopts a mixed-methods approach, strategically integrating quantitative components—derived from the financial and operational data of real-world airline case studies—with qualitative assessments gathered through a structured survey rooted in the CVM. This dual approach ensures both analytical rigour and context-specific adaptability. The combination of numerical modelling and behavioural assessment captures not only the deterministic financial variables but also the perceived value customers attribute to sustainability.

At the core of the quantitative analysis lies the SeCA model, which is implemented in two sequential phases: the Economic Impact phase and the Solutions phase. Within these, a series of equations are applied to translate real airline data into cost structures under SAF and CAF scenarios.

Parallel to the numerical framework, the qualitative dimension of this methodology is operationalised through a survey designed to capture passengers' WTP for greener operations. This survey employs Likert, dichotomous, and proportional response formats, enabling a nuanced understanding of consumer sentiment across multiple price scenarios and operation types. By informing revenue recapture strategies (+PAX and +FARE), the survey results provide empirical grounding for forecasting the acceptability and feasibility of cost-passing mechanisms in a market-sensitive industry.

Finally, the methodological choice to implement case studies of both an LCC and an FSC enhances the generalizability of findings. It enables a comparative analysis that takes into account divergent business models, route networks, and operational scales—each of which significantly impacts the economic viability of SAF deployment.

Thus, this chapter serves as both a technical blueprint and an applied validation of the SeCA model, articulating how sustainable fuel integration can be modelled, tested, and adapted to different strategic realities in the commercial aviation sector.

3.2. MIXED METHODS RESEARCH

The method is a mixed-methods research. This type of research stands out for its versatility and analytical depth. It was chosen primarily because it allows the use of quantitative data to approximate the impact, followed by a qualitative analysis to explore that impact in greater depth.

This methodology also enables the use of sampling to conduct a study and extrapolate the results to a broader population. Furthermore, it supports the application of more efficient questionnaires, combining Likert-scale or dichotomous responses with the possibility of open-ended questions, allowing respondents to elaborate on their opinions.

Qualitative research is an unstructured investigative approach that relies on small samples and aims to provide insights and a deeper understanding of the issue (Malhotra & Birks, 2004). Quantitative research, on the other hand, is a systematic process of collecting observable and measurable data, grounded in the observation of objective facts, phenomena, and events that exist independently of the researcher (Freixo, 2011).

This research was carried out in an initial phase of data collection and processing, which was followed by the development of a questionnaire implemented in five stages:

1. Questionnaire design and development.
2. Pre-testing of the questionnaire allowed for the identification of inconsistencies, ambiguous language, and overly complex questions.
3. Distribution of the questionnaire and follow-up.
4. Data collection and processing.

5. Results analysis.

3.3. DATA COLLECTION METHODOLOGIES

3.3.1. BIBLIOGRAPHIC RESEARCH METHOD

The Literature Review is conducted based on pre-existing material, primarily consisting of scientific articles (Gil, 2002). Gil (2002) developed a framework for classifying bibliographic sources (Figure 9).

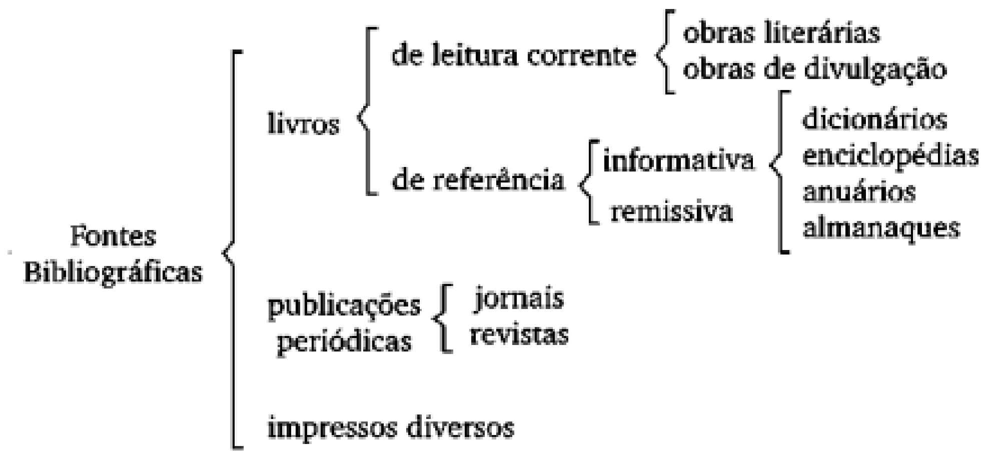

Figure 9 - Classification of Bibliographic Sources
Source – (Gil, 2002)

Leong & Austin (2006) argue that reading, understanding, and analysing existing studies on the research topic helps to establish the foundation of an investigation, as it allows the researcher to identify both what is already known and what remains unexplored.

3.3.2. DOCUMENTARY RESEARCH METHOD

The process of documentary research is, for the most part, similar to that of bibliographic research. The main distinction lies in the sources. While bibliographic research primarily relies on the contributions of various authors regarding a specific topic, documentary research is based on materials that have not yet undergone analytical treatment or that may still be reinterpreted in light of the study's objectives (Gil, 2002).

3.3.3. CASE STUDY

The case study is a widely used research method in the biomedical and social sciences (Gil, 2002). A case study involves an intensive analysis of a single unit, such as an individual, a company, or a community, with a focus on the development factors of that unit (Merriam-Webster, 2009).

The case study is particularly useful when the researcher aims to answer questions such as “how” and “why”, especially when there is limited control over events, and when the focus is on contemporary phenomena within a real-world context (Yin, 2001).

3.4. SAF EM COMPANHIAS AÉREAS (SECA)

As the Literature Review suggests, SAF is currently the best alternative to conventional jet fuel. However, this alternative fuel is economically less viable, which could potentially undermine the airline's competitiveness, particularly in terms of ticket pricing.

The SeCA model is designed to assess the economic impact of an airline operating with SAF up to the legally accepted representation levels. Additionally, this model proposes three solutions to mitigate the foreseeable economic impact associated with the use of SAF. Therefore, this model can be utilised by airlines to estimate the potential economic impact of operating with SAF.

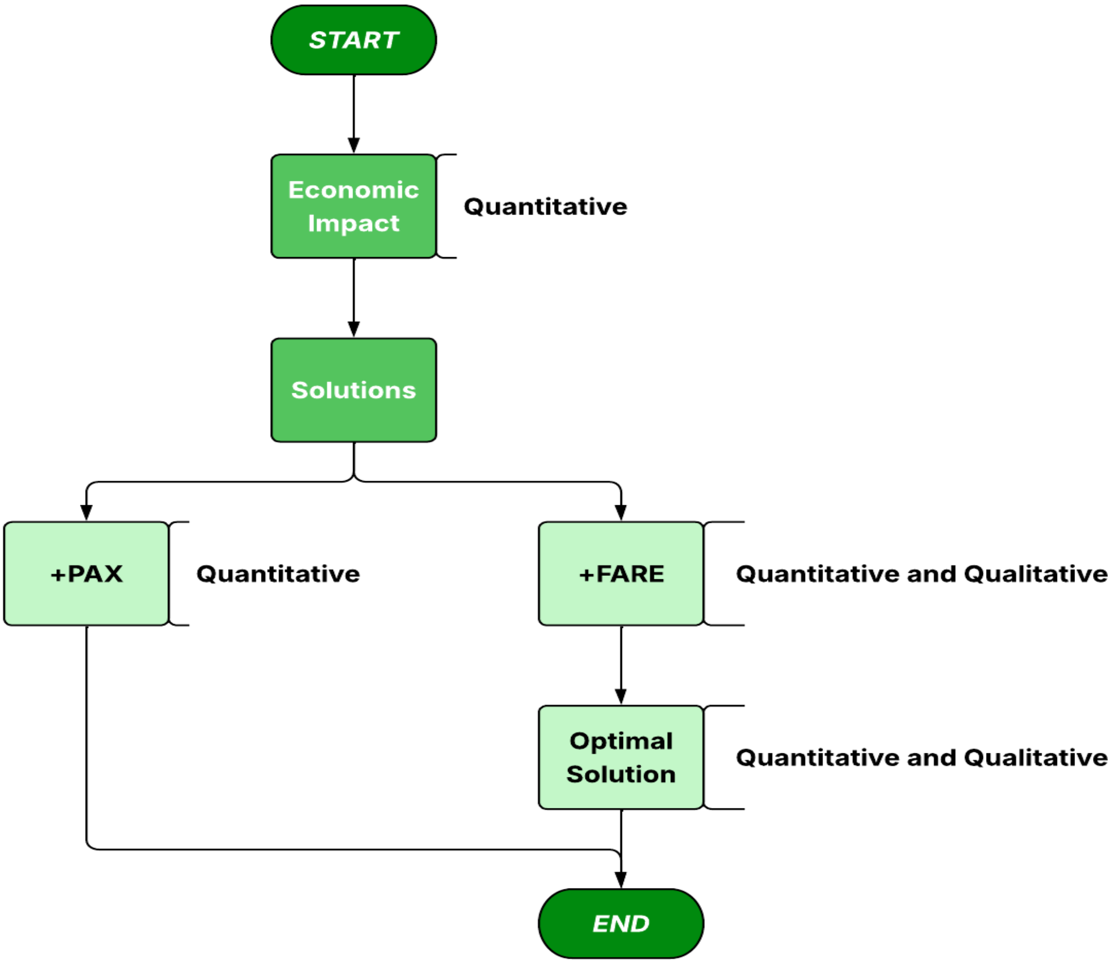

Figure 10 - SeCA's Model Fluxgram
Source: Own Elaboration

Figure 10 presents a strategic decision-support framework that outlines the sequential logic and interdependencies involved in integrating SAF into airline operations while maintaining economic viability. The model is structured around a process-driven analytical flow comprising two primary domains: the assessment of economic impact and the design of revenue-preserving or enhancing solutions.

The workflow begins at the START node and transitions into the first analytical block:

1. Economic Impact (Quantitative Analysis): This component conducts a quantitative assessment of the financial implications of operating with SAF, taking into account the cost disparities between SAF and CAF. It constitutes the cost-side diagnosis and sets the foundation for decision-making by quantifying deviations from conventional operational expenditure.

2. Solutions: In response to the identified Economic Impact, the model introduces a strategic solution-generation block aimed at preserving or recovering the airline's operational margin. This module bifurcated into two core strategic responses:
    a. Passenger Volume Increase (+PAX): A solution grounded in quantitative metrics, this path targets increasing the total number of passengers as a means to amortise costs over a larger customer base.
    b. Fare Adjustment (+FARE): This pathway blends quantitative and qualitative considerations. It involves a refined pricing strategy that includes yield management.
        i. Optimal Solution Integration: The +FARE strategy further leads to an Optimal Solution node, where the system identifies the most viable outcome by integrating both economic metrics and intangible factors. In this phase, a systematic interplay exists between quantitative variables and qualitative dimensions. It enables a holistic decision-making process that considers both measurable outcomes and strategic positioning.

After all, the model concludes at the END node, representing the execution point of the derived solution.

Importantly, the inclusion of an optimisation phase suggests that a feedback loop consistent with systems modelling is in place, allowing for iterative refinement and continuous performance evaluation. Additionally, the framework aligns with the principles of sustainable operations management, effectively balancing environmental compliance and responsibility through the incorporation of SAF, with economic responsibility and operational continuity.

3.4.1. ECONOMIC IMPACT

The first part of the SeCA Model involves determining the Economic Impact of operating with SAF at present. To assess this Economic Impact, three processes need to be completed. Initially, it is necessary to collect data, primarily from the Annual Reports of the airlines. Following this, with the gathered data, a phase of calculations is conducted to obtain the desired Outputs, either to model the cost and assess the impact.

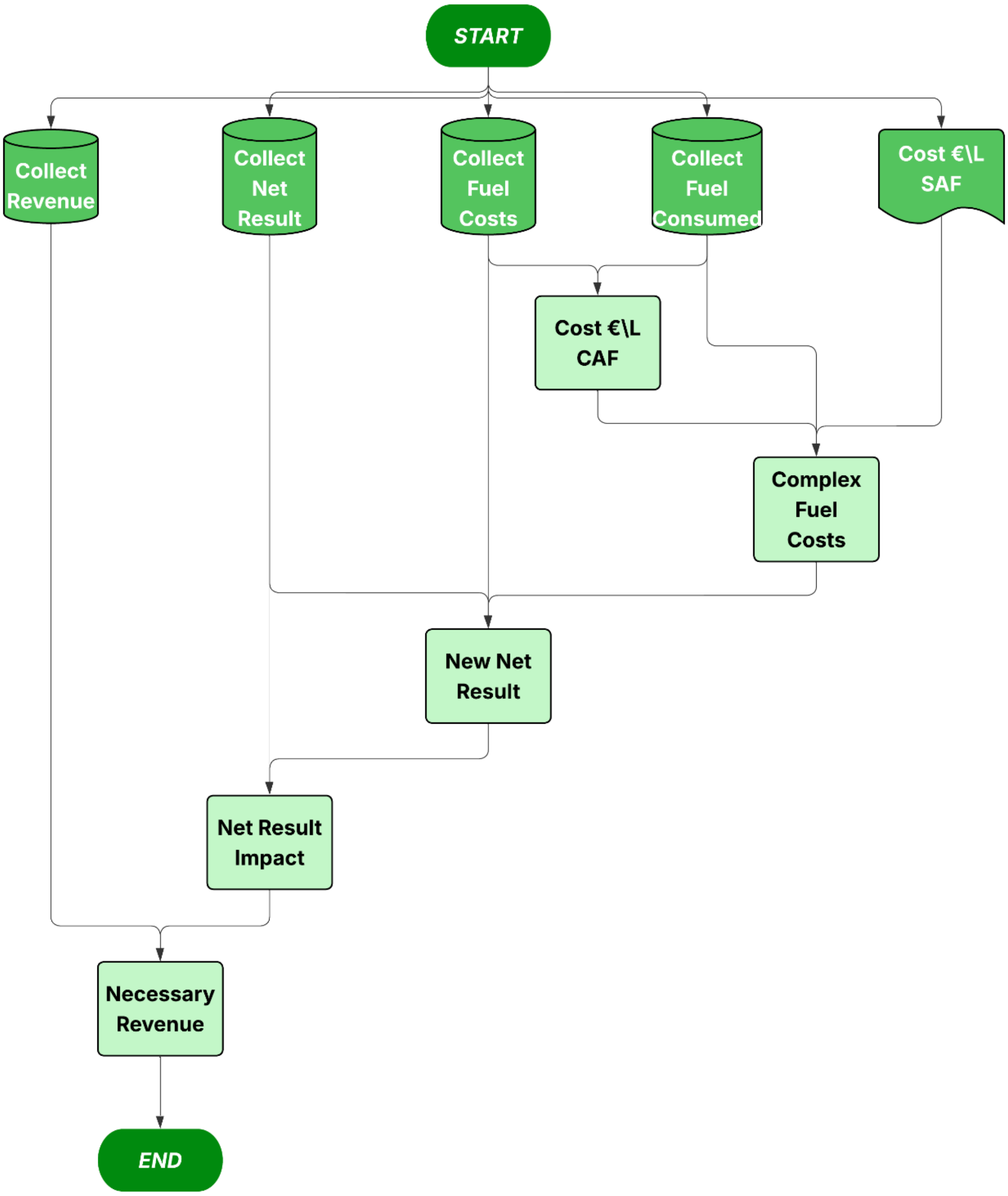

Figure 11 - Economic Impact Fluxgram
Source: Own Elaboration

Figure 11 illustrates a procedural and systems-oriented representation of the method used to quantify the economic repercussions of operating with SAF. This diagram reflects a structured Input-Process-Output (IPO) model, emphasising the causal relationships and data dependencies necessary for a robust economic impact assessment.

The process initiates at the START node and flows through the following stages:

1. Data Acquisition Phase: This phase comprises the systematic collection of primary financial variables that form the baseline for comparative analysis:
    a. Collect Revenue: The total operating revenue of the airline before SAF integration.
    b. Collect Net Result: The current net profit or loss derived under conventional operational conditions.
    c. Collect Fuel Costs: Total expenditure with CAF.
    d. Collect Fuel Consumed: Aggregate fuel volume consumed over the defined period.
    e. Cost €\L SAF: The unit cost of Sustainable Aviation Fuel.
2. Cost Modelling Phase: Utilising the collected data, the model proceeds to compute the revised fuel cost structure under SAF conditions:
    a. Cost €\L CAF: Refers to the unit cost negotiated by the airline procurement regarding the Conventional Aviation Fuel.
    b. Complex Fuel Costs: A composite metric aggregating bot SAF and CAF fuel costs, accounting for volumetric proportions and differentials in price per litre.
3. Impact Assessment Phase: Utilising the outputs from the phase mentioned before, it is now possible to assess the overall economic impact:
    a. Net New Result: Refers to the new Profit and Loss (P&L) of the airline, given that a new fuel cost scenario is being introduced into the analysis.
    b. Net Result Impact: A differential analysis between the initial and revised net results, reflecting the direct economic impact of SAF implementation.
    c. Necessary Revenue: A reverse-calculated threshold revenue required to restore the original net margin, providing a performance benchmark for subsequent strategy information.

The model concludes (END) upon determination of the necessary revenue, which feeds forward into the broader strategic model illustrated in Figure 10.

This workflow exemplifies a deterministic economic stimulation model, suitable for scenario analysis and sensitivity testing. Its modular design allows for dynamic parameter substitution, making it adaptable across various fleet sizes, fuel blend ratios, or cost environments.

Moreover, the approach aligns with corporate sustainability accounting practices, providing quantitative substantiation for environmentally driven decisions. By integrating Life-cycle Cost Analysis (LCCA) principles, the model enables management to assess long-term trade-offs between environmental responsibility and financial viability.

3.4.1.1. DATA ACQUISITION PHASE

To apply this model, the first phase involves data collection. The data that needs to be collected in this phase is listed in Table 14:

Table 14 - Data to Collect (Economic Impact Phase)
Source: Own Elaboration

	Airline
Fuel Costs	-€
Fuel Consumed (Ton)	0
Cost €\L SAF	-€
Revenue	-€
Net Result	-€

3.4.1.1.1. FUEL COSTS

As indicated in the Literature Review, the cost of fuel refers to all expenditures related to the purchase of aviation fuel.

Generally, two main factors drive the increase or decrease in fuel costs for an airline. The first factor is operational volume: the greater the number of flights or operations conducted by an airline, the higher its overall fuel consumption and, consequently, its fuel costs. The second factor relates to market volatility, as the price of crude oil, from which CAF is refined, is highly unstable and subject to frequent fluctuations.

Since this cost represents a significant portion of the operational expenses for most airlines, any reduction in its value will contribute to a more favourable net result. Conversely, an increase in this value can lead to more economic challenges for an airline.

The most appropriate method to retrieve the fuel costs of a given airline is through the analysis of the Annual Reports that all airlines publish.

Figure 12 illustrates the total expenditure on fuel costs for Delta Airlines from 1990 to 2024, providing a clear view of the evolution and trends of this component over the years. This historical perspective helps to understand better how fuel expenses have fluctuated.

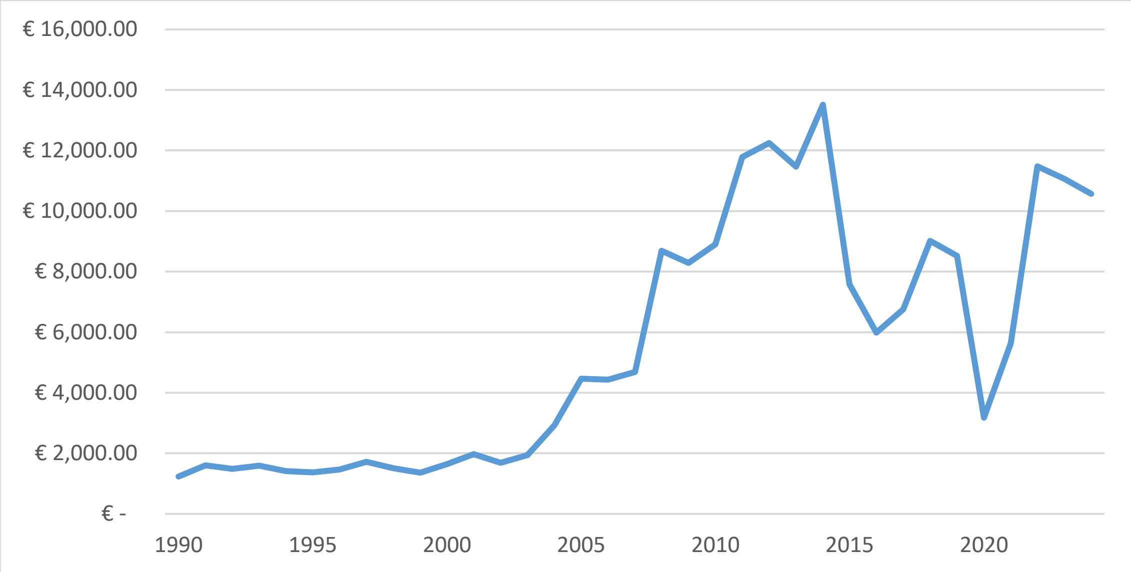

Figure 12 – Delta Airlines Fuel Costs (Million $)
Source – Own Elaboration (Based in the Annual Reports (Delta Airlines, 1994, 1995, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 1996, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2022a, 2022b, 2023, 1997, 2024b, 1998, 1999, 2000, 2001, 2002, 2003))

Over this extended horizon, fuel costs exhibit a general upward trend, punctuated by periods of pronounced volatility. The data reveal three main phases: a prolonged period of relative stability from 1990 to the early 2000s; a phase of accelerated cost increases and turbulence from 2004 to 2014; and finally, a period of extreme fluctuation and partial recovery from 2015 to the post-pandemic period.

During the initial period (1990-2003), fuel costs remained actively contained, fluctuating modestly around the $2 billion to $3 billion range. This phase of equilibrium can be attributed to several macroeconomic and operational factors, including the relatively low and stable price of crude oil following the resolution of the Gulf War, as well as a moderate global demand for aviation services in the pre-globalisation era. Additionally, the absence of significant regulatory pressures concerning carbon emissions allowed airlines to continue their operations with heavy reliance on CAF, without the burden of environmental compliance costs (Yergin, 2008).

The subsequent period (2004-2014) is characterised by a substantial escalation in fuel expenditure, which culminated in a peak surpassing $14 billion in the early 2010s. This steep increase is closely correlated with the rise in global oil prices driven by geopolitical instability, increased energy demand from rapidly industrialising economies, and speculative activities in global commodities markets (Hamilton, 2009). Notably, the 2008 financial crisis induced a temporary dip in fuel costs; however, this was followed by a swift recovery, evidencing the underlying volatility and sensitivity of fuel prices to macroeconomic disruptions. The peak observed between 2012 and 2014 likely reflects the confluence of elevated crude oil prices (Mead & Stiger, 2015), increased airline operations following the recession (Pearce, 2012), and the inherent inefficiencies of legacy aircraft models still present in Delta's fleet at the time (Delta Airlines, 2014).

From 2015 onwards, the data indicate a sharp and sustained decrease in fuel costs, with a nadir occurring around 2016. This reduction aligns with a significant global decline in oil prices, largely precipitated by overproduction by the Organisation of the Petroleum Exporting Countries (OPEC) (European Central Bank, 2016), the emergence of shale oil technologies in North America (Stocker et al., 2018), and broader market corrections. Despite a modest rebound in 2018 and 2019, the data suggest that Delta's fuel expenditures did not return to their earlier peaks, indicating improved fuel hedging strategies, increased operational efficiency, and investments in more fuel-efficient aircraft (Delta Airlines, 2018).

The most dramatic inflexion in Figure 12 occurs in 2020, reflecting the profound impact of the COVID-19 pandemic. With international travel severely restricted, global aviation plummeted, resulting in a precipitous decline in fuel consumption and expenditure (International Civil Aviation Organisation, 2024). This anomaly, although temporary, highlights the sector's extreme vulnerability to global systemic shocks. Following this collapse, a sharp recovery is observed beginning in 2021, as operations gradually resumed and global energy prices surged once more, particularly in the wake of the geopolitical instability introduced by the Russia-Ukraine conflict (International Energy Agency, 2022c). By 2022-2024, Delta's fuel costs once again approached levels exceeding $10 billion, evidencing both recovery in operations and renewed exposure to fuel price inflation.

From a strategic and economic standpoint, Figure 12 demonstrates the vulnerability of commercial airlines to exogenous fuel price shocks. It underscores the critical importance of effective risk management mechanisms, such as hedging instruments and operational efficiency programmes. More fundamentally, it presents a compelling case for accelerating the transition to SAF. While SAF is currently associated with a higher unit cost than CAF, its adoption may, over the long term, offer greater price stability and mitigate exposure to the volatility of fossil fuel markets (International Air Transport Association, 2023). Furthermore, the long-run benefits of SAF must be contextualised within the broader policy objectives of decarbonisation and carbon neutrality (World Economic Forum, 2021).

In conclusion, the evolution of Delta Airlines' fuel costs over the past three decades reflects the broader trends, pressures, and transitions within the global aviation industry. The data encapsulate the sector's economic sensitivity to oil price fluctuations, the disruptive impact of global crises, and the urgent need for a structural change. As fuel remains one of the most significant and volatile cost centres for airlines, the pursuit of sustainable, scalable, and resilient alternatives becomes not only an environmental imperative but also a strategic necessity.

3.4.1.1.2. FUEL CONSUMED

Due to the large scale of the aviation sector, it is expected that vast amounts of fuel are consumed annually during operations.

Three main drivers can significantly influence the total fuel consumption of an airline in any given year. These variables include the total number of flights operated, the nature of the flights – whether they are predominantly long-haul or short-haul operations – and the fuel consumption efficiency of the aircraft types in service.

The number of flights directly correlates with fuel usage, as a greater volume of operations naturally leads to higher consumption. Additionally, the nature of flights plays a crucial role, since long-haul flights, although generally more fuel-efficient per mile flown, involve much longer distances and therefore result in larger absolute fuel consumption. Finally, the aircraft's consumption rate is a determining factor, with new aircraft types typically offering improved fuel efficiency due to advancements in technology and sustainability efforts. In contrast, older and more depreciated aircraft types tend to have higher fuel consumption rates, thereby contributing to an overall increase in the airline's fuel expenditure.

Fuel consumption data for each airline can typically be found in their Annual Reports. These values are usually presented in tonnes or gallons, rather than litres, due to the large quantities involved.

Figure 13 illustrates the fuel consumption values over the years for United Airlines' operations from 1990 to 2024.

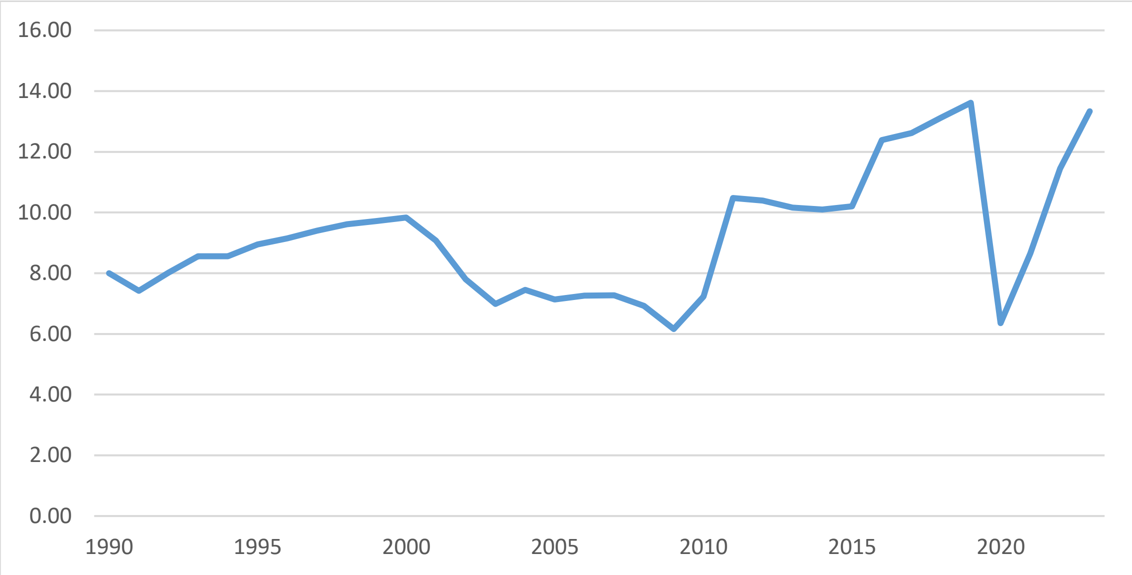

Figure 13 – United Airlines Fuel Consumed (Million Tons)
Source – Own Elaboration (Based in the Annual Reports (United Airlines, 1994, 1995, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 1996, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022b, 2023, 1997, 2024, 1998, 1999, 2000, 2001, 2002, 2003))

In the early 1990s, fuel consumption remained relatively stable, fluctuating around 8 million tons, followed by a gradual upward trend reaching close to 10 million tons by the late 1990s. This progressive increase may be attributed to a steady growth in operational activity and network expansion during that period (United Airlines, 1999).

Around the year 2000, a notable reduction in fuel consumption was observed, which continued through the early 2000s. This decline likely correlates with the industry contraction following the September 11 attacks, which had a profound impact on global air travel demand, resulting in fleet groundings, capacity reductions, and decreased aircraft utilisation rates (Cornwell & Roberts, 2010).

Between 2005 and 2010, fuel consumption stabilised at a lower plateau, indicating a period of consolidation during which United Airlines maintained a reduced but steady operational tempo, primarily influenced by the 2008 recession (Trefis, 2025).

From 2010 onwards, Figure 13 displays a significant inflexion point, with fuel consumption increasing sharply. This trend reflects a period of operational recovery and expansion, mainly driven by network growth strategies, increased aircraft block hours, and the addition of new routes and markets (Grimaldi, 2013). Between 2015 and 2019, consumption levels continued to rise, peaking around 14 million tons, consistent with a strong recovery phase and an aggressive fleet deployment strategy (United Airlines, 2019).

A dramatic decline is observed around 2020, corresponding to the COVID-19 pandemic, during which widespread flight suspensions, reduced Load Factors (LF), and operational standstills led to an unprecedented collapse in aviation demand, resulting in a greater need to consume fuel. Following this, starting in 2021, Figure 13 illustrates a steep recovery trajectory, with fuel consumption increasing rapidly. By 2024, consumption levels are approaching pre-pandemic figures, indicating that United Airlines has largely restored its operational capacity, with fleet reactivation, network restoration, and demand normalisation driving the recovery (United Airlines, 2024).

Overall, Figure 13 highlights the cyclical nature and sensitivity of fuel consumption patterns to external macroeconomic shocks, operational decisions, and global events, as well as the strategic responses taken by United Airlines across different periods.

3.4.1.1.3. COST €\L SAF

To later compare the costs, it is also necessary to determine the cost per litre of SAF. Since the SAF market is still somewhat undeveloped, with limited historical data, SAF prices fluctuate significantly, which may represent an additional risk for airlines considering its use. For this reason, determining a precise €\L value for SAF is challenging. However, the European Civil Aviation Conference (2023) conducted a study in which it developed a table listing the minimum selling prices of SAF per litre, making it possible to estimate the minimum impact an airline might expect when purchasing this alternative fuel. These minimum €\L SAF prices, along with a description of the composition of each SAF type studied, can be found in Table A 4. Additionally, this table includes pioneer values and nth values, which, according to the European Civil Aviation Conference (2023), serve as estimates for the current selling prices of SAF, as well as projections for potential future prices.

3.4.1.1.4. REVENUE

Revenue can be defined as the money generated from business operations and is often referred to by other terms, such as sales (Hayes, 2022). Normally, the revenue values for a given airline can be found in its published annual report. In the aviation sector, there are different types of revenue depending on the focus of the research.

On one hand, if the research focuses on airports, revenue can be divided into aeronautical revenue and non-aeronautical revenue (A. Zhang & Zhang, 2003). On the other hand, if the focus is on airline revenue, it can be categorised into various types, such as fare revenue and ancillary revenue, among others (Doganis, 2019). Additionally, for airlines that are part of a larger group, there can be even more ways to present and analyse their revenue streams. It is evident in the case of the Lufthansa Group, which structures its revenue across various segments, reflecting the diversity of its operations, as shown in Figure 14.

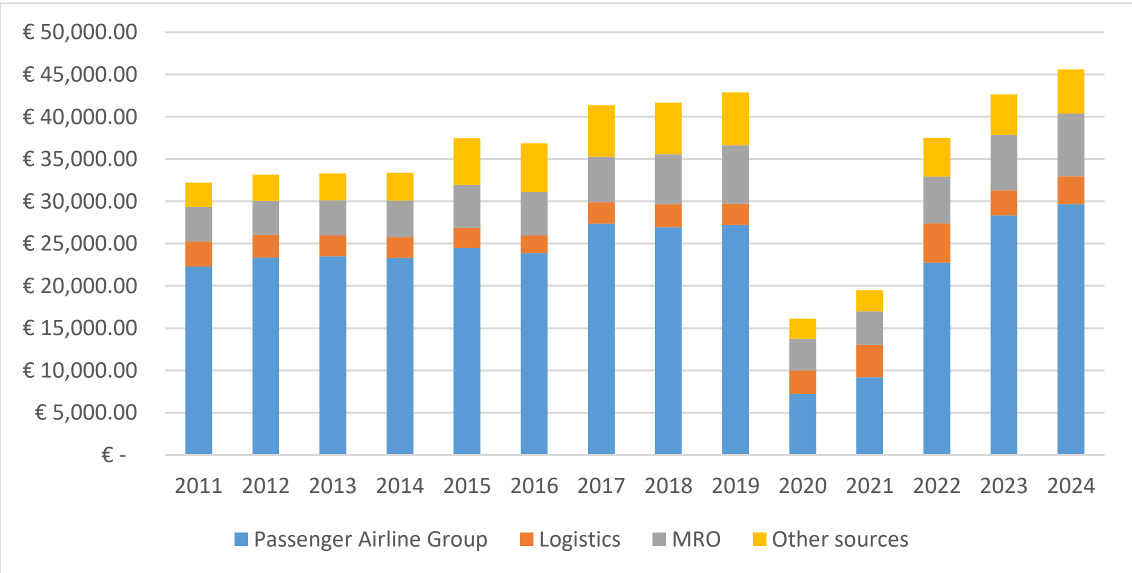

Figure 14 – Lufthansa Revenue by Business Segment (Million €)

Source – Own Elaboration (Based on the Annual Reports (Lufthansa, 2011, 2012, 2021, 2022, 2023, 2024, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020))

This segmentation reflects Lufthansa's diversified operational strategy and the relative contributions of each business unit to the group's financial performance (Lufthansa, 2024).

Between 2011 and 2019, the group experienced a steady growth trajectory, with total revenues increasing gradually from approximately 30 billion euros to nearly 45 billion euros. The Passenger Airline Group consistently represents the dominant revenue stream, reflecting Lufthansa's core activity in passenger transportation across both short-haul and long-haul markets (International Air Transport Association, 2019).

Throughout this period, Logistics (primarily Lufthansa Cargo) and MRO services (Lufthansa Technik) also contributed incrementally to the revenue base, demonstrating the group's strategic focus on diversification of income streams beyond passenger operations (Koch, 2025). Other sources, including catering, IT services, consulting, and other ancillary businesses, provided a smaller yet stable portion of the overall revenue.

In 2020, there was a severe contraction in revenue, dropping below 20 billion euros. This sharp decline aligns with the COVID-19 pandemic's impact, which led to unprecedented travel restrictions, fleet groundings, and a collapse in global passenger demand. The Passenger Airline Group was particularly affected, as reflected by the drastic reduction in its revenue contribution. However, it is noteworthy that Logistics revenues remained relatively resilient, highlighting the increased demand for cargo transport during the pandemic to support global supply chains, particularly for essential goods (Lufthansa, 2020).

From 2021 onwards, Figure 14 displays a robust recovery trend, with total revenues increasing progressively each year. By 2023 and 2024, the Lufthansa Group's revenues are projected to surpass pre-pandemic levels, reaching nearly 50 billion euros. The rebound in passenger traffic primarily drives this recovery, along with the restoration of flight schedules and sustained strength in cargo and MRO activities (Costanza & Prentice, 2021).

The segmental analysis underscores the critical importance of business diversification within the Lufthansa Group's strategy. While passenger transport remains the backbone, the contribution of Logistics and MRO services provided operational resilience during the economic downturn, mitigating some of the adverse effects from the passenger sector collapse.

Overall, the figure highlights the cyclical sensitivity of the aviation sector to external shocks and the vital role of operational flexibility, diversified revenue streams, and strategic business units in ensuring Lufthansa Group's financial stability and sustainable recovery trajectory.

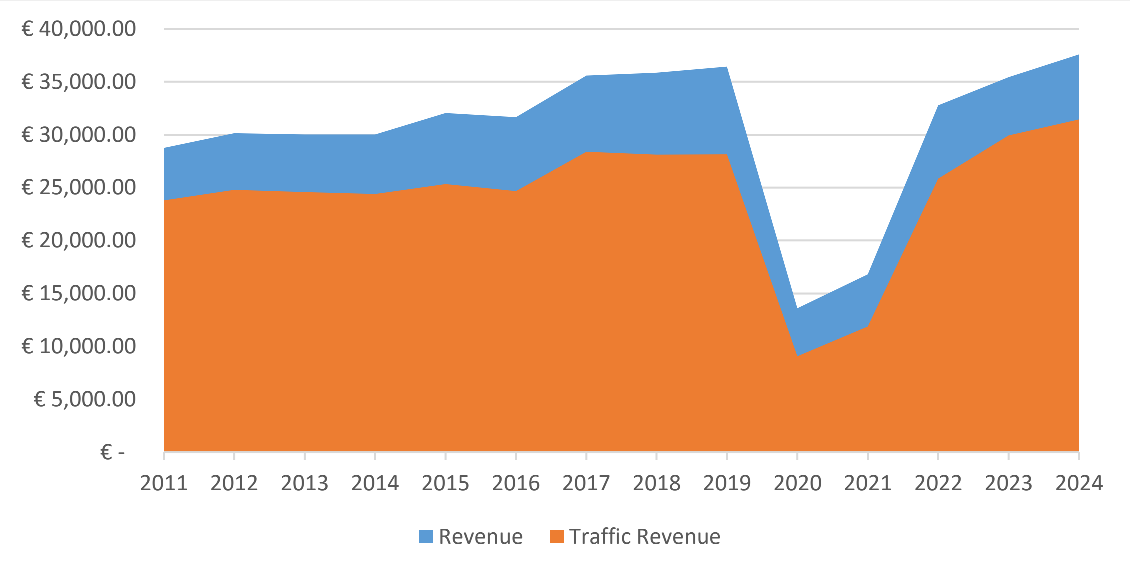

Figure 15 – Lufthansa Traffic Revenue Ratio (Million €)
Source – Own Elaboration (Based on the Annual Reports (Lufthansa, 2011, 2012, 2021, 2022, 2023, 2024, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020))

Figure 15 depicts the evolution of Lufthansa Group's revenue and Traffic Revenue, in million euros, spanning from 2011 to 2024. The values are segmented into Traffic Revenue (depicted in orange), which primarily encompasses revenue generated from passenger transport, and other revenue streams (shown in blue), reflecting ancillary and non-traffic-related income.

Between 2011 and 2019, Traffic Revenue consistently accounted for the majority of Lufthansa's total revenue, underscoring the centrality of core airline operations – passenger and freight transportation – to the group's business model. The overall trend across this pre-pandemic period is one of gradual and stable growth, in line with broader aviation market expansions and Lufthansa's strategic investments in fleet modernisation and network development (Lufthansa, 2019).

A market inflexion point occurred in 2020, where both total revenue and traffic revenue sharply plummeted, corresponding to the COVID-19 pandemic and the resulting collapse in air travel demand. The steep decline in Traffic Revenue highlights the severe operational disruptions caused by global travel restrictions, border closures, and reduced passenger confidence (International Civil Aviation Organization, 2023).

In 2021, a modest partial recovery was observed, followed by a more pronounced rebound from 2022 onwards, as vaccination rollouts, easing of restrictions, and pent-up travel demand facilitated a resurgence in both passenger and cargo operations. By 2023 and 2024, the data suggest that Lufthansa's revenue figures approach, though still slightly trail, pre-pandemic levels, with Traffic Revenue once again dominating the overall revenue structure (Air Transport Action Group, 2024).

A closer look at the proportionality between Traffic Revenue and total Revenue across the entire period reveals a relatively constant ratio, except during the 2020 disruption, when non-traffic revenue sources assumed greater relative importance, highlighting the group's resilience and diversification strategy in times of external shocks (Budd et al., 2020).

In summary, Figure 15 highlights Lufthansa's high dependence on traffic-related revenue, while also illustrating the cyclical vulnerability of airline traffic to global crises and the importance of non-traffic revenue streams as buffers against severe downturns. In the future, the trend supports the view that traffic revenue recovery is pivotal for the full financial normalisation of the Lufthansa Group.

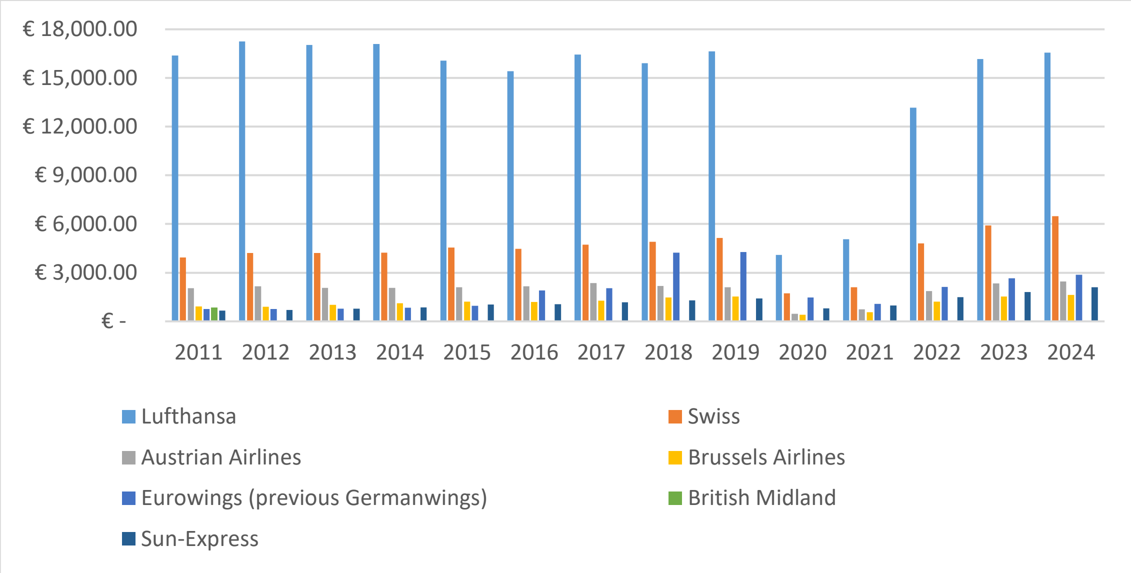

Figure 16 – Lufthansa Group Revenue by Airline (Million €)
Source – Own Elaboration (Based on the Annual Reports (Lufthansa, 2011, 2012, 2021, 2022, 2023, 2024, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020))

Figure 16 presents a longitudinal analysis of the Lufthansa Group's revenue disaggregated by individual subsidiaries – Lufthansa, Swiss, Austrian Airlines, Brussels Airlines, Eurowings (formerly Germanwings), British Midland, and SunExpress – covering the period from 2011 to 2024. The dataset illustrates not only the aggregate revenue contribution of each airline within the group but also the relative performance and strategic evolution of Lufthansa's multi-brand portfolio over time. This analysis offers key insights into the economic composition and diversification within the Group, as well as its resilience in the face of exogenous shocks such as the COVID-19 pandemic.

The primary observation is the persistent dominance of the Lufthansa mainline carrier (depicted in blue), which consistently generates the highest share of the group's revenue across all years. From 2011 through 2019, Lufthansa's revenue remained relatively stable, fluctuating between 15 and 17 billion euros, suggesting a mature and saturated market position. Despite minor year-on-year variations, the data confirm Lufthansa's status as the financial backbone of the group, reflecting its expansive route network, intercontinental capabilities, and premium service offerings (Lufthansa, 2019). Following the onset of the COVID-19 crisis in 2020, Lufthansa's revenue contracted sharply, plunging to under 6 billion euros in 2020. This contraction mirrors the broader collapse in international demand and border closures across all global markets. Notably, the recovery trajectory post-2021 is pronounced, with revenue steadily increasing year-on-year, reaching close to pre-pandemic levels by 2024 (International Civil Aviation Organization, 2021b). This rebound demonstrates the effectiveness of the Group's post-crisis recovery strategies, including capacity restoration, demand stimulation, and cost containment.

Swiss, the second-largest contributor throughout the timeline (represented in orange), consistently generated between 3 and 5 billion euros in annual revenue before the pandemic. Its relatively stable performance reflects the airline's strong positioning within the premium medium and long-haul European market (Centre for Aviation, 2025). Like Lufthansa, Swiss experienced a steep decline in 2020 and 2021, though it also showed signs of a robust recovery thereafter, indicating high elasticity of demand and operational efficiency.

Austrian Airlines and Brussels Airlines, while significantly smaller in scale, maintained modest and stable revenue streams throughout most of the pre-pandemic period. Austrian Airlines, in particular, sustained a revenue range between approximately 1 and 2 billion euros annually (Eurocontrol, 2021). Its comparatively muted growth suggests limited expansion capabilities and competitive constraints in its core Central European markets. Brussels Airlines exhibits a similar revenue profile, but with slightly more volatility. Both carriers experienced sharp revenue declines during pandemic years, with modest rebounds in the post-2021 period. Their slower recovery is highly attributed to market saturation and a constrained strategic importance within the group hierarchy.

Eurowings, including its historical operations under the Germanwings brand, presents a more dynamic pattern. Initially positioned as an LCC or hybrid carrier within the group's strategy, Eurowings underwent several phases of operational restructuring. Its revenue peaked around 2018 and 2019, corresponding with the Group's broader attempt to penetrate the budget travel segment (Lufthansa, 2019). However, since 2019, Eurowings has suffered a significant decline, with limited recovery visible through 2024. This underperformance indicates persistent operational challenges, poor differentiation in the low-cost market, and heightened competition from independent LCCs, which do not operate under an Airline-within-Airline (AwA) business model.

British Midland's revenue contribution ceases after 2012, reflecting the integration and dissolution of the brand following its acquisition and absorption by Lufthansa

(Lufthansa, 2012). This decline is consistent with the group's restructuring during the early 2010s, as it consolidated assets and focused on its core subsidiaries.

SunExpress, a joint venture with Turkish Airlines (SunExpress Airlines, 2025), contributes a minor but relatively consistent stream of revenue throughout the timeframe. While its figures remain below 1 billion euros annually, its stability suggests a sustained niche presence in leisure travel between Central Europe and Turkey.

The period from 2020 to 2021 marks a pronounced inflexion point across all carriers due to the unprecedented global disruption caused by the COVID-19 pandemic. Revenues across the board contracted sharply, with several airlines losing over half of their revenue base within a single fiscal year. This systemic shock exposed the group's vulnerability to global health crises and the extent of fixed-cost burdens in airline operations. Nonetheless, the subsequent years (2022-2024) display clear signs of recovery, albeit uneven across subsidiaries. The most rapid rebounds are observed in Lufthansa and Swiss, indicating the full-service flagship carriers were best positioned to capture returning demand. At the same time, regional and low-cost segments showed more sluggish returns, possibly due to shifting travel preferences or network rationalisations.

In strategic terms, Figure 16 highlights Lufthansa Group's heavy reliance on its primary brand for the majority of its revenue generation, while also underscoring the limitations of diversification within its broader airline portfolio. The relatively modest and stagnant performance of its smaller subsidiaries raises questions about their long-term viability and strategic purpose within the group's consolidated model. Furthermore, the experience of navigating the COVID-19 downturn and recovery phase demonstrates the critical importance of operational scalability, cost discipline, and brand resilience in responding to systemic shocks.

In conclusion, the longitudinal revenue data from 2011 and 2024 encapsulate the Lufthansa Group's strategic evolution, crisis responsiveness, and brand hierarchy. Figure 16 not only reflects performance metrics but also offers a window into deeper structural dynamics affecting the airline group model in a post-pandemic world. For future strategic positioning, greater attention to adaptability, digital transformation, and sustainable practices will be imperative to secure revenue stability and competitive advantage in an increasingly volatile aviation environment.

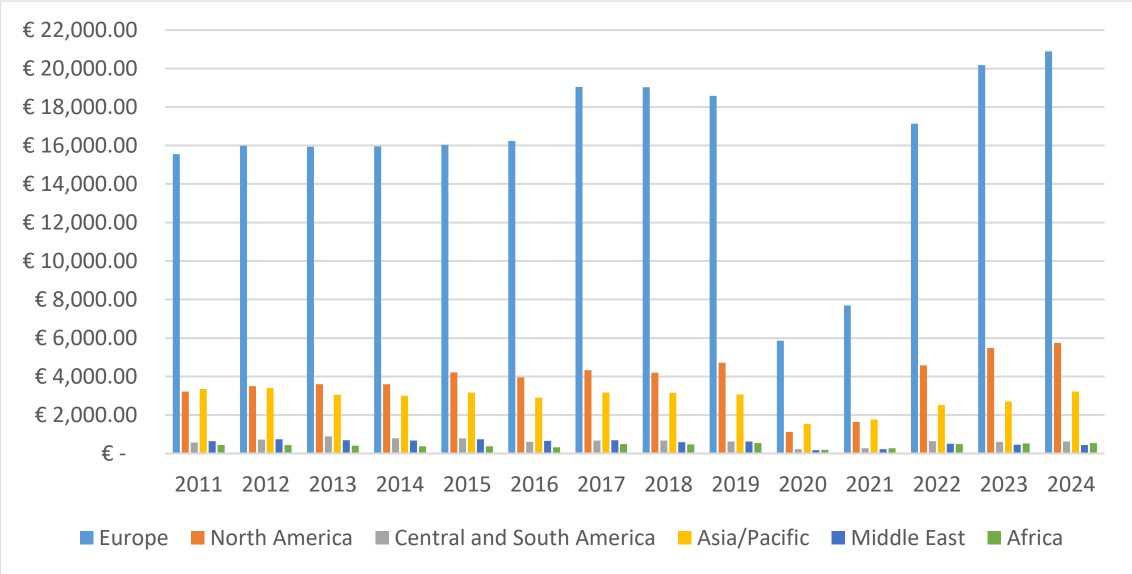

Figure 17 – Lufthansa Group Revenue by Region (Million €)
Source – Own Elaboration (Based on the Annual Reports (Lufthansa, 2011, 2012, 2021, 2022, 2023, 2024, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020))

Figure 17 presents a regional breakdown of Lufthansa Group's revenue generation from 2011 to 2024, detailing performance across six geographical markets: Europe, North America, Central and South America, Asia/Pacific, the Middle East, and Africa. Figure 17 highlights the group's spatial revenue concentration and the temporal shifts in geographic demand patterns, providing critical insights into Lufthansa's international exposure, market dependency, and regional resilience, particularly in response to macroeconomic and epidemiological disruptions.

Europe, as the group's primary operational and commercial base, predictably dominates the revenue structure. Throughout the pre-pandemic period (2011-2019), European revenue remained relatively stable, ranging from approximately € 15 billion to € 18 billion annually. This consistent performance illustrates the significance of intra-European connectivity within Lufthansa's network strategy, as well as the market maturity and saturation characteristics of the continent's aviation sector. Notably, the peak observed in 2018 and 2019 is attributable to optimal capacity utilisation, strong economic conditions in the Eurozone, and heightened business travel demand (Lufthansa, 2019). The revenue sharply contracted in 2020, coinciding with COVID-19-induced lockdowns and airspace restrictions, before exhibiting a pronounced recovery trajectory from 2021 onwards. By 2024, European revenue had surpassed 20 billion euros, exceeding pre-pandemic levels, a reflection of effective operational recalibration and the recovery of pent-up demand in short- and medium-haul travel segments.

North America (NA) is Lufthansa's second most lucrative regional market. The relatively high and increasing revenue from this region reflects the strength of transatlantic operations and the importance of Lufthansa's codeshare agreements and joint ventures, particularly with United Airlines and Air Canada under the Atlantic Joint Venture (Lufthansa Group, 2025). From 2011 to 2019, revenues from NA steadily increased, signalling growing demand for intercontinental travel and sustained corporate mobility between key hubs such as Frankfurt, Munich, New York, and Chicago. As with Europe, NA revenue contracted significantly in 2020 and 2021 but demonstrated a sharp rebound thereafter. By 2024, revenue from this region reached approximately 6 billion euros, underscoring the robustness of the transatlantic corridor and its role as a strategic pillar in Lufthansa's long-haul network.

The Asia/Pacific (APAC) region maintained a moderate but strategically vital position in the revenue portfolio. Despite its relatively lower absolute figures – ranging between 1.5 billion and 3 billion euros pre-pandemic – this region offers high-yield routes driven by business traffic, particularly to China, Japan, and Southeast Asia. However, recovery post-2020 appears more subdued compared to Europe and NA, due to prolonged border restrictions, lagging vaccination campaigns, and geopolitical uncertainties in Asia. This slower rebound highlights the region's vulnerability to external shocks and the need for adaptive capacity planning.

Central and South America (CASA) consistently provided a modest contribution to total revenue. The data reflect limited market penetration in this region, due to structural factors such as regulatory barriers, economic volatility, and a fragmented aviation landscape. However, the relative stability of revenue figures suggests a niche yet consistent demand base, primarily driven by Visiting Friends and Relatives (VFR) traffic and point-to-point operations to key cities such as São Paulo, Buenos Aires, and Mexico City.

The Middle East and Africa (MEA) remain the least significant contributors in absolute terms, generating below 1 billion euros annually for most of the observed period. These figures reflect Lufthansa's relatively limited network in these regions, the dominance of regional competitors such as Emirates and Qatar Airways, as well as geopolitical instability. Nevertheless, the revenue remained remarkably stable throughout the period, indicating a resilient albeit marginal role in Lufthansa's global network.

The most striking inflexion point across all years is 2020, corresponding to the onset of the COVID-19 pandemic. Revenue fell precipitously across all geographies, with Europe and NA experiencing the most pronounced absolute declines. This systemic disruption underscores the aviation sector's acute sensitivity to global crises, particularly those affecting mobility and border policies. However, the recovery patterns differ: while Europe and NA rapidly regain lost ground, APAC and other emerging markets display a more gradual return to growth, suggesting asymmetries in recovery momentum and demand elasticity.

Strategically, the data illustrate Lufthansa Group's strong dependency on European and North American markets, which together account for the overwhelming majority of total revenue. This concentration implies both a strength, in terms of network coherence and market familiarity, and a potential weakness, given the susceptibility to bilateral travel restrictions and macroeconomic dependencies. The relatively stagnant performance in emerging markets may signal underexploited growth potential or the need for refined market entry and expansion strategies.

In sum, Figure 17 provides a comprehensive regional perspective on Lufthansa Group's revenue architecture. It highlights not only the group's historical and projected market distribution but also reveals underlying strategic imperatives, such as the importance of geographical diversification, the necessity for adaptive capacity deployment, and the continued significance of core intercontinental markets in sustaining revenue resilience. The post-pandemic recovery pattern underscores the importance of agility in network planning and the integration of real-time geopolitical and public health risk assessments into strategic decision-making.

3.4.1.1.5. NET RESULT

The net result is the final figure in the income statement, representing revenue minus operating costs, plus financial and extraordinary results, after tax deductions (DECO, 2023). Another definition of Net Result suggests that it is the amount left after subtracting necessary costs and taxes on profits, which is then distributed according to the decision of shareholders (Quintaneiro, 2007). The Net Result can be positive, negative, or zero, corresponding to profit, loss, or a break-even result, respectively. The Net Income of an airline is typically published in its annual financial reports.

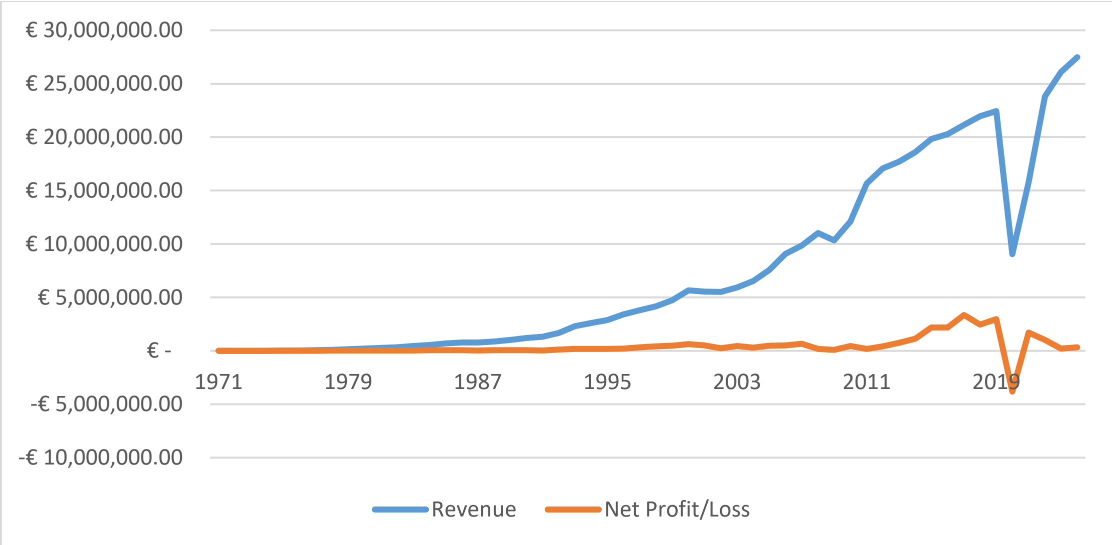

Figure 18 – Southwest Airlines Revenue and Net Result (Million $)
Source – Own Elaboration (Based on the Annual Reports (Southwest Airlines, 1971, 1972, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1973, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 1974, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 1975, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 1976, 2021, 2022, 2023, 2024, 1977, 1978, 1979, 1980))

Figure 18 illustrates the historical trajectory of Southwest Airlines' revenue and net profit/loss from its founding in 1971 through 2024. The visualisation traces the evolution of the carrier's financial performance over more than five decades, highlighting the interplay between topline growth and bottom-line profitability. The figure provides a macroeconomic and strategic lens through which to assess Southwest's operational resilience, cost structure efficiency, and crisis management capability.

The revenue curve (blue line) demonstrates a clear and sustained upward trend, especially pronounced from the early 1990s onward. This exponential growth reflects Southwest's successful execution of a LCC model, grounded in operational simplification, rapid aircraft turnaround, point-to-point routing, and cost discipline. The initial decades (1971-1990) show modest but steady growth, commensurate with network expansion primarily within Texas and the US Southwest region. The revenue acceleration that began in the late 1990s corresponds with an aggressive fleet growth, market liberalisation, and network expansion into new US states.

Between 2001 and 2019, Southwest's revenue grew markedly, rising from below $ 6 billion to $ 20 billion, supported by a scalable operating model, fuel hedging strategies, and high aircraft utilisation. This period also includes resilience in the face of major exogenous shocks, such as the 9/11 terrorist attack and the 2008 financial crisis, with no major revenue collapses observed. The steep revenue contraction in 2020 aligns with the onset of the COVID-19 pandemic, marking the most significant YoY decline in the airline's history. The sharp drop, amounting to nearly 60%, exemplifies the global aviation industry's vulnerability to systemic crises. However, the rapid revenue recovery observed in the subsequent years, culminating in a projected peak above 28 billion dollars by 2024, is indicative of a strong bounce-back, driven by domestic travel demand, cost containment, and Southwest's positioning as a predominantly domestic carrier less exposed to international travel restrictions.

The net profit/loss line (orange) provides additional granularity into Southwest's fiscal wealth. From the early 1980s through 2019, Southwest maintained a rare streak of sustained profitability, a unique feature among global carriers. This consistency highlights superior cost control, robust demand forecasting, and effective yield management. Margins remained positive even during periods when other carriers posted significant losses, particularly in the aftermath of 9/11 and during the 2008-2009 global recession. Notably, the net result remained relatively stable compared to revenue volatility, indicating a resilient cost base.

The exception to this trend occurs in 2020, where the net result turns sharply negative, coinciding with the revenue collapse during the COVID-19 crisis. The recorded loss exceeds $ 3 billion, reflecting an unprecedented operational disruption and the erosion of fixed-cost leverage inherent in airline economics. Despite a partial recovery in revenue by 2021 and 2022, profitability remained volatile, with net results oscillating between modest gains and continued deficits. It reflects lingering cost pressures, capacity management challenges, and demand unpredictability. However, projections for 2023 and 2024 show a stabilisation trend, suggesting a return to pre-pandemic profitability levels, albeit with lower margins than during peak performance years.

Strategically, Figure 18 validates Southwest's reputation as one of the most financially disciplined and operationally stable airlines in the US market. The divergence between revenue and profit lines in recent years serves as a cautionary indicator of structural pressures in the post-pandemic aviation economy, particularly in terms of labour costs, fleet renewal needs, and sustainability investments. Moreover, the airline's resilience is likely supported by its simplified operations, absence of overexposure to international volatility, and a loyal domestic customer base.

In conclusion, Figure 18 encapsulates Southwest Airlines' growth narrative from a regional operator to one of the world's most successful low-cost carriers. The sustained upward revenue trajectory – interrupted only by major crises – alongside historically stable profitability, testifies to the robustness of its business models. Nevertheless, the post-2020 profit fluctuations reveal the increased fragility of even the most stable carriers in the face of global disruptions, underscoring the need for agility, digital transformation, and continued operational efficiency in maintaining long-term financial health.

3.4.1.2. COST MODELLING PHASE

In this phase, based on some of the values previously obtained, the modelling of the new costs will be carried out before advancing to the subsequent Impact Assessment Phase. During this stage, the following values in Table 15 will be calculated:

Table 15 - Calculations to Perform (Cost Modelling Phase)
Source: Own Elaboration

	Airline
Cost €\L CAF	-€
Complex Fuel Costs	-€

3.4.1.2.1. COST €\L CAF

To determine the average cost per litre at which a given airline acquired CAF, it is necessary to gather the two previously mentioned data points—first, the cost of the fuel consumed, and second, the amount of fuel consumed.

To convert the quantity from tonnes to litres, Equation (1) can be used: Litres Consumed (1):

$$Liters\ Consumed\ CAF(l) = \frac{Fuel\ Consumed}{Density\ \times 0.001} \tag{1}$$

The density must be presented in g/cm3, and according to Regulation (EU) No 601/2012, the standardised density of CAF is 0.8 g/cm3 (European Union, 2012)

By obtaining the quantity of fuel consumed in litres by the airlines and the total fuel expenditure, it is possible to determine the Cost per Litre of CAF (Cost €\L CAF) using the following Equation (2):

$$Cost\ €\backslash L\ CAF\ (€) = \frac{Fuel\ Costs}{Liters\ Consumed\ CAF} \tag{2}$$

3.4.1.2.2. COMPLEX FUEL COSTS

To determine the regular Fuel Costs (€) for a given airline, as expressed in Equation (3), two primary data points are required. First, considering that the proportion of SAF currently consumed by the airline is negligible and can therefore be excluded from the calculation, it becomes essential to obtain the Cost €\ LCAF (€), as defined in Equation (2). Second, the total volume of Litres Consumed CAF (l), Equation (1), during the specified period must also be known. These two variables – unit cost and total volume – form the basis for accurately modelling the CAF expenditure over the given timeframe.

Therefore, the Fuel Costs (€), Equation (3), can be calculated using the following formula:

$$Fuel\ Costs\ (€) = €\backslash L\ CAF \times Liters\ Consumed\ CAF \tag{3}$$

From the application of Equation (3), it becomes possible to determine the total Fuel Costs (€) incurred by an airline. However, given that this research extends the analysis to include an additional type of fuel, it is necessary to expand the initial model to accommodate the economic implications of operating with a dual-fuel strategy. In this context, the formulation must evolve to enable the calculation of Complex Fuel Costs (€), as outlined in Equation (4), which encompasses expenditures associated with both CAF and SAF.

To accurately estimate these Complex Fuel Costs (€), four key variables must be obtained. These include the Cost €\L CAF (€), as detailed in Equation (2), and the total volume of Litres Consumed of CAF (l) during the period of the analysis. In parallel, it is essential to use the Cost €\L SAF (€) information, derived from market values or estimated through official databases, such as those listed in Table A4, and the total volume of Litres of SAF consumed, which is determined based on Equation (1). The volume of SAF and CAF consumed by an airline is not constant, but rather contingent upon the proportion of SAF the carrier elects to incorporate into its fuel mix. Several factors, including regulatory constraints, environmental targets, fuel availability, and cost considerations, influence this decision. From a regulatory standpoint, current international standards typically permit a SAF blending ratio of up to 50% in conventional aircraft fuel tanks. Notably, exceptions exist, such as the Synthetised Iso-Paraffins (SIP) transformation pathway, which, due to its specific chemical and certification limitations, is generally restricted to a maximum blend of 10%. Therefore, to determine the "new fuel costs" – Complex Fuel Costs (€), Equation (4) – that include either CAF and SAF consumption, Equation (4) can be used. For this, airlines need to properly determine the amount/representation of SAF and CAF in their consumption plans.

$$Complex\ Fuel\ Costs\ (€) = (€\backslash L\ CAF \times Liters\ Consumed\ CAF)\ (€\backslash L\ SAF \times Liters\ Consumed\ SAF) \quad (4)$$

3.4.1.3. IMPACT ASSESSMENT PHASE

This phase involves determining the assessment of the economic impact. For this, either previously collected and calculated data will be needed. In this Impact Assessment Phase, the following values in Table 16 will be calculated:

Table 16 - Calculations to Perform (Impact Assessment Phase)
Source: Own Elaboration

	Airline
New Net Result	-€
Net Result Impact	-€
Necessary Revenue	-€

3.4.1.3.1. NEW NET RESULT

The Net Result reported by airlines typically encompasses, among other elements, fuel-related expenditures. However, the Net Result conventionally disclosed by the airlines does not incorporate the "new" fuel costs integration – Complex Fuel Costs, Equation

(4) – introduced by the integration of SAF into their regular operations, a central focus of this research. This discrepancy primarily stems from the fact that, despite growing regulatory and societal pressure for decarbonization, SAF usage remains marginal and is not yet systematically reflected in some financial statements or traditional cost structures.

To address this analytical gap, this research introduces the concept of the New Net Result, which can be viewed as an Adjusted Net Result or Revised Net Result, as presented in Equation (5). This revised metric provides a more comprehensive representation of the airline's economic performance in the context of evolving sustainability practices. Specifically, the New Net Result is calculated based on three critical inputs: the company's actual reported net income, the total fuel cost under current operations, and the Complex Fuel Costs (€), as outlined in Equation (4), which accounts for a blended scenario that includes both CAF and SAF. What this Equation (5) intends to do is to erase the previous fuel costs, and instead include the Complex Fuel Costs (€), that take into account SAF incorporation, so that the New Net Result (€) is determined:

$$New\ Net\ Result\ (€) = Net\ Result + Fuel\ Costs - Complex\ Fuel\ Costs \tag{5}$$

3.4.1.3.2. NET RESULT IMPACT

Net Result, as previously defined, results from the subtraction of a company's total costs and tax obligations from its total revenues. In the context of this investigation, it is assumed that the integration of SAF into an airline's operations leads to a structural modification of the fuel cost component. Consequently, if all other financial variables – particularly revenue – remain constant, an increase in fuel-related expenditures due to SAF adoption is expected to exert a negative pressure on the airline's P&L.

To quantify this economic effect, this research introduces the concept of Net Result Impact, described in Equation (6). This metric is derived by calculating the difference between the New Net Result (as determined in Equation (5), incorporating the costs of a dual-fuel scenario) and the reported Net Result of the airline. The resulting value captures the immediate economic burden associated with SAF integration, providing a straightforward yet critical insight into the operational feasibility of sustainable fuel strategies. The Net Result Impact, Equation (6), can be determined using the following formula:

$$Net\ Result\ Impact\ (€) = Net\ Result - New\ Net\ Result \quad (6)$$

To contextualise the magnitude of this impact, a complementary measure is proposed: the Percentage Variation in Net Result (%), as represented in Equation (7). This indicator represents the relative deviation between conventional and adjusted net result values, providing a normalised view of economic distortion. Such a metric is especially relevant for cross-company or cross-scenario comparisons, as it allows decision-makers to evaluate proportional impacts irrespective of firm size or absolute income results. This Percentage Variation in Net Result (%) can be determined using the formula below:

$$\Delta\% = \left| \frac{(Net\ Result - New\ Net\ Result)}{Net\ Result} \right| \times 100 \quad (7)$$

Altogether, this dual-layered approach to impact analysis, through both absolute and relative metrics, not only enhances the granularity of the financial evaluation but also aligns with best practices in sustainability-oriented managerial accounting, where nuanced trade-offs between ecological responsibility and economic performance must be transparently assessed and effectively communicated.

3.4.1.3.3. NECESSARY REVENUE

To fully offset the economic impact previously calculated, stemming from the integration of SAF into regular operations, airlines must strategically increase their total revenue. This adjustment becomes an economic imperative when seeking to maintain pre-SAF levels of profitability, particularly Net Result, despite the incremental cost burden introduced by the adoption of sustainable fuels.

To determine the Necessary Revenue (€), Equation (8), that must be generated to neutralise the adverse economic effect of SAF-related operational costs on Net Result, Equation (8) is introduced. This formulation necessitates two critical data inputs: the airline's current Ticket Revenue figure and the previously calculated Net Income Impact, derived in Equation (6).

$$Necessary\ Revenue\ (€) = Revenue + |Net\ Result\ Impact| \quad (8)$$

The underlying logic of this calculation is based on the fundamental principles of economic equilibrium. That is, any increase in cost – in this case, attributable to the premium associated with SAF procurement – must be offset by a commensurate rise in revenue to preserve economic performance indicators at baseline levels. The model assumes a *ceteris paribus* condition, whereby all other cost categories, operational efficiencies, and market variables remain constant, isolating the SAF effect for analytical precision.

Moreover, Equation (8) serves not merely as a backwards-looking accounting adjustment, but rather as a forward-looking managerial tool. It informs strategic decision-making by quantifying the exact revenue target necessary for economic sustainability under environmentally sustainable operations. Such insights are particularly relevant for route planning, fare structuring, or ancillary service deployment, where marginal gains in revenue can effectively offset the cost premium of low-carbon aviation fuel.

Ultimately, the Necessary Revenue, as indicated in Equation (8), serves as a cornerstone in reconciling sustainable aviation initiatives with economic viability, aligning corporate environmental responsibility with the imperatives of competitive economic performance.

3.4.2. SOLUTIONS

Given that SAF currently lacks economic viability due to its significantly higher cost compared to CAF, the SeCA Model introduces a strategic framework comprising three potential solution pathways aimed at neutralising the resulting financial impact. These pathways are designed to reconcile the pursuit of environmental sustainability with the need to maintain economic equilibrium in airline operations.

Central to this approach is the concept of Necessary Revenue, as quantified in Equation (8), which represents the minimum income required to offset the cost differential introduced by integrating SAF. Building upon this calculation, the model conceptualises a set of interconnected solutions intended to restore the airline’s Net Result to its pre-SAF levels.

The following flowchart presents the proposed solutions in a structured, systems-oriented format. Each solution is rooted in operational and economic levers that airlines can manipulate, either independently or in combination, to bridge the profitability gap caused by the adoption of SAF.

Importantly, the model does not treat these options as isolated fixes but rather as components of a dynamic decision-support system that can be tailored to the strategic context and resource capabilities of each airline. By integrating the principles of systems engineering and sustainable operations management, the SeCA Model enables an iterative and data-driven approach to aligning environmental objectives with economic sustainability in the evolving commercial aviation landscape.

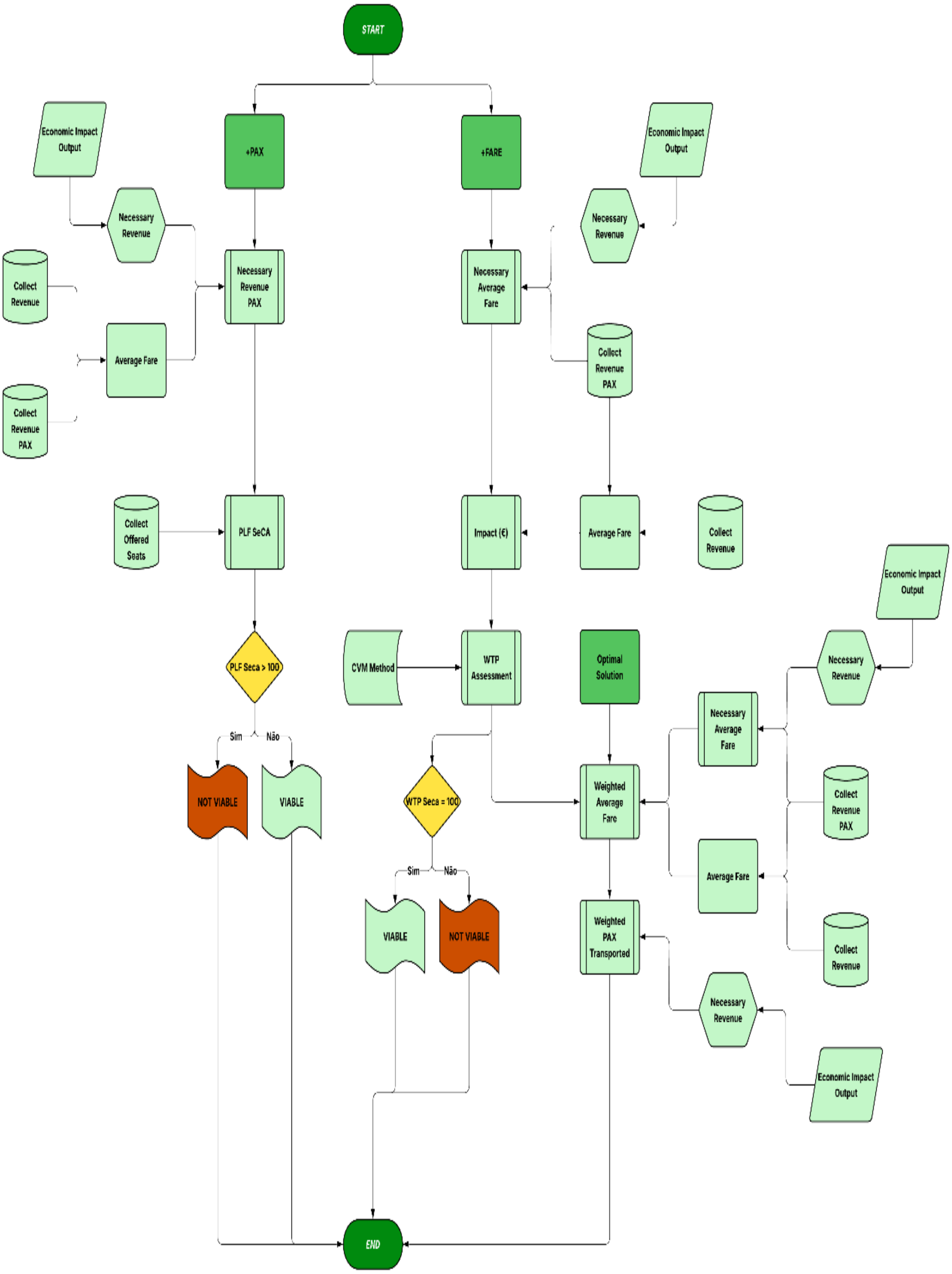

Figure 19 - Solutions Fluxgram
Source: Own Elaboration

Figure 19 outlines a decision-support framework designed to assist aviation stakeholders in identifying viable economic strategies to offset the economic impact of integrating SAF. This figure builds directly on the economic output derived in Figure 11, transitioning from assessment to action by presenting three possible corrective paths:

1. Increasing the Number of Transported Passengers (+PAX).
2. Increase the Average Fare value (+FARE).
3. Optimal Solution Optimisation Strategy.

The passenger growth path begins by evaluating the feasibility of offsetting SAF-related cost increases through expanded traffic. By firstly estimating the volume of passengers required to restore pre-SAF profitability, and secondly calculating the PLF SeCA, which represents the occupancy rate necessary across available seats, a logical checkpoint then assesses whether the required load factor exceeds operational capacity, most critically, a 100% capacity threshold. If the PLF SeCA is greater than 100%, the scenario is automatically deemed unviable, as it suggests a requirement for more passengers than physically possible. Conversely, a PLF SeCA at or below 100% signals that increased demand or more efficient use of existing capacity could feasibly bridge the economic gap. This path is particularly relevant for carriers operating below capacity or in markets with latent demand.

The average adjustment path examines the potential for price optimisation as a means to achieve financial balance. This approach calculates the necessary average fare that would generate the targeted revenue while holding passenger numbers constant. However, fare sensitivity poses a significant risk, especially in price-competitive or elastic markets. To address this, the model integrates a WTP assessment through the CVM, a standard approach in transport economics for evaluating customer acceptance of price changes. The resulting metric, WTP SeCA, is benchmarked against a threshold, typically 100%, to assess its viability. If customers' perceived value supports the increased fare, the strategy is deemed feasible. If not, the price increase is considered unsustainable, indicating a high likelihood of reduced demand or reputational loss.

The third path – Optimal Solution – takes a systems-oriented approach by simultaneously adjusting both fare and passenger volume. This hybrid strategy incorporates an iterative feedback loop that dynamically balances pricing and traffic levels to reach an optimal revenue outcome. It calculates a weighted average fare and weighted number of transported passengers to derive the most efficient combination of both levers. This method is particularly powerful because it recognises the non-linear interdependencies between variables: small fare increases might be acceptable if accompanied by modest passenger growth, and vice versa. The iterative nature of this solution introduces an adaptive layer of decision-making, where each adjustment informs the next, echoing the principles of dynamic systems modelling.

The structure of the framework includes both quantitative parameters, such as cost per passenger, load factor, and total revenue, and qualitative considerations, like customer sentiment, brand perception, and regulatory acceptance. These blended metrics allow decision-makers to go beyond purely economic calculations, considering the broader operational and reputational implications of SAF adoption.

The model's architecture also embodies the concept of feedback loops, commonly found in systems thinking, by allowing for scenario re-evaluation based on actual performance outcomes. For instance, if a fare adjustment initially results in a passenger loss, the system can recalibrate by exploring new fare-volume combinations or integrating real-time elasticity data. This adaptability is crucial in the dynamic context of aviation, where external factors such as fuel price volatility, competitor behaviour, and environmental regulations evolve rapidly.

Moreover, the framework aligns closely with the principles of sustainable operations management. It encourages strategic decisions that do not merely shift economic burdens but actively seek to harmonise environmental goals with economic discipline. By framing the economic impact of SAF as a solvable design problem, rather than a fixed constraint, the model promotes proactive rather than reactive planning.

In essence, Figure 19 transforms the abstract challenges of SAF economic viability into a set of concrete, evaluable paths – each embedded with operational, economic, and behavioural considerations. It is not prescriptive but explanatory, empowering stakeholders to stimulate outcomes, assess feasibility, and make informed, flexible decisions that align with both sustainability commitments and economic imperatives.

3.4.2.1. INCREASE THE NUMBER OF TRANSPORTED PASSENGERS (+PAX)

For the +PAX solution, the idea is to achieve the Necessary Revenue by increasing the Number of revenue passengers while maintaining the Average Fare of the airline.

3.4.2.1.1. DATA ACQUISITION PHASE

As in previous phases of the SeCA Model, before initiating the computational procedures and subsequent evaluation phase, it is essential to gather a specific set of foundational data inputs. These values serve as critical parameters for the forthcoming calculations and are essential for ensuring both the accuracy and relevance of the resulting metrics.

In this case, the data values that need to be collected are listed in Table 17:

Table 17 - +PAX Data to Collect
Source: Own Elaboration

	Airline
Necessary Revenue (€)	-€
Number of Revenue Passengers	0
Average Fare (€)	-€
Number of Seats Offered	0
Passenger Load Factor (%)	%

3.4.2.1.1.1. NECESSARY REVENUE

The value of the Necessary Revenue can be obtained by successfully completing the prior SeCA Model phases.

3.4.2.1.1.2. NUMBER OF REVENUE PASSENGERS

The Number of Revenue Passengers refers to the total number of passengers carried by a specific airline over a given period. In this context, the figure to be collected is the number of paying passengers, also referred to as revenue passengers. This is essential for accurately calculating the average fare, as only the number of purchased tickets should be considered, not the number of occupied seats. The Number of Revenue Passengers is normally presented in the annual reports of the airlines.

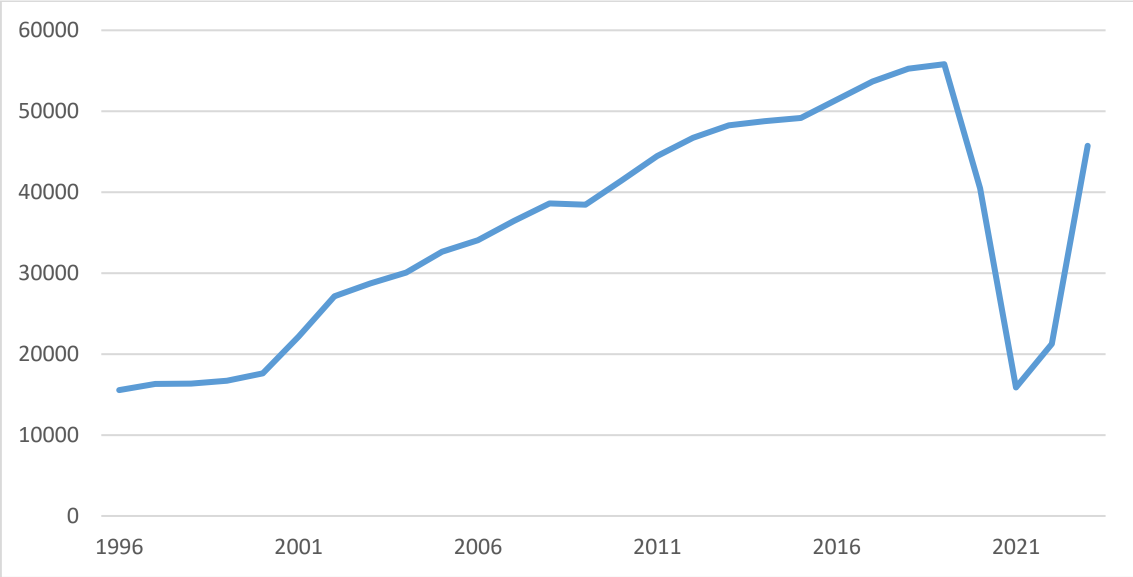

Figure 20 - Qantas Number of Revenue Passengers (in 000')
Source - Own Elaboration (Based on the Annual Reports (Qantas, 1999, 2000, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2001, 2019, 2020, 2021, 2022, 2023, 2002, 2003, 2004, 2005, 2006, 2007, 2008)

Figure 20 illustrates the annual number of revenue passengers carried by Qantas from 1996 to 2023, providing a longitudinal perspective on the airline's operational scale and market recovery following major industry disruptions.

The trajectory from 1996 to 2019 reveals a consistent upward trend in passenger numbers. Starting at approximately 16 million revenue passengers in the late 1990s. Qantas experienced steady YoY growth over the next two decades, peaking at nearly 60 million passengers in 2018-2019. This period coincides with Australia's sustained economic expansion, growing outbound tourism, and Qanta's strategic investments in fleet modernisation and international partnerships. The growth also reflects capacity increases across both domestic and international networks, including the integration of Jetstar on an AwA model, and the development of long-haul and ultra-efficient routes.

The relatively smooth progression through early crises – including the 2001 terrorist attacks, the 2008 global financial crisis, and episodes of fuel volatility – demonstrates Qantas' resilience and strong positioning in the APAC aviation market. Unlike many global carriers, Qantas avoided drastic reductions in passenger volumes during these events, highlighting effective cost management and a relatively robust demand environment in the Australasian region.

However, the dramatic decline that began in 2020 represents a historic deviation from this upward trend. The number of revenue passengers plummeted from roughly 55-60 million to below 15 million, a drop of over 70%. This collapse coincides with the global outbreak of the COVID-19 pandemic and Australia's particularly stringent border closures and travel restrictions. The steep drop reflects both the domestic lockdowns and the prolonged suspension of international operations, especially relevant for a geographically isolated country like Australia.

The minimal recovery observed in 2021 suggests that international routes remained largely dormant during this period. However, by 2022 and 2023, a notable rebound is evident, with revenue passenger figures climbing back above 40 million. This partial recovery highlights pent-up travel demand, the easing of domestic and international restrictions, and Qantas' strategic prioritisation of profitable domestic routes during the initial rebound phase. The fact that recovery remains incomplete as of 2023 highlights ongoing challenges, including aircraft shortages, staffing limitations, and volatile demand patterns.

Strategically, this figure encapsulates both the vulnerability and resilience of a legacy carrier navigating through unprecedented external shocks. The long-term growth trajectory affirms Qantas' ability to scale operations and sustainability in a stable regulatory and economic environment. In contrast, the COVID-19-induced dip highlights the airline's reliance on open borders and international traffic, underscoring the need for operational resilience and scenario planning in future crisis preparedness.

In summary, Figure 20 reflects the evolution of Qantas' revenue passenger volumes across nearly three decades. The consistent pre-2020 growth highlights the effectiveness of strategic expansion, while the severe disruption and gradual recovery post-2020 illustrate the broader impacts of pandemic-induced restrictions on the aviation sector. The rebound trajectory suggests a positive outlook, but it also reinforces the importance of building adaptive and resilient network strategies in a post-pandemic landscape.

3.4.2.1.1.3. AVERAGE FARE

The Average Fare (Avg. F) can be defined as the standard fare applied by a given airline (Bamberger et al., 2004). This Average Fare is subject to various influencing factors (Borenstein & Rose, 1994).

The average Fare of an airline can sometimes be found in its annual report. However, when the company does not publish this value, it is still possible to calculate it. To determine the Average Fare, as shown in Equation (9), two pieces of data are required: Fare Revenue and the Number of Revenue Passengers.

$$Avg.F = \frac{Fare\ Revenue}{Number\ of\ Revenue\ PAX} \quad (9)$$

Figure 21 illustrates the evolution of the Average Fare for both a Low-Cost Carrier (EasyJet) and a Full-Service Carrier (Iberia) over the period from 2004 to 2024.

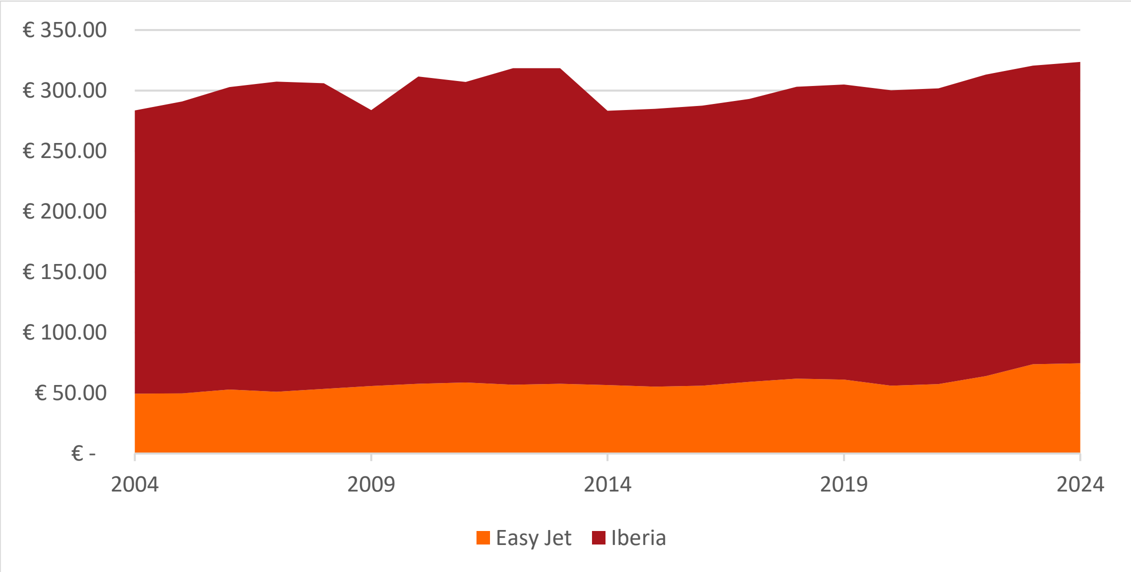

Figure 21 - EasyJet and Iberia Avg. F evolution
Source - Own Elaboration (Based on the Annual Reports (Easyjet, 2005, 2006, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014; Iberia, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024))

The figure highlights a long-term comparison between an LCC (EasyJet) and an FSC (Iberia), providing insight into the differing pricing strategies and market positioning within the European short- and medium-haul segments.

Over the past 20 years, Iberia’s average fare has consistently remained substantially higher than that of EasyJet, aligning with its traditional network carrier business model.

Iberia's fare levels fluctuate between approximately € 250 and € 300, reflecting a premium service offering that typically includes features such as baggage, seat selection, and full-service onboard experiences. These values suggest a relatively inelastic pricing strategy, focused on maintaining margins through a more service-oriented passenger base.

In contrast, EasyJet's average fare remains considerably lower throughout the observed period, generally staying within the 50€-80€ range. This consistent gap highlights EasyJet's low-cost model, which focuses on stimulating demand through lower prices and high seat occupancy. The airline's strategy leans heavily on ancillary revenues (e.g., baggage fees, priority boarding, and food sales) to complement the base fare, which remains aggressively competitive.

From a temporal perspective, both carriers exhibit variations in fares across economic and industry cycles. Slight dips around 2009 and 2020 are linked to the global financial crisis and the COVID-19 pandemic, respectively. Iberia appears to respond to demand shocks with mild fare adjustments, possibly through capacity control or route rationalisation. In contrast, EasyJet maintains a more consistent fare level – a result of volume-based optimisation rather than price-based revenue maximisation.

Post-2020, EasyJet's average fare shows a moderate upward trend, reflecting rising fuel and labour costs, inflationary pressures, and an industry-wide capacity crunch. Iberia fares also edge upwards post-pandemic, signalling both cost pass-through and increased demand for leisure and premium travel as global mobility resumed.

The overall fare disparity between the two carriers underscores fundamental differences in their business models and customer segments. EasyJet prioritises affordability and frequency, appealing to cost-conscious travellers, while Iberia caters to both business and higher-end leisure travellers, offering full-service options including interline and codeshare connectivity. This divergence exemplifies the market segmentation within European aviation, as well as the coexistence of low-cost and legacy models, with overlapping geographic spaces.

In summary, Figure 21 illustrates the persistent cost advantage of LCCs, such as EasyJet, relative to FSCs, such as Iberia. While both carriers are subject to macroeconomic influences, their fare strategies remain anchored to their respective operational models. These patterns highlight how strategic positioning and cost structure significantly influence fare evolution and competitive dynamics within the European air travel market.

3.4.2.1.1.4. NUMBER OF OFFERED SEATS

The number of seats offered by a given airline refers to the total number of seats available for purchase by passengers. This value is primarily influenced by two factors: the number of aircraft the airline operates and the frequency with which each aircraft is utilised. This information is typically provided by airlines in their Annual Reports.

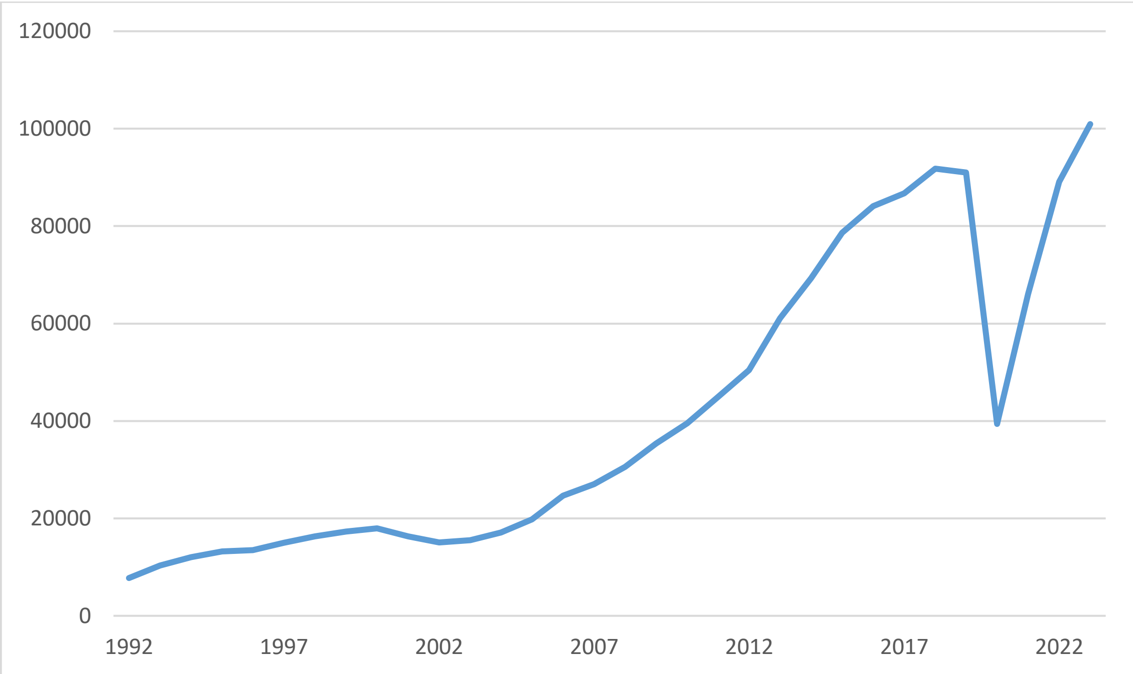

Figure 22 - Number of Offered Seats by Turkish Airlines (in 000')
Source - Own Elaboration (Based in the Annual Reports (Turkish Airlines, 2001, 2002, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2003, 2021, 2022, 2023, 2004, 2005, 2006, 2007, 2008, 2009, 2010))

Figure 22 illustrates the longitudinal progression of available seat capacity offered by Turkish Airlines from 1992 to 2024, serving as a key proxy for assessing both network expansion and strategic capacity management- This metric – commonly referred to in air transport economics as Available Seats (000’) – offers insight into the carrier’s scale of operations, market reach, and its responsiveness to both endogenous corporate strategies and exogenous macroeconomic shocks.

Between 1992 and approximately 2003, Turkish Airlines exhibited a phase of incremental capacity growth, consistent with a conservative route development strategy in line with its status at the time as a primarily regional flag carrier. This phase reflects a combination of factors, including a limited fleet size, constrained international bilateral agreements, and Turkey's then-developing economic conditions. The modest growth can also be attributed to the legacy regulatory environment before the liberalisation of the Turkish aviation sector and limited integration with global airline alliances.

A marginal decline around the early 2000s is perceptible, likely attributable to a combination of external shocks, including the post-9/11 global aviation downturn, economic instability in emerging markets, and the Severe Acute Respiratory Syndrome (SARS) outbreak. This downturn aligns with industry-wide capacity rationalisation strategies, reflecting a shift from growth to risk mitigation.

From 2004 onward, however, the trajectory becomes markedly steep, indicating a transition to an expansionist strategic posture. The seat capacity grows at an accelerated Compound Annual Growth Rate (CAGR), reflecting both fleet enlargement (e.g., wide-body acquisitions such as the Airbus A330 and the Boeing 777) and the proliferation of international routes, especially targeting secondary airports and emerging markets. This period coincides with Turkey's positioning of Istanbul as a strategic intercontinental hub, leveraging its geospatial centrality between Europe, Asia, and Africa – an approach consistent with a hub-and-spoke model aimed at maximising passenger connectivity and aircraft utilisation.

Moreover, Turkish Airlines' aggressive capacity expansion is underpinned by state-aligned strategic planning, including capital investment in infrastructure (notably the opening of the new Istanbul Airport in 2018), supportive national aviation policies, and the airline's integration into the Star Alliance (since 2008). The marked increase in available seats from 2010 to 2019 is indicative of scale economies being realised and the carrier's transformation into a mega-network carrier, aligning with global FSC paradigms.

The abrupt and dramatic decline in seat capacity in 2020 reflects the exogenous demand shock precipitated by the COVID-19 pandemic, which led to a near cessation of international air travel and forced a substantial downsizing in operational scale across the entire industry. The plunge, resulting in a drop of around 40 million available seats, is emblematic of the unprecedented supply-side contraction, as airlines faced fleet groundings, border closures, and suppressed consumer demand.

Yet, the V-shaped recovery observed from 2021 to 2024 is particularly salient. Turkish Airlines demonstrates a rapid restoration and subsequent expansion of seat capacity, surpassing pre-pandemic levels by 2024. This recovery trajectory suggests that the airline employed a flexible capacity restoration strategy, possibly involving the temporary redeployment of wide-body aircraft, realignment of route networks, and a strong emphasis on air cargo operations (as it became one of the few global airlines to expand its cargo division during the pandemic). Additionally, the early reintroduction of long-haul services and the resumption of underserved intercontinental routes contributed to the airline's operational rebound.

In sum, Figure 22 encapsulates Turkish Airlines' strategic evolution from a regionally concentrated carrier to a globally competitive, high-capacity network airline. The long-term trend reflects not only strategic fleet acquisition and infrastructure investment but also the airline's capacity to respond dynamically to systemic disruptions. This performance reinforces Turkish Airlines' reputation as a resilient, state-backed flag carrier with significant geopolitical and commercial significance within the global aviation ecosystem.

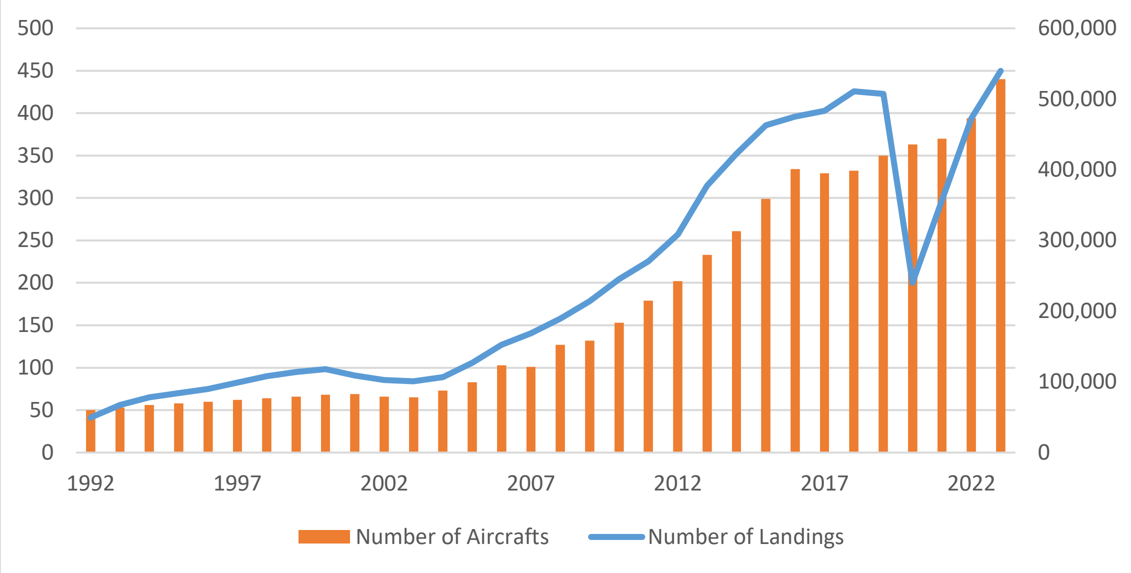

Figure 23 - Number of Landings and Aircrafts of Turkish Airlines
Source - Own Elaboration (Based in the Annual Reports (Turkish Airlines, 2001, 2002, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2003, 2021, 2022, 2023, 2004, 2005, 2006, 2007, 2008, 2009, 2010))

Figure 23 illustrates the evolution of Turkish Airlines' operational capacity over a period spanning from 1992 to 2023, as measured by the number of aircraft in service and the number of landings conducted annually. The graph presents a dual-axis system, where the orange bars represent the number of aircraft (aligned with the left vertical axis), and the blue line reflects the number of landings (aligned with the right vertical axis). Together, these two variables offer valuable insights into the airline's development trajectory, strategic decisions to increase capacity and directly the number of offered seats, and responsiveness to external shocks, such as the COVID-19 pandemic.

In the early 1990s, Turkish Airlines operated with a relatively modest fleet, consisting of fewer than 50 aircraft. This limited capacity is reflected in the relatively low number of landings, which hovered around 50,000 and 100,000 annually during the same period. Throughout the 1990s, both indicators show a slow but steady upward trend, suggesting incremental expansion driven by growing demand and a cautious investment approach. However, this phase of moderate growth gave way to a much more aggressive expansion starting around the early 2000s. From approximately 2004 onward, the number of aircraft and landings both began to accelerate significantly, marking the beginning of a transformative period for the airline.

This period of expansion aligns with Turkish Airlines' strategic ambition to position itself as a major global hub carrier. The rapid increase in fleet size – from just over 100 aircraft in the mid-2000s to over 350 by 2019 – enabled the airline to expand its route network, both domestically and internationally, substantially. Simultaneously, the number of landings increased at an even steeper rate, surpassing 500K annually by the end of the 2010s. This divergence between aircraft count and landings is particularly significant, as it suggests improvements in fleet utilisation and operational efficiency. Aircraft were not only increasing in number but also flying more frequently due to optimised scheduling, shorter Turnaround Times (TATs), and expansion into high-frequency routes.

By 2019, Turkish Airlines had reached its operational peak in the dataset, reflecting both the culmination of years of expansion and the robustness of its business model. However, this trajectory was abruptly disrupted by the global COVID-19 pandemic. In 2020, the number of landings experienced a dramatic and unprecedented decline, falling by more than half compared to the previous years. This sharp drop is consistent with the widespread grounding of fleets and suspension of international travel that characterised the early phase of the pandemic. Interestingly, the number of aircraft remained relatively stable during this period, indicating that the airline opted not to dispose of significant portions of its fleet despite the collapse in demand. This decision suggests a long-term strategic perspective, based on the expectation of a strong recovery and constrained by the complexity of returning leased aircraft or cancelling orders.

The post-pandemic years of 2022 and 2023 reveal a remarkable recovery. The number of landings rebounded rapidly, returning to pre-pandemic levels by 2023. At the same time, the fleet size not only recovered but expanded further, reaching approximately 450 aircraft. This recovery demonstrates Turkish Airlines' operational resilience and adaptability in the face of a systemic disruption. It also reflects the airline's ability to recapture market share and potentially benefit from the temporary weakening of its competitors. The speed and scale of this rebound may also indicate latent demand for air travel in the airline's markets, as well as the successful management of routes and capacity during the recovery phase.

Taken together, the trends shown in Figure 23 encapsulate Turkish Airlines' transformation from a regional carrier into a major global player. The data underscores not only the scale of its expansion but also its capacity to weather crises and position itself for growth in a highly competitive and volatile industry. The synchronised growth in aircraft and landings, interrupted only by a global crisis and followed by a rapid resurgence, speaks to a deeply embedded operational robustness and a well-executed long-term vision. This evolution underscores the importance of infrastructural investments, strategic fleet management, and market positioning as crucial components in developing a resilient airline that can sustain its performance across decades.

3.4.2.1.1.5. PASSENGER LOAD FACTOR

The Passenger Load Factor (PLF) is a key performance indicator in the aviation industry that reflects how efficiently an airline fills available seat capacity. It is expressed as a percentage and calculated by dividing Revenue Passenger Kilometres (RPK) by Available Seat Kilometres (ASK). A higher PLF indicates a better capacity utilisation, which typically translates into improved operational efficiency and cost-effectiveness. For FSC and LCC, the PLF plays a crucial role in assessing both profitability and competitiveness. While LCC generally rely on high load factors to compensate for low ticket prices, FSC aims to strike a balance between load factor, service quality, and yield per passenger. Understanding variation in PLF over time offers valuable insights into an airline's adaptability to market dynamics, demand shocks, and strategic positioning.

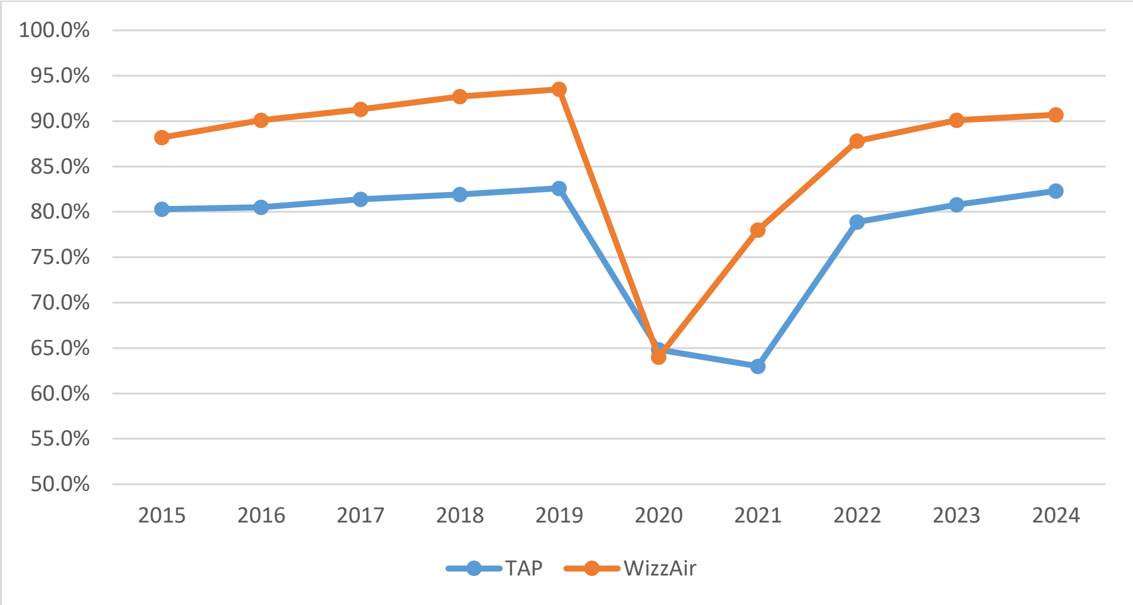

Figure 24 - TAP vs WizzAir Passenger Load Factor
Source: Own Elaboration (Based on the Annual Reports (TAP Air Portugal, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024; WizzAir, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024))

Figure 24 compares the annual PLF of TAP Air Portugal and WizzAir from 2015 to 2024, highlighting the contrasting strategies and resilience of these two airlines' business models over a pivotal decade marked by the COVID-19 pandemic and subsequent recovery.

From 2015 to 2019, WizzAir consistently outperformed TAP in terms of load factor, maintaining values between 87% and 95%, which is a clear hallmark of the LCC model. This model thrives on maximising seat occupancy through aggressive pricing strategies, high aircraft utilisation, and efficient turnaround times. WizzAir's operational model is tailored to achieve high PLFs as a core driver of profitability, and the data support this with near-optimal efficiency right up until the onset of the pandemic.

Conversely, TAP maintained a more modest and stable PLF during the same pre-pandemic period, fluctuating around 80% and peaking at just over 82% in 2019. It is characteristic of FSCs, which operate more complex networks including long-haul and connecting flights, where load factor optimisation coexists with other revenue strategies, such as premium cabin sales, ancillary services, and cargo. The inherently higher operational costs and focus on service quality mean that FSCs, like TAP, often accept slightly lower load factors in exchange for broader strategic objectives.

The year 2020 marks a dramatic turning point for both carriers, with the PLF plunging due to the COVID-19 crisis. Notably, TAP experienced a sharper relative decline, dropping to approximately 63%, while WizzAir saw a steeper absolute drop to about 65%. The near convergence of both values during this period is revealing, underscoring the pandemic's universal impact on air travel demand, regardless of the business model. The narrow margin between TAP and WizzAir in 2020 reflects the extraordinary disruption in passenger volumes and travel restrictions across Europe, leading to unprecedented underutilization of aircraft capacity for both carriers.

Recovery patterns post-2020 diverge significantly. WizzAir's PLF rebounded quickly and robustly, climbing back to 86% by 2022 and stabilising near pre-pandemic levels (around 90%) by 2023 and 2024. This trajectory highlights the flexibility and demand sensitivity of the LCC model, which enabled WizzAir to adjust routes and pricing quickly to recapture leisure travel demand. The return to high load factors further validates the operational leanness and market agility of LCCs in navigating post-crisis volatility.

TAP's recovery, however, has been more gradual. The load factor remained below 80% until 2023, only returning to its 2019 levels by 2024. This slower recovery reflects the more complex challenges faced by FSCs in restoring long-haul services, navigating state aid requirements, restructuring operations, and rebalancing capacity in response to evolving demand patterns. Additionally, FSCs often face more rigid union agreements, fleet composition constraints, and a broader dependency on business travel, which was slower to recover.

In summary, Figure 24 vividly illustrates the structural distinctions between FSC and LCC business models through the lens of Passenger Load Factor performance. While WizzAir leverages high-volume, low-fare strategies to maintain superior seat utilisation, TAP's lower and more variable PLF reflects a broader and more complex operational environment. The COVID-19 period serves as a stress test, temporarily flattening the distinctions, but the subsequent rebound reaffirms the resilience and efficiency of the LCC model in swiftly recovering market share. This comparison highlights how PLF not only mirrors operational performance but also encompasses strategic choices, market segmentation, and organisational agility in an evolving aviation landscape.

3.4.2.1.2. NECESSARY REVENUE PASSENGERS

If the airline chooses to pursue a strategy centred on increasing the Number of Revenue Passengers transported while maintaining its Average Fare (€), Equation (9) it must determine how many additional passengers are required to generate the Necessary Revenue (€), Equation (8), for neutralizing the economic impact of SAF integration. Therefore, the main goal is to identify the passenger volume at which the Net Result of operating with CAF equals the New Net Result, Equation (5), which is the economic result of operating in a dual-fuel strategy.

To perform this calculation, referred to as Necessary Revenue Passengers, Equation (10), the airline must have two key data points:

- The Necessary Revenue, Equation (8), which was calculated earlier, and
- The Average Fare, Equation (9), was either already computed or retrieved from the airlines' annual report.

Therefore, the Necessary Revenue Passengers, Equation (10), can be calculated using the formula below:

$$Necessary\ Revenue\ Passengers = \frac{Necessary\ Revenue}{Average\ Fare} \tag{10}$$

This approach assumes that while the fare per passenger remains unchanged, the airline can bridge the economic gap introduced by SAF adoption purely through increased volume. It is a volume-based recovery strategy that may be suitable for certain market contexts, especially for carriers with high seat availability or excess operational capacity. However, the practicality of this solution depends heavily on demand elasticity, network constraints, and broader market dynamics.

3.4.2.1.3. +PAX SOLUTION CHECK

Assuming the airline adopts a volume-focused strategy while maintaining its average fare, it becomes essential to assess whether the airline has the operational capacity to accommodate this growth without increasing the number of flights; otherwise, more fuel would be consumed. Therefore, the primary goal is to determine whether the current supply of seats, defined by the Number of Offered Seats across existing flights, is sufficient to absorb the necessary increase in passenger volume required to offset the economic impact of SAF integration.

To evaluate this, the airline must calculate the SeCA PLF, which is presented in Equation (11). It requires two critical inputs:

- The Necessary Revenue Passengers, previously determined in Equation (10), and
- The Number of Offered Seats, presenting the airline's supply for the considered period, is available in its Annual Report.

Therefore, the SeCA PLF, Equation (11), can be calculated using the formula below:

$$SeCA\ PLF\ (\%) = \frac{Necessary\ Revenue\ Passengers}{Number\ of\ Offered\ Seats} \times 100 \tag{11}$$

Suppose the resulting PLF value is less than 100%. In that case, this indicates that, from a purely mathematical perspective, it would be possible to transport the additional passengers without increasing the number of flights. In such a case, the efficiency gain would come from optimising seat occupancy rather than expanding operational capacity—an important consideration from both economic and environmental standpoints.

Additionally, to gain a more detailed understanding of the scale of this adjustment, it is useful to compute the +PAX Percentage Variation, as shown in Equation (12). This calculation compares the Number of Revenue Passengers with the Necessary Revenue Passengers, as per Equation (10), thereby quantifying the extent to which the airline must improve its load factor to render the SAF-related economic impact neutral. The formula to determine this +PAX Percentage Variation, Equation (12), should be computed as follows:

$$+PAX\ \Delta\% = \left|\frac{(Number\ of\ Revenue\ \ PAX - Necessary\ Revenue\ PAX)}{Number\ of\ Revenue\ \ PAX}\right| \times 100 \tag{12}$$

To accurately assess and understand the impact of this solution, the same Percentage Variation method can be used to determine the PLF to SeCA PLF, following the formula below:

$$PLF\ \Delta\% = \left|\frac{(PLF - SeCA\ PLF)}{PLF}\right| \times 100 \tag{13}$$

These two analytical steps are particularly relevant when assessing feasibility in practice, as they test the airline's operational capacity. It also provides a basis for strategic decision-making: if required, the PLF exceeds the airline's historical or achievable thresholds, alternative solutions, such as fare adjustments or fleet optimisation, may need to be explored.

3.4.2.2. INCREASE THE AVERAGE FARE (+FARE)

For the +FARE solution, the idea is to achieve the Necessary Revenue by increasing the Average Fare while maintaining the Number of Revenue Passengers of the airline.

3.4.2.2.1. DATA ACQUISITION PHASE

At this stage, no further data collection is required, as all the inputs essential for the analysis and verification of this solution have been comprehensively retrieved and computed during earlier phases of the method.

3.4.2.2.2. NECESSARY AVERAGE FARE

Suppose the airline's strategy is to increase the Average Fare while maintaining the same Number of Revenue Passengers transported. In that case, it becomes necessary to calculate the Necessary Average Fare increment that would allow the company to achieve the previously determined Necessary Revenue. By doing so, the economic impact of incorporating SAF into the airline's operations—within legally accepted blending thresholds—can be neutralised in terms of Net Result.

To compute the Necessary Average Fare (Equation 14), two key data points are needed: the Necessary Revenue, calculated in Equation (8), and the actual Number of Revenue Passengers transported, which can typically be obtained from the airline's Annual Report. The Necessary Average Fare, Equation (14), can be determined using the following formula:

$$Necessary\ Average\ Fare\ (€) = \frac{Necessary\ Revenue}{Number\ of\ Revenue\ Passengers} \tag{14}$$

Once the Necessary Average Fare, Equation (14), is determined, it is possible to calculate the Fare Impact per passenger, Equation (15). This value represents the additional amount each passenger would have to pay to cover the incremental cost associated with the use of SAF. To calculate this, one must compare the Necessary Average Fare, as defined in Equation (14), with the actual Average Fare currently charged by the airline, as obtained via Equation (9) or directly from the company's Annual Report. This comparison provides a tangible measure of how much of the SAF cost could be offset by fare adjustments rather than operational or structural changes.

The Fare Impact (€), Equation (15), can be determined using the following formula:

$$Fare\ Impact\ (€) = \ NecessaryAverage\ Fare - Average\ Fare \tag{15}$$

This analysis provides a clear understanding of the economic feasibility of partially or fully transferring the environmental cost burden to the end customer, serving as a strategic decision-making tool for both airline management and policy designers.

3.4.2.2.3. +FARE SOLUTION CHECK

To assess whether passengers would be willing to pay a premium for their tickets, knowing that the airline is opting to operate with a more sustainable fuel—thus contributing to environmental protection and global sustainability—this study considers that the most effective method is to conduct a structured survey. The goal is to determine whether individuals feel sufficiently environmentally conscious and motivated to support sustainable practices economically through higher ticket fares.

As supported by academic literature, one of the most widely adopted approaches for determining customers' Willingness-to-Pay for environmental improvements is the Contingent Valuation Method. This method falls under the umbrella of direct surveys, specifically customer surveys, which enable engagement with both current and potential clients of a company. Compared to alternative methodologies, direct surveys offer significant advantages, most notably, low implementation cost and minimal time burden for respondents.

The questionnaire developed for this research aligns with the CVM framework and consists of four main groups of questions:

1. Warm-up Questions: designed to familiarise the respondent with the topic and gather basic demographic and behavioural data;

2. *Status Quo* Assessment: which gauges the respondent's current awareness and attitudes toward aviation emissions and environmental challenges;
3. SAF Information Block: a segment that educates respondents on SAF, including its environmental benefits, operational challenges, and regulatory context;
4. Core WTP Questions: aimed at quantifying the amount respondents are willing to pay above the current fare to support SAF integration into airline operations.

Furthermore, the questionnaire is designed to be hybrid, comprising mostly closed-ended questions to facilitate quantitative analysis, while incorporating strategically placed open-ended questions to capture qualitative insights and nuanced perceptions that may inform future research or policy decisions.

Table Ap 1 provides a concise summary of each question of the CVM framework as applied in this investigation, offering a visual representation of the methodological structure.

This approach not only allows airlines to estimate the economic feasibility of transferring part of the SAF cost to passengers but also provides valuable insight into consumer perceptions of sustainability in aviation—a key input for strategic planning, public relations, and environmental policy development.

To determine whether this solution is viable, the WTP must reach 100%, indicating that the public fully accepts the proposed value. If not, it would suggest that there is unclaimed revenue from the Necessary Revenue, Equation (8), previously computed.

3.4.2.3. OPTIMAL SOLUTION

With the outputs obtained from the previous solutions, it is possible to determine the Optimal Solution among the SAF options included in this study. The Optimal Solution is defined as the one that requires the smallest increase in both the airline's Average Fare and the number of Passengers Transported.

To determine this Optimal Solution, it is necessary to have the percentage responses obtained from the questionnaire, along with the airline's current Average Fare – Equation (9) – the Necessary Average Fare – Equation (14) – and the Necessary Revenue

– Equation (8) – so that it is possible to determine the Weighted Average Fare, Equation (16).

Next, the Weighted PAX Transported, Equation (17), is determined using Equation (16). This calculation is based on the previously determined Weighted Required Average Fare, Equation (16), as well as the Necessary Revenue Equation (8).

Once these values are established, two final calculations are carried out to identify the optimal solution for the airline:

1. The Weighted Average Fare (Equation 16) takes into account the weights derived from the percentage responses collected through the questionnaire.
2. The Weighted PAX Transported (Equation 17) which incorporates both the fare and revenue metrics.

These calculations enable the identification of the SAF option that minimises both financial impact and operational disruption, thereby constituting the most efficient and viable strategy for implementation.

Equation (16), related to Weighted Average Fare, can be determined using the following formula:

$$Weighted\ Average\ Fare\ (€) = (\%Yes(CVM) \times Necessary\ Average\ Fare) + (\%No(CVM) \times Average\ Fare) \quad (16)$$

Equation (17), related to Weighted PAX Transported, can be determined using the following formula:

$$Weighted\ PAX\ Transported\ = \frac{Necessary\ Revenue}{Weighted\ Average\ Fare} \quad (17)$$

3.5. CONCLUSION

The methodological framework presented in this chapter establishes a comprehensive, data-driven, and adaptable system for evaluating the economic feasibility of SAF integration in commercial airline operations. The SeCA model emerges as a pivotal analytical tool, providing a holistic lens through which both operational costs and strategic recovery mechanisms can be examined simultaneously.

Through the articulation of three core phases—data acquisition, cost modelling, and impact assessment—this research enables a granular simulation of the economic impact under varying SAF usage scenarios. The inclusion of novel variables such as Complex Fuel Costs and New Net Result allows for a direct and transparent comparison between SAF-integrated and conventional cost structures. These elements are instrumental in bridging the gap between theoretical sustainability aspirations and grounded economic realities.

The decision to adopt a mixed-methods research strategy further enhances the robustness of the methodology. On one hand, quantitative economic modelling delivers precision and replicability, grounded in the operational data of two markedly different airline archetypes. On the other hand, the qualitative contingent valuation survey ensures that consumer-side behaviour is factored into the economic calculus, acknowledging that passenger acceptance—particularly in price-sensitive segments—is a prerequisite for SAF cost recapture strategies to succeed.

Crucially, the model's embedded flexibility—manifested through +PAX, +FARE, and Optimal Solution paths—makes it adaptable to real-world business constraints. Airlines can utilise this methodology not only to anticipate economic disruptions resulting from SAF mandates but also to develop revenue-neutral strategies that align environmental responsibility with long-term commercial viability. By simulating feedback loops and adaptive trade-offs, the SeCA model offers decision-makers a dynamic systems framework, enabling scenario-based planning rather than static forecasting.

Moreover, the methodological emphasis on life-cycle cost analysis and sustainability accounting aligns with emerging global norms and policy directives. As such, the SeCA model is not merely a research tool, but a potential industry benchmark for strategic environmental-economic alignment in the aviation sector.

In conclusion, the methodology developed in this study stands as a technically rigorous and practically relevant contribution to the evolving discourse on sustainable aviation. It transforms the abstract notion of SAF cost challenges into quantifiable, solvable, and communicable models that can inform both corporate strategy and public policy. Through this framework, the aviation sector is equipped with a powerful mechanism to navigate its transition toward decarbonization, without sacrificing economic resilience.

4. ANALYSIS AND DISCUSSION OF RESULTS

4.1. INTRODUCTION

In this chapter, the SeCA model is applied to two distinct airline business archetypes: the low-cost carrier Ryanair and the full-service carrier Emirates. Through a rigorous comparative methodology, this application aims to evaluate the economic and operational impact of incorporating SAF within the fuel mix of both carriers. The analysis employs a multidimensional approach, encompassing both quantitative and qualitative assessments, and is grounded in the empirical foundation established by each airline's 2023 Annual Report.

The core objective of this section is twofold: first, to assess the net economic consequences of substituting CAF with SAF at a 50/50 blend ratio; and second, to evaluate the feasibility of three strategic responses—defined in the SeCA model as the +PAX solution (increase in transported passengers), +FARE solution (increase in average fare), and an optimal mixed strategy—intended to neutralize the profit impact arising from this substitution. The analytical structure is supported by a sequential process which begins with data acquisition, followed by fuel cost modelling, impact assessment, and ultimately solution verification.

The methodological precision is ensured by the application of defined mathematical formulations throughout, including Equations 1 to 17, which govern the computation of fuel conversion rates, complex fuel costs, revised net results, revenue adjustments, and demand-side viability. Additionally, the approach integrates outputs from a CVM-based WTP survey to assess consumer acceptability under each scenario. The inclusion of this behavioural economic dimension is instrumental in validating the real-world applicability of proposed strategies.

By contrasting the economic impact of SAF adoption on two structurally different business models, this chapter not only elucidates the challenges and opportunities associated with sustainable fuel transition but also allows for broader extrapolation of how airline typology influences adaptability. Emirates, operating a long-haul, service-oriented model with a premium pricing strategy, presents an entirely different operational and economic paradigm when compared to Ryanair's short-haul, high-frequency, volume-driven structure. This heterogeneity is analytically leveraged to enhance the robustness of the SeCA model across market segments.

Furthermore, the model also incorporates a systemic feedback loop, as evidenced in the optimisation phase, which aligns with modern systems theory and iterative economic modelling practices.

In summary, this chapter bridges empirical economic data with theoretical modelling to generate actionable insights regarding the economic sustainability of SAF integration. It is structured to identify not only the viability but also the adaptability thresholds of each airline in navigating a low-carbon future, thereby making a substantial contribution to the growing body of literature on sustainable aviation economics.

4.2. SeCA Application to Ryanair and Emirates

4.2.1. Economic Impact

4.2.1.1. Data Acquisition Phase

From the 2023 Annual Reports of Ryanair (2023) and Emirates (2023), it is possible to gather the necessary data for applying the SeCA Model, as presented in Table 18:

Table 18 - Economic Impact Data Collected
Source: Own Elaboration (Based on the Annual Reports (Emirates, 2023; Ryanair, 2023))

	Ryanair	Emirates
Fuel Costs	4 025 700 000.00€	4 406 264 970.00€
Fuel Consumed (Ton)	4955750	8463363
Cost €\L SAF	-€	-€
Revenue	6 930 000 000.00€	21 439 474 885.55€
Net Result	1 314 000 000.00€	2 673 549 195.00€

4.2.1.1.1. Fuel Costs

Despite Emirates being a full-service carrier with a long-haul operational model and a fleet composed primarily of large, fuel-intensive aircraft, such as the A380 and B777, its total fuel costs are only about 9.5% higher than those of Ryanair, with an absolute difference of approximately €400 million. This gap is surprisingly narrow given the significant differences in operational profiles between the two airlines.

Emirates serves long-distance, intercontinental routes, which inherently require more fuel. In contrast, Ryanair operates a dense network of short-haul flights across Europe using a standardised fleet of Boeing 737s aircraft known for their fuel efficiency and optimised for high-frequency, low-cost operations.

To ensure accuracy in comparison, the 2023 annual reports of both airlines were analysed with hedging impacts considered, confirming that existing fuel hedging agreements do not distort the core findings of this assessment.

Ryanair’s elevated fuel expenditure can largely be attributed to its intensive flight schedule, despite operating shorter routes, high fleet utilisation, and substantial passenger volume, all of which contribute to high overall fuel consumption. It reinforces Ryanair’s business model, which depends on minimising costs in other areas to maintain profitability despite significant fuel expenses.

This analysis highlights two key insights: first, Ryanair’s economies of scale and fleet standardisation help contain per-unit fuel costs; and second, Emirates appears to manage its fuel procurement and route optimisation with considerable efficiency, likely benefiting from favourable fuel agreements, potentially enhanced by its strategic geographic positioning.

4.2.1.1.2. FUEL CONSUMED

Emirates consumes about 71% more fuel in total compared to Ryanair. This result is consistent with expectations: Emirates operates long-haul, intercontinental flights, which require greater amounts of fuel per journey. The aircraft operated by Emirates (e.g., A380s and B777s) are designed for range and passenger comfort rather than operational economy.

In contrast, Ryanair’s entire fleet consists of single-aisle Boeing 737 aircraft designed for intracontinental travel with minimal fuel consumption per trip. However, the sheer number of flights operated by Ryanair — with rapid daily rotations — means it still consumes nearly 5 million tons of fuel annually.

The fuel consumption profile thus aligns with the strategic models: volume-based short-haul frequency for Ryanair, versus value-based long-haul connectivity for Emirates.

4.2.1.1.3. COST €\L SAF

Because of the relatively small portion of SAF consumed by airlines nowadays, the data considered for this variable are presented in Table A4.

4.2.1.1.4. REVENUE

Emirates generates over three times the revenue of Ryanair. This difference reflects the nature of their respective business models. Emirates offers premium travel services, including First and Business Class, as well as a robust international cargo segment. Its ticket prices are higher, and its ancillary revenue streams are broader and more diversified.

In contrast, Ryanair operates in the ultra-low-cost segment, where base ticket prices are extremely low, and the company relies heavily on ancillary revenues (such as baggage fees, seat selection, and food sales) to boost its total income. Ryanair's average fare may be low, but it compensates through massive passenger volumes and extremely efficient cost control.

This disparity in revenue indicates that while Emirates captures more revenue, Ryanair focuses on volume over yield, a defining characteristic of LCCs.

4.2.1.1.5. NET RESULT

Therefore, it indicates that Ryanair is more profitable in terms of revenue. It generates more net profit for every euro earned, reflecting the LCC model's efficiency and tight cost discipline. The company has optimised its operations, minimised staff and service costs, and benefits from high aircraft utilisation and a standardised fleet.

Emirates, although more profitable in absolute terms, has a higher cost base due to operating premium services and airport lounges, long-haul aircraft maintenance and fuel burn, higher staff-to-passenger ratio, and costs associated with global hubs and infrastructure.

This analysis underlines the trade-off between scale, service quality, and efficiency. Emirates earns more due to its scale and premium offerings, but at the expense of lower margins. Ryanair, in contrast, extracts maximum efficiency and profitability from a lean operation.

4.2.1.2. COST MODELLING PHASE

4.2.1.2.1. COST €\L CAF

To assess and determine, on average, how much each airline has agreed on paying for a Litre of CAF, Cost €\ LCAF (Equation 2) should be used. Because the data retrieved is provided in tons instead of Litres, Equation 1 needs to be used to transform the number of tons consumed by each airline into the number of Litres consumed individually.

Applying these formulas to the previously collected data, the following values in Table 19 were obtained:

Table 19 - Cost Modelling (Litres Consumed and Cost €\L CAF)
Source: Own Elaboration

	Ryanair	Emirates
Litres Consumed	6194687887	10579203750
Cost €\L CAF	0.6499 €	0.4165 €

Table 19 reveals that Emirates, despite operating long-haul, fuel-intensive aircraft, manages to pay substantially less per Litre of fuel than Ryanair. It is a strategic advantage for Emirates, allowing it to operate large aircraft profitably over long distances. In contrast, Ryanair's higher per-litre cost suggests that its competitive edge lies less in raw fuel pricing and more in operational scale and cost discipline across other areas. Additionally, as mentioned earlier, the geographic position of Emirates may play a crucial role in the discrepancy observed between the values.

4.2.1.2.2. COMPLEX FUEL COSTS

To evaluate the economic impact of introducing Sustainable Aviation Fuel (SAF) into airline operations, it is necessary to calculate the Complex Fuel Costs (Equation 4), which represent the average cost per Litre when both conventional aviation fuel (CAF) and SAF are used together. This value is obtained using Equation 4, which incorporates the cost per litre of CAF (Equation 2), the cost per litre of SAF, and the respective volumes of each fuel type consumed. With this, Table 20 lists the value for both airlines in each SAF-blend scenario.

Table 20 - Complex Fuel Costs
Source: Own Elaboration

	Complex Fuel Costs	
Type of SAF	**Ryanair**	**Emirates**
SAF-A[P]	4,831,432,988.59 €	7,016,670,191.25 €
SAF-A[N]	4,273,911,078.76 €	6,064,541,853.75 €
SAF-B[P]	7,092,494,067.34 €	10,878,079,560.00 €
SAF-B[N]	3,995,150,123.84 €	5,588,477,685.00 €
SAF-C[P]	5,419,928,337.85 €	8,021,694,547.50 €
SAF-C[N]	5,141,167,382.94 €	7,545,630,378.75 €

Table 20 demonstrates that all [N] SAF options analysed present a more economically viable scenario for both airlines. Additionally, it is evident that Ryanair consistently incurs significantly lower gross Complex Fuel Costs compared to Emirates, regardless of the SAF solution considered. This outcome reinforces the trend observed in Table 19, suggesting that Emirates likely benefits from a substantially favourable fuel procurement agreement, which offsets the inherently higher fuel demands of its long-haul, wide-body operations.

4.2.1.3. IMPACT ASSESSMENT PHASE

4.2.1.3.1. NEW NET RESULT

With the introduction of a new fuel-related variable—Complex Fuel Costs—it becomes necessary to recalculate the Net Result for each airline under the defined scenarios. The inclusion of this updated fuel cost structure directly impacts the overall financial outcome, requiring a revised evaluation.

To determine this New Net Result, Equation 5 must be applied. Using this method, Table 21 has been constructed to reflect the updated financial performance under the influence of Complex Fuel Costs:

Table 21 - New Net Result
Source: Own Elaboration

	New Net Result	
Type of SAF	**Ryanair**	**Emirates**
SAF-A[P]	508,267,011.42 €	63,143,973.75 €
SAF-A[N]	1,065,788,921.25 €	1,015,272,311.25 €
SAF-B[P]	(1,752,794,067.34 €)	(3,798,265,395.00 €)
SAF-B[N]	1,344,549,876.16 €	1,491,336,480.00 €
SAF-C[P]	(80,228,337.85 €)	(941,880,382.50 €)
SAF-C[N]	198,532,617.07 €	(465,816,213.75 €)

Table 21 presents the recalculated New Net Result for both airlines after integrating the Complex Fuel Costs into their respective financial outcomes.

4.2.1.3.2. NET RESULT IMPACT

With the New Net Result now determined—factoring in the Complex Fuel Costs arising from a 50% SAF blend—it becomes possible to compare this adjusted outcome with the original (real) Net Result. This comparison enables a more comprehensive evaluation of the economic impact resulting from the partial integration of SAF into airline operations. To quantify this effect, Equation 6 (Net Result Impact) and Equation 7 (Percentage Variation in Net Result) should be applied. These calculations provide a clearer understanding of the economic shift introduced by the SAF incorporation and help assess the overall feasibility and sustainability of this alternative fuel strategy. Table 22 shows both variables determined:

Table 22 - Net Result Impact and Percentage Variation in Net Result
Source: Own Elaboration

	Ryanair		Emirates	
Type of SAF	**Net Result Impact**	**Δ%**	**Net Result Impact**	**Δ%**
SAF-A[P]	(805 732 988.59€)	61%	(2 610 405 221.25€)	98%
SAF-A[N]	(248 211 078.76€)	19%	(1 658 276 883.75€)	62%
SAF-B[P]	(3 066 794 067.34€)	233%	(6 471 814 590.00€)	242%
SAF-B[N]	30 549 876.16€	-2%	(1 182 212 715.00€)	44%
SAF-C[P]	(1 394 228 337.85€)	106%	(3 615 429 577.50€)	135%
SAF-C[N]	(1 115 467 382.94€)	85%	(3 139 365 408.75€)	117%

An analysis of Table 22 reveals that, overall, none of the SAF-blended types prove to be more economically viable than solo-CAF operations, with the sole exception being SAF-B [N] in the case of Ryanair, this is because the cost per Litre of CAF acquired by Ryanair is higher than that of this specific SAF type. This conclusion is supported by the Net Result Impact column, where all values—except for the case as mentioned earlier—are negative. A negative value in this context indicates a reduction in the airlines' profit resulting from the adoption of SAF.

Further insights can be drawn from the Δ% column, which shows that the degree of economic viability varies significantly among SAF types. For instance, SAF-B [N] emerges as the most economically favourable option, owing to its notably lower cost per Litre compared to other SAF alternatives. Conversely, SAF-B [P] is identified as the least economically viable, reflecting its relatively high price point and greater negative impact on net results.

4.2.1.3.3. NECESSARY REVENUE

To offset the economic impact of incorporating SAF and preserve each airline's current operational margin, it is essential to determine the amount of revenue required under each scenario. It means calculating the Necessary Revenue that would allow the airlines to break even, neutralising the economic effect of switching to mixed fuel operation. For this purpose, Equation 8 is applied, leading to the development of Table 23, which outlines the revenue each airline would need to generate to maintain their existing profitability levels despite the increased fuel costs:

Table 23 - Necessary Revenue
Source: Own Elaboration

	Necessary Revenue	
Type of SAF	**Ryanair**	**Emirates**
SAF-A[P]	7 735 732 988.59€	24 049 880 106.80€
SAF-A[N]	7 178 211 078.76€	23 097 751 769.30€
SAF-B[P]	9 996 794 067.34€	27 911 289 475.55€
SAF-B[N]	6 899 450 123.84€	22 621 687 600.55€
SAF-C[P]	8 324 228 337.85€	25 054 904 463.05€
SAF-C[N]	8 045 467 382.94€	24 578 840 294.30€

Analysing Table 23, it becomes evident that SAF-B [N] for Ryanair is the only scenario in which an airline would require less revenue than it generates, with a difference of approximately €30 million below its actual revenue. It suggests that, under this specific SAF scenario, Ryanair could maintain its operational margin without needing to increase its income.

In contrast, for all other SAF scenarios, both Ryanair and Emirates would need to generate additional revenue beyond what was achieved. It underscores the importance of identifying strategic alternatives to meet the Necessary Revenue requirements associated with more costly SAF options.

4.2.2. SOLUTIONS

4.2.2.1. INCREASE THE NUMBER OF TRANSPORTED PASSENGERS (+PAX)

4.2.2.1.1. DATA ACQUISITION PHASE

Before proceeding with the calculation and assessing whether the Solution +PAX is viable, it is necessary to gather a specific set of data. This preliminary data collection is outlined in Table 24, which provides the essential inputs required for the subsequent analysis:

Table 24 - +PAX Data Collected
Source: Own Elaboration (Based on the Annual Reports (Emirates, 2023; Ryanair, 2023))

	Ryanair	Emirates
Necessary Revenue (€)	-€	-€
Number of Revenue Passengers	≈169000000	≈43626000
Average Fare (€)	41.01€	491.44€
Number of Seats Offered	181720430	66706422
Passenger Load Factor (%)	93.0%	65.40%

4.2.2.1.1.1. NECESSARY REVENUE

The Necessary Revenue value, as previously calculated and presented in Table 23, varies depending on both the airline in question and the specific SAF-blend scenario under consideration.

4.2.2.1.1.2. NUMBER OF REVENUE PASSENGERS

Ryanair and Emirates present a stark contrast in terms of operational scale and business models, particularly when analysing the number of revenue passengers. Ryanair, as an LCC, transported approximately 169 million revenue passengers, whereas Emirates, a FSC, recorded around 43.6 million revenue passengers. It means that Ryanair carried nearly four times as many passengers as Emirates.

This disparity can be directly attributed to the different operational strategies each airline adopts. Ryanair operates a high-frequency, short-haul network primarily within Europe, utilising a standardised fleet of Boeing 737 aircraft. These aircraft are optimised for rapid turnarounds and high utilisation, enabling Ryanair to maintain an extremely dense flight schedule. The airline's low-fare, no-frills model encourages high load factors, which supports its strategy of maximising aircraft efficiency and minimising per-passenger costs.

On the other hand, Emirates operates a long-haul, intercontinental network centred around its Dubai hub, utilising wide-body aircraft such as the Airbus A380 and Boeing 777. These aircraft are designed for longer ranges and accommodate multiple travel classes, including premium cabins. As such, while Emirates operates fewer flights and serves fewer passengers overall, the average revenue per passenger is considerably higher due to its premium service offerings and pricing model. The airline also tends to have a slightly lower load factor due to the increased complexity and higher costs associated with long-haul operations.

The revenue passenger figures reflect not only the scale but also the economic structures of these two airlines. Ryanair’s strategy emphasises cost efficiency, high passenger throughput, and minimal service add-ons, allowing it to thrive on volume despite lower margins. Emirates, conversely, focuses on the quality of service, brand positioning, and yield management, aiming to generate more profit per ticket rather than relying solely on volume.

In conclusion, although Ryanair surpasses Emirates in terms of passenger volume, both airlines are successful in their respective markets by optimising different aspects of the airline business. Ryanair capitalises on frequency, aircraft utilisation, and simplicity, while Emirates leverages comfort, service quality, and strategic long-haul routing. These differences profoundly shape how each airline can adapt to future challenges, including the integration of SAF into their fuel mix.

4.2.2.1.1.3. AVERAGE FARE

The average fare of Ryanair and Emirates further highlights the fundamental differences between their business models and operational strategies. Ryanair’s average fare is approximately 41.01€, while Emirates reports an average fare of 491.44€. This enormous gap—more than tenfold—reflects the divergent positioning of these two carriers in the global aviation market.

Ryanair, as a low-cost carrier, structures its business around offering the lowest possible base fares to attract the largest number of passengers. The 41.01€ average fare is the result of this model, with most of the airline's revenue derived not only from ticket sales but also from ancillary services such as baggage fees, seat selection, onboard sales, and priority boarding. This unbundled pricing model enables Ryanair to advertise extremely low fares, sometimes even below its operating costs, while relying on additional charges to remain profitable. It also encourages extremely high aircraft utilisation and rapid turnaround times, thereby minimising idle time and maximising revenue-generating flight hours.

On the other hand, Emirates, as a full-service international carrier, offers a vastly different product. Its average fare of 491.44€ reflects not only the long-haul nature of its routes, which inherently require higher pricing to cover greater fuel consumption, crew costs, and airport fees, but also the inclusion of a comprehensive range of onboard services. Emirates' fare includes meals, entertainment, checked baggage, and, most notably, access to premium cabin options like business and first class, which substantially increase the average revenue per ticket. The airline's branding, customer experience, and fleet of wide-body aircraft all support a premium travel offering, allowing it to charge significantly more than low-cost competitors.

This difference in average fare is also a direct consequence of the passenger demographics each airline targets. Ryanair caters to price-sensitive travellers, such as holidaymakers and budget-conscious business passengers, who prioritise cost over comfort. Emirates, meanwhile, targets a global clientele that often values quality, service, and connectivity, including long-haul tourists, business travellers, and affluent passengers willing to pay more for comfort and convenience.

In summary, the stark contrast between Ryanair's average fare of € 41.01 and Emirates' € 491.44 encapsulates their distinct approaches to air travel. Ryanair relies on cost leadership, volume, and efficiency, while Emirates leverages service excellence, long-haul connectivity, and a premium pricing model. These differences not only define their respective customer bases and competitive strategies but also influence how each carrier can navigate emerging economic and environmental shifts in the aviation industry.

4.2.2.1.1.4. NUMBER OF SEATS OFFERED

The analysis of seat capacity reveals a significant contrast between Ryanair and Emirates, reflecting the distinct operational and strategic models each airline employs.

Ryanair, operating under the LCC model, offered approximately 181720430 seats during the analysed period. This figure is nearly three times higher than that of Emirates, which offered approximately 66,706,422 seats. This discrepancy is not coincidental but rather the result of deliberate business model choices that shape each airline's network, fleet, and cost structure.

Ryanair's operational model is based on high-frequency, short-haul routes within Europe, supported by a standardised and highly utilised fleet of Boeing 737 aircraft. These aircraft are optimised for quick turnarounds and dense seating configurations, allowing Ryanair to operate a large number of flights per aircraft per day. This high level of aircraft utilisation, coupled with minimal ground time and a point-to-point network strategy, enables Ryanair to generate an exceptionally high number of available seats. This seat volume is crucial to the LCC business model, which prioritises cost minimisation and operational scale to support low average fares and high load factors. Every additional seat contributes to spreading fixed costs and maximising revenue opportunities, particularly through ancillary services such as baggage fees, onboard sales, and priority boarding.

In contrast, Emirates operates under a full-service carrier model, focusing on long-haul, intercontinental routes. Its fleet, composed mainly of wide-body aircraft such as the Airbus A380 and Boeing 777, is configured to offer multiple service classes, including premium cabins that offer greater comfort and amenities. As a result, the total number of seats offered is significantly lower than that of Ryanair, reflecting both the longer stage lengths and the lower frequency of flights. Each Emirates flight covers greater distances and generates more revenue per seat, but also incurs higher operational costs, including fuel, maintenance, airport services, and crew accommodations.

The difference in seat supply between the two airlines underscores the structural distinctions between short-haul and long-haul operations. For Ryanair, offering over 181 million seats supports a business model driven by volume and efficiency. Emirates, with approximately 66.7 million seats, emphasises quality of service, connectivity across continents, and premium customer experiences.

Ultimately, the scale of seat deployment is a critical component in evaluating the economic and operational resilience of each airline in the face of industry-wide shifts such as sustainability mandates. The substantial disparity in seat supply between Ryanair and Emirates not only illustrates the contrast between their respective business models but also frames the broader economic implications of transitioning to more sustainable aviation practices.

4.2.2.1.1.5. PASSENGER LOAD FACTOR

Ryanair reported a load factor of 93.0%, which is notably high and reflects the carrier's strong ability to fill seats on its flights. This level of seat occupancy is typical of low-cost carriers, where maintaining high load factors is crucial for achieving profitability. Given Ryanair's low average fare structure and minimal service model, the economic viability of its operations relies heavily on transporting as many passengers as possible per flight. A high load factor enables Ryanair to spread its fixed operational costs across a larger number of paying passengers, thereby reducing the cost per passenger and preserving its competitive pricing. Moreover, this operational metric also signifies effective network planning and pricing strategies that stimulate demand and optimise aircraft utilisation.

In contrast, Emirates recorded a load factor of 65.4%, which is considerably lower than that of Ryanair. While this may appear inefficient at first glance, it must be interpreted within the context of Emirates' full-service carrier model and its focus on long-haul, premium-oriented services. Emirates operates a fleet primarily composed of large, wide-body aircraft designed to serve intercontinental routes, offering a mix of economy, business, and first-class seating. The inclusion of premium cabins inherently reduces the total number of seats per aircraft but increases the revenue potential per passenger. These flights often cover complex route networks and operate at less frequent intervals compared to LCCs, which can lead to lower seat occupancy rates. Additionally, the nature of long-haul travel introduces greater variability in demand due to factors such as seasonality, geopolitical considerations, and international connectivity.

The divergence in load factor between the two airlines is emblematic of the strategic trade-offs between maximising volume and maximising revenue per passenger. Ryanair's exceptionally high load factor indicates a highly optimised short-haul model that focuses on efficiency and cost control. Emirates' lower load factor, on the other hand, reflects a strategic emphasis on service quality, route coverage, and premium offerings rather than volume alone.

In summary, while Ryanair's load factor highlights its effectiveness in maximising capacity utilisation within a volume-driven model, Emirates' figure reflects the complexities and trade-offs inherent in providing long-haul, premium services. Understanding this distinction is crucial when analysing the broader implications of sustainability measures such as SAF adoption across different airline business models.

4.2.2.1.2. NECESSARY REVENUE PASSENGERS

To determine how many passengers the airline would need to transport to maintain its average fare and still reach the necessary revenue, Equation 8 would need to be used. Applying Equation 8 to the data collected and assessed in Table 25 performs as follows:

Table 25 - Necessary Revenue Passengers
Source: Own Elaboration

	Necessary Revenue Passengers	
Type of SAF	**Ryanair**	**Emirates**
SAF-A[P]	188649188	48937571
SAF-A[N]	175053055	47000146
SAF-B[P]	243789062	56794908
SAF-B[N]	168254989	46031433
SAF-C[P]	203000662	50982632
SAF-C[N]	196202596	50013919

Analysing Table 25, titled "Necessary Revenue Passengers," it is possible to get a clear insight into the number of passengers each airline would need to transport under various SAF-blend scenarios to maintain their current average fare while still reaching the Necessary Revenue targets previously established. This calculation, grounded in Equation 8, reflects the operational challenge associated with integrating SAF, especially when economic equilibrium is to be preserved without modifying fare structures.

Upon comparing the values shown in Table 25 to the actual number of revenue passengers reported by each airline—approximately 169 million for Ryanair and 43.6 million for Emirates—it becomes evident that only the SAF-B[N] scenario for Ryanair results in a required passenger count that is lower than the current value. Specifically, the necessary passenger volume under SAF-B[N] stands at approximately 168.3 million, which is marginally below the actual 169 million passengers transported by Ryanair. It indicates that under this particular SAF scenario, Ryanair could theoretically maintain its average fare and still achieve the required revenue without needing to increase passenger volume. This outcome reinforces the previously established conclusion that SAF-B[N] is the most economically viable option for Ryanair, as it aligns more closely with its operational and economic structure.

In contrast, for all other SAF scenarios—across both Ryanair and Emirates—the number of passengers that would need to be transported exceeds the real-world figures. For example, Emirates would need to transport over 50 million passengers under the SAF-C[N] scenario, which represents a substantial increase compared to its actual 43.6 million passengers. This disparity highlights a critical issue: the incorporation of most SAF options would necessitate a significant increase in passenger volumes to maintain the same operational margin levels without altering average ticket prices. Thus, in turn, this places additional pressure on airlines to either stimulate greater demand or enhance load factors, both of which may prove operationally and strategically challenging, depending on market conditions, route networks, and capacity constraints.

Ultimately, Table 25 illustrates a core challenge in SAF implementation from a revenue management perspective. While maintaining fare levels may be desirable from a market positioning and customer retention standpoint, it becomes increasingly difficult without a corresponding and often unrealistic increase in passenger numbers, except in scenarios like SAF-B[N] for Ryanair, where economic feasibility appears more attainable. This further underscores the need for a balanced assessment of SAF adoption strategies, tailored to the structural realities of each airline's business model.

4.2.2.1.3. +PAX SOLUTION CHECK

To evaluate the feasibility of implementing the SAF-blend scenarios without requiring changes to the airlines' average fares, it is not sufficient to merely calculate the number of necessary revenue passengers. It is equally important to assess whether the airline would be capable of transporting this number of passengers, given its installed seat capacity. Thus, this is particularly relevant when the required number of passengers, as previously calculated, exceeds the actual seating capacity available within the airline's operational framework.

To do so, it is necessary to calculate the SeCA-PLF (%)—the seat capacity-adjusted passenger load factor. This metric enables the determination of whether the airline, with its current seat offering, can accommodate the required number of passengers to reach the necessary revenue levels under each SAF scenario. The SeCA-PLF is computed using Equation (11) and represents the ratio between the number of necessary revenue passengers and the available seat capacity. If this ratio exceeds 100%, it indicates that the required demand surpasses the installed capacity and, therefore, cannot be met under current operational conditions. Conversely, if the SeCA-PLF is equal to or lower than 100%, it implies that the demand could theoretically be met within the existing capacity.

The results of these calculations are presented in Table 26, which provides the SeCA-PLF values for both Ryanair and Emirates across various SAF scenarios, along with an indication of viability based on whether the required demand can be absorbed.

Table 26 - SeCA PLF (%)
Source: Own Elaboration

	Ryanair		**Emirates**	
Type of SAF	**SeCA PLF**	**Viability**	**SeCA PLF**	**Viability**
SAF-A[P]	103.81%	✗	73.36%	✓
SAF-A[N]	96.33%	✓	70.46%	✓
SAF-B[P]	134.16%	✗	85.14%	✓
SAF-B[N]	92.59%	✓	69.01%	✓
SAF-C[P]	111.71%	✗	76.43%	✓
SAF-C[N]	107.97%	✗	74.98%	✓

Examining the results presented in Table 26, a clear contrast between the two business models is evident. Emirates, as a full-service carrier, operates with significantly lower load factors than Ryanair, a low-cost carrier that functions near optimal efficiency in terms of seat occupancy. This operational difference results in Emirates maintaining a higher buffer in terms of available seat capacity. As such, in all SAF scenarios presented, Emirates demonstrates SeCA-PLF values well below the 100% threshold, indicating that the necessary demand could be accommodated without any modification to capacity or average fares. Therefore, from a technical viability standpoint, Emirates can absorb the required increase in passengers across all SAF scenarios.

In contrast, Ryanair, with its high baseline load factor and tighter capacity utilisation, presents a more constrained operational structure. The analysis shows that, except for the SAF-B[N] and SAF-A[N] scenarios, all other cases demand more passengers than their current installed capacity can support. Specifically, SAF-B[N] stands out as the only scenario in which the SeCA-PLF (%) drops below the real PLF with 92.59%, meaning Ryanair would have an even smaller PLF. SAF-A[N], though slightly exceeding the real PLF at 96.33%, remains close enough to suggest limited viability, requiring only a marginal increase of 3.33% above the airline's current PLF. In all other scenarios, however, the SeCA-PLF for Ryanair exceeds 100%—most notably in SAF-B[P], which reaches 134.16%—making them operationally unviable under the current business model, as the demand outpaces available capacity.

In summary, while Emirates demonstrates operational flexibility in integrating SAF solutions across the board, Ryanair is significantly more restricted, with only select SAF scenarios—particularly SAF-B[N] and SAF-A[N]—proving viable when maintaining current pricing and capacity structures. It underlines the critical role of business model adaptability in the broader transition toward sustainable aviation practices.

To better understand and quantify the operational and commercial effort required by each airline in response to the adoption of different SAF types, it is essential to measure the variations in passenger demand and load factor that would be necessary. Thus, this can be achieved through the application of Equation (12) to determine the +PAX Percentage Variation—the increase in the number of passengers needed—and Equation (13) to compute the PLF Percentage Variation—the increase in load factor required to meet the minimum revenue threshold. These calculations enable the construction of Table 27, which illustrates the percentage variations for both Ryanair and Emirates across each SAF scenario.

Table 27 - +PAX and PLF Percentage Variations
Source: Own Elaboration

	Ryanair		Emirates	
Type of SAF	**+PAX Δ%**	**PLF Δ%**	**+PAX Δ%**	**PLF Δ%**
SAF-A[P]	11.63%	10.81%	12.18%	7.96%
SAF-A[N]	3.58%	3.33%	7.73%	5.06%
SAF-B[P]	44.25%	41.16%	30.19%	19.74%
SAF-B[N]	-0.44%	-0.41%	5.51%	3.61%
SAF-C[P]	20.12%	18.71%	16.86%	11.03%
SAF-C[N]	16.10%	14.97%	14.64%	9.58%

Table 27 reinforces the preceding arguments and highlights key differences in sensitivity between the two airlines. From the data, it is evident that Emirates has a smoother adjustment path under each SAF scenario, requiring lower percentage increases in either passengers or load factor compared to Ryanair. For Ryanair, the situation is more complex: although SAF-A[N] presents a viable solution with only a modest increase in PLF (3.33%), other options—such as SAF-B[P]—would require a drastic 44.25% rise in passenger numbers, making them far less practical.

Additionally, Ryanair's performance is more sensitive to SAF price increases, especially in cases where the cost of SAF is substantially higher. These variations can escalate exponentially, particularly when compared to the more moderate shifts observed for Emirates. Thus, this underscores how Emirates' business model, with greater flexibility and higher margins, is better positioned to absorb the cost impact of SAF integration without compromising viability.

4.2.2.2. INCREASE THE AVERAGE FARE (+FARE)

4.2.2.2.1. DATA ACQUISITION PHASE

At this stage, no further data collection is required, as all the inputs essential for the analysis and verification of this solution have been comprehensively retrieved and computed during earlier phases of the method.

4.2.2.2.2. NECESSARY AVERAGE FARE

To determine the Necessary Average Fare that each airline must adopt under each scenario (i.e., the SAF type used), Equation (14) is applied. This equation calculates the adjusted average fare needed to maintain revenue without increasing the number of passengers. To assess the Fare Impact (€) that each SAF scenario introduces compared to the base fare, Equation (15) is also applied. This step is essential for quantifying the financial implications of SAF adoption and for guiding strategic decision-making.

By applying Equations (14) and (15) to the evaluated scenarios, Table 28 presents the outcomes:

Table 28 - Necessary Average Fare and Fare Impact
Source: Own Elaboration

	Ryanair		Emirates	
Type of SAF	**Necessary Avg. Fare**	**Fare Impact**	**Necessary Avg. Fare**	**Fare Impact**
SAF-A[P]	€45.77	€4.77	€551.27	€59.84
SAF-A[N]	€42.47	€1.47	€529.45	€38.01
SAF-B[P]	€59.15	€18.15	€639.79	€148.35
SAF-B[N]	€40.83	€-0.18	€518.54	€27.10
SAF-C[P]	€49.26	€8.25	€574.31	€82.87
SAF-C[N]	€47.61	€6.60	€563.40	€71.96

Upon reviewing Table 28, it becomes evident that the average fare adjustments required by both Emirates and Ryanair vary significantly across SAF scenarios. Notably, Ryanair would need to implement higher fare increases in most cases, particularly under SAF-B[P], where the fare impact reaches €18.15—nearly triple that of the more viable SAF-A[N] scenario.

Interestingly, there is one instance—SAF-B[N]—in which Ryanair's necessary average fare slightly decreases compared to its baseline fare. This scenario not only minimises the cost impact but also enhances feasibility, making it a highly favourable option for Ryanair.

For both airlines, scenarios using [P] SAF blends result in higher average fare requirements than their [N] counterparts. Emirates, due to its higher base fare structure, experiences proportionally smaller impacts in most cases, making the integration of SAF more financially manageable.

4.2.2.2.3. +FARE SOLUTION CHECK

To assess whether the Necessary Average Fare could be realistically applied by each airline, a questionnaire was conducted following the CVM model and the structure outlined in Chapter 3. The questionnaire's design is presented in Table Ap 2.

This stage of the analysis focuses on a critical aspect: the public's WTP for the increased fare required under each SAF scenario. As such, the key objective is to determine if respondents would accept fare increases to the level proposed in the Necessary Average Fare calculation. These findings—related to Part D of the questionnaire—are summarised in Table 29, alongside each solution's viability in terms of reaching full (100%) acceptance:

Table 29 - +FARE Solution Check
Source: Own Elaboration

	Ryanair		Emirates	
Type of SAF	**SeCA Avg. Fare WTP**	**Viability**	**SeCA Avg. Fare WTP**	**Viability**
SAF-A[P]	71.23%	✗	29.37%	✗
SAF-A[N]	90.54%	✗	53.52%	✗
SAF-B[P]	24.14%	✗	5.94%	✗
SAF-B[N]	100.00%	✓	72.33%	✗
SAF-C[P]	45.98%	✗	12.68%	✗
SAF-C[N]	54.43%	✗	16.10%	✗

Table 29 reveals that only one scenario—SAF-B[N] for Ryanair—achieved full acceptance (100% WTP). This result is particularly noteworthy because it corresponds to the only case in which the Necessary Average Fare was lower than the airline's current real average fare. Thus, this supports the expectation that lower fare adjustments are more viable.

All other scenarios failed to reach 100% acceptance, rendering them unviable under current WTP conditions. Notably, none of the Emirates solutions met the full acceptance threshold, which underscores the challenge of implementing high SAF-related fare increases in long-haul markets where the base fare is already substantial.

These results underscore that viability depends not only on the value proposed but also on the passengers' perception of the increase and their willingness to absorb it.

4.2.2.3. OPTIMAL SOLUTION

Based on the outputs from the CVM-WTP questionnaire, it is possible to identify the optimal pair of variables—Average Fare and Number of Passengers Transported—required to meet the Necessary Revenue previously defined.

To calculate the Weighted Average Fare, Equation 16 is applied, while the Weighted Number of Passengers Transported is determined using Equation 17. The resulting values, representing the optimal solution for each SAF scenario under the SeCA model, are summarised in Table 30.

Table 30 - Optimal Solution
Source: Own Elaboration

	Ryanair		Emirates	
Type of SAF	**W. Avg. Fare**	**W. PAX Transp.**	**W. Avg. Fare**	**W. PAX Transp**
SAF-A[P]	€44.40	174220707	€509.01	47248173
SAF-A[N]	€42.34	169554633	€511.78	45132047
SAF-B[P]	€45.39	220259037	€500.25	55794697
SAF-B[N]	€40.83	169000000	€511.04	44266105
SAF-C[P]	€44.80	185811952	€501.95	49915503
SAF-C[N]	€44.60	180397655	€503.02	48862190

Across all scenarios, the pair of variables (fare and passenger count) consistently reflects lower values when compared to the combinations obtained under the previous +PAX and +FARE solutions. It implies that the SeCA-based solution offers an optimised path by balancing the fare increase and the number of passengers still willing to travel under the proposed conditions, thus presenting a more realistic and implementable financial model.

4.3. CONCLUSION

The application of the SeCA model to Ryanair and Emirates has yielded profound insights into the heterogeneous economic and operational implications of SAF adoption across different airline business models. By employing a robust analytical framework underpinned by economic modelling, passenger demand elasticity, and behavioural assessment, this chapter confirms that the transition to SAF is not a uniform challenge—it is instead deeply contextual, shaped by variables such as business strategy, fleet structure, route density, and revenue model.

A key finding is the clear asymmetry in economic sensitivity between LCCs and FSCs. Despite operating with narrower margins, Ryanair's volume-centric business model provides greater resilience under certain SAF-blend scenarios, particularly SAF-B[N], where the cost per Litre of SAF is competitively advantageous relative to its baseline CAF procurement. This scenario emerges as both economically viable and operationally implementable for Ryanair, as evidenced by minimal impacts on fares and load factors, and full public acceptability, as determined by the WTP survey. Conversely, Emirates, while benefiting from economies of scale and a favourable CAF agreement, demonstrates greater vulnerability to fare increases due to its higher base fare and less price-sensitive market segments, resulting in diminished WTP levels under nearly all SAF scenarios.

The analysis of the +PAX solution revealed structural constraints in Ryanair's model due to its already near-maximal load factor and tight seat capacity utilisation. In contrast, Emirates exhibits more elasticity in seat availability and can accommodate increased passenger volumes under SAF adoption without major network or fleet adjustments. However, this flexibility is tempered by lower WTP acceptance rates, which challenge the feasibility of fare-based compensatory mechanisms.

Furthermore, the +FARE analysis highlights the nuanced trade-offs between fare adjustments and market acceptability. While Ryanair's low base fare allows for proportional flexibility, Emirates' premium fare structure magnifies resistance to additional charges, especially when passengers are not sufficiently sensitised to the environmental benefits of SAF. The behavioural feedback, as captured through the CVM-based WTP survey, plays a pivotal role in translating financial strategies into socially feasible implementations.

The final segment—Optimal Solution—demonstrates the practical utility of a weighted strategy that balances fare increases and passenger volumes, yielding more realistic outcomes than either of the extreme approaches. This synthesis, enabled by the SeCA model's integrated structure, presents a pragmatic path forward for both airline types, aligning financial sustainability with environmental objectives.

In conclusion, this chapter reinforces the necessity for differentiated strategies in SAF implementation. Policymakers and airline stakeholders must recognise that economic feasibility hinges not only on fuel pricing but also on adaptive business models, consumer sentiment, and systemic optimisation. The SeCA model, as evidenced by its application to Ryanair and Emirates, offers a powerful decision-support tool to navigate this transition, fostering a more resilient and sustainable aviation ecosystem in the decades ahead.

5. CONCLUSION

5.1. GENERAL CONCLUSIONS

The transition from CAF to SAF stands as one of the most pivotal challenges and opportunities confronting the commercial aviation industry in the 21st century. Amid an escalating climate crisis and increasing regulatory, consumer, and investor pressure to decarbonise, the airline sector—historically reliant on fossil fuel-derived kerosene—must redefine its operational paradigms to align with sustainability imperatives. This Dissertation presents a technically grounded and data-rich economic assessment of SAF deployment within two distinct airline business models: Low-Cost Carriers, exemplified by Ryanair, and Full-Service Carriers, represented by Emirates. The methodological backbone, the SeCA model, enabled a comparative and forward-looking simulation of the economic repercussions stemming from SAF usage under both current and projected future scenarios.

In response to the starting research question — “What is the economic impact of operating with SAF on an LCC and an FSC, both today and in the future?” — this study concludes that the current economic impact is significantly negative for both airline models, albeit with differing intensities. However, this adverse economic scenario is not static. In the medium to long term — particularly by 2035 to 2040, as seen if compared the present SAF value with the future SAF acquisition cost — the economic impact is expected to be substantially mitigated through SAF production scale-up, technological learning effects, regulatory incentives, and increased consumer willingness to pay for sustainable air travel. Under these evolving conditions, SAF can become cost-neutral or even economically favourable, especially for FSCs and optimised LCCs, marking a transformative shift from environmental liability to strategic opportunity in airline fuel economics.

Presently, the integration of SAF in daily airline operations is characterised by severe economic constraints. Thus, this is largely attributable to SAF’s high unit acquisition cost, which averages more than three times that of conventional Jet-A1 kerosene, driven by limited feedstock availability, underdeveloped refining capacity, and suboptimal economies of scale. When applied to Ryanair and Emirates, the results confirmed that the adoption of SAF under currently allowed blending ratios results in a significant erosion of net operating margins, with different economic impacts on LCCs and FSCs in the modelled cases. Therefore, this validates Hypothesis H1, demonstrating that, at present, SAF is not economically viable for either model, irrespective of operational efficiency or network configuration.

However, this economic disequilibrium is not immutable. Through the integration of cost modelling forecasts and sensitivity analyses, this study affirms Hypothesis H2: the economic feasibility of SAF usage is expected to improve substantially in the medium- to long-term future. This improvement will be driven by technological maturation of conversion processes (particularly HEFA-SPK, FT-SKA, and future lignin-based methods), enhanced policy mechanisms such as feed-in tariffs and carbon credits, increased consumer WTP for sustainable air travel, and global mandates such as the European RefuelEU Aviation Initiative, which sets minimum SAF usage quotas.

Moreover, the differentiated cost impact across the two airline archetypes validates Hypothesis H3, with LCCs and FSCs having distinct economic impacts depending on the scenario considered.

The SeCA model’s simulation of solution sets—ranging from incremental fare increases to load factor optimisation—demonstrates that economic sustainability is attainable under specific operational adjustments. These findings provide robust support for Hypothesis H4, which posits that viable mitigation mechanisms, including policy incentives, load factor optimisation, dynamic pricing strategies, and targeted passenger engagement campaigns, can offset or mitigate the adverse economic impacts of SAF.

Crucially, the empirical data gathered through the hybrid WTP questionnaire reveal that passengers express a Real WTP differential to support SAF usage. This behavioural insight supports Hypothesis H5, which recognises the social dimension of environmental sustainability as a lever to ease SAF’s economic burdens. The growing public awareness of climate implications and support for green aviation initiatives reinforce the hypothesis that the socio-political momentum behind SAF can translate into economic viability through consumer support.

5.2. OBJECTIVES ACHIEVED

This study was constructed upon a matrix of clearly defined objectives that have been systematically addressed throughout the research:

For the first objective (O1) that set the target to "Determine the cost of operating with SAF today and in the future" this has been achieved by a through a robust cost modelling process involving multi-variable economic input factors (fuel prices per Litre, fuel consumption, SAF blending ratios, and operational revenue), the dissertation quantifies the present-day cost premiums associated with SAF use. Future cost projections, incorporating economies of scale, technology learning curves, and policy incentives, forecast a cost parity scenario by the mid-2030s, with SAF prices converging towards a lower acquisition cost, depending on the region and feedstock pathway.

The second objective (O2), "Assess the economic impact expected for a LCC and a FSC operating with SAF within legally accepted blending levels", was completed using Ryanair and Emirates as proxies, the SeCA model conducted a granular economic analysis that showed Ryanair's and Emirates' economic impact differs even under similar conditions. These figures are aligned with realistic CORSIA-compliant blending scenarios and reflect the unique cost structures and fare elasticity of each model.

For the third objective (O3), which stated "Evaluate whether the passengers' WTP varies and enables the airlines to offset the economic impact," was successfully achieved using a WTP analysis that demonstrated variance among passenger demographics and business models. While passengers flying with FSCs showed a higher inclination to pay a sustainability premium, a segment of environmentally conscious LCC passengers also expressed moderate WTP, especially due to the lower gross value in comparison to the FSC values proposed. On aggregate, the additional revenue recoverable via WTP mechanisms represents a significant contingent upon route length and fare base.

The fourth objective (O4), "Determine ways to reduce or eliminate the economic impact of operating with SAF", was achieved through multiple mitigation strategies, including increased PLF and dynamic average fare recalibration. The optimal scenario suggests that, through a synergy of +PAX (increase in transported passengers) and +FARE (marginal fare adjustments), both LCCs and FSCs could recover from the SAF-induced margin erosion by 2035.

5.3. HYPOTHESIS ASSESSMENT

The hypotheses formulated at the outset of this research were rigorously tested using the SeCA model and supported by both quantitative case study simulations (Ryanair and Emirates) and qualitative insights from the WTP questionnaire. The findings are synthesised below.

H1: Nowadays, the use of SAF is not economically viable for airlines despite their business model. This hypothesis is confirmed.

As evidenced through cost modelling and scenario simulations, the current cost of SAF remains substantially higher than the average value per Litre for CAF. When introduced into airline operations, even under legally accepted blending, SAF imposes a material degradation of profitability metrics. Ryanair's modelled application of SAF resulted in a decrease in net operating result, whereas Emirates also reported a significant economic impact. These outcomes underscore the intrinsic unviability of SAF under present market and technological conditions, across both LCC and FSC business models.

The price differential is further aggravated by the immature production infrastructure and lack of widespread logistical networks to support SAF distribution at scale. Thus, in its current form, SAF remains an economically regressive solution unless it is externally subsidised or internalised through non-market mechanisms.

H2: In the future, SAF will become significantly more economically viable for both LCCs and FSCs. This hypothesis is confirmed.

Economic viability is highly sensitive to temporal dynamics, particularly in terms of technology readiness levels, feedstock diversification, regulatory standardisation, and investor confidence. Based on cost-learning projections—especially in HEFA, ATJ-SPK, and emerging lignin-based conversion pathways—SAF production costs are anticipated to decline. Concurrently, carbon pricing mechanisms and SAF blending mandates (e.g., the EU’s 6% minimum SAF share by 2030) will contribute to internalising the environmental externalities of CAF, gradually narrowing the cost differential.

For LCCs, this transition will still require tighter unit cost control, but SAF will cease to be a systemic threat to profitability. For FSCs, the economics will become even more favourable, as premium passengers' environmental expectations increasingly justify the integration of SAF surcharges into fare structures.

H3: The economic impact of SAF usage differs between LCCs and FSCs: This hypothesis is strongly confirmed.

The SeCA model demonstrates structural and operational asymmetries in how SAF impacts each airline category. LCCs are volume-driven entities with high aircraft utilisation, ultra-lean cost structures, and minimal frills, leaving little room to absorb fuel price shocks.

FSCs, in contrast, benefit from multi-class cabins, auxiliary revenue segments (e.g., cargo, loyalty programs), and longer stage lengths, which dilute the per-kilometre SAF premium. Moreover, FSCs are more capable of integrating environmental sustainability into brand positioning, thereby justifying marginal price hikes.

This divergence in economic resilience also implies that SAF policy design must be nuanced: one-size-fits-all regulations could exacerbate competitive imbalances in the market. However, as expected, the impact of operating with SAF will be substantially higher for airlines that, today, have a more advantageous fuel agreement with their vendors.

H4: Some potential solutions and incentives can mitigate, and potentially even offset, the economic impact of operating with SAF, making it a more economically sustainable solution for airlines. This hypothesis is validated with supporting quantitative evidence.

The most effective mitigation strategies identified include:

- +PAX Strategy;
- +FARE Strategy;
- Optimal Solution.

Therefore, when supported by robust operational strategies and progressive regulatory environments, SAF adoption becomes not only feasible but strategically beneficial in the long term.

H5: The social dimension of environmental sustainability can be a main driver to alleviate some of the economic challenges associated with SAF. This hypothesis is partially confirmed, demonstrating a strong emerging trend.

The behavioural data obtained through the WTP survey indicate a growing willingness among passengers to pay a premium for environmentally responsible travel.

This social norm, when amplified through transparent communication, sustainability branding, and loyalty reward structures, can become a decisive force in bridging the economic gap associated with SAF. While this is not yet a definitive solution, it represents a crucial social catalyst that airlines can harness in parallel with financial and operational levers.

5.4. LIMITATIONS

While this research has been designed to rigorously assess the economic viability of SAF adoption under two contrasting airline business models, it is imperative to acknowledge a series of limitations that constrain the scope and generalizability of the findings.

5.4.1. TEMPORAL AND MARKET VOLATILITY

The aviation fuel market is highly dynamic, influenced by exogenous factors such as geopolitical instability, macroeconomic shifts, and technological disruptions. The cost structures modelled in this study are time-sensitive and may not accurately reflect real-time fluctuations in fuel markets, particularly in the post-2025 horizon. Assumptions regarding the evolution of SAF prices, blending ratios, and regulatory enforcement may vary substantially depending on policy momentum and unforeseen economic shocks.

5.4.2. REPRESENTATIVENESS OF CASE STUDIES

Although Ryanair and Emirates were judiciously selected to represent LCC and FSC models, respectively, the generalisation of these findings to all carriers within each category should be treated with caution. Variability in fleet composition, route network, fuel procurement contracts, and regional regulation can produce divergent economic outcomes not captured by the present analysis.

5.4.3. LIMITATIONS IN PASSENGER BEHAVIOURAL DATA

The WTP component is based on a hybrid survey instrument combining hypothetical and inferred preferences. Despite methodological robustness, this data is inherently subject to hypothetical bias, social desirability bias, and limitations in sample size. Consequently, the elasticity of actual consumer behaviour under real market conditions may diverge from the survey results presented.

5.4.4. EXCLUSION OF NON-FUEL OPERATIONAL FACTORS

While SAF-related fuel economics are thoroughly examined, this study does not incorporate secondary cost dimensions such as changes in maintenance cycles, insurance premiums, or supply chain adaptations. These elements could either exacerbate or mitigate the net economic impact of SAF, warranting a dedicated investigation in future research.

5.5. RECOMMENDATIONS AND FUTURE PROJECTIONS

As this research contributes to the broader academic discourse on aviation sustainability and the economic viability of SAF, it also identifies several areas that warrant further investigation. These topics remain either underexplored or subject to significant future developments that will reshape the underlying assumptions of this Dissertation.

Future academic work should focus on the long-term behaviour of SAF prices under different global energy transition scenarios. The volatility of bio-feedstock markets, the learning curves of different SAF production technologies, and the geographical asymmetries in SAF availability and policy implementation present complex interdependencies that warrant a more advanced econometric or systems dynamics modelling approach. Quantifying these interactions could provide stronger predictive accuracy for SAF price parity timelines and inform better decision-making by both industry stakeholders and regulators.

Furthermore, while this Dissertation investigated the economic implications of SAF adoption through the lenses of an LCC and an FSC, future research could expand the comparative framework to include charter operators or cargo-focused airlines. Each segment of the aviation market operates under distinct economic and operational constraints that may significantly alter the cost-benefit profile of SAF integration. A multi-segment analysis, possibly incorporating alliance dynamics or code-sharing arrangements, would offer a richer understanding of sectoral readiness.

Another avenue for further exploration concerns the consumer dimension, particularly the evolving WTP for environmentally responsible air travel. This Dissertation employed a hybrid survey approach; however, more granular studies using behavioural economics, longitudinal data, or experimental auctions could provide deeper insight into how socio-demographic factors, route characteristics, and brand positioning influence WTP. Such work would strengthen the linkage between SAF investment and demand-side monetisation strategies.

Additionally, the policy landscape around SAF remains fluid and fragmented. Future research should explore the comparative effectiveness of different policy instruments, such as blending mandates, tax credits, public-private partnerships, or carbon credit systems, through cross-country case studies or cost-effectiveness analyses. Understanding which incentive frameworks have demonstrated scalability and economic efficiency in practice could inform supranational policy harmonisation efforts, particularly within the European Union or among ICAO signatories.

It would also be beneficial to extend the SeCA model or similar simulation tools to include a full LCA approach, integrating not only economic but also environmental externalities such as CO_2 abatement costs, water usage, land transformation, and social co-benefits. A techno-economic and environmental model would better reflect the systemic trade-offs and guide more holistic sustainability strategies for the aviation sector.

Finally, the future role of alternative technologies—such as hydrogen-powered aircraft, battery-electric propulsion for short-haul routes, or synthetic fuels derived from captured CO_2—must be considered in conjunction with SAF. These disruptive technologies, although still in an early stage of maturity, could significantly reshape the competitive and regulatory landscape. Comparative scenario analysis between SAF and these emerging propulsion pathways could provide valuable insights into optimal investment strategies under uncertainty.

In summary, while this Dissertation provides a structured economic analysis of SAF usage within commercial aviation, the rapidly evolving nature of sustainable technologies, consumer behaviour, and regulatory systems underscores the need for continued empirical and theoretical research. Such work will be essential in supporting a just, economically rational, and environmentally effective transition toward net-zero aviation.

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APPENDIX 1 – CVM SECA QUESTIONNAIRE STRUCTURE

Table Ap 1 - Questionnaire Structure
Source: Own Elaboration

Question	Scale	Section
1. How regularly do you engage in environmental preservation activities?	Likert Scale	Section (A) – Warm-up Question
2. Were you aware that the aviation sector accounts for more than 2% of global CO_2 emissions?	Dichotomous Scale	Section (B) – *Status Quo* Description
3. Were you aware that the aviation sector accounts for approximately 7.1% of CO_2 emissions in Portugal?	Dichotomous Scale	Section (B) – *Status Quo* Description
4. Are you familiar with the term "sustainable aviation fuels"?	Dichotomous Scale	Section (C) – SAF Description
5. If yes, how?	Open-ended	Section (C) – SAF Description
6. How often do you fly annually?	Proportional Scale	Section (C) – SAF Description
7. Would you be willing to pay more (Value€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
8. Would you be willing to pay more (Value€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
9. Would you be willing to pay more (Value€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
10. Would you be willing to pay more (Value€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
11. Would you be willing to pay more (Value€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
12. Would you be willing to pay more (Value€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
13. Would you be willing to pay more (Value€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination
14. Would you be willing to pay more (Value€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination
15. Would you be willing to pay more (Value€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination
16. Would you be willing to pay more (Value€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination
17. Would you be willing to pay more (Value€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination
18. Would you be willing to pay more (Value€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination

The questionnaire consists of 18 questions, 17 of which are closed-ended and only one is open-ended. Throughout the questionnaire, Likert scales, Dichotomous scales, and Proportional scales were employed.

The first question, which seeks to understand the frequency with which the respondent engages in environmentally sustainable behaviours, falls under Part A of the questionnaire. This section aims to be cognitively accessible while introducing the overarching theme of the study—environmental sustainability. The question uses a Likert Scale, a commonly adopted tool in similar research. This scale offers two main advantages: it is easily interpreted by participants and facilitates straightforward measurement for the researcher.

The second question marks the beginning of Part B and explores the respondent's awareness of global aviation emissions. This question is designed to outline the *status quo* through direct and accessible wording, ensuring that even respondents with limited aviation knowledge can respond meaningfully. Although it touches on a technical aspect, it is informed by Literature Review data. A Dichotomous Scale was chosen for this question, as there are effectively only two possible answers. Thus, this allows the researcher to classify the sample population into two clear groups, avoiding excessive segmentation that might otherwise complicate data analysis or distort outcomes.

The third question follows the same format as the second but focuses specifically on the Portuguese context. Like the previous question, it belongs to Part B. Its objective is to assess awareness regarding CO_2 emissions from aviation within Portugal, as this was the country where the questionnaire was shared. As these emissions are comparatively higher than the global average, this question may help sensitise participants to a lesser-known reality while simultaneously measuring general public knowledge on the matter. The data informing this question comes from a publication in Observador (2021), which cites a study conducted by the environmental Non-Governmental Organization (NGO) Zero. Once again, a Dichotomous Scale was adopted for the same reasons mentioned in the previous question.

The fourth question, which initiates Part C, introduces the concept of sustainable aviation fuels through a simple and direct query intended to assess the respondent's familiarity with the topic. This question also employs a Dichotomous Scale, justified by its clarity and the binary nature of the possible responses—either the participant is familiar with the term or not. It is anticipated that some participants might answer affirmatively while associating the term with fuels other than SAF. To further clarify which types of fuels are familiar to the participants, this question leads into a follow-up query.

The fifth question serves as a follow-up to the previous one and is only shown to respondents who indicated familiarity with the term "sustainable fuels." Also, part of Part C, this is the only open-ended question in the entire questionnaire. It prompts participants to name, based on their own experiences and perceptions, the fuels they consider to be sustainable. Thus, this allows the researcher to identify which specific fuels are most recognised or known within the sample population.

The sixth question, also under Part C, does not directly assess knowledge about SAF, but instead introduces a commercial perspective relevant for later sections, particularly those related to assessing the WTP. This question gauges how frequently respondents travel by air. The responses to this question can later be used to segment WTP data according to the frequency of air travel. A Proportional Scale was used, allowing the creation of travel frequency brackets to accommodate all possible participant profiles.

Following this, an introductory explanatory note is provided to define SAF in simple terms. This note is central to Part C and aims to educate the respondents, ensuring they are well-informed before answering the next set of questions. The note reads: "The aviation sector is currently one of the most polluting industries. SAF is an alternative to traditional aviation fuels. It reuses resources and transforms them through sustainable processes. When used in aircraft, it can reduce CO_2 emissions by up to 80%. However, due to the nature of its production, SAF tends to be relatively more expensive for its users (i.e., airlines)."

After this explanatory note, a Scenario A is introduced, marking the beginning of Part D. This scenario is used as a reference point for the next six questions and reads: "Imagine you purchased a flight ticket for a trip in a LCC at the price of (€X), and the airline operating your flight will be using this sustainable fuel."

The monetary value to be used will depend on the calculated Fare Impact (€) according to Equation (15) of the methodology. The six subsequent questions vary only by the amount of additional cost presented, assessing how much extra the respondent is willing to pay. These questions form the core of the WTP measurement and employ a Dichotomous Scale, as recommended by the Contingent Valuation Method. The additional charges should be presented in ascending order and should include no fewer than three and no more than six different price points.

After completing Scenario A, a second scenario—Scenario B—is presented, also under Part D. This scenario serves as the reference for another series of six questions and reads: “Imagine you purchased a flight ticket for a trip in a FSC at the price of (€X), and the airline operating your flight will be using this sustainable fuel.”

As before, the monetary value will be defined based on the Fare Impact (€) calculated previously. These six follow-up questions differ only in the value of the additional fee and again aim to determine the WTP. They also follow a Dichotomous Scale, in line with CVM guidelines.

The questionnaire was made available through multiple channels and received a total of 994 responses. Given that the target population is considered sufficiently large or undefined, the sample size was calculated assuming a 95% confidence level, a 5% margin of error, and a conservative response distribution of 50%. Under these conditions, the minimum required sample size was estimated at 384 valid responses. Therefore, the number of responses obtained not only meets but significantly exceeds the minimum threshold, increasing the statistical power and reliability of the findings.

APPENDIX 2 – CVM SECA QUESTIONNAIRE STRUCTURE (CASE STUDY RYANAIR – EMIRATES)

Table Ap 2 - Questionnaire Structure (Case Study Ryanair - Emirates)
Source: Own Elaboration

Question	Scale	Section
1. How regularly do you engage in environmental preservation activities?	Likert Scale	Section (A) – Warm-up Question
2. Were you aware that the aviation sector accounts for more than 2% of global CO_2 emissions?	Dichotomous Scale	Section (B) – *Status Quo* Description
3. Were you aware that the aviation sector accounts for approximately 7.1% of CO_2 emissions in Portugal?	Dichotomous Scale	Section (B) – *Status Quo* Description
4. Are you familiar with the term "sustainable aviation fuels"?	Dichotomous Scale	Section (C) – SAF Description
5. If yes, how?	Open-ended	Section (C) – SAF Description
6. How often do you fly annually?	Proportional Scale	Section (C) – SAF Description
7. Would you be willing to pay more (1.47€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
8. Would you be willing to pay more (4.77€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
9. Would you be willing to pay more (6.60€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
10. Would you be willing to pay more (8.25€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
11. Would you be willing to pay more (18.15€) – Scenario A	Dichotomous Scale	Section (D) – WTP Determination
12. Would you be willing to pay more (27.10€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination
13. Would you be willing to pay more (38.01€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination
14. Would you be willing to pay more (59.84€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination
15. Would you be willing to pay more (71.96€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination
16. Would you be willing to pay more (82.87€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination
17. Would you be willing to pay more (148.35€) – Scenario B	Dichotomous Scale	Section (D) – WTP Determination

APPENDIX 3 – SCIENTIFIC PAPER I (28TH ATRS 2025)

Economic Impact of SAF on Airline Business Sustainability: Comparative Analysis between LCCs and FSCs in the Current Landscape and the Future Trends

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Abstract | A much more sustainable aviation sector can be reached by a bigger incorporation of SAF in daily operations, which is currently unfeasible due to low production relative to high demand. Although it is likely to be the aviation fuel of the future, SAF has some disadvantages compared to CAF, with the primary issue being its cost to airlines. While environmentally sustainable, it remains economically unsustainable for airlines, causing a big dilemma for the aviation sector. This study created the SECA method to analyse this predictable economic impact better, proposing three solutions and calculating the economic impact. Two solutions follow a CVM method to determine whether passengers' willingness to pay increases when knowing that the airline is using a much more sustainable fuel to operate. This study specifically focuses on comparing whether an LCC or an FSC can incorporate SAF into their daily operations, measuring their specific economic impacts and potential solutions.

Keywords | Sustainable Aviation Fuel; Business Sustainability; Fuel Costs; Incentives for using SAF; Passengers' Willingness to Pay.

1. Introduction

This research aims to determine the economic impact of an airline operating within the legal limits currently accepted under existing regulations. Sustainable Aviation Fuel has many environmental advantages compared to Carbon Aviation Fuels, which makes it particularly appealing to environmentally concerned stakeholders in the aviation industry. Moreover, SAF is seen by many players as the key element in the 2050 goal to reach net-zero emissions. However, production must start on a large scale to reach this goal. Since 2011, only 450,000 flights have been powered by SAF, representing a very small proportion of the gigantic dimension of the air transport sector (Air Transport Action Group, 2022). Because production is too little for the existing demand and the production costs are still very high, the selling price is not very competitive, especially compared to the price of CAF. Airlines are very sensitive to minor daily changes in fuel prices, and even though there are some economic incentives to use SAF, this factor still works as a disadvantage to it.

Nowadays, this problem might not be the core problem of SAF, mostly because airlines use it optionally, as part of their strategic marketing or operational approaches; however, once the tipping point is reached, airlines will be obligated to use SAF. Business sustainability could be in trouble if SAF's selling price remains high.

2. Literature Review

A growing number of citizens are concerned about the environmental impact of air transport, as aviation is often associated with high carbon emissions and global warming (Chiambaretto et al., 2021). In the last report published by the International Energy Agency (2022) on global CO_2 emissions in 2021, there appears to be an increase of 6% compared to 2020, reaching 36.6 gigatons of carbon dioxide emitted. Specifically talking about the aviation sector, the International Energy Agency (2022a) reported that it represents more than 2% of all CO_2 emissions. These high levels of CO_2 emissions led to the need to create new solutions to the existing aviation fuels (Luiz Da Silva et al., 2012). Beyond this, because petroleum is a finite resource and tends to increase in its selling price in the long term, highlighting the need to develop alternatives (Sharma & Ghoshal, 2015). Kasibhatta (2020) argues that the ideal solution should be renewable, sustainable, efficient, low-cost and with reduced or zero polluting gas emissions. Nowadays, the fuel that meets most of these criteria is SAF.

SAF is an alternative to CAF (Conventional Aviation Fuel) that can be obtained from various materials (Robert et al., 2020). Also, the International Civil Aviation Organization (2022) defines SAF as an AAF (Alternative Aviation Fuel) produced through the transformation of renewable materials or waste derivatives that meet certain established sustainable requirements, that at this moment, and consulting CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) produced by the International Civil Aviation Organization (2021) are mainly two:

I. Reduce carbon emissions.
II. Not to be obtained through biomass associated with high carbon emissions.

CORSIA (2019) identifies the main materials used in producing SAF. As William Walsh stated in the 77th Annual General Meeting of the International Air Transport Association (2021), SAF will play a major role in the decarbonization of the aviation sector where in 2050, this sustainable fuel will be responsible for 65% of all the decarbonization of the sector, targeting the Net Zero Emissions by the middle of the century. SAF has its strengths and weaknesses, as Shahriar and Khanal (2022) point out in their research, but the major advantage compared to the other sustainable solutions is that it can reduce up to 80% of the emissions (International Air Transport Association, 2021b). On top of that, this fuel does not require major modifications to existing aircraft (BP, 2022). However, SAF has a big disadvantage compared to CAF or to other AAF, which is its current high cost of production that also impacts its selling price to the airlines (Shahriar & Khanal, 2022). On top of having very high production costs, SAF also has just a few producers. The Airports Council International and Aerospace Technology Institute (2022) created a map of where all of the SAF's producers are and where the planned new facilities will be. By analysing that map, we can state that nowadays, the SAF producers are World Energy, Total, Neste and Atmosfair. In the future, it is possible to conclude that there will be 57 new facilities planned to be built in the next years. If the number of producers increases, the selling price of SAF will probably decrease mainly because of the increase in the competitiveness of the market. Two more factors have a big impact on the selling price of SAF, having both advantages and disadvantages (Airports Council International & Aerospace Technology Institute, 2022), which is the including the location where SAF is blended with CAF and also the way that SAF is transported from the refinery to the airport itself.

Although the advantages and the need to transition from a non-sustainable fuel to a more sustainable one are widespread, it is also important to point out that the transition needs to be sustainable from an economic point of view. Otherwise, either airlines or passengers may bear the cost of this transition.

Sachs (1993) argues that business sustainability is a result of five dimensions:

I. Social Sustainability means achieving equity in the distribution of income for the inhabitants of the planet.
II. Environmental Sustainability: use of natural resources that are renewable and limit the use of non-renewable resources.
III. Economic Sustainability: Reduce the social and environmental costs.
IV. Spatial Sustainability: achieving a balanced configuration between rural and urban populations.
V. Cultural Sustainability: Ensure the preservation of traditions and cultural diversity.

Other authors defend a more concrete definition, stating that business sustainability depends on environmental, social, and economic variables (Luiz Da Silva et al., 2012). An economic dimension especially focuses on obtaining consecutive profit in an economic result (Fernandes et al., 2018). For the research framework of this study, the most relevant dimensions are the economic, the environmental and their interdependencies. Thomas and Scandurra (2023) believe that airport operators manage an activity with a high economic, social and environmental impact.

Airlines know that SAF is economically less viable than CAF, and it is easy to understand that transitioning to this sustainable fuel could lead to a very complicated economic situation. Fuel costs normally are the first or the second biggest expense on an airline's operational costs (Sibdari, Mohammadian, and Pyke 2018). Fuel costs can hinder the airlines' economic life in a market where airlines always try to increase their operational margins by reducing costs (Hamdan et al. 2022). To better understand the role of fuel costs on the airlines' economic sustainability, Figure 1 shows the analysis of the operational and fuel costs representativeness of the airlines.

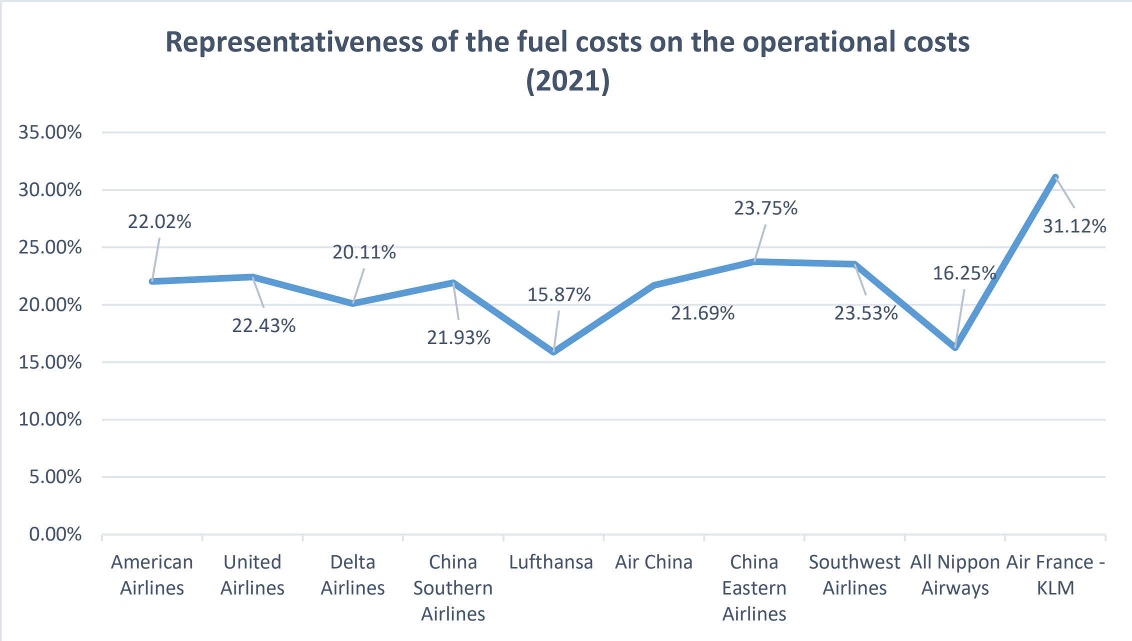

Figure 1. Representativeness of the fuel costs on the operational costs (2021)
Source: Own Elaboration (Based on the annual reports ((Air China, 2022; AirFrance KLM, 2022; All Nippon Airways, 2022; American Airlines, 2022; China Eastern Airines, 2022; China Southern Airlines, 2022; Delta Airlines, 2022a; Lufthansa, 2021; Southwest Airlines, 2021; United Airlines, 2022a)

Figure 1 demonstrates that the claims made in the Literature align with real-world data. It demonstrates that fuel costs are representative of an airline's operational costs. If we add to this the fact that SAF is much more expensive than CAF, it is expected to grow even more in this percentage in this analysis.

To better comprehend that a growth or a reduction in fuel price can greatly influence an airline's financial year, the next graph compares the average fuel price per barrel each year with the actual fuel costs and profit or loss of the airlines. Figure 2 depicts that fluctuations in fuel prices can significantly impact total fuel costs and, consequently, the profit or loss of the airlines.

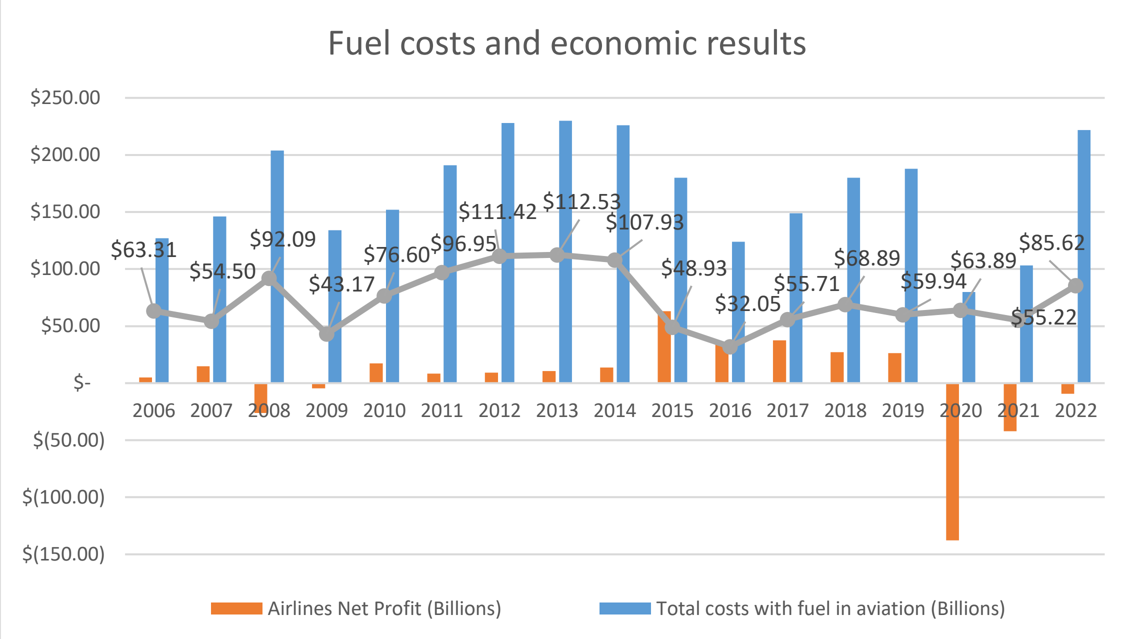

Figure 2. Fuel Costs and Economic Results
Source: Own Elaboration (Based on)

Although some incentives exist to use SAF, Zhang, Butler, and Yang (2020) believe they are still insufficient to develop SAF. One of the main obstacles to using SAF is its high purchasing price, making CAF much more competitive (Pechstein, Bullerdiek, and Kaltschmitt 2020). Therefore, to overcome this obstacle, governments and authorities must create incentives and policies for the SAF to be more attractive than CAF (International Air Transport Association 2018).

From today's incentives, some highlight the others. The European Union Emission Trading Scheme (EU ETS) gives financial incentives to more sustainable aircraft that meet the sustainability criteria and the emission level defined in the RED/REDII (European Union, 2008). The Sustainable Aviation Fuel Act (The House Of Representatives, 2021) aims to establish a credit rate per gallon of SAF, depending on the emissions of that type of SAF. The CORSIA, produced by the International Civil Aviation Organization (2018), aims to reach zero liquid emissions of GHGs.

The WTP (Willingness to Pay) corresponds to the maximum a customer is willing to pay for a product (Hanemann, 1994). Some discussions about the WTP tend to segregate it into Real Willingness to Pay (RWTP) and Hypothetical Willingness to Pay (HWTP), where the main difference is how each is measured. On the one hand, the RWTP is measured by what happens in a customer buying something, for example, in a store, whereas on the other hand, the HWTP can be measured with various types of questionnaires (Miller et al., 2011). This last one is what an investigation measures. There are a lot of ways to measure this HWTP. However, Breidert, Hahsler, and Reutterer (2006) have created Figure 3, which aggregates the most commonly used ones.

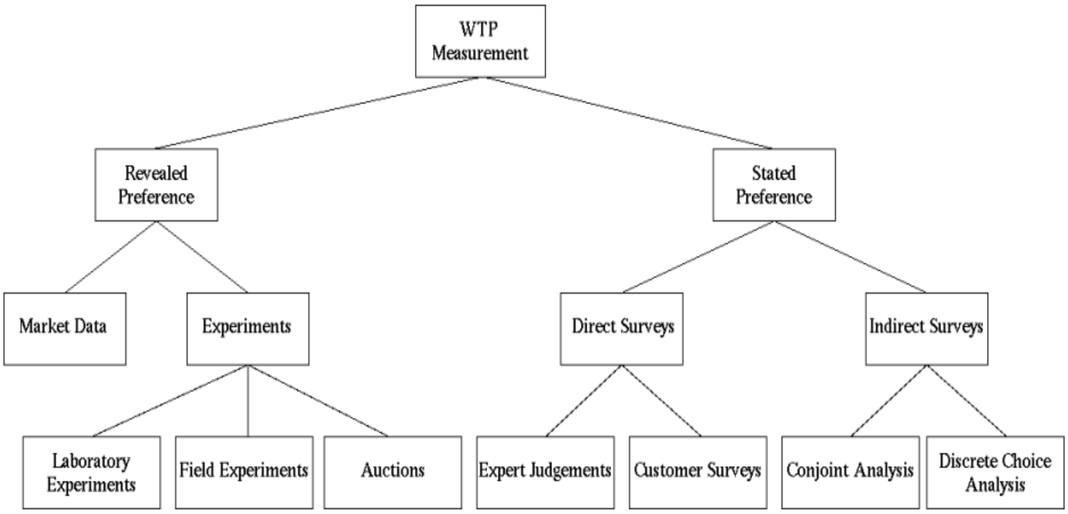

Figure 3. WTP Measurement Methods
Source: (Breidert et al., 2006)

Each of these measurement methods has several ways of developing a study to determine the WTP.

In the aviation sector, to determine the WTP of passengers related to measures that aim to reduce GHG emissions, some authors have used the Contingent Valuation Method (CVM) (Brouwer et al., 2008; Jou & Chen, 2015; Rahim & Shaari, 2017). The CVM is specially used in cost-benefit analysis measures to protect the environment (Burness et al., 1986; Mitchell & Carson, 1989). In the CVM, the respondent is asked about a general topic, for example, how, in his opinion, emissions from air transport can affect human life and the environment. Then a series of impacts are offered to the standard price of a ticket to respond to these questions. A dichotomous scale is given to the respondent so that he can answer either "Yes" or "No" (Shaari, Abdul-Rahim, and Afandi 2020). The main criticisms made by authors of this method are related to reliability, whether the results can be reproduced in other populations, and the validity related to the accuracy of the results (Kealy et al., 1990).

3. Methodology

This study is a mixed one where a quantitative and qualitative methodology is considered. On the one hand, qualitative research is an unstructured research methodology based on small samples that provide insights and help understand the problem (Malhotra & Birks, 2004). On the other hand, quantitative research is a systematic process of collecting observable and quantifiable data based on observing objective facts and events that exist independently of the researcher (Freixo, 2011).

This study includes bibliographical research. Bibliographic research is developed from material prepared, especially scientific articles (Gil, 2002). Leong and Austin (2006) believe that reading, perceiving, and analysing already done investigations helps the researcher establish a foundation for the study base, as it is thus possible to know what is already known and what is unknown. This study also analyses some annual reports published by airlines to utilise some of the data on those reports to process and apply it to the created methodology. A case study is also taken into consideration in this research, especially because utilising a case study is a good tool when the author intends to pose questions such as "how" and "why" (Yin, 2001).

The method created by the author to determine the economic impact on an airline that operates with SAF is SECA (SAF Em Companhias Aéreas), which translates to “SAF in Airlines”. This method starts with calculating the economic impact and proposes three solutions to mitigate this impact.

The first part of the SECA model involves the determination of the economic impact of currently operating with SAF on an airline. It is necessary to complete two processes to determine this economic impact. Firstly, collecting data, mostly from the companies' Annual Reports, is necessary. Then, with the data in hand, calculations are performed to generate the desired results.

Table 1. Data to be Collected (SECA)
Source: Own Elaboration

	Airline
Fuel Costs	- €
Fuel Consumed (Ton)	0
Cost €\L CAF	- €
Cost €\L SAF	- €
Revenue	- €
Profit\Loss Result	- €
Transported passengers	0
Average Fare	- €
Number of Offered Seats	0
Passenger Load Factor	0%

Table 1 depicts the data retrieved, and each of these values can mostly be obtained by analysing the company's Annual Report. However, the Cost €\L SAF isn't normally a value presented nowadays on the airline's Annual Report. SECA model integrates values calculated from other investigation sources, such as Table A1 presented in Annexe 1 created by Hamdan et al. (2022), where the minimum fuel selling price of SAF can be understood.

After collecting all the necessary data, applying some formulas to calculate the economic impact of operating with SAF nowadays is possible, considering that SAF can only represent half of the aircraft's tanks. However, the SAF by the SIP transformation can only represent 10% of the tank. The first formula calculates the Complex Fuel Costs Equation (1), which can be seen as the airline's fuel costs if they have used SAF within the legal limits.

$$Complex\ Fuel\ Costs = (€\backslash L\ SAF \times Liters\ Consumed\ SAF) + (€\backslash L\ CAF \times Liters\ Consumed\ CAF) \quad (1)$$

After calculating these Complex Fuel Costs, it is possible to calculate the New Profit/Loss Result Equation (2), which can be interpreted as the airline's financial result if SAF were used in their daily operations.

$$New\ Profit\backslash Loss\ Result = Profit\backslash Loss\ Result + Fuel\ Costs - Complex\ Fuel\ Costs \quad (2)$$

Because the new economic result is already calculated, it is possible to determine the impact of this SAF incorporation on the airline. This impact can be seen in two ways: the actual Impact on the Profit\Loss Result Equation (3) and the Percentage Variation Equation (4) between the real Profit\Loss Result and the New Profit\Loss Result.

$$Impact\ Profit\backslash Loss\ Result = New\ Profit\backslash Loss\ Result - Profit\backslash Loss\ Result \quad (3)$$

$$\Delta\% = \left|\frac{(Profit\backslash Loss\ Result - New\ Profit\backslash Loss\ Result)}{Profit\backslash Loss\ Result}\right| \times 100 \quad (4)$$

SECA also proposes three solutions to mitigate the economic impact of operating with SAF on an airline. Firstly, it is important to understand that increasing airline revenue is the only way to erase this economic impact. It is necessary to apply the formula of the "Required Revenue" Equation (5) to know how much the airline would need to sell to have no economic impact, which means, in this case, to maintain its operational margin.

$$Required\ Revenue = Revenue + |Impact\ Profit\backslash Loss\ Result| \quad (5)$$

After calculating the Required Revenue, it is possible to start thinking about the possible solution to reach this value. SECA considers that there are three possible ways to get to the Required Revenue. Having its basis that the revenue is calculated by multiplying the Number of Passengers Transported by the Average Fare of the airline, SECA considers that the first solution is increasing the Number of Passengers Transported and maintaining the Average Fare. The second solution is the opposite: maintaining the Number of Passengers Transported and increasing the Average Fare. The third solution uses the outputs of the other two to create an optimal solution where the Number of Passengers Transported and the Average Fare increase, but not as much as in the other two solutions, which translates to less risk and efforts for the airlines and for the passengers.

If the airline opts for the first solution, it must calculate the Required Number of Passengers Transported Equation (6). These values will determine how many passengers the airline would need to transport, maintaining its Average Fare. Secondly, the airline would need to check if this solution is viable to the operation, so it is necessary to calculate the Passenger Load Factor (SAF) Equation (7). With these results, the airline is checking if the increase in passengers would necessarily represent an increase in the number of flights. So, if this value is under 100%, they wouldn't need to increase the number of flights to follow this solution.

$$Required\ Number\ of\ Passengers\ Transported\ = \frac{Required\ Revenue}{Average\ Fare} \tag{6}$$

$$Passenger\ Load\ Factor\ (SAF) = \frac{Required\ Number\ of\ Passengers\ Transported}{Number\ of\ Offered\ Seats} \tag{7}$$

If the airline opts for the second solution, it will calculate the Required Average Fare Equation (8). These values will determine how much the average fare will need to maintain the number of passengers transported, but still reach the Required Revenue. To check if this is a viable or non-viable solution, the airline must calculate the Increase (€) Equation (9) and then develop a CVM-based questionnaire to assess passengers' WTP. This model should describe the scenario, saying the average fare price and then giving the option to the passengers to accept or refuse the increase in the value. Therefore, this will only be a viable option if any value reaches the 100% mark.

$$Required\ Average\ Fare\ = \frac{Required\ Revenue}{Number\ of\ Passengers\ Transported} \tag{8}$$

$$Increase\ (€) = Required\ Average\ Fare\ - Average\ Fare \tag{9}$$

The third option considers the questionnaire results and calculates a Weighted Required Average Fare Equation (10) to reach the optimal WTP. After that, a Weighted Required Number of Passengers Transported Equation (11) is determined. With this, it is possible to reach an optimal solution where the airline has an increase in both variables, but it is a much lower one than the other two solutions.

$$Weighted\ Average\ Fare\ Required = (\%Yes(CVM) \times Average\ Fare\ Required) + (\%No(CVM) \times Average\ Fare \tag{10}$$

$$Weighted\ Required\ Number\ of\ Passengers\ Transported\ = \frac{Required\ Revenue}{Weighted\ Average\ Fare\ Required} \tag{11}$$

4. Results and Discussions

The airlines chosen to take part in this case study were Ryanair to take part in the LCC case, and Emirates to comprehend and analyse a specific FSC. Ryanair was the airline chosen to take part in this investigation, mostly because of two factors, the first one being that they are a very well-known and established Low-Cost Carrier and the second one related to their already assumed intention to be a more sustainable airline, adopting strategies such as using SAF on their daily operations. On the other hand, Emirates was chosen basically because it is a Full-Service Carrier and either because of their already very massive and well-known investments in the development of the SAF industry.

Table 2. Data Collected from Azores Airlines (SECA)
Source: (Emirates, 2023; Ryanair, 2023)

	Ryanair	Emirates
Fuel Costs	4 025 700 000.00€	4 406 264 970.00€
Fuel Consumed (Ton)	4955750	8463363
Cost €\L CAF	0.6499€	0.4165€
Cost €\L SAF	-	-
Revenue	6 930 000 000.00€	21 439 474 885.55€
Profit\Loss Result	1 314 000 000.00€	2 673 549 195.00€
Transported passengers	169 000 000	43 626 000

Average Fare	41.01€	491.44€
Number of Offered Seats	181 720 430	66 706 422
Passenger Load Factor	93.0%	65.4%

Following the steps of SECA and calculating the economic impact, the first thing to be calculated is the Complex Fuel Costs Equation (1) that utilises either the Fuel Consumed (Ton), the Cost €\ LCAF and the Cost €\L SAF. This study's values on the Cost €\L SAF are presented in Annexe 1, mostly because of the lack of information. After calculating the Complex Fuel Costs Equation (1), the New Profit/Loss Results Equation (2) should be determined. For this formula, the data required is the Complex Fuel Costs, the Fuel Costs and the Profit/Loss Result. After this, it is possible to determine the actual Impact Profit\Loss Result Equation (3) alongside the Δ% Equation (4) of operating with SAF compared to a normal CAF operation. For the first formula, the data required is either the New Profit\Loss Result or the Profit\Loss Result, while for calculating Δ%, the data required is the same.

After applying all of these formulas to the list of Types of SAF that the European Civil Aviation Conference (2023) developed, it is possible to create the next table.

Table 3. Economic Impact (SECA)
Source: Own Elaboration

	Ryanair		Emirates	
Type of SAF	Impact Profit\Loss Results	Δ%	Impact Profit\Loss Results	Δ%
A (Pioneer)	(805 732 988.59€)	61%	(2 610 405 221.25€)	98%
A (nth)	(248 211 078.76€)	19%	(1 658 276 883.75€)	62%
B (Pioneer)	(3 066 794 067.34€)	233%	(6 471 814 590.00€)	242%
B (nth)	30 549 876.16€	-2%	(1 182 212 715.00€)	44%
C (Pioneer)	(1 394 228 337.85€)	106%	(3 615 429 577.50€)	135%
C (nth)	(1 115 467 382.94€)	85%	(3 139 365 408.75€)	117%

Analysing Table 3 makes it possible to understand that all types of SAF are not more economically viable than CAF, except for SAF-B (nth) in the Ryanair case, because the €\L of CAF that they acquire is more expensive than the €\L of this SAF type. This conclusion can be made because, looking at the Impact Profit\Loss Results column, it's possible to see that the impact is always positive, which means that in all cases, with the exception already mentioned, the actual Profit\Loss Result of Ryanair and Emirates will tend to decrease this year. Also, analysing the next column, the Δ% one, the study can conclude that there are types of SAF that are less viable and more viable than others. For example, SAF-B (nth) is the type of fuel that tends to be the most economically viable because it has a €\L of SAF much lower than the other types of SAF; however, analysing the SAF-B (Pioneer) is the type of SAF that's less viable, economically speaking.

After calculating the economic impact, it is now possible to follow the steps proposed by SECA to check the proposed solutions. Before analysing the solutions, it is necessary to calculate the Required Revenue Equation (5). Table 4 depicts how much the airlines would need to sell in terms of revenue to have no economic impact because of SAF.

Table 4. Required Revenue (SECA)
Source: Own Elaboration

	Required Revenue	
Type of SAF	Ryanair	Emirates
A (Pioneer)	7 735 732 988.59€	24 049 880 106.80€
A (nth)	7 178 211 078.76€	23 097 751 769.30€
B (Pioneer)	9 996 794 067.34€	27 911 289 475.55€
B (nth)	6 899 450 123.84€	22 621 687 600.55€
C (Pioneer)	8 324 228 337.85€	25 054 904 463.05€
C (nth)	8 045 467 382.94€	24 578 840 294.30€

Table 4 values allow us to proceed to the calculation of the three solutions that SECA proposes. The first solution is the one that maintains the Average Fare of the airline but increases the Number of Passengers Transported. The study has calculated the Required Number of Passengers Transported Equation (6) to determine how many passengers would need to be transported and uses the Required Revenue and the Average Fare to check whether this is viable. It was calculated that the Passenger Load Factor (SAF) Equation (7) needs the data relative to the Required Number of Passengers Transported and the Number of Offered Seats. It is possible to create Table 5 by calculating both of these formulas:

Table 5. First Solution (SECA)
Source: Own Elaboration

	Ryanair		Emirates	
Type of SAF	Passenger Load Factor (SAF)	Viability	Passenger Load Factor (SAF)	Viability
A (Pioneer)	103.81%	✕	73.36%	✓
A (nth)	96.33%	✓	70.46%	✓
B (Pioneer)	134.16%	✕	85.14%	✓
B (nth)	92.59%	✓	69.01%	✓
C (Pioneer)	111.71%	✕	76.43%	✓
C (nth)	107.97%	✕	74.98%	✓

After analysing this solution, it is possible to understand that not all solutions are viable depending on the type of SAF that is considered. Firstly, analysing the Emirates case, it's possible to understand that actually every single type of SAF is viable, only because of a mathematically rational approach that remains on the fact that the PLF (SAF) is never higher than the 100% mark. On the other hand, analysing the Ryanair case, this is not the case, because in some cases the PLF (SAF) is higher than 100% which means that the airline would need to increase its capacity in order to meet a higher demand. Thus, this happened on the LCC and not on the FSC because, in this case, Emirates still had a much lower PLF than Ryanair, which meant that they had more room to be filled in comparison to Ryanair.

The second solution assumes that the best strategy is to increase the Average Fare and maintain the Number of Passengers Transported. To determine how much the Average Fare would need to grow to achieve the Required Revenue, the SECA proposes to calculate the Required Average Fare Equation (8) and then calculate the Increase (€) Equation (9) to determine how much each Average Fare would grow.

To calculate the Required Average Fare (8), the necessary data is the Required Revenue and the Number of Passengers Transported, whereas to calculate the Increase (€) Equation (9), the data required is the Required Average Fare and the Average Fare.

Table 6. Second Solution (SECA)
Source: Own Elaboration

	Ryanair		Emirates	
Type of SAF	Required Average Fare	Increase (€)	Required Average Fare	Increase (€)
A (Pioneer)	45.77€	4.77€	551.27€	59.84€
A (nth)	42.47€	1.47€	529.45€	38.01€
B (Pioneer)	59.15€	18.15€	639.79€	148.35€
B (nth)	40.83€	0.18€	518.54€	27.10€
C (Pioneer)	49.26€	8.25€	574.31€	82.87€
C (nth)	47.61€	6.60€	563.40€	71.96€

From Table 6, it is possible to conclude what the Required Average Fare would be to reach the Required Revenue and how much the Average Fare would increase. Having both these values, it is then possible to create the questionnaire based on the CVM model. There is one case where the Average fare would decrease, which means that in this case, this fuel would be more economically viable.

The study created a questionnaire following the CVM structure, and the results are presented in Figure 4 and Figure 5. With this questionnaire, it is possible to measure if the passengers' WTP suffers any change when knowing that the airline they are flying in is using a more sustainable fuel that contributes to the protection of the environment and the development of the industry itself.

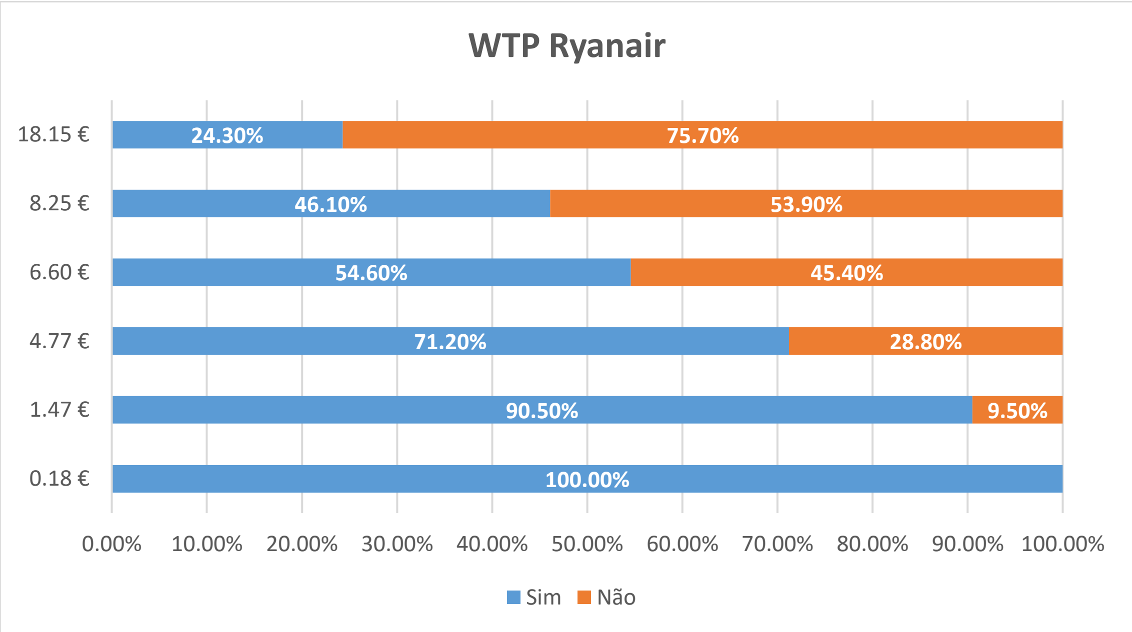

Figure 4. WTP (Ryanair)
Source: Own Elaboration

Figure 4 depicts the results of the CVM questionnaire to determine whether or not the passengers' WTP would increase when knowing that they are contributing to the development and protection of the planet, in the case of the LCC business model. Analysing Figure 4, it's possible to conclude that only one of these solutions is viable, because there is one scenario where the Average Fare would decrease, which means that everyone is willing to pay less, resulting in 100% acceptance. The problem of not reaching the 100% mark is that the Required Revenue is not reached, so the airline will still be negatively impacted by operating with SAF. However, from this figure, there are other conclusions to retain, the first one being that people are willing to pay more to contribute to protecting the environment.

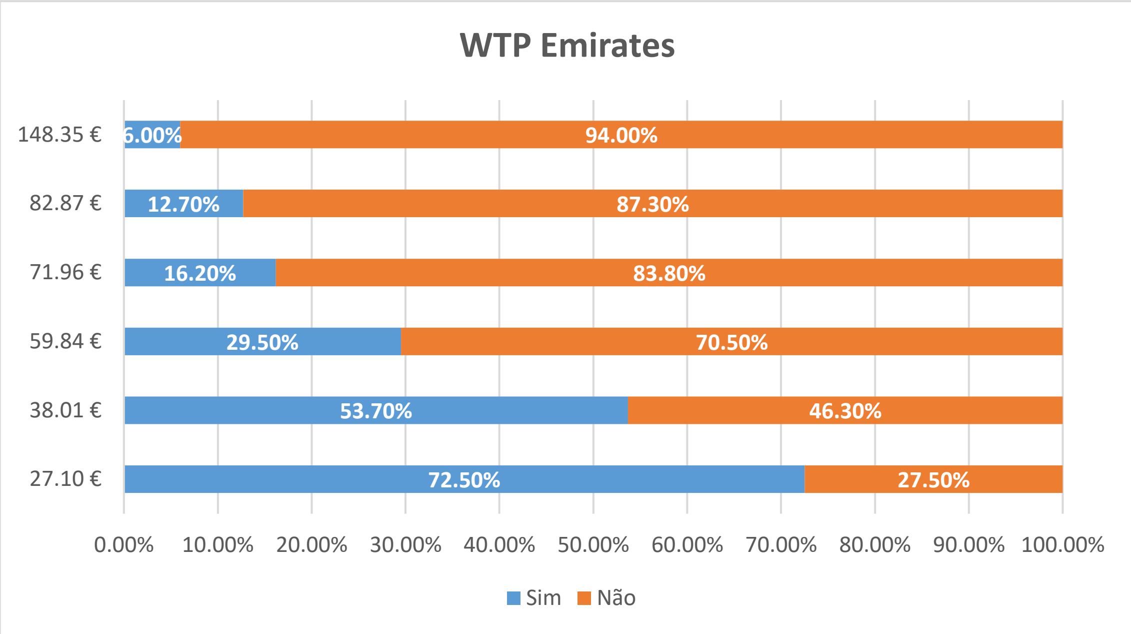

Figure 5. WTP (Emirates)
Source: Own Elaboration

Figure 5 depicts the results of the CVM questionnaire to determine whether or not the passengers' WTP would increase when knowing that they are contributing to the development and protection of the planet, in the case of the FSC business model. Analysing Figure 5, it's possible to conclude that none of these solutions is viable, because none of them reach the 100% acceptance mark. In this case, actually, this solution is far less close to being viable in comparison to the LCC, mainly because its Increase (€) is higher than in Ryanair's case.

In contrast, the value of the Increase (€) increases, the percentage of people willing to pay decreases and the percentage of people not willing to pay increases. The outputs of this second solution are also used in the third solution. The next conclusion to retain is that it is possible to watch a standard.

As mentioned, the third solution uses the outputs of the second solution and determines what could be an optimal solution. This solution calculates the minimum that the Required Average Fare and the Required Number of Passengers Transported need to grow to reach the Required Revenue. Firstly, the study has calculated the Weighted Required Average Fare Equation (10) that uses the outputs of the CVM questionnaire and the Average Fare and the Required Average Fare. Secondly, the Weighted Required Number of Passengers Transported (11) to be calculated needs either the Weighted Required Average Fare or the Required Revenue.

Table 7. Third Solution (SECA)
Source: Own Elaboration

	Weighted Required Average Fare		Weighted Required Number of Passengers Transported	
Type of SAF	Ryanair	Emirates	Ryanair	Emirates
A (Pioneer)	44.41 €	509.09 €	174203738	47240660
A (nth)	42.34 €	511.85 €	169535941	45125896
B (Pioneer)	45.42 €	500.34 €	220094562	55784534
B (nth)	40.83 €	511.09 €	168979920	44261868
C (Pioneer)	44.81 €	501.96 €	185753730	49913699
C (nth)	44.61 €	503.10 €	180336655	48855022

Table 7 shows that it is possible to preview the best solution for either Ryanair or Emirates. This solution could be the best, mostly because it is the one where there are smaller adjustments to each variable, the Fare and the Number of Passengers. By taking into account the percentages of people willing and not willing to pay a value, it's possible to determine a fare that is a bit higher than the Average Fare but still is viable to be sold.

5. Conclusion

This study aimed to assess the economic impact on airlines operating with SAF compared to the same airline operating with CAF using the SECA model created by the author, which later proposes three solutions to turn the expected negative economic impact obsolete. As mentioned, SAF is seen as the future of aviation in terms of fuel, not only in the mid-term but also in the long-term, with future alternatives like hydrogen expected to be more viable and less polluting. Today's airlines also demonstrate that SAF is a viable option regarding its environmental sustainability. However, small production in a big industry, such as aviation, is difficult to implement and develop SAF production. The small production of a big demand also creates the selling prices of SAF, which are substantially higher than CAF. Therefore, this could discourage some airlines from opting out of this fuel because economic sustainability may be under more pressure as the costs increase.

The case study chosen for this research was Ryanair and Emirates to evaluate which business model performs better under the pressure of being more sustainable from an environmental point of view, knowing that economically, there is a significant impact. After analysing the economic impact, the investigation followed the SECA steps and calculated the three solutions that the model proposes.

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Annexe 1- Minimum SAF Selling Price per Litre

Table A1. The minimum fuel selling price of SAF
Source: (European Civil Aviation Conference, 2023)

Type of SAF	Minimum Selling Price (Litre)	Conversion Method
SAF-A (Pioneer)	1.74 €	ATJ
SAF-A (nth)	0.81 €	ATJ
SAF-B (Pioneer)	1.58 €	GFT
SAF-B (nth)	0.70 €	GFT
SAF-C (Pioneer)	1.89 €	HEFA
SAF-C (nth)	1.35 €	HEFA

The difference between the Pioneer's and nth's fuels is related to what this type of feedstock combined with a specific conversion method, in average costs nowadays and what is expected to be its price in the future when the processes and technologies influence the selling price of SAF to be cheaper.

APPENDIX 4 – SCIENTIFIC PAPER II (27TH ATRS 2024)

SAF Economic Impact on Aircraft Operations: Case Study LCC vs FSC (to be considered to best student paper award)

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Abstract | A much more sustainable aviation sector can be reached by a bigger incorporation of SAF in daily operations, which nowadays is impossible due to the low production compared to the high demand. Despite probably being the future aviation fuel, SAF has some disadvantages compared to CAF, the main one related to the airline's sale price. Being sustainable to the environment and unsustainable from an economic point of view to the airlines is a big dilemma for the aviation sector. This study created the SECA method to better analyze this predictable economic impact, proposing three solutions and calculating the economic impact. Two solutions follow a CVM method to determine whether passengers' willingness to pay increases when knowing that the airline is using a much more sustainable fuel to operate. This study in specific focuses on comparing whether a LCC or a FSC can incorporate SAF on their daily operations measuring their specific economic impacts and potential solutions.

Keywords | Sustainable Aviation Fuel; Business Sustainability; Fuel Costs; Incentives for using SAF; Passengers' Willingness to Pay.

APPENDIX 5 – SCIENTIFIC PAPER III (26TH ATRS 2023)

SAF Economic Impact on Aircraft Operations: Case Study SATA Azores Airlines (to be considered to best student paper award)

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Abstract | A much more sustainable aviation sector can be reached by a bigger incorporation of SAF in daily operations, which nowadays is impossible due to the low production compared to the high demand. Despite probably being the future aviation fuel, SAF has some disadvantages compared to CAF, the main one related to the airline's sale price. Being sustainable to the environment and unsustainable from an economic point of view to the airlines is a big dilemma for the aviation sector. This study created the SECA method to analyze this predictable economic impact better, proposing three solutions and calculating the economic impact. Two solutions follow a CVM method to determine whether passengers' willingness to pay increases when knowing that the airline is using a much more sustainable fuel to operate.

Keywords | Sustainable Aviation Fuel; Business Sustainability; Fuel Costs; Incentives for using SAF; Passengers' Willingness to Pay; Business Models.

APPENDIX 6 – SCIENTIFIC PAPER IV (IX RIDITA 2024)

Towards Sustainable Aviation: Assessing Airport's Progress Towards Net Zero Emissions by 2050

Introduction

This research seeks to determine the progress of a particular airport infrastructure, in this case Changi Airport, towards reducing its emissions of polluting gases, with a view to achieving the 2050 Net Zero goal.

Environmental sustainability is one of the three pillars of sustainability as a whole. As a result, it is imperative to take action and set goals as we see the deterioration of environmental sustainability. The goal of Net Zero by 2050 arises from this and seeks to reduce polluting gas emissions to acceptable levels for environmental preservation. With this in mind, and focusing on the aeronautics sector, this reduction is really important and must be carried out in the most varied areas of the sector. Above all, it is necessary to reduce the emissions of polluting gases from airlines, with airport infrastructures appearing as a secondary, but considerable, priority.

Airport infrastructure emissions can be measured in a number of ways, but the ACI methodology is used for segmenting emissions by source, which is divided into scopes.

This research develops a methodology that seeks to make predictions and thus determine whether the future for any airport infrastructure in terms of emissions is bright. The Airport Progress Scope Emissions, the name adopted for the methodology, has a quantitative aspect, with the collection and mathematical processing of data, and a qualitative aspect with the justification of why there has been an increase or decrease in emissions, as well as what the airport infrastructure has planned for the future in order to contribute to a reduction in emissions, across the three Scopes.

ANNEXE 1 – CORSIA SUSTAINABILITY CRITERIA APPLICABLE FOR BATCHES OF CORSIA ELIGIBLE FUEL PRODUCED BY A CERTIFIED FUEL PRODUCER BEFORE 1 JANUARY 2024

Table A1 - CORSIA Sustainability Criteria Applicable for Batches of CORSIA Eligible Fuel Produced by a Certified Fuel Producer Before 1 January 2024
Source: (International Civil Aviation Organization, 2021a)

Theme	**Criteria**
1 – Greenhouse Gases	Criterion 1.1: CORSIA eligible fuel will achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
2 – Carbon Stock	Criterion 2.1: CORSIA eligible fuel will not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands, as these lands all have high carbon stocks.
	Criterion 2.2: In the event of land use conversion after 1 January 2008, as defined based on the Intergovernmental Panel on Climate Change (IPCC) land categories, direct land use change (DLUC) emissions will be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value will replace the default ILUC value.

ANNEXE 2 – CORSIA SUSTAINABILITY CRITERIA APPLICABLE FOR BATCHES OF CORSIA ELIGIBLE FUEL PRODUCED BY A CERTIFIED FUEL PRODUCER ON OR AFTER 1 JANUARY 2024

Table A 2 - CORSIA Sustainability Criteria Applicable for Batches of CORSIA Eligible Fuel Produced by a Certified Fuel Producer on or After 1 January 2024
Source: (International Civil Aviation Organization, 2021a)

Theme	Criteria
1 – Greenhouse Gases	Criterion 1.1: CORSIA eligible fuel will achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
2 – Carbon Stock	Criterion 2.1: CORSIA eligible fuel will not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands, as these lands all have high carbon stocks.
	Criterion 2.2: In the event of land use conversion after 1 January 2008, as defined based on the Intergovernmental Panel on Climate Change (IPCC) land categories, direct land use change (DLUC) emissions will be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value will replace the default ILUC value.
3 – Greenhouse Gas Emissions Reduction Permanence	Criterion 3.1: Operational practices will be implemented to monitor, mitigate and compensate any material incident of nonpermanence resulting from carbon capture and sequestration (CCS) activities.
4 - Water	Criterion 4.1: Operational practices will be implemented to maintain or enhance water quality.
	Criterion 4.2: Operational practices will be implemented to use water efficiently and to avoid the depletion of surface or groundwater resources beyond replenishment capacities.
5 - Soil	Criterion 5.1: Agricultural and forestry best management practices for feedstock production or residue collection will be implemented to maintain or enhance soil health, such as physical, chemical and biological conditions.
6 - Air	Criterion 6.1: Air pollution emissions will be limited.
7 - Conservation	Criterion 7.1: CORSIA SAF will not be made from biomass obtained from areas that, due to their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area, unless evidence is provided that shows the activity does not interfere with the protection purposes.
	Criterion 7.2: Low invasive-risk feedstock will be selected for cultivation, and appropriate controls will be adopted with the intention of preventing the uncontrolled spread of cultivated alien species and modified microorganisms.
	Criterion 7.3: Operational practices will be implemented to avoid adverse effects on areas that, due to their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area.
8 - Waste and Chemicals	Criterion 8.1: Operational practices will be implemented to ensure that waste arising from production processes, as well as chemicals used, are stored, handled, and disposed of responsibly.
	Criterion 8.2: Responsible and science-based operational practices will be implemented to limit or reduce pesticide use.
	Criterion 8.3: Operational practices will be implemented to prevent, minimise, and mitigate any damage from the unintentional release of fossil resources, fuel products, and/or other chemicals.
9 – Seismic and Vibrational Impacts	Not applicable
10 - Human and Labour Rights	Criterion 10.1: CORSIA SAF production will respect human and labour rights.

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

ANNEXE 3 – CORSIA SUSTAINABILITY CRITERIA APPLICABLE FOR BATCHES OF CORSIA LOWER CARBON AVIATION FUEL PRODUCED BY A CERTIFIED FUEL PRODUCER ON OR AFTER 1 JANUARY 2024

Table A 3 - CORSIA Sustainability Criteria Applicable for Batches of CORSIA Lower Carbon Aviation Fuel Produced by a Certified Fuel Producer on or After 1 January 2024
Source: (International Civil Aviation Organization, 2021a)

Theme	Principle	Criteria
1 – Greenhouse Gases	Principle: CORSIA LCAF should generate lower carbon emissions on a life cycle basis.	Criterion 1.1: CORSIA LCAF will achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
2 – Carbon Stock	Principle: CORSIA LCAF should not be made from feedstock obtained from land/aquatic systems with high biogenic carbon stock.	Criterion 2.1: CORSIA LCAF will not be made from feedstock that is either obtained/extracted from land or aquatic ecosystems converted after 1 January 2008 that was primary forest, wetlands, peat lands, coral reefs, kelp forests, seagrass meadows, estuaries, tidal salt marshes or mangrove forests or contributes to degradation of the carbon stock in primary forests, wetlands, peatlands, coral reefs, kelp forests, seagrass meadows, estuaries, tidal salt marshes or mangrove forests as these systems all have high carbon stocks.
		Criterion 2.2: In the event of land use conversion after 1 January 2008, as defined based on the Intergovernmental Panel on Climate Change (IPCC) land categories, direct land use change (DLUC) emissions will be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value will replace the default ILUC value. Where there is no default ILUC value, DLUC will be calculated and used in place of a default ILUC value.
3 – Greenhouse Gas Emissions Reduction Permanence	Principle: Emissions reductions attributed to CORSIA LCAF should be permanent.	Criterion 3.1: Operational practices will be implemented to monitor, mitigate and compensate any material incident of non-permanence resulting from carbon capture and sequestration (CCS) activities.
		Criterion 3.2 Operational practices and financial measures will be implemented to monitor, mitigate and compensate any material incidence of greenhouse gas release resulting from the closure and post-closure period of oil and gas wells.
4 - Water	Principle: Production of CORSIA LCAF should maintain or enhance water quality and availability.	Criterion 4.1: Operational practices will be implemented to maintain or enhance water quality.
		Criterion 4.2: Operational practices will be implemented to use water efficiently and to avoid the depletion of surface or groundwater resources beyond replenishment capacities.

5 - Soil	Principle: Production of CORSIA LCAF should maintain or enhance soil health.	Criterion 5.1: Operational practices will be implemented to maintain or enhance soil health, such as physical, chemical and biological conditions.
6 - Air	Principle: Production of CORSIA LCAF should minimise negative effects on air quality.	Criterion 6.1: Air pollution emissions will be limited.
7 - Conservation	Principle: Production of CORSIA LCAF should maintain biodiversity, conservation value, and ecosystem services.	Criterion 7.1: CORSIA LCAF will not be made from feedstock from areas that, due to their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area, unless evidence is provided that shows the activity does not interfere with the protection purposes.
		Criterion 7.2: Low invasive-risk feedstock will be selected for cultivation, and appropriate controls will be adopted with the intention of preventing the uncontrolled spread of cultivated alien species and modified microorganisms.
		Criterion 7.3: Operational practices will be implemented to avoid adverse effects on areas that, due to their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area.
8 - Waste and Chemicals	Principle: Production of CORSIA LCAF should promote responsible management of waste and the use of chemicals.	Criterion 8.1: Operational practices will be implemented to ensure that waste arising from production processes, as well as chemicals used, are stored, handled and disposed of responsibly.
		Criterion 8.2: Responsible and science-based operational practices will be implemented to limit or reduce flammable, corrosive and toxic chemical use.
		Criterion 8.3: Operational practices will be implemented to prevent, minimise, and mitigate any damage from the unintentional release of fossil resources, fuel products, and/or other chemicals.
9 – Seismic and Vibrational Impacts	Principle: Production of CORSIA LCAF should minimise seismic, acoustic, and vibrational impacts.	Criterion 9.1: Operational practices will be implemented to minimise seismic impacts related to surface, subsurface, and underwater activities.
		Criterion 9.2: Operational practices will be implemented to minimise acoustic energy and vibrational impacts related to surface, subsurface, and underwater activities.
10 - Human and Labour Rights	Principle: Production of CORSIA LCAF should respect human and labour rights.	Criterion 10.1: CORSIA LCAF production will respect human and labour rights.
11 - Land use rights and land use	Principle: Production of CORSIA LCAF should respect land rights and land use rights, including	Criterion 11.1: CORSIA LCAF production will respect existing land rights and land use rights, including indigenous peoples' rights, both formal and informal.

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

ANNEXE 4 – SAF SELLING PRICE

Table A 4 - SAF Selling Price
Source: (European Civil Aviation Conference, 2023)

Type of SAF	Minimum Selling Price (Litre)	Conversion Method
SAF-A[P]	1.74 €	ATJ
SAF-A[N]	0.81 €	ATJ
SAF-B[P]	1.58 €	GFT
SAF-B[N]	0.70 €	GFT
SAF-C[P]	1.89 €	HEFA
SAF-C[N]	1.35 €	HEFA