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8. Carbon: Baseline

Prepared for the Airports Commission

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Contents

Executive Summary

This report provides a baseline to support the assessment of the three shortlisted airport schemes against the Airports Commission's objective of minimising carbon emissions in airport construction and operation. The three schemes are:

- Gatwick Airport Second Runway (Gatwick 2R) promoted by Gatwick Airport Limited (GAL);
- Heathrow Airport Northwest Runway (Heathrow NWR) promoted by Heathrow Airport Limited (HAL); and
- Heathrow Airport Extended Northern Runway (Heathrow ENR) promoted by Heathrow Hub (HH).

The module considers estimates of baseline ('do minimum') and future runway scheme ('do something') emissions as far as is possible given the detail available at this stage. The baseline assumes the 'do minimum' base case defined as *'how the airport will develop in the absence of a scheme to deliver an additional runway'*. Carbon emissions related to the future operation of Gatwick and Heathrow based on most recent 2030 master plans are considered and reported on separately. The Heathrow 2030 master plan is taken to be the baseline for both Heathrow Airport expansion schemes as it is identical in carbon terms for both development options.

In establishing the baseline for a 60 year appraisal, the do minimum has a base date of 2025 (Gatwick 2R) and 2026 (Heathrow NWR and ENR) in line with assumed opening dates of 'do something' development, and corresponding end dates at 2085 / 2086. Comparisons for the years 2030, 2040 and 2050 are considered.

Five areas are identified by the Appraisal Framework where emissions may change:

- increased airport capacity leading to a net change in air travel;
- departure and arrival route changes through altered flight operations;
- construction of new facilities and surface access infrastructure;
- airside ground movements and airport operations; and
- changes in non-aviation transport patterns brought about by a scheme's surface access strategy

Table A1 outlines the areas that have been considered within this appraisal.

Table A1: Areas covered by this appraisal

Appraisal Framework Emissions Area	Reported in:
Increased airport capacity	Total aircraft emissions from ATMs, including cruise.
Route changes	Departure and arrival route impacts [qualitative commentary only].
Construction	Carbon emissions from infrastructure construction.
Airside ground movements	Airside (aircraft) ground movement emissions [subset of aircraft emissions].
Airport operations	Airport operations emissions from energy and fuel use.
Changes in non-aviation transport	Passenger surface access emissions.

Gatwick Airport Baseline

Analysis of the Gatwick baseline carbon emissions is based on the published single runway masterplan through to 2030, and the Do Minimum passenger and ATM forecasts developed by the Airports Commission. This sees ATMs at broadly around the 280,000 level between 2020 and 2050, with a variance of up to 8,000 ATMs. There is limited construction of infrastructure during this period under the do minimum scenario. The most significant volume of emissions are related to air travel, but these decrease slightly over the period, linked to improved fuel efficiency of airline fleets. Surface access emissions remain the second largest source of CO2 and reduce over the assessment period, with fluctuations linked to annual passenger numbers. Emissions from buildings and airport operations also reduce over time, most significantly due to the presumed decarbonisation of grid electricity.

Table A2 outlines the carbon baseline for Gatwick Airport.

Table A2: Carbon assessment findings for the Gatwick Airport baseline

Area of Emissions	2030	2040	2050	60 year appraisal 2025-2085
	tonnes of carbon dioxide (tCO_2)			
Air travel (ATMs) (UK aviation total)	3,893,295 (39,193,204)	3,961,133 (39,489,040)	3,860,892 (37,514,764)	238,421,704 (2,327,372,378)
Airside ground movements	134,673	135,988	138,308	8,385,010
Passenger surface access journeys	288,863	297,307	308,530	18,541,500
Airport operations energy & fuel use	36,867	27,467	24,320	1,632,411
Total operational CO_2 emissions	**4,219,025**	**4,285,907**	**4,193,742**	**258,595,615**
Construction of infrastructure*	n/a	n/a	n/a	3,016,218

* Construction emissions are actually calculated as CO_2 equivalent, or CO_2e.

Air travel (Air Transport Movements)
The baseline level of emissions for air travel at Gatwick remains around 3.9 million tonnes CO_2 over the assessment period, reflecting some growth in Air Transport Movements (ATMs) from 277,000 in 2025 (up from approximately 265,000 in 2012) to 285,000 in 2050 and improved fuel efficiency.

Ground movements (Component of air travel)
These emissions should be considered a subset of air travel related emissions. Baseline emissions due to ground movements are forecast to increase slightly over the assessment period, with variation associated with the growth in ATMs.

Departure & arrival route impacts
Emissions impacts from route changes cannot be calculated at this stage of assessment. Greatest impact will be from airspace redesign above 7000ft.

Passenger surface access transport
Estimated using the currently assumed modal share between private vehicle, rail and coach, baseline emissions due to surface access passenger journeys have

been calculated to increase by almost 7% (against an increase in annual passengers of 13%) between 2030 and 2050. Freight emissions are not calculated.

Airport operations (fixed infrastructure and ground support equipment)
Baseline emissions due to energy use in operations are expected to reduce across the study period. This can be attributed to the anticipated decarbonisation of the grid, due to the dominance of electricity consumption in airport energy use. Local activity to manage energy and fuel use may reduce operational emissions further.

Construction of airport facilities & SA infrastructure
There is limited large scale construction at Gatwick Airport, as indicated within GAL's 2030 master plan. While full details of how the construction spend will be distributed is not available, calculated emissions due to construction activity overall are within the range expected for the construction indicated.

Heathrow Airport Baseline

Analysis of the Heathrow baseline carbon emissions is based on the published two runway masterplan through to 2030, and the Do Minimum passenger and ATM forecasts developed by the Airports Commission. This sees ATMs at broadly around the 480,000 level between 2020 and 2050, with a variance of up to 12,000 ATMs. There is significant construction of infrastructure during this period under the do minimum scenario, as the airport toastrack configuration is completed, replacing older terminals and expanding satellite capacity. The most significant volume of emissions are related to air travel, but these decrease over the period, linked to changes to the Heathrow fleet, improved fuel efficiency of aircraft present within that fleet. Surface access emissions remain the second largest source of CO2 and increase over the assessment period, with growth linked to annual passenger numbers and the proportion of those who use surface access to reach the airport. Emissions from buildings and airport operations also reduce over time, most significantly due to the presumed decarbonisation of grid electricity.

Table A3 outlines the carbon baseline for Heathrow Airport.

Table A3: Carbon assessment findings for the Heathrow Airport baseline

Area of Emissions	2030	2040	2050	60 year appraisal 2025-2085
	tonnes of carbon dioxide (tCO_2)			
Air travel (ATMs) (UK aviation total)	20,099,848 (39,193,204)	19,184,305 (39,489,040)	16,570,400 (37,514,764)	1,076,713,933 (2,327,372,378)
Ground movements (component of air travel)	396,313	396,855	385,891	23,795,682
Passenger surface access journeys	373,888	413,575	469,066	27,145,524
Airport operations energy & fuel use	125,336	91,962	81,007	5,377,172
Total operational CO_2 emissions	**20,599,072**	**19,689,842**	**17,120,473**	**1,109,236,629**
Construction of infrastructure*	n/a	n/a	n/a	13,514,607

* Construction emissions are calculated as CO_2 equivalent, or CO_2e.

Air Travel (Air Transport Movements)
The baseline level of emissions for air travel at Heathrow drops from 20 million tonnes CO_2 in 2030 to around 16.6 million tonnes in 2050. The decrease over time reflects a reduction in ATMs (from 484,000 in 2025 to 471,000 in 2050), and aircraft efficiency improvements.

Ground movements
These emissions should be considered a subset of air travel related emissions. Emissions due to airside ground movements reduce by 10,000 tonnes over the assessment period, associated with the reduction in ATMs.

Departure & arrival route impacts
Emissions impacts from route changes cannot be calculated at this stage of assessment. Greatest impact will be from airspace redesign above 7000ft.

Passenger surface access transport
Estimated using the currently assumed modal share between private vehicle, rail and coach, baseline emissions due to surface access passenger journeys have been calculated to increase by almost 25% (against a net increase in passengers of 10%) between 2030 and 2050. Freight emissions are not calculated.

Airport operations (fixed infrastructure and ground support equipment)
Baseline emissions due to energy use in operations are expected to reduce across the study period. This can be attributed to the anticipated decarbonisation of the grid, due to the dominance of electricity consumption in airport energy use. Local activity to manage energy and fuel use may reduce operational emissions further.

Carbon emissions from infrastructure construction
There will be significant construction at Heathrow Airport under the do minimum scenario as derived from HAL's 2030 master plan. Overall emissions due to construction activity are within the range expected for the construction planned.

1. Introduction

This report has been prepared to provide evidence to support Module 8: Carbon. Under this module the objective is to minimise carbon emissions in airport construction and operation.

This report identifies the baseline for carbon (dioxide) emissions for these schemes:

- Gatwick Airport Second Runway (Gatwick 2R) promoted by Gatwick Airport Limited (GAL);
- Heathrow Airport Northwest Runway (Heathrow NWR) promoted by Heathrow Airport Limited (HAL); and
- Heathrow Airport Extended Northern Runway (Heathrow ENR) promoted by Heathrow Hub (HH).

The module considers estimates of baseline ('do minimum') and future runway scheme ('do something') emissions as far as is possible given the detail available at this stage. The baseline assumes the 'do minimum' base case defined as *'how the airport will develop in the absence of a scheme to deliver an additional runway'*. Carbon emissions related to the future operation of Gatwick and Heathrow based on most recent 2030 master plans are considered and reported on separately. The Heathrow 2030 master plan is taken to be the baseline for both Heathrow Airport expansion schemes as it is identical in carbon terms for both development options.

In establishing the baseline for a 60 year appraisal, the do minimum has a base date of 2025 (Gatwick 2R) and 2026 (Heathrow NWR and ENR) in line with assumed opening dates of 'do something' development, and corresponding end dates at 2085 / 2086. Comparisons for the years 2030, 2040 and 2050 are considered.

Based on the United Nations Framework Convention on Climate Change approach to allocating emissions, those from aviation are attributed to a state from its domestic flights and allocated from international flights by departing state, using Bunker Fuel sales and agreed emissions factors[1]. By this measure, aviation emissions account for about 6% of the greenhouse gas (GHG) emissions in the UK (Dft, 2013), and also represent a similar percentage of total global aviation emissions, although the UK share is expected to fall over the next 20 – 30 years due to rapid growth in developing aviation markets such as China, India, and Latin America (Sustainable Aviation, 2012).

According to the Department for Transport's (DfT) published data "Total greenhouse gas emissions from transport" for 2011 (DfT, 2012), UK domestic / international aviation emissions represent 21.6 % of the transport sector's GHG contribution to the UK's carbon footprint. This compares to 67.5% of transport emissions being related to road vehicles (40% attributable to cars, 14% to heavy goods vehicles) and 10.9% to rail, domestic / international shipping and other[2].

Although a small proportion of UK GHG emissions, the absolute volume of those attributed to aviation has increased significantly since 1990; the importance of managing carbon emissions in aviation is thus understandably recognised by major stakeholders including the UK Government (DECC, 2012) and the European

[1] Other mechanisms for allocating emissions have been discussed: see e.g. Lee, David and Owen, Bethan (2006) and Southgate, (2013)

[2] Other mainly consists of 'military aircraft and shipping' and 'aircraft support vehicles'.

Commission (EC, 2011), the Committee on Climate Change (CCC), the aviation industry (e.g. Sustainable Aviation, ACI and IATA) (IATA, 2014) and environmental NGOs (Greenpeace 2009).

In terms of UK aviation GHG emissions from air transport movements (ATMs) dominate the CO_2 impacts of aviation. That said, all airport activities (construction and operation) have emissions implications. As well as the flights, surface access is a particularly significant source of airport carbon emissions (as noted in DfT Aviation Emissions Forecasts 2009 (DfT, 2009)). Energy used for day-to-day operations in buildings and on the airfield, together with water use, waste management and construction / demolition result in carbon emissions, either directly or (mostly) indirectly.

Therefore the Appraisal Framework identifies five areas where it is considered that there could be an emissions impact. The Appraisal Framework also highlights some other aspects of emissions that are not airport specific (such as non- CO_2 effects). Such effects are not quantified in this report due to calculation uncertainty.

Five areas are identified by the Appraisal Framework where emissions may change:

- increased airport capacity leading to a net change in air travel;
- departure and arrival route changes through altered flight operations;
- construction of new facilities and surface access infrastructure;
- airside ground movements and airport operations; and
- changes in non-aviation transport patterns brought about by a scheme's surface access strategy

Table 1.1 outlines the areas that have been considered within this appraisal.

Table 1.1: Areas covered by this appraisal

Appraisal Framework Emissions Area	Reported in:
Increased airport capacity	total aircraft emissions from ATMs, including cruise
Route changes	departure and arrival route impacts [qualitative commentary only]
Construction	carbon emissions from infrastructure construction.
Airside ground movements	airside (aircraft) ground movement emissions [subset of aircraft emissions]
Airport operations	airport operations emissions from energy and fuel use
Changes in non-aviation transport	passenger surface access emissions[3]

[3] Ideally all surface transport emissions would be reported; at this stage, emissions associated with freight have not been quantified as there are limited baseline data available.

2. Methodology and Legislation

This section covers:

- An outline of the baseline carbon emissions methodology across the different sources within the appraisal framework
- Key legislation and relevant guidance applicable to aviation carbon
- Summary of key assumptions and limitations

2.1 Methodology

Carbon dioxide (CO_2) emissions (often referred to by the shorthand of "carbon emissions") from anthropogenic sources are contributing to global warming. This contribution occurs irrespective of where the emissions are released; it is the magnitude that is important. Carbon is therefore different to air quality emissions, where spatiality is important. This affects how carbon emissions are investigated.

Due to the range of CO_2 emissions considered in this baseline assessment, a number of different methods and inputs have been used to calculate the emissions. In all cases, the driving data are those from the Airport Commission Demand Forecasts 2014 (both Passengers and ATMs). To address the five areas where emissions may change due to airport scheme development, this report applies the follow methodologies.

- Total aircraft emissions from ATMs, including cruise - have been estimated based on the methodology used by the UK Department for Transport (DfT) Aviation Forecasts (DfT, 2011b and DfT, 2013);
  - Departure and arrival route impacts – are not calculated here as there is currently insufficient input data available to support robust emissions calculation. Most emissions benefits will come from routes above 7000ft.
  - Airside (aircraft) ground movement emissions – are forecast on a pro-rata basis from historic reported emissions associated with the relevant components of the Landing and Take-Off (LTO) cycle from both Gatwick (GAL, 2014) and Heathrow (HAL, 2014), giving an emissions / ATM value, applied to future ATMs.
- Passenger surface access emissions – are calculated following the methodology as described in the DfT Aviation Forecast 2008, with some adjustments to account for surface access mode share from Jacobs analysis.
- Airport operational emissions from energy and fuel use – are forecast on a pro-rata basis using reported energy use / emissions and changes in passenger numbers or area of main buildings.
- Carbon emissions from infrastructure construction - are estimated based on indicative costs for master plan developments, using benchmarks from WRAP (2013)

The required timescale for this assessment is from the indicated opening year for each new runway option and then for a period of 60 years. The suggested opening year for the proposals is 2025 for Gatwick Airport and 2026 for Heathrow Airport. The Airports Commission Assessment of Need Carbon Capped (AoN Carbon Capped) provides forecasted carbon emissions for the period 2011 – 2050. It does not provide forecasted carbon emissions for the period 2051 to 2085 (Gatwick) or

2086 (Heathrow). Where sufficient information to forecast beyond 2050 does not exist, this has been assumed to remain static after 2050.

For clarity and brevity, only results for the opening year, 2030, 2040 and 2050 are displayed in the body of the report. For datasets from between the opening year and 2050 please refer to Appendix C.

The methods used to identify the carbon impacts are as follows (for a more detailed methodology, see Appendix B).

2.1.1 Total aircraft emissions from ATMs

These emissions have been calculated to provide data to understand the carbon effects of the Appraisal Framework's area of "*increased airport capacity leading to a net change in air travel*", based on the methodology used by the UK Department for Transport (DfT) Aviation Forecasts.

For forecasting of carbon emissions from flights, the UK Department for Transport (DfT) has developed a set of aviation carbon emissions forecast modelling tools. The DfT provides carbon emissions for each UK airport, alongside forecasts of passenger numbers and air transport movements, on a periodic basis (most recently in DfT, 2009, DfT, 2011b and DfT, 2013).

The Airports Commission Do Minimum (DM) and AoN Carbon Capped[4] 2014 are used as the major source for baseline and scheme assessment (they provide passenger numbers, ATMs and carbon outputs). The AoN Carbon Capped Forecast 2014 contains estimated carbon emissions for all UK airports each year from 2011 to 2050 for:

- A baseline (no new runway) scenario; and,
- The proposed new runway schemes (in different scenarios: this assessment uses AoN Carbon Capped as noted above[5]).

The following aspects of aircraft emissions are included in the model carbon output (DfT, 2009):

- All domestic passenger flights within the UK;
- All international passenger flights departing UK airports;
- All passenger aircraft while on the ground in the UK (e.g. taxi-ing);
- All domestic freighter aircraft within the UK;
- All international freighter aircraft departing UK airports; and
- All freighter aircraft while on the ground in the UK (e.g. taxi-ing).

2.1.2 Departure and arrival route impacts

Available data on departure and arrival routes has been reviewed to determine the possibility of estimating carbon emissions impacts of the Appraisal Framework's area of "*departure and arrival route changes through altered flight operations*". At

[4] The carbon capped forecast restricts demand for air travel to that which can be met under a UK aviation emissions total of circa 37.5 million tonnes CO_2 in line with the CCC recommendations.
[5] Alternative scenarios include Low Cost is King and Global Growth, which see different allocation of ATMs and fleet mixes. There is also a carbon traded interpretation of all scenarios, which considers the effect of trading carbon to allow the rest of the UK economy to address the total emissions cap, rather than restricting aviation demand. This assessment uses the AoN Carbon Capped scenario for clarity.

this stage of airport expansion proposals, route changes and flight operations are not developed in sufficient detail to estimate emissions impacts. Indicative routes (that were developed as a result of a workshop between the Commission, the CAA, NATS and the promoters, for noise modelling purposes) do not allow for any meaningful calculation of carbon emissions impacts to be assessed.

UK airspace, together with that of the rest of Europe is subject to redesign for enhanced safety, efficiency and environmental reasons (CAA, 2011). The Future Airspace Strategy (FAS) indicates that it will deliver 500,000 tonnes of CO_2 savings through more efficient aircraft routing. The major changes in routes that will offer emissions savings will partially come from routes to 7000ft but mostly above this altitude, as other environmental priorities (particularly around overflight of built up areas and noise management) take precedence below 7000ft (CAA, 2011). Further assessment of carbon emissions impacts of departure and arrival routes must be undertaken when sufficient information is available.

2.1.3 Airside (aircraft) ground movement emissions

These impacts have been assessed to provide data to understand the carbon effects of the Appraisal Framework's area of the first aspect of "*airside ground movements and airport operations.*" The calculation gives CO_2 emissions due to airside ground movements resulting from aircraft landing / take-off rolls, taxi, hold and at-stand engine (including auxiliary power units – APU) use.

These emissions are *not* additional to the total aircraft emissions from ATMs, as they are already included by the DfT methodology used. Ground movement emissions are calculated to show a key part of the Landing and Take Off (LTO) cycle that the airport can influence through e.g. terminal, stand and taxiway design; Collaborative Decision Making (CDM); and procedures such as reduced engine taxi (Sustainable Aviation, 2010) and provision of Fixed Electrical Ground Power (FEGP).

The method used for this basic assessment uses historic reported emissions associated with LTO from Gatwick (GAL, 2014) and Heathrow (HAL, 2014) and respective ATMs in those years in order to give LTO emissions / ATM. The proportion of the LTO which is ground based is then determined using ICAO Times-in-Mode (TIM) and thrust settings, resulting in an ICAO-Times estimate: a factor that is applied to the total LTO to determine the ground based proportion. A sensitivity is also generated utilising times in mode submitted by the proposers, which is presented within our results as "HAL/GAL Reported Times" forecast. This is then factored to reflect the AoN Carbon Capped Forecast ATMs for the different schemes.

2.1.4 Passenger surface access emissions

These impacts have been assessed to provide data to understand the carbon effects of the Appraisal Framework's area of the first aspect of "*changes in non-aviation transport patterns brought about by a scheme's surface access strategy.*" The full methodology used for passenger surface access emissions is explained in detail in Annex I of UK Air Passenger Demand and CO_2 Forecasts (DfT, 2009). Using figures provided by DfT, based on AoN Carbon Capped Forecast 2014, the model calculates vehicle-km (private car) and passenger-km (rail and coach) from UK origin / destinations on a regional basis, using a 2008 modal share forecast (derived from the CAA annual passenger survey) to generate activity data; carbon emissions are then calculated using factors derived from WebTAG 2014 (private vehicle) or Defra 2014 (rail and coach). It is acknowledged that modal share of travel to the airports concerned has changed over the last six years and will change to reflect surface access strategies. For this reason, for Gatwick and Heathrow only, a supplementary calculation is presented, through adjusting the point of origin modal share to reflect the 2030 regional modal share identified in the Jacobs Surface Access analysis (Jacobs, 2014b 2014c 2014d).

WebTAG emissions factors may only be forecast to 2035 due to data limitations, and Defra emissions factors do not reflect future changes to the carbon intensity of rail or coach journeys. The output of the model gives five year interval data (2020 to 2050); surface access emissions are then forecast forwards to 2085 / 2086 presuming no change to passenger numbers, mode share or emissions factors.

2.1.5 Airport operations

These impacts have been assessed to provide data to understand the carbon effects of the Appraisal Framework's area of the second aspect of "*airside ground movements and airport operations*", through calculating emissions associated with the operation of an airport related to the day-to-day electricity, gas and other fuel usage of that airport. Other carbon emissions associated with consumables, such as refrigerants or operational waste, are acknowledged but have not been included in this assessment due to insufficient data being available for robust carbon analysis (although see the waste section of the Place Baseline and Assessment Reports for waste arisings) and as these are a relatively minor source of CO_2e emissions.

For the purposes of this forecast the following energy consumption drivers have been applied: electricity consumption is closely related to passenger numbers; gas consumption is closely related to the internal floor area of the airport terminals; and other fuel use (e.g. ground transportation) is closely related to the number of ATMs.

Future emissions factors for each of these consumables were identified. For electricity this utilised the tables produced by the Interdepartmental Analysts' Group (IAG) on Energy and Climate Change for long term emissions factors from energy generation (DECC, 2014). For gas and fuel, the current values reported in the Defra Greenhouse Gas Conversion Factor Repository were used and presumed to hold across the assessment period (in line with DfT Aviation Forecast 2009, Annex I).

2.1.6 Carbon emissions from infrastructure construction

These impacts have been assessed to provide data to understand the carbon effects of the Appraisal Framework's area of "*construction of new facilities and infrastructure*", and the forecasts are estimated based on indicative costs for master plan developments derived from the Cost and Revenue reports assessment of core construction (Jacobs, 2014a), using benchmarks from the WRAP Resource use benchmarks tool, for embodied carbon emissions (WRAP, 2013).

The estimation includes emissions that are a result of the energy expended in order to produce the materials used (embodied carbon) and the emissions due to fuel use on site.

Emissions that result from the transport of material to site and emissions that result from the removal of waste from the construction site are discussed but not quantified, as insufficient information exists at this stage to estimate construction transport fuel use in a robust manner.

It should be noted that construction emissions are by necessity reported as CO_2e, whereas aviation (aircraft and surface access) and estate operational emissions are reported as CO_2 (to be consistent with other DfT Aviation Forecast and CCC reporting: the difference in the CO_2 and CO_2e for these other emissions sets is always less than 1% and is not considered of significance given the assumptions and uncertainties in activity inputs required at this stage).

2.1.7 Monetisation of carbon emissions

Having established an emissions level for each assessment year, establishing a carbon value was accomplished through the use of the Green Book Supplementary Guidance (DECC-IAG, 2014) published by the Interdepartmental Analysts' Group (IAG) on Energy and Climate Change, which includes tables showing the projected carbon values within the European Union Emissions Trading Scheme (EU ETS). These forecast values are the recommended valuation method for incorporating carbon emissions assessments into benefit-cost analysis and other policy analysis.

The carbon emissions totals for a given year are multiplied by the carbon price for that year, and then discounted in accordance with Green Book guidance (HM Treasury, 2011). Due to the long term nature of this appraisal, with an assessment period of 60 years and looking 70 years into the future, the assumption of a declining long-term discount rate was utilised. For values in the years 2014 to 2044, the discount rate applied is 3.5%, for 2044 to the end of the assessment the discount rate applied is 3%. If the appraisal period were to extend beyond 2089 then a lower discount rate would be applied to that period.

No monetised values are presented in the baseline report, but are presented as covering change in emissions between baseline and scheme developments in the associated assessment report.

2.2 Legislation

The Climate Change Act 2008 ("the Act'') established a legally binding target to reduce the UK's greenhouse gas emissions by at least 80% below base year (1990) levels by 2050. The UK's carbon budgets as described within the Act set an envelope for UK emissions. However, while domestic aviation emissions are included within UK carbon budgets, international aviation emissions are excluded.

A number of problems with inclusion of international aviation (and shipping) emissions within the UK's carbon budgets and carbon target were identified. These difficulties remain broadly unresolved, and a decision on how to include international aviation carbon emissions within targets was deferred in 2012 (DECC, 2012).

The Committee on Climate Change (the CCC) has provided advice on the consequences of including international aviation emissions in UK carbon budgets and the 2050 target in the 2012 report "*Scope of carbon budgets – Statutory advice on inclusion of international aviation and shipping*", which recommended that such emissions be included in the 2050 target. The CCC has stated its position as follows:

- Long term aims for aviation emissions should reflect international/EU approaches rather than unilateral UK action, given risk of emissions leakage. However, planning assumptions are useful to inform the strategy for meeting the overall 2050 emissions target.

- An appropriate planning assumption for 2050 aviation emissions is to be around 2005 levels (i.e. 37.5 MtCO2). This is achievable through measures which are feasible, and is consistent with government and industry analysis, and objectives of the industry at UK and global levels.

The UK Government has noted that as "*aviation is predominantly international then a global regulatory framework is best placed to control aviation's carbon emissions*." (DECC 2012).The only currently agreed international regulatory framework is the European Union Emissions Trading Scheme (EU ETS) as applied to aviation. The EU-ETS is a carbon 'cap and trade' system launched in 2005 aimed at reducing industry's greenhouse gas emissions to a given level (cap) in the most cost-effective way (trade) amongst its participants. The level of the cap reduces over time.

Following Europe-wide agreement to EU Directive 2008/101/EC in 2008, aircraft operators were included in EU ETS from January 2012. All flights beginning and ending in Europe were included in ETS, although some exemptions applied. On 12 November 2012 the European Commission (EC) proposed to defer the requirement for airlines to surrender emission allowances for flights into and out of Europe until after the 2013 International Civil Aviation Organization (ICAO) General Assembly. The proposal was approved by the European Parliament and the Council on 24 April 2013. This became known as 'Stop the Clock'. After the ICAO General Assembly in September 2013, the EC proposed an amendment to the EU ETS for a European Regional Airspace Approach which was rejected by the European Parliament. A compromise agreement to limit the application of the scheme to an intra-European Economic Area (EEA) scheme came in to force on the 16th April 2014.

At a global level the International Civil Aviation Organization (ICAO) has committed to publish an agreed market-based measure (MBM) – carbon emissions trading or emissions offsetting – at its next General Assembly in 2016 with a view to the implementation from 2020.

Airports themselves are subject to carbon emissions and energy efficiency legislation. Larger airports are covered by the EU ETS if they have sufficient installed heat or power generation. Most airports in the UK are covered by the Carbon Reduction Commitment (CRC) Energy Efficiency Scheme – a requirement to buy allowances based on qualifying carbon emissions, alongside other reporting and documentation requirements.

New buildings and major refurbishments are covered by 'Part L Conservation of fuel and power' in the UK Building Regulations, and may also be subject to local planning requirements in this regard (e.g. local planning policy responding to Greater London Authority requirements).

The Climate Change Act also included provisions for the Adaptation Reporting Power which required those responsible for national infrastructure to prepare climate change adaptation risk assessments and action plans. Both Gatwick and Heathrow Airports produced their first assessments and plans in 2011.

In addition to regulatory requirements, the international commercial aviation industry has developed a series of voluntary commitments to address carbon emissions. The industry umbrella group, the Air Transport Action Group (ATAG - an alliance of airlines, airports, aircraft manufacturers and air navigation service providers), has published three targets within a roadmap for aviation carbon emissions to 2050. ACI's Airport Carbon Accreditation Scheme has already been noted. In the UK, 'Sustainable Aviation' is a group, similar to ATAG but UK focused, which has produced a roadmap of how carbon emissions from aviation may be reduced through increased fuel efficiency, the use of biofuels and market-based measures .

2.3 Assumptions and limitations

2.3.1 Total aircraft emissions from ATMs, including cruise

This appraisal uses ATMs, passenger and carbon data as generated by the AoN Carbon Capped. Sense checks have been undertaken, but no independent analysis of ATMs and carbon deriving from full flight has been attempted. The scenario that forms the basis of this appraisal is Do Minimum (DM) and AoN Carbon Capped (i.e. carbon emissions out-turn for UK aviation system in 2050 is circa 37.5 million tonnes). In the do minimum scenario, growth in ATMs is not constrained by planning caps, but practical available capacity.

For aircraft emissions, any increase or decrease in ATMs forecast under the other scenarios, or in the traded rather than capped carbon arena, results in broadly proportionate changes to carbon emissions, with minor variation due to changes in fleet mixes under the other scenarios. The full methodology for aviation emissions, including full assumptions, is presented in the DfT Aviation Forecast documents (DfT, 2011b and DfT, 2013).

2.3.2 Departure and arrival route impacts

At this stage of airport expansion proposals, route changes and flight operations are not developed in sufficient detail to estimate emissions impacts. Indicative routes (that were developed as a result of a workshop between the Commission, the CAA, NATS and the promoters, for noise modelling purposes) do not allow for any meaningful calculation of carbon emissions impacts to be assessed.

Further assessment of carbon emissions impacts of departure and arrival routes must be undertaken when sufficient information is available.

2.3.3 Airside (aircraft) ground movement emissions

ATMs are assumed as above. Emissions due to ground movements are included within the aircraft emissions figures as per the DfT Aviation Forecast methodology.

The estimations that have been made here for this portion of aircraft emissions are based on two calculations, as described in the methodology.

The first calculation uses the ICAO-Times Approach to calculation and a presumed ground movement factor derived from published information on LTO cycle at Gatwick and Heathrow Airports. This data source introduces a limitation in that ground based emissions per ATM are assumed to remain the same over time derived from a 2013 base, whereas local initiatives and technology improvements are expected to reduce the relative carbon intensity of this LTO aspect. These emissions are a subset of, and not in addition to, the overall ATM emissions.

The second calculation, applies the ICAO TIM and thrust setting information used for calculating air quality impacts, supplemented for sensitivity by using information supplied by Gatwick and Heathrow Airports regarding their existing / forecast baseline TIMs. In addition to assuming the accuracy of this data, this again introduces a limitation, as changes to airport design, and possibly aircraft fleets, will introduce variance.

2.3.4 Passenger surface access emissions

Passenger numbers are derived from AoN Carbon Capped Forecast.

Activity data are provided by DfT using the model as presented in Annex I of the DfT Aviation Forecast 2009. The full assumptions are presented in the original documentation. This method has a further limitation for this appraisal in using the 2008 "point of origin modal share" as derived from the CAA survey.

A sensitivity test was undertaken using adjusted 2030 modal share projection, derived from Surface Access analyses and the relevant assumptions (Jacobs, 2014b, 2014c, 2014d). The 2030 sensitivity test could only be applied to Gatwick and Heathrow, and not the remaining airports in the UK system, due to lack of data on forecast modal share.

Although it is acknowledged that both freight transport and staff travel to work may have some significance in terms of emissions footprints, emissions associated with these aspects of surface access have not been quantified as there are limited baseline data available. Given the uncertainty regarding freight tonnages and workforce, and distances travelled from and to airport, it was concluded that no robust pro-rata method could be identified at this stage, given the range of variables involved in activity data.

Emission Factors are derived from WebTAG 2014 and Defra Greenhouse Gas Conversion Factor Repository 2014. It is assumed that vehicle-km factors follow the WebTAG trajectory to 2035, at which point they are assumed static. Rail and Coach passenger-km factors are assumed to remain as 2014 in line with DfT 2009 method.

2.3.5 Airport operations emissions from energy and fuel use

The methodology as described assumes relationships between driving factors (passenger numbers, ATMs and floor area of terminals) based on publicly reported emissions and energy use. These are approximate only and are known to be subject to change due to efficiency improvements.

Emission factors are derived from IAG carbon valuation toolkit (Supporting Tables; Table 1 – Electricity and Table 2a - Fuels). Detailed assumptions regarding these factors are stated in other documents available from the Green Book supplementary guidance section of GOV.UK webpage.

2.3.6 Carbon emissions from infrastructure construction

The activity data for construction cost, phasing and footprints were taken from the Revenue and Cost Identification report (Jacobs, 2014a).

The emissions calculation method utilised WRAP benchmark factors; this places a limitation on the estimation as airport projects are not recorded in sufficient number to be part of the WRAP benchmark lists. For this reason, projected capital spend for each proposal was divided amongst different building / project types, assigned based on their use and similarity to the types listed in the WRAP benchmarking tool.

An estimation was made of an emissions factor for spend on runways and taxiways, derived from first principle estimation of materials used combined with materials factors from the Defra GHG repository. This is shown in Appendix B.

Several assumptions were made regarding the project phasing:

- The spend estimates were allocated into phases; as there was no clear indication about how the carbon intensity may vary across these phases it was decided to allocate the carbon emissions from fuel use and embodied carbon with the same ratio as spend per phase;
- Where construction is thought to occur prior to the assessment period it has been assumed to occur in the first year of the assessment period. It should be noted that this assumption this will impact the monetisation, as the real value of carbon over this time period fluctuates;
- Emissions although indicated as CO_2 are calculated as CO_2e.

2.3.7 Monetisation of carbon emissions

The monetisation has made use of the IAG supporting tables and Green Book discounting guidance in order to place a value upon the change in emissions brought about by each proposal. The core assumption is that EU ETS prices, as a way to value carbon-affecting projects, remain within the Low to High boundaries. While both the Central result and the Low to High range are presented for the baseline and the proposals, it is possible that there could be significant deviation from these values. For example, the demand scenario utilises the carbon capped assumption which assumes a given carbon price in order to deliver the required capped volume of emissions in 2050. Other scenarios are highly likely to result in different carbon prices to deliver a similar net impact across a wider carbon market.

2.3.8 Further limitations

As noted, emissions have been presented as CO_2 for consistency with Committee on Climate Change approaches and DfT Aviation Forecasts.

The variance between CO_2 and CO_2e (that is $CO_2 + CH_4 + N_2O$) is less than 1% in all cases, but is not reported for clarity and significance reasons.

The appraisal does not attempt to consider aviation non-carbon impacts (such as radiative forcing). Although this changes the overall emissions impact, the science regarding the effect remains uncertain, and these effects occur at high altitude and regardless of the scheme. Non-carbon impacts are not reported for clarity and uncertainty reasons.

3. Gatwick Airport

This section covers the following for Gatwick Airport:

- Study Area
- Baseline assessment for aircraft, surface access, operations and construction
- Conclusions

3.1 Study Area

For the Gatwick Airport Second Runway proposed development the study area is defined as Gatwick Airport, as developed in the published single runway master plan (GAL, 2012).

3.2 Baseline assessment

3.2.1 Total aircraft emissions from air transport movements (ATMs)

Table 3.1 presents the baseline (single runway, do minimum, carbon capped) carbon emissions from the DM Forecast 2014, for departing flights from Gatwick Airport for selected years between 2025 and 2050 alongside the total carbon emissions from all UK flights and the percentage of the UK total that occurs with flights from Gatwick. Figure 3.1 presents the full 25 year period emissions graphically.

Table 3.1 – Baseline CO_2 emissions: departing flights Gatwick Airport for 2025 – 2050

Year	Number of passengers	Numbers of ATMs	Gatwick Airport, tonnes CO_2	UK Total, tonnes CO_2	% of UK ATM emissions
2025	39,447,192	276,706	4,378,003	38,846,345	11.3
2030	41,082,700	277,919	3,893,295	39,193,204	9.9
2040	44,241,800	280,633	3,961,133	39,489,040	10.0
2050	46,589,192	285,420	3,860,892	37,514,764	10.3

While between 2025 and 2030, emissions are forecast to drop by about 11%, it can be seen that in the carbon capped scenario during the period 2030 to 2050 carbon emissions remain mostly steady (0.8% less in 2050 compared to 2030).

The explanation for this comes from the changes in the 3 drivers of aviation carbon emissions which are:

- distances flown by aircraft (determined by destination & route);
- fuel efficiency of the aircraft fleet (determined by airframe and engine); and
- type of fuel used (determined by carbon content of aviation fuel).

Figure 3.1 - Baseline CO_2 emissions: departing flights Gatwick Airport for 2025 – 2050

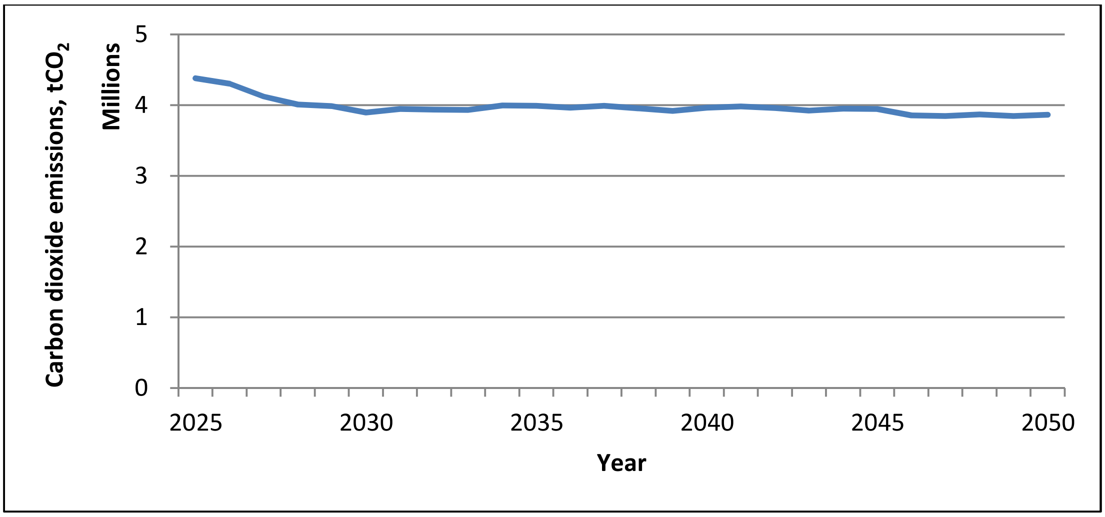


Figure 3.2 shows the changes in passenger numbers and ATMs during the period 2025 – 2050 at Gatwick Airport with one runway, as forecast in the AoN Carbon Capped.

Figure 3.2 – Gatwick Passenger numbers / ATMs 2030 – 2050

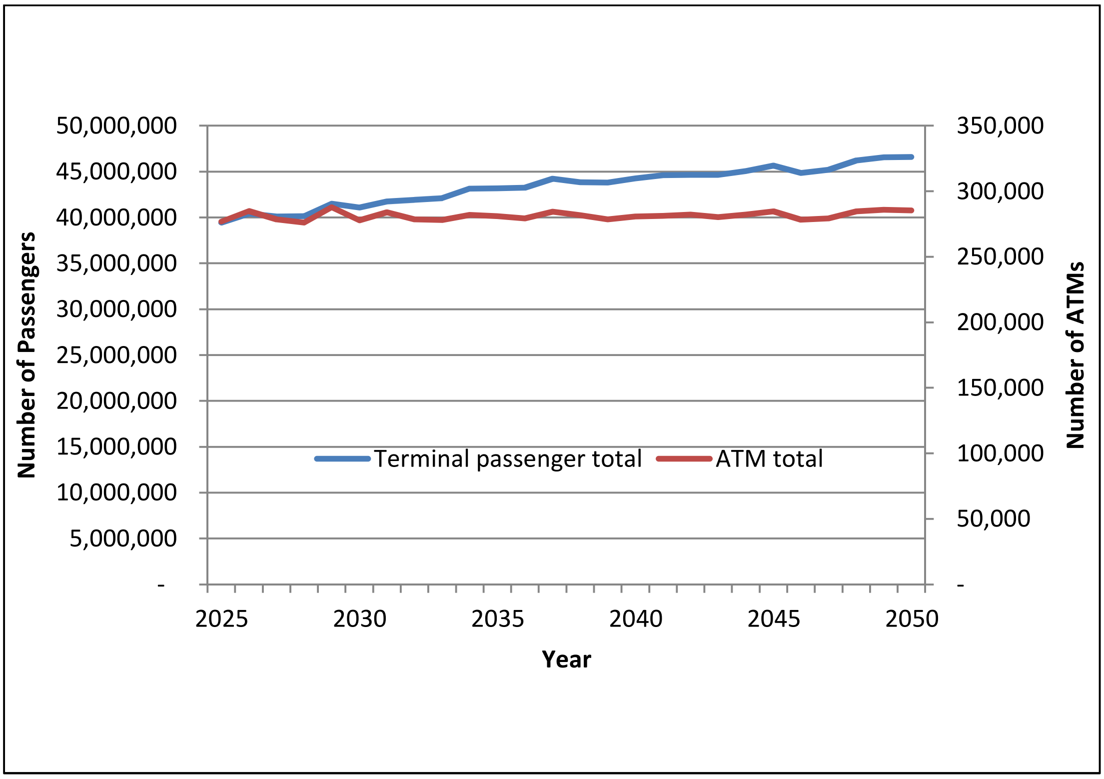


Figure 3.2 shows that the number of ATMs at Gatwick Airport (a key determinant of aviation carbon emissions) increases slightly during the period 2025-2050. Therefore, an increase in carbon emissions would be expected, if fuel burn per ATM remained the same. The reduction in carbon per ATM that is seen is due to a combination of aircraft fleet changes (from fleet mix and technological improvements) and alternative fuels. The model uses predictions of future fleets, of

which some of the emissions that would result from their use are currently known to be improved from current models.
The change in biofuel use is a modest increase of 2% over this period, suggesting that it is the aircraft fleet changes that are responsible for the majority of the carbon reduction per ATM seen in the 'do minimum' single runway baseline forecast. The baseline forecast is driven by a combination of these inputs; therefore the magnitude, and the relative contributions of each aspect, cannot be identified from the model output contained in the DM or AoN Carbon Capped Forecast 2014.

Carbon emissions from flights departing Gatwick Airport have not been modelled for the period 2050-2085, and so for analytical purposes are presumed to remain static. Biofuel use within aviation might be expected to increase further during this period. Future generation aircraft would also be expected to continue to become more fuel-efficient and it may be that we see some new aircraft designs and technology, such as blended-wing aircraft and open-rotor engines, which will give a step-change improvement in fuel efficiency and a commensurate reduction in carbon emissions.

There is significant uncertainty however over the magnitude and timing of these changes. A balance will also be made with increased passengers and the number of ATMs which could off-set the reduction in carbon per ATM. Again, there is significant uncertainty with passenger and ATM numbers so far in the future, so post-2050 forecasts are assumed to hold steady for the purpose of this assessment.

3.2.2 Airside ground movements

Using the predicted air traffic movements between 2025 and 2050, the emissions that result from airside ground movements at Gatwick have been estimated as detailed in the methodology. The results can be seen in Table 3.2.

Table 3.2 - Gatwick ground movement emissions over time, and baseline ATMs.

Year	Airside Ground Movements at Gatwick Airport, tonnes CO_2 (ICAO-Times)	Airside Ground Movements at Gatwick Airport, tonnes CO_2 (GAL Reported times)
2025	134,085	128,569
2030	134,673	129,132
2040	135,988	130,393
2050	138,308	132,617

Due to the relationship with ATMs, these emissions follow the path set by the DM demand forecast, with low variance over the period of 2025 to 2050 and a 3% increase in annual emissions between the start and end of the period.

It can be seen that using the promoter reported Times in Mode at Gatwick, rather than the ICAO TIMs, results in a slightly reduced volume of emissions associated with ground movements. Airport design and operational improvements can help manage this source of emissions.

3.2.3 Passenger surface access emissions

Using the outputs of the DfT's surface access model, updated with 2014 projected emissions factors, the passenger surface access emissions profile of Gatwick for five year periods between 2025 and 2050 was produced using the 2008 mode share and updated emissions factors. Selected emissions years are shown in Table 3.3.

Table 3.3 - Gatwick surface access emissions

Year	Emissions due to surface access to Gatwick Airport, tonnes CO_2	Emissions due to surface access to UK airports[6], tonnes CO_2	Gatwick % of total UK airport surface access carbon emissions
2025	335,167	1,886,064	17.8
2030	288,863	1,800,361	16.0
2040	297,307	2,003,151	14.8
2050	308,530	2,324,692	13.3

During the 2025 to 2050 period, Gatwick's emissions due to surface access initially reduce, aligned with emissions factor improvements for private road vehicles, before increasing again in line with passenger numbers. Emissions are therefore expected to fall significantly in the period between 2025 and 2030 but climb after this point.

Sensitivity: 2030 Modal split
A sensitivity scenario was developed in which the 2030 regional mode share as derived from the Surface Access Appraisal (Jacobs, 2014b) was used to adjust point of origin mode share. The result of utilising this adjustment can be seen in Table 3.4.

It can be seen that, in this alternative baseline, emissions attributed to Gatwick are lower, due to a significantly greater proportion of journeys being made by rail mode, compared to private vehicle.

Table 3.4 – Surface Access emissions from the 2030 Modal split baseline Gatwick.

Year	Baseline emissions due to surface access to Gatwick Airport, tonnes CO_2
2025	256,474
2030	247,490
2040	255,313
2050	264,012

The regional mode share can be seen in Table 3.5.

Table 3.5 - 2030 Modal split baseline Gatwick

Region	Rail	Bus / Coach	Private vehicle
Inner London	81%	10%	8%
Outer London	41%	10%	48%
South East (not London)	24%	7%	69%
East Midlands	22%	10%	68%
East of England	27%	18%	55%
North East	43%	25%	31%
North West	45%	16%	39%
Scotland	69%	9%	22%
South West	19%	16%	65%
Wales	16%	31%	54%
West Midlands	20%	32%	48%

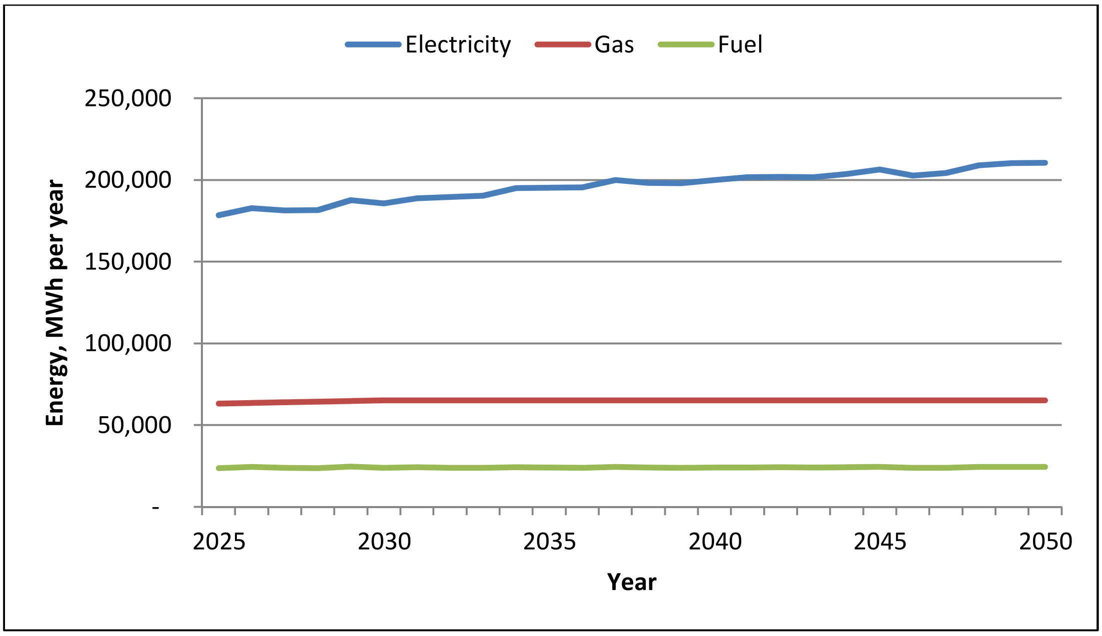
[6] The DfT derived surface access model uses a set of 28 Airports, as listed in Appendix B

Yorkshire and the Humber	39%	13%	48%

3.2.4 Airport operations emissions from energy and fuel use

As previously stated, the emissions that result from airport operations are calculated based on existing baseline energy consumption and predicted changes based on forecast changes to passenger numbers, building floor areas and ATMs. There is no defined construction plan for the single runway master plan between now and 2030; however the small amount of additional terminal space that has been estimated is assumed to be fully operational footprint by 2030.

Figure 3.3 - Energy use at Gatwick, by source, between 2025 - 2050



The resultant estimated energy levels between 2025 and 2050, as seen in Figure 3.3, are expected to be a reasonable estimate of the energy use at Gatwick, barring any major technological or policy changes. Gatwick has already published indicative targets for energy and emissions reduction over time (GAL, 2010), suggesting that energy savings and carbon are likely to be delivered compared to our assumptions.

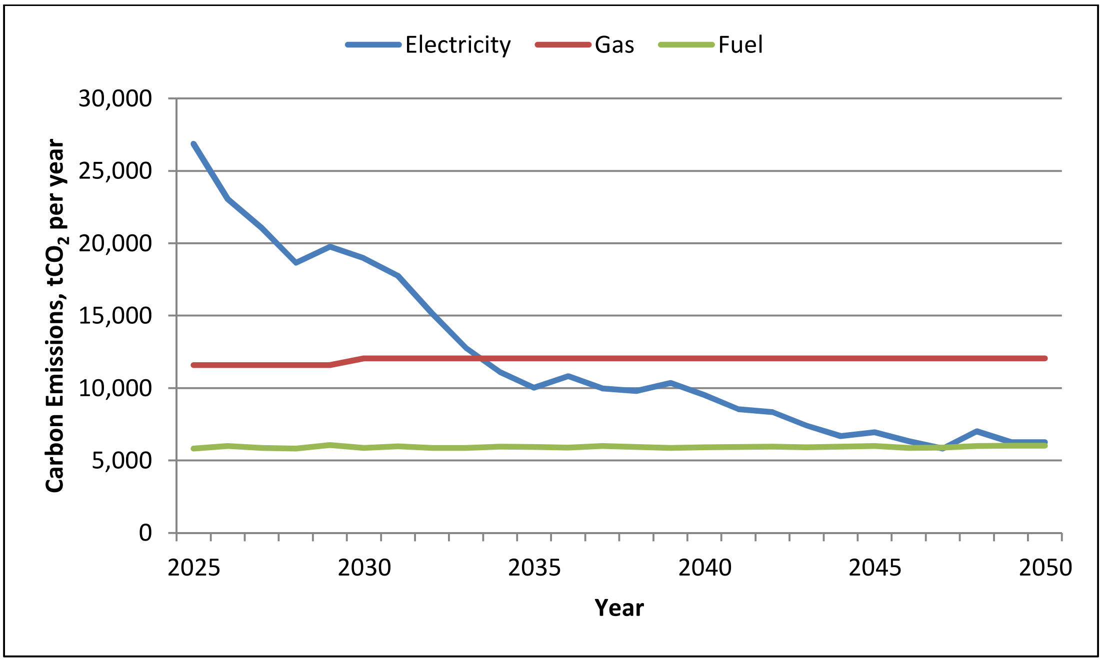
To present a conservative estimate, as the detail of the design and technology balance that would be required to meet the stated energy and carbon reduction ambitions is not available at this time, no such reductions have been assumed in this current analysis.

The resultant emissions that occur due to this energy use are shown in Table 3.5 and depicted graphically in Figure 3.4. Due to the assumed decarbonisation of the grid indicated by electricity emissions factors in the IAG "Valuation of energy use and greenhouse gas emissions for appraisal" toolkit, emissions are expected to decrease over time, despite increases in passenger numbers, ATMs and the airport's terminal footprint.

Table 3.6 - Gatwick operational emissions 2025-2050.

Year	Emissions due to electricity use at Gatwick Airport, tonnes CO_2	Emissions due to gas use at Gatwick Airport, tonnes CO_2	Emissions due to fuel use at Gatwick Airport, tonnes CO_2	Emissions due to airport operation at Gatwick Airport, tonnes CO_2
2025	26,869	11,591	5,831	44,291
2030	18,969	12,041	5,857	36,867
2040	9,511	12,041	5,914	27,467
2050	6,264	12,041	6,015	24,320

Figure 3.4 - Gatwick operational emissions 2025-2050



3.2.5 Carbon emissions from infrastructure construction

Analysis of the Gatwick master plan (GAL, 2012) determined the core construction spend that is to occur at Gatwick between 2020 and 2030. The analysis (Jacobs, 2014b) for the core construction spend at Gatwick did not determine the split between different construction areas.

The total spend was entered into the benchmarks calculator as the category “Other buildings”. This resulted in a total carbon footprint of 3,405,369 tCO_2.

Table 3.7 – Baseline Carbon emissions due to construction at Gatwick.

Emissions	Baseline (2025 – 2030)
Embodied Carbon	3,405,369
Carbon emissions due to fuel use in construction	25,281

3.3 Conclusion

Analysis of the Gatwick baseline carbon emissions is based on the published single runway masterplan through to 2030, and the Do Minimum passenger and ATM forecasts developed by the Airports Commission. This sees ATMs at broadly around the 280,000 level between 2020 and 2050, with a variance of up to 8,000 ATMs. There is limited construction of infrastructure during this period under the do minimum scenario. The most significant volume of emissions are related to air travel, but these decrease slightly over the period, linked to improved fuel efficiency of airline fleets. Surface access emissions remain the second largest source of CO2 and reduce over the assessment period, with fluctuations linked to annual passenger numbers. Emissions from buildings and airport operations also reduce over time, most significantly due to the presumed decarbonisation of grid electricity.

Annual carbon emissions for the Gatwick baseline in 2030, 2040 and 2050 are presented in the Table 3.8:

Table 3.8 – Baseline Carbon Emissions – Gatwick Single Runway Master Plan.

Area of Emissions	2030	2040	2050	60 year appraisal 2025-2085
	tonnes of carbon dioxide (tCO_2)			
Air travel (ATMs) (UK aviation total)	3,893,295 (39,193,204)	3,961,133 (39,489,040)	3,860,892 (37,514,764)	238,421,704 (2,327,372,378)
Airside ground movements	*134,673*	*135,988*	*138,308*	*8,385,010*
Passenger surface access journeys	288,863	297,307	308,530	18,541,500
Airport operations energy & fuel use	36,867	27,467	24,320	1,632,411
Total operational CO_2 emissions	**4,219,025**	**4,285,907**	**4,193,742**	**258,595,615**
Construction of infrastructure*	n/a	n/a	n/a	3,016,218

* Construction emissions are calculated as CO_2 equivalent, or CO_2e.

Surface access carbon emissions have been limited to passenger travel only, and emissions related to freight and staff travel have not been quantified, again due to insufficient data. The carbon emissions calculated for 'Construction of new facilities and infrastructure' are calculated as tCO_2e (tonnes of CO_2 equivalent). Emissions from air travel and surface access, and operational energy and fuel use are reported as CO_2. The difference between CO_2 and CO_2e for these sources is less than 1%. The 60 year appraisal period is the sum of the total carbon emissions in each of the 60 years from assumed scheme opening date (2025).

The greatest volume of carbon emissions in years 2030, 2040 and 2050 come from total aircraft emissions from ATMs due to air travel. Of this total, approximately 10% of the carbon emissions are produced from aircraft operations within the airport LTO (including APU use). The UK target for aviation emissions that has been proposed is $37.5MtCO_2$ annually from 2050. The findings show that this will be met in 2050 (UK total $37.515MtCO_2$), because the carbon price assumed in the model run was adjusted for this outcome (the 'carbon capped' scenario). Aircraft emissions show no clear trend over the period of analysis, remaining around 3.9Mt CO_2.

Emissions from ground movements grow slightly from around 135,000 tonnes in 2030 to 138,000 tonnes in 2050; broadly linked to the reduction in ATMs and aircraft fleet changes. This represents only around 3.5% of the total aircraft related CO_2 emissions.

The carbon emissions arising from passenger surface access are the second highest source category after those from air travel, 288,863tCO_2 in 2030. The carbon emissions from passenger journeys increase in 2040 and again in 2050 to 308,530tCO_2, an increase of 6.8% compared to 2030. This reflects a 20% increase in passenger numbers and modelling results that suggest a slightly increased number of passengers accessing the airport via surface modes (from 94% to 99%), together with a slight offset from fuel efficiency benefits in road vehicles .

Airport operations emissions from energy and fuel use at the airport total 36,867tCO_2 in 2030 and decrease in 2040 and again in 2050. This reduction in carbon emissions over time (34% reduction in 2050 compared to 2030) is driven by the decarbonisation of grid electricity supply.

The carbon emissions from infrastructure construction for the baseline do minimum scenario (Gatwick Airport's master plan to 2030 and no second runway) from construction is 3,430,651 tCO_2 in total. Approximately a third of this construction has been estimated to occur in the period of 2017 to 2025.

4. Heathrow Airport

This section covers the following for Heathrow Airport:

- Study Area
- Baseline assessment for aircraft, surface access, operations and construction
- Conclusions

4.1 Study Area

For the alternative schemes proposed at Heathrow Airport the study area is defined as Heathrow Airport, as developed to 2030 in the most recently published (draft) two runway master plan (HAL, 2013).

4.2 Baseline assessment

4.2.1 Total aircraft emissions from air transport movements (ATMs)

Table 4.1 presents the carbon emissions from the AoN Carbon Capped for all departing flights from Heathrow Airport between 2026 and 2050, with the current two runways, alongside the total carbon emissions from all UK flights and the percentage of the UK total that occurs with flights from Heathrow. Figure 4.1 presents the same carbon emissions graphically.

Table 4.1 – CO_2 emissions: departing flights Heathrow Airport 2025 – 2050

Year	Number of passengers	Numbers of ATMs	Heathrow Airport, tonnes CO2	UK Total, tonnes CO2	% of UK ATM emissions
2025	81,099,696	480,532	20,265,433	38,846,345	52.2
2030	84,919,152	483,856	20,099,848	39,193,204	51.3
2040	88,614,304	484,517	19,184,305	39,489,040	48.6
2050	93,533,736	471,132	16,570,400	37,514,764	44.2

Across the 2025 to 2050 period, carbon emissions decrease by approximately 18%. Between 2025 and 2035 emissions remain steady, while it can be seen that in the carbon capped scenario during the period 2035 to 2050 carbon emissions reduce more significantly. This reflects both a slight reduction in ATMs (although more passengers are served) and improvements to aircraft technology.

The explanation for this comes from the changes in the 3 drivers of aviation carbon emissions which are:

- distances flown by aircraft (determined by destination & route);
- fuel efficiency of the aircraft fleet (determined by airframe and engine); and,
- type of fuel used (determined by carbon content of aviation fuel).

Figure 4.1 - CO_2 emissions: departing flights at Heathrow Airport for 2025 – 2050

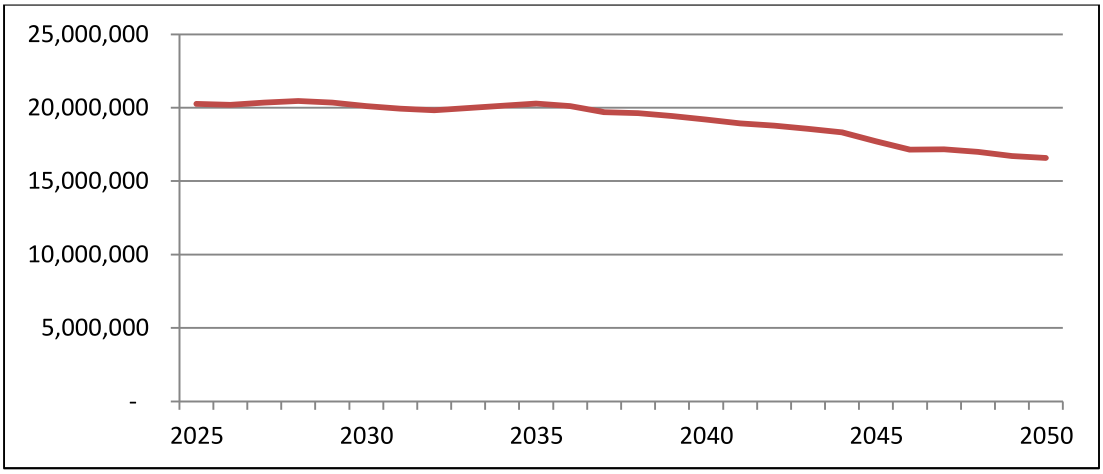
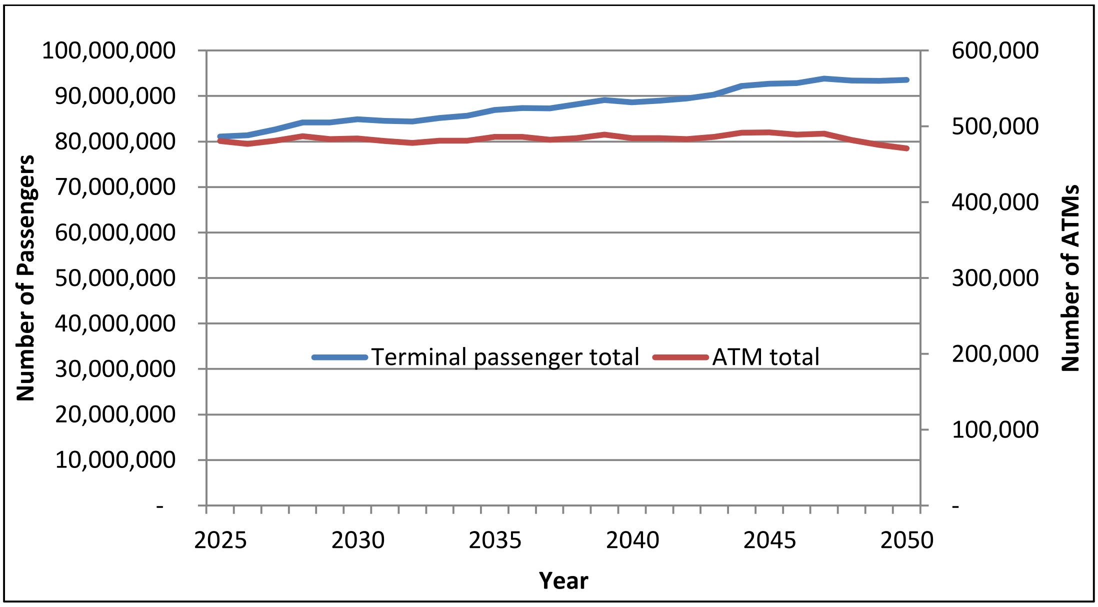


Figure 4.2 shows the changes in passenger numbers and ATMs at Heathrow Airport during the period 2025 – 2050.

Figure 4.2 - Passenger numbers / air transport movements (ATMs) 2030 – 2050



The number of ATMs at Heathrow Airport increases during the period 2025-2047 (from 480,000 to 490,000) but then falls in the remaining 3 years (3.9% - to 471,000). Passenger numbers continue to increase. Therefore, a similar increase in carbon emissions would be expected over the period 2025-2047, if fuel burn per ATM remained the same. The reduction in carbon per ATM that is seen is due to a combination of aircraft fleet changes (from fleet mix and technological improvements) and alternative fuels.

The change in biofuel use is a modest increase of 2% over this period, suggesting that it is the aircraft fleet changes that are responsible for the majority of the carbon reduction per ATM seen in the ‘do minimum’ two runway baseline forecast. The baseline forecast is driven by a combination of these inputs; therefore the magnitude, and the relative contributions of each aspect, cannot be identified from the model output contained in the DM or AoN Carbon Capped Forecast 2014.

Carbon emissions from flights departing Heathrow Airport have not been modelled for the period 2050-2085, and so for analytical purposes are presumed to remain static. Biofuel use within aviation might be expected to increase further during this period. Future generation aircraft would also be expected to continue to become more fuel-efficient and it may be that we see some new aircraft designs and technology, such as blended-wing aircraft and open-rotor engines, which will give a step-change improvement in fuel efficiency and a commensurate reduction in carbon emissions.

There is significant uncertainty however over the magnitude and timing of these changes. A balance will also be made with increased passengers and the number of ATMs which could off-set the reduction in carbon per ATM. Again, there is significant uncertainty with passenger and ATM numbers so far in the future, so post-2050 forecasts are assumed to hold steady for the purpose of this assessment.

4.2.2 Ground movements

Using the forecast air traffic movements between 2025 and 2050, the emissions that result from airside ground movements at Heathrow have been estimated. These can be seen in Table 4.2.

Table 4.2: Heathrow airside (aircraft) ground movement emissions.

Year	Airside Ground Movements at Heathrow Airport, tonnes CO_2 (ICAO-Times)	Airside Ground Movements at Heathrow Airport, tonnes CO_2 (HAL Reported times)
2025	390,677	311,963
2030	396,313	314,121
2040	396,855	314,550
2050	385,891	305,860

Due to the relationship with ATMs, these emissions follow the path set by the DM Forecast, with low variance over the period of 2025 to 2047 with a 2% increase over this period, followed by a reduction, down 2% from 2025, and 4% from the 2047 peak. It can be seen that the methodology that utilised the reported TIMs at Heathrow results in reduced emissions associated with ground movements, compared to the ICAO-Times approach. This is due to the locally informed ground times being shorter than those assumed in ICAO-Times Approach.

4.2.3 Passenger surface access emissions

Using the outputs of the DfT's surface access model, updated with 2014 projected emissions factors, the emissions profile of Heathrow between 2025 and 2050 was produced using the 2008 mode share and updated emissions factors. This is shown in Table 4.3.

Table 4.3 - Heathrow surface access emissions 2025 - 2050

Year	Emissions due to surface access to Heathrow Airport, tonnes CO_2	Emissions due to surface access to all airports, tonnes CO_2	Heathrow % of total carbon emissions due to surface access
2025	372,712	1,813,730	20.5
2030	373,888	1,800,361	20.8
2040	413,575	2,003,151	20.6
2050	469,066	2,324,692	20.2

The general trend of surface access emissions, assuming the 2008 modal share, is for growth over the period from 2025 to 2050 of just under 100,000 tonnes. The change in emissions broadly reflects the growth in passenger numbers that reach the airport by surface access, which causes this emission area to increase even while total passenger numbers are constrained.

Sensitivity: 2030 Modal split
A sensitivity scenario was developed in which the 2030 regional mode share as derived from the Jacobs Surface Access Analysis (Jacobs, 2014c and 2014d) was used to adjust point of origin mode share. The result of utilising this adjustment can be seen in Table 4.4.

Table 4.4 - 2030 Modal split baseline Heathrow

Region	Rail	Bus / Coach	Private vehicle
Inner London	64%	4%	33%
Outer London	30%	6%	64%
South East (not London)	32%	21%	47%
East Midlands	24%	24%	52%
East of England	39%	13%	49%
North East	66%	10%	24%
North West	85%	5%	10%
Scotland	43%	9%	48%
South West	17%	25%	58%
Wales	15%	36%	49%
West Midlands	26%	25%	50%
Yorkshire and the Humber	68%	19%	13%

It can be seen that, in this alternative baseline, emissions attributed to Heathrow are lower, due to a significantly greater proportion of journeys being made by rail mode, compared to road by private vehicle. Nevertheless the trajectory in emissions growth (of c. 90,000 tonnes) remains dominated by passenger numbers as the determining variable.

The regional mode share can be seen in Table 4.5

Table 4.5 – Surface Access emissions with 2030 mode share

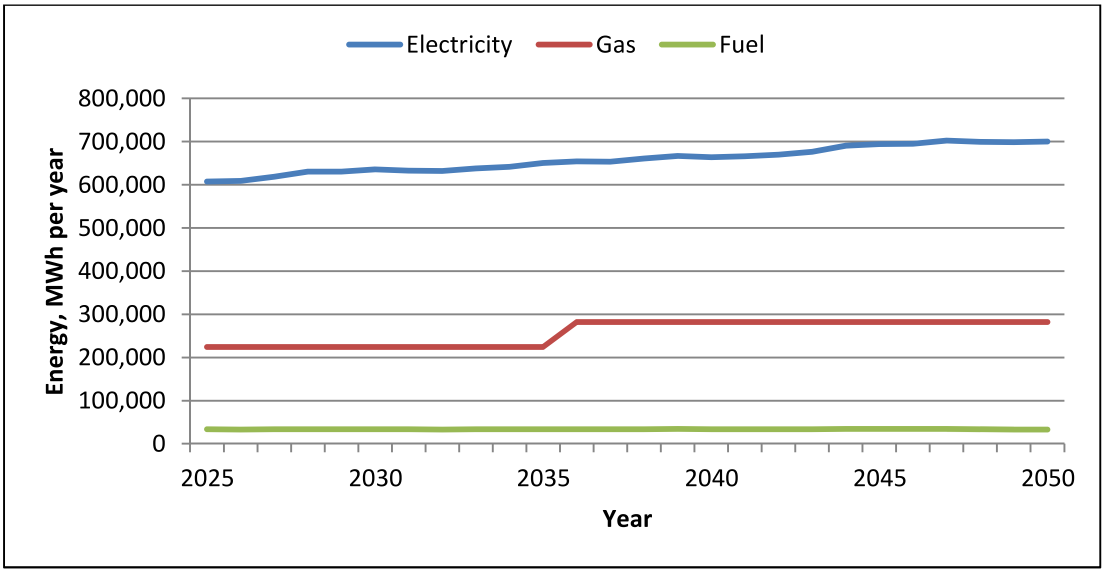
Year	Baseline emissions due to surface access to Heathrow Airport, tonnes CO_2
2025	315,545
2030	321,635
2040	358,267
2050	406,562

4.2.4 Airport operations emissions from energy and fuel use

As previously stated, the emissions that result from airport operations are calculated based on existing baseline energy consumption and predicted changes based on forecast changes to passenger numbers, building floor areas and ATMs. Construction on additional terminal space, in the baseline scenario, is thought to end by 2036. Therefore indicative operational emissions linked to development are assumed to be fully operational by 2036.

The resultant estimated energy levels between 2025 and 2050, as seen in Figure 4.3, are expected to be a reasonable estimate of the energy use at Heathrow, barring any major technological or policy changes. Heathrow has already published indicative targets for energy and emissions reduction over time (HAL, 2014), suggesting that energy savings and carbon are likely to be delivered compared to our assumptions. However, as the detail of the design and technology balance that would be required to meet the stated ambitions is not available at this time, no such reductions have been assumed in this current analysis.

Figure 4.3 - Energy use at Heathrow, by source, between 2025 and 2050

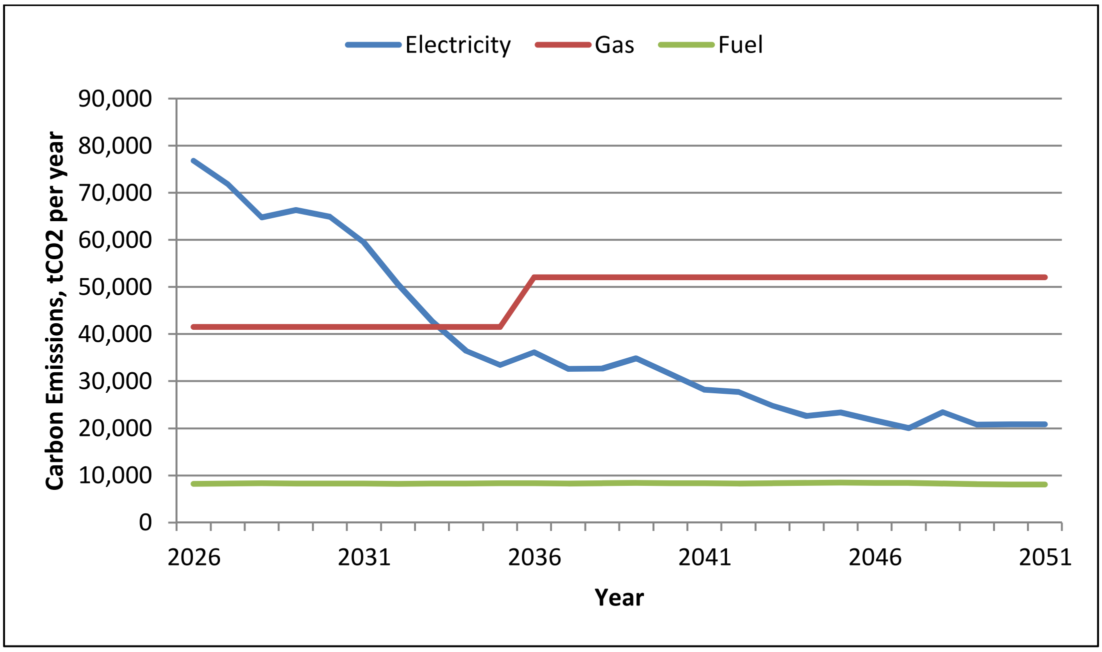


The resultant emissions that occur due to this energy use are shown in Table 4.6 and depicted graphically in Figure 4.4. Due to the assumed decarbonisation of the grid indicated by electricity emissions factors in the IAG "Valuation of energy use and greenhouse gas emissions for appraisal" toolkit, emissions are expected to decrease over time, despite increases in passenger numbers, ATMs and the airport's terminal footprint.

Table 4.6 - Heathrow operational emissions 2025-2050.

Year	Emissions due to electricity use at Heathrow Airport, tonnes CO_2	Emissions due to gas use at Heathrow Airport, tonnes CO_2	Emissions due to fuel use at Heathrow Airport, tonnes CO_2	Emissions due to airport operation at Heathrow Airport, tonnes CO_2
2025	91,490	41,520	8,242	141,251
2030	64,937	41,520	8,299	114,756
2040	31,552	52,099	8,310	91,962
2050	20,827	52,099	8,081	81,007

Figure 4.4 - Heathrow operational emissions over time



4.2.5 Carbon emissions from infrastructure construction

The analysis of the Heathrow master plan (HAL, 2014) determined the core construction spend that is to occur at Heathrow. The analysis (Jacobs, 2014b) for the core construction spend at Heathrow allocated spend between different construction areas. The total spend was entered into the benchmarks calculator, assigned to the appropriate categories. This resulted in a total carbon footprint of 13,514,607 tCO_2.

The embodied carbon and emissions due to fuel use that are thought to occur during this period can be seen in Table 4.7

Table 4.7 - Carbon emissions from infrastructure construction at Heathrow

Year	Baseline
Embodied Carbon	13,325,975
Carbon emissions due to fuel use in construction	188,633

4.3 Conclusion

Analysis of the Heathrow baseline carbon emissions is based on the published two runway masterplan through to 2030, and the Do Minimum passenger and ATM forecasts developed by the Airports Commission. This sees ATMs at broadly around the 480,000 level between 2020 and 2050, with a variance of up to 12,000 ATMs. There is significant construction of infrastructure during this period under the do minimum scenario, as the airport toastrack configuration is completed, replacing older terminals and expanding satellite capacity. The most significant volume of emissions are related to air travel, but these decrease over the period, linked to changes to the Heathrow fleet, improved fuel efficiency of aircraft present within that fleet. Surface access emissions remain the second largest source of CO2 and increase over the assessment period, with growth linked to annual passenger numbers and the proportion of those who use surface access to reach the airport.

Emissions from buildings and airport operations also reduce over time, most significantly due to the presumed decarbonisation of grid electricity.

Annual carbon emissions for the Heathrow baseline in 2030, 2040 and 2050 are presented in Table 4.8:

Table 4.8 – Baseline Carbon Emissions – Heathrow Do Minimum Master plan

Area of Emissions	2030	2040	2050	60 year appraisal 2025-2085
	tonnes of carbon dioxide (tCO_2)			
Air travel (ATMs) (UK aviation total)	20,099,848 (39,193,204)	19,184,305 (39,489,040)	16,570,400 (37,514,764)	1,076,713,933 (2,327,372,378)
Ground movements (component of air travel)	*396,313*	*396,855*	*385,891*	*23,795,682*
Passenger surface access journeys	373,888	413,575	469,066	27,145,524
Airport operations energy & fuel use	125,336	91,962	81,007	5,377,172
Total operational CO_2 emissions	**20,599,072**	**19,689,842**	**17,120,473**	**1,109,236,629**
Construction of infrastructure*	n/a	n/a	n/a	13,514,607

* Construction emissions are calculated as CO_2 equivalent, or CO_2e.

In addition, the surface access carbon emissions have been limited to passenger travel only, and emissions related to freight and staff travel have not been quantified, again due to insufficient data. The carbon emissions calculated for 'Construction of new facilities and infrastructure' are calculated as tCO_2e (tonnes of CO_2 equivalent). Emissions from air travel and surface access, and operational energy and fuel use are reported as CO_2 The difference between CO_2 and CO_2e for these sources is less than 1%. The 60 year appraisal period is the sum of the total carbon emissions in each of the 60 years from assumed scheme opening date (2025).

The greatest volume of carbon emissions in years 2030, 2040 and 2050 come from total aircraft emissions from ATMs due to air travel. Of this total, approximately 2% of the carbon emissions are produced from aircraft operations within the airport LTO (including APU use). The UK target for aviation emissions that has been proposed is 37.5MtCO_2 annually from 2050. The findings show that this will be met in 2050 (UK total 37.515MtCO_2), because the carbon price assumed in the model run was adjusted for this outcome (the 'carbon capped' scenario). Aircraft emissions reduce over the period of analysis, from just over 20.0 million tonnes CO_2 to around 16.5 million tonnes CO_2, reflecting reduced ATMs and increased fuel efficiency from fleet changes.

Emissions from ground movements fall from around 396,000 tonnes in 2030 to 386,000 tonnes in 2050; broadly linked to the reduction in ATMs and aircraft fleet changes. This represents a significant on airport emissions source, but is only around 2% of the total aircraft related CO_2 emissions.

The carbon emissions arising from passenger surface access are the second highest source category after those from air travel, 373,888tCO_2 in 2030. The carbon emissions from passenger journeys increase in 2040 and again in 2050 to

469,066tCO_2, an increase of 25.5% compared to 2030. This reflects a 10% increase in passenger numbers and modelling results that suggest a significantly increased number of passengers accessing the airport via surface modes (from 66% to 90%).

Airport operations emissions from energy and fuel use at the airport total 125,336tCO_2 in 2030 and decrease in 2040 and again in 2050. This reduction in carbon emissions over time (35.4% reduction in 2050 compared to 2030) is driven by the decarbonisation of grid electricity supply.

The carbon emissions from infrastructure construction for the baseline do minimum scenario (Heathrow Airport's master plan to 2030 and no additional runway) from construction is 3,803,046tCO_2 in total. There are no emissions associated with this source in 2040 and 2050 because the baseline master plan considered does not extend beyond 2030.

Glossary

The following table lists and explains key technical terms used in this report.

AC	Airports Commission
AMSL	Above Mean Sea Level
ATM	Air Transport Movement
CAA	Civil Aviation Authority
Carbon capped	The demand modelling scenario that presumes that flights will be limited to levels which emit less than 37.5 MtCO2
Carbon dioxide (CO2	The principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1
Carbon traded	The demand modelling scenario that presumes that air travel will fall within the European Union's Emissions Trading Scheme.
Collaborative Decision Making (CDM)	A process aimed to aims to improve the operational efficiency of all airport operators, involving real time information sharing between airport operators, aircraft operators, ground handlers and air traffic control.
Defra	Department for Environment Food and Rural Affairs
DfT	Department for Transport
Emissions	In the climate change context, emissions refer to the release of greenhouse gases and/or their precursors and aerosols into the atmosphere over a specified area and period of time.
Equivalent CO2 (carbon dioxide)	The concentration of carbon dioxide that would cause the same amount of radiative forcing as a given mixture of carbon dioxide and other greenhouse gases.
LCY	London City Airport
LTN	Luton Airport
NATS	The provider of UK national air traffic control services
NO2	Nitrogen Dioxide
NOx	Generic term for mono-nitrogen oxides NO and NO2
O&D	Origination and Destination Passengers, i.e. passengers beginning or ending their journey at that airport
PM2.5 & PM10	Concentrations of Particulate Matter for which the European Union has set limits
Radiative forcing	Radiative forcing is the change in the net vertical irradiance (expressed in Wm-2) at the tropopause due to an internal change or a change in the external forcing of the climate system, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun. Usually radiative forcing is computed after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with all tropospheric properties held fixed at their unperturbed values
Renewables	Energy sources that are, within a short time frame relative to the

	Earth's natural cycles, sustainable, and include non-carbon technologies such as solar energy, hydropower, and wind, as well as carbon-neutral technologies such as biomass
SEN	Southend Airport
STN	Stansted Airport
tCO2e	Tonnes of carbon equivalent
TIM	Time in mode

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Appendix A Carbon Assessment Background

This report has been prepared to provide evidence to support the Airports Commission's Appraisal Framework Module 8: Carbon. The purpose of this module is to minimise the carbon emissions associated with construction and with the day-to-day ground operations associated with infrastructure once it has been delivered.

The module considers estimates of baseline ('do minimum') and future runway scheme ('do something') emissions as far as is possible given the detail available at this stage. The baseline assumes the 'do minimum' base case defined as *'how the airport will develop in the absence of a scheme to deliver an additional runway'*. This takes account of any proposed changes to the airports as indicated in their respective current master plans.

This report identifies the carbon (dioxide) emissions associated with the development of these schemes:

- Gatwick Airport Second Runway promoted by Gatwick Airport Limited (GAL)
- Heathrow Airport Northwest Runway promoted by Heathrow Airport Limited (HAL)
- Heathrow Airport Extended Northern Runway promoted by Heathrow Hub (HH)

In establishing the baseline for a 60 year appraisal, the do minimum has a base date of 2025 (GAL) and 2026 (HAL & HH) in line with assumed opening dates of 'do something' development, and an end date at 2085 / 2086. Comparisons for the years 2030, 2040 and 2050 are considered.

Aviation emissions account for about 6% of the greenhouse gas (GHG) emissions in the UK (Department for Transport, January 2013), and the UK also accounts for a similar percentage of total global aviation emissions, although it is expected to fall over the 20 – 30 years due to rapid growth in developing aviation markets such as China, India, and Latin America (Sustainable Aviation, 2012).

According to the Department for Transport's published data "Total greenhouse gas emissions from transport" for 2011, UK domestic / international aviation emissions represent 21.6% of the transport sector's GHG contribution to the UK's carbon footprint. This compares to 67.5% of transport emissions being related to road vehicles (40% attributable to cars, 14% to heavy goods vehicles) and 10.9% to rail, domestic / international shipping and other[7].

However, whilst aviation represents relatively small proportion of UK Greenhouse gas emissions the absolute volume has increased significantly since 1990; the importance of managing carbon emissions in aviation is thus understandably recognised by major stakeholders including the UK Government (DfT, 2011a) and the European Commission (European Commission, 2011), the Committee on Climate Change (CCC), the aviation industry (e.g. Sustainable Aviation, ACI and IATA) (IATA, 2014) and environmental NGOs (Greenpeace, 2009).

In terms of UK aviation GHG emissions from air transport movements (ATMs) dominate the CO_2 impacts of aviation. That said, all activities associated with the

[7] Other mainly consists of 'military aircraft and shipping' and 'aircraft support vehicles'.

construction and operation of an airport have carbon emissions implications. As well as the flights, surface access is a particularly significant source of carbon emissions (as noted in DfT Aviation Emissions Forecasts 2009). Additionally, energy used for day-to-day operations in buildings and across the airfield results in carbon emissions. Finally, energy and materials used in construction result in an embodied carbon emissions impact, similar to any other major construction activity.

Therefore the Appraisal Framework identifies five areas where it is considered that there could be an emissions impact. The Appraisal Framework also highlights some other aspects of emissions that are not airport specific (such as non-CO2 effects). These effects are not quantified in either baseline or assessment, due to calculation uncertainty, and their non-applicability to options appraisal at this stage.

The Appraisal Framework identifies five areas where carbon emissions may change as a result of an airport scheme, which are:

- increased airport capacity leading to a net change in air travel;
- departure and arrival route changes through altered flight operations;
- construction of new facilities and surface access infrastructure;
- airside ground movements and airport operations; and
- changes in non-aviation transport patterns brought about by a scheme's surface access strategy i.e. passenger surface access journeys to and from a UK airport; and, where possible, freight journeys.

Although the Appraisal Framework carbon module does not make reference to it, there is an established method for reporting airport carbon emissions in accordance with the internationally recognised Greenhouse Gas (GHG) Protocol (Greenhouse Gas protocol, 2012)

This allocates emissions to 'Scopes' dependent on the degree of control the airport operator has over their management.

- Scope 1 refers to emissions resultant from direct fuel burn locally (e.g. oil, gas);
- Scope 2 refers to emissions resultant from on-site use of electricity that has been generated elsewhere.
- Scope 3 refers to emissions resultant from others energy use (e.g. aircraft engine fuel, third party vehicles, construction, waste).

The GHG Protocol as applied to Aviation is well explained by Airports Council International (ACI) Europe and through the ACI the Airports Carbon Accreditation Scheme (ACAS) (ACI, 2009). For clarity the equivalent GHG scopes of emissions from different sources assessed within the Appraisal Framework module are shown below.

Within this baseline report and in the assessment of the schemes, emissions areas are considered according to the significance of their effect: aviation transport related emissions (ATMs and surface access); airport facilities operational emissions and airport and surface access infrastructure construction emissions.

They are reported as follows:

- total airport aviation emissions from ATMs, including cruise; [Scope 3]
    - departure and arrival route impacts; [Scope 3]
    - airside (aircraft) ground movement emissions [Scope 3]

- passenger surface access emissions[8] [Scope 3]
- airport operations emissions from energy and fuel use [Scope 1, 2; some 3]
- embodied carbon emissions from infrastructure construction [Scope 3].

Carbon emissions related to the future operation of Gatwick and Heathrow based on a 2030 master plan are considered and reported on separately. The Heathrow 2030 master plan is taken to be the baseline for both Heathrow Airport expansion schemes as it is identical in carbon terms for both development options.

The focus of this baseline carbon assessment is based on the documents identified in the Appraisal Framework, supplemented by the use of information on Scheme Designs submitted to the Commission by promoters, supported by publicly available information where appropriate. The baseline report appraisal chapters are structured as follows:

- *Study area*
- *Areas of carbon emissions*
- *Conclusion*

The Climate Change Act 2008 (''the Act'') established a legally binding target to reduce the UK's greenhouse gas emissions by at least 80% below base year (1990) levels by 2050. The UK's carbon budgets as described within the Act set an envelope for UK emissions. However, while domestic aviation emissions are included within carbon budgets, international aviation emissions are excluded.

A number of problems with inclusion of international aviation (and shipping) emissions within the UK's carbon budgets and carbon target were identified. These difficulties remain broadly unresolved, and a decision on how to include international aviation carbon emissions within targets was deferred in 2012 (DECC, 2012).

The Committee on Climate Change (the CCC) has provided advice on the consequences of including international aviation emissions in UK carbon budgets and the 2050 target in the 2012 report "*Scope of carbon budgets – Statutory advice on inclusion of international aviation and shipping*", which recommended that such emissions be included in the 2050 target. The CCC has stated its position as follows (CCC, 2013):

- Long term aims for aviation emissions should reflect international/EU approaches rather than unilateral UK action, given risk of emissions leakage. However, planning assumptions are useful to inform the strategy for meeting the overall 2050 emissions target.
- An appropriate planning assumption for 2050 aviation emissions is to be around 2005 levels (i.e. 37.5 MtCO2). This is achievable through measures which are feasible, and is consistent with government and industry analysis, and objectives of the industry at UK and global levels.

The UK Government has noted that as "aviation is predominantly international then a global regulatory framework is best placed to control aviation's carbon emissions." (DECC 2012).The only currently agreed international regulatory framework is the European Union Emissions Trading Scheme (EU ETS) as applied to aviation. The EU-ETS is a carbon 'cap and trade' system launched in 2005 aimed at reducing

[8]Ideally all surface transport emissions would be reported; at this stage, emissions associated with freight and staff travel have not been quantified as there are limited baseline data available.

industry's greenhouse gas emissions to a given level (cap) in the most cost-effective way (trade) amongst its participants. The level of the cap reduces over time.

Following Europe-wide agreement to EU Directive 2008/101/EC in 2008, aircraft operators were included in EU ETS from January 2012. All flights beginning and ending in Europe were included in ETS, although some exemptions applied. On 12 November 2012 the European Commission (EC) proposed to defer the requirement for airlines to surrender emission allowances for flights into and out of Europe until after the 2013 International Civil Aviation Organization (ICAO) General Assembly. The proposal was approved by the European Parliament and the Council on 24 April 2013. This became known as 'Stop the Clock'. After the ICAO General Assembly in September 2013, the EC proposed an amendment to the EU ETS for a European Regional Airspace Approach which was rejected by the European Parliament. A compromise agreement to limit the application of the scheme to an intra European Economic Area (EEA) scheme came in to force on the 16th April 2014.

At a global level the International Civil Aviation Organization (ICAO) has committed to publish an agreed market-based measure (MBM) – carbon emissions trading or emissions offsetting – at its next General Assembly in 2016 with a view to the implementation from 2020.

Airports themselves are subject to carbon emissions and energy efficiency legislation. Larger airports are covered by the EU ETS if they have sufficient installed heat or power generation. Most airports in the UK are covered by the Carbon Reduction Commitment (CRC) Energy Efficiency Scheme – a requirement to buy allowances based on qualifying carbon emissions, alongside other reporting and documentation requirements.

New buildings and major refurbishments are covered by 'Part L Conservation of fuel and power' in the UK Building Regulations, and may also be subject to local planning requirements in this regard (e.g. local planning policy responding to Greater London Authority requirements).

The Climate Change Act also included provisions for the Adaptation Reporting Power which required those responsible for national infrastructure to prepare climate change adaptation risk assessments and action plans. Both Gatwick and Heathrow Airports produced their first assessments and plans in 2011.

In addition to regulatory requirements, the international commercial aviation industry has developed a series of voluntary commitments to address carbon emissions. The industry umbrella group, the Air Transport Action Group (ATAG - an alliance of airlines, airports, aircraft manufacturers and air navigation service providers), has published three targets within a roadmap for aviation carbon emissions to 2050. ACI's Airport Carbon Accreditation Scheme has already been noted. In the UK, 'Sustainable Aviation' is a group, similar to ATAG but UK focused, which has produced a roadmap of how carbon emissions from aviation may be reduced through increased fuel efficiency, the use of biofuels and market-based measures.

Appendix B Methodologies and limitations

Carbon dioxide (CO_2) emissions (often referred to as just carbon) from anthropogenic sources are contributing to global warming, leading to climate changes. This contribution occurs irrespective of where the carbon emissions are released; it is the magnitude of emissions that is important. Carbon is therefore different to air quality and noise, where spatiality is important. This affects how carbon emissions are investigated.

Due to the range of CO_2 emissions considered in this baseline assessment, a number of different methods and inputs have been used to calculate the emissions. The largest volume of emissions (aircraft movements and surface access) have been estimated based on the methodology used by the UK Department for Transport (DfT) Aviation Forecasts: aviation emissions are assessed as described in the DfT Aviation Forecast 2011 (DfT, 2011b) and the DfT Aviation Forecast 2013 (DfT 2013) and surface access as described in the DfT Aviation Forecast 2009 (DfT, 2009) (with some adjustments to take account of indicated 2030 mode share). Emissions associated with altered flight operations have not been calculated because there is insufficient information on air space routing and management changes for the future runway 'do something' proposals. Operational emissions have been forecast based on reported energy use / emissions and changes in passenger numbers or area of main buildings. Construction emissions have been estimated based on indicative costs for master plan developments, using benchmarks from the WRAP AggRegain CO_2 Carbon Emissions Calculator Tool (WRAP, 2010), for embodied carbon emissions.

Increased airport capacity leading to a net change in air travel

The DfT modelling tools have been used to produce a forecast of passengers, ATMs and carbon emissions for the Airports Commission, which will be referred to within this document as the AoN Carbon Capped. For forecasting of carbon emissions from flights, the UK Department for Transport (DfT) has developed a set of aviation carbon emissions forecast modelling tools which utilise data from various sources, including the UK National Atmospheric Emissions Inventory (UK NAEI), which provides annual carbon emissions for UK airports based on 'bunker' fuel sales i.e. jet fuel sold to aircraft operators. Using this model the DfT provides carbon emissions for each UK airport, alongside forecasts of passenger numbers and air transport movements, on a periodic basis and recently in 2011 (DfT, 2011b) and 2013 (DfT, 2013).

The AoN Carbon Capped contains estimated carbon emission for all UK airports each year from 2011 to 2050 for:

- a baseline (no new runway) scenario; and,
- a series of assessment of the proposed new runway scenarios.

This data has been used to provide carbon emissions data for this assessment (the Jacobs assessment). For each of the three proposed new runway schemes, a comparison is made in this assessment of the 'do something' with the baseline scenarios. The AoN Carbon Capped, which uses DfT modelling, has been used because:

- it enables a common approach to be applied across the 2 airports and 3 new runway options;

- it has also been run for each of the runway 'do something' options' (carbon capped) so that a comparison can be made with data produced by the same model;
- it has been subject to development over a number of years, and adjusted to take account of external views;
- it has been tested against historical carbon emissions reported through the NAEI for which it provides good agreement;
- there is a thorough and transparent description of the forecasting methodology and the assumptions made provided in the DfT reports; and,
- it provides consistency with existing carbon forecasts that the DfT have produced and are used elsewhere, such as by the UK Committee on Climate Change (CCC).

The required timescale for this assessment is from the indicated opening year for each new runway option and then for a period of 60 years. The suggested opening year is 2025 for a second runway at Gatwick Airport and 2026 for a third runway at Heathrow Airport. The AoN Carbon Capped provides forecasted carbon emissions for the period 2011 – 2050. It does not provide forecasted carbon emissions for the period 2051 to 2085 (Gatwick) or 2086 (Heathrow). Some commentary of how carbon emissions may change during this period is provided in this assessment. Further modelling has not been undertaken for the period 2051 – 2086 because it is considered that there is too much uncertainty this far in the future.

Carbon emissions from aircraft are a direct result of the type and amount of fuel burnt. The three drivers of aviation carbon emissions are the:

1. distances flown by aircraft – the number of flights (ATMs), the destination, the routing including any stacking or other delays;
2. fuel efficiency of the aircraft – this changes with time through the introduction of new technologies and aircraft types; and,
3. type of fuel used – the amount of carbon associated with a tonne of fuel burnt is different, and lower, for alternative fuels.

The AoN Carbon Capped is based on the DfT forecasting methodology. Very simply, the DfT modelling estimates:

- the national demand for air passengers;
- allocates this demand to airports/routes;
- then allocates these passengers to Air Traffic Movements (ATMs) (number and type); and calculates carbon emissions for these ATMs based on a number of assumptions.

The DfT Aviation Forecasts reports for 2011 and 2013 provide a detailed description of the methods, models and assumptions used to calculate forecasted UK aviation carbon emissions. Figure A1 presents a summary of the framework of the modelling process. The AoN Carbon Capped carbon emissions used in this assessment are based on the assumptions used in the DfT central forecast range. Table A1 presents the assumptions used for the central demand growth scenario.

Figure A1: UK aviation forecasting framework. Department for Transport, UK Aviation Forecasts 2011, August 2011, Figure 2.2

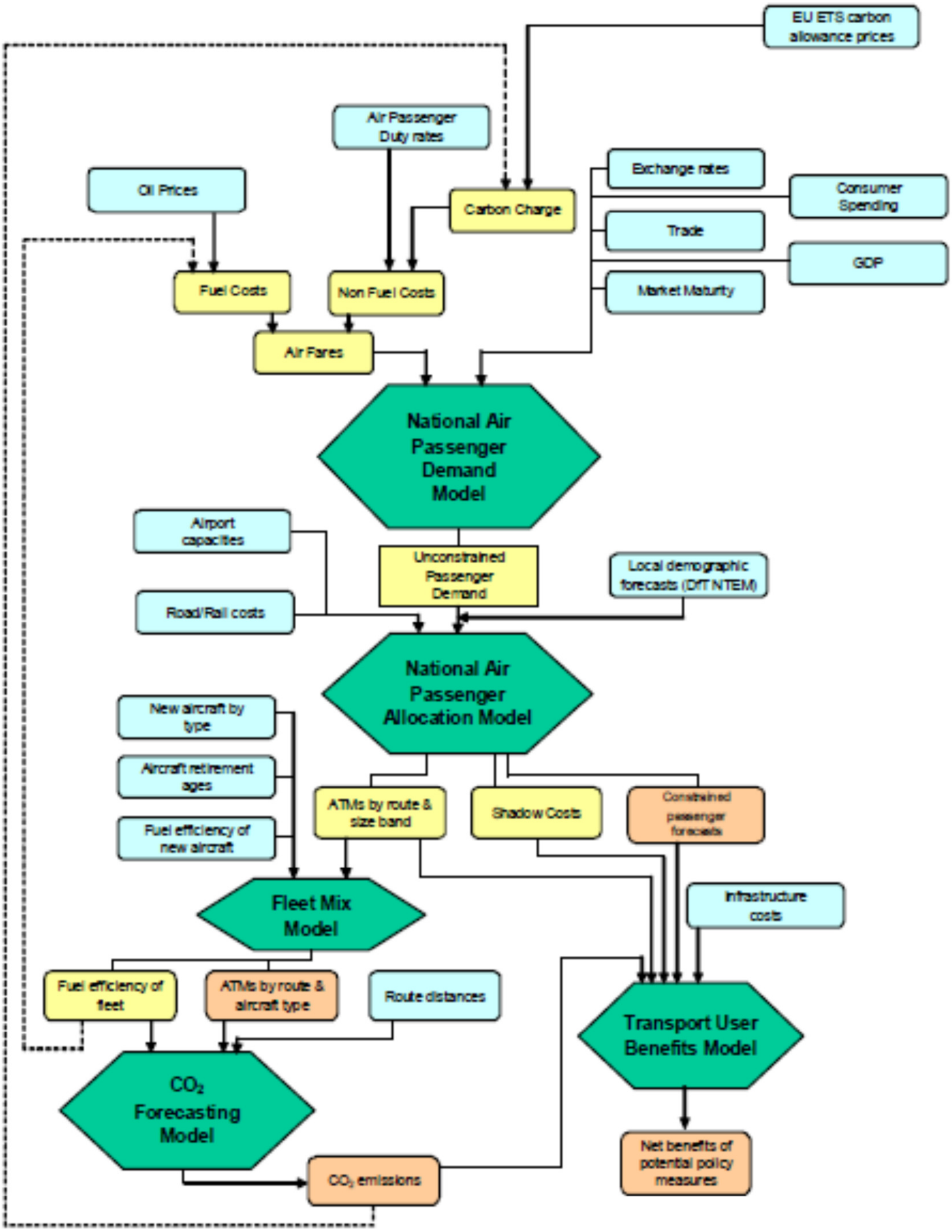

Table A1: Department for Transport, UK Aviation Forecasts 2013, January 2013, Table 3.12: CO_2 emissions variable range assumptions, Central: central demand growth +.

Central: central demand growth +
• No regulatory CO_2 standard; • Standard DfT aircraft retirement ages of 22 years; • No retro-fitting; • 2020 future generation having a 17.5-21.5% fuel burn improvement on 2000 standard types, the 2030 future generation having a 24.5-27.5% improvement and the 2040 future generation having a 29.5-31.5% improvement; • No net air traffic management system gains as improvements from SESAR and other programmes are assumed to accommodate the growth in ATMs without further deterioration in levels of service; • No improvement from airline operational efficiency practices; and, • 0.5% biofuel use in 2030 rising to 2.5% by 2050.

The forecast is also based on a 'carbon capped' scenario in which the DfT modelling assumes a higher carbon price to ensure that the forecast aviation carbon emissions meet the current UK target of a return to 2005 carbon emissions from UK aviation by 2050 (37.5 $MtCO_2$ per year). The same methodology and assumptions are used for the 'do minimum' and 'do something' forecast scenarios other than changes in the number of passengers, number of ATMs and aircraft fleet mix. Table A2 presents the assumptions made in the AoN Carbon Capped for the ATM capacity of new runways at Gatwick and Heathrow.

Table A2: Airports Commission: Appraisal Framework, April 2014

Proposer	Descriptor	Assumption	Scenario reference
Gatwick Airport Limited	Gatwick Second Runway (Gatwick-2R)	Additional runway capacity of 260,000 ATMs is provided in 2025 (540,000 ATMs in total), though there is a phasing of associated infrastructure	s06
Heathrow Airport Limited	Heathrow North West (Heathrow-NWR)	Additional runway capacity of 260,000 ATMs is provided in 2026 (740,000 ATMs in total), though there is a phasing of associated infrastructure	s05
Heathrow Hub Ltd	Heathrow Hub (Heathrow-ENR)	Additional runway capacity of 220,000 ATMs is provided in 2026 (700,000 ATMs in total), though there is a phasing of associated infrastructure	s04

The AoN Carbon Capped contains carbon emissions for flights departing each UK airport for each year. The other greenhouse gases, N_2O and CH_4, are not included in this forecast or DfT model calculations. The DfT report states that this is because about 99% of the climate impact of aviation is a result of CO_2 emissions, with about 1% being made up by these other greenhouse gases (DfT, 2011a). Using the 2014 emissions factors provided by the UK Department for Environment, Food and Rural

Affairs (DEFRA), CO_2 is calculated to be 95% of the total greenhouse gas emissions and 5% comes from N_2O and CH_4. In order for consistency with other DfT work, and that of the CCC, we consider CO_2 only in this analysis. No recalculations have been made for N_2O and CH_4. If this had been done, it would increase the carbon emissions reported here, represented as CO_2 equivalent, by about 5%.

Aircraft engine emissions released at high altitude have warming and cooling effects, depending on the emission and a variety of other factors, which are thought to almost double the climate change impact of aviation compared to CO_2 alone (Lee, 2010). However, there is considerable uncertainty over the magnitude of these impacts. A more thorough discussion is given in the Airports Commission Discussion Paper on aviation and climate change (Airports Commission, 2013). The non-CO_2 effects of aircraft at high altitude are not included in the AoN Carbon Capped or in this assessment.

The assessment described in the following sections by Jacobs is based on the AoN Carbon Capped which provides commonality across the two airports and three new runway proposals. Each of the three proposers of a new runway option (Gatwick Airport Limited (GAL), Heathrow Airport Limited (HAL) and Heathrow Hub Limited (HH)) have provided to the Airports Commission some carbon emissions data which is also discussed in this report, and a comparison is made in the carbon assessment report between the two approaches where possible.

Airside ground movements

Emissions due to airside ground movements result from aircraft taxi, hold and at stand engine use (including auxiliary power units – APUs). These are considered within this assessment as both reduced delays from avoided congestion and airport design issues (e.g. taxiways and stand locations) to determine the level of emissions that result due to these movements if all else (i.e. aircraft type, engine type and fuel type) is equal.

These emissions (like those from arrival and departure route changes as indicated by the delays proxy) are included as part of increased airport capacity leading to a change in demand, but are calculated separately in order to determine their significance.

The method used for this basic assessment uses the reported emissions associated with Landing and Take-Off (LTO) from both Heathrow (Heathrow Airport Ltd, 2014a) and Gatwick (Gatwick Airport Ltd, 2014) and the reported ATMs in those years in order to create a factor representing LTO emissions per ATM.

The proportion of this LTO which can be attributed to ground movements must then be determined. Information from the International Civil Aviation Organization (ICAO) (ICAO, 2011) indicated the average time spent in the LTO cycle and the average time spent at each of the four modes of aircraft thrust levels covered by the LTO cycle (Taxi-in/out, Take-off, Climb-out and Approach) – these are referred to as the Time in Mode. Using both these figures allowed for the generation of a thrust-seconds value, and allowed for taxiing as a proportion of the whole LTO cycle to be determined. The ground movement factor used was 33% of the total LTO cycle when calculated with the ICAO times. Conducting the same analysis of the provided times in mode for Heathrow Airport and Gatwick Airport, augmented by ICAO thrust setting data and times where required, found the ground emission factors to be 26% and 31% respectively. It is acknowledged that the master plan design of the airports, in terms of potential reductions to taxi time (e.g. through the implementation of

Rapid Exit Taxiways), will reduce the emissions per ATM, however this has not been assessed at this time due to limited data in both baseline and development scenarios and to the scale of reduction that these changes may make.

The ground based emissions per ATM are then multiplied by the ATMs per year as forecast for that proposal within the AoN Carbon Capped as an indicative projection of ground emissions.

Altered flight operations

The available data on departure and arrival routes has been reviewed to determine the possibility of estimating carbon emissions impacts of the Appraisal Framework's area of "*departure and arrival route changes through altered flight operations*". Unfortunately, at this stage of airport expansion proposals, route changes and flight operations are not developed in sufficient detail to estimate emissions impacts. Indicative routes (that were developed as a result of a workshop between the Commission, the CAA, NATS and the promoters, for noise modelling purposes) are not suitably defined for airspace design, and do not extend far enough to allow for any meaningful calculation of carbon emissions impacts to be assessed.

UK airspace, together with that of the rest of Europe is subject to redesign for enhanced safety, efficiency and environmental reasons (CAA). The Future Airspace Strategy (FAS) indicates that it will deliver 500,000 tonnes of CO_2 savings through more efficient aircraft routing. The major changes in routes that will offer emissions savings will partially come from routes to 7,000ft but mostly above this altitude, as other environmental priorities (particularly around overflight of built up areas and noise management) take precedence below 7,000ft (DfT, 2014).

Further assessment of carbon emissions impacts of departure and arrival routes must be undertaken when sufficient information is available.

Non-aviation emissions resultant from airport operation

The non-aviation emissions resultant from airport operations is defined as the emissions due to passenger travel, and other surface access to the airport. In order to calculate changes in non-aviation transport patterns brought about by a scheme's surface access strategy it is necessary to calculate a baseline on passenger surface access journeys to / from the airport. Due to limited availability of data, and no widely recognised methodology, freight journey emissions are not quantified. Similarly, due to uncertainty regarding the workforce, and the distances that would be travelled to and from the airport, on staff journeys to work, it was concluded that no robust pro-rata method could be identified at this stage, given the range of variables involved in activity data, although such information is available in sustainability performance data published by GAL and HAL.

The full methodology used for passenger surface access emissions is explained in detail in Annex I of UK Air Passenger Demand and CO_2 Forecasts (DfT, 2009).

The model makes use of forecasts of demand for travel to each of the UK's airports[9], from UK origin / destinations on a regional basis, and by using a 2008

[9] The airports used are: Aberdeen, Birmingham, Bournemouth, Bristol, Cardiff, East Midlands, Edinburgh, Exeter, Gatwick, Glasgow, Heathrow, Humberside, Leeds/Bradford, Liverpool, London City, Luton, Manchester,

modal share forecast (derived from the CAA annual passenger survey) then calculates an estimate of emissions due to surface access. As this modal share was the latest used in DfT's CO_2 estimates it has been applied to the modelling. However, it is acknowledged that modal share in the relevant areas have changed over the last six years, and are likely to continue to change. For this reason, for Gatwick and Heathrow only, a 2030 modal share calculation has been undertaken, by adjusting the local point of origin modal share to reflect the 2030 modal share as identified within the Jacobs Surface Access analysis (Jacobs, 2014b, 2014c, 2014d). What this means is that each Origin-Destination pair was individually factored based on the overall mode share calculation. This allows for a sensitivity to be produced utilising the 2030 modal share.

The emissions factors within the model were checked and where necessary replaced with the most up to date emissions factors derived from Webtag 2014 and CarbonSmart GHG Reporting factors from Defra, which were not available in the original data set.

The output of the model was a set of emissions for five year intervals between 2020 and 2050. In order to generate the expected emissions in the intervening years, a simplifying assumption has been made that emissions follow a linear progression between these data points

It is assumed that the 2030 modal split calculated in the Surface Access Report applies to Heathrow and Gatwick from 2025, as some enabling works and policies that cause the shift to the 2030 modal split may already be in place.

Airport operations

Emissions associated with the operation of an airport primarily relate to the day-to-day electricity, gas and other fuel usage of that airport. Other carbon emissions impacting consumables, such as refrigerants or operational waste, are acknowledged but have not been included in this assessment as these are a relatively minor source of carbon dioxide equivalent.

An assessment was made of current electricity, gas and fuel usage. This was done using the figures reported by GAL and HAL both as part of their submission to the Airports Commission and as part of their normal annual reporting processes. The current emissions of Heathrow Airport, as reported by Heathrow Hub, were also from HAL's reporting. Where required, these usages were converted to approximate energy demand through reverse calculation using reported emissions and the relevant Defra emissions factors.

Airports Council International (ACI) (ACI, 2012) identifies a key environmental indicator of energy performance per m^2 of Terminal, and the related Airports Carbon Accreditation Scheme (ACI, 2009) identifies a key indicator of carbon performance per passenger. Based on these agreed indicators, and Jacobs' experience and observations a series of correlations were determined between these operational emissions and key airport inputs to estimate baseline and scheme emissions in a comparative manner. For the purposes of this forecast the following energy consumption drivers have been applied: electricity consumption is most closely related to passenger numbers; gas consumption is most closely related to the

Newcastle, Newquay, Norwich, Southend, Southampton, Stansted, Teesside, Blackpool, Doncaster Sheffield, Prestwick footprint area of the airport terminals; and other fuel use is most closely related to the number of ATMs. For passenger numbers and ATMs the figures reported in the DfT Aviation forecasts under the different proposals were used, while for the terminal footprint the assumptions related to project phasing used in the construction assessment were used with the difference that the terminal area, and therefore the associated gas use, would not be completed until the end of the phase. This results in a stepped increase in footprint as different phases are completed.

Future emissions factors for each of these consumables were identified. For electricity this utilised the tables produced by the Interdepartmental Analysts' Group (IAG) for long term emissions factors from energy generation[10]. For gas and fuel, the current values reported in the Defra conversion factors repository were used and projected forward, although it is recognised that some small variance might be anticipated in fossil fuel carbon intensity.

Construction of new facilities and infrastructure

Carbon emissions due to construction have been estimated from the airport's planned construction based on their proposal master plans. The estimation includes the carbon emissions that are a result of the energy expended in order to produce the materials used ("embodied carbon") and the emissions due to fuel use on site. The emissions that result from the transport of material to site and emissions that result from the removal of waste from the construction site are qualitively discussed but not quantified. Insufficient information existed to measure these effectively, as described below. It should be noted that construction emissions are reported as CO_2e, whereas aviation and surface access emissions are reported as CO_2 (to be consistent with other DfT Aviation Forecast and CCC reporting).

When estimating embodied emissions, the primary resource is the University of Bath's Inventory of Carbon and Energy (University of Bath, 2011), and/or the Defra Greenhouse Gas Conversion Factor Repository (DEFRA, 2014), or a bespoke tool that utilises these sources such as the Environment Agency Construction Carbon Calculator[11]. However, these require relatively detailed breakdowns of materials that can be identified in a comparable manner across the 'do minimum' and 'with development' scenarios; however, comparable materials schedules are not currently available. The WRAP tool "Resource efficiency benchmarks for construction projects" (WRAP, 2013) was identified as an industry recognised method that allows a level of comparable analysis between baselines and schemes. The tool uses embodied carbon factors that have been calculated for a variety of infrastructure and building projects, with the possibility of entering inputs in terms of construction value and internal floor area. In addition, there are carbon outputs for fuel use on a project calculated using construction value, and so these aspects of the tool were applied to calculating the carbon associated with construction of the proposals.

The WRAP tool also allows for a calculation of construction, demolition and excavation (CDE) waste. However, due to the variable nature of this data and the emissions factors for these categories it has not been included in any of the totals for this category. Where indicative calculations were done, it showed that the emissions associated with CDE waste would be between 1% and 10% of the construction total.

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[10] Table 1: Electricity emissions factors to 2100, kgCO2e/kWh, DECC IAG, "Tables 1-20: supporting the toolkit and the guidance"
[11] The promoters have used such an approach where they have provided estimated construction emissions associated with their schemes

It is acknowledged by WRAP (WRAP, 2013) that the WRAP benchmarking tool's factors are of variable robustness. In order to minimise the impact of this variability the 50% percentile value has been taken in each case.

Due to the large proportion of the project footprint that would be made up from runway, taxiway and stand space (with considerable taxiway construction expected even under baseline scenarios), bespoke factors were developed for these categories. This was done through the use of material factors from Defra Greenhouse Gas Conversion Factor Repository applied to the expected material volumes in Taxiways, Aprons and Stands, and in Runways and Shoulders, and can be seen in Table A3.

Table A3: Carbon factors constructed for Taxiways and Runways

	Material	Volume (m^3)	t CO_2e
Taxiway, Aprons, Stands	Dry Lean Concrete (DLC)	0.30	0.09
	Pavement Quality Concrete (PQC)	0.40	0.12
	tCO_2e per £100k		67.86
Runway and Shoulders	Mastic Asphalt wearing course	0.05	0.00
	Base Course	0.14	0.00
	Reinforced concrete	0.20	0.06
	Lean Concrete	0.15	0.04
	Granular fill	0.30	0.01
	tCO_2e per £100k		60.68

In order to calculate emissions associated with the baseline an estimate was made utilising the Gatwick Airports Limited and Heathrow Airports Limited master plans (Jacobs, 2014a). These costs were allocated within construction types benchmarked in the WRAP benchmarking tool. In addition to a comparison with the proposers' submissions, a sense check was performed by comparing with other estimates for airports and large infrastructure projects (Building.co.uk).

The spend estimates for airport infrastructure was allocated into phases with information on spend, by category of construction available; as there was no clear indication about how the carbon intensity may vary within these phases it was decided to allocate the carbon emissions from fuel use and embodied carbon equally across the years of the phase. For surface access construction, spend estimates were available by year for each proposal, so they were allocated appropriately. During the reviews of the updated scheme designs, it is considered to be unlikely that sufficient additional detail about the phasing of construction will be developed in order to significantly improve these assumptions. However, should information become available this assumption could be refined and improved. For the purposes of absolute emissions, construction that is thought to occur prior to the assessment period has been added to the emissions total for the assessment period. For valuation purposes, emissions prior to the assessment period are valued according to the year of emission and added to the total costs; this prevents over-valuing early emissions.

Monetisation of carbon emissions

Having established an emissions level for each assessment year, establishing a carbon value was accomplished through the use of the Interdepartmental Analysis Group's Green Book Supplementary Guidance, which includes tables showing the future expected carbon values within the European Union Emissions Trading Scheme (DECC, 2014) (EU ETS). These predicted values are the recommended valuation method for incorporating carbon emissions assessments into benefit-cost analysis and other policy analysis.

The carbon emissions totals for a given year are multiplied by the carbon price for that year, and then discounted in accordance with Green Book guidance (HM Treasury, 2011). Due to the long term nature of this appraisal, with an assessment period of 60 years and looking 70 years into the future, the assumption of a declining long-term discount rate was utilised. For values in the years 2014 to 2044, the discount rate applied is 3.5%, for 2044 to the end of the assessment the discount rate applied in 3%. If the appraisal period were to extend beyond 2089 then a lower discount rate would be applied to that period.

The presented values are the DECC Central forecast for the EU ETS prices, and also the range of Low to High.

Assumptions and limitations

Total emissions from ATMs

The carbon assessment of this topic relies upon the AC adjusted DfT aviation forecasts. While a sense check was applied to the results, the model is necessarily built upon assumptions. Among assumptions which lie behind this data are:

- Assumptions of predicted aircraft sizes (in order to determine "seat-kilometres");
- An uplift of 8% to the seat-kilometres level to represent sub-optimal routeing and stacking at airports during periods of congestions; and
- Assumptions of the level of fuel burn by different aircraft types, derived from an adjusted "CORINAIR Emission Inventory Guidebook" (EMEP/EEA, 2009 and 2013).

In addition, the input assumptions utilised for the prediction demand forecasts themselves, which result in the ATMs and passenger numbers used within this assessment, include factors such as economic performance, oil price, exchange rate movements, carbon costs, fuel efficiency changes, tax rates and potential trip length. A fuller explanation of these assumptions can be found in the original texts (DfT, 2011b).

It should be noted that the modelled demand scenario utilised for the baseline assessment and for all proposal assessments has been the carbon capped (37.5 $MtCO_2$) and the central demand growth forecast.

Departure and arrival route impacts

Available data on departure and arrival routes has been reviewed to determine the possibility of estimating carbon emissions impacts of the Appraisal Framework's area of "*departure and arrival route changes through altered flight operations*". At this stage of airport expansion proposals, route changes and flight operations are not developed in sufficient detail to estimate emissions impacts. Indicative routes (that were developed as a result of a workshop between the Commission, the CAA, NATS and the promoters, for noise modelling purposes) do not allow for any meaningful calculation of carbon emissions impacts to be assessed.

UK airspace, together with that of the rest of Europe is subject to redesign for enhanced safety, efficiency and environmental reasons (CAA). The Future Airspace Strategy (FAS) indicates that it will deliver 500,000 tonnes of CO_2 savings through more efficient aircraft routing. The major changes in routes that will offer emissions savings will partially come from routes to 7000ft but mostly above this altitude, as other environmental priorities (particularly around overflight of built up areas and noise management) take precedence below 7000ft (DfT, 2014). Further assessment of carbon emissions impacts of departure and arrival routes must be undertaken when sufficient information is available.

Ground movement emissions

It should first be remembered that, as explained in the methodology, aircraft ground movements are already incorporated within the overall emissions from ATMs.

The estimations that have been made here for this portion of aviation carbon are based on two calculations, as described in the methodology. For the first calculation, the ATMs predicted within the AC adjusted DfT aviation forecasts, and the carbon emissions for the LTO cycle, as reported by Heathrow Airport and Gatwick Airport are used. This latter data source also builds a limitation into the predictions made – that, even if operating an entirely newly designed runway, the average emissions per ATM will remain the same. In addition to the potential change that runway design and management would affect upon this value, considerations of the increase in the use of biofuels and other fuel-use reduction measures do not affect the prediction. For the second calculation, the ICAO TIM and thrust setting information, used for calculating air quality impacts, were utilised, in conjunction with information supplied by HAL and GAL regarding their existing TIMs. In addition to assuming the accuracy of this data, this again places a limit on the predictions, as potential improvements in runway design can change the amount of time spent in groundside modes.

Passenger surface access journeys

The methodology used for calculating the emissions from passenger surface access journeys is described in more detail in the methodology section, and the original documentation (DfT, 2009). In summary, the method utilises the outputs of the demand forecasting process, in terms of travel demand from each UK zone to each airport. The mode share used is that reported in the CAA 2007/2008 passenger interview survey. For this analysis, the emission factors were updated using WebTAG and the Defra GHG repository. The use of these sources assume that emissions factors for road transport will follow the path predicted and that emissions factors for rail and bus / coach travel will remain relatively static.

The method used assumes that the 2008 mode shares are both valid currently, and that they will remain approximately stable throughout the assessment period. It is acknowledged that this is unlikely, and a limitation to the assessment. As described in the methodology, a 2030 sensitivity was developed. This could not be used as a substitute for the 2008 mode shares, however, as the 2030 levels were only determined for Heathrow and Gatwick, and not any other airports.

Airport operational emissions
The methodology that was adopted to calculate the operational emissions implies the assumptions that have been made. These are as repeated here.

- That there is a relationship between electricity use and passenger numbers (kWh/ PAX);
- That there is a relationship between heating (gas) use and terminal floor space (kWh/m^2), and;
- That there is a relationship between airport fuel use and the number of flights (kWh/ATM).

The numbers used to determine these factors were either directly from public reports and proposal documentation from HAL and GAL, or derived from information in those documents. Use of these factors places a limit of the predictions, as it assumes that this relationship will remain valid throughout the assessment period. If emissions were to decouple from these indicators this would not be modelled in this assessment (an example would be the substitution of gas heating for electric heating, or alternative generation).

In order to determine the carbon emissions from these energy uses, use was made of the IAG supporting tables and the Defra GHG repository in order to determine the carbon emission factors of electricity and fuel use. The use of the Defra emission factors for fuel and gas for the entire assessment period implies that the efficiency of fuel and gas is unlikely to significantly change in this time.

Embodied carbon emissions from infrastructure construction

The estimation of the carbon emissions made use of the estimates made for construction cost, phasing and footprints through the Jacobs Revenue and cost identification report.

The method used utilised WRAP benchmark factors; as acknowledged in the methodology, this places a limitation on the estimation as airport projects are not recorded in sufficient number to be part of the WRAP benchmark lists. For this reason, the spend for each proposal was divided amongst different building / project types, assigned based on their use and similarity to the types listed in the WRAP benchmarking tool.

An estimation was made of an emissions factor for spend on runways and taxiways, derived from first principle estimation of materials used combined with materials factors from the Defra GHG repository.

Several assumptions were made regarding the project phasing:
For the Heathrow baseline, spend by year and construction category has been estimated; this spend is allocated through the tool as described above.
For the Gatwick baseline, spend by year was only assessed as a total. In order to use this, an analysis of the Gatwick Masterplan was conducted, which identified land-use changes. Using the proportion of land-use change, augmented through the descriptions of projects, allowed for a split between spend on taxiways/stands and spend on ancillary buildings.

Monetisation of carbon emissions

The monetisation has made use of the IAG supporting tables and Green Book discounting guidance in order to place a value upon the change in emissions brought about by each proposal. The core assumption is that EU ETS prices, as a way to value carbon-affecting projects, remain within the Low to High boundaries. While both the Central result and the Low to High range are presented for the baseline and the proposals, it is possible that there could be significant deviation from these values. For example, the demand scenario utilised the carbon capped assumption – this carbon cap may have a knock-on impact to carbon prices over the assessment period, dependent on how they have been derived.
No monetisation is included within the baseline report. This is presented in the assessment report, comparing the baseline against the scheme development impacts.

Further limitations

As noted, emissions have been presented as CO_2 for consistency with Committee on Climate Change approaches and DfT Aviation Forecasts.

The variance between CO_2 and CO_2e (that is $CO_2 + CH_4 + N_2O$) is less than 1% in all cases, but is not reported for clarity and significance reasons.

The appraisal does not attempt to consider aviation non-carbon impacts (such as radiative forcing). Although this changes the overall emissions impact, the science regarding the effect remains uncertain, and these effects occur at high altitude and regardless of the scheme. Non-carbon impacts are not reported for clarity and uncertainty reasons.

Appendix C Full Tables

Gatwick Airport

Table C1 – Baseline CO_2 emissions for flights at Gatwick Airport for 2025 – 2050

Year	Number of passengers	Numbers of ATMs	Gatwick Airport, tonnes CO_2	UK Total, tonnes CO_2	% of UK ATM emissions
2025	39,447,192	276,706	4,378,003	38,846,345	11.3
2026	40,416,144	284,865	4,303,039	38,953,641	11.0
2027	40,103,888	278,460	4,122,703	39,046,762	10.6
2028	40,153,040	276,160	4,007,941	39,297,453	10.2
2029	41,504,760	287,843	3,984,513	39,269,477	10.1
2030	41,082,700	277,919	3,893,295	39,193,204	9.9
2031	41,742,044	283,949	3,946,395	39,178,500	10.1
2032	41,924,976	278,474	3,935,045	39,168,898	10.0
2033	42,107,912	277,984	3,931,140	39,386,017	10.0
2034	43,156,656	282,063	3,994,040	39,823,762	10.0
2035	43,182,224	281,052	3,988,466	40,099,757	9.9
2036	43,250,640	279,287	3,961,122	40,073,885	9.9
2037	44,223,944	284,448	3,991,509	39,739,856	10.0
2038	43,838,808	281,665	3,954,443	39,717,424	10.0
2039	43,793,728	278,613	3,916,736	39,587,773	9.9
2040	44,241,800	280,633	3,961,133	39,489,040	10.0
2041	44,606,632	281,295	3,981,130	39,397,436	10.1
2042	44,642,696	282,151	3,957,375	39,256,244	10.1
2043	44,633,376	280,338	3,921,082	39,128,328	10.0
2044	45,062,960	282,224	3,947,604	38,868,876	10.2
2045	45,663,888	284,534	3,944,532	38,366,080	10.3
2046	44,848,640	278,261	3,852,920	37,790,912	10.2
2047	45,195,152	279,279	3,843,823	37,941,245	10.1
2048	46,216,776	284,542	3,866,189	37,744,332	10.2
2049	46,543,632	285,962	3,845,414	37,475,627	10.3
2050	46,589,192	285,420	3,860,892	37,514,764	10.3

Table C2 - Gatwick ground movement emissions over time, and baseline ATMs.

Year	Airside Ground Movements at Gatwick Airport, tonnes CO_2 (ICAO-Times)	Airside Ground Movements at Gatwick Airport, tonnes CO_2 (GAL Reported times)
2025	134,085	128,569
2026	138,039	132,360
2027	134,935	129,384
2028	133,820	128,315
2029	139,482	133,743

Year	Airside Ground Movements at Gatwick Airport, tonnes CO_2 (ICAO-Times)	Airside Ground Movements at Gatwick Airport, tonnes CO_2 (GAL Reported times)
2030	134,673	129,132
2031	137,595	131,934
2032	134,942	129,390
2033	134,704	129,162
2034	136,681	131,058
2035	136,191	130,588
2036	135,336	129,768
2037	137,837	132,166
2038	136,488	130,873
2039	135,009	129,455
2040	135,988	130,393
2041	136,309	130,701
2042	136,723	131,099
2043	135,845	130,256
2044	136,759	131,132
2045	137,878	132,206
2046	134,838	129,291
2047	135,332	129,764
2048	137,882	132,209
2049	138,570	132,869
2050	138,308	132,617

Table C3 - Gatwick surface access emissions

Year	Emissions due to surface access to Gatwick Airport, tonnes CO_2	Emissions due to surface access to UK airports, tonnes CO_2	Gatwick % of total UK airport surface access carbon emissions
2025	335,167	1,886,064	17.8
2026	325,906	1,868,923	17.4
2027	316,646	1,851,783	17.1
2028	307,385	1,834,642	16.8
2029	298,124	1,817,501	16.4
2030	288,863	1,800,361	16.0
2031	289,751	1,814,236	16.0
2032	290,639	1,828,111	15.9
2033	291,527	1,841,987	15.8
2034	292,415	1,855,862	15.8
2035	293,302	1,869,737	15.7
2036	294,103	1,896,420	15.5
2037	294,904	1,923,103	15.3
2038	295,705	1,949,785	15.2
2039	296,506	1,976,468	15.0
2040	297,307	2,003,151	14.8

Year	Emissions due to surface access to Gatwick Airport, tonnes CO_2	Emissions due to surface access to UK airports, tonnes CO_2	Gatwick % of total UK airport surface access carbon emissions
2041	298,214	2,029,207	14.7
2042	299,120	2,055,263	14.6
2043	300,027	2,081,319	14.4
2044	300,934	2,107,375	14.3
2045	301,840	2,133,431	14.1
2046	303,178	2,171,683	14.0
2047	304,516	2,209,935	13.8
2048	305,854	2,248,187	13.6
2049	307,192	2,286,440	13.4
2050	308,530	2,324,692	13.3

Table C4 – Surface Access emissions from the 2030 Modal split baseline Gatwick.

Year	Baseline emissions due to surface access to Gatwick Airport, tonnes CO_2
2025	256,474
2026	254,678
2027	252,881
2028	251,084
2029	249,287
2030	247,490
2031	248,466
2032	249,441
2033	250,416
2034	251,392
2035	252,367
2036	252,956
2037	253,545
2038	254,134
2039	254,723
2040	255,313
2041	255,944
2042	256,575
2043	257,206
2044	257,838
2045	258,469
2046	259,578
2047	260,686
2048	261,795
2049	262,904
2050	264,012

Table C5 - Gatwick operational emissions 2025-2050.

Year	Emissions due to electricity use at Gatwick Airport, tonnes CO_2	Emissions due to gas use at Gatwick Airport, tonnes CO_2	Emissions due to fuel use at Gatwick Airport, tonnes CO_2	Emissions due to airport operation at Gatwick Airport, tonnes CO_2
2025	26,869	11,591	5,831	44,291
2026	23,040	11,591	6,003	40,634
2027	21,057	11,591	5,868	38,516
2028	18,662	11,591	5,820	36,072
2029	19,759	11,591	6,066	37,415
2030	18,969	12,041	5,857	36,867
2031	17,744	12,041	5,984	35,769
2032	15,157	12,041	5,868	33,066
2033	12,753	12,041	5,858	30,652
2034	11,090	12,041	5,944	29,075
2035	10,019	12,041	5,923	27,983
2036	10,804	12,041	5,885	28,731
2037	9,977	12,041	5,994	28,012
2038	9,799	12,041	5,936	27,776
2039	10,342	12,041	5,871	28,255
2040	9,511	12,041	5,914	27,467
2041	8,540	12,041	5,928	26,509
2042	8,347	12,041	5,946	26,334
2043	7,406	12,041	5,908	25,355
2044	6,676	12,041	5,947	24,665
2045	6,948	12,041	5,996	24,985
2046	6,320	12,041	5,864	24,226
2047	5,822	12,041	5,885	23,749
2048	7,007	12,041	5,996	25,044
2049	6,258	12,041	6,026	24,325
2050	6,264	12,041	6,015	24,320

Heathrow Airport

Table C6 – CO_2 emissions: departing flights Heathrow Airport 2025 – 2050

Year	Passenger numbers	Numbers of ATMs	Heathrow Airport, tonnes CO_2	UK Total, tonnes CO_2	% of UK ATM emissions
2025	81,099,696	480,532	20,265,433	38,846,345	52.2
2026	81,351,320	476,975	20,204,599	38,953,641	51.9
2027	82,655,128	480,962	20,342,023	39,046,762	52.1
2028	84,185,600	487,113	20,459,874	39,297,453	52.1
2029	84,189,488	483,026	20,336,902	39,269,477	51.8
2030	84,919,152	483,856	20,099,848	39,193,204	51.3
2031	84,513,368	480,553	19,928,335	39,178,500	50.9
2032	84,430,592	477,917	19,820,408	39,168,898	50.6
2033	85,170,368	481,251	19,973,802	39,386,017	50.7
2034	85,642,456	481,178	20,137,089	39,823,762	50.6
2035	86,917,336	486,188	20,289,779	40,099,757	50.6
2036	87,367,408	486,311	20,116,734	40,073,885	50.2
2037	87,267,448	482,402	19,692,333	39,739,856	49.6
2038	88,216,296	484,506	19,617,253	39,717,424	49.4
2039	89,081,304	488,880	19,435,975	39,587,773	49.1
2040	88,614,304	484,517	19,184,305	39,489,040	48.6
2041	88,979,848	484,430	18,931,814	39,397,436	48.1
2042	89,473,080	483,076	18,767,864	39,256,244	47.8
2043	90,318,584	485,965	18,567,747	39,128,328	47.5
2044	92,192,896	491,781	18,311,565	38,868,876	47.1
2045	92,683,728	492,155	17,706,780	38,366,080	46.2
2046	92,813,600	489,153	17,134,355	37,790,912	45.3
2047	93,797,064	490,259	17,164,010	37,941,245	45.2
2048	93,422,864	482,063	16,984,573	37,744,332	45.0
2049	93,312,432	475,577	16,706,133	37,475,627	44.6
2050	93,533,736	471,132	16,570,400	37,514,764	44.2

Table C7: Heathrow airside (aircraft) ground movement emissions

Year	Airside Ground Movements at Heathrow Airport, tonnes CO_2 (ICAO-Times)	Airside Ground Movements at Heathrow Airport, tonnes CO_2 (HAL Reported times)
2025	390,677	311,963
2026	390,677	309,654
2027	393,943	312,242
2028	398,981	316,235
2029	395,633	313,582
2030	396,313	314,121
2031	393,608	311,976
2032	391,449	310,265
2033	394,180	312,430
2034	394,120	312,382
2035	398,223	315,635
2036	398,324	315,715
2037	395,122	313,177
2038	396,846	314,543
2039	400,428	317,382
2040	396,855	314,550
2041	396,783	314,493
2042	395,674	313,614
2043	398,041	315,490
2044	402,804	319,266
2045	403,111	319,509
2046	400,652	317,560
2047	401,558	318,278
2048	394,845	312,957
2049	389,532	308,746
2050	385,891	305,860

Table C8 - Heathrow surface access emissions 2025 - 2050

Year	Emissions due to surface access to Heathrow Airport, tonnes CO_2	Emissions due to surface access to all airports, tonnes CO_2	Heathrow % of total carbon emissions due to surface access
2025	372,712	1,813,730	20.5
2026	384,112	1,868,923	20.6
2027	381,556	1,851,783	20.6
2028	379,000	1,834,642	20.7
2029	376,444	1,817,501	20.7
2030	373,888	1,800,361	20.8
2031	376,700	1,814,236	20.8
2032	379,511	1,828,111	20.8
2033	382,323	1,841,987	20.8
2034	385,134	1,855,862	20.8
2035	387,946	1,869,737	20.7
2036	393,072	1,896,420	20.7
2037	398,197	1,923,103	20.7
2038	403,323	1,949,785	20.7
2039	408,449	1,976,468	20.7
2040	413,575	2,003,151	20.6
2041	420,039	2,029,207	20.7
2042	426,503	2,055,263	20.8
2043	432,967	2,081,319	20.8
2044	439,431	2,107,375	20.9
2045	445,895	2,133,431	20.9
2046	450,529	2,171,683	20.7
2047	455,163	2,209,935	20.6
2048	459,798	2,248,187	20.5
2049	464,432	2,286,440	20.3
2050	469,066	2,324,692	20.2
2051	469,066	2,324,692	20.2

Table C9 – Surface Access emissions with 2030 mode share

Year	Baseline emissions due to surface access to Heathrow Airport, tonne CO_2
2025	315,545
2026	316,763
2027	317,981
2028	319,199
2029	320,417
2030	321,635
2031	324,479
2032	327,323
2033	330,167
2034	333,012
2035	335,856
2036	340,338
2037	344,820
2038	349,303
2039	353,785
2040	358,267
2041	363,884
2042	369,500
2043	375,117
2044	380,734
2045	386,350
2046	390,393
2047	394,435
2048	398,477
2049	402,519
2050	406,562

Table C10 - Heathrow operational emissions 2025-2050.

Year	Emissions due to electricity use at Heathrow Airport, tonnes CO_2	Emissions due to gas use at Heathrow Airport, tonnes CO_2	Emissions due to fuel use at Heathrow Airport, tonnes CO_2	Emissions due to airport operation at Heathrow Airport, tonnes CO_2
2025	91,490	41,520	8,242	141,251
2026	76,808	41,520	8,181	126,509
2027	71,877	41,520	8,249	121,646
2028	64,802	41,520	8,355	114,677
2029	66,380	41,520	8,285	116,185
2030	64,937	41,520	8,299	114,756
2031	59,498	41,520	8,242	109,260
2032	50,552	41,520	8,197	100,269
2033	42,720	41,520	8,254	92,494
2034	36,447	41,520	8,253	86,220
2035	33,399	41,520	8,339	83,258
2036	36,146	52,099	8,341	96,587
2037	32,605	52,099	8,274	92,979
2038	32,657	52,099	8,310	93,067
2039	34,842	52,099	8,385	95,327
2040	31,552	52,099	8,310	91,962
2041	28,213	52,099	8,309	88,621
2042	27,705	52,099	8,286	88,091
2043	24,820	52,099	8,335	85,254
2044	22,620	52,099	8,435	83,154
2045	23,355	52,099	8,441	83,896
2046	21,663	52,099	8,390	82,152
2047	20,012	52,099	8,409	80,520
2048	23,457	52,099	8,268	83,825
2049	20,778	52,099	8,157	81,034
2050	20,827	52,099	8,081	81,007

Appendix D Data and Factors Used

Defra energy and fuel use CO_2 factors		
Aviation turbine fuel	3.150 tCO2/t	Emissions factor used in AoC Carbon model
Natural Gas Carbon Factor	0.18497 kgCO2/kWh	Defra (2014), assumed to remain static 2014 - 2086
Gasoil Carbon Factor	0.25359 kgCO2/kWh	
Diesel Carbon Factor	0.24615 $kgCO_2$/kWh	
Webtag derived & Defra surface access CO2 factors		
Road (personal car) 2020	0.000102 tCO_2/veh.km	Derived from Webtag 2014
Road (personal car) 2025	0.000087 tCO_2/veh.km	
Road (personal car) 2030	0.000077 tCO_2/veh.km	
Road (personal car) 2035 on	0.000074 tCO_2/veh.km	
Rail Travel	0.000047 tCO_2/pass.km	Defra (2014), assumed to remain static 2014 - 2086
Coach & Bus Travel	0.000029 tCO_2/pass.km	
Defra embodied CO2e factors		
Aggregates	11.0 $kgCO_{2e}$/t	Defra (2014), used in make-up of Taxiway and Runway factors
Average construction	74.0 $kgCO_{2e}$/t	
Asbestos	27.0 $kgCO_{2e}$/t	
Asphalt	39.2 $kgCO_{2e}$/t	
Concrete	134.8 $kgCO_{2e}$/t	
WRAP Embodied Construction Factors (WRAP 2013)		
All (average)	115.8493	tCO2e / £100k Embodied carbon emissions by construction project value
All Infrastructure	50.88447	
All Buildings	135.9155	
All linear infrastructure	51.834	
Infrastructure (other)	40.38125	
Buildings (other)	142.01	
Linear infrastructure (highway)	51.834	
Infrastructure (utilities)	38.30584	
Buildings (offices)	156.2633	
Buildings (health)	1.26	
Buildings (residential)	17.31603	
Buildings (retail)	0.53	
Buildings (education)	0.63	
All Buildings	1.060961	tCO2e / £100k Fuel consumption per construction project value
Buildings (houses)	1.309454	
Buildings (other)	1.054277	
Infrastructure (other)	3.805276	
Buildings (office)	1.1146	
Buildings (retail)	1.645876	
Buildings (health)	0.929652	
Buildings (education)	1.054944	
Buildings (residential)	0.5229	

Buildings (industrial)	1.382853	
Data used to derive energy and carbon activity data		
Total LTO cycle emissions (Heathrow)	1.2 MtCO2	2010: 477,000 ATMs Heathrow Expansion Carbon Footprint
Total LTO cycle emissions (Gatwick)	393,660 tCO2	2012 "Aircraft" emissions Gatwick A11 Carbon
Gatwick - Regulated Gas (MWh)	62,661	Gatwick (Appendix A 32)
Gatwick - Total Electricity (MWh)	153,700	
Gatwick - Regulated Electricity (MWh)	86,700	
Gatwick - Unregulated electricity (MWh)	67,000	
Gatwick - Total Energy (MWh)	216,361	
Gatwick - Fuel Consumption (MWh)	62,661	Appendix A11 Calculated from Fuel CO2
Heathrow - Regulated Gas (MWh)	224,464	Heathrow (2013) Heathrow calculated from CO2 split on total energy presented in proposal
Heathrow - Total Electricity (MWh)	519,596	Heathrow (2013) Heathrow calculated from CO2 presented in proposal
Heathrow - Total Energy	744,060	Heathrow (2013)