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Effects of the RefuelEU Aviation regulation on the aviation sector in Finland

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Abstract

The European Union's objective of climate neutrality by the year 2050 demands rapid steps from all sectors, including the aviation sector, which currently accounts for 4% of the total GHG emissions in the European Union. As a part of its 'Fit for 55' climate strategy, the EU has adopted Regulation (EU) 2023/2405 - commonly referred as ReFuelEU Aviation - which introduces mandates on the use of Sustainable Aviation Fuels (SAF) across commercial aviation within all Member States seeking to reduce emissions from air transport through increased uptake of cleaner alternatives to fossil-based jet fuel.

This Master's thesis investigates the anticipated impacts of the ReFuelEU Aviation regulation, with a particular focus on its operational implications for airlines and aviation fuel suppliers in Finland. The analysis explores how the regulation may influence operational procedures, fuel logistics, and compliance strategies within the national aviation ecosystem. Emphasis is placed on understanding both the challenges and opportunities posed by the SAF blending mandates, including the introduction of synthetic aviation fuels (eSAF), and the operational restrictions of the anti-tankering provision.

The study draws its data from regulatory document analysis, stakeholder perspectives, and emission datasets to assess the regulation's role in supporting the sustainable transformation of European aviation. The findings of the study indicate that Finland is well positioned to comply with the regulation, although concerns were voiced among the stakeholders about the steep progression of the SAF mandate, as well as the uncertainties regarding eSAF availability. Operational effects of the regulation include changes in fuel load and route planning, particularly under the limitations imposed by the regulation's anti-tankering mandate. Quantitative projection analysis on the Finnish aviation emission data reveals that the regulation will lead to a meaningful reduction in aviation related emissions, underlining its importance in sustainable transformation in the aviation sector.

Keywords Sustainable Aviation Fuel, SAF, Aviation, ReFuelEU

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Euroopan Unionin tavoitteet ilmastoneutraalisuudesta vuoteen 2050 mennessä edellyttävät nopeita toimia kaikilta sektoreilta, myös ilmailun alalta, joka vastaa tällä hetkellä noin neljästä prosentista EU:n kasvihuonepäästöistä. Osana laajempaa 'Fit for 55' ilmastostrategiaansa EU on hyväksynyt asetuksen (EU) 2023/2405, joka tunnetaan myös nimellä ReFuelEU Aviation. ReFuelEU velvoittaa jäsenvaltioita käyttämään uusiutuvia lentopolttoaineita (SAF) kaupallisessa ilmailussa vähentääkseen fossiilipohjaisista lentopolttoaineista aiheutuvia päästöjä.

Tämä maisterintutkielma tarkastelee ReFuelEU -asetuksen vaikutuksia erityisesti suomalaisten lentoyhtiöiden ja lentopolttoaineen valmistajien operatiiviseen toimintaan, kuten polttoainelogistiikkaan sekä sääntelyn noudattamiseen liittyviin strategioihin. Erityishuomiota kiinnitetään muun muassa SAF-sekoitusvelvollisuuteen, synteettisten lentopolttoaineiden (eSAF) käyttöönottoon sekä lentojen tankkeroinnin kieltävään mandaattiin.

Tutkimus pohjautuu eri määräysten kirjallisuuskatsaukseen, sidosryhmille suoritettuihin haastatteluihin, sekä kansallisen ilmailun päästödatan tarkasteluun. Tutkimuksen tulokset osoittavat, että Suomi on hyvässä asemassa määräyksen vaatimusten täyttämisessä, vaikka sidosryhmät toivat esiin huolia muun muassa SAF-velvoitteen jyrkästä kasvusta sekä synteettisten polttoaineiden saatavuuteen liittyvistä epävarmuuksista. Määräyksen operatiiviset vaikutukset nähdään polttoainelogistiikan sekä lentoreittien suunnittelussa. Kvantitatiivinen tarkastelu Suomen ilmailun päästöistä osoittaa, että määräyksellä on merkittävä vaikutus päästöjen vähentämisessä, mikä korostaa sen tärkeyttä ilmailualan kestävän kehityksen tukemisessa.

Avainsanat Uusiutuva lentopolttoaine, SAF, ilmailu, ReFuelEU

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Preface

I want to express my deepest gratitude to Professor Osiris Valdez Banda and my thesis advisor Pasi Piirainen for their advice and guidance and for making this thesis possible. I would also like to extend my thanks to the professionals at Neste and Finnair who participated in the interviews and generously shared their knowledge and expertise. Writing the thesis was not an easy task, but all the more enjoyable. What makes it even more enjoyable, is that it marks the end of my 10-year-long studies at Aalto University. I am happy that this long journey will end on a thesis that I can be truly proud of.

The best things in life happen in a flash, but not without a lifetime of preparation.

Lastly, I want to thank my family and especially my partner for their continuous support and patience.

Helsinki, 28.07.2025
Pietari Reijonen

Abbreviations

ATR	ATR-72, a narrow-body aircraft used by Finnair
CAF	Conventional Aviation Fuel
GHG	Green House Gas
HEFA	Hydroprocessed Esters and Fatty Acids
ICAO	International Civil Aviation Organization
IATA	International Air Transport Association
EASA	European Union Aviation Safety Agency
ECAC	European Civil Aviation Conference
EEA	European Economic Area
eSAF	Synthetic Aviation Fuel
PtL	Power-to-Liquid, an alternative fuel production pathway
SAF	Sustainable Aviation Fuel
SBC	Synthetic Blend Component
UCO	Used Cooking Oil

1 Introduction

According to the International Civil Aviation Organisation (ICAO) [1] aviation is a significant contributor in Green House Gas (GHG) emissions, accounting for about 4% of the total GHG emissions in the European Union, and this number is only expected to increase. The rate that the aviation industry is expanding also calls for action in emission reduction: ICAO [2] estimates that the passenger air traffic in Europe will grow more than 3% yearly until the year 2050. The seemingly small percentages of aviation related emissions compared to other industries are still significant, since emissions produced at high altitudes have a much greater impact due to the higher altitude that the pollutants are emitted [3]. The European Union's objectives on climate neutrality by the year 2050 demand rapid steps for every Member State to decarbonise. For the aviation sector, this necessitates the ramp-up of Sustainable Aviation Fuels (SAF), and stricter regulation in the industry to ensure equality inside the Union, without disturbing the connectivity that the air transportation offers.

SAF is a key tool in reducing the emissions in aviation. In the recent years, many legislative bodies around the world have been enforcing emission cutting schemes by introducing SAF as a part of their legislation. Similarly, the European Union has set a goal, part of the 'Fit for 55' package [4], to cut the emissions in the EU by 55% by the year 2030 compared to the year 1990 level, and to make EU climate-neutral by the year 2050. A big part of this EU legislation update for the aviation industry is the RefuelEU Aviation regulation [5], which will, among other things, mandate a gradual increase in the use of SAF.

However, the legislation will bring new responsibilities to multiple operators ranging from fuel suppliers to aircraft operators. Although some countries have enforced their own SAF mandates, RefuelEU Aviation is the first Unionwide legislation that will mandate minimum shares of SAF to be used in commercial aviation. Additionally, the regulation also mandates the introduction of synthetic aviation fuel (eSAF), and poses restrictions on fuel tankering procedures. The step towards emission cutting is significant given the time period that the legislation is set to take force, and considering the low levels of SAF demand in recent history: in 2022, SAF covered less than 0,05% of the total uplifted fuel in the Union [6]. Starting in 2025, the regulation imposes a minimum share of 2% of SAF, incrementally increasing the mandated percentage up to 70% by the year 2050 [5].

The existing research on SAF often focuses on the economic impacts of sustainable aviation or the feasibility of different SAF feedstocks. This thesis aims to analyse the implications of the regulation in Finland, providing a valuable case study given the unique geographical situation in Finland and its commitment to sustainability objectives. It will also provide a more holistic understanding of the regulation's implementation by focusing on operational impacts such as changes in flight operations and fuel sourcing, and regulatory compliance such as policy enforcement. The analysed data consist of state-of-the-art research, industry standards and directives, interviews with industry professionals, emission data sets, and flight data specifically in Finland.

Based on the identified gap in research and the relevancy of the topic, this study aims to address the following research questions and subquestions:

1. What are the anticipated impacts of RefuelEU Aviation on the Finnish aviation sector, and how will these affect airlines and fuel suppliers?
    a. How will the operational effects of the regulation impact the flight operations and fuel sourcing?
    b. How will the Finnish airlines adapt to the regulatory requirements of the regulation?
    c. What are the capabilities of compliance in the future?
2. How will the regulation contribute to reducing the environmental impact of the aviation sector?

This study will contribute to understanding how the RefuelEU Aviation regulation transition will impact a specific national context, providing insight on the practical implications of the regulation by focusing on operational and environmental effects. It aims to evaluate the consequences of the regulation, identifying specific national issues that arise in compliance for Finland. Utilising a mixed-method research approach with both qualitative and quantitative methods, the thesis will address critical intersection of global climate policy, national decarbonisation goals and industry transformation. As the official title of the RefuelEU regulation sets to "ensure a level playing field for sustainable air transport" in the EEA (European Economic Area), this study will view the regulation with a focus on national perspective specifically Finland.

This thesis is structured as follows: Chapter 2 reviews the theory and the state-of-the-art literature on the topic of sustainable aviation. It covers the definition and production of Sustainable Aviation Fuels, providing insights on emission offsetting schemes, relevant legislation, and previous research. Chapter 3 explains and reasons the thesis methodology used for answering the research questions. Chapter 4 analyses and discusses the findings of the study motivated by the research questions. The topics raised in the interviews with the industry professionals are depicted and discussed, and the implications of the effects posed by the ReFuelEU Aviation regulation are presented. To answer the second research question, the relevant data for the quantitative analysis is examined. The fifth and final chapter concludes the thesis, provides evaluation of critical issues demanding attention, discusses the thesis' validity and limitations, and suggests possible future research.

2 Background on Sustainable Aviation

In Finland, aviation is a critical part of economy and transportation, accounting for about 4% of the total national Green House Gas (GHG) emissions [7]. Finland has moved rapidly towards decarbonisation and has an ambitious plan to reach carbon neutrality by the year 2035 [8]. An example of this devotion is the national fuel producer Neste Oyj, which has been a strong leader in Sustainable Aviation Fuel (SAF) and other biofuel production, starting SAF production as early as 2016 [6]. With plans on increasing the SAF output nationally, Finland can be considered to be in the forefront of the green transition.

This chapter provides the necessary background information to understand the intricacies of sustainable aviation and the regulations and standards concerning SAF. The first Section 2.1 explains the definition and production of SAF. Section 2.2 discusses the standards and regulation concerning SAF, and Section 2.3 presents the emission reduction schemes that relate to SAF. The Section 2.4 presents the relevant previous research on the topic of sustainable aviation and SAF.

2.1 Sustainable Aviation Fuel

2.1.1 Definition

The definition of SAF is a complex term that requires understanding of aviation fuel production, industry standards, and current aviation regulation.

The term SAF is used to describe sustainably produced aviation fuel from renewable or waste-based sources that meet certain sustainability criteria [9]. SAFs are so called drop-in jet fuels, meaning they are fully compatible with existing jet engines. For the time being, SAF always consist of mixture of the “pure” SAF produced from certain sustainable feedstock, called Synthetic Blend Component (SBC), and Conventional Aviation Fuel (CAF). This is because ASTM (formerly known as American Society for Testing and Materials), an organisation responsible of developing and publishing international standards, limits the maximum blend ratios for SBC and CAF on different conversion processes, the highest percentage being 50% [10]. Hence, any blend of SBC and CAF to any concentration can gain the status of SAF. Traditionally, the sustainability of fuel is associated with the biological property of the fuel, which might not be true for all SAF production pathways. Additionally, the term Synthetic Blend Component can be misleading, since these SBCs can be produced both from biological or non-biological sources, rendering them respectively non-synthetic or synthetic. The term will be used in this thesis when the differentiation from SAF is needed. SBC can also be referred to as neat SAF or unblended SAF for clarity [11]. The fully synthetic aviation fuels, which can be produced for instance by capturing carbon from air and then synthesising it into liquid hydrocarbons, are usually called eSAF, eFuels, or PtL (Power-to-Liquid). The key in emission reduction in synthetic fuel production is using renewable energy in the production processes. It is important to remember that even if the aviation fuel is synthetic, it does produce emissions, as any other fuel, when burned.

According to the International Aviation Transportation Association's (IATA) definition [12], purely fossil-based aviation fuel cannot gain the status of SAF. Additionally, SAF has to reach specific emission reduction levels compared to CAF in lifecycle emissions to be eligible for different emission trading/offsetting schemes [13]. The emission trading and offsetting schemes relevant for ReFuelEU regulation are discussed in Section 2.2. The fossil-based aviation fuels produced with a focus on reduced emissions are called Lower Carbon Aviation Fuels (LCAF) or Reduced Carbon Aviation Fuels [5].

2.1.2 Production

SAF production follows the ASTM D7566 - Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons - standard. It mandates the chemical criteria that the fuel must meet, ensuring that the use of the fuel is safe. So far, 11 conversion processes for SAF from different alternative feedstocks are approved by ASTM, presented in the annexes of ASTM D7566. [10] The processes allowing SBC and CAF blend ratio up to 50% include: Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene (FT), Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources (FT-SKA), Alcohol to jet synthetic paraffinic kerosene (ATJ-SPK), Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids (HEFA-SPK), and Catalytic hydrothermolysis jet fuel (CHJ) [14]. In addition, ASTM allows the blending of other approved conversion process products to smaller ratio than 50% (see ASTM D1655). The SAF production process flowchart is presented in Figure 1, depicting the different SBC production pathways from different feedstocks, SBC blending with CAF to produce SAF. After the blending with CAF, the produced SAF should comply with ASTM D1655 Standard Specification for Aviation Turbine Fuels requirements. These are the same requirements that are posed to CAF, which include for instance the limits for freezing point, conductivity, density, flash point, and specific energy for the fuel. [15]

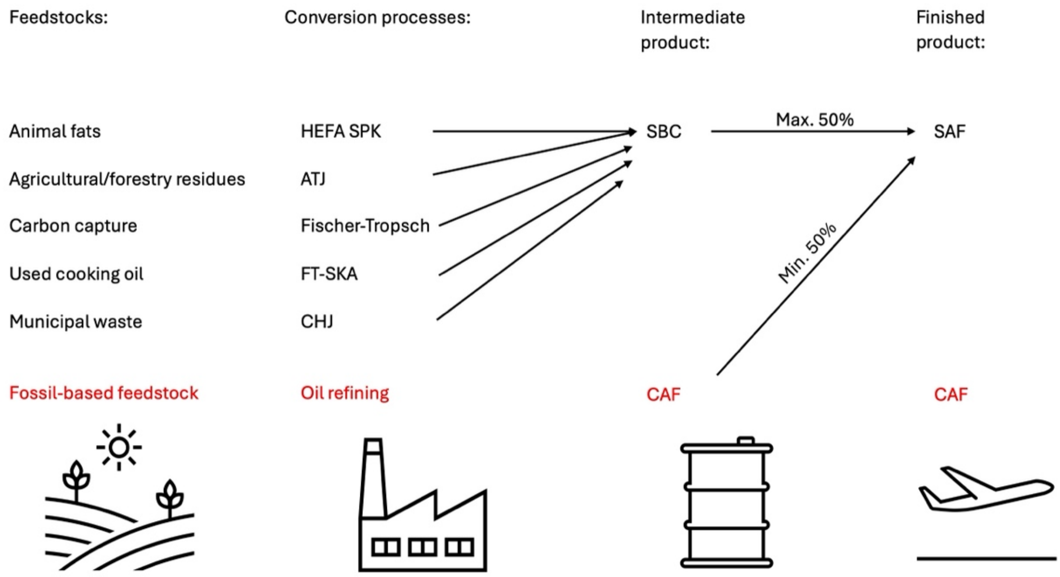

Figure 1 SAF production flowchart

Optimally, during its combustion, SAF would release the carbon that the feedstock biomass had absorbed through its growth, closing the carbon cycle and rendering the SAF carbon neutral. However, there are emissions associated with the production of SAF, including emissions produced during feedstock harvesting, transportation, and refining the fuel. Additionally - as mentioned - for the time being, SAF contains a portion of fossil-based CAF. Nevertheless, these factors considered, the life-cycle emissions reduction of SAF can be over 80% for certain conversion processes compared to CAF [16]. Additionally, research shows that SAF produces less sulphur dioxide during its combustion compared to CAF [17]. Hence, the emissions reduction during the production of the fuel is of paramount importance to the whole life-cycle emissions of the fuel. For fully synthetic aviation fuels (eSAF) the emission reduction percentage can be as high as 100%, as presented by FTI Consulting in their article [18].

In Finland, Neste produces their version of SAF, named Neste MY Sustainable Aviation Fuel, from the HEFA-SPK conversion process [11]. HEFA-SPK conversion pathway uses hydrotreating to convert renewable materials such as, specifically in Neste's case, used cooking oil and animal fat waste, into SBC. Then, as explained in Subsection 2.1.1, the SBC is blended with CAF up to 50% blend ratio to produce SAF. Neste is an international leader in SAF production with a national SAF output in Finland at 0,1 MT in the year 2023. [6] Neste also has refineries in Rotterdam and Singapore, but the SAF output of these refineries is not in the scope of this thesis, even though the ReFuelEU Aviation regulation does not mandate the SAF, or its feedstock, to be produced inside the European Union [5].

Due to the more complex production process, the logistical challenges of obtaining suitable feedstocks, as well as the low demand and regulatory requirements related to SAF, it was approximately 3.4 times more expensive than CAF in 2023 [6]. In contrast, CAF is produced through a mature and highly optimized production process, supported by a well-established infrastructure and readily available feedstock. Fortunately, the ReFuelEU Aviation regulation provides measures in effort to close the price gap between CAF and SAF [5]. These measures are further discussed in the next section.

2.2 Legislation and standards

There are multiple governing regulations concerning aviation fuels, including EU directives and international industry standards. National regulation and incentives on SAF usage exist in a few Member States, but were generally not implemented before the ReFuelEU Aviation regulation. These included for example the early national SAF mandates of France [19] and Norway [20].

The ReFuelEU Aviation regulation, formally known as Regulation 2023/2405 of the European parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport, is a key element in the EU's environmental framework 'Fit for 55'. The aim of the ReFuelEU Aviation regulation is to create harmonised and uniform Sustainable Aviation Fuel guidelines for all EU Member States. [4]

The ReFuelEU regulation mandates the minimum shares for SAF and synthetic aviation fuels (eSAF) to be used in commercial aviation departing at Union airports. The Union airport status is gained for all EU airports which see an annual passenger traffic of more than 800,000 passengers or 100,000 tonnes of cargo [5]. In Finland, two airports have reached these requirements: Helsinki-Vantaa Airport, with more than 16 million passengers in 2024, and Rovaniemi Airport with approximately 948,000 passengers in 2024 [21]. Aircraft operator in the regulation is defined as an instance (person or a company) that has operated at least 500 commercial passenger flights in the previous year [5]. The regulation demands this SAF mandate implementation responsibility from the fuel suppliers, leaving the airlines' role more on reporting SAF usage and monitoring emissions. More about the airlines' obligations are discussed later in this section.

Having begun in January 2025, the ReFuelEU Aviation regulation ensures a steady increase in SAF uptake starting from 2% (by weight) up to 70% in 2050. Given the high potential for emission reduction of synthetic aviation fuels, the regulation also mandates the gradual uptake of eSAFs within the mandated SAF, starting from 1,2% in 2030, increasing to 35% in 2050. [5] The mandated percentages are presented in Figure 2, with the total mandated percentage displayed on top of each bar. The inclusion of synthetic fuel mandate signals EU's intents to accelerate advanced non-biological fuels alongside the SAF made from biological feedstocks.

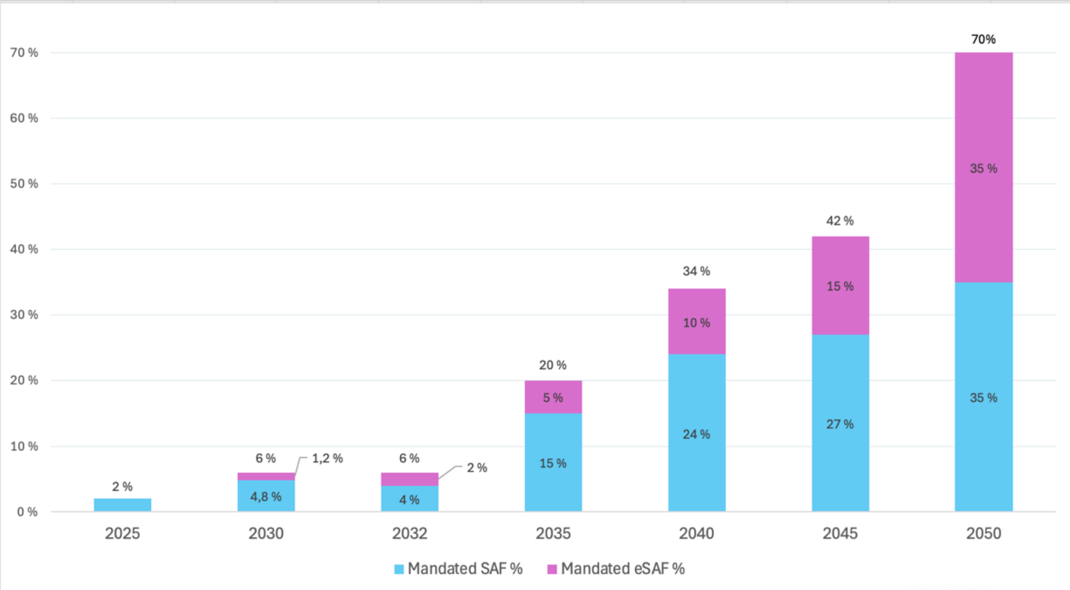

Figure 2 SAF and eSAF mandate percentages of ReFuelEU Aviation

The ReFuelEU regulation incorporates some flexibility mechanisms to support the industry during certain transition periods. One such mechanism allows the fuel suppliers to comply with the SAF mandate not at each individual airport, but rather by averaging the required SAF across all the Union airports they supply within the reporting period. [22] This means that the fuel suppliers are allowed to provide aviation fuel with higher concentration of SAF to certain airports (with possible infrastructure already in-place) to compensate the lower concentration on other airports (which might have insufficient infrastructure or limited availability to SAF) [5]. This flexibility measure is set to end in 2034, assisting the fuel suppliers to have time to develop infrastructure and scale-up SAF production [22]. The ReFuelEU regulation also excludes all military aviation or humanitarian aviation including search, rescue, or ambulance flights, from taking part in the mandates [5].

To enforce the commitment to sustainability goals, the ReFuelEU regulation mandates the scope of the regulation to cover 95% of the total departing flights from all airports located on the Union territory. In addition, any Union airport not reaching the compliance thresholds (in passenger traffic or cargo amount) for the regulation should be able to request to be treated as partaker in the regulation.

Other major measure to implement compliance by the regulation is penalties for non-compliance. The penalties are proportioned according to the environmental harm and damage created to the internal market by the non-compliance. Additionally, fuel suppliers are mandated to supply the market with corresponding amount of SAF to the shortfall of reporting period subject to penalties. The regulation mandates the revenue generated from these penalties to be used for SAF innovation projects, SAF production, or measures to bridge the price gap between CAF and SAF. [5]

One of the most prominent requirement for aircraft operators in the ReFuelEU Aviation regulation is the so called anti-tankering mandate [5]. Fuel tankering is a procedure where, due to a multitude of reasons including fuel availability, fuel price, and turn-around schedule, the airline could refuel all the needed fuel for the round-trip in the departing airport. This extra weight created by the extra fuel increases not only the fuel consumption of the flight, but also the emissions load and the system-wide fuel usage. The ReFuelEU regulation mandates the airlines to uplift 90% of their yearly required fuel at Union airports. Similarly, non-compliance in this mandate is a subject of penalty. [5] As argued by Rutherford et al. [23], the SAF mandates of the ReFuelEU regulation alone could incentivise airlines to purchase CAF from non-Union airports effectively avoiding the mandates. Tankering procedures, although saving money from the aircraft operators, are a major environmental burden, as reported by Eurocontrol [24]. Hence, the introduction of tankering restrictions is a major step towards sustainability.

All of the mandated SAF that is uplifted in the Union Airports must meet the sustainability criteria set in the EU Renewable Energy Directive (RED), a regulation which is referred to multiple times in the ReFuelEU Aviation regulation. RED mandates the renewable energy targets in the EU, setting the objective for renewable energy usage to 42,5% by the year 2030. [25] Finland has exceeded the RED renewable energy target with 50,8% of the energy consumed being renewable in the year 2023 [26]. RED also provides eligibility criteria for different biofuels. The eligibility criteria for SAF include lifecycle emission saving thresholds and limitations to the conversion process feedstocks, forbidding the eligibility of “high land usage” and “food and feed crops” feedstocks [25]. The SAF production should not displace land usage from traditional food production or pose a risk for biodiversity [5].

The ReFuelEU regulation also mandates the aircraft operators to inform the consumers of the level of emission performance of a flight in the form of an environmental label. These standardized labels should be based on SAF usage and CO_2 emission metrics, enforcing transparency and guiding consumers towards cleaner choices. The regulation does not yet mandate the aircraft operators to display the labels, but enforces “acts to establish a labelling system…”. [5]

As an EU regulation, ReFuelEU Aviation is directly applicable in Finland, and national measures are being made to facilitate it into the domestic legal context, most notably amending of the Finnish Aviation Act. The Finnish Transport and Communications Agency (Traficom) and the Finnish Energy Authority (Energiavirasto) are appointed as the competent authorities responsible for overseeing the enforcement of the ReFuelEU regulation [27].

2.3 Emission reduction schemes (carbon offsetting)

To promote sustainable aviation a multitude of emission reduction schemes have been introduced worldwide. These schemes offer an alternative means for aircraft operators to complement their emission reduction efforts. The reduction systems are based on the “polluter-pays” rule, meaning the right to emit pollutants needs to be purchased.

International Civil Aviation Organisation (ICAO) introduced the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016, aiming for carbon neutral growth from the year 2020 onwards. The scheme is voluntary until 2027, after which it will become compulsory with certain exceptions for developing countries. CORSIA is a market based offsetting scheme, pushing the participating operators to offset emissions produced by their international flights (between participating states) through obtaining emission credits or allowances from credit market with limited amount of allowances. These credits can be obtained either by using CORSIA-eligible aviation fuels or purchasing carbon offsets from approved emission reduction projects, such as renewable energy projects or reforestation projects. The CORSIA emission baseline was set as the average emissions covered by the scheme between the years 2019-2020. The participating operators need to offset any emissions exceeding this baseline. CORSIA does not obligate emission offsetting on domestic flights. [28] Finland implemented the use of CORSIA in its pilot phase starting in 2021 [29].

The European Union Emissions Trading System (EU ETS) was first implemented in 2005, and the aviation industry joined the scheme in 2012. EU ETS is a carbon emission trading scheme intended to reduce the Green House Gas (GHG) emissions in the EEA. EU ETS is a so-called cap-and-trade scheme, limiting emissions over an area for specified pollutants, and then allowing trading of emission rights within that area. The tradeable emission allowances are received by each Member State to cover certain level of emissions from flights annually. In the aviation sector, 15% of these allowances are then auctioned between the Member States. EU ETS instructs the revenue from the auctions to be used in climate related investment purposes. The baseline emissions of EU ETS is set on a level of 95% of the emissions produced in the years from 2004 to 2006. The amount of free allowances is also reduced annually and they are intended to be phased out after 2025, ensuring an incentive on the reduction of emissions. [30]

EU ETS scheme also reserves allowances in support of covering the price gap between CAF and SAF (or other eligible alternative aviation fuel) for the amount of the uplifted renewable fuels [30]. This is where ReFuelEU can help to reduce compliance costs for participating operators as the emission targets are reached more easily by using more SAF.

The ReFuelEU regulation forbids the aircraft operators from claiming benefits from the use of a batch of SAF from more than one emission scheme at a time [5].

2.4 Previous research

The research around sustainable aviation revolves around various themes including the economic competitiveness, and feedstock feasibility, policy transition, global and national decarbonisation challenges, as well as the reception of the ReFuelEU regulation. This section reviews the state-of-the-art research found relevant for the thesis.

Within the broad landscape of research, a notable gap is identified by Anderson et al. [31], who concluded that the social science research concerning SAF is dominated with quantitative research, leaving qualitative research, especially incorporating interviews, underrepresented. This highlights the importance of qualitative research in emerging technologies, such as SAF, presented similarly in their study. The need for more holistic research is further supported by discussion on sustainability as a primary principle in policy making. McManners [32] argues that in order to reach true sustainability in aviation, sustainability should be viewed as the policy driver, rather than just an adjustment to existing policies. This perspective aligns with the views of Gössling et al. [33], who emphasise the dialogue-like property of sustainability policies, especially in biofuels, where consumers positively influence the demand for sustainable products or services, prompted by more enforcing policies and encouraging new innovations.

Implementing new policies, however, does create its own challenges. These challenges in the global and national decarbonisation policies are presented in a study done by the independent research and consultancy organisation CE Delft in 2016 [29], where the researchers compared the emission reduction/offsetting schemes CORSIA and EU ETS. While the study considered CORSIA as a significant milestone for international emission reduction efforts, it lacks the ambition to reach similar results of the EU ETS. Similarly, Gössling et al. [34] criticized CORSIA for its unsignificant contribution to emission reductions compared to EU ETS citing previous critiques by Becken et al. [35] and Scheelhaase et al. [36]. Larsson et al. [37] further emphasizes that the multiple exemptions in the emission trading schemes will risk weakening the ambitions on sustainability goals especially in developing countries.

In parallel with policy developments, technical research has shown promising results for SAF performance. Kroyan et al. [17], using their Jet-model simulation, studied the performance and emissions of SAF against CAF, concluding the potential for SAF to outperform conventional fuels both in fuel consumption and environmental impact. Although SAF might be overall better fuel compared to CAF, Chiaramonti [38] reminds in their study, that for example the pyrolysis biofuel process technology took more than 30 years to reach industrial scale from the initial laboratory work. Thus, the mandates for sustainability developments are highly important in adopting new technologies.

Recent legislative developments have also sparked academic interest in sustainable aviation, and particularly SAF implementation across the EU. The ReFuelEU Aviation regulation has generated a number of studies focusing on the implications of the mandates on differing operators in the aviation industry. A European Commission study by Giannelos et al. [39], sets out to assess policy options for large scale SAF production that the ReFuelEU implicates in the whole of EU, whereas Erriu et al. [40] explored the ReFuelEU regulation and policies promoting SAF through the national context of Italy with a stakeholder survey, offering more focused insights how ReFuelEU interacts at local level. Both studies conclude that SAF is an encouraging solution for reaching sustainability, but stress the importance of coherent and well aligned policies to further improve SAF transition. Exploring the effects of SAF implementation in the light of recent EU emission laws, Petal [41] concluded similarly that a local level case studies on SAF are needed. Larsson et al. [37] also suggest that national sustainability policies can be easier to implement than international policies, since they act under single jurisdiction with uniform objectives. These national changes could be more flexible and less bureaucratic than their international counterparts.

3 Methods

This chapter outlines the methodological approach adopted for this thesis to examine the national implications of the ReFuelEU Aviation regulation within the Finnish aviation sector. Given the novelty and the complex interaction of the regulation with multiple regulatory, operational, and environmental domains, a multidisciplinary approach combining qualitative and quantitative methods was deemed necessary. Therefore, this mixed-method research integrates document analysis, semi-structured stakeholder interviews, grounded theory, qualitative coding, and time series analysis to produce a comprehensive understanding of the regulation's likely impacts on the Finnish aviation context.

As described by Creswell [42], a mixed-method research allows for the development of more complete findings through the integration of different data sources and analytical techniques. In this thesis, qualitative document analysis was used to interpret the regulatory texts, standards, and directives, whereas quantitative data, such as emission metrics, were used to validate the findings through time series analysis. The mixed-method research approach was identified as a key area of improvement by Anderson et al. [31] in the field of sustainable biofuels. They highlighted the importance of local level analysis to be able to assess the full impact of sustainability and biofuel development for current and future generations. Using the mixed-method design allows a more comprehensive understanding of the ReFuelEU regulation's implications on the aviation sector.

Operational and regulatory effects of this legislative amendment are tangible and immediate areas of impact, addressing the identified gap in research. Operational effects, like changes in flight operations, fuel sourcing and infrastructure, and regulatory effects like compliance requirements and incentive mechanisms are central in understanding how the regulation will be implemented in practice. Evaluating future compliance capabilities is critical given the deliberate nature of policy transitions, and examining how the regulation influences the strategic decisions can reveal how the affected organisations will adapt to the regulation. The environmental effects, which the regulation is set to minimize, are a key factor in determining whether the regulation has met its objectives. A fact-based quantitative analysis will be feasible only when the first reporting period set by the regulation has ended, and therefore the study will rely on estimating the magnitude of the regulation's impact to the environment based on extrapolated data. Economic consequences, while important, will not be thoroughly quantified in this study given the volatility of the market dynamics. Possible new innovations in the fuel production or limitations in feedstock availability could shift the market quickly rendering the long-term economic analysis useless.

3.1 Document Analysis

Document analysis served as the primary method for examining the legislative, technical, and regulatory context of SAF deployment in Europe. The core materials comprised of EU legal texts, primarily the ReFuelEU Aviation regulation (2023/2405) [5], the Renewable Energy Directive (2023/2413) [25], and the EU Emission Trading System directive (2003/87/EC) [30], as well as international frameworks such as the ASTM standards specifying the fuel requirements and approved SAF conversion processes [10], and ICAO CORSIA scheme for international carbon offsetting [13]. The document analysis method is well-suited for examining official documents and used alongside with grounded theory approach, as identified by Bowen [43].

The sources were identified through a systematic search of institutional databases, such as Aalto University repository Aaltodoc, and LUT University repository LutPub, and academic platforms such as Google Scholar and ResearchGate. For industry standards and publications, organizations such as IATA (International Air Transport Association), ICAO (International Civil Aviation Organization) and EASA (European Union Aviation Safety Agency) web archives were used. Additionally, EuroStat and StatFin were used to obtain statistical data, and Eurlex for legal references. The search was limited to English and Finnish results only.

A framework synthesis approach was employed to guide the document analysis, combining elements of content and thematic analysis [44]. A set of predefined coding categories were derived from the roles and responsibilities of key stakeholders in the SAF transition, and further mirrored against the research questions. The review was conducted using keywords such as “SAF”, “aviation”, “sustainable aviation fuel”, and “ReFuelEU”, with the aim of identifying core issues concerning SAF transition, current status of readiness for the law amendment, feedstock feasibility, economic implications of SAF ramp-up, and technological advancements related to SAF. The selected articles and publications combined with the methodological approach provide support in analysing and understanding the topics and research questions at hand. The top-down approach from international level to the specific national context on aviation in Finland offers informative insights on the differences and specialities of the scope of the study. As emphasised by Anderson et al. [31] in their study on the social science applications in aviation biofuel research, the need for local-level analysis on sustainability fuel developments is much needed, and this thesis aims to address that gap.

These texts together provided a backbone for SAF definition, fuel law enforcement in aviation, and global alignment and compliance regarding Sustainable Aviation Fuels. The material was selected with the help of thesis advisor, by screening the material for themes suitable for comparison in regard to this study, by finding the material that supported thematic comparisons, and by finding the most frequently cited research on sustainable aviation.

3.2 Semi-structured Interviews and Grounded Theory

Semi-structured interviews with chosen industry professionals were conducted to provide insight in stakeholder perspective about the ReFuelEU Aviation regulation, and to gather extensive qualitative data for the research. Due to the novelty of the ReFuelEU Aviation regulation, many affected organisations have not had the opportunity to gather public material on the regulation's implications, and hence, the interviews were deemed necessary. The interviews were prepared with guidelines presented by Bearman [45], aiming to generate rich descriptive data and reveal areas of interest. Two representatives, from the largest Finnish airline and fuel supplier, were interviewed. The interviewees were selected based on their merits on sustainable aviation and the ReFuelEU Aviation regulation. The thematic focus of the interviews was on the ReFuelEU regulation, bounded by the research questions. The interviews were transcribed, coded in conjunction with the methods presented above, and analysed based on the research questions.

The analysis was further supported by grounded theory, allowing emerging themes to complement and expand the predefined categories [46]. Knowing the unexplored operational and strategic responses to the ReFuelEU Aviation law amendment in Finland, grounded theory research method provides a highly valuable method to develop the theoretical framework directly from the data rather than relying on pre-existing hypothesis. Grounded theory research method enables the qualitative research itself to produce the theories and models, as the empirical data is being analysed. This could aid in capturing emerging challenges that quantitative research alone cannot reveal. [47]

The grounded theory approach together with the conducted semi-structured interviews enabled the examination from a different perspective, drawing attention to the stakeholder readiness, revealing areas of misalignment between regulatory expectations and practical capacity, as well as highlighting uncertainties.

3.3 Qualitative Coding

The thesis also employed qualitative coding strategies to identify patterns and areas of interest from the research material and interview transcripts. The coding was conducted as a top-down deductive coding approach, meaning there were predetermined codes based on the research questions and thematic scope of the thesis. The coded themes were linked to the identified operators or organisations that are affected by the ReFuelEU regulation in the scope of the thesis. The organisations affected are aircraft operator (Finnair Oyj), aviation fuel producer (Neste Oyj), Union airport managing body (Finavia Oyj), and competent authority (Traficom).

3.4 Time Series Analysis

To address the second research question, a quantitative time series analysis was done, following Box et al. [48], on the current state of Finland's aviation related emissions and the ReFuelEU law amendment's environmental effects. Emission reports related to aviation GHG emissions, as well as domestic and international traffic data in Finland were extracted from StatFin (Tilastokeskus) and EuroStat (Statistical office of the European Union) databases. The collected data included several csv- and tsv-files, that were first cleaned and reformatted, and then analysed to gain insights on the relevant statistics for the research question. A trend analysis was conducted on the GHG emission and passenger datasets to reveal the pre-implementation baseline. The years from 2015 to 2019 were selected as the timeframe for the baseline levels used in the forecasts due to the effects of the COVID-19 pandemic. A static industry growth percentage of 3% was selected on the basis of ICAO's report [2] and from calculations from the datasets. A life-cycle emission reduction percentage of 80% was calculated for mandated SAF amounts [11]. After that, hypothetical trajectories were formulated posing the SAF blending mandates on the emission data. The quantitative analysis was done using Microsoft Excel-software. Even though this thesis focuses on the ReFuelEU regulation's implications in the Finnish aviation sector, it was important to include the international flight data from and to Finland in the analysis dataset to get a more well-rounded view of the regulation's effect.

Table 1 summarises the research methods applied to answer the research questions.

Table 1 Methodological approach for the thesis

Method:	**Research question:**	**Source:**
Semi-structured interviews	1	[49], [50]
Grounded theory	1	[46], [47]
Document analysis	1	[43]
Qualitative coding	1, 2	[47]
Time Series Analysis	2	[48]

4 Results and discussion

This chapter presents and discusses the findings of the study based on the semi-structured interviews, relevant literature, and the analysed datasets. The results are structured around the research questions introduced in the thesis introduction. The combined results and discussion section aims to provide an integrated comprehension on how the ReFuelEU Aviation regulation is expected to influence the Finnish aviation industry both in operational and environmental aspects. For the purposes of the thesis, it was vital to research the implications of the ReFuelEU Aviation regulation on a home-base aircraft operator and on a national fuel supplier. Finnish aviation sector offers a unique example on such research, since both of these operators are partly government owned and most notable operators in their respective fields in Finland.

First, the impacts of the ReFuelEU regulation are discussed in respect to the interviewed stakeholders in Section 4.1. In Section 4.2, the operational effects are analysed, further building on the first research question on Section 4.3 on regulatory effects. The second research question is analysed in Section 4.4, presenting the forecasted environmental impacts of the regulation.

4.1 The Impact of ReFuelEU on Key Operators

4.1.1 Aircraft Operators

Finnair is the national aircraft carrier of Finland, operating to approximately 100 destinations from its Helsinki Airport hub [51]. Finnair has a fleet of 80 aircraft, including the aircraft operated by Norra [52].

In the interview conducted for this thesis, Finnair expressed strong support on the ReFuelEU Aviation regulation, particularly emphasising SAF usage mandates. The Finnair representative stated that "voluntary SAF purchases have not taken off - the mandate is necessary”. This aligns with McManners [32] and Gössling et al. [33], who both suggest that it is policies that should lead sustainability transitions, rather than the transition following market signals retrospectively. Additionally, the practical experience of Finnair had showed that voluntary demand and contributions for SAF are very low, even though the public perception of biofuels in Finland was found positive by Siivari et al. [53].

The key concerns raised in the interview included the steep ramp-up of SAF mandates, especially the 2030 eSAF ramp-up where the introduction of synthetic aviation fuels is necessary, and the ungoverned SAF pricing by the fuel distributors. The Finnair representative stated that now that the SAF usage is mandated by the regulation, the pricing needs clear mechanisms and transparency. The SAF mandate gradation is discussed further in Section 4.3.2.

Any national mandates were not supported by Finnair, as any inequal mandates inside the EU could distort the market, making it more difficult for national operators to compete in the market. The Finnair representative also expressed concerns of the cost increase introduced by the more expensive SAF, as well as possible mandate non-compliance penalties passed down to the consumer, reflected as higher ticket prices. The representative indicated that competitiveness of the national airline carrier could be compromised due to excessive price increases. [50] This concern is emphasized when the mandated SAF percentages increase over time, potentially leading to further increases in operating costs and, consequently, ticket prices. Finland, with its unique geographical traits, is very dependent on the connectivity that the nationally upkept airport network offers. Helsinki Airport being the only profitable airport in Finland, and Finnair the sole operator to some of the more remote airports, the government involvement in the air transport services is pivotal [8].

The Finnair representative mentioned the optional SAF charge available for consumers when purchasing flight tickets from Finnair, where - unfortunately - very few consumers are ready to pay any additional optional SAF charges that would then be used to allocate more funds into SAF acquisition by Finnair in addition to the mandated amount. This highlights the misalignment between policy ambitions and industry readiness - a recurring theme in policy implementation literature emphasised by Erriu et al. [40].

4.1.2 Fuel suppliers

Neste, as the leading and only SAF producer in Finland is well prepared to meet the short-term requirements of the ReFuelEU Aviation regulation. Neste has a refinery in Porvoo, as well as several terminals all across Finland. According to Neste representative [49] and EASA SAF market report [6] Neste's domestic production capacity is sufficient to supply the anticipated 15 kiloton SAF requirement resulting from the 2% mandate starting in 2025. Production capacity in Porvoo refinery alone is estimated to exceed Finland's SAF needs sixfold, at 100 kilotons per annum [6]. Additionally, Neste has production sites in Rotterdam and Singapore that allow Neste to manage supply on a global scale.

Due to Neste's large SAF production capacity, the interviewed representative expressed concern over the non-linear ramp-up of the SAF blending mandate, describing the increase from 6% in 2030 to 20% in 2035 as unrealistic and as a potential flaw in the regulatory design of ReFuelEU Aviation [49]. These comments align with Finnair's concerns and reflect a broader industry apprehension documented by Erriu et al. [40]. Moreover, large SAF production numbers in the early phases of ReFuelEU lead ultimately to a situation where the supply exceeds the demand. In contrast, the HEFA-SPK conversion process - which is dominating the current SAF market supply - with its limited feedstocks could tip the demand into exceeding the supply as early as in 2035, as stated by the recent report by SkyNRG and ICF [54].

Neste also welcomed the fact that ReFuelEU operates as a penalty-based mandate. Unlike in the road transport section, where there the buyout options enable the operators to avoid biofuel usage mandates, in air transport under the ReFuelEU regulation, operators are compelled to pay penalties for non-compliance. The penalty-based approach provides predictability for the fuel producers and investors, since the penalties guarantee certain level of mandated demand and mitigates the risk of buyers to opt out when SAF costs are high. Conversely, the Neste representative raised concerns about fuel distributors inflating the SAF-related surcharges, making SAF appear more expensive than its market price - an issue that has already been noted by IATA [55], and also brought up in the discussion by the Finnair representative [50]. The Rovaniemi Airport case (see subsection 4.3.1) illustrated the logistical and administrative challenges in responding to newly qualifying Union Airports in the interview.

The HEFA-SPK process, which Neste uses for their SAF production, is one of the most mature and commercially viable SAF production processes [56]. Neste has been a global pioneer in SAF production, but fully synthetic eSAF production is still in early development stages. As of 2024, Neste had no full-scale eSAF production underway [49]. This supports earlier observations by Chiaramonti [38], who noted that SAF production technologies often face long industrialisation timelines. While the non-synthetic SAF meets current mandates, and the SAF production is on a sufficient level, the eSAF mandate requirement beginning in 2030 introduces strategic risks, since no plans for eSAF production are yet concrete. Furthermore, the higher SAF and eSAF blend ratios will eventually require the certification of 100% SAF (100% SBC) blend use, which is not currently permitted under existing fuel specifications [10]. As stated by Orpana [57], the ASTM standardisation of new fuel feedstocks or blend ratios is time consuming, usually taking years. The responsibility to certify the future fuels (blends and alternative feedstocks) is on the fuel supplier [49].

The Neste representative emphasized that it would be beneficial for all parties - and the environment - if the 100% SAF blends would be certified swiftly [49]. In previous literature, the sentiment was shared by Orpana. Unfortunately, the 100% SAF blends require testing and alteration in jet engine technology, and hence it is likely to take time. [57]

4.2 Operational Effects of the ReFuelEU Regulation

The implementation of the ReFuelEU Aviation regulation introduces several operational changes for stakeholders in Finnish aviation industry. These changes affect fuel logistics, flight planning, infrastructure, and supply chain planning. This section presents and discusses the key operational impacts identified during the stakeholder interviews and document analysis.

4.2.1 Fuel Tankering

One of the most immediate impacts of ReFuelEU are the operational changes due to anti-tankering rules. As explained in Chapter 2, Section 2.2, fuel tankering is a procedure, where all the needed fuel for a round-trip is uplifted in the departure airport to avoid more expensive fuel purchases at the destination. Fuel tankering can also be done for compelling reasons, such as fuel unavailability at the destination airport. The ReFuelEU Aviation regulation's anti-tankering mandate makes dedicated tankering procedures a subject of penalty, with exceptions on safety-critical operations, such as humanitarian aviation or ambulance flights. [5]

The anti-tankering mandate does not directly affect Finnair's domestic flight operations, since the operational and economic benefits from tankering domestic flights are negligible. In contrast, international flights to nearby countries are affected by the regulation's anti-tankering mandate. Flights to destinations like Tallin, Oslo, Riga, and Stockholm can be no longer executed with tankering procedures. The operational changes in the routes mentioned above were described by the Finnair representative as "manageable, but requiring new planning tools and crew training", particularly in ATR-72 aircraft operations. The anti-tankering mandate for these flights might require recalibration of fuel load planning, changes in flight schedules due to longer turn-around times, and certifying qualified fuelling personnel at destinations. [50]

The operational adjustments echo the findings of Tabernier et al. [58], who warned about the increased emission of fuel tankering procedures. The Neste representative described the environmental effects of the anti-tankering mandate even more substantial than the first steps of SAF mandate [49] due to the immediate emission reduction of the anti-tankering mandate. This is supported by the findings of Rutherford et al. [23] in their study where they concluded that the SAF mandates alone could weaken SAF sales. Hence, the anti-tankering rule is welcomed by the representatives and anticipated to achieve its environmental intentions.

4.2.2 Logistical and Supply Chain Adjustments

One of the operational implications of the ReFuelEU Aviation is the changes SAF allocation at Finnish airports. Due to Rovaniemi Airport gaining the Union airport status in 2024, Neste amended their supply chain to match the SAF needs of northern Finland by commencing in SAF transports to their Kemi terminal [49]. The regulatory effects of this change in process are discussed in Subsection 4.3.1. The sudden need for SAF in the far north introduced an operational problem for Neste. Supplying jet fuel from warmer climate to colder environment during the winter season could result in ice particle formation in the tanks due to the temperature differences. This could also affect the aircraft operator in the form of anti-icing operations, creating longer turn-arounds and increased costs. [49]

The Neste representative noted that inevitable jet fuel blending operations add cost and complexity, and may become a bottleneck if not addressed. As of 2025, all SAF (the blend of CAF and SBC) must be blended by the producer of the fuel. When blending SBC to certified batch of fuel, the new batch must then be certified again, meeting the ASTM fuel specifications [10]. Looking ahead, the Neste representative stated that the potential certification of 100% SAF blend would require significant changes in airport infrastructure. The in-airport blending of SAF is not permitted, and unblended SAF (neat SAF, SBC) and fossil-based fuels would need parallel fuel systems, should they exist at the same time. [49]

4.3 Regulatory Adaptation and Compliance

The key areas of concerns emerged in the stakeholder interviews were the misalignment of ReFuelEU Aviation and EU ETS framework reporting mechanisms, and the steep progression of the SAF mandates.

4.3.1 Regulatory Framework Misalignment

Frustrations were voiced by both Neste and Finnair concerning the ReFuelEU and EU ETS reporting criteria. Where the ReFuelEU allows the SAF supplied to be averaged over all of the Union airports within the country, EU ETS does not recognise this boundary. The mandate may be fulfilled on paper, but EU ETS credits may be lost if the SAF was not physically uplifted at an ETS-reporting airport, concluded the Finnair representative. This issue reveals potential structural misalignment in the EU climate instruments, an issue that Gössling et al. [33] noted when critiquing the fragmented governance in sustainable aviation.

Rovaniemi Airport offers an example of the difficulties in the reporting misalignment of EU ETS and ReFuelEU. While the Rovaniemi Airport, having over 800,000 annual passengers in the previous year (2024) [21], qualifies as a Union airport and falls under the ReFuelEU Aviation SAF mandate, the fuel suppliers are not required to physically supply the mandated SAF volumes at Rovaniemi Airport. Instead, fuel suppliers are allowed to meet the SAF mandate by allocating the required amount across any other Union airport they supply fuel to, as long as the total volume of SAF meets the mandate. [5] This would lead into disadvantage on aircraft operator side, since the aircraft operator cannot report the SAF for their flights departing from

Rovaniemi Airport under EU ETS unless the fuel was actually physically uplifted at that airport [50]. Consequently, Neste started providing the mandated SAF blend to Rovaniemi Airport through its Kemi terminal in effort to support operators in securing the EU ETS support [49].

The Rovaniemi Airport surpassing the ReFuelEU Aviation SAF mandate threshold also introduced an additional regulatory concern. The extreme seasonal fluctuations of traffic volumes at Rovaniemi Airport added uncertainty in the airport's potential to surpass the mandate threshold, and when the threshold was ultimately surpassed in late 2024, the short notice left little time for supply chain planning. This "threshold-airport" problem might be introduced for any airport seeing number of passengers or cargo volumes nearing the regulation's thresholds. This problem could renew itself every year, bringing sudden compliance burdens, unexpected costs, and increased planning. In the Finnish Lapland, the high seasonal traffic fluctuations introduced by tourism might yield in unexpected threshold crossings in the future, as what happened with Rovaniemi in late 2024.

4.3.2 SAF Mandate Gradation

A key concern raised by both of the interviewed representatives relates to the rate at which the SAF mandate increases under ReFuelEU Aviation. According to the ReFuelEU regulation, SAF mandates begin at 2% in 2025, raising to 6% (an increase of 4 percentage points) in 2030, and then raising to 20% (an increase of 14 percentage points) in 2035, ultimately reaching 70% at 2050. These substantial increases that happen every five years were found concerning by the interviewees. All the mandated SAF percentages are presented in Figure 2. A more linear progression would allow more time for investments and production to answer the increasing demand, stated the Finnair representative [50]. Similar comments were provided by the Neste representative, stating that the steep steps of the mandates, combined with no to little transition periods, are a potential "design flaw" in the regulation that hopefully could be rectified in future amendments [49]. The Neste representative referenced the United Kingdom's [59] more gradual SAF mandate approach as preferable, enabling smoother SAF and eSAF scale-up and investments. The UK's SAF mandate percentages are presented in Figure 3, starting from 2,041% of SAF in the year 2025. The synthetic fuel mandate is introduced in the UK already in the year 2028 starting with 0,215% of eSAF.

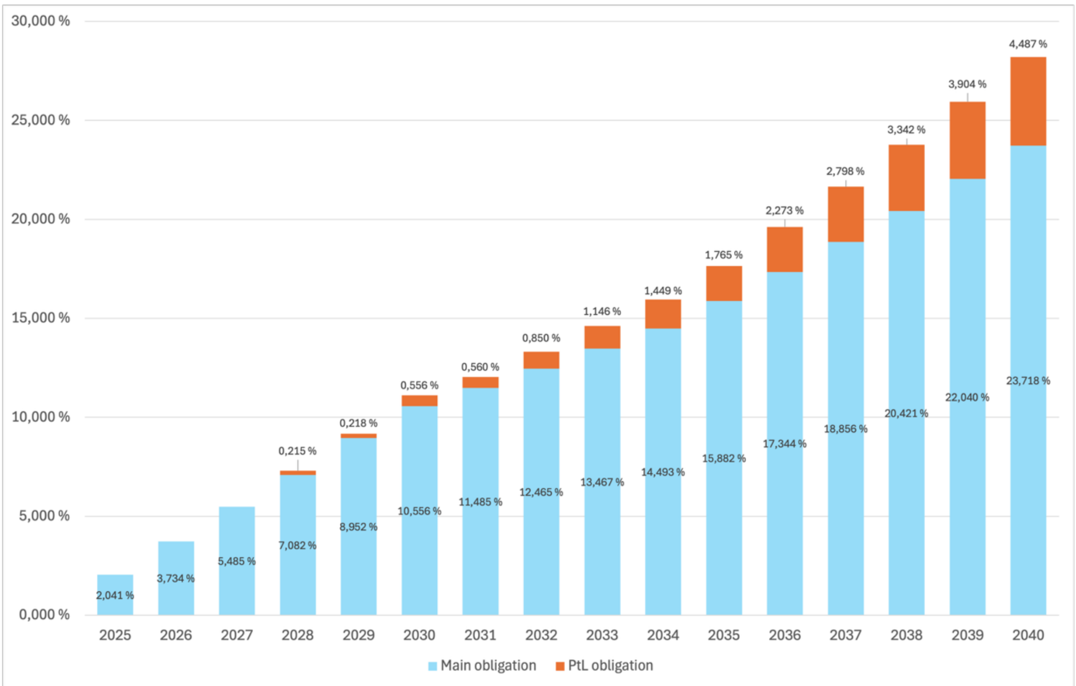

Figure 3 SAF mandates in the UK

Figure 4 presents both, the UK's SAF mandate and the ReFuelEU SAF mandate aggregated in one table. This clearly shows the steep progression of ReFuelEU SAF mandate compared to the UK's close to linear SAF mandate. The objectives and the level of mandated SAF in the UK are to be confirmed until there is greater certainty of the available SAF supply [59], and hence the UK's SAF mandate is yet to be set for the years following 2040. Therefore, in Figure 4 the UK's SAF mandate from the year 2040 onwards is extrapolated from the existing data expecting similar close to linear increase (shown in green). An exponential trendline represents the aggressive steepness of the ReFuelEU Aviation SAF mandate (orange dotted line). Although being more modest than the ReFuelEU SAF mandate, the UK's SAF mandate has been praised for its more linear progression [50] [49].

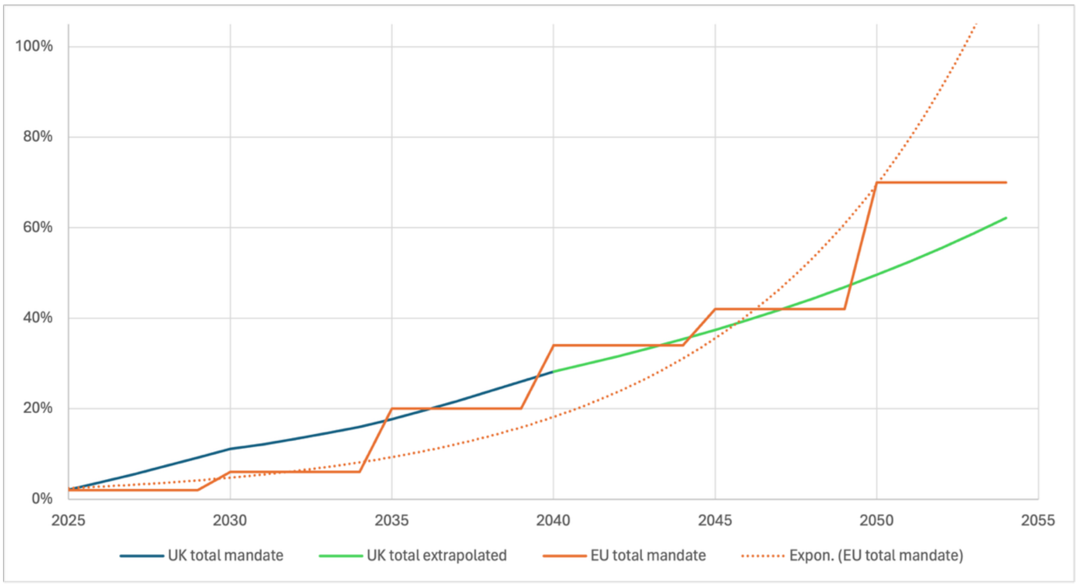

Figure 4 SAF mandates of the UK and ReFuelEU

The eSAF mandate for synthetic fuels was expressed as "especially concerning" by the Finnair representative, citing both high production costs and uncertainty of commercial scale availability [50]. The claim is echoed by Giannelos et al. [39] in their study, where stakeholders across the board expressed their concern in the SAF mandates being introduced faster than the SAF production capacity. The perspective was also supported by Italian aviation industry stakeholders in Erriu et al. [40] survey, where they reported that SAF production ramp-up was viewed as overly ambitious, identifying limited infrastructure and high cost differential as critical barriers.

4.4 Environmental Contributions of ReFuelEU

4.4.1 Time Series Analysis

In order to answer the second research question, the environmental effects of the ReFuelEU Aviation regulation were evaluated with a time series analysis on the relevant emission data. This analysis, also reviewing the historical emission and passenger statistics in Finland, created data-derived forecasts and trajectories of the evolvement of emission levels in Finland post-implementation.

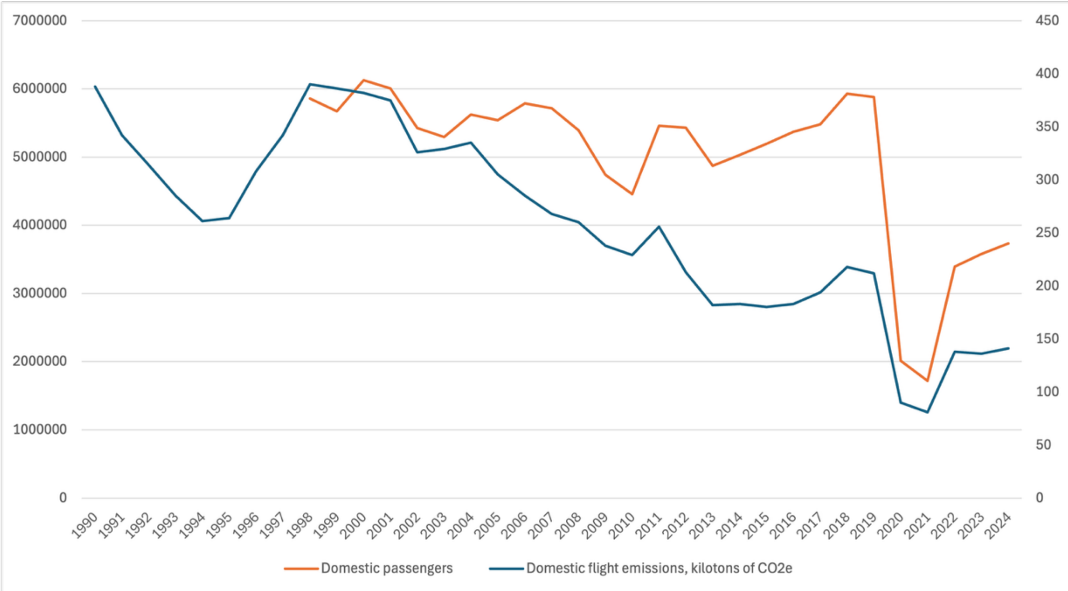

Figure 5 Domestic CO_2e emissions of the aviation industry and number of domestic flight passengers in Finland 1990-2024

Figure 5 presents the total amount of domestic flight CO_2-equivalent emissions and the number of domestic flight passengers between the years 1990-2024. The data on number of passengers was only available from the year 1998 onwards. The unit of the emissions is kilotons of CO_2e (thousand tonnes of CO_2-equivalent), presented in the right-side y-axis. The figure shows that domestic air transport indicators have decreased in the reviewed timeframe. It also reveals that the number of passengers (in domestic aviation) does correlate to generated emissions. As mentioned in Section 3.4, for a feasible quantitative analysis, it is not sufficient to review only the domestically generated flight emissions, but it's necessary to also include the international flight emissions to and from Finland.

Figure 6 presents the sum of domestic and international flight emission data from 1990 to 2024 in Finland. In addition, it presents the national 1990 emission level and 45% of that level. As mentioned in Chapter 1, the EU's 'Fit for 55' package aims to cut the EU emission levels by 55% compared to the year 1990 level by the year 2030. The reduction of 55% is hence 45% of the 1990 emission levels. The 'Fit for 55' target being an EU-domestic target means that it applies to multiple industries in all of the Union Member countries, and hence, comparing it to one specific industry of one specific country does not yield sensible results. This study identifies this limitation, but uses the 55% reduction from 1990 level as a baseline for domestic emission reduction benchmarking. As part of the 'Fit for 55' package for Finland, the EU has set an obligation to reduce non-EU ETS emissions by 50% from the year 2005 level by the year 2030 [60].

Even though the domestic flight emission and passenger amount trends point downwards in Figure 5, Figure 6 displays that the emissions from international flights reported in Finland are actually increasing. The flight emissions fell under the 1990 level for the first time since the year 1998 in 2020 during the COVID-19 pandemic.

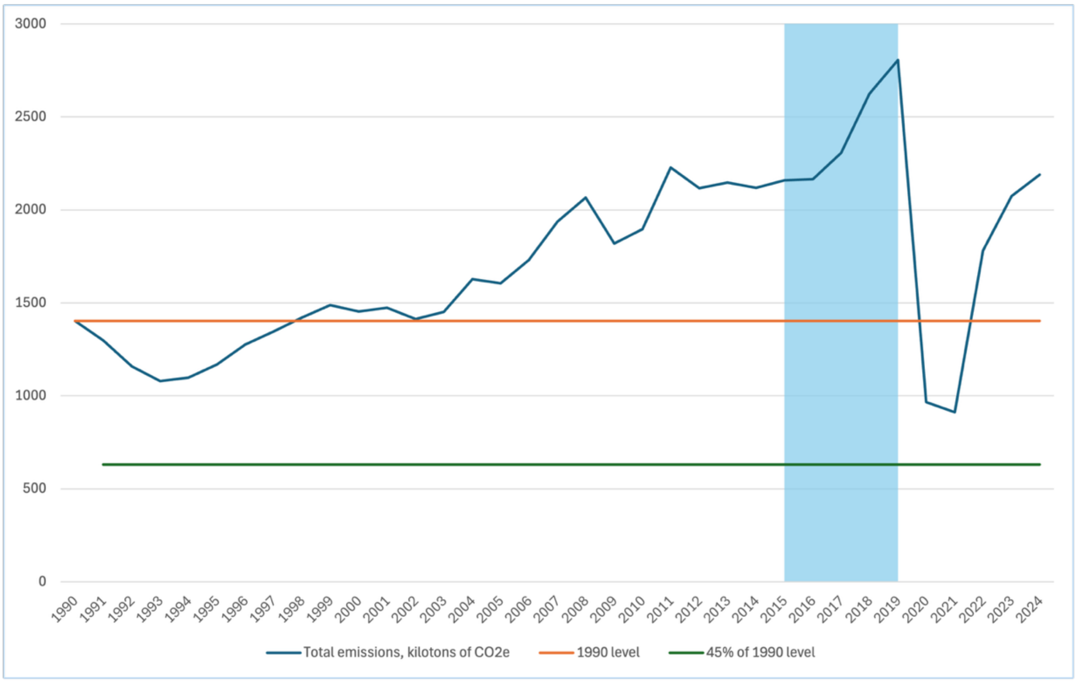

Figure 6 Total flight emissions in Finland 1990-2024

For a feasible quantitative review, presenting the most recent relevant development of the aviation industry in Finland, the years from 2015 to 2019 were selected as the basis for forecasting the future data (highlighted in blue in Figure 6). This selection was done due to the COVID-19 pandemic, which affected the aviation industry not only in Finland, but all over the world from the year 2020 onwards. In Finland, the flight emissions and number of air traffic passengers had increased steadily throughout the years before the unexpected COVID-19 pandemic [21].

Figure 7 presents the total flight emissions in Finland between the years 2015-2019, where a clear upwards trend can be detected. The linear regression trendline (dotted line) has a positive slope value of 175,3, meaning the absolute annual increase in emissions with the linear model was 175,3 kilotons of CO_2e. The average annual growth of emissions as a percentage of the total emissions for this timeframe was 5,37%. For the number of passengers in Finland this growth was 5,47% for the same time period. However, the average growth of air traffic passenger amount in the EU was estimated by ICAO to be 3% [2], which conforms to the average growth of 3% in air traffic passengers in Finland between the years 1998-2015. This implicates faster growth of air traffic in Finland between the years 2015-2019 compared to the EU average. Hence, for a more realistic forecast, the EU average of 3% was chosen as the annual growth estimate.

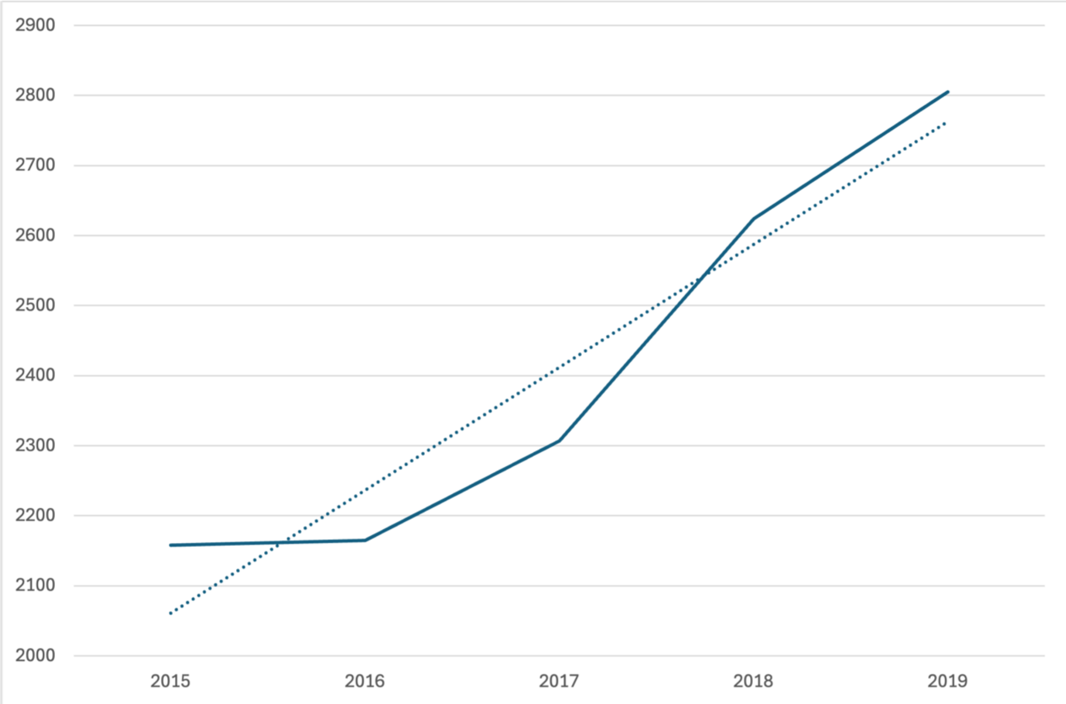

Figure 7 Total flight emissions in Finland 2015-2019

4.4.2 SAF Mandate Projection

As mentioned earlier, for a feasible projection forecast of the post-implementation emissions the years from 2020 to 2024 were disregarded due to the effect of the COVID-19 pandemic. A life-cycle emission reduction of 80% for SAF compared to CAF was used for this analysis. Neste states [11] that their HEFA-SPK pathway achieves on average (depending on available feedstock) 79,93% lifecycle emissions reduction compared to CAF production, aligning somewhat with the findings of De Jong et al. [61], who calculated a 68% reduction for used cooking oil-based SBC on the HEFA conversion process. The calculation for the life-cycle emission reduction is presented in Table 2, drawing its data from Neste [11].

Table 2 Life-cycle emission reduction calculation

Feedstock:	Life-cycle emission factor, gCO_2e/MJ	Life-cycle emission reduction, %
Baseline CAF	**89**	**0,00%**
Tallow	22,5	74,72%
UCO	13,9	84,38%
Corn oil	17,2	80,67%
Average	17,86666667	79,93%

The produced emissions and uplifted fuel are assumed to be directly proportional in this analysis. There could be small differences in specific energies of fuels from different feedstocks, altering the direct proportionality of burned fuel and emissions created, but they are considered to be negligible in this study. Figure 8 presents the projected CO_2e emissions from 2015 to 2054 without the implementation of any SAF mandates in Finland. The projection uses 3% industry growth percentage supported by the assumption of ICAO in their report [2]. The COVID-19 pandemic is marked with grey, denoting the disregarded time period.

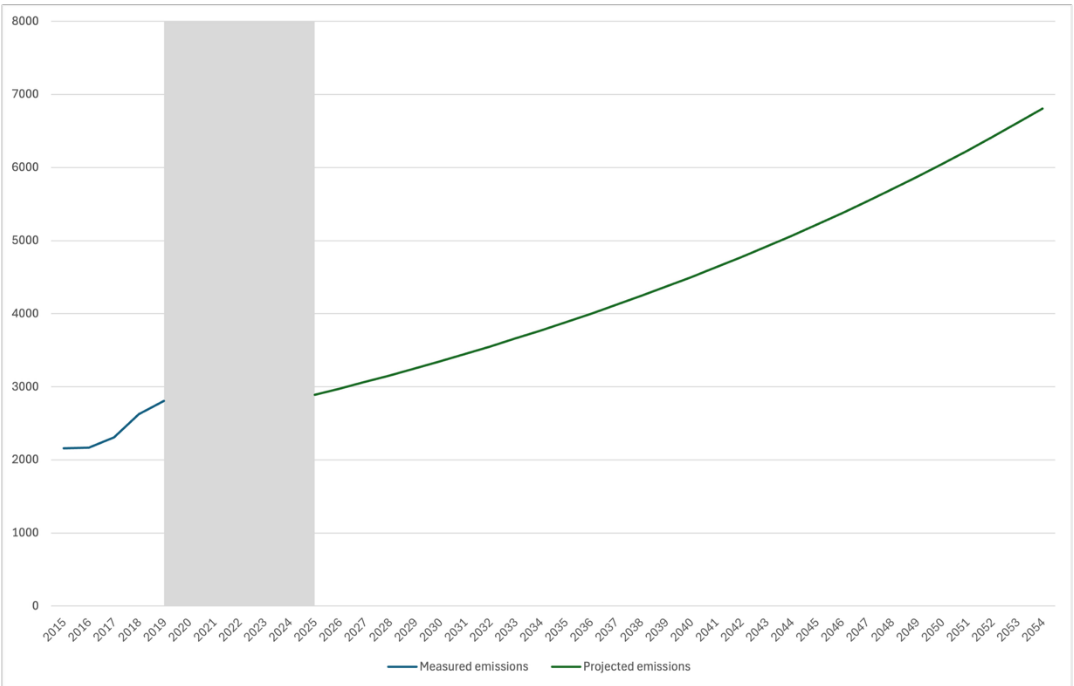

Figure 8 Projected CO_2e emissions with 3% growth

As can be seen in Figure 8 - even with the more modest 3% growth percentage - the flight emissions in Finland could double from the 2025 level by the year 2050, if no action is taken.

Figure 9 presents the estimated CO_2e flight emissions with the mandated SAF percentages of the ReFuelEU Aviation regulation compared to no-mandate scenario. The SAF mandated portion of the emissions is calculated to be reduced by the life-cycle emission reduction percentage of 80% and also calculated to retain the 3% industry growth.

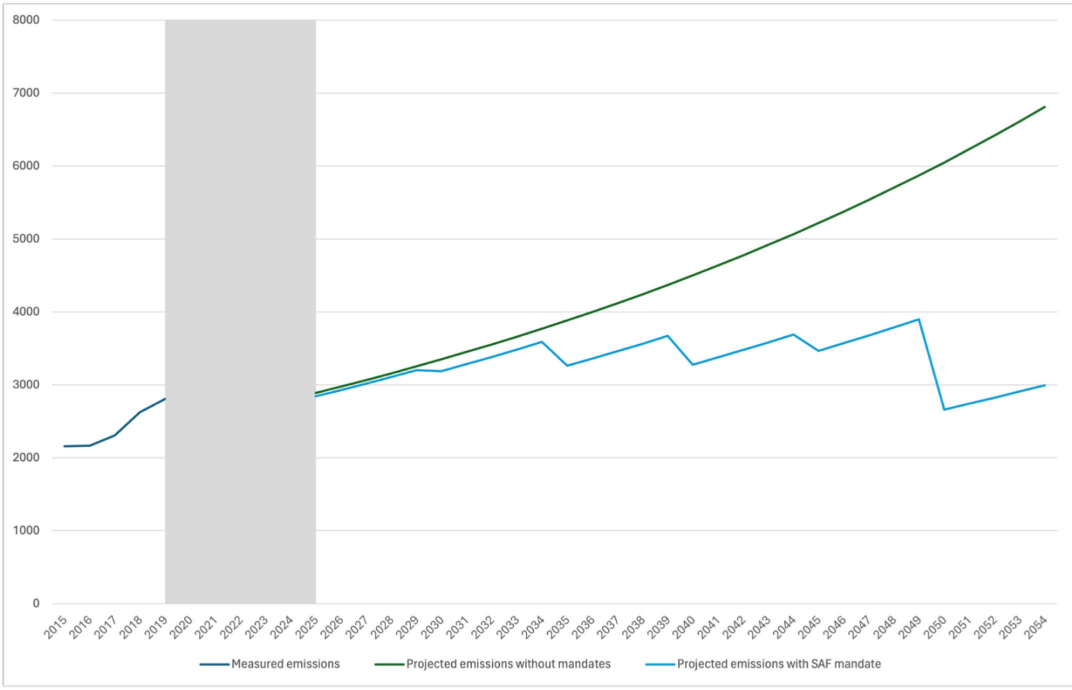

Figure 9 Projected emissions with SAF mandate

The scenario modelling predicts that the 2% SAF blend mandate from 2025 onwards could reduce the total flight emission in Finland by 1,6% or 46,22 kilotons in 2025 alone. Following the projection further, the absolute emission reduction is estimated to yield a sum of 245,42 kilotons of CO_2e from 2025 to 2030. This first 2% step of the ReFuelEU SAF mandate - although modest - is significant. This is because in the EU, and specifically in Finland, there is a good level of readiness for the first years of the mandate: it is easily executed, and the results are noteworthy. In Finland, during the first five years of the mandate this would mean a reduction of nearly double of the annual emissions created by domestic flights alone. This 1,6% reduction conforms to the findings of EASA in their CO_2e emission reduction projection under the ReFuelEU SAF mandates [62], where they compare the emissions reduction to the year 2020 baseline. The SAF mandate alone could cut the emission levels to pre-implementation level (2025) by the year 2050. However, the SAF mandate is not the ReFuelEU Aviation regulation's only tool for emission reduction.

The introduction of synthetic fuel (eSAF) mandates beginning in the year 2030 are presented in Figure 10. The purple line represents the emission reduction with minimum required share of eSAF within the total mandated SAF amount. For example, in the year 2030, the required eSAF content in the total SAF blend is 1,2 percentage points, which corresponds to 20% in the overall SAF amount. The ReFuelEU Aviation regulation specifies only minimum thresholds for eSAF content in the total SAF blend, and these minimum values are used in this analysis. The life-cycle emission reduction for eSAF in this analysis is estimated to be 90% compared to CAF. Even though the mandated percentage shares for eSAF are lower than those for SAF (except from the year 2050 onwards), as presented in Figure 2, the life-cycle emission reduction achieved by eSAF are greater. When using sustainably produced electricity, the carbon-capture PtL-technology could reach reduction percentages up to 100%, but a more realistic 90% was chosen for this analysis [18].

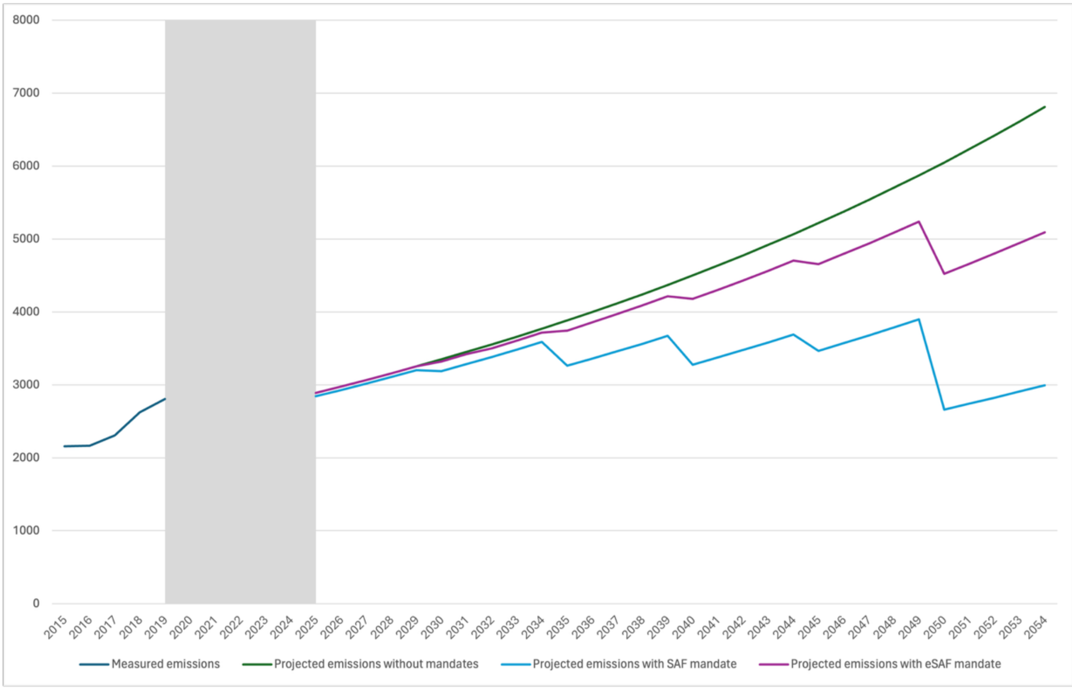

Figure 10 Projected emissions with SAF and eSAF mandates

Figure 11 presents the projected emissions without mandates, SAF and eSAF mandate emission projections separately, as well as emission projection of both mandates summed. As seen in Figure 11, the emission reduction potential naturally increases with higher blending mandates. Due to the 3% industry growth, the reduction is relatively slow at the first stages of the mandates. As mentioned earlier in this section, the early steps of the mandate with seemingly marginal emission reductions are still of great significance. The introduction of eSAF mandate together with SAF mandate could help to cut the projected emissions near to the pre-implementation level by the year 2040, ten years earlier than with the SAF mandate alone.

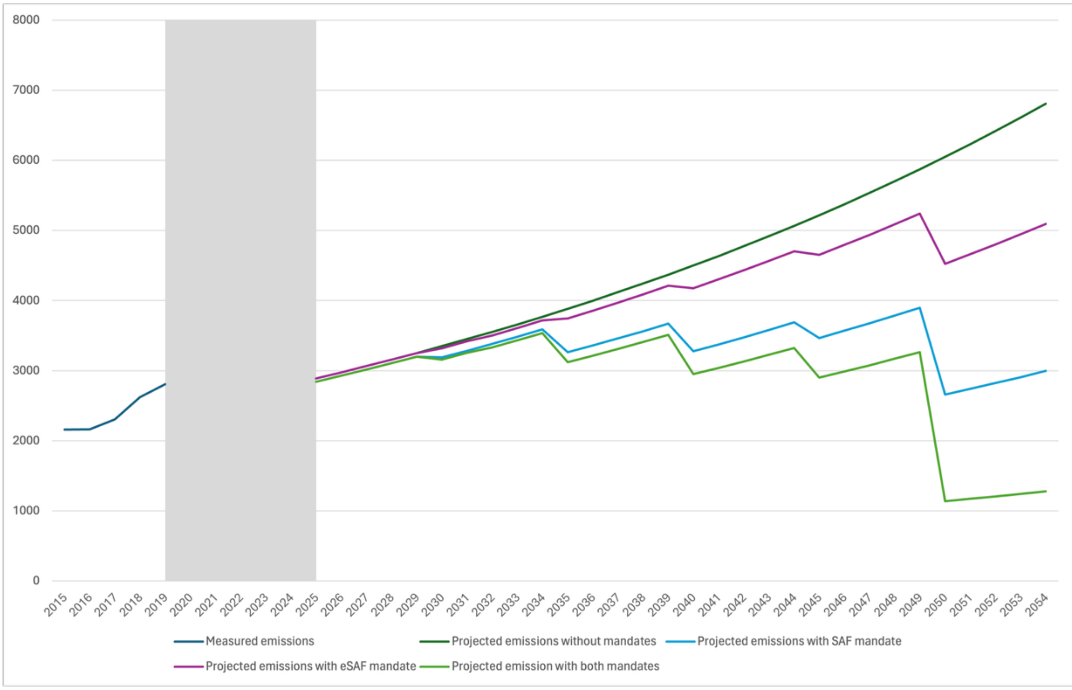

Figure 11 Projected emissions of both mandates and their sum

The potential emission reduction of each ReFuelEU mandate step compared to the no-mandate scenario are presented as percentages in Table 3. By the year 2050, the SAF and eSAF mandates could, based on this analysis, bring a reduction of 81,2% compared to the scenario without mandates (taking into account the 3% industry growth). EASA estimates two scenarios for the emission reduction of the ReFuelEU regulation [62], in which they compare the emission reduction of the SAF mandates to the RED fossil fuel baseline of 94 gCO_2e/MJ [25]. The more ambitious of these scenarios employ the same lifecycle emission reduction percentages as in this thesis. The side-by-side review of the results from this thesis analysis and EASA's report are not directly comparable, since the EASA analysis compares the reduction to a static baseline, and this thesis employs a static growth. According to EASA, the more ambitious scenario yields a reduction of 59,5% in CO_2e emissions [62].

Table 3 SAF and eSAF mandate emission reduction compared to projected emissions

Year	Reduction SAF mandate	Reduction eSAF mandate	Total reduction
2025-2029	1,6%	0,0%	1,6%
2030-2034	4,8%	1,2%	6,0%
2035-2039	16,0%	3,6%	19,6%
2040-2044	27,2%	7,2%	34,4%
2045-2049	33,6%	10,8%	44,4%
2050-2054	56,0%	25,2%	81,2%

As mentioned in Subsection 4.4.1, the ‘Fit for 55’ package’s target on cutting the EU-wide emission by 55% by the year 2030 cannot be directly portrayed to aviation specific emissions in Finland, since the target reduction comprises of multiple industries inside multiple countries. In addition, some industries are a subject of more strict and urgent emission regulation, whereas some industries do not see the same level of effort in emission reduction. Furthermore, in order to see the see the full picture of emission levels in Finland, carbon sinks would have to be taken into consideration. Despite the limitation in comparability, the 1990 emission level and 45% of that level are presented in some figures in this thesis to display the magnitude of emissions on today’s scale, and to put the potential reduction of emissions introduced by the mandates into perspective.

Figure 12 presents the total emission reduction potential of the RefuelEU SAF mandate together with the ‘Fit for 55’ target levels. As seen in the figure, the emission reduction potential of ReFuelEU SAF mandates could help to reduce the flight emissions in Finland down to the year 1990 emission level by the year 2050.

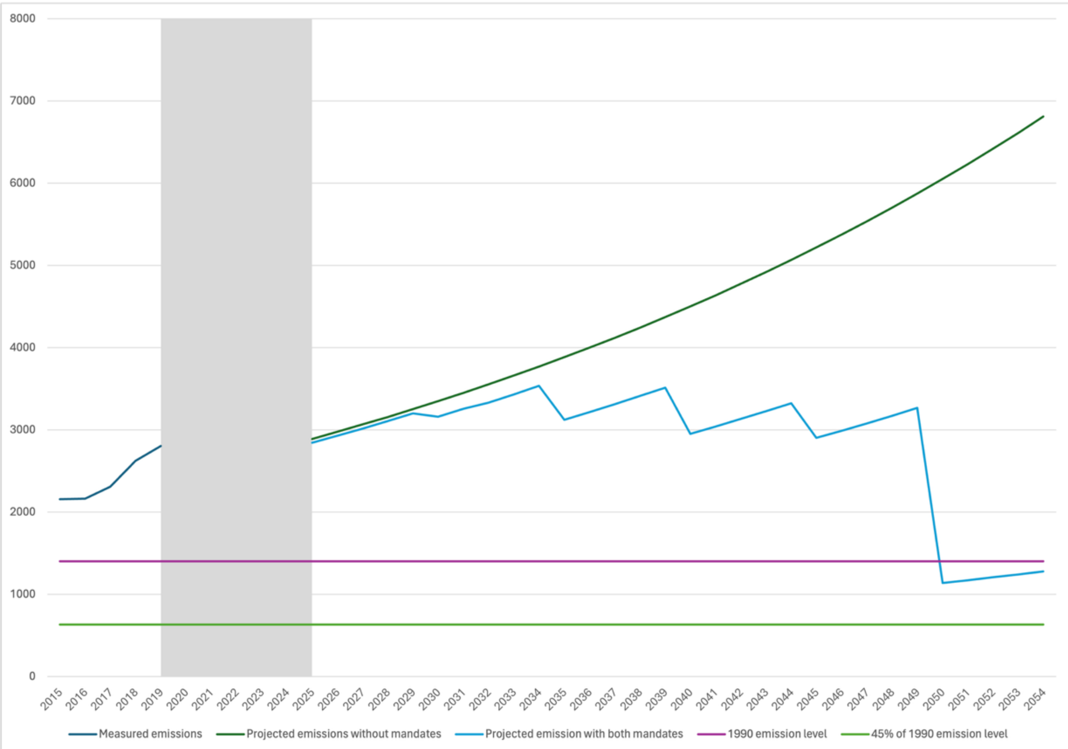

Figure 12 Projected emissions compared to 1990 and the 'Fit for 55' target levels

4.4.3 Anti-tankering Mandate

The anti-tankering mandate of ReFuelEU Aviation is expected to decrease the amount of emissions in the EU, but the environmental effect can be factually quantified only when the operational effects concretize on the aircraft operators. A high-level comparison of post-implementation emissions compared to the pre-implementation levels could reveal the anti-tankering mandate's effects to some extent, but in order to see the full effect, reporting data from aircraft operators would be needed. To be able to assess these effects in greater detail, data on the amount of tankered flights would be needed, which was not publicly available at the time of making this thesis. This puts extra emphasis on the reporting and transparency of environmental indicators of varying operators.

Tabernier et al. [58] estimate that in 2018, 21% of the flights of the members of the ECAC (European Civil Aviation Conference) - which includes all EU member states - performed tankering operations. This accounts for an additional 901 kilotons of CO_2 emissions per year for ECAC member flights. The average additional fuel burn for tankered flights vary between 2,5%-4% per hour of flight, depending on the type of aircraft. [58] Applying these numbers would mean that 21% of the flights would see a reduction of 2,5% to 4,5% in fuel consumption, which is directly proportional to emissions. As said, for Finland specific review more detailed data on tankering in Finland would be needed.

5 Conclusion

This thesis aimed to assess the anticipated impacts of ReFuelEU Aviation regulation on the Finnish aviation sector. By focusing on airlines, airports, and fuel suppliers, the study evaluated the operational and environmental implications of the regulation. A mixed-method approach was adopted, combining document analysis style literature review, stakeholder interviews, and emission-based data extrapolation to address the research questions.

5.1 Key findings

The findings of the study indicate that while the ReFuelEU Aviation is generally seen as a necessary step towards decarbonisation, there are significant concerns about the pace of the SAF mandate ramp-up and the lack of harmonisation across EU regulatory frameworks. Both of the interviewed stakeholders identified a need for better alignment between ReFuelEU and EU ETS reporting. Operational adaptations caused by the ReFuelEU regulation, such as changes to tankering strategies and SAF allocation, have already commenced at key airports. The steep steps in the ReFuelEU Aviation SAF mandate were seen by both interviewed parties as a potential flaw in the regulation, that could be rectified with a more linear progression. This issue was also identified in a stakeholder interview study done to the Italian aviation industry by Erriu et al. [40].

On the environmental side, modelling suggests that SAF uptake has the potential to significantly reduce lifecycle aviation emissions, particularly when produced with high life-cycle emission reduction potential pathways such as HEFA-SPK or synthetic pathways. As the SAF supply chain matures, coordinated public and private efforts are essential to accelerate the synthetic eSAF development and to ensure economic feasibility. This is especially true in Finland, since no domestic eSAF production is yet underway.

However, the blending infrastructure, domestic eSAF production limitations, and cost barriers remain limiting factors. The emission reduction of the anti-tankering mandate remains unknown until quantifiable data is available.

5.2 Policy and Industry Implications

The findings emphasize the importance of policy coherence across EU regulatory instruments. Misalignment between the EU ETS and ReFuelEU frameworks could risk penalising compliant operators. The findings of this study, similar those with Erriu et al. [40], underline a critical gap between policy ambition and current technological and market readiness regarding the SAF mandate ramp-up. As stated by Erriu et al., the regulation's credibility might be compromised, should the SAF mandate targets surpass the feedstock production capabilities [40]. Transition periods and tax subsidies could be a solution that could mitigate the effects of lack in production of synthetic fuels, further alleviating the cost-gap between different pathway fuels (CAF/SAF/eSAF).

The effects of the anti-tankering mandate of ReFuelEU were not seen as a major concern for the air transport operations in Finland. This might not be the case for Central-European countries with operators flying to nearby neighbouring country Union airports that do not necessarily have the operational readiness or infrastructure for sudden increase in fuel uplift. A key factor supporting tankering procedures is the need to maintain flight schedule punctuality, since airlines are legally required to compensate passengers for certain delays under the EU Regulation (EC) No 261/2004 [63]. Hence, the introduction of the anti-tankering mandate could shift the industry's operational priorities towards fuel availability and turnaround efficiency. The affected aircraft operators may need to reassess their scheduling buffers to mitigate the risk of delays that could lead to compensation claims. In this context, ensuring fuel supply reliability becomes not only a sustainability issue, but also a major driver for regulatory compliance and quality of services.

5.3 Suggestions for Future Research

The study identifies several opportunities for future research. A full lifecycle emission analysis on SAF once the ReFuelEU reporting data becomes available could give a clearer view if the regulation will reach reduction in GHG emissions, and at which magnitude. A comparative study to similar Union nations about ReFuelEU implementation could identify the best practices and pitfalls. A follow-up qualitative study involving broader range of stakeholders including regional airports and logistics providers could provide a more comprehensive understanding on the operational effect of the regulation. Especially interesting could be to focus on the time after the year 2034, when the transition period for SAF supply averaging mentioned in Chapter 2. ends, and SAF (and eSAF, which has been introduced already by then) will have to be physically uplifted at every Union airport.

Nation and industry specific levels for the 'Fit for 55' package targets could be quantified in order to compare the aviation industry emission reductions to EU-wide targets. This could be done by evaluating the urgency of emission reduction in each industry, making sure that the comparative size of the industry accounts for large enough reduction when summed with other industries, hence reaching the emission reduction targets.

5.4 Limitations and Validity of the Study

The study benefits from a multidisciplinary perspective and qualitative data from stakeholders. However, some limitations exist. The quantitative analysis on environmental impact relies on forecast extrapolation rather than actual post-implementation data, due to the regulation's recent enactment. The estimated industry growth and life-cycle emission reduction percentages are in reality subjects to great variation, which were modelled with static values in this thesis.

In this study, the comparison of emission reduction projections to the 'Fit for 55' target was done despite the fact that the absolute target level needed to reach the package's goals does not conform to the aviation specific national levels of 1990 in Finland. This choice was deliberate, and was done keeping in mind, that if all the emission reductions from each industry will reach the reduction target, the common target will be reached as well.

The quantitative analysis of this study does not take into account the emission reduction potential of the anti-tankering mandate of the ReFuelEU Aviation regulation. The reduction cannot be quantified until the first reporting period has ended and unless the aircraft operators disclose how much of their tankering procedures have reduced post-implementation. The emission reduction projection does not take into account the possible advancements in jet turbine technology, which might - along with inevitable aircraft fleet updates - help bring down the emission loads in Finland. On the other hand, predicting the industry growth based on the EU average could not represent the true industry growth in Finland, as was seen in the years from 2015 to 2019, where the aviation industry growth in Finland surpassed the EU average.

Despite these limitations, the results offer a credible early insight into the national implications of the ReFuelEU regulation and highlight areas for further monitoring and research.

The validity of the study is supported by the credibility of its data sources and the methodological efforts applied in gathering of the findings from multiple domains. The consistency of the stakeholder perspectives advocate the validity of the findings and the focus of the study. Additionally, the emission reduction estimates by EASA [62] present comparable estimates of reduction potential that reinforce the plausibility of the quantitative findings of the study.

5.5 Final Remarks

The transition towards more sustainable aviation represents one of the most significant challenges - and opportunities - for the aviation industry in the upcoming decades. The ReFuelEU Aviation is an ambitious step forward, but to succeed, it necessitates the cooperation of governments, aviation industry operators, and consumers. Fortunately, Finland has been a pioneer in the green transition, making the national sustainability consensus clear. While the regulation might meet its targets in Finland, the case might be different for a Union nation with more international connectivity and saturation in the market competition.

5.6 Accessibility

This thesis has been prepared with attention to accessibility both in content and format. All primary and secondary sources used in the research were publicly available, apart from the ASTM standards. The interviewees provided the information with consent, and datasets were retrieved from open access repositories. These measures ensure the transparency and reproducibility of the study.

Lastly, the thesis is designed to be accessible to multidisciplinary audiences by avoiding overly technical language and by explaining the engineering and legal concepts clearly.

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