FRAZER-NASH CONSULTANCY
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Decarbonising General Aviation

Understanding the Carbon Footprint of General Aviation

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Executive Summary

Introduction

The UK government has committed to achieving Net Zero emissions by 2050, including within the aviation sector. The Climate Change Committee's (CCC) advice points to an average 96% reduction by 2050 across the economy compared to 1990 levels. Aviation is recognised as being difficult to decarbonise, and under the CCC's 'balanced net zero pathway' aviation emissions are projected to decline 40% by 2050 from 2019 levels, with residual aviation emissions needing to be offset by greenhouse gas removals in order to achieve net zero. The most optimistic 'tailwinds' scenario shows that a near complete decarbonisation of aviation may be possible with demand reduction and ambitious scale-up of the availability of biofuels and synthetic jet fuels.

Whilst General Aviation (GA) has a smaller carbon footprint than scheduled commercial aviation, its aircraft types and ground infrastructure are more diverse. GA comprises any civil aircraft operation other than commercial air transport. It includes essential public services like search and rescue and emergency services, as well as pilot training, private and official flights and hobby flying.

The decarbonisation of the UK economy creates both risks and opportunities for the GA sector. If the sector fails to keep up with the pace of decarbonisation delivered across the wider economy, it could be disproportionally impacted by future net zero policy such as carbon taxation. The resulting costs to the sector could far outweigh the costs of implementing the solutions.

The aims of this research project are to establish a carbon baseline for GA, to identify existing infrastructure, future opportunities for decarbonisation and green infrastructure, the cost of green infrastructure and make recommendations to help the sector decarbonise. The study considers emissions from the aircraft as well as ground infrastructure.

GA Carbon Baseline

The carbon baseline (for 2019) calculated in this research is as follows:

Ground Infrastructure ($ktCO_2e$)	
Ground vehicles	5.8
Buildings	4.5
Hangars	2.6
Maintenance	2.2
Training	0.3
Runway lighting	0.2
Total	**15.5**

Aircraft ($ktCO_2e$)	
Flights	708
Ground movements	71
Total	**779**

The GA carbon footprint is dominated by emissions from aircraft, with the total GA emissions being 795 kt CO_2e emitted in 2019. Business flights are responsible for approximately 75% of these. Emissions from ground infrastructure, whilst comparatively small, are still significant at around 15.5 kt CO_2e, dominated by emissions from ground vehicles, electricity consumption and natural gas.

Decarbonisation solutions

We identified 24 separate solutions for decarbonising ground infrastructure, ranging from low-cost low-tech solutions like improving operational procedures to reduce energy wastage, behaviour change and renewable electricity tariffs, to more costly technology-based solutions like electric vehicles, heat pumps and localised hangar heating. We estimate that the low-cost solutions that are easy to implement could deliver approximately 25% of the decarbonisation required by 2050. The remaining 75% will involve either significant cost or the removal of other significant barriers to implementation. However, all technologies required, exist today and are already proven.

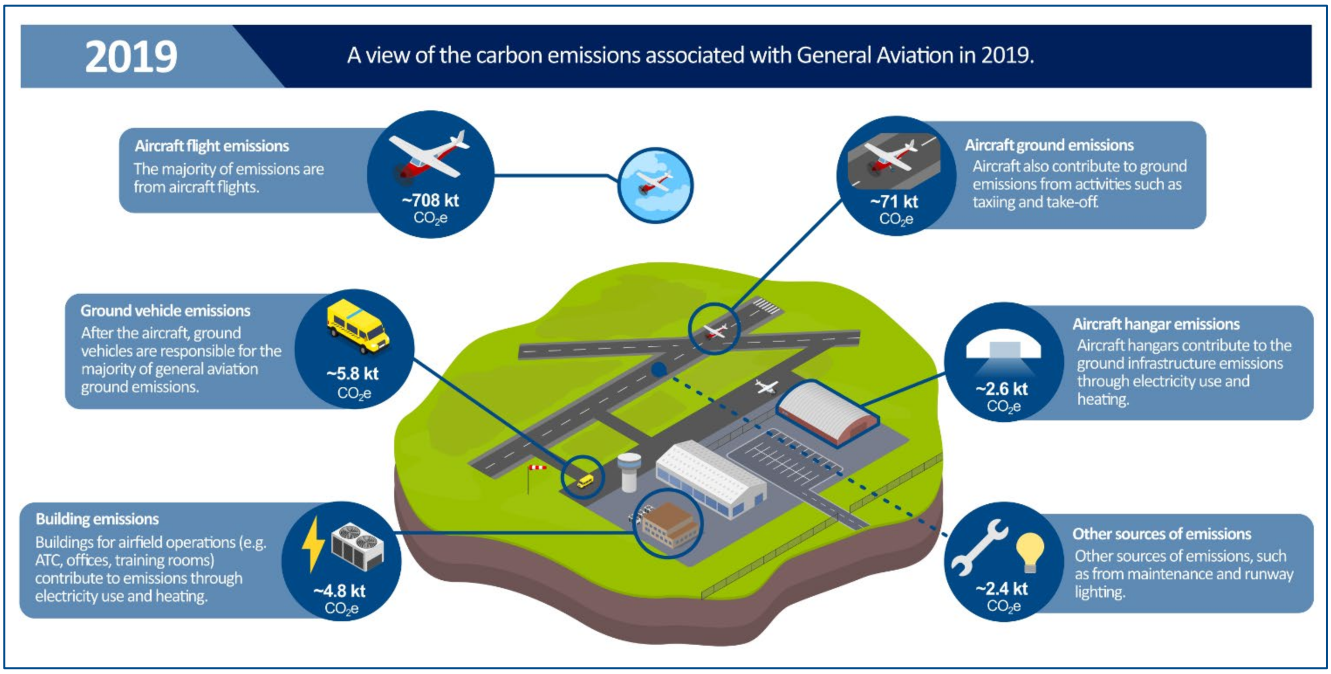
Decarbonising aircraft emissions is far more challenging. We identified 10 separate solutions for aircraft, ranging from moderate cost solutions like improving aircraft traffic management, sustainable aviation fuels and conducting more training via flight simulators, to high-cost solutions like aircraft engine replacement and new types of aircraft powered by electricity and hydrogen where these become commercially and operationally viable.

Enabling decarbonisation

Delivering the levels of decarbonisation needed for net zero will require the roll-out of a wide range of solutions at scale across the entire GA sector. There are significant decarbonisation opportunities with technologies that are already proven and can be implemented immediately. A number of barriers to implementation will need to be addressed, including the airfields' ability to access the capital to finance the solutions. The degree of change to operational norms and commercial models implied by these solutions is significant, so there is likely to be some natural resistance to change. Not least, a significant source of income for airfields is currently derived from fossil fuel sales. Therefore, it is important to act fast to consult with and provide clear and effective guidance to airfields, to enable them to understand, plan for and deliver this change with confidence.

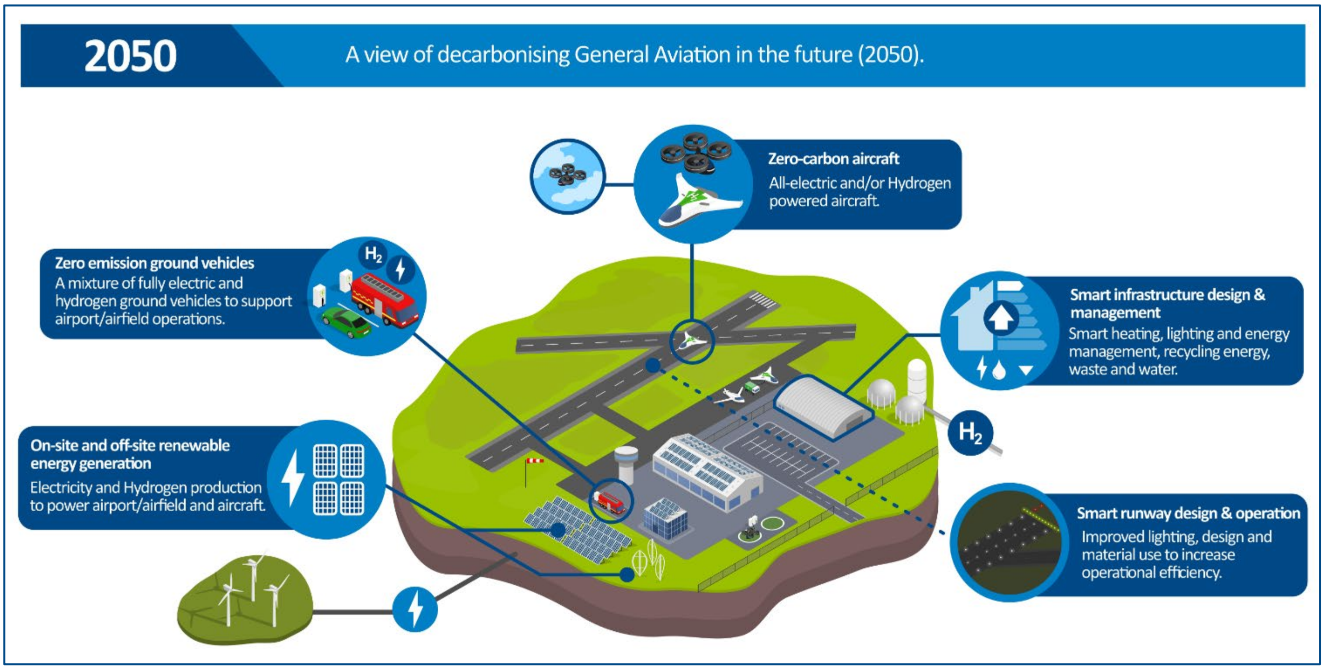
The benefits GA provides to the economy and wider communities cannot be overlooked due to the positive impacts it has on the UK aviation industry and personnel involved. However, aviation presents many complex challenges with regards to decarbonisation, and demand reduction will likely be an important method to achieve net zero and reduce residual emissions. The opportunities presented by net zero are also important to the future of the GA sector. Improving energy efficiency and switching to renewable energy sources will reduce operational costs and improve resilience. The sector also has an important role to play in the development of next generation aircraft and ground infrastructure, which could have benefits beyond GA, in the scheduled commercial aviation sector both domestically and internationally.

Overview of GA emissions in 2019



This infographic highlights the carbon emissions from different areas of the airfield, from the aircraft themselves, to the ground vehicles and buildings.

A vision of low carbon GA in 2050



This infographic provides a summary of the high-level solutions that could help GA achieve net zero by 2050, including zero carbon aircraft, zero emissions ground vehicles, smart heating, lighting and energy management, smart runways and on-site and off-site renewable energy generation.

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1 Introduction

1.1 Context and aims of this report

The government has committed to achieving Net Zero emissions by 2050, including within the aviation sector [1]. It is recognised that it may not be possible to fully decarbonise the aviation sector by 2050, however steps are required to reduce carbon emissions from aviation in order to achieve the UK's Net Zero ambitions. It is likely that this will be achieved through a combination of demand reduction and alternative technologies such as electric flight and alternative fuels [2].

Whilst General Aviation (GA) has a smaller carbon footprint than scheduled commercial aviation, the aircraft types and ground infrastructure it encompasses are more diverse. GA comprises any civil aircraft operation other than scheduled commercial air transport. It includes search and rescue, emergency services, private jets, helicopters and light aircraft as well as gliders and ballooning.

The aims of this research project are to establish a carbon baseline for GA, to identify existing infrastructure, future opportunities for decarbonisation and green infrastructure, the cost of green infrastructure, and make recommendations to help the sector decarbonise. We undertook interviews and developed case studies of a sample of GA airfields to understand the carbon emissions from their ground infrastructure and extrapolated our findings to estimate the sector's infrastructure-related emissions. We estimated emissions from UK registered aircraft using records held by the CAA of the number of hours flown by each aircraft type. We identified a range of decarbonisation solutions for the sector, identified barriers to implementation, and evaluated their potential carbon impact, cost and ease of implementation. We used an in-house decarbonisation forecast tool to estimate the potential decarbonisation that could be achieved between 2019 and 2050 to inform our recommendations.

1.2 Report structure

This section presents the context of the study and background to the GA sector. Section 2 outlines the methodology we used to establish the carbon baseline. A summary of the type of information gathered from the airfield case studies is given in Section 3. The carbon baseline results are presented in Section 4. Section 5 describes and evaluates the solutions available to decarbonise the sector, and the potential decarbonisation that can be achieved by 2050. Conclusions and recommendations are given in Section 6.

1.3 Overview of General Aviation Airfields

Previous research performed by York Aviation [3] identified that there are approximately 900 active airfields across the country. We have used the information in this study to shape our categorisation of airfields and size of the sector. The York Aviation study focussed on the economic contribution of GA to the UK economy. Therefore, it contains records of the facilities at GA airfields (including hangarage, maintenance facilities, training schools, runway lighting and fuel storage/sales) which are indicators of carbon emissions. Figure 1.1 illustrates the range of facilities (hangarage/lighting/maintenance/training/fuel sales) available at the airfields. This shows that a large proportion of the airfields have no formal facilities.

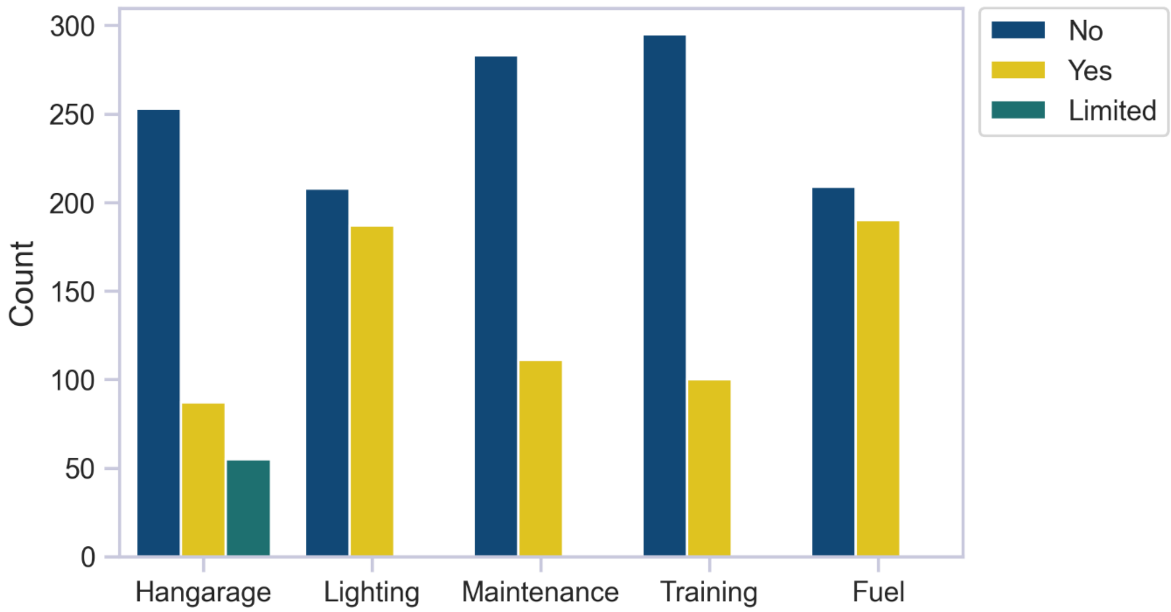

Figure 1.1: Summary of facilities available at GA airfields in the UK

We used these data to categorise the airfields as follows:

- Category 1: More than 2 facilities available, more than 50 aircraft on site
- Category 2: More than 2 facilities available, less than 50 aircraft on site
- Category 3: 2 facilities available
- Category 4: 1 facility available
- Category 5: No facilities available

Table 1.1 presents a description of the airfield categories and lists which case studies fall into these categories. Figure 1.2 presents the number of airfields in each category. The majority of airfields in the database are small airfields with only one facility available (category 4). Category 1 has the lowest number of airfields, approximately 40.

Table 1.1: Description of airfield categories and the categories of the case study airfields

Category	Description	Case study airfields
1	Major GA Aerodromes. All are CAA licensed and most have hard surfaced runways with ATC and navigational aids, maintenance and fuel facilities and a large number of resident aircraft. Many also have resident training schools.	Brighton City Airport, Blackpool Airport, IWM Duxford, London Elstree Aerodrome
2	Described as 'developed GA Aerodromes'. Many are licensed and around half have grass runways but have fewer facilities than Category 1 aerodromes.	City Airport (Manchester Barton), Solent Airport
3	These are described as 'basic GA Aerodromes'. Generally, this category is similar to Category 2 but with even less infrastructure and less evidence of usage. Many of these aerodromes are operated by clubs and any are used by gliders or microlights.	Old Buckenham Airfield, Derby Airfield
4	These are described as 'developed airstrips' and include aerodromes. Generally unlicensed grass strips in rural areas with very basic facilities.	Temple Bruer Airfield, Great Oakley Airfield
5	These are very basic farm strips airstrips, such as Pear Tree Farm, with a short grass runway, few if any facilities, and usually privately owned.	-

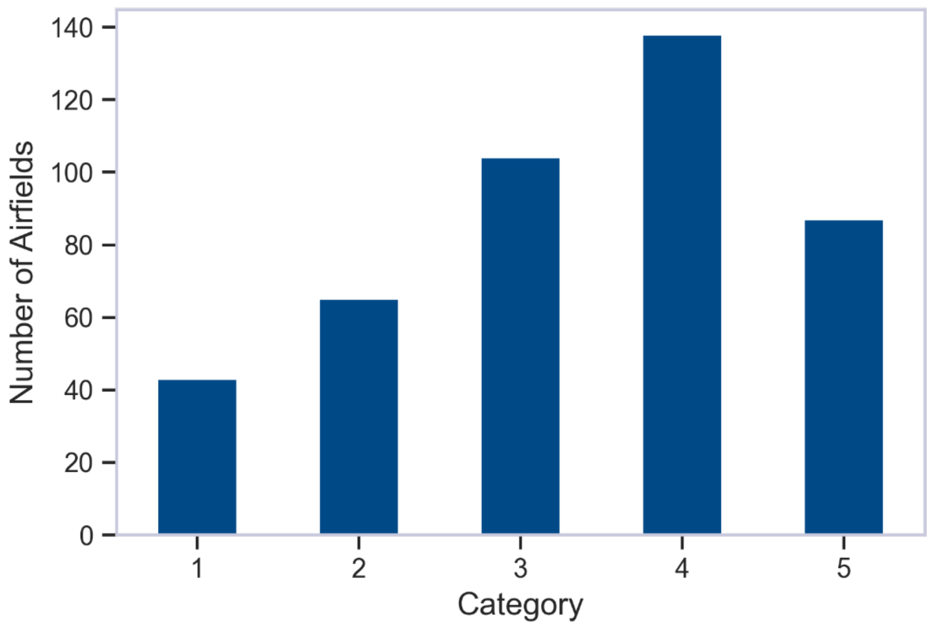

Figure 1.2: Number of airfields in each category

1.4 Overview of General Aviation Aircraft

GA encompasses flying activities such as:

- Business aviation
- Emergency services and search and rescue

- Leisure flights of light aircraft and helicopters
- Pilot training and test flights
- Gliding
- Microlights
- Hot air balloons
- Parachuting
- Model aircraft flying
- Hang gliding

In support of this research the Civil Aviation Authority (CAA) provided records [4] of the total hours flown in a given year for all UK registered aircraft. Figure 1.3 presents a summary of the number and variety of GA aircraft in the UK in 2019. This shows that the majority of the GA aircraft in the UK are fixed-wing landplanes, with microlights and gliders being the second most populous. The majority of the fixed-wing landplanes are in the 751 to 5700 kg weight category, with the next most populous being the lowest weight category of 1 to 750kg. Figure 1.4 shows the variation in total hours flown in a year by different aircraft types. Fixed-wing landplanes have the most flight hours, with approximately 600,000 hours flown in 2019. There is a noticeable reduction in the number of hours flown by fixed-wing aircraft over the period 2005-2020. By comparison, helicopters flew approximately 200,000 hours in 2019, and the number of hours flown has remained approximately constant over time. Annex A gives examples of aircraft in each category.

The CAA also publishes details of aircraft movements at international and regional airports across the UK [5], including a breakdown of the purpose of aircraft movements. Figure 1.5 collates this information from 2015 to 2021. The total number of movements has remained reasonably consistent, although the impact of the Covid-19 pandemic is visible in the reduced number of movements in 2020 and 2021. The majority of flights are by aero clubs, along with private flights and test and training flights. There is some seasonal variation in the number of flights, with more flights being taken in the summer months, as shown in Figure 1.6[1]. This seasonal variation is driven predominantly by greater demand for aero club and private flights in the summer, with less variation in the number of business flights throughout the year.

[1] The year chosen is 2019 to avoid the impact of Covid-19 lockdowns on the number of flights.

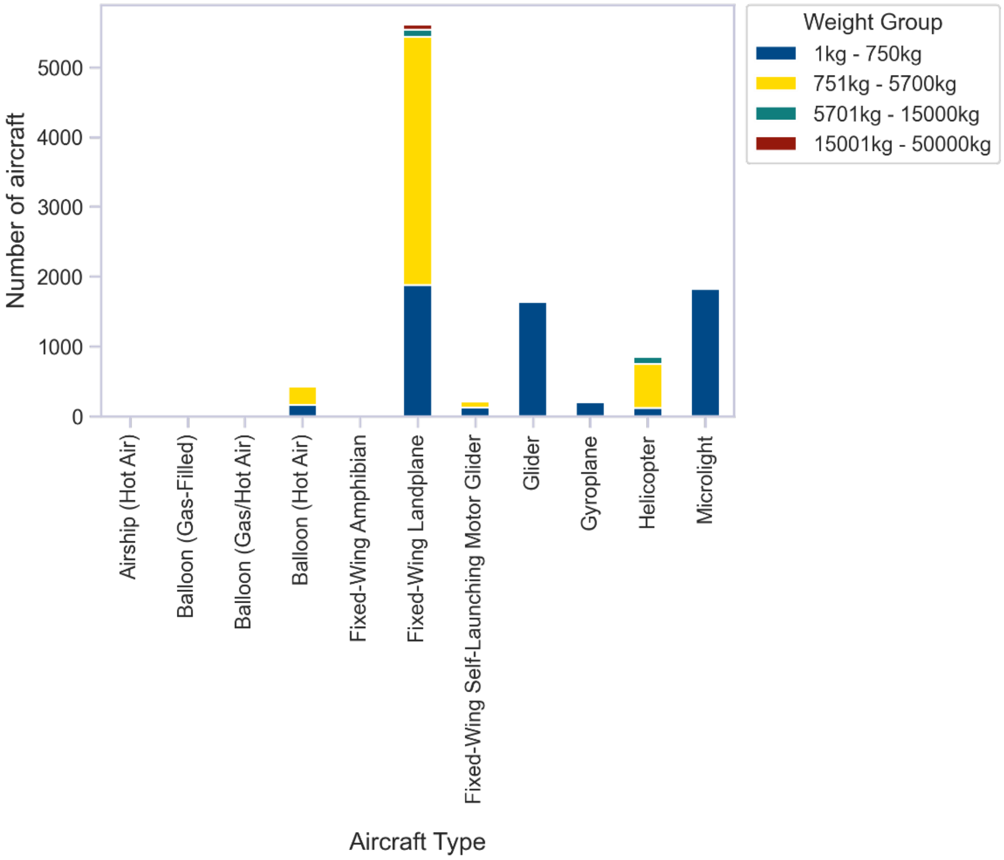

Figure 1.3: Number of UK registered GA aircraft in 2019 by aircraft type broken down by weight [4]

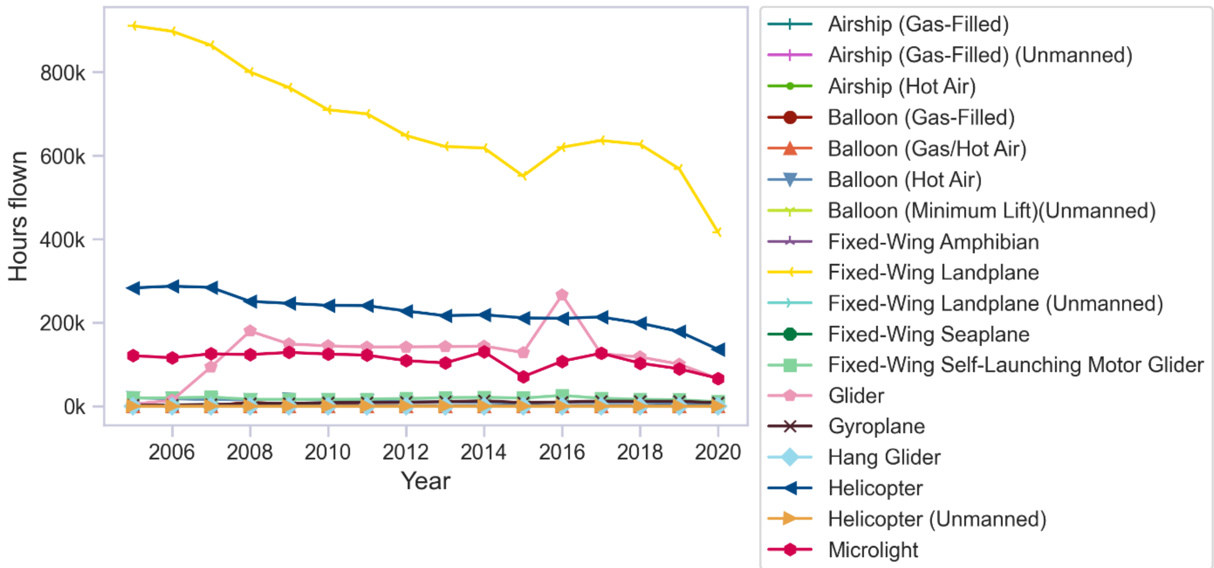

Figure 1.4: Flight hours by aircraft type from 2005 to 2020 (data taken from the CAA flight hours database [4])

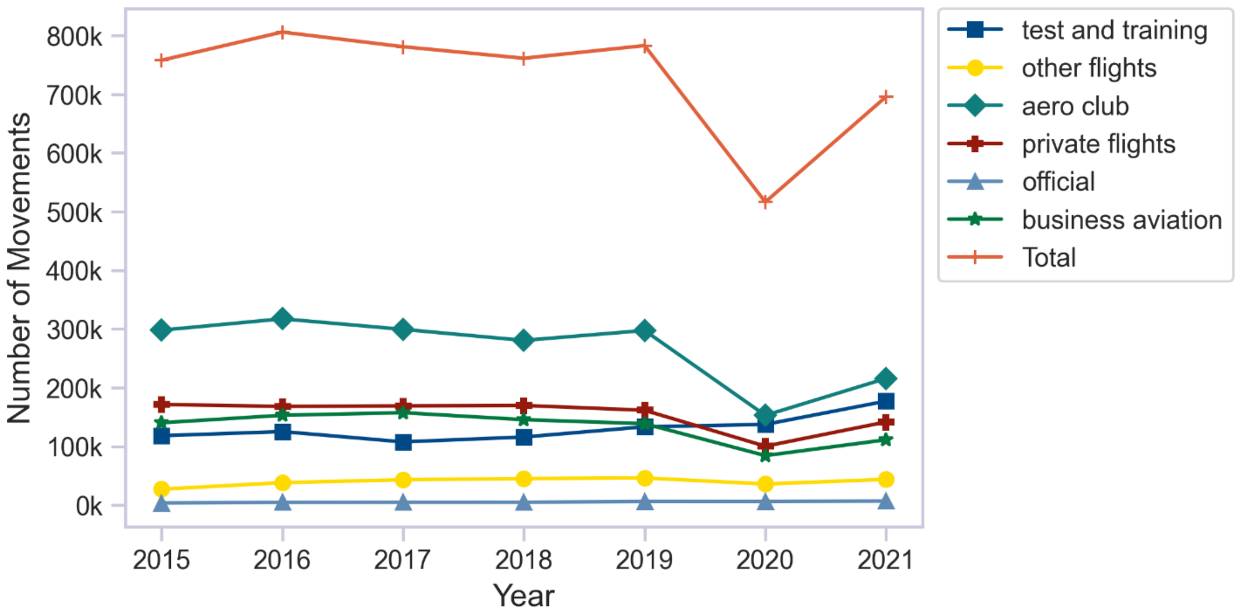

Figure 1.5: Non-commercial flight movements at CAA airports over time, broken down by flight purpose (data taken from the CAA airports data [5]). It is noted business aviation also includes air taxis.

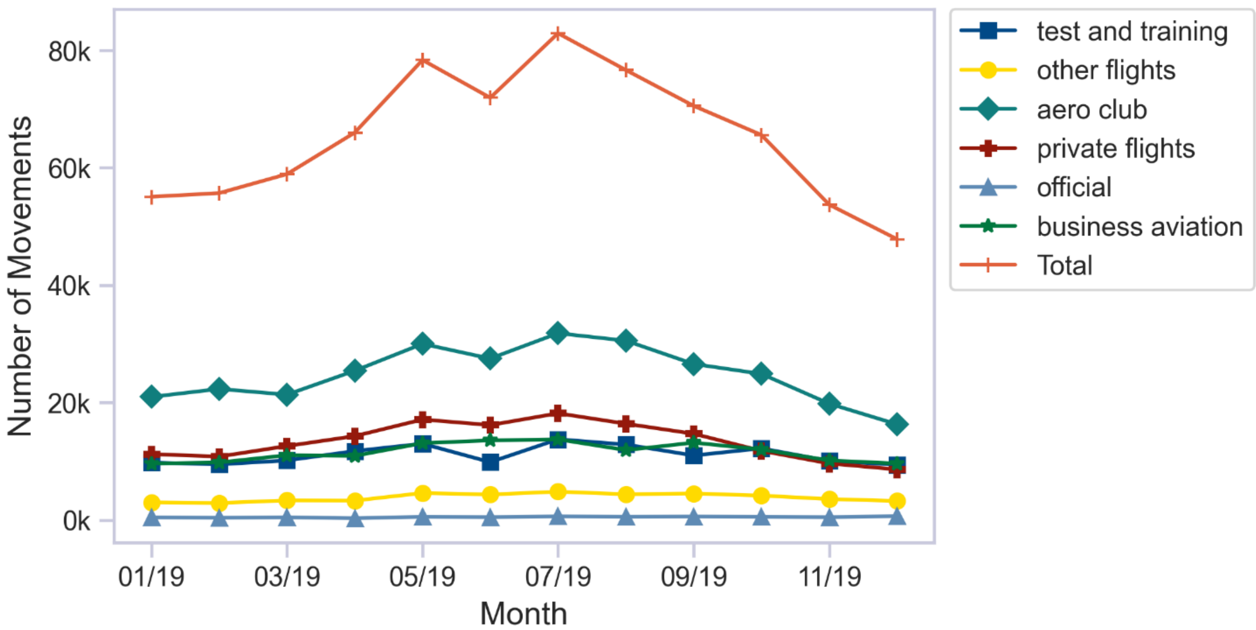

Figure 1.6: Seasonal variation in non-commercial flight movements at CAA airports over 2019, broken down by flight type and total number of flights (data taken from the CAA airports data [6]). Note, business aviation includes air taxis.

2 Carbon Baseline Methodology

This section outlines the methods used to establish the carbon baseline. The data sources used in this research are described in Section 2.1. The methods for estimating the carbon emissions from the ground infrastructure and aircraft are given in Sections 2.2 and 2.3 respectively.

2.1 Data sources

The following data sources were used:

Ground infrastructure

- Data received from case studies and interviews. This generally consisted of annual utilities breakdown, list of ground vehicles, site facilities list, aircraft movements data and fuels sales data. Data was received from four category 1 airfields, two category 2 airfields, two category 3 airfields and two category 4 airfields.
- York Aviation database of airfields [4]: This database contains details of the facilities at the 394 airfields in the UK, along with the number of resident aircraft and information on whether they are specialists in particular areas of GA. A more complete list of airfields exists, as issued alongside research into a strategic network of GA aerodromes [6], however it does not contain details of the facilities available at these airfields. The airfields omitted from the York Aviation database are small landing strips in fields and commercial airports with GA facilities.
- Chartered Institution of Building Services Engineers (CIBSE) energy benchmarking tool [7]: This tool uses energy data as it becomes available to provide relevant and reliable benchmarks that represent the current trends of energy use in buildings. Predominantly TM46 and Guide F energy benchmarks were used in this report.

Aircraft

- CAA flight hours data [5]: This database details the total hours flown by UK-registered aircraft each year from 2005 to 2020.
- CAA flight movements data [6]: Details of GA flight movements at regional airports and larger airfields is published by the CAA monthly. It contains details of the number of movements (take-offs and landings) and the purpose of the flight (for example, training or Business Aviation).
- Estimation of fuel consumption rates for different aircraft types sourced from the internet. A detailed breakdown is provided in Annex A.1.

Emissions factors

- UK Government Greenhouse Gas Conversion Factors [8]: The government specifies emissions factors for use in greenhouse gas reporting. These include emissions factors for aviation fuel, as well as those associated with the energy consumed by the ground infrastructure.

2.2 Ground Infrastructure

2.2.1 Estimation of emissions using case study data

We estimated ground infrastructure emissions by extrapolating data obtained via case studies up to the whole sector. Case studies were conducted both in person and through telephone interviews, spread across the five airfield categories defined in Section 1.3. A description of the airfields featured in the case studies is given in Section 3.

We focussed our efforts towards Category 1 (four interviews), as these sites have the largest individual carbon footprints. Given the lack of infrastructure present at Category 5 airfields we did not include any case study interviews, instead basing our estimates on observations from other case study sites.

During the case studies we targeted four main areas to help build an accurate carbon footprint for each site and better understand their energy consumption:

- Facilities and infrastructure
- Typical operating day
- Energy consumption and spend
- Environmental opportunities and initiatives

We then used publicly available data [7] to develop the information gathered from sites to estimates of carbon emissions. This included typical energy consumption rates associated with the following areas:

- Office space including air traffic control where relevant
- Ground maintenance vehicles and fire vehicles
- Hangarage
- Aircraft maintenance facilities
- Training facilities
- Runway lighting

2.2.2 Key assumptions

We made the following assumptions in the calculation of the carbon baseline:

- The method we used is based on the assumption that the case studies were representative of their category. Best efforts were made to select a variety of airfields from each category to ensure the sector was most accurately represented as a whole (for example, by ensuring we interviewed airfields with all the facilities detailed in Figure 1.1).
- Where information regarding specific areas of an airfield’s energy consumption was unavailable, we made estimates based on a combination of observations made on site visits, discussions with the airfield managers and CIBSE industry standard benchmark figures [7].

2.2.3 Uncertainty

Uncertainty in our emissions calculations is moderate. The key limitations in our approach giving rise to this uncertainty are described below:

- We visited only a limited number of airfields. By their nature, GA airfields are highly individual and varied. For example, one airfield may specialise in historic aircraft whereas another may specialise in helicopter activities and the ground emissions for each of these will be notably different. Whilst we attempted to use a mix of airfields of different sizes and specialisms, there may be extrapolation errors in our estimates.
- GA airfields can contain numerous businesses, both aviation and non-aviation related. It was not always possible to obtain energy usage data for all GA activities on the airfields visited as part of the case studies. Emissions from these businesses were estimated from industry benchmarks.
- Annual consumption figures obtained from the case studies provide only a snapshot of one year in time. Figures associated with heating, in particular, have potential to vary considerably year-to-year due to weather variations.

2.3 Aircraft

We used two methods to estimate the carbon emissions from GA aircraft. Firstly, we used the CAA flight hours data and fuel consumption rates. Secondly, we calculated emissions based on estimates of volumes of aviation fuel sold from GA airfields, based on data gathered in our case studies.

2.3.1 Estimation of carbon emissions via flight hours data

We calculated the carbon emissions for aircraft by multiplying the total flight hours in a year by the typical fuel consumption for that aircraft type and the emissions factor for the fuel used by that aircraft (either Avgas or Jet A1). This is shown pictorially in Figure 2.1.

The greenhouse gas conversion factors [8] used in this work do not include uplift factors for the non-CO_2 climate change effects of aviation (including radiative forcing). The methodology report that accompanies the greenhouse gas conversion factors [9] suggests a multiplier of 1.9 to take account of these effects, however there is a high level of uncertainty in this multiplier and it is the subject of active research. It should therefore be noted that the carbon emissions presented in this report do not reflect the full climate impact of GA flights. This is consistent with the approach taken in the CCC’s Aviation Summary [10].

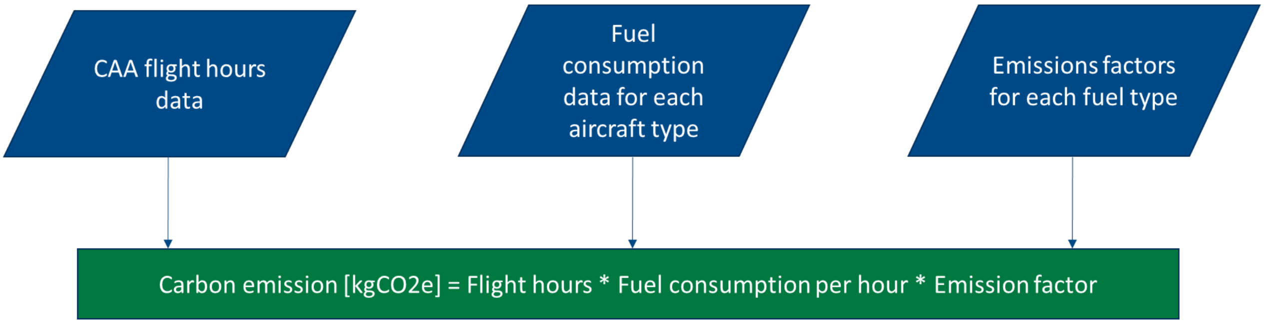

Figure 2.1: Calculation of carbon emissions from GA aircraft via the CAA flight hours data

2.3.2 Estimating carbon emissions via fuel sales

We used an alternative method to estimate carbon emissions from aircraft, by multiplying the estimated volume of aviation fuels sold by the emissions factor for the fuel, as shown in Figure 2.2. The estimated total volume of fuels sold was derived from extrapolation of fuel sales volumes from the case studies. After completing the calculations, we discounted this method because it was clear there were significant gaps in the fuel sales data and extrapolation errors. However, should better fuel sales data become available in future, this method may be useful.

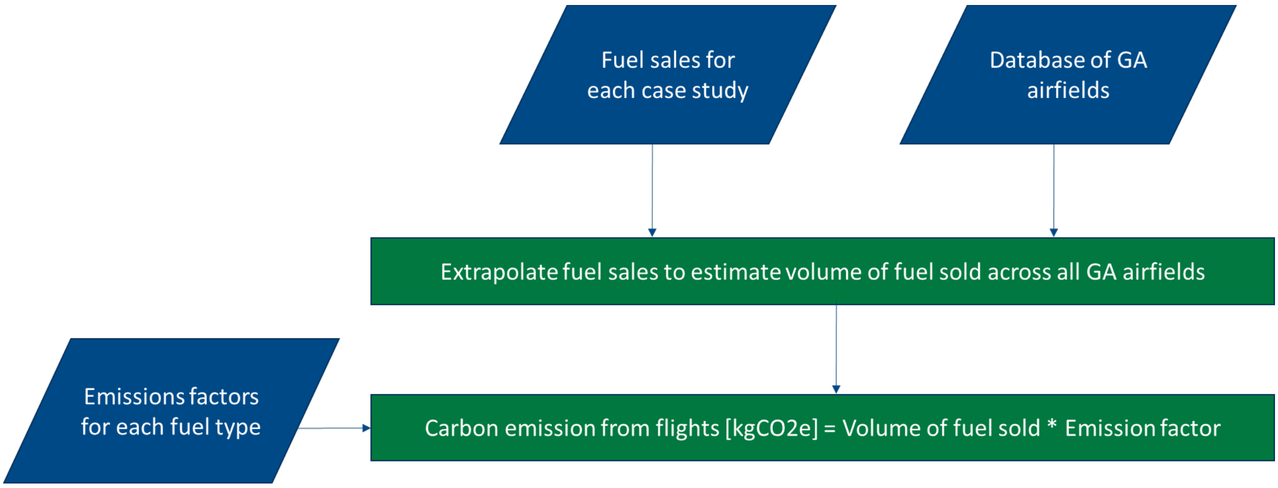

Figure 2.2: Calculation of carbon emissions from GA aircraft via the fuel sales data

2.3.3 Key assumptions in the methodology

We made the following key assumptions as part of this research:

- The CAA flight hours database contains data for both commercial and GA aircraft, but does not explicitly differentiate between GA and scheduled commercial aviation. In order to remove the commercial flights, we assumed that commercial flights were represented by the following aircraft:
  - All Airbus aircraft with weight >50000kg
  - All ‘ATR’ aircraft with weight 15001kg to 50000kg
  - All ‘BAE’ aircraft with weight 15001kg to 50000kg, and all BAE Jetstream aircraft
  - All Boeing 7 series aircraft with weight >50000kg apart from Boeing 727 aircraft

- All Britten Norman BN2B aircraft
- All Canadair aircraft with weight 15001kg to 50000kg, excluding the Canadair CL600 2B16
- All De Havilland DHC6 and DHC8 aircraft
- All Dornier 228 aircraft
- All Embraer EMB145/EMB135 'ERJ' aircraft
- All Lockheed L188 aircraft with weight >50000kg
- All McDonnell Douglas DC-9 aircraft with weight >50000kg
- All Saab 340 and 2000 aircraft

These exclusions are made on a 'best-endeavours' basis, and there may be commercial aircraft that have not been excluded. Similarly, there may be some GA aircraft that have been excluded as a result of that particular aircraft model being used predominately for scheduled commercial purposes (for example, the B-N BN2B is likely used for a mix of scheduled commercial and GA, however the primary usage is scheduled commercial flights).

- Fuel consumption rates were not available for all aircraft used in GA, so we grouped aircraft into categories and applied a representative fuel consumption rate for the group. Our calculation of emissions based on flight hours data is based on estimates of typical fuel consumption rates for the given aircraft types.

2.3.4 Uncertainty

Key sources of uncertainty in the calculations are described below:

- There is considerable uncertainty in published fuel consumption rates. For example, real world fuel consumption is affected by many variables including flight distance, altitude, type of flying activity and meteorological conditions. For example, we observed that the distance aircraft were required to taxi varied considerably depending on the airfield. In addition, whilst the fuel consumption rates we used are representative for the aircraft categories, they do not account for variations within the categories The EMEP/EEA air pollutant emission inventory guidebook 2019 [10] estimates there is an uncertainty of 15-40%.
- The CAA flight hours database is likely to be incomplete for GA aircraft, because some flights may not be recorded, leading to a potential under-estimate of sector emissions. In addition, the database only contains UK-registered aircraft and therefore excludes any flights taken by other aircraft (e.g. N registered aircraft).
- The CAA flight hours database does not contain details on the duration of flights. This affects the number of landings and take-offs (LTOs), and hence the total emissions associated with each flight.

When dealing with uncertainties of this size, it is good practice to apply an uplift factor to reduce the risk of under-estimation. We have applied an uplift of 25% as a round number indicative of the scale of under-estimation we think likely based on our research, in order to provide a conservative estimate of sector-wide emissions.

3 Summary of Case Studies

The case studies conducted through in-person site visits and telephone interviews offered a valuable insight into the both the ground operations and airfield activities of the full range of GA airfields. The main purpose of these case studies was to generate an understanding of energy consumption from all aspects of the airfield sites, which would then be scaled up to all GA airfields as a whole. No two GA airfields are the same and all offer a unique combination of facilities and opportunities. To try and account for this, a spread of airfields from category 1 through to category 4 was chosen for the case studies. Category 5 airfields were not chosen due to their lack of on-site infrastructure and their comparatively small footprint. An overview of each airfields selected is given in Sections 0 to 3.10.

Airfields were contacted by the Department for Transport to invite them to take part in the research. All airfields that responded were interviewed, either in person or via a video conference meeting. A charity donation was made on behalf of each participating airfield to their chosen charity as an incentive to take part.

A typical on-site case study generally took the form of a half-day site visit with the airfield manager while telephone interviews were held via a 1-hour Microsoft Teams call with actual meeting durations varying depending on the complexity of the airfield operations. A discussion guide was prepared in advance in conjunction with DfT and this was followed for all interviews to ensure that the information was obtained in a consistent manner. The key areas of conversation were:

- Facilities and infrastructure on site
- Typical operating day, i.e., better understanding energy intensive operations on site, operating hours and routines associated with ground maintenance and operations.
- Energy consumption/spend
- Environmental projects and initiatives

3.1 Key Findings from Case Studies

We gathered both quantitative data, such as energy and fuel consumption, and qualitative data, such as opinions on the barriers to the decarbonisation of GA. We used this data to inform the decarbonisation solutions described in Section 5.

One key issue highlighted repeatedly from the qualitative part of the project was the ageing infrastructure within the sector. Across the spectrum of airfields, many facilities on site are more than 40 years old with many sites having structures dating back to WWII. This was particularly noticeable in Category 3 and 4 airfields, many of which operate out of temporary building structures and portacabins (for example, Temple Bruer or Old Buckenham), presenting a significant opportunity for energy efficiency upgrades.

As sites increase in complexity so too do the number of facilities, businesses, and stakeholders on site. This consequently led to difficulties obtaining absolute energy consumption figures due to complex metering arrangements (notably at the category 1 airfields such as Brighton Airport or Blackpool Airport). On the other hand, smaller airfields do not have this same issue as many sites have only one electrical supply and no connection to natural gas due their more isolated nature.

Site vehicle fleet sizes vary depending on the size of the airfield. Fleets include ground maintenance vehicles for the mowing of runway strips or sweeping of tarmac surfaces, fire vehicles, portable fuel bowsers and general site transportation vehicles.

Hangars and maintenance areas generally consist of large unheated warehouse type buildings with high bay lighting. Heating from natural gas burners was only observed at the larger Category 1 and 2 airfields.

Many airfields involved in this study were already starting to implement some upgrades with decarbonisation benefits, such as LED lighting, insulation and electrification of heat. Capital expenditure, regulatory limitations and lack of knowledge with regards to decarbonisation were all highlighted as blockers towards helping many of the airfields decarbonise.

3.2 Blackpool Airport (Category 1)

Airfield Operations Summary:

Blackpool airport is at the centre of the Blackpool Airport Enterprise Zone and provides a gateway to the North West's business and leisure destinations. It supports a number of businesses including helicopter flights to oil and gas platforms, the North West Air Ambulance, flying schools and private flights. There are approximately 42,000 flight movements in a year and most of the hangars and buildings are deteriorating due to age and require either maintenance or a complete overhaul.

Decarbonisation opportunities and challenges:

The airport has an aim to achieve Net Zero of ground operations by 2050. This includes replacing old hangars with more energy-efficient versions, moving the air traffic control building to improve operational efficiency, installing solar panels, and switching to LED lighting. Funding issues are a key challenge for the airfield due to the large amount of resource spent on short term maintenance of existing aging facilities. Due to planning constraints, there is limited opportunity for solar panels on site, but this is still being considered. Works are estimated to cost £4-5 million for new facilities to replace the old. They are looking to improve their current fuel tanks and will explore how to cater for both electric and hydrogen aircraft provided there is the appropriate demand. Offshore windfarm developers have also approached the airport and are exploring how they can provide the airport with green energy as well.

	Related Infrastructure	Response
Ground infrastructure	Buildings	1x Control tower 4x Flight schools 11x Hangar facilities housing multiple businesses as well as North West Air Ambulance 1x Office block
	Runways	1,869m tarmac 974m tarmac
	Fuel Storage	Avgas and JetA1 available
Aircraft	Common Aircraft Type	Light training aircraft, light twins, helicopters, corporate jets.
	Based Aircraft	Approximately 100 based aircraft
	Purpose of Flights	75% aero club, training, or private. 5% business and corporate 15% offshore helicopters
	Fuel Availability/Type	Avgas and Jet A1
Vehicles	Maintenance vehicles	3x Fire and rescue vehicles 2x Tractors for grassland management 1x diesel ops vehicle
	Other Site Vehicles	None
Energy Consumption	Electricity	233,950 kWh (equivalent to 60 tCO_2e)
	Heating fuel	72,000 kWh (equivalent to 14 tCO_2e)
	Diesel (site vehicles)	25,000 Litres (equivalent to 65 tCO_2e)
	Petrol (site vehicles)	None

3.3 Brighton City Airport (Category 1)

Airfield Operations Summary:

Brighton City (Shoreham) Airport is located approximately two kilometers west of Shoreham-by-Sea, in the Adur district of West Sussex, England. Founded in 1910, it is the oldest airport in the UK and the oldest purpose-built commercial airport in the world still in operation. The main terminal building is a Grade 2 listed 1970s art deco building and there are ~46,000 flight movements in a year made up of a mixture of training and private aeroplane and helicopter activities. The freehold belongs to the local council, but the site has been split in two, with one part allocated for airfield related activities and the other for other buildings on site. There is a mains gas supply to site for heating of the terminal building and office space and there are no heated hangars on site. The predominant sources of ground infrastructure emissions are electricity, natural gas and ground vehicle fuel consumption.

Decarbonisation opportunities and challenges:

The listed status of the terminal building presents challenges for renovation. However the building also presents significant opportunities to improve energy efficiency and reduce the electricity and natural gas. These range from simple insulation and LED lighting upgrades to the potential utilisation of the flat roof and hangar roof areas for solar panels. Due to the capital expenditure required for these upgrades, they are not currently a priority for the airport.

Interest was expressed with regards to electric aircraft, however they commented that further regulation is needed to account for safety and battery range. Due to the small scale of operations and low demand, offering Sustainable Aviation Fuels (SAF) is not currently viable.

	Related Infrastructure	Response
Ground infrastructure	Buildings	Main terminal building (1970s) 1x fire station 1x restaurant/café within the main terminal building 1x large hangar store 10+ large hangar buildings/industrial units housing businesses on site
	Runways	1,036m tarmac 799m grass

		408m grass 700m grass
	Fuel Storage	Avgas and Jet A1 are stored in an 18,000L bowsers, there is also a diesel store on site for site maintenance vehicles.
Aircraft	Common Aircraft Type	Fixed wing aircraft. Majority being single engine piston or twin engine piston. Helicopters
	Based Aircraft	55 - 70 private/training aircraft
	Purpose of Flights	Flight training Private flying Business flights
	Fuel Availability/Type	Avgas 100LL and Jet A1
Vehicles	Maintenance vehicles	3x fire engine 2015 Isuzu pick up 1x Scania fire truck 1x Site pick-up truck 1x Tractor 2x passenger transport vehicles 1x quad bike
	Other Site Vehicles	None
Energy Consumption	Electricity	226,760 kWh (equivalent to 58 tCO_2e)
	Natural Gas	187,200 kWh (equivalent to 36 tCO_2e)
	Diesel (site vehicles)	15,000 Litres (equivalent to 39 tCO_2e)
	Petrol (site vehicles)	None

3.4 City Airport (Manchester Barton) (Category 2)

Airfield Operations Summary:

City Airport is located just west of Manchester in Barton-upon-Irwell, Greater Manchester. It has a dedicated heliport and its location means that it is often used for business travel to local attractions such as Old Trafford Football Stadium and Cricket Ground. It is also a base for police helicopters and air ambulance who use portable lighting when using the airfield at night. There are ~47,500 flights in a year, of which ~9,500 are helicopter flights. About 50% of the flight movements are associated with flight schools.

Decarbonisation opportunities and challenges:

There is great potential for solar panels on site which is currently being investigated. This was however previously rejected due to the complexities with connecting it with the national grid.

They are in conversation with developers of eVTOL drones about developing 'vertiports' and are considering electric car charging facilities for visitors. They are interested the practicalities of electric planes and use by their flight schools on site. Financial barriers and the implications of charging times on the number of flights a flight school can do in a day means they are currently not considered feasible for the level of activity at City Airport.

The control tower on site was built in 1933 and is a listed building presenting challenges for upgrades. There is also a portacabin adjacent to the control tower and the heliport, which was built in the 40/50s, with office buildings added in the 80/90s. Many of the buildings on site would benefit from energy efficiency upgrades due to their age. However, this is not a financial priority for the airport at present.

	Related Infrastructure	Response
Ground infrastructure	Buildings	3x Hangars 1x Maintenance hangar which is heated by an oil burner system 1x Heliport Maintenance facilities 5x Flight schools Office space 1x Café
	Runways	532m grass 621m grass 518m grass 400m grass
	Fuel Storage	Avgas, Jet A1 and Diesel are all stored on site.
Aircraft	Common Aircraft Type	Light aircraft, microlights (both types), helicopters, occasional PC12 Single Engine

		Turboprops.
	Based Aircraft	90 including 6 helicopters
	Purpose of Flights	Private flying, visitors, training and business activities
	Fuel Availability/Type	Avgas and Jet A1
Vehicles	Maintenance vehicles	1x Tractor 2x fire vehicles (4x4 Landrover) 1x ops vehicle (4x4 Landrover) 1x flatbed truck
	Other Site Vehicles	None
Energy Consumption	Electricity	93,601 kWh (equivalent to 24 tCO_2e)
	Heating fuel	16,500 kWh (equivalent to 3 tCO_2e)
	Diesel (site vehicles)	10,000 Litres (equivalent to 26 tCO_2e)
	Petrol (site vehicles)	None

3.5 Derby Airfield (Category 3)

Airfield operations summary:

Derby Airfield is a private family run business and is the only CAA licensed aerodrome in Derbyshire. It offers flight training and aircraft maintenance alongside more general airfield operations. There are ~18,000 flight movements in a year with a significant proportion of these flights coming from training activities. The airfield has no gas supply meaning the predominant sources of ground emissions are electricity consumption and ground vehicle fuel consumption.

Decarbonisation opportunities and challenges:

The airfield has recently been connected to a 3-phase electricity supply and has investigated installing solar panels on the roofs of hangars with the possibility of battery storage. It was deemed that a 50-70kW system could be installed on hangar roof space, but solar glare was a potential restriction that needed to be considered. There is currently no official decarbonisation strategy for the aerodrome. However small steps such as a progressive upgrade to LED lighting site-wide are being made. Financial limitations are the main barrier to the progression of larger decarbonisation projects.

Interest was expressed with regards to electric aircraft. However they feel further regulation is needed to account for safety and battery range.

	Related Infrastructure	Response
Ground infrastructure	Buildings	Aerodrome offices, reception and flight school meeting rooms are housed within 3 portacabin blocks. All are electrically heated with no gas connection and are 30+ years old showing signs of age. 1x old hangar (~80 years old) 1x newer hangar (2018) 1x hangar under construction 1x maintenance hangar
	Runways	547m grass 453m grass 594m grass
	Fuel Storage	Small bowser with solar-powered pump for regular plane refiling with a larger mobile bowser used as the main Avgas fuel store
Aircraft	Common Aircraft Type	Fixed wing aircraft. Approximately 90% single engine piston, with the remainder twin engine piston.
	Based Aircraft	35 private aircraft 12 training aircraft
	Purpose of Flights	Approximately 65% flight training and 35% private flying.
	Fuel Availability/Type	Avgas 100LL
Vehicles	Maintenance vehicles	2x fire vehicles 5x tractors available for runway maintenance 1x Digger 1x Dumper truck
	Other Site Vehicles	None

Energy Consumption	Electricity	70,075 kWh (equivalent to 18 tCO_2e)
	Natural Gas	None
	Diesel (site vehicles)	3,684 Litres (equivalent to 10 tCO_2e)
	Petrol (site vehicles)	None

3.6 Great Oakley Airfield (Category 4)

Airfield Operations Summary:

Great Oakley Airfield is based on a farm on the east coast of England close to Harwich in Essex. A lot of the facilities and vehicles are common to both the farm and the airfield. The airfield has a large amount of aircraft storage for its size with one building that is leased to another firm to maintain gliders. The airfield buildings are not connected to the gas mains and the airfield is used by private members and visitors making up ~1800 movements per year.

Decarbonisation opportunities and challenges:

Despite the small site, the airfield is well advanced with decarbonisation measures. Most notably the farm has solar panels on site and an electric charging point used by an electric Pipistrel aircraft that regularly visits. They are next investigating a battery storage system to make better use of solar energy throughout the winter months.

There was a recent investment upgrade from a 3m to a 5m wide mower which has reduced airfield cutting time from 5 to 3 hours (in the summer this could be a daily activity). This has reduced fuel consumption. No hangars are heated and there are very basic clubhouse facilities which would benefit from energy efficiency upgrades; however this is not regularly used.

	Related Infrastructure	Response
Ground infrastructure	Buildings	1x Clubhouse 3x Hangars
	Runways	600m grass 850m grass
	Fuel Storage	There is no fuel store on site
Aircraft	Common Aircraft Type	All fixed wing single engine piston aircraft and gliders.

	Based Aircraft	20 private aircraft
	Purpose of Flights	Private flying
	Fuel Availability/Type	None
Vehicles	Maintenance vehicles	1x Tractor
	Other Site Vehicles	None
Energy Consumption	Electricity	11,920 kWh (equivalent to 3 tCO_2e)
	Natural Gas	None
	Diesel (site vehicles)	1,200 Litres (equivalent to 3 tCO_2e)
	Petrol (site vehicles)	None

3.7 IWM Duxford (Category 1)

Airfield Operations Summary:

Duxford Airfield is located south of Cambridge and specialises in historic aircraft. The airfield is owned by the IWM and is the site of the Imperial War Museum Duxford and the American Air Museum. Due to the antique nature of the planes, the hangars need to be heated to a minimum of 13°C throughout the year. There are ~45,000 flight movements a year, with 40% of the movements being from resident aircraft. Duxford hosts several air shows throughout the year.

Decarbonisation opportunities and challenges:

There is currently no official decarbonisation strategy for the airfield, however a progressive upgrade to LED lighting is being implemented. Financial limitations are the main barrier to the progression of larger decarbonisation projects such as roof-mounted solar panels. The airport already has EV charging available as all museum vehicles on site are electric.

There are two 100-year-old Belfast hangars on site, used for the maintenance and storage of aircraft. These are both listed buildings so present challenges with regards to renovation works. The heating of these large, uninsulated spaces throughout winter with large oil burners is highly inefficient.

As most aircraft on site are of historical significance, this makes retrofit to more efficient engine parts less suitable, so opportunities to reduce the aircraft emissions are limited.

	Related Infrastructure	Response

Ground infrastructure	Buildings	2x Cafes 1x Restaurant 2x Flying schools 1x Control room and office (mixture of gas central heating and electric heating) 2x 100-year-old Belfast hangars 1x 1940s hangar
	Runways	1,503m tarmac 880m grass
	Fuel Storage	Avgas and JetA1 available
Aircraft	Common Aircraft Type	Light training aircraft, light twins, helicopters, corporate jets.
	Based Aircraft	70 aircraft
	Purpose of Flights	40% of movements from home based and private flying with other from visiting aircraft and military training
	Fuel Availability/Type	Avgas and Jet A1
Vehicles	Maintenance vehicles	2x Fire and rescue vehicles 2x Tractors for grassland management 1x diesel ops vehicle
	Other Site Vehicles	None
Energy Consumption	Electricity	178,400 kWh (equivalent to 45.6 tCO_2e)
	Heating fuel	688,000 kWh (equivalent to 131 tCO_2e)
	Diesel (site vehicles)	19,000 Litres (equivalent to 49 tCO_2e)
	Petrol (site vehicles)	None

3.8 London Elstree Aerodrome (Category 1)

Airfield Operations Summary:

London Elstree is a 24-hour aerodrome, servicing those wanting fast access into London. It offers aircraft maintenance. There are 76,000 movements a year, about 20% of which are helicopters. Newer office buildings on site have LED lighting and are heated electrically using a heat pump.

Decarbonisation opportunities and challenges:

There is not currently a formal decarbonisation plan in place on site. However, steps to reduce energy consumption on site are being taken with progressive upgrades from old aging, inefficient infrastructure. Solar panels have been investigated at the airfield, but this has not been pursued due to issues with planning. Investigations are also ongoing into running eVTOL aircraft to Heathrow. The airfield has previously stocked SAF, but it was not economic to continue due to low demand.

Interest was expressed with regards to electric aircraft. However they feel further regulation is needed to account for safety and battery range.

	Related Infrastructure	Response
Ground infrastructure	Buildings	1x Cafe 8x Flying schools 1x Maintenance facility 1x Office space (new buildings have LED lighting and are heated via a heat pump) 30 - 45k sqft of old hangars (50 to 70 years old) 2 newly built hangars
	Runways	650m tarmac
	Fuel Storage	Avgas and JetA1 available
Aircraft	Common Aircraft Type	Single engine piston aircraft (64%), twin engine piston aircraft (6%), turbine aircraft (4%), piston engine helicopters (18%), turbine engine helicopters (8%).
	Based Aircraft	150 aircraft
	Purpose of Flights	Private 5%

		Training 60% Business 35%
	Fuel Availability/Type	Avgas and Jet A1
Vehicles	Maintenance vehicles	2x fire vehicles 1x Heavy tug 1x Small tug 1x Tractor for lawn maintenance 1x diesel ops vehicle
	Other Site Vehicles	None
Energy Consumption	Electricity	305,550 kWh (equivalent to 78 tCO_2e)
	Heating fuel	144,000 kWh (equivalent to 27.6 tCO_2e)
	Diesel (site vehicles)	15,000 Litres (equivalent to 39 tCO_2e)
	Petrol (site vehicles)	None

3.9 Old Buckenham Airfield (Category 3)

Airfield Operations Summary:

Old Buckenham is located southwest of Norwich. Its services include flight training, an on-site museum, aircraft maintenance, aircraft storage and a small cafe. It is also home to an on-site electric aircraft development site, which includes all the required system components to assess the potential for renewable flight operations (from flight to battery storage). There is a flight club based on site and approximately 20,000 movements per year with a quarter of these from training activities. Office areas use an oil heating ststem while all other facilities are connected to the electricity grid only. Hangars are not heated. The café, training facilities and museum are electrically heated.

Decarbonisation opportunities and challenges:

Old Buckenham is well advanced with decarbonisation measures and is relatively well prepared for future change towards electric aircraft. It was the first in the UK to install and commission an electric aircraft charging point, available for public use. The charging station is powered by a 50kW solar roof and they have plans to install another 5 such stations on site.

There are further opportunities to improve energy efficiency on site, by upgrading aging infrastructure, most of which is temporary portacabins and corrugated iron WWII buildings.

Further options being investigated include the use of automated electric mowers for cutting the airfield strips. However these mowers have not yet been approved by the CAA.

	Related Infrastructure	Response
Ground infrastructure	Buildings	1x Flying school 6x Hangars for storage/maintenance 3x WWII museum/storage hangars 2x portacabins for office space
	Runways	780m tarmac 460m grass 430m grass
	Fuel Storage	Fuel is also sold on site through a 1930s 13,500 litre mobile bowser
Aircraft	Common Aircraft Type	All fixed wing 4 to 2 seater Cessna aircraft.
	Based Aircraft	40 Based aircraft 3 training aircraft and all others privately owned. Aircraft on site are generally 4 to 2 seater Cessna
	Purpose of Flights	Private flying, visitors and training
	Fuel Availability/Type	Avgas
Vehicles	Maintenance vehicles	2x Tractor 2x London taxi 2x Buggy (unleaded)
	Other Site Vehicles	None
Energy Consumption	Electricity	21,910 kWh (equivalent to 6 tCO_2e)
	Oil	3,660 kWh (equivalent to 1 tCO_2e)
	Diesel (site vehicles)	700 Litres (equivalent to 2 tCO_2e)
	Petrol (site vehicles)	300 Litres (equivalent to 0.6 tCO_2e)

3.10 Solent Airport (Category 2)

Airfield Operations Summary:

Solent Airport, formerly Daedalus Airfield, is owned by Fareham Borough Council and operated by Regional & City Airports (RCA), which may introduce commercial operations soon. Facilities at Solent Airport include a newly CAA licensed aerodrome with a new runway surface, aircraft refuelling, on-site engineering, hangarage, outdoor parking, along with flying tuition and flight experiences.There are two maintenance companies on-site, along with four flying schools.

The airport has both WWII and new infrastructure with partial gas central heating in office terminal buildings. There is no lighting on the runway, but they are looking to install this soon to facilitate an increase in night flying and more chartered flights. There are approximately 35,000 movements per year, with 50% from flying schools and 10% from chartered aircraft.

Decarbonisation opportunities and challenges:

The control tower was built in 1943, with some of the space being refurbished in 2018 (installing modern lighting and gas central heating). The older parts of the building have no heating and would benefit from further renovations.

The airfield is exploring the implementation of electric aircraft charging points to facilitate crossings to France and is looking to switch Avgas from UL100 to UL91 but is experiencing challenges around reliable supply.

There is an area of land earmarked for solar panels and both RCA and the council are both working on decarbonisation strategies. The council is switching to electric vehicles and is also looking at options to reduce emissions from the airfield.

	Related Infrastructure	Response
Ground infrastructure	Buildings	1x Control tower with café 4x Flight schools 3x WW2 hangars 2x New hangars (less than 4 years old)
	Runways	1,298m tarmac 670m grass
	Fuel Storage	Avgas – tank has 20,000L capacity. JetA1 – tank has 30,000L capacity.

Aircraft	Common Aircraft Type	Smallest aircraft are De Havilland DH60G Gipsy Moth, Largest is Britten-Normal Islanders and T -There are some rotary aircraft based on site, and lots of business rotary aircraft use the airfield including the air ambulance BM700.
	Based Aircraft	20 based aircraft
	Purpose of Flights	Private flying, visitors, training and business activities
	Fuel Availability/Type	Avgas and Jet A1
Vehicles	Maintenance vehicles	1 x diesel tractor for maintaining the gas strip (ran by the local council). 2x diesel fire support vehicles: 1 TACR2 range rover, 1 Mercedes ex fire vehicle. 1x diesel ops vehicle (ford ranger). 1x diesel corporate minibus (8-seater) – used mainly for airfield tours. 1x diesel Jet A1 fuel bowser.
	Other Site Vehicles	None
Energy Consumption	Electricity	201,960 kWh (equivalent to 51 tCO_2e)
	Heating fuel	60,000 kWh (equivalent to 11.5 tCO_2e)
	Diesel (site vehicles)	15,000 Litres (equivalent to 39 tCO_2e)
	Petrol (site vehicles)	None

3.11 Temple Bruer Airfield (Category 4)

Airfield Operations Summary:

Temple Bruer is a private airfield primarily used as a private members' flying club just south of Lincoln. With only 15 members (12 active), this small operation has 3 hangars and a mobile home clubhouse. There are no fixed office spaces and no additional on-site businesses. The site has no gas connection. Electricity is used for heating and lighting in the clubhouse, lighting in the hangars and small electric power for basic kitchen facilities.

Decarbonisation opportunities and challenges:

Interest was expressed with regards to electric aircraft, and they are exploring ground/roof mounted solar panels to facilitate this and cover on site electrical consumption. They are aware of the proof-of-concept electric aircraft but they feel further regulation is needed to account for safety and battery range.

They feel there are many challenges with the uptake of SAF and the challenges with establishing a consistent supply.

	Related Infrastructure	Response
Ground infrastructure	Buildings	1x Mobile home clubhouse 2x Hangars built ~25 years ago. 1x Hangar built ~10 years ago.
	Runways	500m grass
	Fuel Storage	There is no fuel store on site
Aircraft	Common Aircraft Type	All fixed wing single engine piston aircraft.
	Based Aircraft	15 private aircraft
	Purpose of Flights	Private flying
	Fuel Availability/Type	None
Vehicles	Maintenance vehicles	1x Tractor
	Other Site Vehicles	None
Energy Consumption	Electricity	13,497 kWh (equivalent to 3 tCO_2e)
	Natural Gas	None
	Diesel (site vehicles)	4,000 Litres (equivalent to 9 tCO_2e)
	Petrol (site vehicles)	None

4 Carbon Baseline for General Aviation

The following section presents the carbon emissions for the GA infrastructure (Section 4.1) and aircraft (Section 4.2). The main findings are summarised in the figure below showing that the overall GA sector emits an estimated 795 kt CO_2e with 2% (15.5kt CO_2e) attributed to the ground infrastructure and operations and 98% (779 kt CO_2e) attributed to aircraft flights and ground movements. The aircraft emissions include an uplift of 25% to account for uncertainty in the calculation (see Sections 2.3.4 and 4.2.1). The uncertainty in the ground infrastructure emissions is discussed in Sections 2.2.3 and 4.1.1.

Table 4.1: Summary of GA emissions

Ground Infrastructure ($ktCO_2e$)	
Ground vehicles	5.8
Buildings	4.5
Hangars	2.6
Maintenance	2.2
Training	0.3
Runway lighting	0.2
Total	**15.5**

Aircraft ($ktCO_2e$)	
Flights	708
Ground movements	71
Total	**779**

4.1 Ground Infrastructure

4.1.1 Breakdown by category

A total emissions breakdown by category of airfield is presented in Figure 4.1 with the associated figures tabulated in Table 4.2. Category 1 airfields represent just 11% of known UK airfields and account for 42% of the emissions, with Category 2 airfields representing 16% of UK airfields and accounting for 38%. Categories 3-5 account for 73% of known UK airfields but collectively only represent the remaining 20% of ground infrastructure emissions.

Category 1 is the only category in which ground vehicle emissions are not the highest source of emissions. Instead, most emissions arise from the electricity consumption and fossil fuel heating of buildings. This is due to these larger airfields being able to support a much greater diversity of activities and businesses, and larger buildings with a greater heating demand. This was particularly noticeable from the case studies at the category 1 airfields of Brighton City and Blackpool airport that have significant hangarage facilities capable of supporting over more than 5 businesses on site each.

Category 3, 4 and 5 airfield emissions are dominated by emissions from vehicles, including those used for runway grass cutting or hard runway sweeping, people movement and fire vehicles. The data shows that 77% of ground emissions from these airfields come from ground vehicles with the next largest emissions sources being buildings and hangarage. This was highlighted in case study visits where smaller airfields such as Great Oakley and Temple Bruer have less facilities on site however the maintenance of the runways is very similar to comparably larger airfields.

Whilst there is reasonable confidence in the estimation of the emissions from category 2 to 5 airfields, there is greater uncertainty in the emissions from category 1 airfields. This is due to the more varied operations and activities at these airfields (for example, City Airport hosted a busy heliport, whereas Blackpool Airport supports helicopter flights to oil and gas platforms). The total emissions presented in Table 4.2 are therefore likely to be an under-estimate of the ground infrastructure emissions.

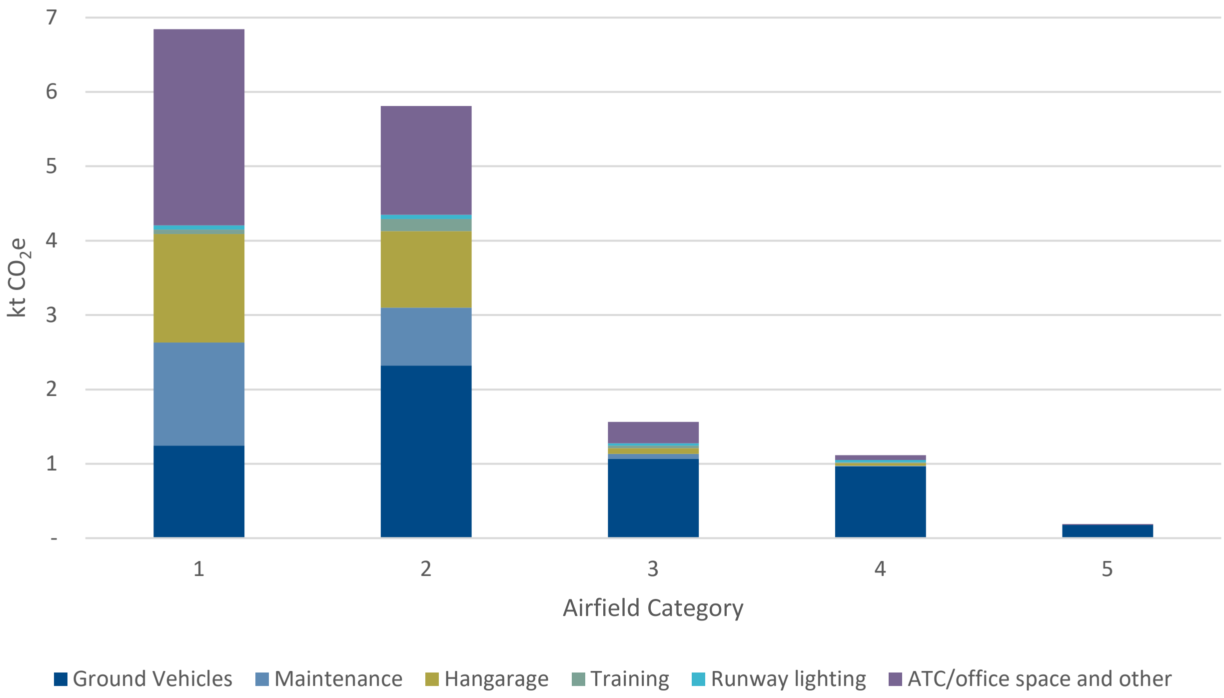

Figure 4.1: Ground infrastructure emissions by airfield category

Table 4.2: Ground infrastructure emissions by airfield category

Category	Ground Vehicles	Maintenance	Hangarage	Training	Runway lighting	ATC, Office space and other terminal buildings	Total (kt CO2e)
1	1.2	1.4	1.5	0.1	0.1	2.6	**6.8**
2	2.3	0.8	1.0	0.2	0.1	1.5	**5.8**
3	1.1	0.1	0.1	0.0	0.0	0.3	**1.6**
4	1.0	0.0	0.0	0.0	0.0	0.1	**1.1**
5	0.2	0.0	0.0	0.0	0.0	0.0	**0.2**
Total (kt CO2e)	**5.8**	**2.2**	**2.6**	**0.3**	**0.2**	**4.5**	**15.5**

4.1.2 Breakdown by activity

Figure 4.2 and Table 4.3 shows the emissions broken down by activity, showing electricity consumption and ground vehicle emissions as the two largest sources, accounting for 35% and 37% of emissions respectively. It was observed from the case studies that a significant amount of ground vehicle emissions arise from airfield maintenance such as grass runway mowing and routine checks, bird scaring and sweeping on tarmac runways. Electricity from the buildings on site generally came from lighting and small power items such as IT equipment and kitchen equipment with some smaller airfields not connected to the gas mains using electric heating.

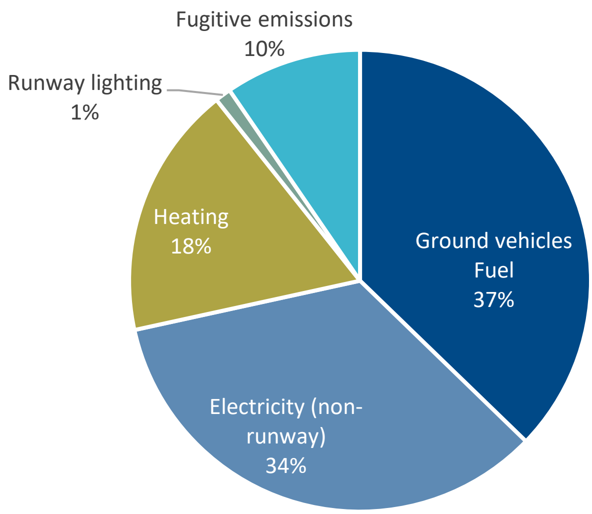

Figure 4.2: Ground infrastructure emissions by activity

Table 4.3: Ground infrastructure emissions by activity

Infrastructure	kt CO2e
Ground vehicles (fuel)	5.8
Electricity (non-runway)	5.3
Heating	2.8
Runway lighting	0.2
Fugitive emissions	1.5

4.1.3 Breakdown by building type

Emissions from airfield buildings and hangars include electricity-related emissions, fossil fuel heating-related emissions, and fugitive emissions of refrigerant gases. The relative proportions of these varies significantly depending on the function of the building. Figure 4.3 shows the breakdown of building-related emissions by building type. The majority of the energy use in hangars is electricity whereas, the energy use in maintenance and office space is more evenly split between electricity and gas.

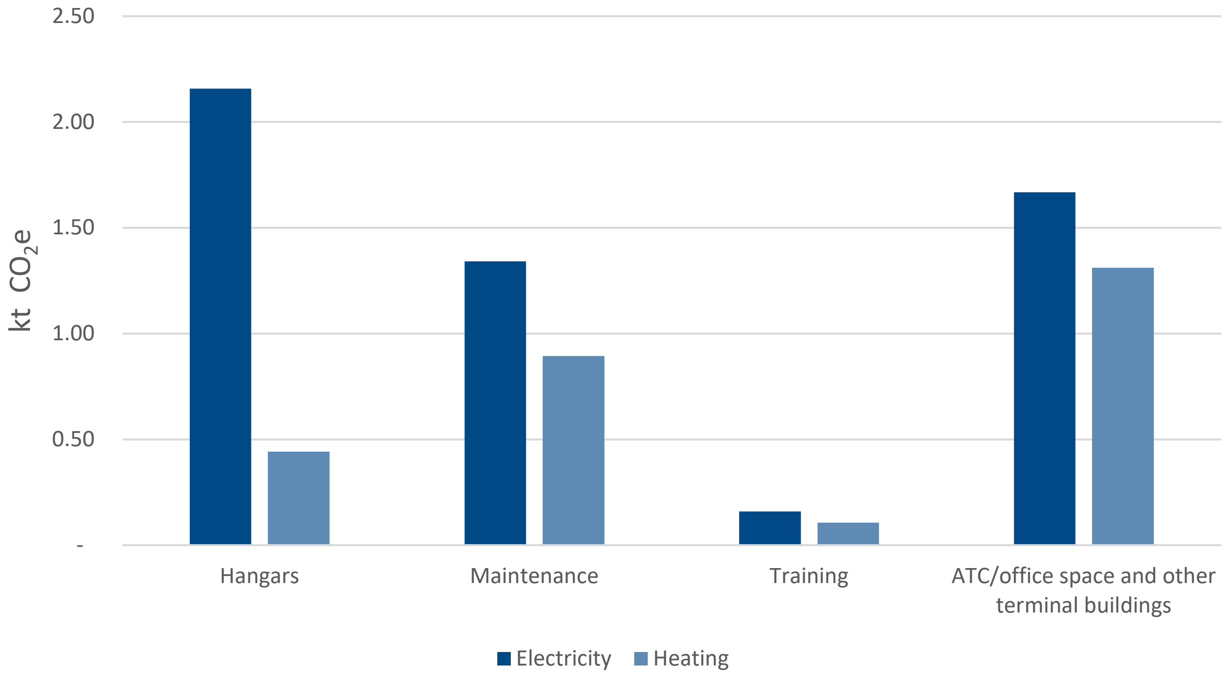

Figure 4.3: Ground infrastructure building-related emissions by building type

In general, airfields in Categories 1-4 have hangars with electric lighting, but only Categories 1 and 2 have heated hangars. This explains the large electricity consumption relative to heating for hangar spaces as there are more unheated hangars than heated across the sector as a whole. The large proportion of hangars without heating is also indicative of their operation where they are used as storage facilities and heating is not required.

There are fewer maintenance facilities relative to the number of hangars hence the lower emissions. Larger maintenance facilities at Category 1 and 2 airfields have a greater heating demand.

Training facilities, ATC, office space and other buildings generally contain small electrical equipment and basic kitchen facilities, and are often heated by natural gas central heating. As would be expected due to activity levels, there was a great variety in ATC activities from category 1 airfields such as Brighton City Airport that has significant IT electrical equipement to aid these activities, down to category 3, 4 and 5 airfields such as Derby and Great Oakfield which have much more manual analog systems with basic radio and tracking facilities.

4.2 Aircraft

In 2019 we estimate that there were emissions of 708 kt CO_2e from GA aircraft whilst in-air. For comparison, it is estimated that scheduled domestic commercial flights within the UK 2019 produced ~1500 kt CO_2e [10]. Figure 4.4 and Table 4.4 present the total carbon emissions from GA aircraft over time. Note that these results include an uplift of 25% to account for uncertainties in the method (see Section 2.3.4). The majority of the emissions come from fixed-wing, with the next largest contributor being helicopters. Figure 4.4 also presents the breakdown of the ‘all other aircraft’ emissions by aircraft type. Balloons and microlights are the next largest emitters. Figure

4.5 and Figure 4.6 present a breakdown of the 2019 carbon emissions by aircraft type and fixed-wing aircraft weight. 68% of the carbon emissions were from fixed-wing landplanes, with 62% of these emissions being from fixed-wing landplanes in the 15,001kg to 50,000 kg weight category.

There are also ground emissions associated with aircraft, for example, when they are taxiing to the runway. The exact number of LTOs is unknown (see Section 2.3.4), however we estimated this at 10% of the flight emissions [12] (the sensitivity in Section 4.2.1 also supports this estimate). In 2019, we therefore estimate ground emissions from GA aircraft were ~71 kt CO_2e.

There is a noticeable reduction in the total carbon emissions from GA aircraft over time. This is due to a reduction in the number of hours flown by fixed-wing aircraft. On the other hand, emissions from helicopters have remained relatively constant (apart from a small reduction in 2020 concurrent with the Covid-19 pandemic). The other types of GA aircraft make a comparatively small contribution to the sector's emissions but note that compared to other sectors (e.g. road transport) the emissions from these aircraft are still very high. Carbon emissions from GA aircraft are somewhat seasonal as there are generally more flights in the summer months than in the winter (see Figure 1.6).

Figure 4.7 presents the carbon emissions from fixed-wing subdivided by weight. This shows that the majority of the carbon emissions from fixed-wing landplanes are those in the 15,001 – 50,000kg weight category. In contrast, the majority of hours flown were by lighter aircraft in the 751 – 5,700 kg category (Table 4.5).We estimate that these comprise predominantly of aircraft used for Business Aviation. From Figure 1.5 we estimate that a significant proportion of the remaining aircraft emissions are those associated with aero club or private flying.

4.2.1 Sensitivity Studies

We assessed the extent to which our estimates were sensitive to assumptions about average flight duration, taking into account LTOs. We tested this by adding an additional LTO factor to each flight using the thrust settings and time spent in mode in Table 2.2 of the EMEP/EEA air pollutant emission inventory guidebook 2019 [11]. Figure 4.8 presents the results of this sensitivity for fixed-wing aircraft, showing a variation of up to 10% in emissions calculations depending on assumed flight length (when a flight duration of 1 hour is assumed). This is small compared to the uncertainty in the fuel consumption data (up to 40%). If the fuel consumption of all aircraft were 40% higher, then the estimated carbon emissions from aircraft would increase by 40%. However, this would be a maximum. To produce a conservative yet realistic estimate we applied an uplift of 25% to the estimate of carbon emissions from GA aircraft.

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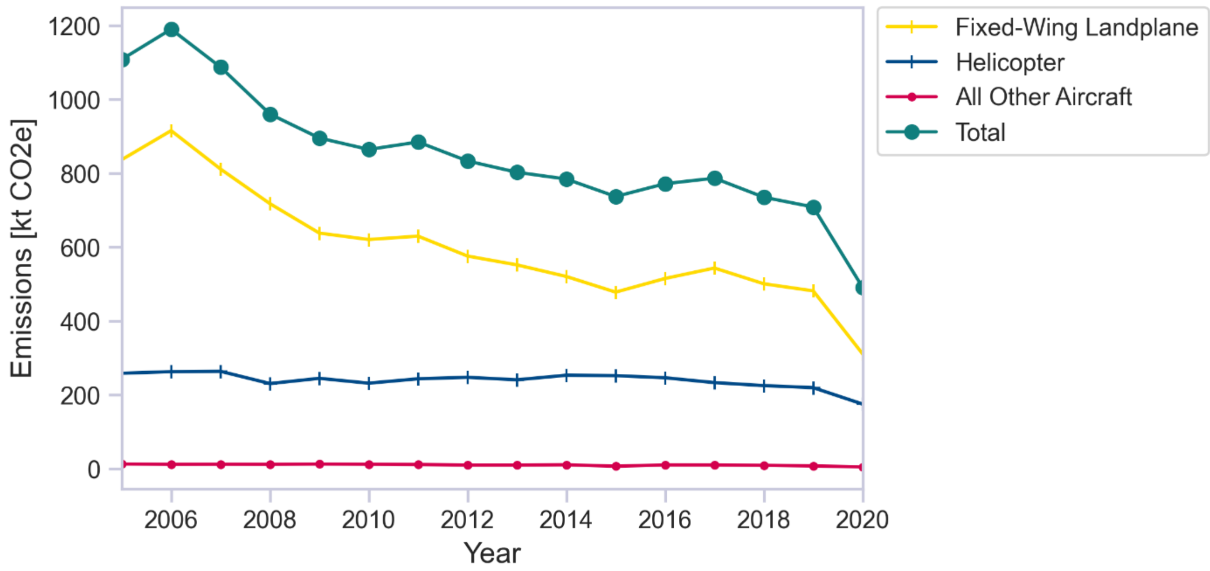
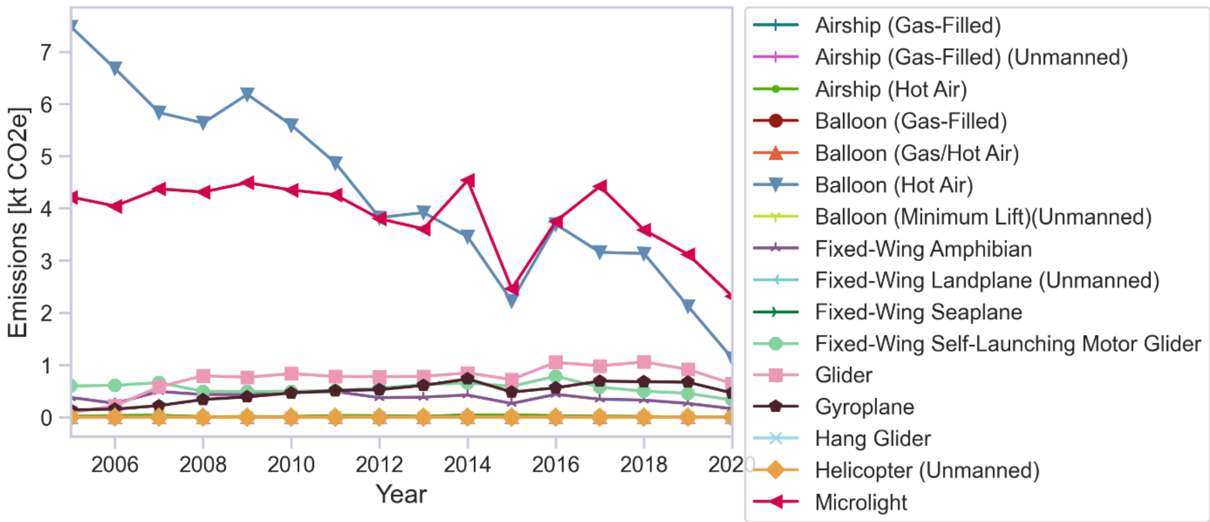
Table 4.4: Estimation of carbon emissions from GA aircraft

Year	Fixed-wing landplane (kt CO_2e)	Helicopter (kt CO_2e)	All other aircraft (kt CO_2e)	Total (kt CO_2e)
2005	837	259	13	1108
2006	915	263	12	1190
2007	811	264	12	1087
2008	718	231	12	960
2009	638	245	13	895
2010	620	232	12	864
2011	630	243	11	884
2012	576	247	10	833
2013	552	241	10	802
2014	520	253	11	784
2015	478	252	7	737
2016	515	246	10	772
2017	543	233	10	787
2018	501	225	9	735
2019	481	219	8	708
2020	311	175	5	491

Note, the emissions in 2020 were significantly lower due to the impact of the Covid-19 pandemic.



(a)



(b)

Figure 4.4: Carbon emissions by aircraft type (a) for all aircraft and (b) for aircraft except fixed-wing landplane and helicopter (manned flights)

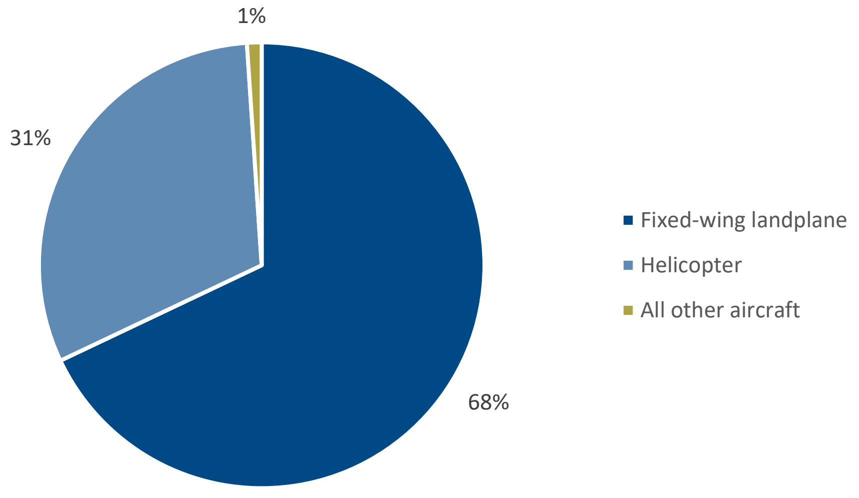


Figure 4.5: Proportion of total emissions from different types of GA aircraft in 2019

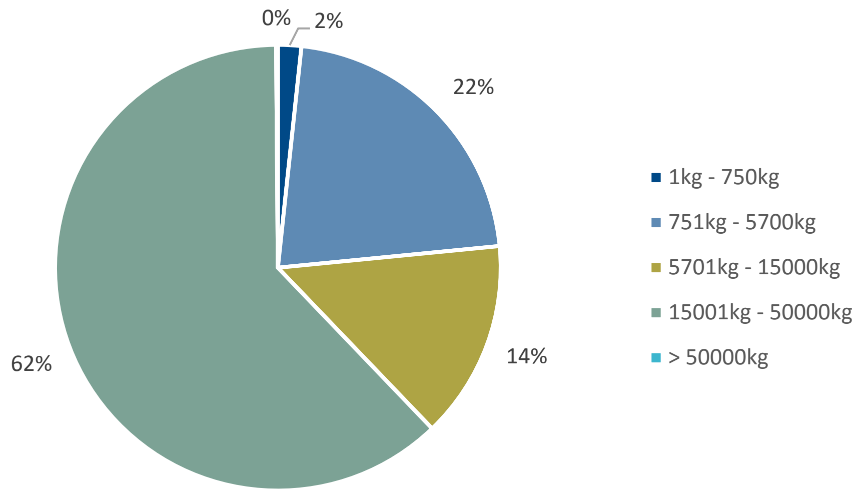


Figure 4.6: Proportion of emissions from fixed-wing aircraft in 2019, sub-divided by aircraft weight

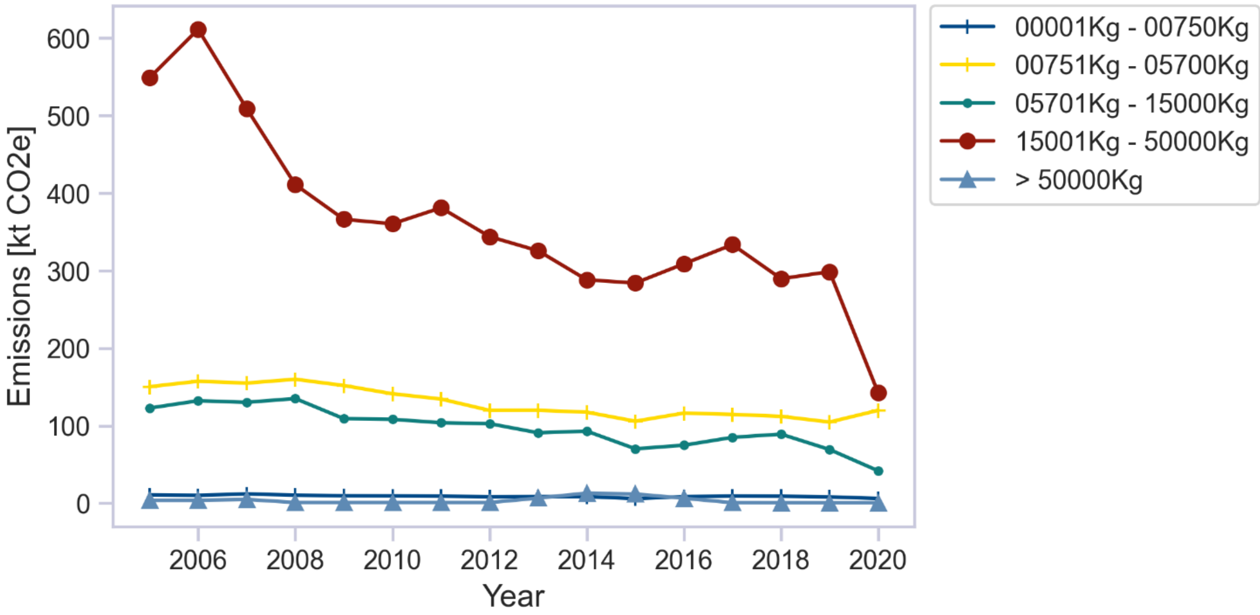


Figure 4.7: (a) Fixed-wing landplane carbon emissions, subdivided by aircraft weight

Table 4.5 Comparison of hours flown in 2019 by fixed-wing aircraft, subdivided by aircraft weight, and their respective carbon emissions

Aircraft weight (kg)	Hours flown in 2019	Carbon emissions (kt CO2e)
1 – 750	76,765	8
751 – 5,700	413,348	105
5,701 – 15,000	24,119	69
15,001- 50,000	53,938	299
> 50,000	108	1

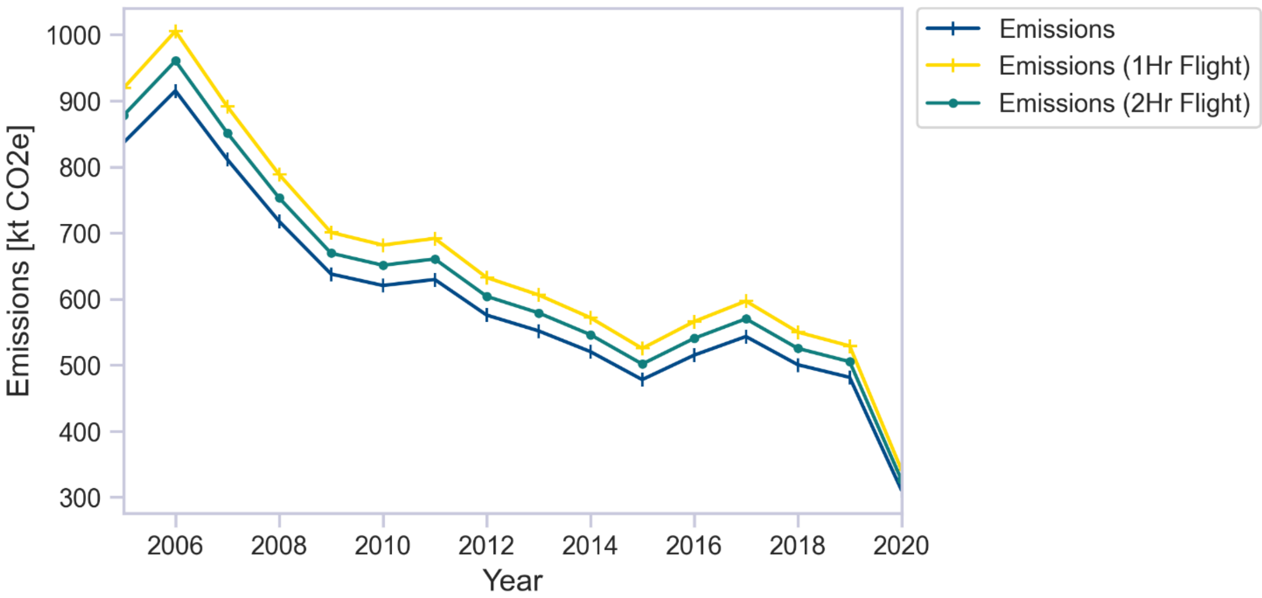


Figure 4.8: Sensitivity to assumptions on flight length for fixed-wing aircraft

4.3 Carbon baseline

The GA carbon baseline is approximately 795 kt CO2e in 2019. This footprint is dominated by aircraft emissions, which make up about 98% of the total. A summary of the carbon emissions in GA is displayed graphically in Figure 4.9. Figure 4.9 highlights the carbon emissions from different areas of the airfield, from the aircraft themselves, to the ground vehicles and buildings.

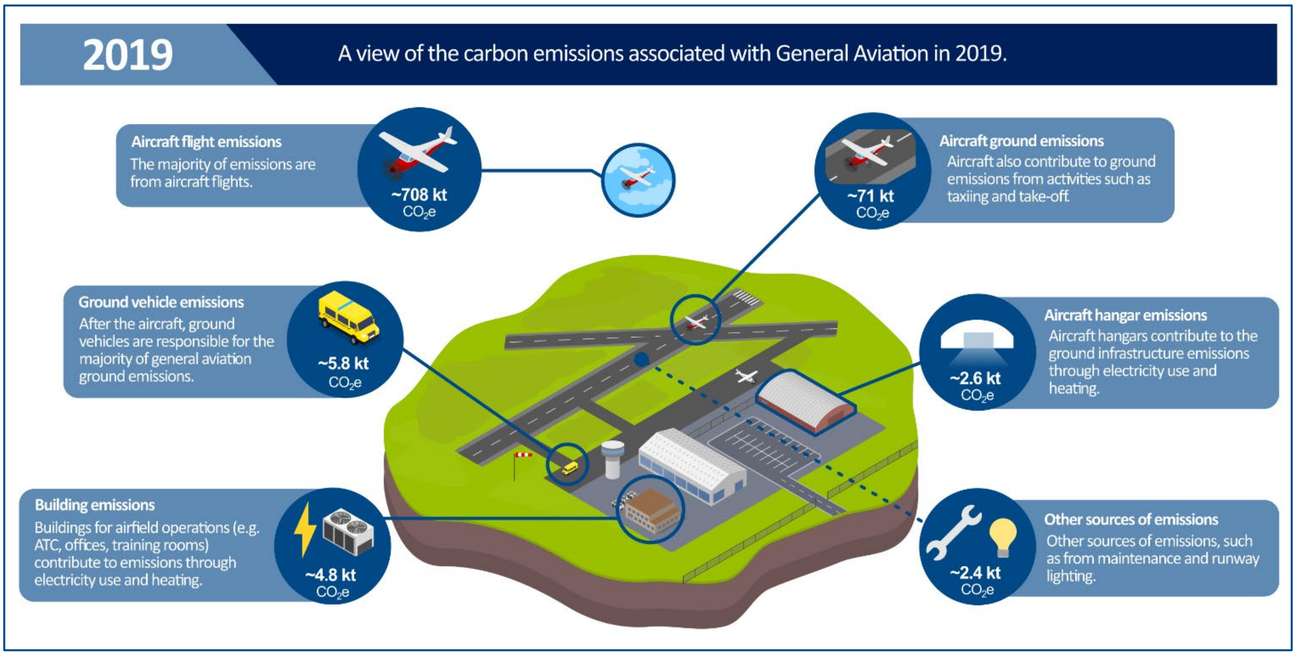


Figure 4.9: Summary of the carbon emissions in GA in 2019.

5 Decarbonisation of General Aviation

5.1 Decarbonisation context

On the 'balanced net zero pathway' developed by the Climate Change Committee (CCC) the UK economy will have to decarbonise by, on average, 96% by 2050 compared to 1990 levels, or 93% compared to 2017 levels [2].Aviation is recognised as being difficult to decarbonise, and the CCC has provided sector specific advice on aviation [10]. Under the 'balanced net zero pathway' aviation sector emissions are projected to decline 40% by 2050 from 2019 levels, with net zero being achieved through greenhouse gas removals. It is worth noting that the CCC's most optimistic 'tailwinds' scenario shows that a near complete decarbonisation of the sector may be possible with demand reduction of 15% and ambitious scale-up of the availability of biofuels and synthetic jet fuels.

The GA sector, as described in this report, includes both aircraft emissions and ground infrastructure emissions. The GA sector is difficult to decarbonise due primarily due to technological and financial barriers that were continually raised from the case study discussions, especially with smaller airfield operations. Legislative and planning barriers to the uptake of new technologies such as solar panels and electric aircraft were also highlighted. Aircraft emissions are by far the largest contributor to GA emissions and many decarbonising technologies are of a low technology readiness level and will be expensive to implement on a large-scale.

In order to assess the measures that will be needed to decarbonise GA, we have assumed that the sector will need to reduce emissions from ground infrastructure at the same rate as the economy average, and from aircraft at least at the same rate as the CCC's balanced net zero pathway for aviation, and preferably more so, recognising that there may be more scope for demand reduction in GA than in scheduled commercial aviation.

5.2 Approach to evaluating solutions

We used the baseline calculations to identify decarbonisation categories. These are:

- Aircraft
  - Flights
  - Ground movements (taxiing etc.)
- Ground infrastructure
  - Buildings
  - Hangars
  - Ground vehicles

For each category, we identified a range of issues, barriers to decarbonisation, and solutions based on insight gained through our case study site visits and interviews, professional knowledge and research. We assessed solutions using High, Medium and Low categories for carbon impact, cost, and ease of implementation, and used a scoring matrix to group solutions into the following implementation categories:

- **Do now** – no or low-cost solutions that are readily implemented.
- **Plan for** – proven solutions that require moderate to significant effort and/or cost to implement.
- **Evaluate** – more costly solutions that will be effective in some situations subject to evaluation.
- **Monitor** – future solutions that require further development before they can be adopted at scale.

In order to identify which solutions are likely to be the most important and explore the scale of solution deployment required under net zero scenarios, we modelled the potential for decarbonising the sector using our in-house decarbonisation forecasting tool. In this forecasting, we assumed the solutions would be implemented in the order determined by the carbon management hierarchy:

1. AVOID – stop doing legacy activities that are no longer necessary, e.g. by mothballing empty buildings.
2. REDUCE – conduct activities more efficiently by reducing waste, e.g. by improving insulation.
3. REPLACE – replace emission sources with lower carbon alternatives, e.g. by installing renewable energy.

In assessing the impact, cost and ease of implementation of the solutions we used our professional judgement guided by research and consultation with Frazer-Nash decarbonisation and aviation specialists. As with any forecast the results are only indicative.

5.2.1 Assessment criteria

5.2.1.1 Carbon impact

This is the estimated individual contribution made to either ground infrastructure decarbonisation or aircraft decarbonisation by the solution, assuming that the full range of solutions are implemented in the order determined by the carbon management hierarchy. The high/medium/low (HML) categories for this are given in Table 5.1.

Table 5.1: HML criteria for carbon impact

H	M	L
Significant contribution to sector decarbonisation	Moderate contribution to sector decarbonisation	Low contribution to sector decarbonisation

5.2.1.2 Cost impact

This is the estimated capital cost of implementing the solution at a typical airfield, excluding operational costs and savings associated with the solution. Financial barriers to decarbonisation projects were a common theme throughout many of the case studies conducted. This was raised across all category 1-5 airfields. The HML categories for this are given in Table 5.2.

Table 5.2: HML criteria for cost impact

H	M	L
>£500k (large airfield) >£100k (small airfield)	£50k-£500k (large airfield) £10k-£100k (small airfield)	<£50k (large airfield) <£10k (small airfield)

5.2.1.3 Ease of implementation

This is the extent to which deployment of the solution is currently hindered by barriers to implementation. From the case studies the unique nature of each GA airfield was highlighted, this could in turn mean that some measures are easier to implement than others depending on the airfield, but this has also been factored in here as a consideration. For example, City Airport (Manchester) had investigated solar panels but was unable to get appropriate connections to the national grid and planning for them. The HML categories for this are given in Table 5.3.

Table 5.3: HML criteria for ease of implementation

H	M	L
Significant barriers to implementation	Moderate barriers to implementation	Low barriers to implementation

5.3 Decarbonisation solutions

Table 5.4 and Table 5.5 list the solutions we identified and our assessment of carbon impact, cost and ease of implementation.

Table 5.4: Decarbonisation solutions for ground infrastructure

	Solution	Impact	Cost	Barriers
Do now: no or low cost solutions that are readily implemented				
AVOID	**Close unused buildings** Close unused or low usage buildings and facilities to reduce site energy needs	L	L	L
REDUCE	**Operational Procedures** Update procedures to improve energy efficiency (e.g. reduce time hangar doors left open while heating on)	M	L	L
REDUCE	**Heat Reflective Surfaces** Apply white paint and reflective materials to reduce heat radiation.	M	L	L
REDUCE	**Behaviour changes** Implement policies such as switch-off campaigns to reduce wasted energy	L	L	L
REPLACE	**LED Lights** Switch to LED lights to cut electricity needs	L	L	L
REPLACE	**Renewable electricity via green tariff** Purchase renewable electricity via the grid via green tariff backed by REGOs	M	L	L
Plan for: proven solutions that require moderate to significant effort and/or cost to implement				
REDUCE	**Building Insulation** Insulation techniques to reduce heat loss (foam, double glazing)	H	M	L
REPLACE	**Electric ground vehicles** Use zero emissions electric ground vehicles	H	H	M
REPLACE	**Electrification of Heating** e.g. via air/ground source heat pumps, thermal energy storage and aquifers	H	H	M
REPLACE	**Localised hangar heating** Replace current hangar heating with more efficient electric options such as radiant tube heating	H	M	L
REPLACE	**Drones** Use drones for tasks such as for bird scaring. This is currently done with vehicles such as fire trucks.	M	L	M
REPLACE	**Low-GWP refrigerants** Use low-GWP refrigerants where refrigeration systems exist (by replacing high-GWP)	L	M	L
Evaluate: More costly solutions that will be effective in some situations subject to evaluation				
REDUCE	**Optimise electrical distribution** Reconfigure electrical distribution systems to improve efficiency and integrate on-site renewable generation	H	H	H
REDUCE	**Passive daylight features** Utilise passive daylight lighting (e.g. skylights) to reduce dependency on lighting.	M	M	M
REDUCE	**Building Management Systems (BMS)** Automate and optimise lighting and HVAC systems.	M	H	L
REDUCE	**Replanning of airfield layout** Move building or runway positions to reduce taxi distance. Alternatively, reduce the number of runways used	L	H	M
REPLACE	**Anaerobic Digesters** Use Biogas as a source of electricity production for ground vehicles/auxiliary systems	H	H	M
REPLACE	**Building Replacement** Wholesale replacement of buildings where more cost effective than refurbishment	H	H	M
REPLACE	**Renewable electricity via direct line** Only buy energy from suppliers that use renewable generation sources.	M	L	M
REPLACE	**On-site wind power** Implement wind turbines to reduce dependency on power grid	M	H	H
REPLACE	**On-site solar power** Implement solar power to reduce grid dependency	M	H	H
Monitor: Future solutions that require further development before they can be deployed at scale				
REPLACE	**Hydrogen powered ground vehicle** Use hydrogen powered ground vehicles (only water emissions)	H	H	M
REPLACE	**On-site hydrogen power generation** Hydrogen fuel cells for on-site power generation	M	H	H
REPLACE	**Passive heat transfer systems** Interseason Heat Transfer Systems use surface embedded heating pipes that prevent ice formation on tarmac in winter and can harvest heat energy in summer months.	L	H	H

Table 5.5: Decarbonisation solutions for aircraft

	Solution	Impact	Cost	Barriers
Plan for: proven solutions that require moderate to significant effort and/or cost to implement				
REDUCE	**Aircraft Traffic Management** Increase efficiency of aircraft traffic management in both the air and on the ground	M	M	H
REPLACE	**Sustainable Aviation Fuel (SAF)** Increase use of SAF	M	M	H
Evaluate: More costly solutions that will be effective in some situations subject to evaluation				
REDUCE	**Predictive Maintenance** Use tools such as Artificial Intelligence (AI) to make maintenance planning and scheduling more efficient	L	M	M
	Flight Simulators Use flight simulators as much as possible during training to reduce aircraft flight hours	L	M	H
	Fuel Efficiency Improved efficiency of aircraft powertrains (engines) and airframe aerodynamics to reduce fuel consumption	M	H	M
	Ground Power Connection Using electric ground power during aircraft flight checks instead of on-board petrol APU for aircraft that have one.	L	M	M
Monitor: Future solutions that require further development before they can be deployed at scale				
REDUCE	**Electrically towed taxi** Tow aircraft to runway during taxi using electric vehicles (e.g. Taxibots)	M	M	M
REPLACE	**Hydrogen Aircraft** Use hydrogen powered aircraft	H	H	H
	Electric Aircraft Use electric powered aircraft	H	H	H
	Zero Carbon Fuel Production Onsite production of SAFs and hydrogen	H	H	H

A more detailed description including a summary of the barriers to implementation is provided in Annex B.1.

5.4 Potential implementation pathways

Figure 5.1 and Figure 5.2 show a summary of the potential decarbonisation that we estimate could result from deployment of the solutions listed above, between now and 2050. These projections are modelled for both aircraft and ground infrastructure solutions separately from two perspectives. The first perspective is the impact of the different cost categories (low / medium / high) of solutions, and the second perspective categorises the solutions by action category (do now / plan for / evaluate / monitor). These projections assume flat demand (i.e. the volume of activity in the sector stays constant at 2020 levels). Figure 5.1 shows that for the ground infrastructure, low-cost solutions will achieve some of the decarbonisation required, however the remainder will require significant financing. On the other hand, the solutions to deliver this decarbonisation are already proven. Figure 5.2 shows that, for aircraft, significant financing will be required to meet the decarbonisation required under the CCC's balanced net zero pathway, but it would be possible with sufficient investment to achieve much greater decarbonisation of GA. We estimate that proven solutions already exist to achieve more than the decarbonisation required for the balanced net zero pathway, however further technologies could deliver an even greater reduction.

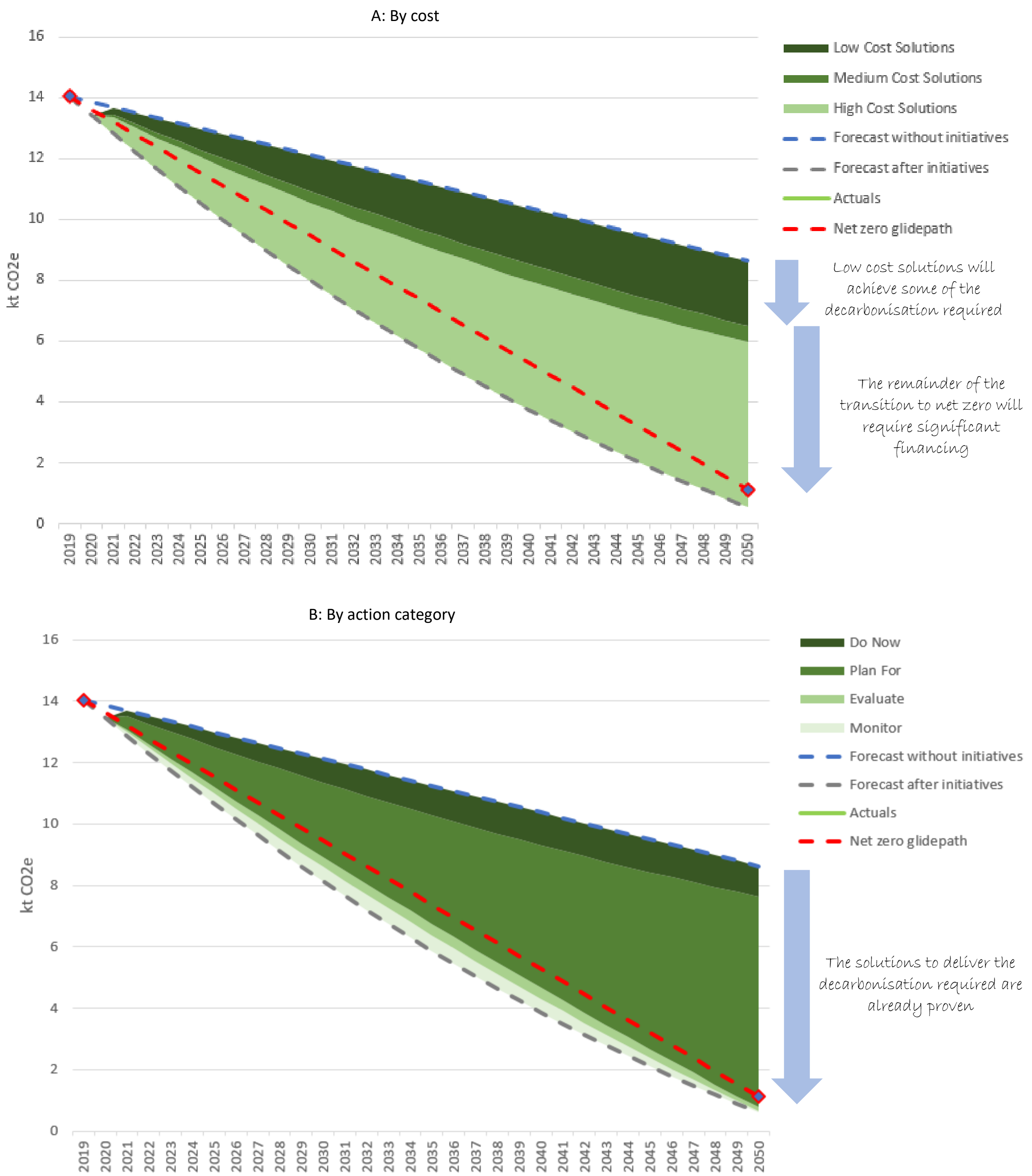
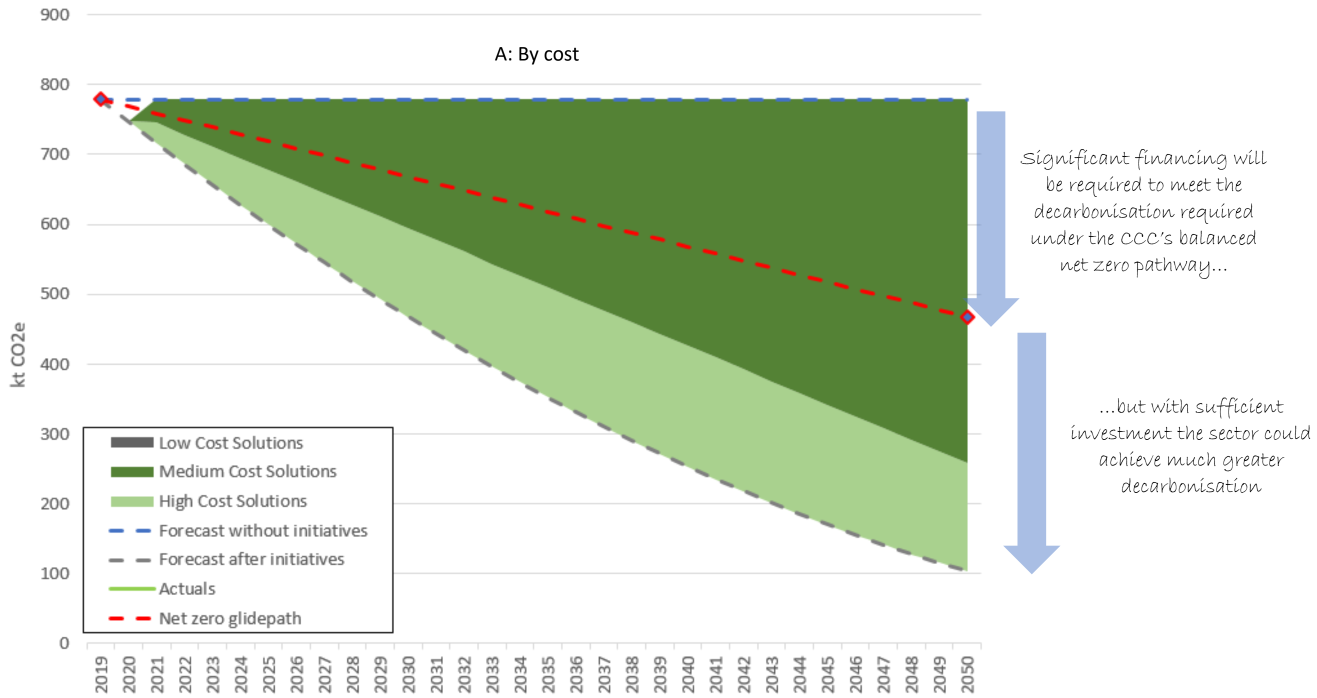


Figure 5.1: Potential impact of solutions for the ground infrastructure



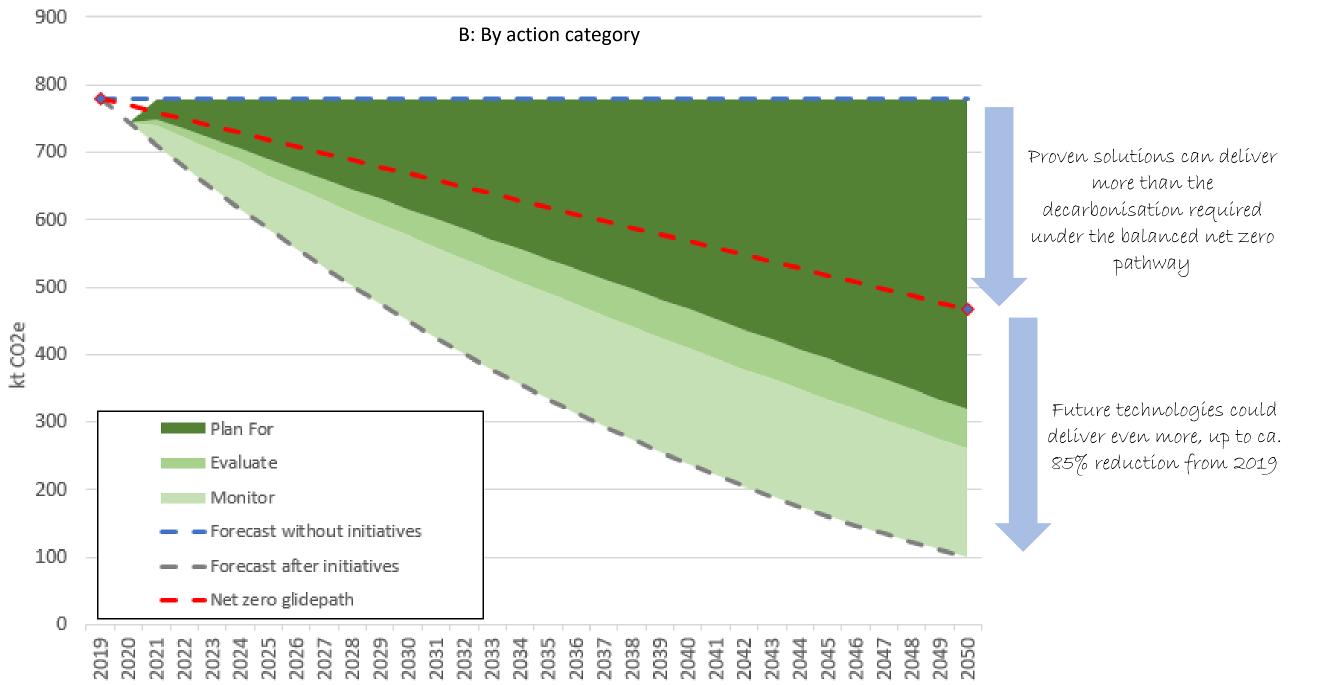


Figure 5.2: Potential impact of solutions for the aircraft

5.5 Summary of decarbonisation solutions

Figure 5.3 provides a graphical summary of the high-level solutions that could help GA achieve net zero by 2050. It presents a future airfield, highlighting a range of green technologies that may be in place. These include zero carbon aircraft, zero emissions ground vehicles, smart heating, lighting and energy management, smart runways and both on-site and off-site renewable energy generation.

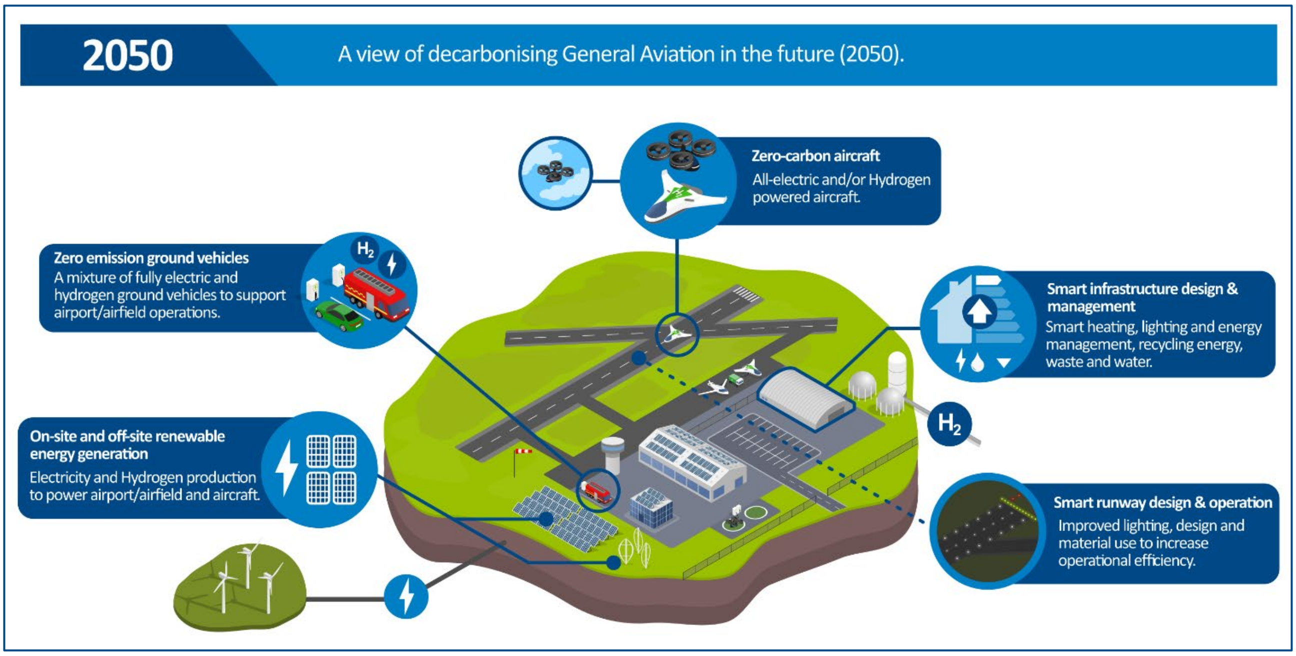


Figure 5.3: An illustration of potential solutions that would allow GA to achieve net zero by 2050

6 Conclusions and Considerations

6.1 GA carbon baseline

The GA carbon baseline is approximately 795 kt CO2e. This footprint is dominated by aircraft emissions, which make up about 98% of the total. Because the solutions to aircraft emissions are quite different to those for the ground infrastructure, it is useful to consider these two footprints separately. Table 6.1 summarises the baseline.

Table 6.1: GA carbon baseline for 2019 (kt CO_2e)

Ground Infrastructure	
Ground vehicles	5.8
Buildings	4.5
Hangars	2.6
Maintenance	2.2
Training	0.3
Runway lighting	0.2
Total	**15.5**

Aircraft	
Flights	708
Ground movements	71
Total	**779**

The volume of emissions from aircraft can be attributed to the inherently high energy intensity of flying, which today is almost exclusively powered by fossil fuels. Following aircraft, ground vehicles are the second largest source of emissions. As with aircraft, this is due to them being powered by fossil fuels.

Buildings have two principal sources of CO_2e emissions; fossil fuels used for heating and electricity use. The majority of heating is currently provided by fossil fuels. Electricity is generally obtained from the grid, although there is some on-site generation. There are many ways in which energy is lost from GA buildings, and if these issues were addressed the energy needs of these buildings would reduce. The most significant cause of wasted energy is a lack of modern insulation and double-glazed windows, due to the age of many GA buildings.

Energy metering and payment arrangements are not always optimal resulting in a lack of awareness of energy usage in some GA buildings. In some cases there is a disconnect between who operates the building and who pays for the energy, and sometimes payment for energy is incorporated as a fixed cost in their rent. Without knowing where energy is wasted, airfields cannot implement targeted solutions.

Within hangars, heating is often provided to the whole building in order to maintain comfortable working temperatures. However, there is significant wastage as the hangars are often very large spaces with poor insulation. This issue is worsened by the main doors often being left open for extended periods of time to move aircraft, letting heat escape. In summer, hangars can become too hot, requiring more energy consumption for cooling.

6.2 Decarbonising GA

6.2.1 Ground infrastructure

There is a wide range of solutions available to decarbonise GA's ground infrastructure. We identified 24 separate solutions, listed in Table 5.4, ranging from low-cost low-tech solutions like improving operational procedures to reduce energy wastage, behaviour change and renewable electricity tariffs, to more costly technology-based solutions like electric vehicles, heat pumps and localised hangar heating. We estimate that the low-cost solutions that are easy to implement could deliver approximately 25% of the decarbonisation required by 2050. The remaining 75% will involve either significant cost or the removal of other significant barriers to implementation. However, all the technologies required exist today and are already proven.

Without changes to the policy landscape or airfields' ability to access the capital to finance the solutions, there is a risk that the sector will fail to decarbonise sufficiently. Furthermore, if the sector falls behind in the journey to net zero, there is a risk that it will face disruption and even higher costs associated with future net zero regulation. Therefore, we recommend that DfT develop plans to overcome the current barriers to implementation (refer to Annex B.1) through targeted policy and financing support.

6.2.2 Aircraft

Decarbonising aircraft emissions is far more challenging. We identified 10 separate solutions (Table 5.5) ranging from moderate cost solutions like improving aircraft traffic management, sustainable aviation fuels and conducting more training via flight simulators, to high-cost solutions like aircraft engine replacement and new types of aircraft powered by electricity and hydrogen where these become commercially and operationally viable. Significant financing over an extended period will be required to meet the decarbonisation of 40% required under the CCC's balanced net zero pathway. However, that level of decarbonisation is possible with technologies that are already proven. Future technologies like affordable electric and hydrogen powered flight could enable a much greater level of decarbonisation, potentially up to around an 85% reduction compared to 2019 levels.

The emissions from aircraft are directly proportional to the demand, i.e. number and duration of flights. The aviation sector presents a complex net zero challenge in a highly regulated sector and direct aircraft emissions account for the overwhelming majority of these emissions. With regards to decarbonisation there are significant opportunities with technologies that are already available to reduce these emissions whilst accommodating growth of this sector. A careful balance must be struck in order to accommodate sustainable sector growth in the long term to align whilst contributing to national efforts to decarbonise and achieve net zero. DfT should consider measures to reduce demand of unsustainable carbon intensive flights. For example, we estimate that 75% of aircraft emissions come from Business Aviation. Reducing these flights by half would therefore reduce the sector's aircraft emissions by approximately 37%, almost all the decarbonisation required under the balanced net zero pathway. This creates the potential to decarbonise faster and more deeply than the scheduled commercial aviation sector, reducing the future burden associated with offsetting residual emissions in order to achieve net zero.

The DfT should continue to build upon its current programme of work to support the development low carbon flight technologies such as the recently undertaken ZEFI project [13]. As the decarbonisation of aircraft relies on technology maturing, efforts should focus on ensuring that these technologies arrive as early as possible. Extending and expanding support for schemes such as the Future Flight Challenge could enable this.

6.3 Drivers and enablers

The decarbonisation of the UK economy as set out in the Government's Net Zero Strategy creates both risks and opportunities for the GA sector. If the sector fails to keep up with the pace of decarbonisation delivered across the wider economy, it could be disproportionally impacted by future net zero policy such as carbon taxation. The costs to the sector resulting from a failure to decarbonise could far outweigh the costs of implementing the solutions.

Delivering the levels of decarbonisation needed to achieve net zero will require the roll-out of a wide range of solutions at scale across the entire GA sector. However, many of the solutions currently have significant barriers to implementation. Furthermore, the degree of change to operational norms and commercial models implied by these solutions is significant, so there is likely to be some natural resistance to change if the barriers are not adequately addressed. Not least, a significant source of income for airfields is currently derived from fossil fuel sales. Therefore it is important for DfT to act fast to consult with and provide clear and effective guidance to airfields, to enable them to understand, plan for and deliver this change with confidence. This could include recognition schemes and tailored guidance for 'Leading', 'Intermediate' and 'Beginning' airfields for example.

Delivering the solutions will require the barriers to implementation to be reduced or removed. In particular there is a need for policy changes (for example in the areas of air traffic management regulation and planning) and financing of solutions requiring high capital costs. This study does not provide a detailed analysis of the policy and financing interventions required, but the barriers to implementation described in Annex B.1 provide a useful reference for further work to develop such interventions.

The opportunities presented by net zero are also important to the future of the GA sector. Improving energy efficiency and switching to renewable energy sources will reduce operational costs and improve resilience. The sector also has an important role to play in the development of next generation aircraft and ground infrastructure, which could have benefits beyond GA, in the scheduled commercial aviation sector both domestically and internationally. Airfields which can play an active role in the development of low carbon flight, and provide low carbon infrastructure like electric vehicle charge points, will become more attractive to customers and unlock opportunities for growth. DfT should consider how it can help airfields realise these opportunities.

6.4 Summary of Considerations

GA airfields should:

- Assess the business risks and opportunities presented by the transition to net zero
- Review the list of solutions provided in this report, and consider wider opportunities that may not be listed here
- Implement the solutions, where applicable, listed under the ‘do now’ category immediately
- Develop a short-term action plan to implement applicable solutions listed under the ‘plan for’ category
- Identify applicable solutions listed under the ‘evaluate’ category and assess the site-specific costs, benefits and feasibility of these, including any key dependencies.
- Identify financing requirements and key decision points for applicable solutions
- Develop action plans to progress medium to long term solutions
- Engage with DfT, other airfields, industry bodies and other stakeholders to share knowledge, overcome barriers to implementation and unlock opportunities
- Monitor the development of solutions listed under the ‘monitor’ category.

DfT should:

- Provide clear and effective guidance to airfields, to enable them to understand, plan for and deliver the transition to net zero with confidence.
- Raise awareness of decarbonisation solutions and existing funding sources.
- Develop plans to help airfields overcome the current barriers to implementation of decarbonisation solutions (refer to Annex B.1) through targeted policy and financing support.
- Consider ways to reduce demand for carbon-intensive flying, mindful of the industry’s need to adapt to a low carbon economy through a commercially viable transition.
- Consider ways to promote efficient use of GA flights, either through flight sharing or other emissions saving measures.
- Conduct further research into the costs, benefits and feasibility of decarbonisation solutions in order to provide effective guidance to the sector.
- Consider how it can help airfields realise the opportunities associated with the development of low carbon flight and ground operations.
- Engage with airfields, industry bodies and other stakeholders to share knowledge, overcome barriers to implementation and unlock opportunities.

- Engage with other government departments and policy makers in order to promote effective and equitable incentives for decarbonisation, and to stimulate innovation and the scale-up of low carbon aviation technologies.

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Annex A - Fuel Consumption Data for Different Aircraft Types

A.1 Fuel consumption data

Aircraft type	Weight Group	Engine Class	Number of Aircraft	Example Aircraft Types	Typical fuel use	Typical fuel burn	Units	Reference
AIRSHIP (GAS-FILLED)	00751kg - 05700kg	PISTON	6	A-60+	Aviation spirit	4	gal/hr	https://www.airshipsonline.com/airships/A60/Index.htm
	15001kg - 50000kg	PISTON	1	AIRLANDER 10	Aviation spirit	42	l/hr	No flight hours logged - assume same as equivalent sized fixed-wing landplane
AIRSHIP (GAS-FILLED) (UNMANNED)	00001kg - 00750kg	ELECTRIC	1		None	0	kg/hr	Assume no emissions as electric motor
		PISTON	1	GA22 MKII	Aviation spirit	36.5	l/hr	No flight hours logged - assume same as equivalent hot air
AIRSHIP (HOT AIR)	00001kg - 00750kg	PISTON	10	CAMERON DP-70	Aviation spirit	36.5	l/hr	From research airships tend to have a 2 cylinder engine, similar to that of a small 2 seater plane, so use the same data as fixed-wing landplane 1kg-750kg
	00751kg - 05700kg	PISTON	26	GEFA-FLUG AS 105 GD	Propane	60	kg/hr	https://www.cameronballoons.co.uk/c/download/GEFA-FLUG-GD4-GD6-Flight-Manual.pdf
BALLOON (GAS-FILLED)	00000kg	-	4	COLT AA-1050	None	0	kg/hr	Assume a gas filled balloon has no fuel - https://en.wikipedia.org/wiki/Gas_balloon
	00001kg - 00750kg	-	9	LBL 14M	None	0	kg/hr	Assume a gas filled balloon has no fuel - https://en.wikipedia.org/wiki/Gas_balloon
	00751kg - 05700kg	-	14	203T HIFLYER	None	0	kg/hr	Assume a gas filled balloon has no fuel - https://en.wikipedia.org/wiki/Gas_balloon
BALLOON (GAS/HOT AIR)	00001kg - 00750kg	-	1	CAMERON R-15	None	0	kg/hr	Assume a gas filled balloon has no fuel - https://en.wikipedia.org/wiki/Gas_balloon
	00751kg - 05700kg	-	9	CAMERON R-77	None	0	kg/hr	Assume a gas filled balloon has no fuel - https://en.wikipedia.org/wiki/Gas_balloon

Aircraft type	Weight Group	Engine Class	Number of Aircraft	Example Aircraft Types	Typical fuel use	Typical fuel burn	Units	Reference
BALLOON (HOT AIR)	00000kg	-	50	COLT FLYING ICE CREAM CONE	Propane	40	kg/hr	Assume the same as 1-750kg category
	00001kg - 00750kg	-	1088	CAMERON V-77	Propane	40	kg/hr	https://www.baileyballoons.co.uk/environmental-policy/#:~:text=An%20average%20flight%20of%20one,producing%20120kg%20of%20carbon%20dioxide.)
	00751kg - 05700kg	-	1486	CAMERON N-90	Propane	228	l	None found - https://en.wikipedia.org/wiki/Hot_air_balloon#Fuel_tanks has a calculation which suggests a typical heavy balloon has 3 76l fuel tanks
BALLOON (MINIMUM LIFT)(UNMANNED)	00000kg	-	99	SCRUGGS BL2B	Propane	40	kg/hr	No flight hours logged - assume same as small hot air balloon
	00001kg - 00750kg	-	1	LILLIPUT TYPE 4	Propane	40	kg/hr	No flight hours logged - assume same as small hot air balloon
FIXED-WING AMPHIBIAN	00001kg - 00750kg	PISTON	8	PEREIRA OSPREY 2	Petrol (100% mineral petrol)	17	l/hr	https://www.searey.com/about-us/faq/
	00751kg - 05700kg	PISTON	15	LAKE LA-250	Aviation spirit	14	gal/hr	https://bwifly.com/cessna-182-operating-cost/#:~:text=The%20Cessna%20182%20burns%20about,run%20between%20%2484%20per%20hour. - google search shows that the Cessna 182 might be more efficient at cruise, but this seems like a reasonable estimate
		TURBOPROP	3	CESSNA 208	Aviation spirit	180	l/hr	https://en.wikipedia.org/wiki/Cessna_208_Caravan#:~:text=The%20airplane%20typically%20seats%20nine,nmi%20(370%20km)%20stages.

Aircraft type	Weight Group	Engine Class	Number of Aircraft	Example Aircraft Types	Typical fuel use	Typical fuel burn	Units	Reference
	05701kg - 15000kg	PISTON	1	PBY-5A	Aviation spirit	86	gal/hr	https://www.aopa.org/news-and-media/all-news/2014/august/pilot/f_pby
FIXED-WING LANDPLANE	00001kg - 00750kg	ELECTRIC	2	VIRUS SW 128	None	0	kg/hr	Assume no emissions as electric motor
		PISTON	4096	EUROPA	Aviation spirit	36.5	l/hr	1.A.3.a Aviation 2019.pdf - take the highest fuel consumption for non-Cessna aircraft (table 3.9)
		TURBOJET	1	SOMERS KENDALL SK1	Aviation turbine fuel	800	l/hr	No flight hours logged - assume same as heavier plane
	00751kg - 05700kg	ELECTRIC	1	NXTE	None	0	kg/hr	Assume no emissions as electric motor
		PISTON	7288	PIPER PA-28-161	Aviation spirit	42	l/hr	1.A.3.a Aviation 2019.pdf - take the highest fuel consumption for Cessna single engine aircraft (table 3.8)
		TURBOFAN	111	CESSNA 510	Aviation turbine fuel	135	gal/hr	https://aviatorinsider.com/airplane-brands/cessna-525/#:~:text=In%20zero%2Dwind%20conditions%2C%20the,around%20135%20gallons%20per%20hour.
		TURBOJET	59	JET PROVOST T MK5A	Aviation turbine fuel	800	l/hr	https://www.yakuk.com/aircraft/l-29-flight-report/#:~:text=Fuel%20consumption%20is%20approximately%20800%20lts%20per%20hour%20%2C%20low%20and%20fast.
		TURBOPROP	263	BEECH B200	Aviation turbine fuel	135	gal/hr	https://www.guardianjet.com/jet-aircraft-online-tools/aircraft-brochure.cfm?m=Beech-King-Air-B200-21
	05701kg - 15000kg	PISTON	22	DOUGLAS DC-3C-R-1830-90C	Aviation spirit	200	gal/hr	https://www.mcnallyinstitute.com/how-does-a-b17-engine-work/
		TURBOFAN	241	CESSNA 560XL	Aviation turbine fuel	203	gal/hr	https://jetadvisors.com/cessna-citation-v-performance/ https://compareprivateplanes.com/articles/dassault-falcon-200-ownership-operating-costs

Aircraft type	Weight Group	Engine Class	Number of Aircraft	Example Aircraft Types	Typical fuel use	Typical fuel burn	Units	Reference
								https://jetadvisors.com/beechjet-400a-performance/ https://compareprivateplanes.com/articles/bombardier-learjet-45-ownership-operating-costs#:~:text=The%20Bombardier%20Learjet%2045%20can%20cruise%20at%20up%20to%2051%2C000,Gallons%20per%20Hour%20(GPH).
		TURBOJET	66	HAWKER HUNTER MK.58	Aviation turbine fuel	2114	l/hr	https://www.jeversteamlaundry.org/vampires.htm#:~:text=Specific%20fuel%20consumption%3A%201.3%20lb,(2114%20litres%20per%20hour).
		TURBOPROP	143	SD3-60 VARIANT 100	Aviation turbine fuel	425	kg/hr	https://urga.com.ua/en/samolet-saab-340b.html https://www.aerospace-technology.com/projects/jetstream41/#:~:text=The%20typical%20fuel%20burn%2C%20420kg,loaded%20range%20of%201%2C430km.
	15001kg - 50000kg	PISTON	7	DOUGLAS DC-6A	Aviation spirit	203	gal/hr	No data found so take emissions factor from larger piston aircraft (https://www.mcnallyinstitute.com/how-does-a-b17-engine-work/)
		TURBOFAN	345	CANADAIR CL600-2B16 (604 VARIANT)	Aviation turbine fuel	383	gal/hr	https://www.guardianjet.com/jet-aircraft-online-tools/aircraft-brochure.cfm?m=Embraer-Legacy-500-190 https://jetadvisors.com/embraer-legacy-shuttle/#:~:text=On%20average%2C%20the%20engines%20burn%20313%20gallons%20of%20fuel%20per%20hour. https://jetadvisors.com/global-express-performance/
		TURBOJET	7	DH110 SEA VIXEN	Aviation turbine fuel	383	gal/hr	No data found, assume similar to TURBOFAN

Aircraft type	Weight Group	Engine Class	Number of Aircraft	Example Aircraft Types	Typical fuel use	Typical fuel burn	Units	Reference
		TURBOPROP	20	HS.748 SERIES 2A	Aviation turbine fuel	760	kg/hr	https://www.rocketroute.com/aircraft/atr-72-212. Note that there are no GA aircraft in this category.
	> 50000kg	TURBOJET	3	AVRO VULCAN B2	Aviation turbine fuel	13950	lb/hr	https://www.key.aero/forum/historic-aviation/64315-vulcan-fuel-consumption
		TURBOPROP	0	-	Aviation turbine fuel	760	kg/hr	No flight hours logged once commercial aircraft excluded, assume same as lower weight category
		PISTON	4	TEKEVER AR5 EVOLUTION MK 2	Aviation spirit	36.5	l/hr	No flight hours logged, assume same as fixed-wing landplane
FIXED-WING LANDPLANE (UNMANNED)	00001kg - 00750kg	PISTON	1	UNMANNED AIRCRAFT SYSTEM HERTI	Aviation spirit	42	l/hr	No flight hours logged, assume same as fixed-wing landplane
	00751kg - 05700kg	PISTON	2	HAWK I ARROW	Aviation spirit	9	gal/hr	No flight hours logged, assume same as larger seaplane
FIXED-WING SEAPLANE	00001kg - 00750kg	PISTON	3	AVRO 504L	Aviation spirit	9	gal/hr	http://www.pilotfriend.com/aircraft%20performance/Maule/18.htm
	00751kg - 05700kg	ELECTRIC	3	E1 ANTARES	None	0	kg/hr	https://en.wikipedia.org/wiki/Lange_Antares
FIXED-WING SELF-LAUNCHING MOTOR GLIDER	00001kg - 00750kg	PISTON	269	SCHEIBE SF25C	Aviation spirit	10	l/hr	https://www.planecheck.com/index.asp?ent=da&id=45491&cor=y
		PISTON	202	GROB G109B	Aviation spirit	12	l/hr	http://www.pilotfriend.com/aircraft%20performance/Grob/3.htm#:~:text=109%20claims%20a%2030%3A1,about%2012%20litres%20per%20hour.

Aircraft type	Weight Group	Engine Class	Number of Aircraft	Example Aircraft Types	Typical fuel use	Typical fuel burn	Units	Reference
	00751kg - 05700kg	-	2316	SCHLEICHER AS-K 13	None	0	kg/hr	No engine - assume no emissions
GLIDER	00001kg - 00750kg	ELECTRIC	29	GLASFLUGEL 304 ES	None	0	kg/hr	No engine - assume no emissions
		PISTON	290	VENTUS-2CT	Aviation spirit	13.25	l/hr	https://assets.publishing.service.gov.uk/media/58c91411ed915d603800015c/Schleicher_ASW_27-18E__ASG_29E__glider_G-VLCC_03-17.pdf https://www.schempp-hirth.com/fileadmin/schempp-hirth/Resources/Documents/Prospekte/Duo_Discus_XLT_EN.pdf
		TURBOJET	25	GLASFLUGEL 304 S	Aviation turbine fuel	60	kg/hr	https://aeropedia.com.au/content/jonker-salplanes-js-3-rapture/
		-	1	NIMBUS-2CS	None	0	kg/hr	No engine - assume no emissions
	00751kg - 05700kg	PISTON	28	ARCUS T	Aviation spirit	25	l/hr	http://all-aero.com/index.php/60-gliders/9674-schempp-hirth-hs-3-nimbus--hs-5-nimbus
		PISTON	542	ROTORSPORT UK MTOSPORT	Aviation spirit	20	l/hr	https://assets.publishing.service.gov.uk/media/5422eba9e5274a13140000a9/Rotorsport_UK_MT-03__G-TATA_09-09.pdf https://verticalmag.com/features/rotorcraft-flying-magni-m16-gyroplane/#:~:text=With%20an%20average%20fuel%20burn,for%20at%20least%20three%20hours.
GYROPLANE	00001kg - 00750kg	PISTON	1	SHIRAZ	Aviation spirit	20	l/hr	No flight hours logged, assume same as smaller plane

Aircraft type	Weight Group	Engine Class	Number of Aircraft	Example Aircraft Types	Typical fuel use	Typical fuel burn	Units	Reference
	00751kg - 05700kg	-	8	NOVA VERTEX 22	None	0	kg/hr	No flight hours logged, assume no emissions
HANG GLIDER	00001kg - 00750kg	PISTON	7	DOODLE BUG/TARGET	None	0	kg/hr	No flight hours logged, assume no emissions
		PISTON	367	ROBINSON R22 BETA	Aviation spirit	8.5	gal/hr	https://robinsonheli.com/r22-series/#:~:text=R22%20BETA%20II%20Helicopter&text=A%20powerful%20engine%2C%20a%20lightweight,due%20to%20R22's%20large%20windows.
HELICOPTER	00001kg - 00750kg	PISTON	658	ROBINSON R22 BETA	Aviation spirit	8.5	gal/hr	https://www.airtechnology.be/Air_Technology_Belgium/R44.html#:~:text=The%20Raven%20I's%20distinctive%20aerodynamic,to%2016%20gallons%20per%20hour.
	00751kg - 05700kg	TURBOFAN	2	SA319B	Aviation turbine fuel	40	gal/hr	No flight hours logged, assume same as turboshaft
		TURBOJET	1	REACTION DRIVE ROTORCRAFT	Aviation turbine fuel	40	gal/hr	No flight hours logged, assume same as turboshaft
		TURBOPROP	3	AGUSTA AW119 MKII	Aviation turbine fuel	40	gal/hr	No fuel consumption data found, assume same as turboshaft
		TURBOSHAFT	1157	BELL 206B	Aviation turbine fuel	40	gal/hr	http://www.wwheli.com/jetrangerspecifications.htm https://www.flyingbulls.at/en/fleet/eurocopter-ec135 https://en.wikipedia.org/wiki/Robinson_R66#:~:text=The%20turbine%20burns%20Jet%2DA,hook%20as%20an%20optional%20equipment.

Aircraft type	Weight Group	Engine Class	Number of Aircraft	Example Aircraft Types	Typical fuel use	Typical fuel burn	Units	Reference
		PISTON	1	BRISTOL 171 MK HR-14	Aviation spirit	8.5	gal/hr	No flight hours logged, assume same as smaller helicopter
	05701kg - 15000kg	TURBOSHAFT	311	SIKORSKY S-92A	Aviation turbine fuel	185	gal/hr	http://c.eqcdn.com/_dd8aab8a04e2ee6f234e39f46fda9064/eragroupinc/db/61/546/spec_sheet/S92+GWE+Spec+Sheet_02_2016.pdf http://c.eqcdn.com/_a15f1bfe5225ae94a025b4998691df71/eragroupinc/db/61/472/spec_sheet/AW139+Spec+Sheet_09_16_2016.pdf
		PISTON	2	SCHIEBEL CAMCOPTER S-100	Aviation spirit	8.5	gal/hr	No flight hours logged, assume same as small helicopter
HELICOPTER (UNMANNED)	00001kg - 00750kg	ELECTRIC	15	SILENT 2 ELECTRO	None	0	kg/hr	Assume no emissions as electric motor
MICROLIGHT	00001kg - 00750kg	PISTON	5649	PEGASUS XL-R	Aviation spirit	12	l/hr	https://www.g-tlac.com/comco-ikarus-c42/c42a/ https://assets.publishing.service.gov.uk/media/5423027a40f0b61346000c13/Pegasus_Quantum_15-912__G-EMLY_12-10.pdf http://www.pmaviation.co.uk/gt450.html
		TURBOJET	3	GLOW	Aviation turbine fuel	800	l/hr	No flight hours logged, assume the same as a fixed-wing plane

Annex B - Barriers to the Decarbonisation of GA

B.1 Barriers to decarbonisation of GA

B.1.1 Ground Infrastructure

	Solution	Impact Rating Justification	Barriers	Opportunities
Do now: no or low-cost solutions that are readily implemented				
AVOID	**Close unused buildings** Close unused or low usage buildings and facilities to reduce site energy needs	By closing unused or un-needed buildings, the power usage and associated emissions can be stopped. This significantly reduces energy needs and therefore demands of a site.	There will be still some associated cost with buildings that have been shut down but not demolished	This could lead to a potential reassessment of how an airfield is laid out, and what facilities are needed
REDUCE	**Operational Procedures** Update procedures to improve energy efficiency (e.g. reduce time hangar doors left open while heating on).	This is a cheap and effective measure of reducing energy (mainly heat) waste. Lost heat is one of the larger sources of wasted energy so addressing this issue reduces site energy use (and therefore impact).	This is a bespoke solution that will have to be done on a case-by-case basis	Potentially a very quick and easy way to lower emissions
REDUCE	**Heat Reflective Surfaces** Apply white paint and reflective materials to reduce heat radiation.	This solution reduces heat loss by radiation in winter, and heat gain in summer, providing a passive method for climate control. Reducing the amount of heating and cooling required in buildings is an effective method of reducing associated emissions.	Cost benefit analysis of whether this is worthwhile should be done on a case-by-case basis, need to factor in need to maintain/repaint markings	Reduction in energy used to condition hangars in hot weather/summer months
REDUCE	**Behaviour changes** Implement policies such as switch-off campaigns to reduce wasted energy	This a cheap and effective way to reduce energy use and therefore any associated emissions. This is scored as low impact as it is difficult to consistently implement and will mainly address electricity wastage (lights, computers left on etc.), which are low impact in comparison to other issues (e.g., heat waste). If sources of electricity are decarbonised or solutions such as LED lights are used, the impact of this solution relative to others is minimal.	Achieving behaviour change is a workplace culture issue, which can be difficult to implement to its full potential.	Is an easy way to cut emissions and waste
REPLACE	**LED Lights** Switch to LED lights to cut electricity needs	Whilst LED lights provide a good reduction in power use (30%), lighting only makes up a small proportion of electricity use on sites, and so would have a small effect when factoring in emissions from fossil fuel heating and running ground vehicles.	None foreseen, LEDs are made to fit a variety of sockets including older types.	Increased energy efficiency, reduced cost
REPLACE	**Renewable electricity via green tariff** Purchase renewable electricity via the grid via green tariff backed by REGOs	Contributes towards net zero electricity emissions but does not address emissions associated with heating or ground vehicles (e.g. burning of fossils fuels). There is potential for greenwashing if this does not go hand in hand with energy reduction.	Difficulties in verifying source is using 100% renewable energy, hard to guard against "greenwashing". May be a small price premium compared to standard electricity.	A very quick way to make a positive impact by sending a demand signal to electricity generators.

Plan for: proven solutions that require moderate to significant effort and/or cost to implement				
REDUCE	**Building Insulation** Insulation techniques to reduce heat loss (foam, double glazing)	This solution would have a large impact on the reduction of heating emissions and electricity usage (if electric heating is used).	Cost-benefit analysis needs to be done to ensure this option is better than replacing a building Could require significant time/cost to do	Improving thermal efficiencies of buildings can significantly reduce power consumption. More reliably heated buildings improves morale/perception of those who use them
REPLACE	**Electric ground vehicles** Use zero emissions electric ground vehicles	Ground vehicles are a large contributor to ground emissions. Switching to electric vehicles could completely stop direct ground vehicle emissions (though increases electricity demand).	Cost of implementation. Requires charging infrastructure and enough vehicles for continuous operation. Specialist vehicles (e.g., fire trucks) have not yet been developed	Improves public perception. Ground vehicles are a large part of airfield emissions. Electric vehicles are significantly cheaper to run, are quieter, more reliable, and require less maintenance
REPLACE	**Electrification of Heating** Can be done through air/ground source heat pumps, potentially combined with thermal energy storage	Can eliminate emissions associated with fossil fuel burn for heating solutions (18% of ground emissions). This does increase demand on the electricity grid but this drawback can be countered through use of other solutions discussed and decarbonisation of the grid.	For heat pumps, performance and efficiency are dependent on outdoor temperatures and will have decreased performance in off-design conditions, bespoke design may be required. Thermal energy storage has seen little adoption to date.	Enables the removal of onsite gas use and so achieves a major target of decarbonising airports. Various options are available suitable for a wide range of environments. Heat pumps can make use of existing plumbing and radiators.
REPLACE	**Localised hangar heating** Replace current hangar heating with more efficient electric options such as radiant tube heating	A large proportion of heating emissions are due to wasted heat energy when using hangars.	Cost of implementation. Most energy efficient methods still use conventional fuels as a power source. Hangars are hard to temperature control due to the large volume.	Increases energy efficiency of hangars Boosts morale of maintenance staff Potential for a degree of automated temperature control
REPLACE	**Drones** Use drones for tasks such as for bird scaring	A method of reducing the use of ground vehicles for bird scaring by replacing them with drones. This solution does not completely remove the need for ground vehicles but should be viewed as a method of reducing their emissions until they can be effectively decarbonised.	Can provide cheap and immediate solutions to issues such as the high carbon intensity of ground vehicles	Main challenge is identifying where drones can be implemented quickly, cheaply and effectively. In the case of UAS use there will be challenges around obtaining approval for safe operation in an airfield environment.
REPLACE	**Low-GWP refrigerants** Use low-GWP refrigerants where refrigeration systems exist (by replacing high-GWP)	Only impacts fugitive emissions which is a small proportion of emissions.	Not all cooling systems are compatible with low GWP refrigerants. There may be some upfront costs, depending on the modifications that are needed.	Some systems can accommodate a simple switch out and replacement with a low GWP alternative, so are cheap to upgrade. Reduction of fugitive emissions, which have a much higher climate global warming potential than CO_2.

Evaluate: More costly solutions that will be effective in some situations subject to evaluation				
REDUCE	**Optimise electrical distribution** Reconfigure electrical distribution systems to improve efficiency and integrate on-site renewable generation	Enables airfields to identify and eliminate where there is wasted energy. This solution would usually be required to integrate renewable energy generation into airfields effectively. Impact is deemed high as it allows for other decarbonising solutions to be used.	Costs and logistics required in changing power infrastructure may be large. Most successful microgrids are ones that maximise onsite renewable energy generation. Generation and storage capacity needs to be large to support peak demands. Maintaining power supply during construction is a challenge.	Enables greater ability to track and control power consumption at an airport. Microgrid technology is being implemented in civil airports such as JFK Terminal One where it is expected to reduce fuel consumption of the terminal by 30%.
	Passive daylight features Utilise passive daylight lighting (e.g. skylights) to reduce dependency on lighting.	Reduces electricity consumption and associated emissions by a significant amount.	Cost associated with installation. Passive daylight systems can be as simple as skylights but can be as complex as mirror tunnel systems.	Could potentially greatly reduce lighting demand of buildings.
	Building Management Systems (BMS) Automate and optimise lighting and HVAC systems.	Will reduce heating and electricity emissions by reducing wastage, but cannot eliminate them. Impact is limited compared to other solutions.	Cost of implementation due to the need for additional sensors and instruments. Sometimes the cost-benefit of such as system is not favourable. BMS/EMS systems are susceptible to having blind spots if not fully integrated into building design. Difficult to scale.	A method of ensuring that energy usage is low as possible within a site. A way of identifying where energy is being wasted.
	Replanning of airfield layout Move runway position to reduce taxi distance or reduce number of runways used	Will reduce impact of ground vehicle and aircraft taxi emissions. However, does not eliminate them and there are more effective methods of tackling these issues.	Expensive and will take a large amount of time. Will render airfield inoperable if there is not an available alternative runway	Can improve efficiency of ground operations significantly
REPLACE	**Anaerobic Digesters** Use Biogas as a source of electricity production for ground vehicles/auxiliary systems	Biogas has the potential to reduce greenhouse gas emissions greatly. This could be used to address ground vehicles, heating needs and electricity production.	Potentially expensive to implement	Technology is mature. Can feed organic waste products from the airport into the feed stock. Whilst commercial value is currently low, this could increase as the cost of diesel increases. There is potential that bio-gas facilities could be used to make SAFs, enabling airfields to produce their own aviation fuel onsite.
	Building Replacement Wholesale replacement of buildings where more cost effective than refurbishment	Rebuilding enables design around efficiency and energy performance so could cut demand of heating and electricity greatly.	Cost/time and carbon impact of demolition and construction works It has been noted that new hangars have a slower uptake of usage, there may be costs preventing uptake	Large reduction in emissions from inefficiencies of old buildings New facilities more likely to attract new business/increase perception of an airfield
	Renewable electricity via direct line Only buy energy from suppliers that use renewable generation sources.	Contributes towards net zero electricity emissions but does not address emissions associated with heating or ground vehicles (e.g. burning of fossils fuels).	Dependant on availability of local renewable generation facilities. Requires contract negotiation. May be expensive compared to green tariff electricity.	A potentially very quick way to decarbonise electricity used onsite. Transparency over electricity generation Resilience to electricity price escalation or power interruption
	On-site wind power Implement wind turbines to reduce dependency on power grid	Whilst renewable energy generation methods will reduce or eliminate electricity associated emissions. They will not be able to be implemented at all airfields, so as a general solution their impact is limited.	Poses a potential hazard to aircraft, as a result vertical axis wind turbines may be the only viable option. Will need to obtain correct permissions. Cost of installation Intermittent supply, so needs to be bolstered by energy storage and/or grid connection	Increase energy independence and reduced reliance on grid. Potential to sell excess energy back to grid to generate income. Resilience to electricity price escalation
	On-site solar power Implement solar power to reduce grid dependency	Whilst renewable energy generation methods will reduce or eliminate electricity associated emissions. They will not be able to be implemented at all airfields, so as a general solution their impact is limited.	Glare from solar panels pose a potential risk to pilots. Require space, may not be practical to implement. Cost of installation Intermittent supply, so needs to be bolstered by energy storage and/or grid connection	Increase energy independence and reduce reliance on grid. Potential to sell excess energy back to grid to generate income. Resilience to electricity price escalation

Monitor: Future solutions that require further development before they can be deployed at scale				
REPLACE	**Hydrogen powered ground vehicles** Use hydrogen powered ground vehicles (only water emissions)	Eliminates CO_2 emissions from ground vehicles (the largest contributor to ground emissions).	Cost of implementation. Storage and procurement of hydrogen, which is not yet widely available. Technology exists but has not been fully exploited. Specialist vehicles (e.g. fire trucks) have not yet been developed.	Opportunity to have a common fuel source for both aircraft and ground vehicles in the long term. Ground vehicles are a large part of airfield emissions. Specialist ground vehicles can potentially be retrofitted with an H_2 internal combustion engine
	On-site hydrogen power generation Hydrogen fuel cells for on-site power generation	Would enable sites to produce their own carbon-free electricity. The current cost of implementation is high, so widespread implementation is unlikely in the short term.	Concern regarding safety of hydrogen storage. Technology has not matured yet.	Avoid need to use power grid and eliminates associated carbon emissions. Potentially a reliable source of clean and cheap energy in the longer term
	Passive heat transfer systems Interseason heat transfer systems use surface embedded heating pipes that prevent ice formation on tarmac in winter and can harvest heat energy in summer months.	A method of reducing emissions from heating. Quantifiable impact is difficult to predict accurately but estimated to be low compared to other solutions	Would require runway/taxiway/parking stands to be out of action for a significant period in order to install system, incurring monetary losses on-top of cost of system.	A way of both preventing the use of de-icing liquid (a pollutant) and harvesting heat in the summer months.

B.1.2 Aircraft

	Solution	Impact Rating Justification	Barriers	Opportunities
Plan for: proven solutions that require moderate to significant effort and/or cost to implement				
REDUCE	**Aircraft Traffic Management** Increase efficiency of aircraft traffic management in both the air and on the ground	Aircraft have the largest carbon impact, increasing efficiency of operations and thus preventing/reducing emissions can greatly reduce emissions without the need for technological development or great investment.	Process could be difficult and lengthy if requiring oversight from CAA.	May not require any technological improvements Can improve operators and pilots' experience of using the airport as well as reducing emissions
REPLACE	**Sustainable Aviation Fuel (SAF)** Increase use of SAFs	SAF does lead to a net reduction in CO_2 over its life cycle, with some sources (such as IATA) claiming an 80% life cycle reduction. However, though SAFs are promising there are issues regarding integration into the supply chain and cost that may prevent widespread adoption. Furthermore, there is a need to ensure quality and origin of feedstock. SAFs are an important step to decarbonisation but should not be considered an end solution.	SAFs are generally viewed negatively by airfields and pilots. SAFs are difficult to source, supply is often unreliable. SAFs are currently expensive compared to standard aviation fuels.	If the supply/cost issues of SAFs can be addressed, it may be the preferred option. Most likely to mature first of all zero carbon technologies in development.
Evaluate: More costly solutions that will be effective in some situations subject to evaluation				
REDUCE	**Flight Simulators** Use flight simulators as much as possible during training to reduce aircraft flight hours	Simulators could be used to reduce the number of additional flying hours and produce much less CO_2 per hour than an aircraft, reducing CO_2 emissions from flight training. However, current regulations require a minimum number of hours on an aircraft type, which in a general aviation context is not permitted to be conducted in simulators.	Ensuring there are enough simulators Ensuring that time in simulators is adequate. Costs can be high h.	Potential to bring down the usage of aircraft for training by a considerable amount.
REDUCE	**Predictive Maintenance** Use tools such as AI to make maintenance planning and scheduling more efficient	Will help to reduce emissions associated with maintenance and can support improving operational procedures. However, overall impact on carbon emissions of this solution is likely to be small.	Though AI-enabled predictive maintenance has been applied successfully in civil aviation, there are still issues with applying it to more complex component and maintenance environments. Technology would need to be tailored to aircraft type, adding time, cost and increased complexity. This makes it applicable to large fleets (flight schools) but less practical for hobby users.	Reduces maintenance costs and aircraft down time. Breakthroughs in AI technology could bring down the cost of implementation and improve effectiveness.
REDUCE	**Fuel Efficiency** Improved efficiency of aircraft powertrains (engines) and airframe aerodynamics to reduce fuel consumption	Current predictions estimate an improvement in aviation efficiency of roughly 2% per annum. Whilst this would result in a cumulative reduction of around 61% by 2050, this is investment dependent and is a slow method of decarbonisation.	Is dependent on technological development occurring. May not necessarily happen quickly in GA without outside involvement.	Reduce aircraft energy needs and therefore emissions
REDUCE	**Ground Power Connection** Using electric ground power during aircraft flight checks instead of on-board petrol APU for aircraft that have one.	This could greatly reduce ground emissions of some aircraft. However, the proportion of GA aircraft this applies to is limited (approximately 8%) and ground emissions are only a small proportion of total flight emissions.	Time and monetary cost of implementing such a system into terminals of already operating airports	Significantly cut ground emissions from some aircraft
Monitor: Future solutions that require further development before they can be deployed at scale				
REDUCE	**Electrically towed taxi** Tow aircraft to runway during taxi using electric vehicles (e.g. Taxibots)	Could eliminate most of ground emissions (up until take-off). Ground emissions make up approximately 10% of aircraft emissions. This would be a moderate reduction in total GA emissions (5-7%).	Current development is geared towards commercial/civil aviation. Would require some technological investment as a result. Would need enough electric tractors to ensure queues do not develop	Could significantly reduce the fuel burned (and thus CO_2 emitted) during taxi Reduction in fuel costs
REPLACE	**Hydrogen Aircraft** Use hydrogen powered aircraft	The only emission from hydrogen aircraft is water. Aircraft greenhouse gas emissions would be reduced to those associated with hydrogen production and aircraft maintenance/production.	The technology is at an earlier stage of development when compared to electric aircraft. Price of new aircraft. There are concerns about the safe storage of hydrogen.	A potential route to zero-emissions flight in the longer term
REPLACE	**Electric Aircraft** Use electric powered aircraft	No direct emissions from electric aircraft so aircraft CO_2 emissions could be eliminated. However, the true carbon impact depends on how their power is sourced (i.e. wind farms, nuclear etc.), and other emissions such as maintenance and production/disposal.	Technological issues (range and charging times) are currently limiting development and adoption of electric aircraft. Increased load on the power grid. Price of new aircraft.	Can eliminate direct emissions from aircraft.
REPLACE	**Zero Carbon Fuel Production** Onsite production of SAFs and hydrogen	This solution helps to reduce and resolve the issues that limit the effectiveness of SAFs (as addressed earlier), the key barriers being cost and availability. Therefore, despite this being an indirect solution, its impact could be high as it will accelerate effective SAF usage.	Reduce the cost availability barriers that exist with these solutions	This will be expensive to implement. There are issues concerning space availability which will limit which sites can adopt this solution.

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