Flight100 Carbon Lifecycle Assessment

End-to-end CO_2 Mapping and Mitigation

June 2024

ICF

Executive Summary

Flight100 served as a powerful demonstration of sustainable aviation fuel's (SAF's) technical viability to fully replace fossil fuels in jet engines. The aviation sector, including Virgin Atlantic (VAA) and the UK Government, have committed to achieving Net Zero carbon emissions by 2050 at the latest. SAF, as a drop in fuel (can be blended with Jet A-1 and used to power current aircraft), provides airlines with a decarbonisation lever. Presently, SAF is made from a range of feedstocks ranging from waste oils, fats, municipal solid waste, and woody biomass and can deliver a 60%-85% lifecycle carbon reduction compared to its fossil Jet A-1 counterpart. However, today the blend ratio of SAF to fossil Jet A-1 is currently capped at 50% by the ASTM. However, as the SAF industry grows and sustainable aviation fuel is used in larger volumes, it will be increasingly necessary to blend at higher ratios to fully harness the carbon mitigating potential of SAF.

As part of Flight100, Virgin Atlantic and ICF assessed the full-scope lifecycle emissions of the 100% SAF flight and a baseline London Heathrow to New York, John F. Kennedy flight, and used carbon removals to mitigate the residual emissions to achieve a net neutral balance of carbon in the atmosphere, hereafter referred to as net zero in this report. This report provides a detailed insight into the methodology and results, while highlighting areas for potential further work and applicability for other carriers.

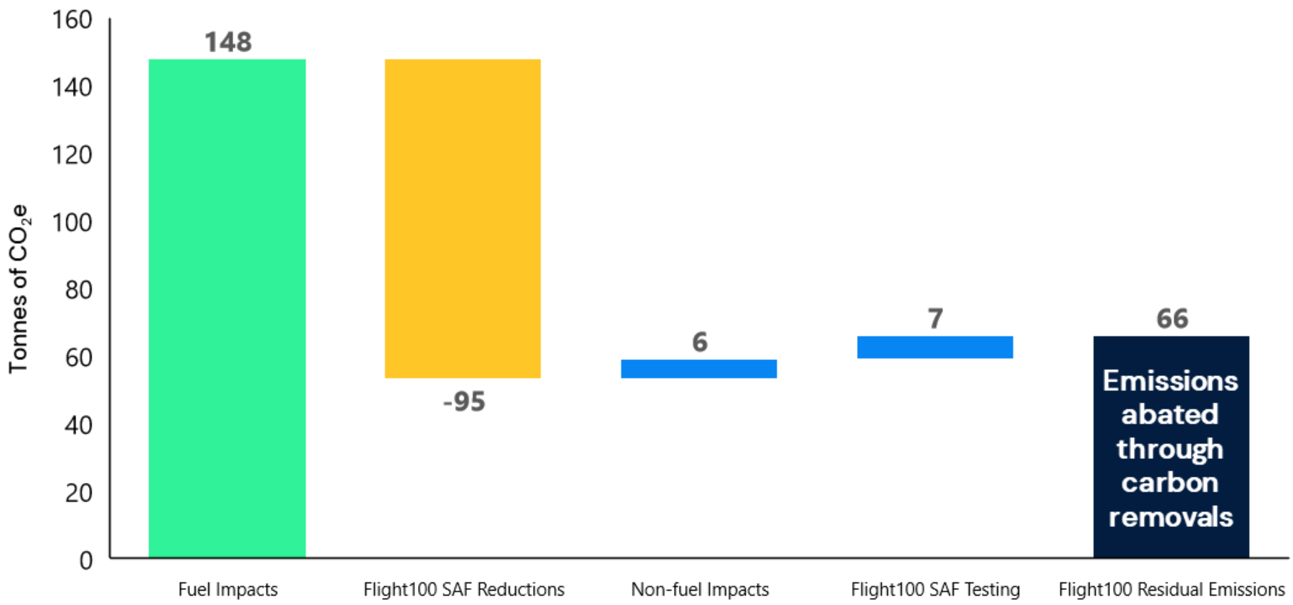
Objectives of the Flight100 lifecycle assessment working group:

- Quantify the level of carbon abatement that 100% SAF can deliver if used on a typical flight, when compared against the fuel burn and non-fuel lifecycle impact of a baseline VAA 787 LHRJFK flight.
- Provide a comprehensive understanding of the carbon impacts of aviation operations beyond the traditional fuel-related reporting boundary.
- Demonstrate options and feasibility of greenhouse gas removals and ensure the residual carbon emissions of Flight100 are mitigated.

This analysis focused on measuring the full lifecycle to ensure residual emissions would be abated to zero and the development of a lifecycle assessment (LCA) framework that could be applied across the aviation industry.

Flight100 assessed lifecycle impact totalled 160.6 tonnes CO_2e with 100% of emissions abated

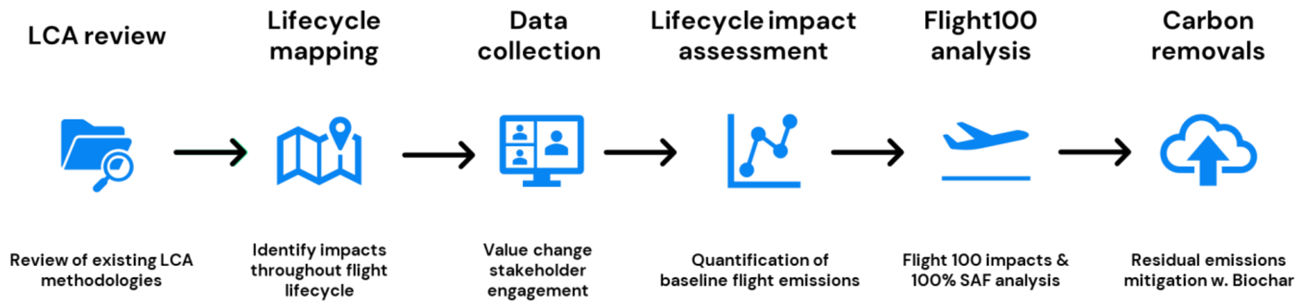
Tonnes of CO_2e



ICF analysis

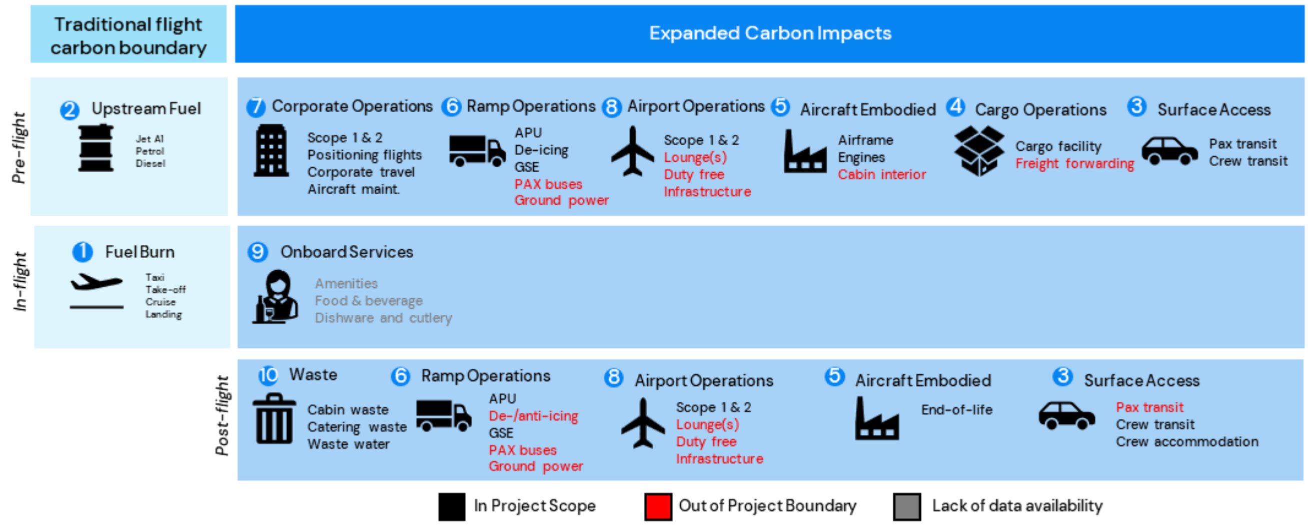
Methodology overview

Working through this novel end-to-end LCA, it was evident that a standard approach would not be fit for purpose. As a result, several UK and international standards have been integrated to capture the project and value chain complexities.



During the LCA mapping and inventory analysis stage, Virgin Atlantic and ICF identified the aviation related activities that are required to operate a VAA flight from Heathrow. Ten categories were identified which contribute to a flight's lifecycle carbon impact: fuel burn, upstream fuel, surface access, cargo operations, aircraft production, ramp operations, corporate operations, airport operations, onboard services, and waste. The attributable processes (individual activities) were then mapped and integrated into the LCA.

Flight 100's LCA carbon assessment scope extended beyond the traditional flight carbon boundary

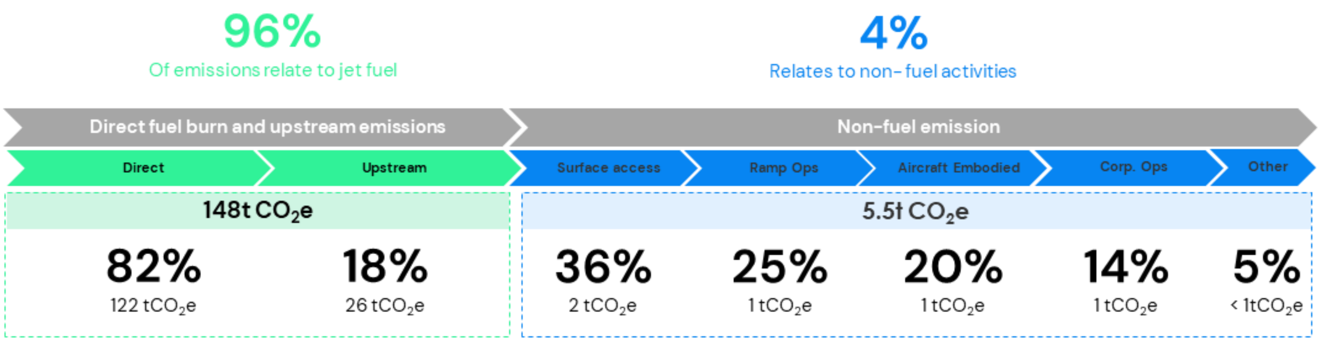


For each attributable process, ICF and Virgin Atlantic collaborated with the relevant process owner(s) to observe, collect, and measure the carbon impact of each activity for a 787 VAA LHRJFK flight. Over eight months, 10 stakeholder groups were engaged (Virgin Atlantic, Heathrow, Dnata, Boeing, Cobalt, Gate Gourmet, Menzies, Delta, JFK T4, MNH Sustainable Cabin Services) and over 86 unique data points were collected. The thoroughness of the lifecycle mapping and subsequent data collection process led to a primary data collection rate of 98%.

Assessing the Results

For a baseline VAA 787 LHRJFK flight, the emissions were calculated as **153.74 tonnes** of CO_2e. Examining the carbon reporting boundaries, 96% of the baseline flight's impact fell within the traditional flight carbon boundary (aircraft-related fuel combustion and upstream emissions) with 4% of the impact residing in the expanded LCA boundary (non-aircraft fuel activities, hereafter referred to as non-fuel activities in this report).

The impact of a baseline LHRJFK 787-9 flight were calculated to be 153.74 tonnes of CO_2e



The average carbon intensity (CI) of the SAF used on Flight100 was 31.69 gCO_2e/MJ, a ~64% reduction compared to Jet A-1 fuel (89 gCO_2e/MJ). The use of 100% SAF resulted in a residual impact of Flight100 of **58.46 tonnes** CO_2e compared to a baseline VAA 787 LHRJFK flight. Accounting for the carbon derived from Flight100 SAF testing campaign (6.88 tonnes CO_2e), to ensure engine and APU compatibility and safety, the total residual carbon to be abated through removals totalled **65.34** tonnes.

The Role of Carbon Removals

To deliver a net zero emissions Flight100, Virgin Atlantic partnered with carbon removals experts, Supercritical, to identify and source high quality UK-based biochar credits on the voluntary carbon market. These were used to mitigate the residual CO_2e that in-sector mechanisms could not reduce. In total, 66 tonnes of biochar credits from the Carbon Hill project in Wales were retired, mitigating the 65.34 tonnes CO_2e of residual emissions.

Industry Learnings

SAF plays a crucial role in reducing lifecycle emissions impacts, but aviation must address emissions across the full value chain to fully decarbonise. This includes mitigating carbon impacts from pre-, in-, and post-flight operations. This will require collaborative efforts across the value chain, including airlines, airport, ground service equipment (GSE) providers, in-flight caterers, cargo handlers, and waste disposal providers.

The collaboration demonstrated in the Flight100 project to map the emissions impact from operating a commercial service can serve as a model for future initiatives. Lacking sector-wide guidance for appropriately measuring Scope 3 emissions, the full scope and scale of non-fuel burn related emissions remains ill-defined. Developing a standardised, industry-specific LCA methodology will be key to understanding and mitigating these emissions as the industry works towards decarbonising the customer journey. While the non-fuel emission sources only represented 4% of total emissions for this transatlantic flight, they would drive a significantly greater portion of emissions for short-haul aviation. For comparison, the results were extrapolated to a London to Milan flight, which estimated that the non-fuel emissions would represent 15% of total emissions. This non-negligible impact, ancillary benefits (such as reduced waste and local air pollution), and potential to decarbonise some of these sources faster than the fuel uplift, should provide encouragement for a greater focus on these sources in the future.

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Chapter 1: An Aviation Milestone

1. An Aviation Milestone

On November 28th, 2023, Virgin Atlantic operated Flight100, the world's first transatlantic flight operated using 100% sustainable aviation fuel. This groundbreaking project represented a milestone for the decarbonisation of the aviation sector by demonstrating the potential for SAF to fully replace fossil Jet A-1 in existing aircraft. This is necessary because while SAF is chemically very similar to fossil Jet A-1, the different feedstocks and manufacturing approaches mean that it lacks certain compounds (such as aromatics), which impacts the fuel systems and engines. To mitigate these impacts, the blend ratio (i.e. mix) of SAF to fossil Jet A-1 is currently capped at 50% by the ASTM to ensure all compounds are present in sufficient quantities for safe operation. As the SAF industry scales and sustainable aviation fuel is used in greater volumes, it will be increasingly necessary to blend at higher levels to fully harness the benefits of SAF and achieve decarbonisation goals. Flight100 was a powerful demonstration of SAF's technical viability to fully replace fossil fuels in commercial aviation.

Flight100's route on November 28th 2023 from London Heathrow to New York JFK

Virgin Atlantic, the UK Government, and the global aviation sector have all committed to achieve Net Zero carbon emissions by 2050 at the latest. SAF is playing a central role to reduce the sector's greenhouse gas (GHG) emissions impacts by meaningfully reducing fuel carbon intensity. However, aviation is a complex sector to decarbonise, and a practical strategy must encompass and address the emissions created across the full value chain of the sector.

Within the aviation sector, carbon measurement usually focuses on the Scope 1 impact, which are the direct emissions resulting from is combustion, and are sometimes called the tailpipe emissions. While these Scope 1 emissions dominate the aviation carbon footprint, this approach overlooks the Scope 3 emissions, which include the indirect emissions created from the supporting value chain, such as ground service equipment, operational support, and infrastructure. While smaller, these emission sources represent important opportunities for mitigation. The first step to achieve this is a comprehensive mapping of the sources and volumes, which has been conducted for Flight100 and presented in this report.

Organisational emissions are classed by scope corresponding to their origin

Scope 1

Direct emissions occur from sources owned or controlled by the company

Scope 2

Indirect emissions are from the generation of purchased energy.

Scope 3

Indirect emissions are a result of an organization's operations, but are not owned or controlled by the company

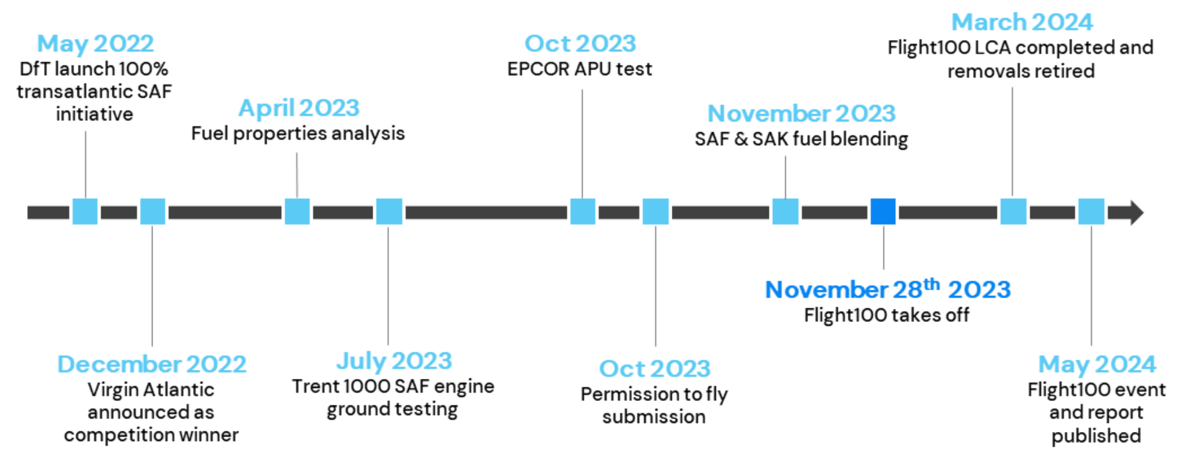
A key challenge to measuring the value chain emissions was the lack of a consistent measurement methodology. Many methodologies have been developed and tailored for specific sectors, but as the aviation value chain includes such a variety of activities, no standard methodology exists. Recognising this, LCA best practice was adapted to quantify the CO_2e impacts of a typical VAA LHR-JFK flight.

This methodology was then applied to identify and quantify the full end-to-end carbon emissions for the Flight100. By conducting this first-of-a-kind analysis, ICF and Virgin Atlantic aim to provide a replicable framework, which can be adopted by industry stakeholders to improve the understanding of the carbon impacts of their operations, supporting decarbonisation action throughout the aviation value chain. This report provides detailed insight into the methodology developed, results, and applicability for other organisations.

1.1. Project Structure

In May 2022, the UK Government's Department for Transport, in partnership with Innovate UK, launched a competition for £1m funding to support the first transatlantic flight on a commercial aircraft using 100% sustainable aviation fuel. In December 2022 Virgin Atlantic were awarded the funding and commenced the project.

Virgin Atlantic 100% transatlantic SAF flight (Flight100) project timeline



Flight100 Project Objectives

Technical Capabilities

- Deliver a transatlantic flight on 100% SAF and with net zero emissions
- Operate the flight within 12 months of winning the competition funding and commencing the project

Technical Advancement

- To build on previous research and demonstration events. This is to further the understanding of the technical and operational feasibility of using 100% SAF in a commercial passenger aircraft
- Demonstrate the commercial and operational viability of using 100% SAF on a flight in both engines, operated on a Virgin Atlantic 787-9 commercial passenger aircraft from London Heathrow to New York JFK
- To deliver technical and safety considerations for the airframe, APU, and engines in order to secure approvals for a 100% SAF flight
- Gather meaningful data to accelerate 100% SAF certification processes and scientific research in on SAF, emissions, contrails, and route management

Environmental Improvements

- Provide a positive example of the transition to SAF to increase consumer confidence in the safety and environmental benefits of SAF

Carbon Removals

- Demonstrate options and feasibility of greenhouse gas removals, and ensure the flight achieves net zero emissions

Industry Collaboration

- Prompt domestic and international industry collaboration to facilitate the flight
- Create a viable industry case study demonstrating innovation, analysis and lessons learnt to benefit the UK aviation industry and wider stakeholders

Delivering Flight100 required a collaboration of several organisations driving the aviation decarbonisation, bringing together a team from industry, academia, and government. The project was structured into key workstreams, each delivering critical outputs for the successful delivery of the flight and the associated research objectives.

Virgin Atlantic Flight 100 Workstream Participants		
Flight 100 Activity	Workstream Description	Stakeholders Involved
SAF testing, safety & approvals	Gain the regulatory and technical approvals to operate the flight on 100% SAF blend	virgin atlantic; BOEING; ROLLS ROYCE
	Deliver technical reports, engine modifications and airframe approvals, and ASTM approval for 100% SAF blend	air bp; VIRENT
	Achieve air worthiness approval and permit to fly	UK Civil Aviation Authority; Federal Aviation Administration
Fleet & operations	Flight and fuel optimisation programme including single engine taxiing, flight optimisation and inflight efficiencies	virgin atlantic
	Operational efficiency initiatives working with ground partners	Heathrow
Lifecycle carbon emissions and carbon removals	Assess the lifecycle emissions of the 100% SAF flight to capture the savings vs. typical baseline and quantify the required carbon removals to mitigate residual emissions to zero	ICF
	Biochar carbon removals to address residual emissions not abated through SAF and efficiency measures	Supercritical
Non-CO_2 effects of flying	Use the flight to further understanding of non-CO_2 impacts of flying and mitigation and verification approaches	Imperial College London; University of Sheffield; RMI

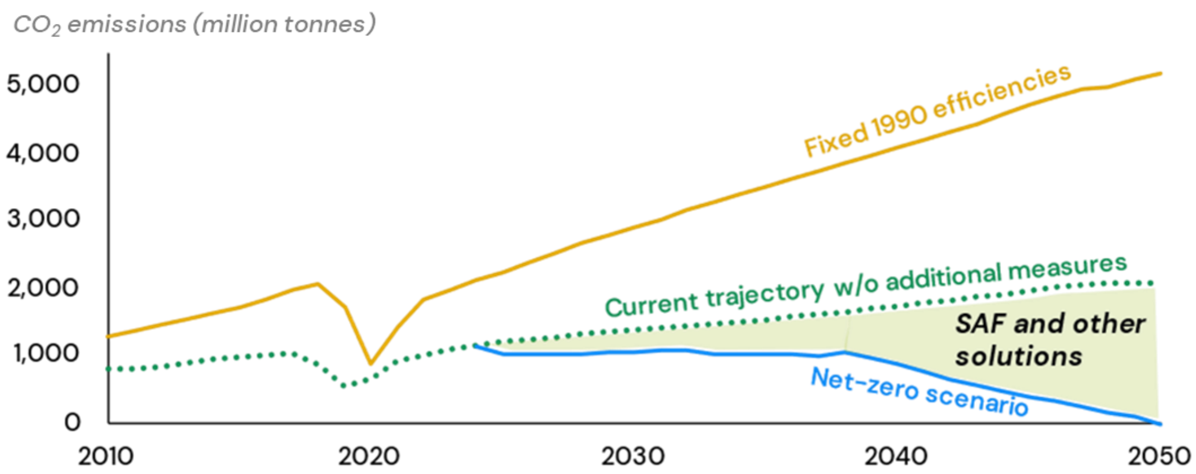
Flight100 Consortium Member | Supporting Party

1.2. Carbon Impact of Aviation

The aviation industry is a crucial driver of the global economy, connecting people, businesses, and supply chains over extraordinary distances. However, propelling nearly 5 billion people per year at great speed and altitude, over long distances, consumes significant amounts of energy, and emits an equally significant volume of GHG emissions. The industry is accelerating efforts to address this environmental footprint, driven by the accepted understanding of the damage GHG emissions cause to the global climate and the mounting pressure from passengers, investors, governments, and society. Several interlocking commitments have been made by nations, representative organisations, and individual companies to reduce the net emissions from aviation to zero by 2050, and analyses have shown that a basket of measures will be essential to achieve this commitment. This includes innovative aircraft technologies (such as electric and hydrogen aircraft), operational improvements, carbon removals, and crucially, the widespread adoption of SAF.

Flight is demanding and requires safe fuels with minimal volume and mass for a given quantity of energy. Kerosene is almost a perfect fuel from this perspective, with over 40x the energy per kg of the best batteries, a high volumetric energy density, and excellent storage properties. SAF enables the beneficial properties and existing infrastructure to continue to be used, while reducing emissions. The graph below depicts the sector's deployment of the decarbonisation basket of measures for achieving Net Zero by 2050 and emphasises that while more efficient aircraft are crucial to limit fuel use, SAF and other additional measures are crucial to achieve Net Zero emissions by 2050.

SAF is crucial to achieve the aviation sector's net zero ambitions



ATAG Waypoint 2050 report, https://aviationbenefits.org/media/167187/w2050_full.pdf

1.2.1. United Kingdom Aviation Ambitions

In 2022, the UK unveiled its Jet Zero Strategy, a blueprint detailing the Government's approach to achieving a carbon-neutral aviation sector by 2050[1]. This commitment was reinforced by the inclusion of the UK's share of international aviation emissions in the sixth Carbon Budget. The Jet Zero Council (JZC) is a government-led partnership between industry, academia and government, which driving the delivery of innovation and technology to decarbonise aviation.

[1] https://assets.publishing.service.gov.uk/media/62e931d48fa8f5033896888a/jet-zero-strategy.pdf

In line with its ambitious Jet Zero Strategy, the UK has set a target of blending 10% SAF by 2030, supported by a SAF blending mandate that will start in 2025 and increase over the following decades. Achieving this mandate will require an estimated 1.2 million tonnes and 7 million tonnes of SAF by 2030 and 2050[2], respectively. The industry will need to rapidly develop and scale to achieve these targets.

1.2.2. Virgin Atlantic Aviation Commitment

Virgin Atlantic recognises the urgent need for action across our industry, committing to Net Zero emissions by 2050, and establishing several intermediate targets to ensure accountability against the decarbonisation trajectory. This includes a short-term target for reduced emissions intensity, followed by mid- and long-term absolute reduction targets.

A portfolio of mechanisms is in use to achieve these targets. The use of the most efficient aircraft available is key to ensure that as little fuel as possible is consumed. Efficient operations, including weight reductions, route planning, and other initiatives, are similarly important. However, while these measures can greatly reduce emissions, increased use of sustainable aviation fuel is crucial to further reduce emissions.

Virgin Atlantic has established a near-term target to blend 10% SAF by 2030 and is actively collaborating with multiple producers to ensure production scales to meet this demand. Against this context, the 100% transatlantic SAF flight represents a key achievement in Virgin Atlantic's broader sustainability journey, demonstrating that full replacement of fossil fuel with SAF is operationally feasible in today's engines, airframes and infrastructure, and showing the feasibility for SAF use to scale to the magnitude required. Flight100 also showed that it takes a concerted and collaborative effort to achieve these targets, with organisations from energy, aviation, academia, and public sector working together to solve the challenging problems.

[2] https://www.sustainableaviation.co.uk/wp-content/uploads/2023/04/Sustainable-Aviation-SAF-Roadmap-Final.pdf

Flight100 has reinforced Virgin Atlantic's commitment to Net Zero 2050 and interim targets

2026	2030	2040
15% gross reduction in CO_2/RTK	15% net reduction in CO_2 emissions against a 2019 baseline **10% of fuel sourced from SAF**	40% net reduction in total CO_2 emissions

Virgin Atlantic have been committed to innovation, action, and transparency to reduce their environmental impact for over a decade. Aviation fuel accounts for >90% of their scope 1 and 3 carbon emissions, as a result Virgin Atlantic have relentlessly focussed on reducing these emissions through several key decarbonisation levers.

Virgin Atlantic's Sustainability Action

Aligned with expert industry views on the potential technologies that materially contribute towards decarbonisation, Virgin Atlantic are focussed on three key areas that the carrier can control to achieve its Net Zero ambition.

Fleet renewal and operational efficiency

- The biggest technology lever available to airlines to reduce carbon emissions is more fuel-efficient aircraft. In 2023, Virgin Atlantic added a further three aircraft to their fleet, including two A330neo and one A350neo, to total 41 aircraft across the fleet, replacing older, less efficient aircraft.
- Virgin Atlantic now operate a fleet with an average age of just 7 years, and 76% next generation aircraft mix.
- In 2023, 87% of Virgin Atlantic's overall capital expenditure related to new fleet and engine investment.
- Virgin Atlantic deploy operational efficiency measures as part of the day-to-day operations, including route planning, weight reduction and constant review of waste carried, to minimise fuel burn.
- Behavioural economics and data science-based applications are used to provide the flight deck with both inflight and post flight feedback on how to fly more efficiently from a fuel burn perspective, while still complying with all standards of fuel management and flight safety.
- In 2023, Virgin Atlantic saved 7,500 tonnes of Jet A-1 equivalent to 23,700 tonnes of CO_2, through operational efficiency initiatives, including pilot technique, ground operations, weight reduction and flight planning optimisation.

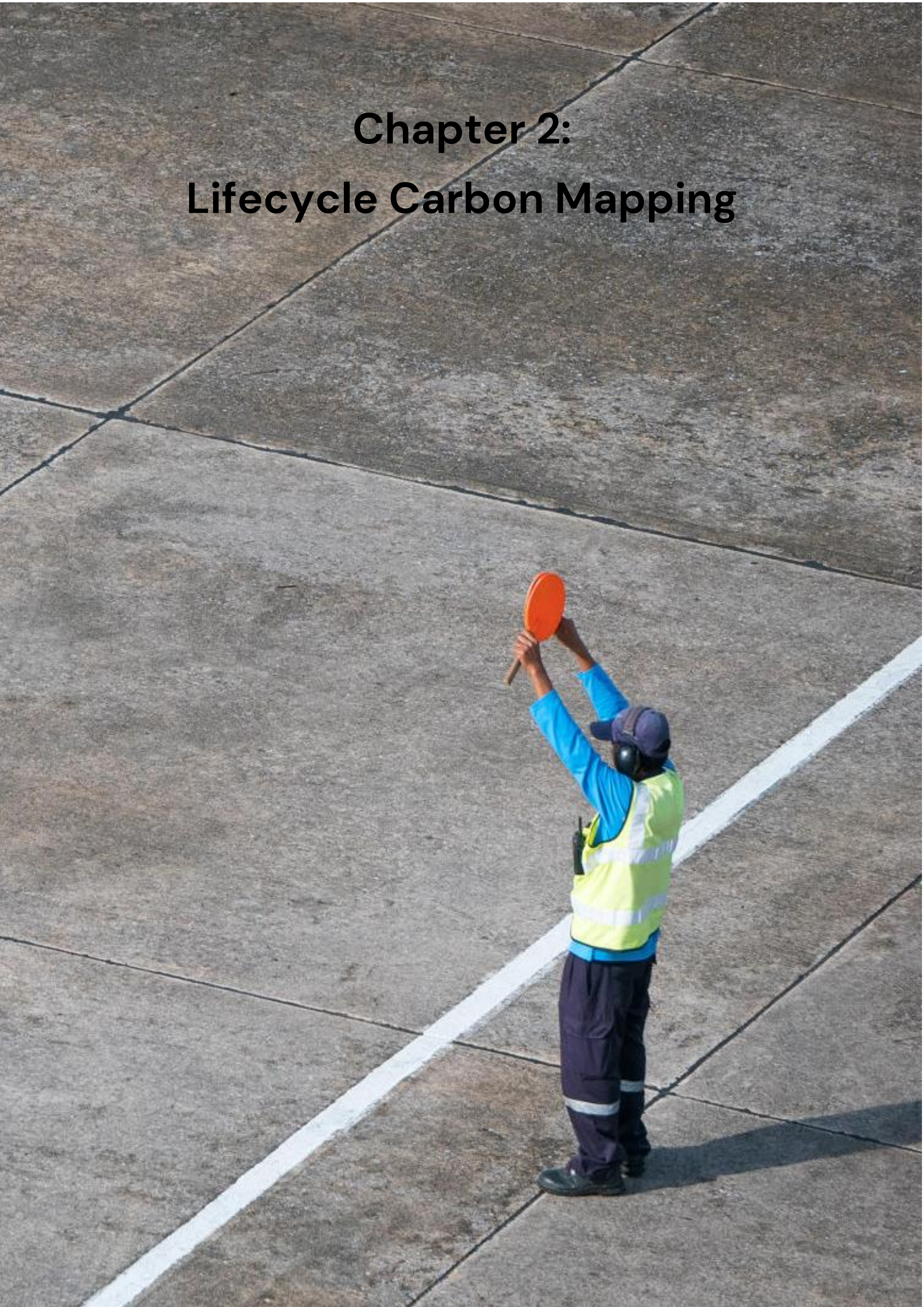
Sustainable Aviation Fuel

- SAF is a key lever to reducing emissions. Virgin Atlantic have been championing the development for over 15 years.
- Committed to 10% SAF by 2030
- In the last two years (2022 and 2023) Virgin Atlantic have taken delivery of almost 4,000 tonnes of SAF into the network.
- Virgin Atlantic have committed to purchasing 10 million USG of SAF from Gevo and have non-binding MOUs with LanzaTech and Air Company for a further 13m USG and 10m USG respectively, covering 65% of the volume needed to hit their 10% target.

Carbon offsets and removals

- Virgin Atlantic's priority is to reduce carbon emissions from fleet, fuels, and operational efficiencies as far as possible. However, technology constraints will likely drive the need for carbon offsets and removals to address residual emissions.
- On the pathway to net zero, Virgin Atlantic's residual net carbon emissions will be reduced by investing in carbon offset and removal projects and funding emissions reductions through the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).
- The need for carbon offsets and removals was a decisive factor when deciding to mitigate any residual emissions from Flight100 using carbon removals, as this ensured lessons could also be gained in this field.

Chapter 2:
Lifecycle Carbon Mapping



2. Lifecycle Carbon Mapping

The first step to reducing emissions is the selection and use of a robust methodology for their measurement, and carbon lifecycle assessments are one of the most widespread tools to achieve this.

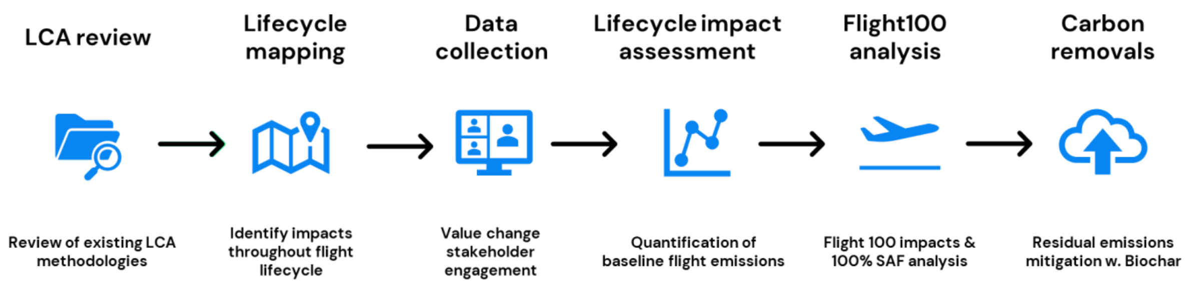
Carbon LCA provides a quantitative framework to identify and quantify the environmental impacts of a product and/or service over all of its life cycle stages. This helps industries and organisations to assess and evaluate the cradle-to-grave environmental impacts of their products.

Within the aviation sector, LCA has historically been used only to assess the carbon intensity of fuels. While fuel burn represents the majority of aviation's climate impact, this exclusive focus on fuel has neglected the wider value chain impacts from the industry. This has resulted in some organisations overlooking important opportunities to reduce emissions.

The narrow scope of LCA deployment to date is in part due to the current lack of need. The reporting requirements in aviation are varied, and most airlines typically disclose emissions in line with their national and regional environmental compliance obligations (EU ETS, UK ETS, and CORSIA). Additional social and governance reporting obligations adds to this administrative burden, challenging many airlines to go beyond the current scope of reporting requirements.

Flight100 served as an ideal testbed for a full LCA, encompassing a much wider scope than typically used. In the context of the flight, this provided the structure to calculate, reduce, and offset the full emissions scope. It is hoped that this calculation is useful when extrapolated to the aviation industry, providing insights to the supply chain emissions that many other airlines may not have the resources to conduct.

The Flight100 LCA baseline was calculated for a typical Virgin Atlantic Boeing 787 flight from London Heathrow to New York JFK, capturing the full value chain impacts of operating the flight – including pre-flight operations (e.g. emissions embodied in the aircraft), flight ops (fuel and onboard service), to post-flight operations (such as waste disposal and many others). Assessing these impacts reflects the vital role SAF can and will serve in reducing the sector's emissions when compared to Jet A-1. Additionally, quantifying the residual carbon SAF cannot mitigate throughout the wider value chain highlights the need for additional decarbonisation initiatives to address non-fuel burn related impacts. While this analysis was done for a single flight, the results provide insights for every airline.



2.1. Overview of Current Guidance

Lifecycle assessment identifies and quantifies the environmental externalities of a product throughout its lifecycle, from material extraction to end of life. A robust LCA requires the assessment scope, system boundary and granularity to be tailored to the product, industry and intended use. As a result, the depth, and the breadth of LCAs will vary significantly across industries.

Depth and Breadth of LCAs

LCA methodology can be categorised into three levels based on technological details:

Conceptual LCA: First level of LCA based on limited environmental aspects of few life cycle stages. The results might be useful for qualitative reporting of assessment results, but not suitable for corporate marketing or explicit publication of LCA study.

Simplified LCA: Comprehensive assessment using generic datasets covering the whole life cycle of a product/system of processes. This consists of a screening of life cycle stages, simplification of LCA results for future recommendation and assuring the reliability of the analysis results.

Detailed LCA: Comprehensive with the full consideration of each life cycle stages with system-specific datasets and analysed in detail for further process improvement. A detailed LCA is conducted through the collection of primary data with supporting secondary data where needed.

https://www.sciencedirect.com/book/9780323854511/life-cycle-assessment-for-sustainable-mining

Below is an overview of the five LCA standards used to guide this project. From these standards, guidance has been drawn on identifying lifecycle stages and attributable processes, drawing system boundaries, and methodological approaches for data collection, quantification, and materiality evaluation.

Lifecycle Assessment Standards Utilised

Greenhouse gas protocol (GHGp) Product Standard

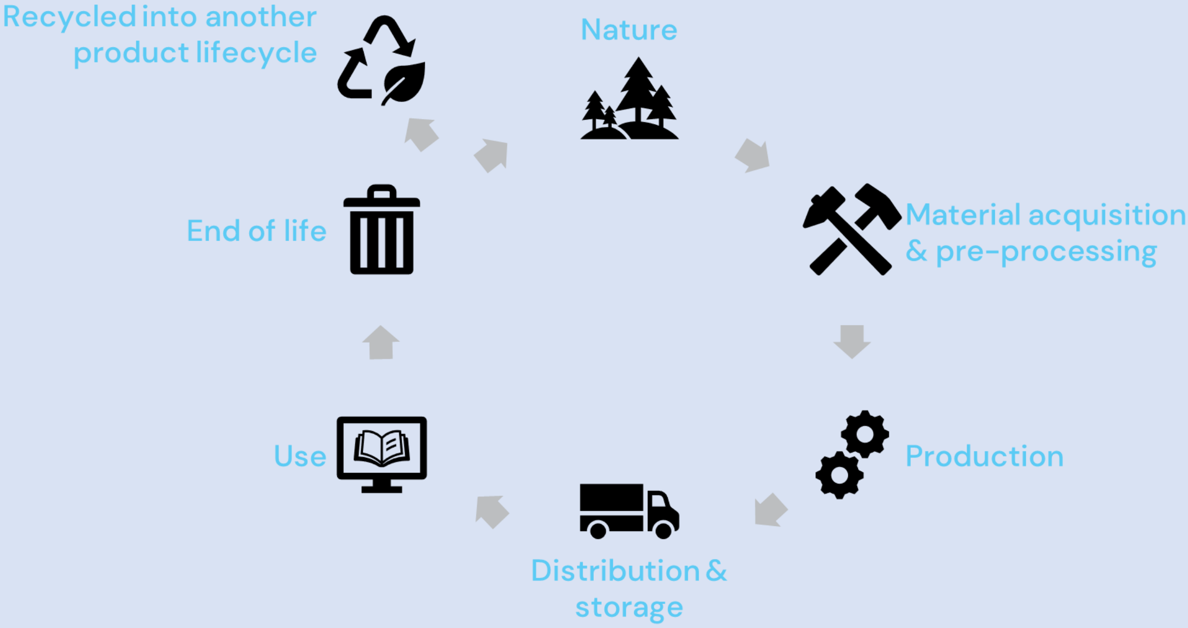
- The GHGp Product Standard is an internationally recognized framework for assessing and quantifying the carbon footprint of a product throughout its entire life cycle.
- This standard helps organizations measure emissions associated with a product's life cycle, including raw material extraction, production, distribution, use, and disposal.
- The GHGp is suitable for businesses looking to assess and reduce the carbon footprint of their products and supports transparency in reporting to stakeholders.
- The GHGp Product Standard facilitates the identification of emission hotspots in a product's life cycle, enabling companies to make informed decisions for reducing environmental impacts.

ISO 14040 (Life Cycle Assessment: Principles and Framework)

- ISO 14040 is an international standard that outlines the general principles and framework for conducting Life Cycle Assessment (LCA) studies.
- It provides a structured approach to LCA, emphasizing goal and scope definition, life cycle inventory analysis, impact assessment, and interpretation of results.
- ISO 14040 is widely used as a foundational framework for conducting LCAs across various industries and sectors.
- The guidelines ensures consistency and comparability of LCA studies, aiding organizations in assessing the environmental impacts of products or processes comprehensively.

ISO 14044 (Life Cycle Assessment: Requirements and Guidelines)

- ISO 14044 is an international standard that complements ISO 14040 by providing detailed requirements and guidelines for conducting specific Life Cycle Assessment (LCA) studies.
- The standards offer guidance on data quality, life cycle inventory analysis, impact assessment, interpretation, and reporting.
- ISO 14044 serves as a valuable reference for organizations conducting LCAs in various contexts, including product assessments and environmental declarations.
- The framework enhances the robustness and transparency of LCA studies, helping organizations make informed decisions based on reliable and consistent environmental information.



PAS 2050

- PAS 2050, developed by the British Standards Institution (BSI), is a publicly available specification that focuses on measuring the carbon footprint of goods and services
- It provides a standardized methodology for assessing the greenhouse gas emissions associated with a product's life cycle, including production, distribution, and disposal.
- PAS 2050 is widely used for carbon footprint assessment and reduction strategies in various industries, helping organizations understand and reduce their environmental impact
- This framework enables companies to assess and communicate the carbon footprint of their products in a consistent and credible manner, promoting eco-friendly practices and aiding consumers in making informed choices

ISO 14083 (Quantification and reporting of greenhouse gas emissions arising from transport chain operations)

- Airlines must consider the entire transport chain, from origin to destination, when assessing emissions
- Airlines should report emissions for both passenger and freight transport chains
- Airlines must source data as inputs for GHG calculations
- The quantification of GHG emissions of a transport chain shall include the following processes, which produce GHG by combustion, regardless which organization operates them:

    - Vehicle operational processes
    - Hub equipment operational processes
    - Vehicle energy provision processes
    - Loaded and empty trips made by vehicle(s)
- Application of cut-off criteria to a given transport chain can rely on the following three quantifications:
    - Transport activity: inclusion in the study of all inputs that cumulatively contribute more than a defined percentage of the transport activity within the chain
    - Energy: inclusion in the study of all inputs that cumulatively contribute more than a defined percentage of the transport activity within the chain.
    - Environmental significance: inclusion of all GHG sources that cumulatively contribute more than a defined percentage of the GHG emissions of the chain

The LCA conducted for Flight100 embodies a comprehensive approach, drawing from a diverse range of global and UK carbon and product lifecycle assessment standards. All LCA approaches will have their limitations, making it important to understand what risks may be present while working to mitigate said limitations.

Working through this novel LCA, it was evident that applying a one-size-fits-all approach for the LCA would not be fit for purpose. As a result, a multitude of approaches have been deployed to address project and value chain complexities.

2.2. Lifecycle Assessment Framework Deployed

To guide the development of the Flight100 LCA, the ICF and Virgin Atlantic team used the ISO 14040 LCA methodology, complemented with elements of other methodologies for boundary setting and data collection. To ensure an LCA is robust and sufficient in its depth and breadth, it must clearly define the goal and scope, inventory analysis, an impact assessment, and an interpretation of results.

ISO 14040 Life Cycle Assessment Methodology

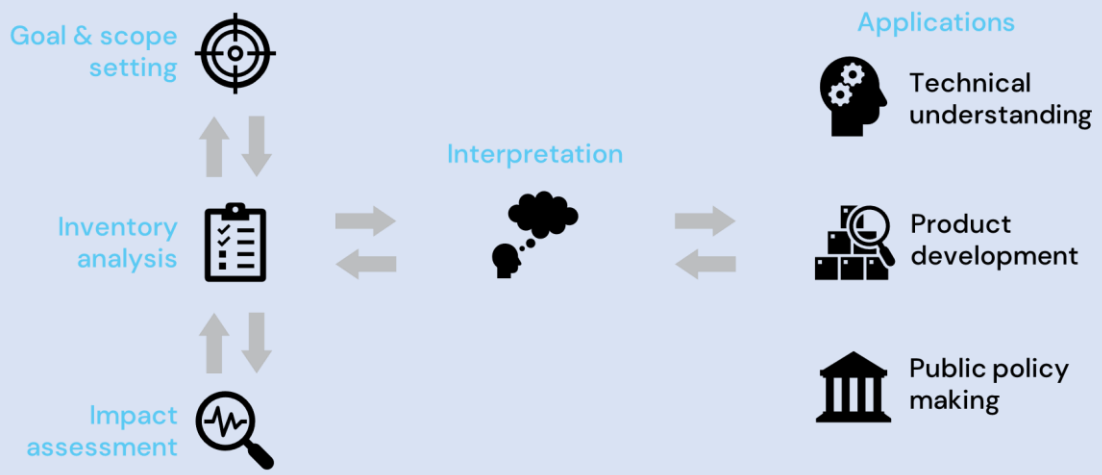
ISO 14040 Life Cycle Assessment Best Practices provides procedural guidance for conducting LCAs. To ensure compliance with global standards, the 100% SAF LCA has been undertaken in-line with the following four phases:

Goal and Scope Definition: The LCA process commences with a clear definition of its objectives, scope, and boundaries. This is where the facets of the product's life cycle evaluated, the environmental impact categories of interest are identified, and the system boundaries are established.

Life Cycle Inventory Analysis (LCI): The LCI phase entails the systematic compiling of data related to the product system under evaluation. This data includes inputs, outputs, and processes across the entire life cycle. The goal is to create an inventory of environmental flows, from resource extraction to disposal.

Life Cycle Impact Assessment (LCIA): The LCIA phase takes the collected inventory data and assesses the environmental significance of the results. It involves the quantification of the product's impact on selected environmental categories, such as greenhouse gas emissions.

Life Cycle Interpretation: The final phase of LCA serves as the culmination of the study. Here, the results from LCI and LCIA are examined and discussed, ultimately leading to conclusions, recommendations, and decisions aligned with the predefined goals and scope of the analysis.



These LCA guiding principles and methodological process supported the objective to provide and develop a robust framework for evaluating carbon emissions associated with the aviation sector. The ISO guidelines provided a framework for structuring lifecycle stage mapping, data collection, impact evaluation, and carbon quantification.

2.2.1. Lifecycle Assessment Goal and Scope Setting

The ISO 14040 LCA guidelines require the assessment goals and scope to be established prior to the analysis. This should include the rational for the LCA, the application of the results and the audience for the work. The scope of an LCA must present the functions of the system being evaluated and establish a functional unit of study. A functional unit is a measure of the performance of the functional outputs of the product system and is effectively the quantity of a product for which the lifecycle impacts are going to be evaluated within a given LCA i.e., the reference unit of the study.

Flight100 LCA Goal and Scope Setting

Problem Statement: Lack of visibility as to the scale of Scope 3 and non-fuel burn aviation related emissions & quantifying the level of carbon abatement flying on 100% SAF can deliver.

Goal: When compared against the standard fuel burn and LCA impact of a VAA 787 LHRJFK flight, quantify the level of carbon abatement which 100% SAF could deliver if used on a typical flight.

Application of Results: Comprehensive with the full consideration of each life cycle stages with system-specific datasets and analysed in detail for further process improvement. A detailed LCA is conducted through the collection of primary data with supporting secondary data where needed.

Intended Audience: Primarily aviation industry stakeholders, including airlines, airports, original equipment manufacturers (OEMs) and service providers, as well as passengers/general audience.

Functional Unit of Study: Virgin Atlantic one-way 787 LHRJFK flight.

2.2.2. Defining the Lifecycle System

A product system defines the upstream and downstream processes which feed into and comprise the product. In a standard LCA these activities would typically include components and materials manufacturing, distribution, use and disposal of the product. Typical product lifecycle stages, as depicted in section 2.1, are ill-suited to assess a flight as a product. For example, for any given individual flight, there are no conventional pre-processing, production, distribution, or end of life impacts. The raw material extraction, end-of-life impacts, and material acquisition required to operate a flight occur at varying stages of an aircraft's lifespan are not synonymous with each flight operated.

As such, to thoroughly define the lifecycle system boundaries of a single flight, an aviation specific product system had to be developed to inform boundary setting, impact identification and data collection as system boundaries determine which activities are included within an LCA.

This required an aviation specific product system to be developed for the boundary setting, impact identification and data collection.

Per ISO ISO14025:2006 guidelines, if guidance for the product being considered does not exist, the system boundary shall be clearly defined for each product, and its underlying processes with consideration given to the material contribution that different processes within the system boundary will make to the total GHG emissions of said product. When evaluating a single flight as a product, the product system comprises not only the flight itself but also all the upstream and downstream processes integral to its operation.

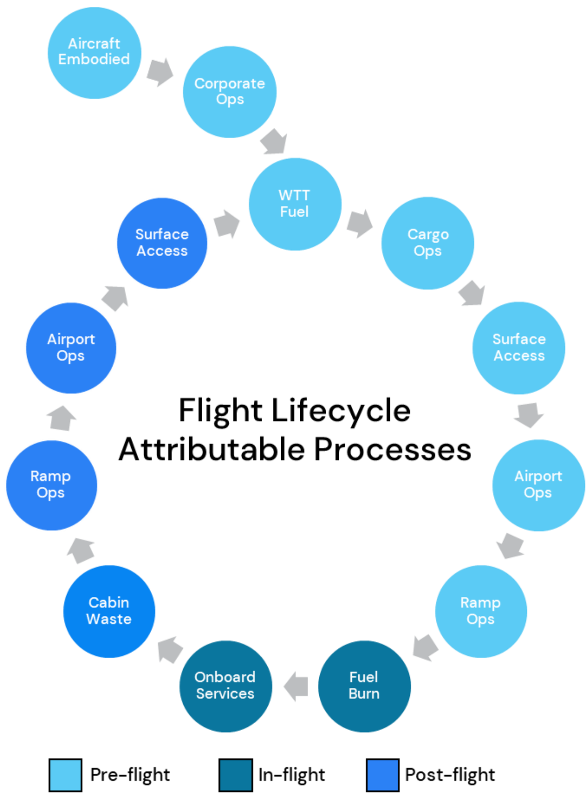
To suit the functional unit of study (a VAA one-way 787 LHRJFK flight), the lifecycle of the product was established to contain three phases: pre-flight, in-flight, post-flight. Breaking the lifecycle of a one-way flight into these three lifecycle phases captures all processes associated with the product under evaluation.

Lifecycle stages of a flight were developed to suit the unique nature of the product

Contained within each of the three lifecycle stages are several attributable processes which are the individual activities which contribute to the overall environmental impact of the product, the one-way LHRJFK flight. During the LCA methodology development, Virgin Atlantic and ICF worked to identify the aviation related activities which are imperative to operating the functional unit of study. These activities are mapped below and are colour coded to their respective lifecycle stage. The detailed lifecycle stage map encompasses all pre-, in-, and post-flight activities that occur throughout the full aviation value chain.

Certain activities such as ramp and airport operations and surface access occur at both flight origin and destination. The occurrence of the same impact categories in multiple lifecycle stages is an additional consideration that conventional LCA guidance does not account for. However, it was important that the multiplicity of these impacts was captured within the aviation value chain LCA. As aviation is a geographically diverse industry, the surface access, airport, and ramp operation impacts will vary significantly from airport to airport and especially from region to region.

Identified processes contained within a one-way flight's lifecycle



A complete and detailed LCA needs to be based on complete product information with respect to its components and the materials of the components. The developed lifecycle stage product map enabled a detailed and complete inspection of the individual environmental flows and activities through the flight's lifecycle.

2.2.3. System Boundary Drawing & Inventory Analysis

When conducting an LCA, the system boundaries determine which activities and processes shall be included within the final environmental impact figure. The system boundary determines which lifecycle stage processes are to be included within the final LCA. Establishing the inventory of activities contained within each attributable process was crucial for drawing the LCA boundaries. The lifecycle inventory analysis phase involved compiling the complete list of inputs and outputs for the one-way flight across its lifecycle stages.

Lifecycle Stage Impact Categories

Central to any LCA is identifying the significant activities which exists throughout the entire life cycle of a product.

1. **Fuel Burn:** Aviation turbine fuel (Jet A-1, kerosene) burnt on the aircraft during on stand taxi-out, take-off, cruise, landing, and taxi-in. Fuel consumption measured from departure to arrival. Fuel burn includes consumption by the auxiliary power unit (APU) on stand.

2. **Upstream Fuel:** Carbon impacts associated with Jet A-1 extraction, refining, transportation, and production prior to combustion. Classified as well-to-tank impacts (WTT).

3. **Surface Access:** Categorised by passenger and crew impacts reflecting how individuals travel to the airport. Assesses modes of transport used as well as distance travelled. Additional impacts include crew transportation and accommodation during layovers.

4. **Cargo Operations:** Capturing the impact of cargo operations associated with belly freight cargo on a given flight. Following the cargo journey from when it arrives at the carrier's cargo facility to the aircraft.

5. **Aircraft Embodied:** The environmental impacts of aircraft materials, manufacturing and end of service activities, and engine manufacturing. Captures supply chain, OEM Scope 1 and 2, and aircraft end of disassembly and disposal impacts.

6. **Ramp Operations**: All ground support equipment (GSE) operating when the aircraft is on stand prior to departure and following arrival.

7. **Corporate Operations:** Airline operational emissions, including Scope 1 and Scope 2 emissions from activities under operational control, including positioning and maintenance flights, scope 3 emissions associated with business travel.

8. **Airport Operations:** Departure and arrival airport's Scope 1 and Scope 2 emissions

9. **Onboard Services:** Embodied carbon of carrier soft product covering, food and beverage, amenities, and additional soft product offerings.

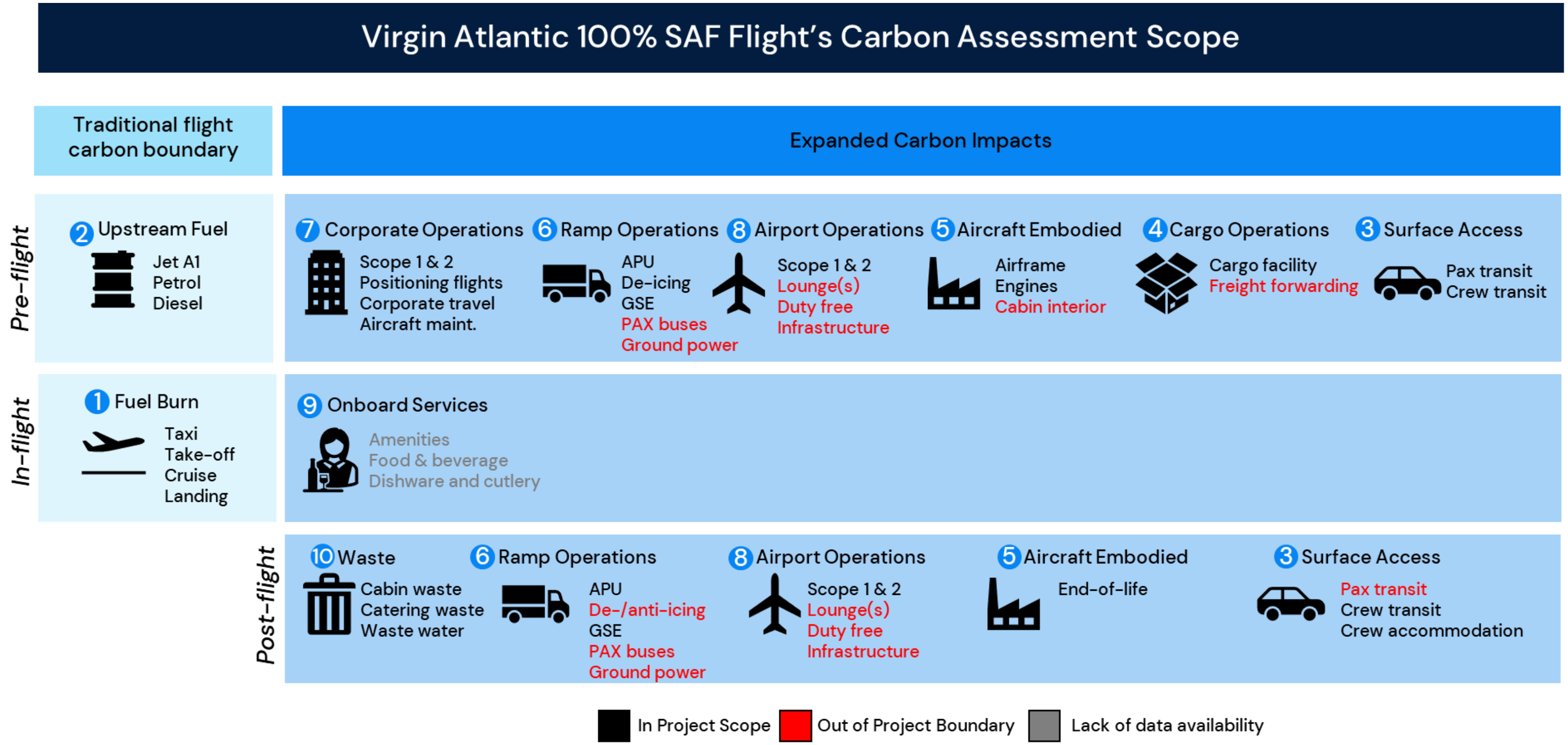
10. **Waste:** Disposal and treatment of waste generated in-flight and disposed of through various waste streams. Inclusive of food and beverage and cabin waste.

The selection of unit processes and carbon to be included within the product system and carbon inventory depends on the scope and objectives of the study. Ideally, all processes associated with the product should be considered. However, practical constraints may necessitate the exclusion of some processes, and those that only make minor contributions to the overall environmental load may be excluded based on immateriality[3].

While some activities have been excluded based on immateriality, some equally immaterial processes have been included within the scope. This decision was made where the activity may meet the immaterially criteria but had data that was easily accessible and was feasible to include. Although a conventional LCA may enforce the cut-off criteria more stringently, it is hoped that including these selected minor sources provides a more complete picture – allowing assumptions on immaterial to be evidenced (or disproved) for future LCAs.

The figure below outlines which activities were included and excluded within their respective attributable process as part of the LCA, across pre-flight, in-flight, and post-flight lifecycle stages. Drawing from International Organisation for Standards (ISO)S, GHGp and PAS 2050 guidelines, the exclusion of individual lifecycle stages and/or processes is permitted if it does not significantly change the overall conclusions of the study. The decision to omit lifecycle stages and/or individual processes is clearly stated during the Life Cycle Impact Assessment (LCIA) with the reasons for omission justified. The boundary drawn for the Flight100 LCA ultimately excludes activities not directly attributed to operating a one-way flight, where VS had limited influence on activity, where primary and secondary data was unavailable, or where impacts were immaterial.

[3]https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pd


Virgin Atlantic 100% SAF Flight's Carbon Assessment Scope
Traditional flight carbon boundary
Expanded Carbon Impacts
Pre-flight
2 Upstream Fuel
Jet A1
Petrol
Diesel
7 Corporate Operations
Scope 1 & 2
Positioning flights
Corporate travel
Aircraft maint.
6 Ramp Operations
APU
De-icing
GSE
PAX buses
Ground power
8 Airport Operations
Scope 1 & 2
Lounge(s)
Duty free
Infrastructure
5 Aircraft Embodied
Airframe
Engines
Cabin interior
4 Cargo Operations
Cargo facility
Freight forwarding
3 Surface Access
Pax transit
Crew transit
In-flight
1 Fuel Burn
Taxi
Take-off
Cruise
Landing
9 Onboard Services
Amenities
Food & beverage
Dishware and cutlery
Post-flight
10 Waste
Cabin waste
Catering waste
Waste water
6 Ramp Operations
APU
De-/anti-icing
GSE
PAX buses
Ground power
8 Airport Operations
Scope 1 & 2
Lounge(s)
Duty free
Infrastructure
5 Aircraft Embodied
End-of-life
3 Surface Access
Pax transit
Crew transit
Crew accommodation
In Project Scope
Out of Project Boundary
Lack of data availability

Chapter 3:

Lifecycle Impact Assessment

3. Lifecycle Impact Assessment

During the Lifecycle impact assessment phase, the carbon emission impacts within the LCA scope were calculated.

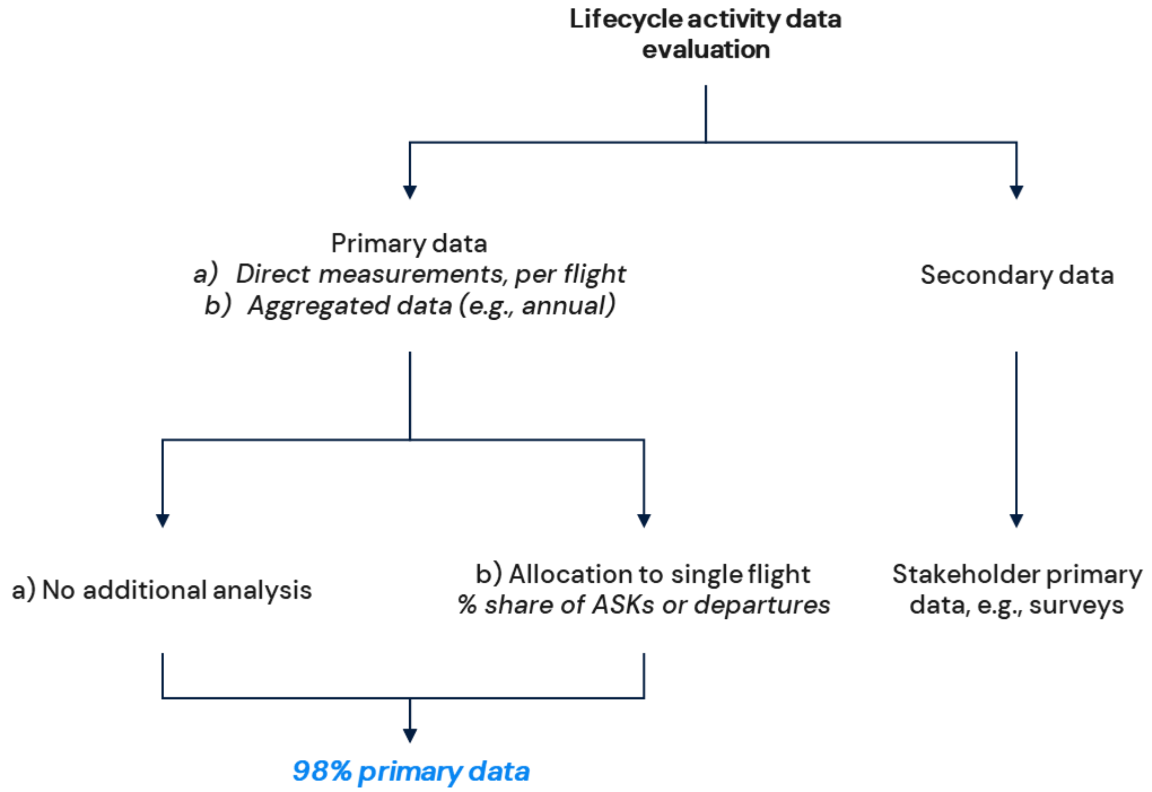
In accordance with ISO 14040 Life Cycle Assessment Methodology, the Life Cycle Impact Assessment (LCIA) stage includes identifying and evaluating attributable processes to supply invaluable information regarding the size and scale of emission sources throughout a flight's life cycle. The aggregation of data serves to pinpoint the most significant emission sources ("hot spots"), within distinct life cycle stages and across the broader product system.

The data collection phase was central to developing a precise understanding of the environmental impact of a baseline flight and for assessing the carbon savings achieved by 100% SAF. This section provides a detailed overview of the LCIA process along with the LCA results for a baseline VAA 787 LHRJFK flight.

Within the LCIA framework, utilising an attributional approach leverages primary data measured through activity analysis or directly provided by stakeholders. To meet PAS 2050 standards, throughout the LCIA, stakeholder collaboration ensured that all GHG emissions occurring within the defined system boundary were subject to evaluation.

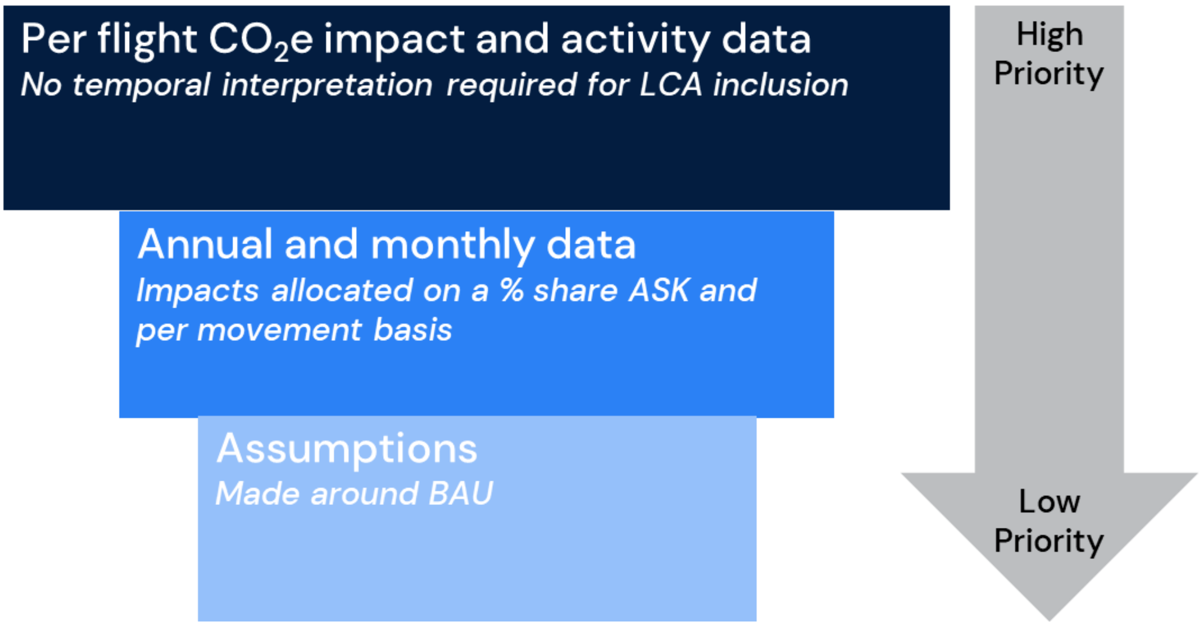
The data quality of emissions occurring within the system boundary are of paramount importance. The data gathering approach for this LCA was rooted in the attributional method while adhering to PAS 2050 standards. As outlined by PAS 2050, for processes owned or operated by Virgin Atlantic, an emphasis was placed on primary data, ensuring that a minimum 60% of GHG emissions were calculated from emission factors derived from primary activity data in the supply chain. Through a thorough stakeholder engagement process, **over 98% of the LCA activity data collected was primary data**.

Data collection process flow diagram utilising in Flight100 data collection



Primary activity data was gathered from either a) direct measurement on an individual flight basis or, b) aggregated activity data over a given timescale (typically annual or monthly). For activity data collected on a per flight basis, no additional analysis was required prior to applying the relevant emissions conversion factor.

Hierarchy of data collection approaches utilised for the LCIA



For primary activity data aggregated over a reporting timescale, these impacts required allocation to a single flight prior to the application of an emissions conversion factor. The allocation methodology will be covered in more detail in the subsequent sub-sections. Generally, the per flight impacts were allocated based on i) a single LHRJFK flight's percentage share of Virgin Atlantic's total LHR available seat kilometres (ASKs), ii) a flight's percentage share of Virgin Atlantic's global ASKs or, iii) a percentage share of Virgin Atlantic's total annual flights.

For some attributable impact categories, primary data collection was not required as data had been previously collected by value chain partners as part of their respective carbon management initiatives. For example, in the instance of passenger transit to LHR as part of the surface access impact category, the Heathrow team provided comprehensive survey results which captured how over 23 million passengers arrived at Heathrow in 2022 along with average distance travelled by mode of transit. The use of secondary data (stakeholder primary data) served to ensure that the assessment remained robust and accurate when primary data was not directly measured or collected by either Virgin Atlantic or ICF.

In rare instances attributable processes have been excluded from the carbon inventory. Such exclusions were made only under specific circumstances and reflect data gaps and an inability to ascertain extrapolated or proxy data. Such exclusions are duly disclosed in the impact analysis below, accompanied by clear justifications for exclusion.

Lifecycle impact assessment emission data overview

	Data stakeholder	Data used	Primary?
Fuel burn	Virgin Atlantic	Seasonal avg. LHRJFK 787-9 2022 fuel burn	Yes
Surface access	Virgin Atlantic, Heathrow	Crew transport and hotel LHR pax transport survey	50/50
Cargo operations	Virgin Atlantic, dnata	Dnata facility and vehicle consumption	Yes
Aircraft embodied	Boeing	787-9 lifecycle emissions, Boeing calculated (ISO14067)	Yes
Ramp operations	Cobalt, dnata, Menzies Aviation, Virgin Atlantic, Delta, Gategourmet	Vehicle, APU fuel, de-icing, GSE fuel, catering facility energy consumption	Yes
Corporate operations	Virgin Atlantic	Virgin Atlantic annual scope 1 and 2 emissions	Yes
Airport operations	T4 JFK International Air Terminal, Heathrow	Heathrow annual scope 1 and 2 emissions JFK annual scope 1 and 2 emissions	Yes
Onboard services	Virgin Atlantic	Separate LCIA cup and blanket wrap study conducted by ICF	Yes
Waste	Gategourmet, mnh	Catering and on-board waste weight	Yes

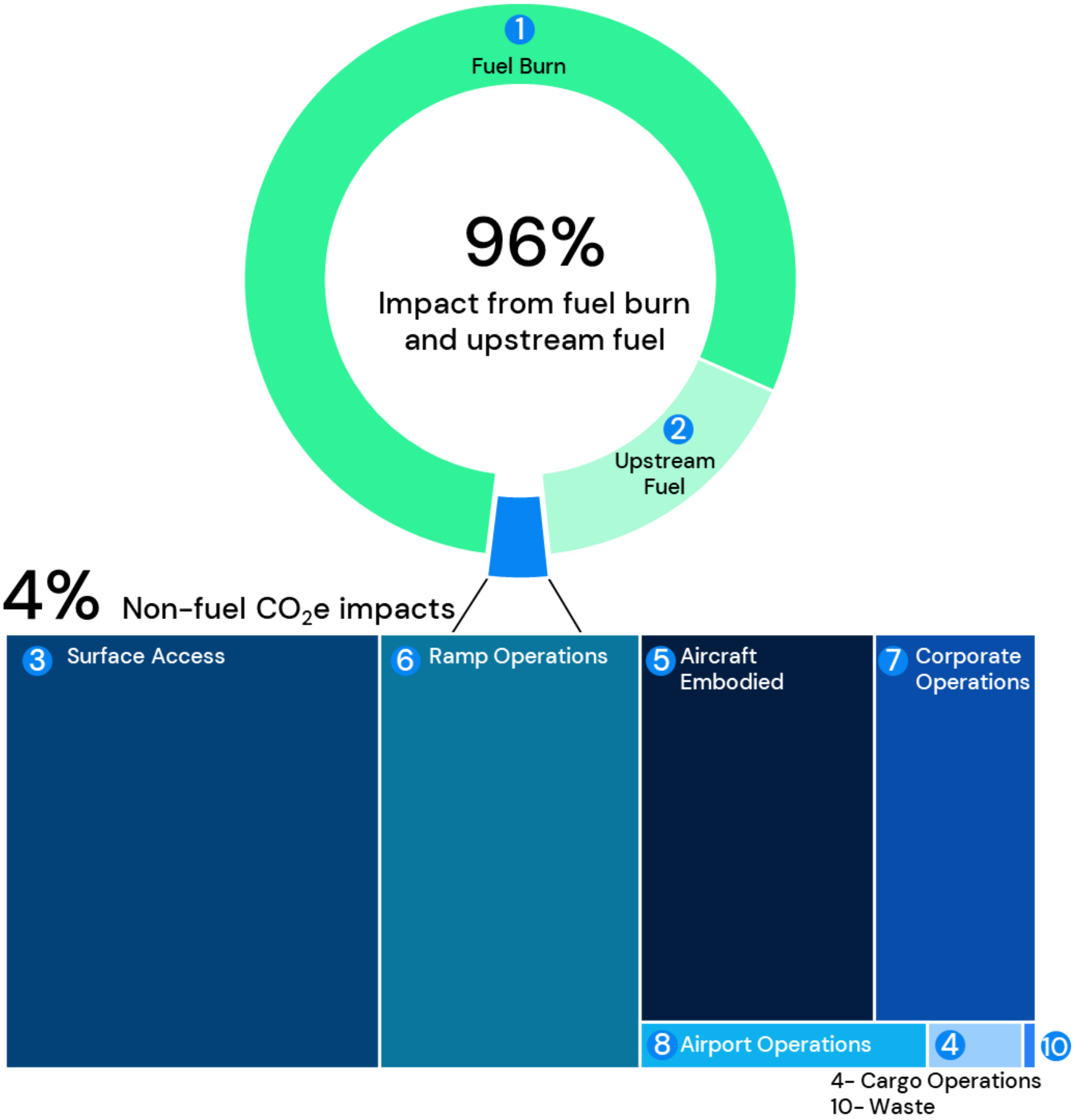
The data gathering approach prioritised available per flight activity data, resorting to annual and monthly data if the former was unavailable. Primary data gathering was the dominant form of data collection with supplier and service provider owned data occasionally serving to alleviate data collection requirements.

3.1. Baseline CO_2e Impact

The results of the LCIA phase offers an insight into the scale and role of the individual client impacts monitored for a product system throughout the lifecycle of the product. The individual activities that comprise the ten impact categories are aggregated to provide the baseline CO_2e (carbon dioxide equivalent) figure for a standard VAA 787 LHR-JFK flight. Assessing emissions on the basis of CO_2e ensured that this LCA captured the impact of carbon dioxide, but also the other Kyoto Protocol greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). To calculate the contribution of the activities identified within each attributable processes' inventory, activity data was multiplied with its corresponding UK government greenhouse gas reporting 2023 conversion factor[4]. This calculation methodology delivered the baseline carbon estimate of **153.74 tonnes of CO_2e**.

[4]https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023

The traditional carbon accounting scope accounted for 96% (148.16 tonnes CO2e) of the impacts from a baseline VAA LHRJFK 787 flight



As seen in the figure above, 96% of the lifecycle emissions impact from a typical Virgin Atlantic 787 LHRJFK flight results from impact categories 1 and 2 – fuel burn and upstream fuel impacts. The 96% is representative of the traditional aviation carbon impact assessment boundary while the remaining 4% of the CO_2e impact falls within the expanded evaluation boundary. The subsequent subsections provide the carbon contributions of the lifecycle stage impact categories. Overall impacts are presented alongside insight into the activities monitored, data collected, allocation methodology deployed, assumptions made, and boundary exclusions (where relevant).

3.1.1. Fuel Burn

Fuel Burn: 80% of full flight impacts

122.47 tonnes CO_2e

Direct emissions (scope 1 tank-to-wake) are created from the burning of fossil Jet A-1 by an aircraft in flight. Virgin Atlantic accurately track the fuel burn of every flight flown, monitoring this through their own 'Sustainability Warehouse' database. This allowed a highly accurate calculation of the emissions from fuel burn.

Components & Data Collected

Average tonnage of Jet A-1 consumed by Virgin Atlantic's 787-9 aircraft operating LHR-JFK between September - November 2022. Data accurately measured and collected by Virgin Atlantic's flight ops and efficiencies team directly from the aircraft. The data specifically reflects the same route and aircraft type as Flight100. The seasonal component of the data collected, reflecting a baseline sampled during the same time of year as Flight100, accurately captured the seasonal variability in fuel consumption due to weather conditions.

Allocation Methodology & Emissions Calculation

Data collected on a per flight basis, no further allocation required.

UK Government 2023 aviation turbine fuel emissions factor applied to average fuel consumption.

Assumptions Made

Fuel consumption reflects total block fuel consumption, including APU usage pre-departure and post-arrival and taxi-in/out. Average fuel consumption Sep-Nov.

3.1.2. Upstream Fuel

Upstream Fuel: 17% of full flight impacts

25.69 tonnes CO_2e

The indirect emissions (scope 3 well-to-tank) from fossil Jet A-1 used for a flight, upstream from point of combustion, including extraction, production, and transportation.

Components & Data Collected

Average tonnage of Jet A-1 consumed by Virgin Atlantic operated Boeing 787-9 aircraft operating LHR-JFK between September - November 2022.

Average volume of Jet A-1 burned by APU on the ground per flight. This is estimated based on average 787-9 APU usage time by Virgin Atlantic on stand, monitored by flight ops teams and average 787-9 APU fuel flowrate, provided by the OEM.

Allocation Methodology & Emissions Calculation

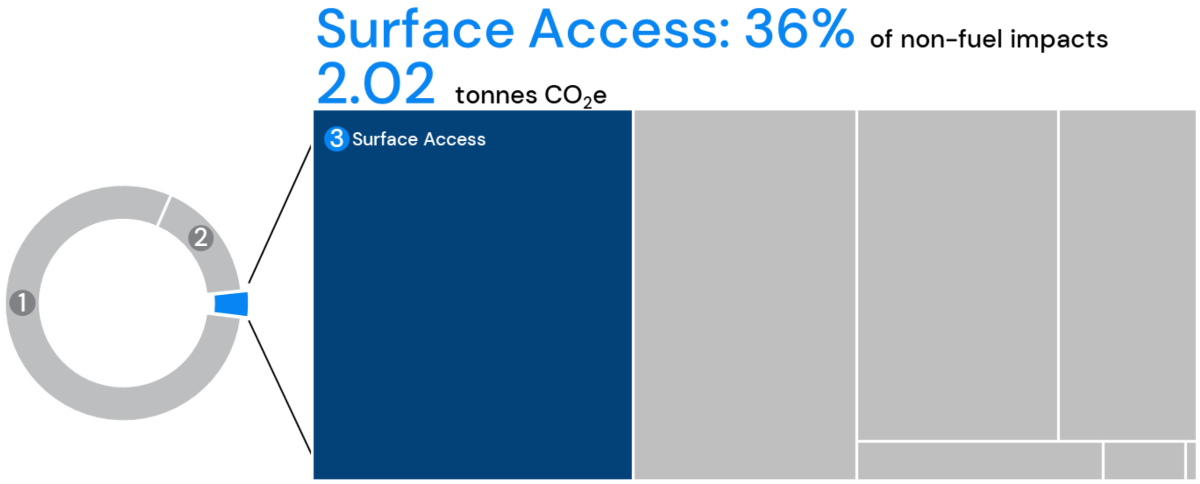
Data collected on a per flight basis, no further allocation required.

UK Government 2023 aviation turbine fuel upstream well-to-tank emissions factor applied to average fuel consumption.

Assumptions Made

Median APU usage time during a turnaround of an aircraft on the ground was used, rather than mean APU usage per sector flown, to avoid double counting of taxi fuel consumption.

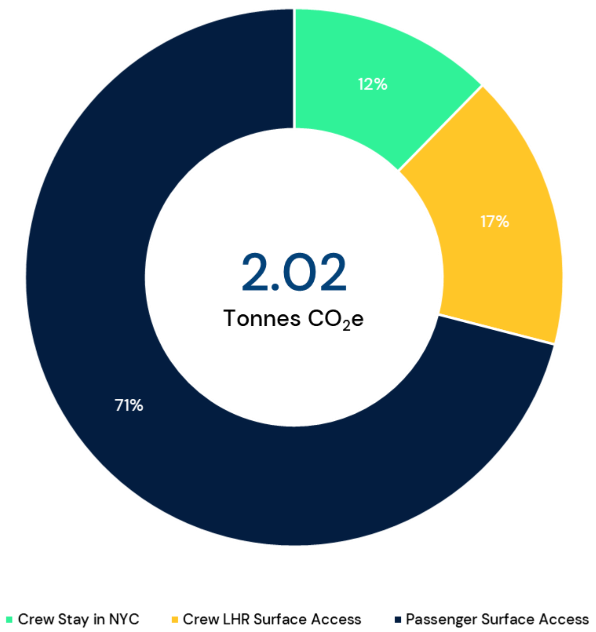
3.1.3. Surface Access



The emissions from passenger and Virgin Atlantic crew ground transport to Heathrow airport, and the crew hotel and transport emissions in New York during layover.

Components & Data Collected

Assessing surface access impacts consisted of three main activities: i) passenger travel to Heathrow, ii) crew commuting to Heathrow, and iii) crew layover transportation and accommodation. The activity data was gathered through detailed survey analysis pertaining to the modes and distances of passenger and crew transport to Heathrow.



Additionally, attention was given to the environmental impacts associated with crew accommodation, considering the number of nights spent in a hotel in New York on a typical LHRJFK layover. Hotel impacts were supplemented with examining the mode of transit used for crew transport from JFK airport to the designated NYC hotel.

Allocation Methodology & Emissions Calculation

Passenger and crew transport survey results were collated and used to reflect the share of different transport modes (car, coach, bus, underground, train) and average distance travelled. This share of transport modes was allocated across an average number of passengers on a typical LHRJFK flight. UK government emissions factors by mode of transport were then applied to distances to provide total emissions.

Hotel stay emissions were allocated to 15 crew for a single night stay by applying a UK government average hotel stay emissions factor for the United States.

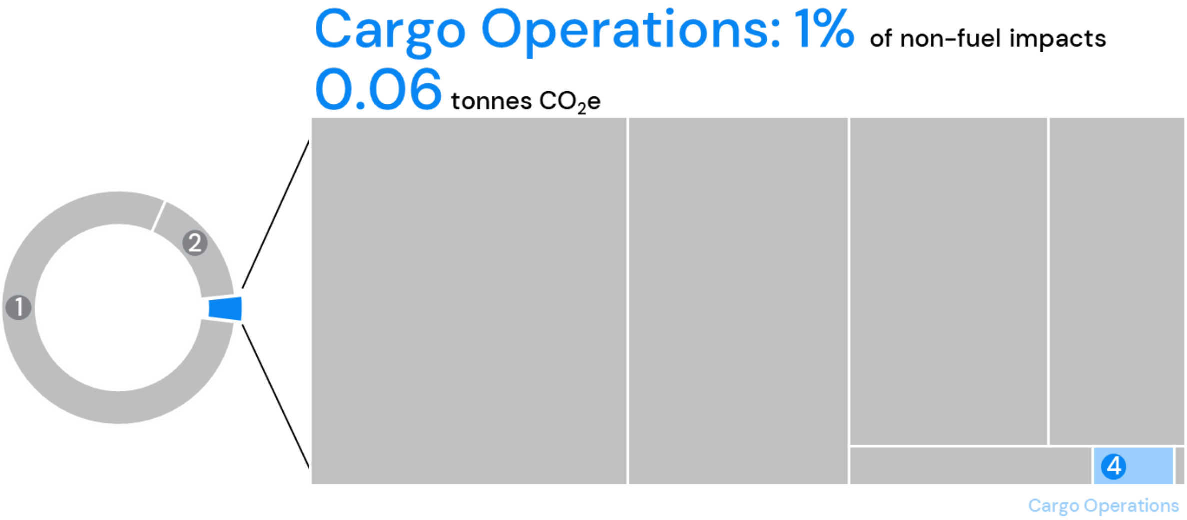
Assumptions Made

Typical operating crew of 15 on Virgin Atlantic 787 LHRJFK flight. One hotel room per crew member. Minimum of a 24-seat diesel vehicle is used for NYC hotel transportation. Average VAA LHRJFK seasonal load factors for number of passengers.

Boundary Exclusions

The onward travel of passengers after arrival at JFK to further destinations was excluded.

3.1.4. Cargo Operations



Engaging with Dnata, Virgin Atlantic's cargo logistics partner at London Heathrow, the carbon impact of air freight handling and operations for a flight was assessed.

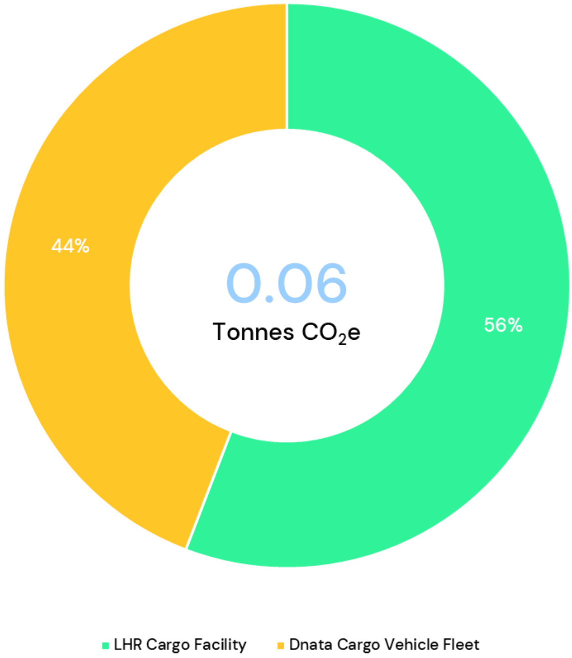
Components & Data Collected

Dnata's Heathrow facility electricity, gas, and refrigerant annual reported consumption. Quantity and type of vehicles utilised for facility and ramp operations. Volume of fuel consumed for vehicle fleet. Average trip distance from facility to stand. Average number of trips taken to load a standard LHRJFK flight. Yearly, monthly, and average freight tonnage on VAA's LHRJFK route for a 787

Allocation Methodology & Emissions Calculation

Corresponding UK government emissions factors were applied to the collected activity data across facility energy consumption, refrigerants consumption and cargo vehicle mileage to calculate the total emissions impact of cargo operations.

Quantifying the per flight share of Scope 1 and Scope 3 carbon impacts was carried out on an activity share basis. Facility-wide activity and emissions data was allocated to a single LHRJFK flight based on the percentage share of VS cargo flown on the route. Route level data was then apportioned on a per flight basis in line with frequency.

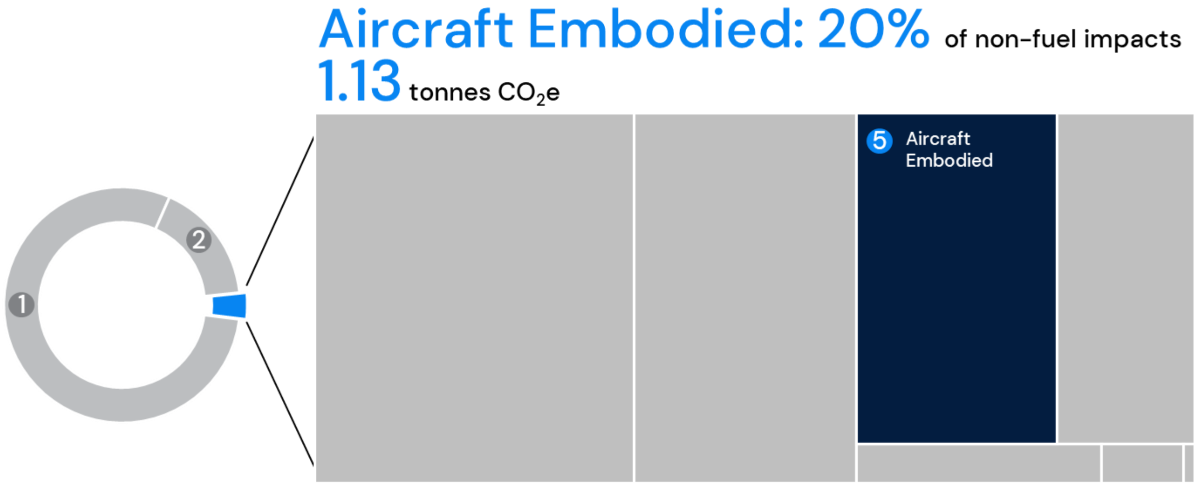


Boundary Drawn

For cargo impacts, freight forwarding has been excluded from the assessment. The manner in which cargo is delivered to Dnata and subsequently Virgin was deemed to fall outside the defined product scope.

Air cargo freight forwarding often involves multiple legs in a journey from start to finish, e.g., a shipment from JNB South Africa to JFK USA may typically be routed via LHR UK. The upstream transport of this cargo results in lifecycle emissions associated with its full journey. The upstream transportation activity emissions of cargo freight forwarding prior to the VS LHRJFK flight was excluded, as this activity sits outside of Virgin Atlantic's operational control. VS have no influence over mode, distance or weight of cargo shipped upstream prior to reaching the VS leg of the journey. These emissions should be accounted for in by the air freight service provider of the upstream transport.

3.1.5. Aircraft Embodied

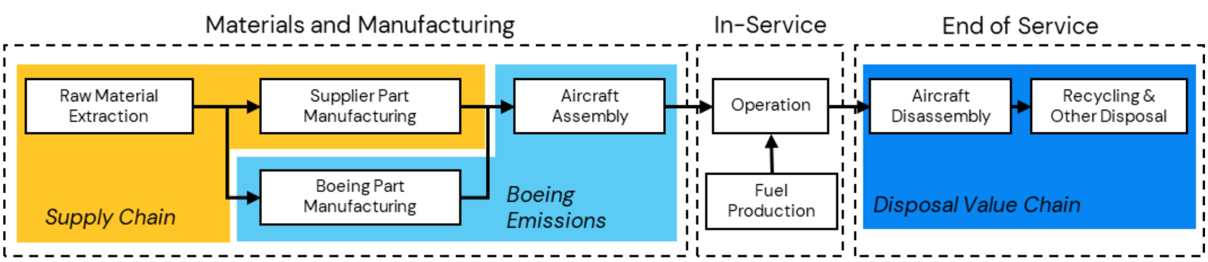


Components & Data Collected

Within the LCA, aircraft embodied emissions refers to the carbon emitted throughout the aircraft's supply chain, materials, manufacturing, and end of life activities. The Boeing Sustainability and Eco-Demonstrator teams provided the following lifecycle GHG insights of the 787 Dreamliner.

The supply chain, Boeing emissions, and disposal impacts were assessed in-line with the GHGp. In addition, the Boeing methodology underpinning the product LCA is consistent with ISO14067 (Carbon Footprint of a Product). This is near identical to ISO14040, except for the sole focus on global warming potential (GWP).

Boeing 787 Dreamliner lifecycle global emissions (GWP100)

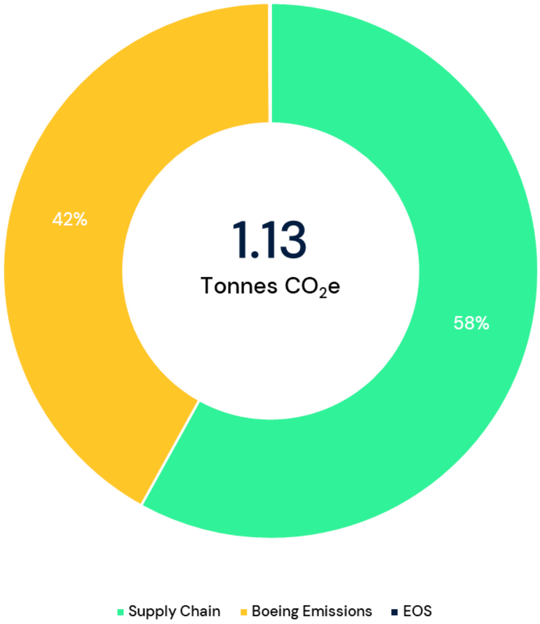


Source: Boeing

Allocation Methodology & Emissions Calculation

The embodied supply chain, Boeing emissions, and end-of-service emissions were provided as a total over the aircraft's lifetime.

Per flight carbon allocation embodied emissions was calculated assuming 575 annual flights with an operating life of 21.54 years, as estimated by Boeing. This time span is anticipated fleet average longevity and is not intended to represent maximum aircraft lifetime capability.



The embodied and aircraft usage values provided by Boeing values are estimations and are based on expectations and assumptions. These values are not guarantees and are subject to uncertainties and changes in circumstances that are difficult to predict.

The final embodied emissions of the 787 Dreamliner totalled 1.13 tonnes of CO_2e per flight.

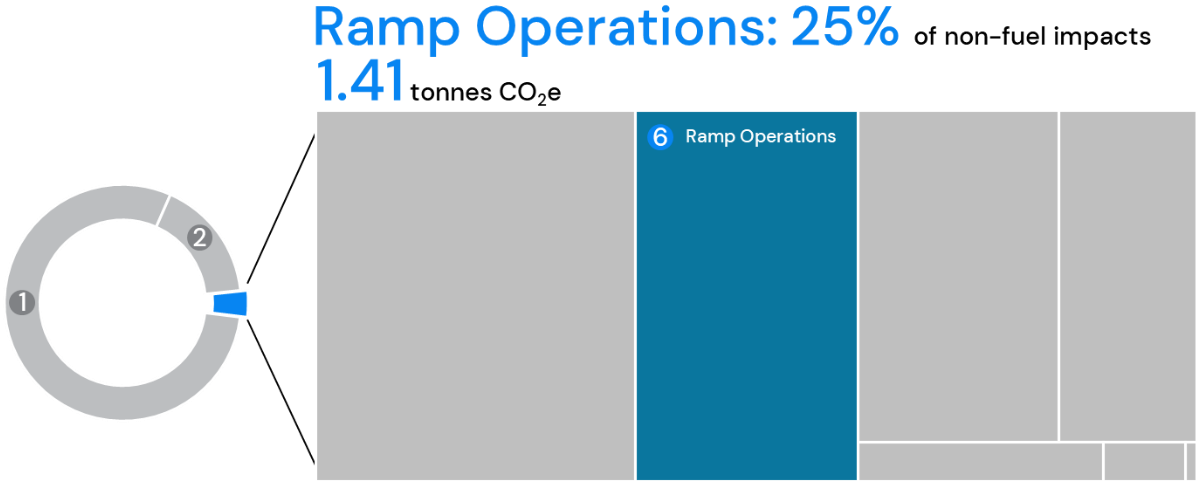
Assumptions Made

The raw material extraction, manufacturing, assembly, and end-of-service figures provided by Boeing were based on the 787-10 aircraft. Flight100 was conducted on the smaller 787-9 variant. As such, the total 1.13 tonnes of CO_2e figure would be marginally smaller for Flight100 due to the reduced material requirements.

Boundary Drawn

The embodied emissions associated with the cabin interior of the aircraft have been excluded from the LCA, for several reasons. Firstly, data availability is limited, and would therefore make replicating this approach consistently, difficult. Secondly, cabin interiors are refreshed multiple times during the lifetime of an aircraft's operation. This makes allocating embodied emissions of a cabin to an individual flight very tricky, as; this refresh may occur at different intervals in an aircraft life depending on the specific carrier operating it, each cabin may have a materially different embodied emissions value depending on the materials and options specified, and different cabins will have different end-of-life pathways depending on geographic location and cabin materials used. These complexities in allocating a consistent value to a single flight therefore led us to exclude this from the analysis.

3.1.6. Ramp Operations



Assessing the impact of ramp operations required engaging with the various stakeholders involved in ramp operations, including:

- Cobalt – provide ground handling services at Heathrow,
- Gate Gourmet – catering service provider,
- Menzies – anti-icing and de-icing service provider,
- Virgin Atlantic Heathrow team,
- Delta – ground handing service provider for Virgin Atlantic at JFK, and
- JFK Terminal 4.

Components & Data Collected

Virgin Atlantic: Ground operations vehicle fleet and APU fuel burn

Menzies: Anti- and De-icing fluid consumption

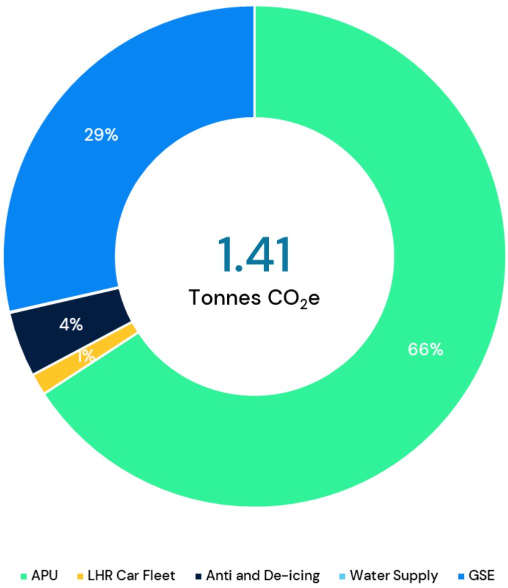
Gate Gourmet: Purchased electricity and heat, energy & water consumption from dishwashing, and Fuel use from ramp vehicles and transportation)

Cobalt: GSE diesel use (higher loader and push back tug), GSE electricity use (belt loader and electric baggage tug)

The emissions from ground service equipment at JFK receiving the inbound flight were assessed using measured fuel consumption during a turn (the processes undertaken to prepare an aircraft for departure), provided by Virgin Atlantic's EJV partner, Delta. This included the total fuel consumption during an aircraft's preparation to depart from a LHR stand by 4 baggage tractors, 1 belt loader and 2 container loaders, typically used on a single turn by Delta equipment. Fuel consumption was multiplied by tank-to-wake and well-to-tank emissions factors. No allocation was required as data reflected the energy/emissions associated with a single flight.

Allocation Methodology & Emissions Calculation

Virgin Atlantic: Utilised VAA median turn usage per sector, which was then correlated with the APU GEN ON litre per hour burn rate. Sum of VAA petrol and diesel consumption based on miles driven in 2022. Allocated on a VAA LHR ASK percent share basis.



Menzies: De- and anti-icing fluid use in 2022 totalled 2,625,462 litres which was then distilled into a fluid per LHR movement total of 5.45 litres.

Gate Gourmet: 2022 total UK activity data allocated to VAA based on the proportion for which services are provided: 62% at LHR and 57% at LGW.

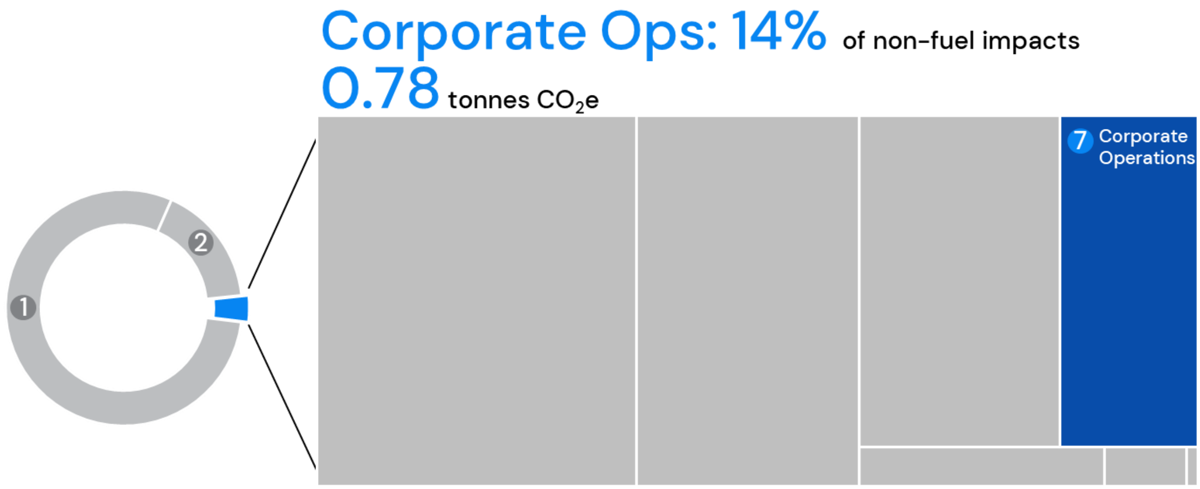
Cobalt: Per movement diesel consumption of GSE totalled 8.32 litres in November, reflecting the operating month of Flight100. Per movement electricity consumption of GSE totalled 6.03 kWh in November, reflecting the operating month of Flight100.

Delta + JFK T4: The emissions from ground service equipment at JFK receiving the inbound flight were assessed using measured fuel consumption during a turn, provided by Virgin Atlantic's EJV partner, Delta. No allocation was required as data reflected the energy/emissions associated with a single flight.

Boundary Drawn

Specific elements of the ramp operations were excluded from the LCIA. The use of passenger buses from Heathrow departure gates to the aircraft was not included due to their infrequent use, it was deemed unrepresentative of a typical baseline flight. The use of ground power, where the aircraft is supplied with electricity from the airport stand rather than running the APU, was not explicitly reflected in this LCIA, as it is not always available. By excluding, the LCIA took a conversative view of emissions impact reflecting aircraft APU use instead, with a higher impact compared to renewable electricity use at Heathrow.

3.1.7. Corporate Operations



While Virgin Atlantic publishes Scope 1 and 2 impacts within its annual report, the evaluation scope was expanded to include additional activities in-line with the GHGp Scope 3 reporting standards.

Components & Data Collected

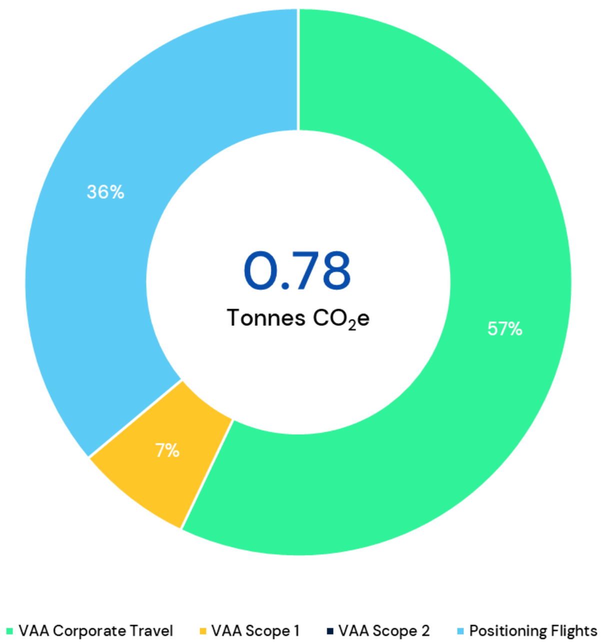
Scope 1: Natural gas, fuel, and refrigerant use. Scope 2: Corporate office electricity consumption. Captured the per seat carbon impact of all Virgin corporate travel across Upper, Premier, and Economy classes in 2019. Assessed the associated fuel burn from VAA positioning flights in 2022 for maintenance, non-revenue positioning, and end of lease purposes.

Allocation Methodology & Emissions Calculation

All corporate operation emissions impacts were distributed equally based on the number of revenue flights Virgin Atlantic operated in the reporting year. This serves to reflect that these activities support each movement equally, regardless of ASK.

Scope 1 and 2 emissions (already publicly reported) were allocated on this basis.

Corporate travel impacts were shared equally across the total number of flights in 2022 for a shared impact, using UK government emissions factors to calculate the emissions impact.

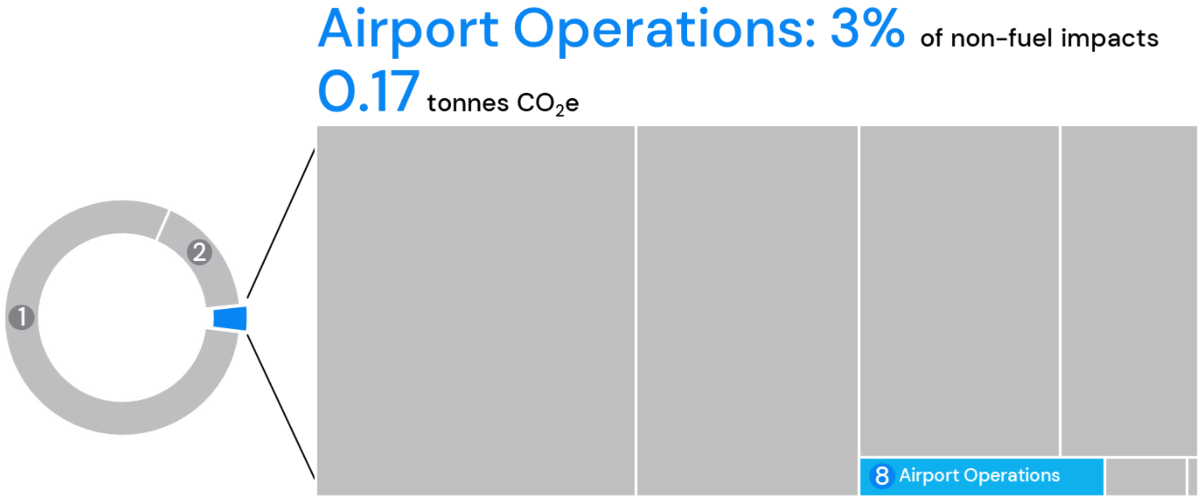


The emissions impact resulting from the positioning flights, calculated using UK government emissions factors for aviation turbine fuel, was equally allocated across VAA's total number of flights in 2022 for a shared impact.

Assumptions Made

A market-based approach for scope 2 emissions, reflecting VAA's purchase of 100% renewable electricity has been used and therefore, no Scope 2 carbon impact has been allocated to the baseline flight LCA. 2019 figures were deployed to assess the impacts of corporate travel to avoid an inaccurate representation of activity due to Covid-19.

3.1.8. Airport Operations



Assessing the carbon impact of airport operations required working in collaboration with Heathrow's carbon team and JFK Terminal 4.

Components & Data Collected

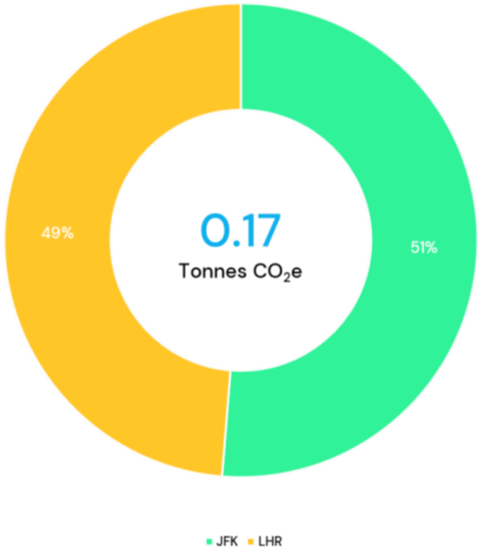
LHR's impacts were distilled into Scope 1 and 2. In 2022, Heathrow reported Scope 1 emissions totalling 29,806 tonnes of CO_2e. For 2022, Heathrow reported electricity consumption of 272,609,855 kWh making its Scope 2 emissions 52,717 tonnes of CO_2e on a location-based approach.

JFK impacts were distilled into Scope 1 and 2. Scope 1 total emissions. JFK airport 2022 annual scope 1 emissions, reported in annual report. Excluded from the LCA boundary were the associated emissions from infrastructure and terminal construction.

Allocation Methodology & Emissions Calculation

Heathrow and JFK scope 1 emissions data collected. Heathrow and JFK scope 2 emissions calculated using UK government location-based grid emissions factor and US EPA New York grid emissions factor respectively.

JFK emissions allocated proportionally to a single flight based on Virgin Atlantic % share of total annual movements at JFK. Heathrow emissions allocated on a proportion of total Heathrow movements basis.



Assumptions Made

Allocating a percent share of LHR's Scope 1 impacts to the baseline flight required calculating intensity per movement. With 367,158 passenger movements in 2022, the pro-rated impact per flight was 0.08 tonnes of CO_2e. As LHR purchase verifiable renewable energy credits to cover annual consumption, no LHR Scope 2 carbon impact has been allocated to the baseline flight LCA.

Boundary Exclusions

The impact of certain parts of the airport operation were excluded from the LCIA. The energy consumption and emissions impact of premium passenger departure lounges, duty free facilities and general terminal infrastructure was excluded from the analysis. These elements are out of Virgin Atlantic's control and serve passengers for multiple airlines. Furthermore, with the inclusion of Heathrow's scope 1 and 2 emissions (allocated to a single flight), it was deemed that the general airport operations required to support the operation of a single flight were adequately captured.

3.1.9. Onboard Services

Boundary Exclusions

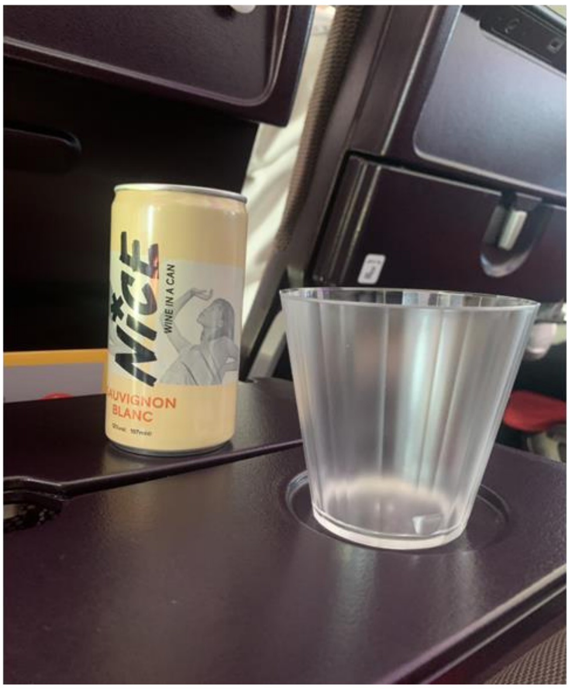
The impact of onboard services, including amenities, food & beverages as well as the dishwashing and embodied impact of crockery, used in the typical service provided to passengers, has been excluded from this LCIA. Data availability of the onboard services and the subsequent emissions impact was limited, and this source was therefore excluded. The large number of individual components, from ingredients, packaging and different products makes accurate assessment of onboard services difficult. Capturing these emissions is an important potential area for future work.

Initiatives Taken

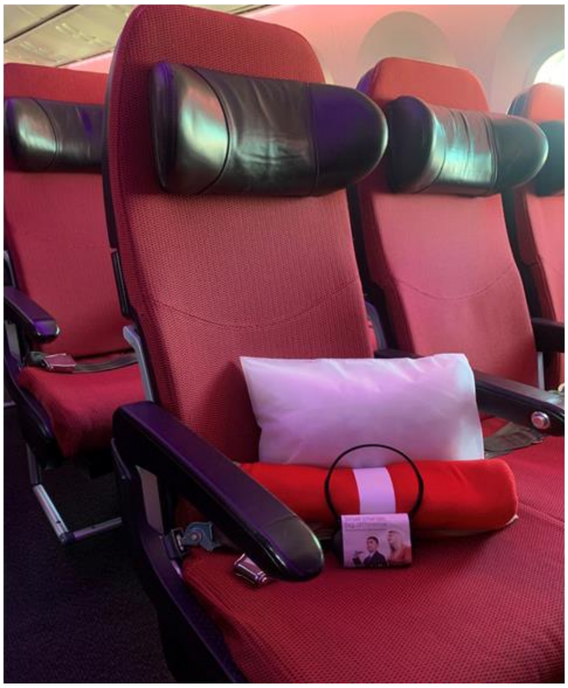
Despite excluding onboard services from the scope of the carbon LCIA, Virgin Atlantic is committed to minimising onboard waste and eliminating virgin single-use plastics. Virgin

Atlantic has worked to reduce or replace 90% of virgin single use plastic inflight items, the equivalent of 61.4m flown items per year. As part of its target of continued commitment to reducing single use plastics, Virgin used Flight100 as a testbed to trial single use plastic alternatives. During the flight, blankets in Premium and economy classes were wrapped in a paper band rather than the usual single-use plastic and the single-use cold beverage cups were replaced by a multiuse alternative. Introducing these products onboard capitalised on the Flight100 sustainability testbed to work towards its Net Zero ambition by exploring environmentally oriented cabin product alternatives. Virgin Atlantic is currently evaluating the environmental and cabin performance of the trialled products as it continues to reduce the use of single-use plastics.

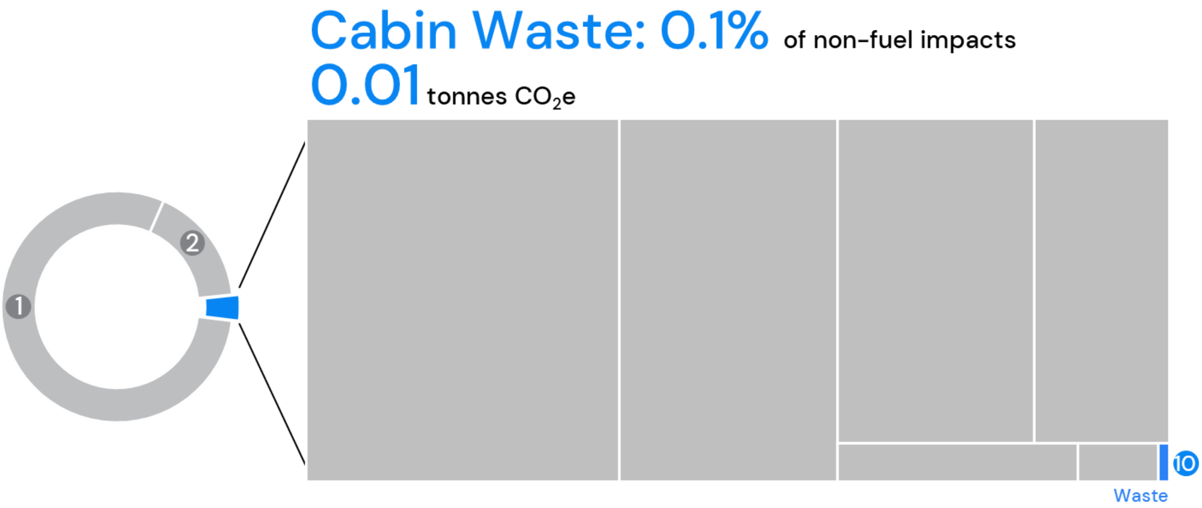
Flight100 clear tritan rotable cup



Flight100 plastic free blanket wrap



3.1.10. Waste



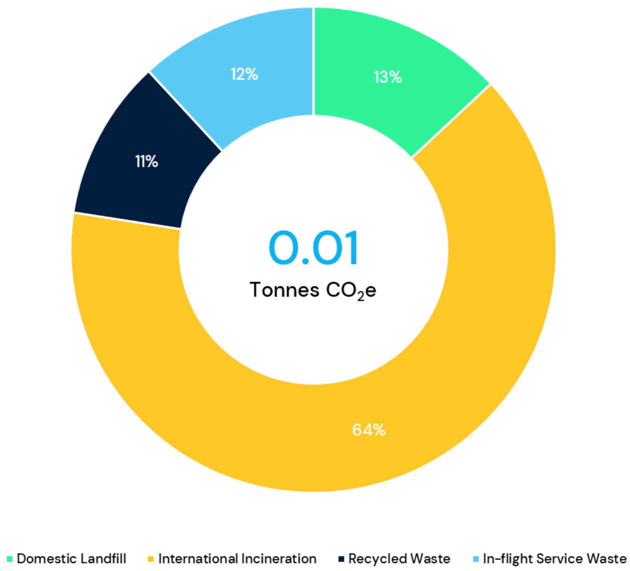
Virgin Atlantic has two waste management services provides at LHR: MHN and Gate Gourmet. Each stakeholder oversees specific waste streams and supported this data collections process.

Components & Data Collected

In-flight service waste comprising of amenity kits, cardboard & paper, electrical waste and plastics. Food and beverage waste comprising of recycling and energy recovery disposal streams.

Allocation Methodology & Emissions Calculation

For Gate Gourmet waste management, single flight data on waste volumes was provided by waste stream. MHN in-flight service waste data was provided for 2022 by total volume by product category which was then allocated to the baseline flight on an ASK share basis.



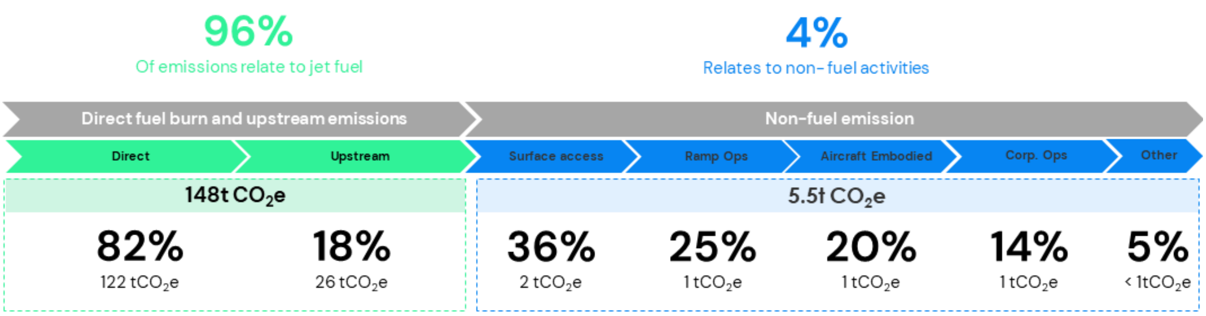
Assumptions Made

Due to data availability challenges at JFK, LHR waste figures have been captured as part of the LCA. Recognising that waste handling, management, and disposal processes do vary at the two airports, it was determined that utilising LHR figures as a stand in for the one-way operations provided a more comprehensive picture than excluding the attributable process from the LCA.

3.2. Discussion of Results

The lifecycle inventory result of a one-way VAA 787 LHRJFK flight under the LCA study was obtained by summing up all fractional contributions contained within each impact category. For a VAA 787 LHRJFK flight, the impacts were calculated to be **153.74 tonnes of CO_2e**. Examining the carbon reporting boundaries, 96% of the baseline flight's impact fell within the traditional flight carbon boundary with 4% of the impact residing in the expanded LCA boundary.

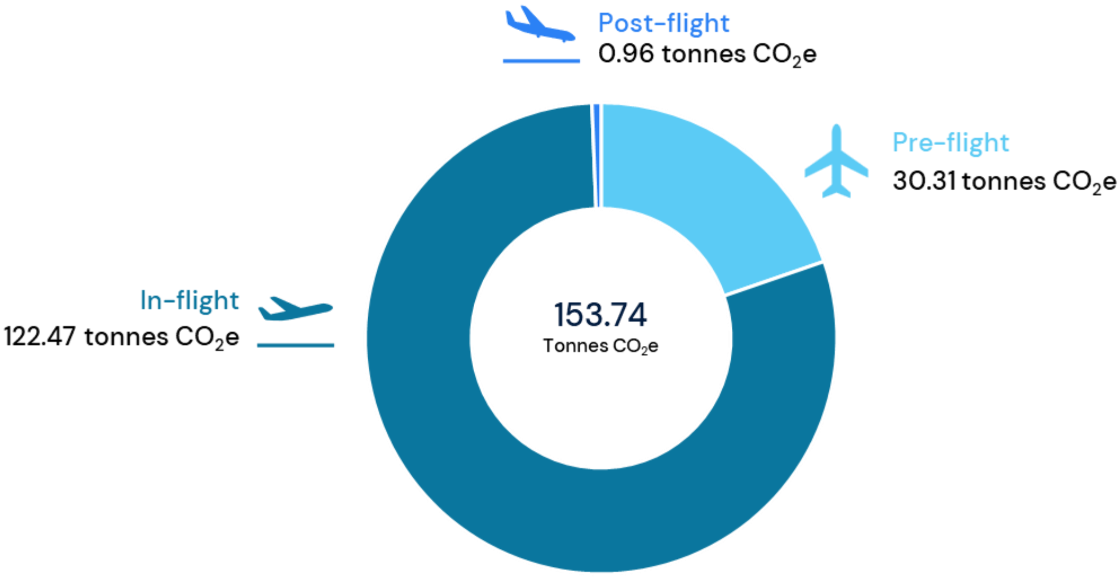
Using UK Government conversion factors and 98% primary data, impacts of an LHRJFK 787-9 flight were calculated to be 153.74 tonnes of CO_2e



Virgin Atlantic Baseline Flight LCA Results Analysis			
Impact category	Scope	Tonnes CO_2e	Share of Baseline Flight
Tradition flight carbon boundary			
Fuel Burn	1	122.47	79.67%
Upstream Fuel	2	25.69	16.71%
Expanded LCA boundary			
Surface Assess	3	2.02	1.32%
Cargo Operations	3	0.06	0.04%
Aircraft Embodied	3	1.13	0.74%
Ramp Operations	3	1.41	0.91%
Corporate Operations	2&3	0.78	0.51%
Airport Operations	3	0.17	0.11%
Onboard Operations	3	-	-
Waste	3	0.01	0.005%

The results of the LCIA also drive the identification of key environmental issues related to the product throughout its entire life cycle. These impacts were disproportionately spread across the three identified lifecycle stages as seen in the figure below. In-flight impacts, comprised of fuel burn, accounted for 79.7% of lifecycle impacts where pre-flight activities made up 19.7% of CO_2e impacts and post-flight activities only making up 0.6% of carbon impacts.

In-flight activities, driven by fuel burn, accounted for 80% of a VAA 787 LHRJFK baselines flight's carbon impact



3.2.1. Flight100 Specific Impacts

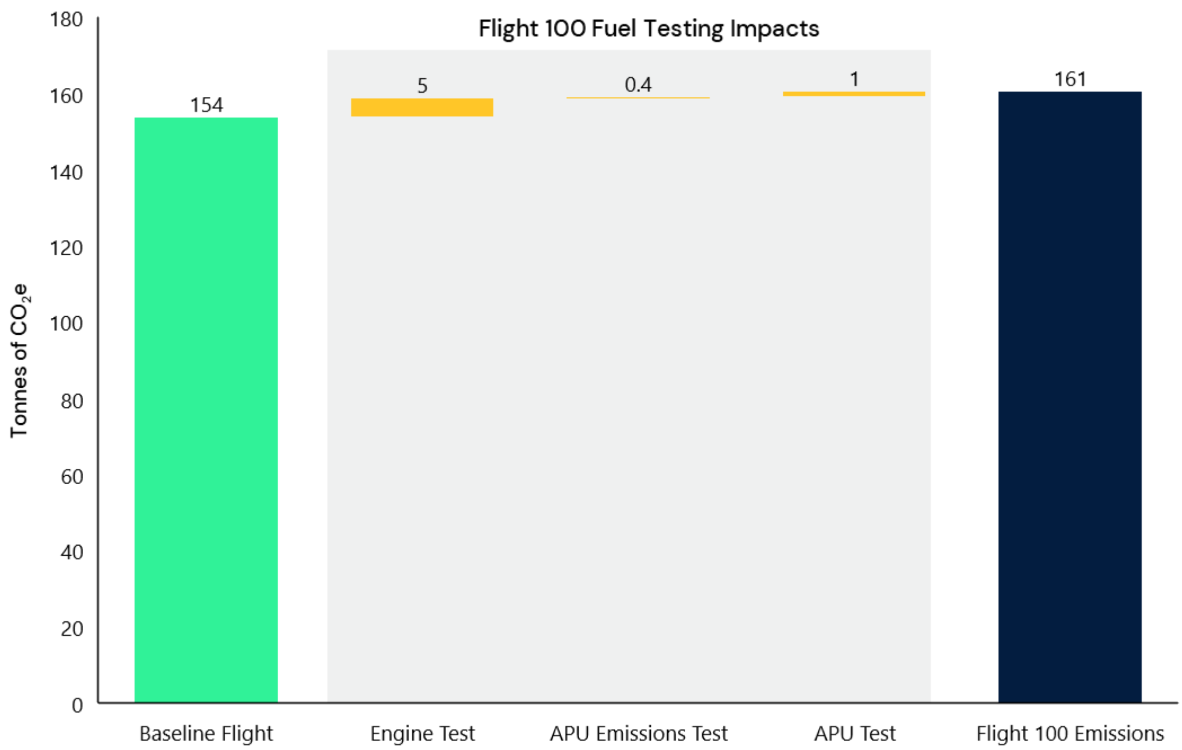
To ensure the safety of operating a transatlantic flight on 100% SAF and to assess the carbon abatement levels of the SAF to be used, Flight100 specific testing was conducted in the leadup to November 2023. These additional activities, while falling outside the traditional flight LCA boundary have been captured within this assessment to ensure complete carbon abatement.

In Flight100, Virgin Atlantic strived to achieve as close to a net zero emissions operation as possible. To achieve this, the scope was expanded beyond the flight to include the unique fuel testing and certification campaign emissions. These additional impacts were split between the engine, APU, and emissions testing.

Additional Impacts: 6.88 tonnes CO_2e

The largest Flight100 specific impact came from the engine test where Virgin Atlantic and Rolls-Royce conducted a ground test on the Rolls-Royce Trent 1000 engine in July 2023. Utilising the unique SAF-SAK blend accounted for 73% of additional carbon impacts.

Flight100 testing impacts increased carbon abatement requirements for net zero emissions by 6.88 tonnes



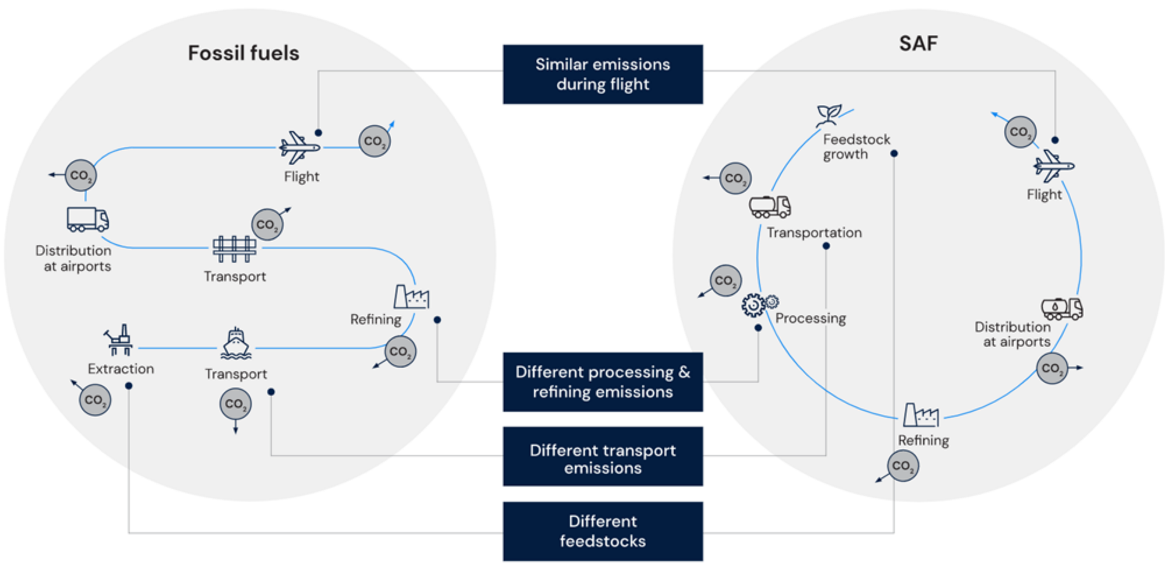
Including these additional activities contributed an additional 6.88 tonnes of CO_2e to Flight100s baseline carbon impact, bringing total baseline emissions to **160.61 tonnes of CO_2e**. Including the emissions from Flight100 specific activities served to ensure that the complete scope of initiative related carbon impacts were able to be addressed. The 160.61 tonnes of CO_2e served as the final total for which SAF, operational efficiencies and market based measures were deployed to secure a net zero emissions Flight100 initiative.

Chapter 4:
Flight 100 Carbon Reduction Measures

4. Flight100 Carbon Reduction Measures

In today's evolving landscape, SAF is crucial to achieving carbon emissions reductions and more environmentally responsible air travel. SAF is an alternative aviation fuel that (1) meaningfully reduces the lifecycle carbon emissions compared to fossil fuels, and (2) can be blended and used in conventional aircraft as a drop-in solution, with no modification to the engines, fuel systems, or ground infrastructure. The minimum emissions reduction depends on the certification scheme used, although this is typically at least 50%. The maximum emissions reduction can be substantially greater than 100%. Most SAF available today is manufactured from waste fats and oils through the HEFA production pathway and averages an emissions reduction at least 60%.

Fossil Fuels vs SAF lifecycle carbon differences



Source: ATAG Waypoint 2050

SAF is not a homogenous product; and is characterised by various technological processes and feedstocks. Currently, there are eight established pathways and three co-processing SAF production methods that have received approval from the American Society of Testing and Materials (ASTM). These pathways allow many combinations of feedstocks, pre-processing, and conversion techniques.

Certified SAF Production Pathways Under ASTM

Pathway	Abbreviation	Feedstock	Blending Limit
FT-SPK	FT	Biomass (e.g. trash/rubbish, forestry residues, grasses)	50%
FT-SPK / A			10%
HEFA-SPK	HEFA	Lipids & fats, oils, greases (e.g. Used Cooking Oil (UCO), tallow, DCO)	50%
HFS-SIP	-	Sugars to hydrocarbon (e.g. molasses, sugar beet, corn dextrose)	
ATJ-SPK	ATJ	Agricultural waste (e.g. forestry slash, crop straws), waste CO_2	50%
ATJ-SK / A			10%
CH-HK	-	Plant and animal fats, oils and greases (FOGs)	50%
HC-HEFA-SPK	HEFA	Bio-derived hydrocarbons, fatty acid esters	10%
Co-processed HEFA	Co-processing	Fats, oils, and greases (FOG) co-processed with petroleum	5%
Co-processed FT		Fischer-Tropsch hydrocarbons co-processed with petroleum	
Co-processed biomass		Biomass co-processed with petroleum	

The lifecycle carbon intensity of the fuel quantifies the emission reduction compared to traditional fossil fuels, with a baseline set at 89 gCO_2e/MJ[5]. The evaluation of fuel emissions encompasses the entire life cycle, from the well to wake. The final emissions calculation aggregates the sources and sinks arising during fuel origination, production, transport, and consumption.

4.1 Flight100 Sustainable Aviation Fuel

The SAF used for Flight100 was a unique blend of two types of SAF: 87.37% HEFA (Hydroprocessed Esters and Fatty Acids) supplied by AirBP and 12.63% SAK (Synthetic Aromatic Kerosene) supplied by Virent, a subsidiary of Marathon Petroleum Corporation. The HEFA was made from waste fats such as used cooking oil, greases, and animal tallow. The SAK is made from extracted plant sugars, with the remainder of the plant proteins, oil

[5]https://www.icao.int/environmentalprotection/CORSIA/Documents/CORSIA_Eligible_Fuels/CORSIA_Supporting_Document_CORSIA%20Eligible%20Fuels_LCA_Methodology_V5.pdf

and fibres continuing into the food chain. SAK was needed for the 100% SAF flight to provide the fuel with the required aromatics for engine and fuel system functions.

The fuel powering Flight100 was a unique SAK-SAF blend supplied by Virent and AirBP

The SAK was provided by Virent, Inc. Virent's technology can use sugar feedstocks from multiple sources for its process to produce SAK. These feedstocks may include various sugar types from a variety of plant-based feedstocks, including currently available sugars from corn, sugar cane, and beets, as well as lignocellulosic sugars from forestry residues, corn stover (stalks, leaves and cobs left after corn is harvested), bagasse and more. Initial process plants will use commercially available sugars and then transition to lignocellulosic sugars once available at scale and quality.

The fuel for the Virgin Atlantic flight was produced at Virent's demonstration plant located in Madison, Wisconsin, USA which is a demonstration scale (~150 litre per day of hydrocarbons) refinery and is primarily used to provide engineering information and products for testing/regulatory approvals and product demonstrations. SAK is currently at the final stages for ASTM balloting under ASTM D7566.

SAK & Virent Insights

Virent is focused on commercialising its technology with multiple feedstocks in multiple regions and markets. The aim is to produce a low carbon intensity SAF that also has other non-CO_2 benefits such as lower particulate matter and the ability to facilitate higher blends of SAF in the current infrastructure.

The development of bio-based aromatics enhances SAF blending and enables 100% SAF to be used in existing aircraft and fuelling system infrastructure. In line with international jet fuel standards (Jet A-1), synthetic fuel requires 8-25% aromatic content to help prevent fuel leakage, increase lubricity, and ensure proper fuel system performance. Up until now this has been achieved by blending SAF with conventional fuel. However, the BioForming process has changed this by converting plant sugars into a bio-aromatic product, BioForm SAK.

SAK supplies the necessary aromatics for fuel and can be blended with a range of other SAFs, accelerating the shift from conventional fuel to SAF compatible with existing aviation technology. The various demonstration flights using BioForm SAK have also shown that SAK can be a 'normaliser' to ensure different SAF blendstocks can be brought within specification and meet aviation performance criteria. Virent has specifically designed the BioForming S2A technology to produce an aromatic fuel component that not only helps meet current Jet A-1 specifications, but also helps provide a cleaner burning fuel free of naphthalenes, thereby reducing particulate matter emissions.

Virent are currently partnering with JM to license our BioForming S2A technology to rapidly deploy worldwide. Main areas development that Virent is committed to is the continued exploration of reducing the carbon intensity of operations at commercial scale. These activities for decarbonisation sourcing include lower carbon intense feedstocks with improved agricultural practices, renewable utilities (renewable electricity, renewable natural gas), implementing efficient plant design to reduce overall utility demand and maximisation of feedstock yields, and H2 plant technology along with carbon capture and sequestration.

Virent SAK demonstration facility

Source: Virent

4.1.1. Final Carbon Intensity Reduction

The carbon savings achieved through 100% SAF were calculated against the baseline 787 LHRJFK fuel burn calculations detailed earlier in this report. The fuel burn in Flight100 was approximately 2.5 tonnes less than the recorded baseline (a 6.5% reduction), driven by the fuel efficiency measures outlined in section 4.2, as well as the lower load factor. To accurately present the carbon savings of what 100% SAF would deliver for a typical VAA LHRJFK commercial flight, the following analysis deploys the baseline fuel consumption of 38.53 tonnes of fuel, effectively adjusting Flight100 to provide a like-for-like comparison to a typical flight.

Virgin Atlantic Flight100 SAF Carbon Reduction			
Consideration	Baseline Flight	Flight100	Saving
Fuel Consumption	38.53 tonnes	38.53 tonnes[1]	-
Fuel Carbon Intensity	89 gCO_2e/MJ	31.69 gCO_2e/MJ	64.4% reduction
Flight Carbon Emissions	148.16 tonnes CO_2e	52.70 tonnes CO_2e	95.46 tonnes CO_2e

As depicted in the table above, the final carbon intensity (CI) of the SAF used on Flight100 was 31.69 gCO_2e/MJ, a ~64% reduction compared to kerosene. This delivered 95.30 tonnes of CO_2e savings.

4.2 Fuel Efficiency and Energy Saving Initiatives

Virgin Atlantic deployed a range of fuel efficiency initiatives to reduce fuel consumption during Flight100. These initiatives represent a mix of applications and approaches that Virgin Atlantic a) deploy as business as usual (BAU) throughout day-to-day operations of regular scheduled flights as part of standard fuel savings procedures, and b) have deployed specifically for Flight100.

From the perspective of this LCA, the impact of these initiatives to reduce fuel burn are already accounted for in the final fuel figure that was burnt on the flight. This section provides an overview of these initiatives deployed for Flight100, and the extrapolated savings attributable to each initiative.

In total, these initiatives reduced SAF burn of Flight100 by 2,191 kg fuel burn saved from initiatives (see below), compared to flight plan trip fuel the without the initiative applied. Saving the equivalent of c. 8,400 kg CO_2e emissions from burning traditional fossil Jet A-1.

Flight100 Fuel Efficiency Initiatives

Operational efficiencies at Virgin Atlantic include route planning, weight reduction and constant review of waste carried are part of the day-to-day routine operations to minimise fuel burn. In 2023, Virgin Atlantic saved approximately 7,500 tonnes of Jet A-1 (28,805 kg of CO_2e) through its operational efficiency initiatives.

Reduced contingency fuels

- Reduced Contingency Fuel (RCF) is an item in the planned fuel that is calculated by the flight planning system. Depending on regulations, it is normally 5% of 3% of

the trip fuel. It is meant to cover wind deviation compared to the forecast etc. and acts as a margin/buffer for the trip fuel
- Reducing the contingency fuel allows the aircraft to carry less fuel onboard and therefore saves the cost to carry the difference compared to a standard 3% of trip fuel.
- Flight100 saved 75kg of SAF burn during the flight thanks to this RCF initiative

Reduced potable water

- Potable water is mainly used in the lavatory, but also for passengers' hot drinks (coffee, tea). The volume of potable water onboard a given flight is defined during the flight planning process
- Virgin Atlantic use an internal model to estimate the optimum amount of potable loaded, depending on the number of passengers onboard. This has been implemented instead of taking a standard generic amount. It makes the aircraft lighter and saves the fuel needed to carry the weight difference.
- Virgin Atlantic uses this reduced potable water initiative as BAU across the fleet on a day-to-day basis
- Flight100 saved 39 kg of SAF burn during the flight through this initiative

Reduced taxi time

- The taxi time from departure gate out to the runway at Heathrow was reduced by working with airport operations to ensure as an efficient taxi out as possible.
- By reducing taxi out time, the aircraft consumes less fuel due to the reduced time running the engines over the duration of the flight.
- Flight100 was able to reduce taxi out time, saving 340 kg of SAF burn.

Reduced engine taxi in

- The reduced engine taxi initiative involves only using a single engine on our twin engine aircraft to taxi into the arrival gate at the airport.
- By reducing engine use when taxiing, the aircraft consumes less fuel, while maintaining the same capability to taxi on the ground.
- Flight100 was able to deploy RETI, saving 31 kg of SAF burn during taxi

Auxiliary Power Unit runtime reduction

- The APU is a small engine in the back of the aircraft that provides power to the aircraft when the engines are off. It is primarily used for cooling the cabin before take-off
- The use of APU fuel burn can be reduced by relying on alternative power sources to meet carry out the tasks performed by the APU
- Using ground-based equipment that is more energy efficient and can rely on low carbon electricity rather than fuel burn in the APU can support us reducing our emissions from APU usage
- Flight100 saved 202 kg of SAF burn through reduced APU usage

Enroute initiatives, saved 1,504 kg of fuel on Flight100

FliteDeck Advisor

- Jeppesen FliteDeck Advisor (FDA) is an app provided by Boeing and is deployed across Virgin Atlantic's B787-9 fleet as a BAU initiative
- The FDA app is a mobile flight optimisation application that gives pilots an optimum Cost Index (CI) to fly in cruise depending on the flight conditions (pressure, temperature etc) and the performance of the specific tail that is flying
- Flight100 saved 741 kg of SAF burn during the flight through FDA

Continuous descent

- Continuous descent approach (CDA) is when the aircraft will descent from top of descent to the runway without having to level off.
- Levelling off increasing fuel burn, these are affected by ATC to ensure that sufficient spacing between aircraft is ensured during landing.
- This is equivalent to saving 763 kg of SAF burn

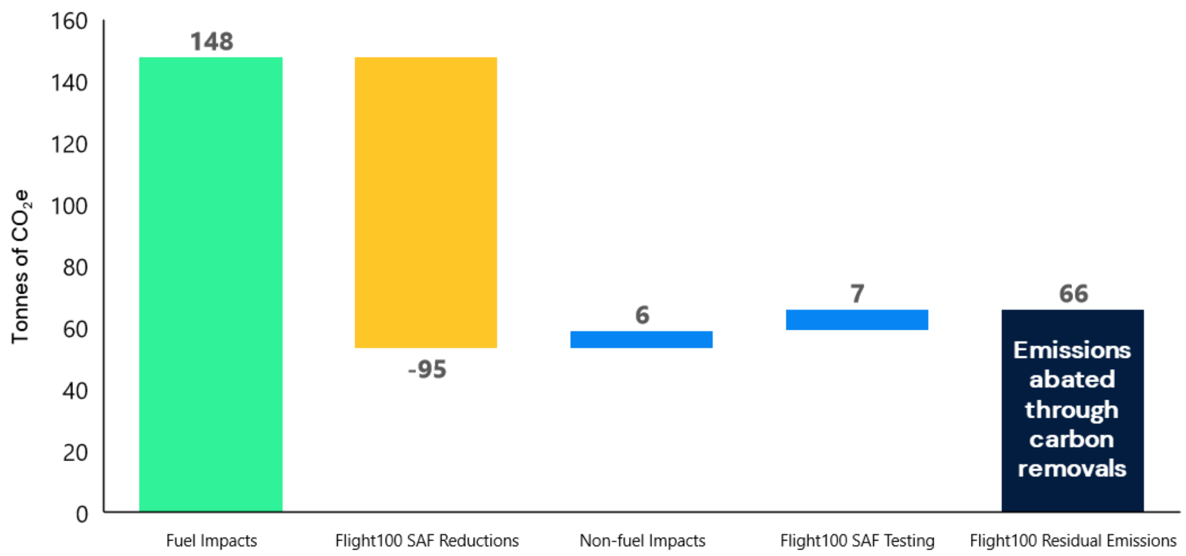
Chapter 5: Residual Emissions and Carbon Removals

5. Residual Emissions and Carbon Removals

The remaining emissions from the flight, 65.3 tonnes CO_2e, represent the residual carbon that could not be mitigated through the in-sector measures outlined in the previous chapter. To address these residual emissions, Virgin Atlantic retired 66 tonnes of carbon removal credits (0.7 tonnes above the emitted amount).

When compared to the baseline flight, 100% SAF and flight efficiency measures resulted in 65.3 tonnes of CO2e requiring abatement through market-based measures

Tonnes of CO_2e



Out-of-sector abatement measures include purchases of emission reduction (avoidance) and carbon removal credits, which represent the carbon reduction or removal occurring outside of the sector of operation, in this case, aviation. These reductions/removals are traded on the voluntary carbon market as credits, where one credit equates to the measurable and verifiable reduction or removal of one tonne of carbon dioxide from the atmosphere, by climate action projects certified under an internationally recognised carbon standard. After a credit is purchased, it is retired so it cannot be counted again.

Market Based Measures for Carbon Abatement

Not all carbon credit projects are created equally. Broadly speaking, there are two types: Carbon avoidance & reductions offsets and removals

Carbon avoidance/reductions offsets[6]

- Avoid or reduce emissions through renewable energy projects to replace fossil fuels, or by improving efficiency
- Avoid or reduce emissions by protecting ecosystems and their soils and vegetation from damage or degradation
- Reduce emissions by capturing and storing fossil carbon from industrial point sources or fossil-fuelled power stations

Carbon removals

- Offsets that represent avoidance or reductions of CO_2 being released to the atmosphere (emissions avoidance offsets), enhancing the carbon stored in the biosphere, such as by restoring healthy ecosystems (e.g., woodlands, grasslands, wetlands, and marine habitats) or enhancing soil carbon on agricultural land
- Removals physically remove CO_2 from the atmosphere through natural and engineered technologies, and permanently store it, and create carbon removal credits to help finance this activity

The avoidance offsets support activities such as renewable energy installations, forest protection, distribution of more efficient domestic appliances and improvement of industrial processes. While many of these activities are important, the market faces several challenges, including difficulty in verifying the volume and permeance of the credits issued.

The carbon removal market is smaller, more expensive, but typically more robust. Rather than avoiding emissions, removal markets are characterised as the permanent removal of carbon from the atmosphere. They are delivered by nature-based solutions such as afforestation, technological solutions such as Direct air capture, and hybrid solutions such as biochar and enhanced rock weathering.

A key goal of Flight100 was to use high-quality carbon removals to tackle the residual emissions from the 100% SAF flight, ensuring that the emission compensation strategy was:

- Compliant with the DfT competition rules – stronger net zero credentials
- Providing long-lived, durable removal of carbon from the atmosphere using credits with high environmental integrity

[6]https://www.smithschool.ox.ac.uk/sites/default/files/2024-02/Oxford-Principles-for-Net-Zero-Aligned-Carbon-Offsetting-revised-2024.pdf

- Preference was given to projects taking place in geographies relevant to Flight100

Furthermore, Virgin Atlantic's ambition in using carbon removals for Flight100 was to:

- Demonstrate demand and support for the scale up of carbon removals in the UK.
- Climate leadership – following best practice in Net Zero aligned carbon offsetting, supporting use of carbon removals.
- Advocate for the inclusion of carbon removals in the Carbon Offsetting and Reduction Scheme for International (CORSIA), bringing the aviation industry approach to offsetting into alignment with net zero goals and leading out-of-sector guidance.

Based on these goals and criteria, Virgin Atlantic decided to **use biochar carbon removal credits**, as from all the durable carbon removal options, it the only method mature enough to provide reliable and cost-effective removal today.

5.1. Biochar

Biochar is a form of charcoal that is produced through the process of pyrolysis, which involves heating biomass feedstock - organic materials such as wood waste and crop residues in the absence of oxygen. The resulting biochar is a stable form of carbon that can be added to soil to improve its fertility and sequester carbon.

Biochar helps mitigate climate change by locking carbon out of the atmosphere in a stable form for centuries. When incorporated into soil, biochar enhances its ability to retain water and nutrients, promoting better plant growth. However, the effectiveness of biochar as a carbon removal method depends on factors such as feedstock type, its alternative uses, production methods, and soil conditions. Biochar deployment also needs to consider emissions to air from the pyrolysis process and the chemical composition of the resulting biochar to avoid polluting soils with heavy metals or polyaromatic hydrocarbons. Biochar has significant potential to remove carbon and improve soil fertility on a global scale, which its ability to make the best use of biomass feedstocks of no other significant use or benefit.

Virgin Atlantic selected Carbon Hill, a small-scale biochar producer in Wales as their biochar carbon removal credit provider.

The feedstock to produce biochar is typically waste biomass, in Carbon Hill's case this is hedgerow cuttings and green waste from local parks and gardens. This biomass contained temporarily stored carbon that was removed from the atmosphere by plants through photosynthesis. Without undergoing the pyrolysis process, this carbon would be re-released through the burning or decomposition of waste biomass. While biochar itself could also be burned in the presence of oxygen (as charcoal can be), the application and mixing with soils prevents this from ever happening.

Biochar charcoal product

Source: Carbon Hill Project

Biochar being spread onto fields

Source: Carbon Hill Project

When biochar is buried or added to soils, most of the carbon can remain there for decades to millennia, given the right conditions. Furthermore, spreading of biochar on farmland brings additional co-benefits, such as yield improvements and reduced need for fertilisers. Biochar improves soil quality by helping to restore degraded soils, improving agricultural productivity, and helping soils retain water.

Biochar is a heterogenous material that consists of two distinct carbon pools with different degrees of durability: labile and recalcitrant (stable, aromatic) fraction; larger recalcitrant fraction means better durability, as the stable polycyclic aromatic carbon has been shown to persist over 1,000 years in soils. The ratio between these two pools depends on pyrolysis conditions such as pressure and temperature and the feedstock itself. The molar ratio between hydrogen and carbon (H:C) is used as a proxy for the degree of aromatization, as it can be easily and precisely measured. A ratio below 0.4 indicates a high portion (~75%) of the stable, aromatic carbon.

Biochar carbon credits are calculated to have a durability of 100 years, the amount of carbon stored by 1 credit will be 1 tonne of CO_2; this may mean a slightly higher amount (buffering) needs to be sequestered in the first place. From there, the two respective carbon pools show distinct degradation dynamics, each following a degradation curve. Labile pool will mostly be degraded by then, but the aromatic pool, which in biochar is created in high enough temperatures from woody biomass represents about 75% of carbon mass, is expected to persist over 1,000 years.

As with all carbon offsets and removals, permanence of CO_2 removal can vary between technologies and individual projects. The permanence of biochar's carbon removal capability, currently evaluated at medium permeance, can vary from 100s-1000s of years depending on factors such as soil type and temperature. For example, colder soils result in slower degradation. The science of biochar permanence is still evolving, staying up to date with latest firmer scientific consensus is key to selecting the most effective and permanent removals.

In collaboration with Supercritical, Virgin Atlantic have undertaken a detailed selection and due diligence process, evaluation projects on an individual basis, to ensure the highest quality biochar carbon removal credits were selected for this process.

5.2. Carbon Hill Selection Process

To find and procure the right project, Virgin Atlantic partnered with carbon removals specialists, Supercritical.

Supercritical is a vetted carbon removal purchase platform. It carefully vets and selects carbon removal projects based on criteria such as additionality, feedstock sustainability, completeness of life cycle assessment and net positivity on environmental components other than climate. Supercritical matches suppliers of carbon removal methods with buyers through their marketplace. Where needed Supercritical pre-purchases removals to provide funding to suppliers of carbon removal methods.

The selection process involved Virgin Atlantic setting key criteria for the project, and utilising Supercritical' s vetting process to ensure the best project was selected

Rigorous Vetting

Extra due diligence beyond existing standards

Additionality, permeance, co-benefits, future potential

PURO certification

Approved biochar standard

Ensures robust and durable removals

2023 vintage

CO_2 sequestered in the same year as Flight 100

UK-based project

Supporting UK removals industry

5.2.1. Carbon Hill Vetting Process

The Supercritical vetting process provided an additional layer of due diligence to the carbon removals process. The Supercritical climate team deploy a rigorous process to ensure only high-quality carbon removals are included, with only 11.5% of biochar projects passing vetting.

Through this robust vetting process, Virgin Atlantic ensure the environmental integrity of the credits being used to achieve net zero emissions for Flight100.

Having met the Virgin Atlantic criteria and passed Supercritical vetting, Carbon Hill biochar was selected as the provider of credits.

Virgin Atlantic Flight 100 Carbon Removal Vetting Process		
Consideration	**Requirement**	**Project Characteristics**
Removal	Only removals accepted, no avoidance or reduction offsets	• CO_2 is taken out of the short biogenic cycle and stored in a more stable biochar material mixed with soils • 2023 vintage • UK based project
Net negativity	A project's removal must be net of lifecycle emissions	• Detailed LCA including, feedstock production, transport, pyrolysis, packaging, and biochar application
MRV + Registry	Projects must have MRV and unique retirement on an established registry	• PURO.Earth registry
Additionality + Leakage	The removal must not have occurred in the absence of a market for offset credits	• Minimal risk of leakage from counterfactual use of hedgerow feedstock as bioenergy, as hedgerow cuttings are underutilised, with enough feedstock for both uses
No significant harm	Projects must cause no ecological, economic, or social harm	• Sustainable feedstock that does not contribute to deforestation • Pyrolysis unit was designed to produce minimal emissions to air - unique integral flue gas filtration technology removes over 99% of SO2 and CHI, and up to 95% of NOx
Durability	Durability must be well established and be conservative	• Pyrolysis temperature at 800 degrees and the H:Cord ratio of 0.11 for the majority of means that biochar is high durability • One carbon credit represents 1 tonne stored at 100 years, and a significant portion of that carbon will likely remain in soils for at least 1,000 years
Co-benefits	Environmental, social, economical co-benefits must be present	• Biochar application to soils leads to improved soil fertility and reduced emissions from soils • Mixing with compost make soil application particularly beneficial, as biochar helps soil retain beneficial components introduced to soil with compost • Carbon Hill is located in Powys region that was ranked 162/180 UK regions in terms of GDP per capita in 2020, bringing jobs and revenue into the region
Future potential	Projects must have significant future scaling potential	• Currently in pilot system scale, with the aim to roll out dozens of pyrolysis units to process waste biomass in the UK and overseas

Carbon Hill is a biochar company owned by the Jones family, located at the Caebardd farm in Wales, UK. Carbon Hill has designed a pyrolysis thermal combustion system, which innovatively utilises new technologies to produce biochar with minimal emissions. A pilot system is under operation at Caebardd, but the company aims to roll out more pyrolysis units to process waste biomass in the UK and overseas.

Carbon Hill's Biochar plant pyrolysis thermal combustion system

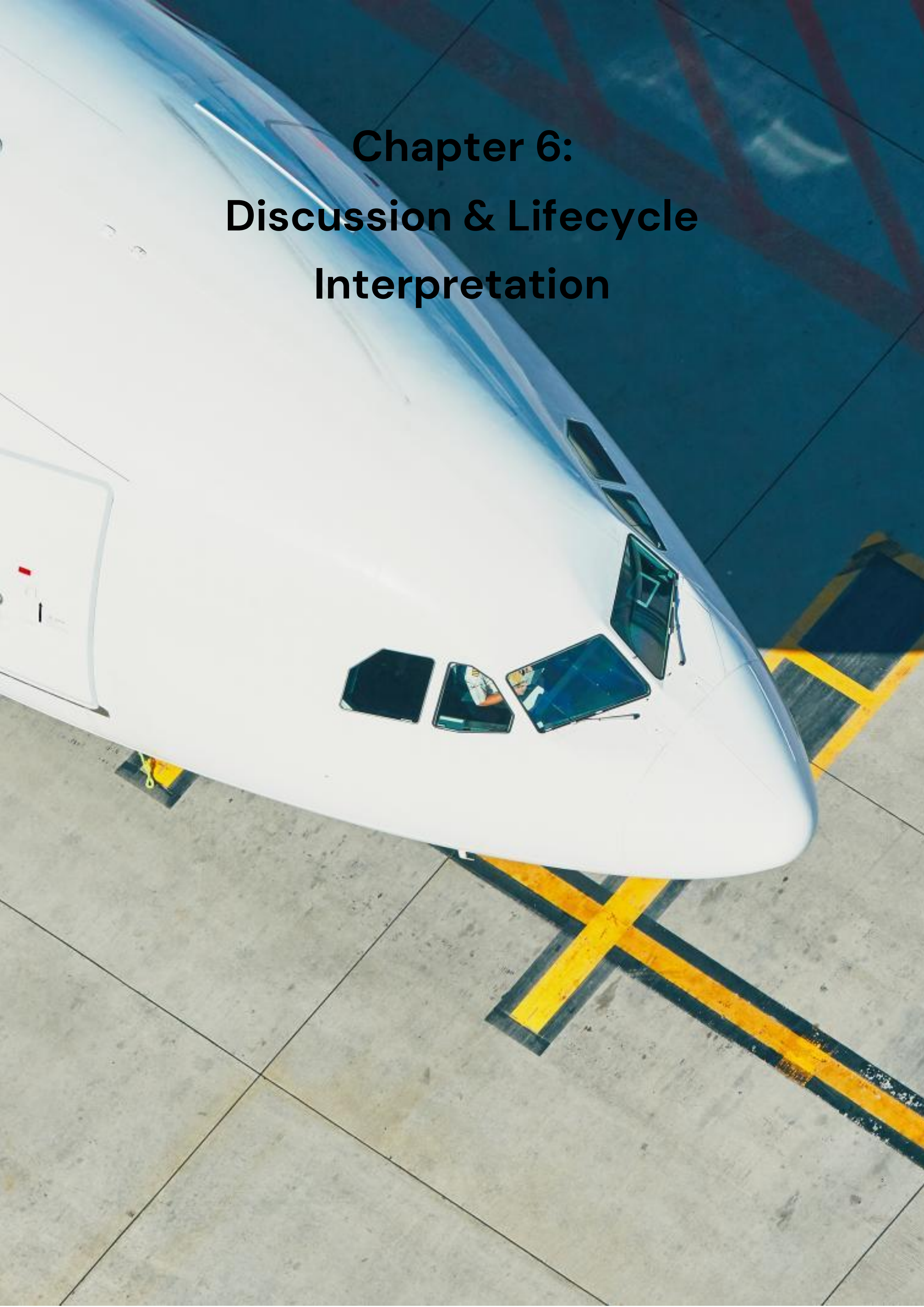
Source: Carbon Hill Project

Carbon Hill uses two streams of waste woody biomass for their biochar: Hedgerow cuttings from farm fields, ubiquitous in rural England and Wales. The other is Green Waste Over Size (GWOS) from local green waste from parks and gardens. The baseline activity for the feedstock is biodegradation or combustion which would return the CO_2 to the atmosphere, but the pyrolysis process combined with subsequent application of biochar in soil, transforms this short-lived biogenic carbon into durable carbon storage. Carbon Hill's process results in a pyrolysis temperature at about 800 degrees and an H:Corg ratio comfortably under 0.4 (a vetting requirement of Supercritical), ensuring the biochar produced is of a high quality in terms of durability, expected to persist for 1,000s years.

The project represents innovative use of waste biomass material, and produces high-quality, durable biochar. Application of biochar to soils has additional benefits, especially when it is co-applied with compost.
Ultimately, Virgin Atlantic were able to procure Carbon Hill biochar removal credits that ensured high quality and strong environmental integrity, delivering durable long-term storage with a high level of confidence and scientific due diligence to support this. These

credits ensured the residual emissions of Flight100 have been mitigated using quality UK-based carbon removals, in alignment with net zero offsetting principles.

Chapter 6:
Discussion & Lifecycle Interpretation



6. Discussion & Lifecycle Interpretation

The objective of this first of its kind carbon flight LCA was to map the end-to-end customer journey, identifying key environmental issues and hotspots, serving as a starting point for reducing emissions associated with the full flight lifecycle.

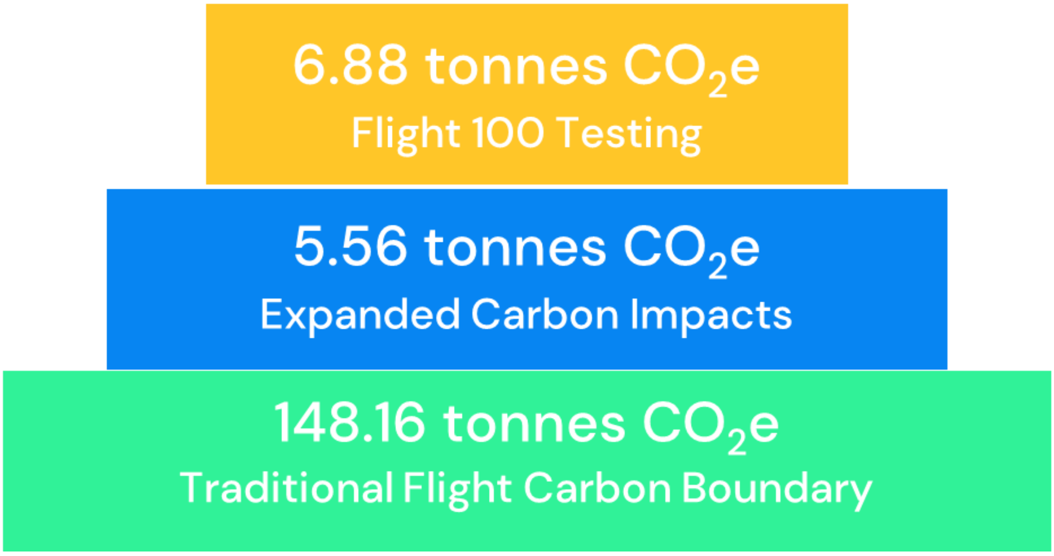
Through active stakeholder engagement, the results of the LCA while specific to Virgin Atlantic, provided insight into aviation's wider environmental impacts while highlight the tools and technologies available for carbon abatement.

While the importance of SAF for decarbonising aviation is unquestioned, without addressing environmental impacts from the entire lifecycle, neither individual carriers nor the industry as a whole will not achieve Net Zero by 2050. As demonstrated by the LCA and abatement results, SAF, even if availability, cost, and technological challenges are overcome, can only get the sector most of the way there.

The flight LCA provided Virgin Atlantic and can offer other carriers the insight necessary to identify decarbonisation 'easy wins', action which can be carried out today while SAF production and use is scaled. Furthermore, as the prevalence and availability of carbon removals grows within the aviation sector, LCAs will play a vital role in calculating the quantity of removals required for net-zero emissions i.e. mitigating the residual operational carbon not abated through SAF and future next generation aircraft technology.

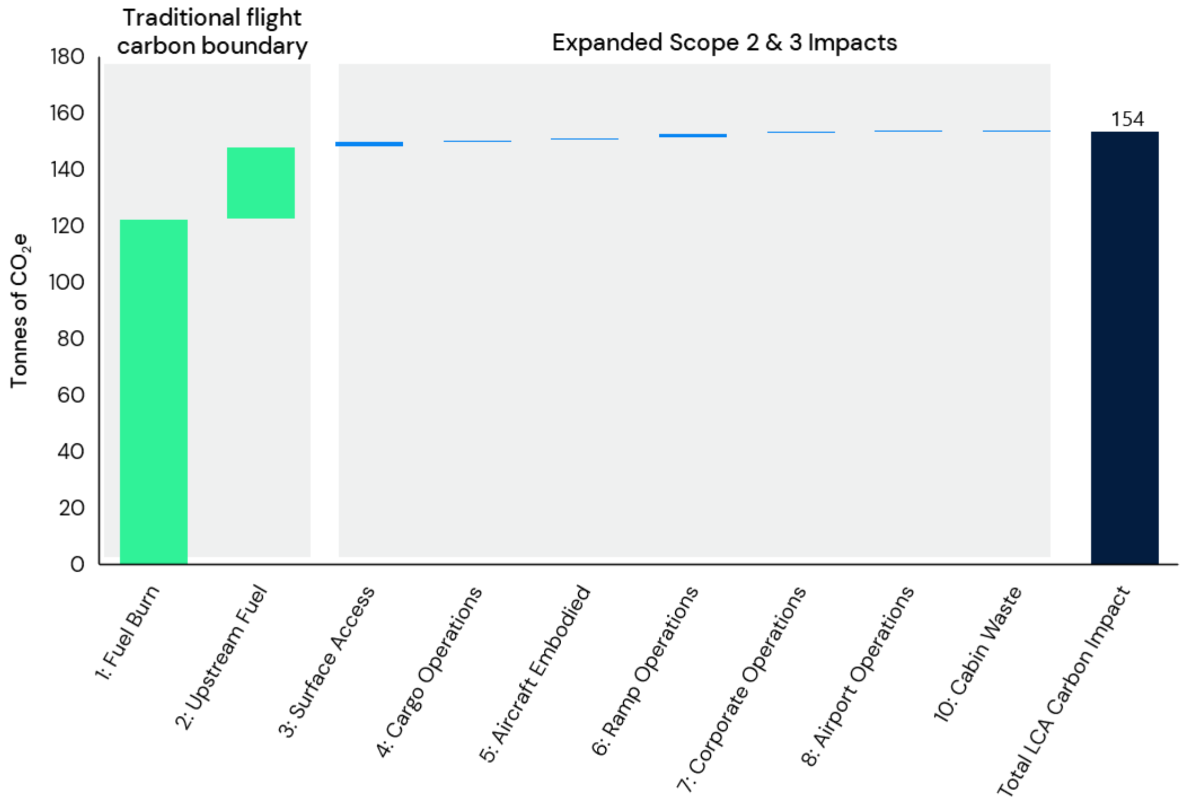
The lifecycle interpretation serves as a natural conclusion to the LCA where findings from the inventory analysis and the impact assessment are combined to distil key takeaways. The figure below calls out the origin of Flight100's carbon impacts, with 100% SAF serving to only reduce impacts from the traditional flight carbon boundary.

Resulting net zero emissions impact of Flight100 required abating 160.61 tonnes of carbon through SAF, operational efficiencies, and removals



Despite the marginal carbon impacts of the activities under the expanded LCA scope, as outlined in the graph below in blue, non-fuel burn impacts must be addressed for the industry to truly achieve Net Zero.

Cumulative carbon impacts of a baseline Virgin Atlantic 787 LHRJFK flight are dominated by the traditional flight carbon boundary



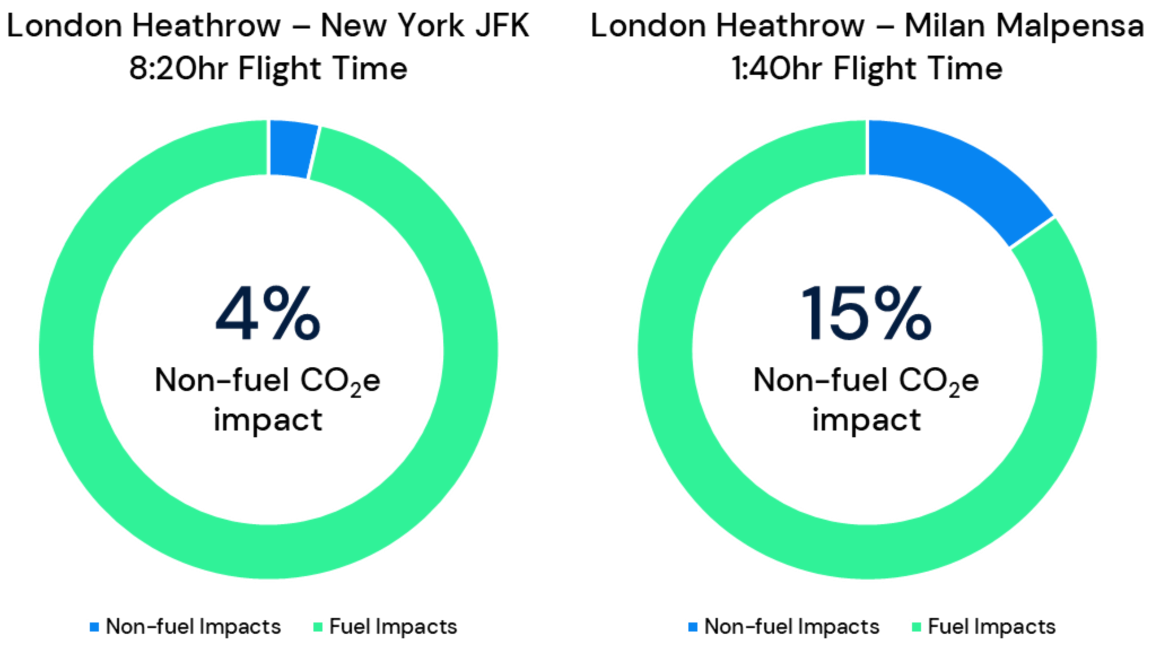
Current LCA guidance on materiality would suggest that non-fuel burn impacts not need to be included in this LCA as the threshold for materiality at 96% had been met through fuel related impacts alone.

However, while the expanded Scope 2&3 impacts only accounted for 4% of the total carbon impact of the baseline 787 LHRJFK flight, the need to quantify and address non-fuel related impacts is captured in the figure below.

Depending on route profile and length, additional analysis highlights that the percent share of non-fuel burn impacts is variable. Utilising Virgin Atlantic's fuel burn model, which enables the estimation of fuel burn based on AC-type, load factor, cargo, and flight time, offers the ability to conduct a comparative analysis.

Over the Covid-19 pandemic, Virgin Atlantic operated several flights to Milan, MXP. To assess the variability in the percent share of non-fuel burn impacts, model parameters were set to align with Flight100 (189 PAX and 14.9 tonnes of cargo on a 787-9) for the LHR-MXP route. With a duration of 1 hour and 40 minutes, under the same Flight100 baseline characteristics, fuel burn on the route totals 8.11 tonnes. On the Milan route, non-fuel carbon impacts accounted for 15% of total emissions compared to only a 4% share for the Flight100 baseline.[7]

With comparable take off weights, the share of non-fuel burn impacts on Virgin Atlantic's 787 short-haul flight, increased by 275%



[7] 275% increase of non-fuel carbon impacts share, from 4% to 15%

The significant increase in the percent share of non-fuel related impacts as part of the flight's carbon footprint signifies that wider value chain carbon impacts cannot be ignored. The scale of non-fuel related impacts will vary from carrier to carrier and from route to route but by working to decarbonise these activities, significant carbon abatement can be achieved throughout the sector as SAF is being scaled and increasingly utilised. The need to decarbonise wider value chain activities becomes more important on shorter routes given the larger percent share in the flight carbon footprint.

Undertaking the Flight100 LCA has highlighted that the impacts of getting passengers from A to B is only one piece of the aviation decarbonisation puzzle. While carriers can support the reduction of their largest CO_2 impact through increased SAF offtakes & investments and flight efficiency measures, SAF alone will not deliver a Net Zero sector. Results captured the carbon impacts of the activities and processes which are critical to commercial aviation (cargo, airport operations, GSE, etc). If the aviation sector is commitment to achieving Net Zero by 2050, mitigating value chain emissions must be part of the decarbonisation mission. However, to decarbonise Scope 3 emissions, the industry must develop a methodology to better quantify and monitor the extent of their impacts.

Working with stakeholders to complete the Flight100 LCA quantified the emissions produced through Virgin Atlantic's value chain. While non-fuel burn impacts only accounted for 4% of emissions on the VAA LHRJFK route, the scale of every airline's non-fuel burn carbon impact will be unique to their operations, fleet, and network. The impact of attributable processes across each carrier's value chain will have varying levels of carbon impact based on national conversion factors, stakeholder processes, and commitment to decarbonisation. Subsequently, the scale and variety of Scope 3 decarbonisation opportunities will differ across the sector.

While the LCA results are specific to Virgin Atlantic's LHRJFK route, the lifecycle stage mapping methodology offers a replicable framework for carriers to quantify their respective Scope 3 emissions. Undertaking the Flight100 LCA has enabled Virgin Atlantic, its suppliers, and partners to identify Scope 3 mitigation opportunities throughout the carrier's value chain. Developing a standardised industry methodology for assessing Scope 3 impacts, inclusive of all flight lifecycle stages, will present distinct opportunities for the industry to collectively reduce its environmental impact.

Lessons Learnt & Industry Takeaways

- Improving data availability throughout the value chain will be crucial for tracking progress against industry Net Zero ambitions

- Decarbonising flight Scope 3 emissions needs to be viewed as a shared responsibility with carrier's working alongside their service provides to capitalise on "low-hanging fruit" and tackle the more complex challenges
- As the scale of non-fuel burn impacts will vary by route length, carrier operations, and by region, Scope 3 emission measurement requires standardisation to establish boundary and scope setting
- While SAF may be primary driver for industry decarbonisation, Flight100 showed that even 100% SAF is not enough to achieve Net Zero highlighting the need for additional decarbonisation measures to be developed

6.1. SAF Availability and the Need for Scale

Despite the collective acknowledgment of SAF's pivotal role in decarbonising aviation, current production volumes remain insufficient to meet global demand. The gap between demand and supply presents a substantial challenge to realising not only ambitious policy mandates but also the long-term sustainability goals set forth by airlines.

To meet global climate targets and aviation's growing demand for SAF, the volume of sustainable aviation fuel must rise substantially. The Waypoint 2050 report by ATAG emphasises the monumental shift required to achieve sustainability goals. It estimates that by 2050, aviation will demand between 330 million and 445 million metric tons of SAF. Despite the anticipation of increased SAF production capacity in the near term, global SAF production in 2022 remained less than 0.1% of the global supply of fossil-based fuel, at 240,000 tonnes. This increased to 500,000 tonnes in 2023.[8] Consequently, a scarcity premium is likely to persist, especially in markets expected to witness substantial SAF penetration.

SAF production faces several limitations, including underdeveloped technologies, nascent logistics systems, and emerging production approaches that contribute to high costs. The industry's maturation and scaling will likely drive down production costs, but this cost reduction will be partially offset by the necessity of adopting more advanced technologies to access a wider range of feedstocks to deliver high carbon reductions through via the Power to Liquid and Fischer Tropsch SAF production pathways through the use of renewable energy and hydrogen.

Currently, the aviation industry primarily relies on the HEFA pathway to process waste oils and fats into fuel. While this pathway is producing SAF today, its feedstock availability

[8] https://www.iata.org/en/pressroom/2023-releases/2023-12-06-02/

remains extremely limited. Only a fraction of the aviation industry can be decarbonised using HEFA feedstocks with short-term outlooks suggesting that the demand for UCO/Tallows is on track to match total supply by 2027 (IEA).

The path to a sustainable aviation future remains lengthy, with commercial SAF production still in its nascent stages. While momentum in the SAF industry is building, organisational capacity and further policy support will be critical to scale SAF production, but this takes time, limiting deployment rates in the interim.

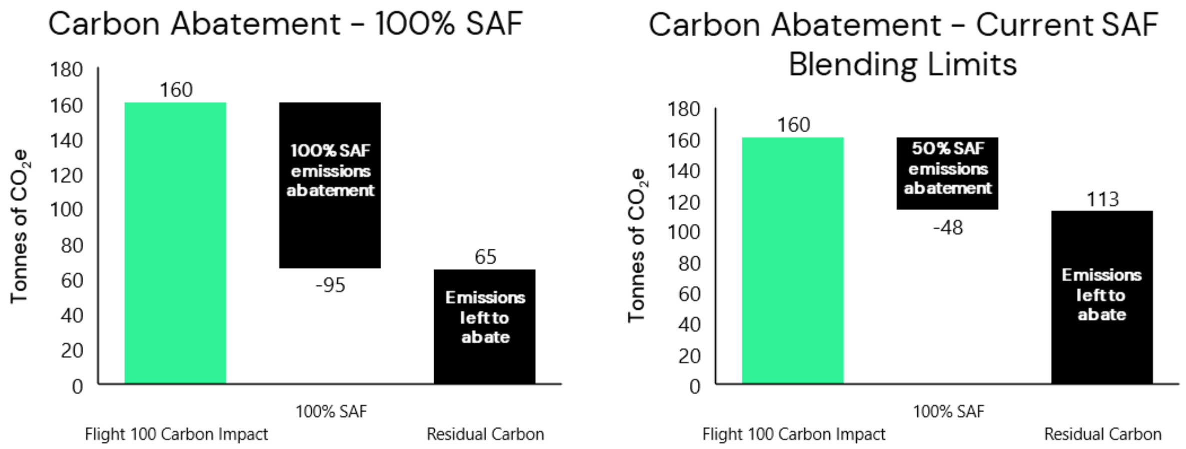
Given the urgent need to decarbonize and the current limitations in SAF production, it's essential to expand decarbonisation efforts beyond the use of SAF alone. While SAF will play a central role in decarbonising the sector, short-term action to mitigate the non-fuel burn, carbon aviation supporting impacts presents an opportunity to achieve short-term wins. Decarbonisation action does not exist in a vacuum, action can be taken to address 'low-hanging fruit' while aviation, governmental, and fuel stakeholders work to scale SAF production and deployment.

To achieve Net Zero 2050, the innovation and investment needed across all available feedstocks and technologies must be harnessed to maximise SAF volumes as well as continuing the research and development needed to bring new zero emission aircraft to market.

Without the incorporation of SAF, airlines would be compelled to curtail their activities significantly or face passing through incurred carbon costs to their customers making travel and global connectivity increasingly inaccessible. Consequently, the industry is actively engaging in the development of robust SAF strategies, driven by both policy mandates and their commitment to sustainability.

Flight100 was groundbreaking from a technological standpoint as today, SAF has a 50% blending limit, meaning that SAF cannot make up more than half of the fuel used to power a flight. The graph below highlights the additional carbon abatement delivered by exceeding the 50% HEFA blending cap. Using the same fuel outside of the Flight100 initiatives would have resulted in 113 residual tonnes of CO_2e requiring mitigation. This highlights the need for certifying an increase in SAF blending limits and the importance of developing robust market based and value chain measures to address residual carbon while blending caps remain in place.

An additional 47 tonnes of carbon abatement was secured by flying on 100% SAF



6.2. Carbon Removals in Aviation

Out-of-sector mitigation through offsets and removals will have a significant role in decarbonising aviation and achieving net zero. Industry roadmaps illustrate their necessity whilst fleet and operation efficiencies reach their limit, and SAF and zero emissions flight technologies further develop.

"There is no Net Zero scenario without carbon removal."

- IPCC, 2022

Carbon reductions must always be the priority, but once their limits are reached, the aviation industry should increasingly use high-quality carbon removals to compensate for residual emissions, in addition to carbon offsets. Virgin Atlantic's purchase of removal credits is representative of the minority of emissions compensation actions. Most offsets that are bought to compensate for aviation emissions are of the emission avoidance and reduction type.

There are likely two reasons for this: the first is that the cost of high-quality carbon removal credits is much higher than that of conventional emission avoidance/reduction credits. The second is that the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the global aviation offsetting initiative under the International Civil Aviation Organization (ICAO), does not currently allow credits from carbon removal-specific registries, such as Puro.

CORSIA publishes a list of programmes that are eligible for its programme. None of the carbon removal specialised registries, such as Puro, are currently listed. In fact, at the time of writing, only two programmes are officially listed by ICAO as compliant for CORSIA Phase 1 (2024-26) compliance period[9].

For science-based, Net Zero aligned offsetting, carbon removals must happen in parallel to emissions reductions, not sequentially[10]. This approach is reinforced by the convergence of SBTi and Oxford Principals guidance into a single message: companies must both reduce and remove in parallel, starting now. However, significant investment and R&D is needed in the short-term to scale carbon removal capacity to the scale required by 2050.

Carbon removals are a fundamentally important mitigation measure in the limited arsenal of measures available to aviation. Carbon removals offer the most scientifically robust and durable method to mitigate these emissions. In a world where the sector is striving to achieve Net Zero goals and ambitious carbon targets, there must be an increased focus towards carbon removals to ensure Net Zero aligned offsetting takes hold.

Under the current SBTi guidance for Corporate Net Zero Standard, companies wishing to establish near- and long-term targets aligned with a global warming scenario of 1.5°C must reduce value chain emissions to a residual level of no more than 10% of a baseline at net zero by 2050 or earlier. Only then can companies use carbon removals to neutralise residual emissions to zero or beyond with 'beyond value chain mitigation'. Under the latest SBTi interim sector guidance for aviation, carbon removals cannot be used to achieve near-term aviation science-based targets. Whilst carbon offsets and removals are not currently accepted to meet near-term targets, they will undoubtedly have a significant role to play in meeting longer-term decarbonisation goals. As such the SBTi should reassess the current 10% cap on removals as a means to achieve Net Zero. To date, only 2 of 25 near-term SBTs currently committed or set by airlines are aligned to the 1.5°C pathway.[11] Whist carbon offsets and removals are not currently accepted to meet near-term targets, they will undoubtedly have a significant role to play in meeting longer-term decarbonisation goals. As such the SBTi should reassess the current 10% cap on removals as a means to achieve Net Zero.

If carbon removal is to reach the scale required by 2050, then aviation as an industry must act today. ICAO should take supportive action to broaden the scope of CORSIA eligible emissions units to include carbon removals registries and, therefore, eligibility of carbon removal credits. With greater availability and emphasis on carbon removals from

[9] https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/CORSIA%20Eligible%20Emissions%20Units_Nov2023.pdf
[10] https://www.smithschool.ox.ac.uk/sites/default/files/2024-02/Oxford-Principles-for-Net-Zero-Aligned-Carbon-Offsetting-revised-2024.pdf
[11] https://sciencebasedtargets.org/companies-taking-action

the aviation industry, CORSIA and airlines can collaboratively support the scaling of these initiatives. This will help overcome one of the key barriers to carbon removal investment, cost, by driving down the price of removal credits.

Virgin Atlantic's use of biochar, and the due diligence process in selecting these credits, exemplifies a robust approach to carbon credit selection. Where the provenance and durability of carbon credits have been increasingly called into question in recent times, it is more important than ever that a robust process of due diligence is used to ensure high quality, durable carbon credits are deployed effectively to address residual aviation emissions.

6.3. Virgin Atlantic's Commitment

Effective decarbonisation of aviation requires the collaboration and unified efforts of all stakeholders. Virgin Atlantic are committed to collaborating with the aviation industry and continuing to contribute towards the vital research that is needed to accelerate the pace of change in the aviation sector. Whether that be supporting scaling the use of SAF and unlocking blending limits, contributing to the research into non-CO_2 effects of flying, or driving the understanding of the full lifecycle impacts of flying across the value chain, Virgin Atlantic are committed to do this work in the most accountable and transparent way.

The lifecycle analysis detailed in this report, undertaken in collaboration with ICF and with the support of multiple stakeholders across the aviation value chain, is a testament to the collaboration and partnership the industry is capable of.

Flight100 has demonstrated that whilst fuel and SAF are the fundamental cornerstones of operating and decarbonising commercial flight, the wider value chain has a significant role to play in reducing the environmental impacts and enhancing the transparency and insights of the broader operation.

Moving forward, Virgin Atlantic will continue to champion partnership and innovation, working with in partnership with our value chain stakeholders to further improve our understanding and transparency of lifecycle emissions and decarbonisation opportunities.

Flight100 Key Takeaways

- Whilst fuel is the most material emissions impact from commercial flights, all industry stakeholders and service providers have a role to play in decarbonising the sector

- The need to decarbonise wider value chain activities becomes more important on shorter routes given the larger percent share in the flight carbon footprint

- A full end-to-end lifecycle of a flight has proven a valuable exercise in identifying impact areas and highlighting where decarbonisation measures can make a difference – such as passenger ground transport

- The LCA of Flight100 has shone a spotlight on the benefits of 100% SAF, reducing fuel related emissions by 64% vs. Fossil Jet A-1, but highlights the wider impacts that SAF cannot and will not mitigate

- Only through this lifecycle perspective can the industry understand the necessary levers and actors to address in mitigating these residual emissions

- Industry collaboration across the value chain is needed to develop this first-of-a-kind hybrid lifecycle analysis approach undertaken by ICF and Virgin Atlantic, to develop a standardised recognised methodology to allow aviation stakeholders to specifically measure the end-to-end emissions impact of a flight

- Emissions reductions through efficiency improvements and operational change across the lifecycle of a flight will require broad industry collaboration to identify opportunities and implement change

- Where residual lifecycle flight emissions remain and cannot be addressed through reductions and efficiencies, carbon removals offer the most scientifically robust and durable method to mitigate these emissions. In keeping with best practice principles

- Carbon removals will play a key role in aviation decarbonisation to address residual emissions after SAF has been deployed. Carbon removals registries should therefore be included in CORSIA, and aviation should support the carbon removals market to ensure availability for future emissions to be addressed

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ICF (NASDAQ:ICFI) is a global consulting and digital services company with over 9,000 full- and part-time employees, working across different sectors and economic areas. Our aviation experts work across the aviation value chain, supporting our clients navigate the complexities and uncertainties as the aviation industry endures COVID-19 and increasingly looks to reduce its environmental impact.

Our team brings experience from successfully delivering sustainability projects both within aviation and out-of-sector. Our aviation experience ranges from policy analysis with the UK, US, and EU on the ETS, CORSIA, EVs, and biofuels, to detailed advisory on airline sustainable fuel offtake contracts and decarbonisation strategies. Most recently our team supported JetBlue to contract one of the largest SAF offtakes to date, and we've purchased SAF Certificates from IAG to address our own staff travel emissions. Our experts can draw on best-practice developed while successfully delivering sustainability projects for over 75 Global FT500 leading companies, and we supported the first US greenhouse gas inventory, the first mandatory greenhouse gas reporting program, the first federal agency climate adaptation program, and the development of China's emissions trading scheme. Learn more at icf.com/aviation.