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8. Carbon: Assessment

Prepared for the Airports Commission

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Contents

Executive Summary

This report provides an assessment of the three shortlisted airport schemes against the Airports Commission's objective of minimising carbon emissions in airport construction and operation. The report has been prepared to provide evidence to support the Airports Commission's Appraisal Framework Module 8: Carbon, (Airports Commission, 2014) and identifies the potential impact of the three proposed schemes in terms of carbon (dioxide) emissions:

- Gatwick Airport Second Runway (Gatwick 2R) promoted by Gatwick Airport Limited (GAL)
- Heathrow Airport Northwest Runway (Heathrow NWR) promoted by Heathrow Airport Limited (HAL)
- Heathrow Airport Extended Northern Runway (Heathrow ENR) promoted by Heathrow Hub Limited (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 for Gatwick 2R and 2026 for 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.

The Appraisal Framework identified 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 where the elements of Appraisal Framework are addressed within this appraisal.

Table A1: Appraisal Framework topics within this report

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 & fuel use.
Changes in non-aviation transport	Passenger surface access emissions.

Carbon Assessment – Gatwick Airport Second Runway

Analysis of the Gatwick second runway scheme carbon emissions is based on the two runway masterplan submitted by GAL, and the AoN Carbon Capped passenger and ATM forecasts developed by the Airports Commission. This sees ATMs grow from around the 290,000 in 2025 to 476,000 in 2050, with a steady growth and some annual variance. There would be significant construction of infrastructure during the early years of the scheme, although new terminal capacity would not added until after new runway capacity.

The most significant volume of emissions are related to air travel, and these would increase steadily over the period aligned with ATMs, but at a slower rate linked to improved fuel efficiency of airline fleets. Surface access emissions remain the second largest source of CO_2 and increase over the assessment period, linked to annual passenger numbers. Emissions from buildings and airport operations initially increase, but then reduce and remain steady as carbon intensity per passenger and per m^2 reduce over time, most significantly due to the presumed decarbonisation of grid electricity.

Table A2 outlines the findings of the carbon assessment for Gatwick 2R in terms of the change in tonnes of carbon dioxide. Table A3 details the net present value (£) for the predicted change.

Table A2 - Carbon assessment findings for Gatwick 2R: change in tCO_2

Area of Emissions	2030	2040	2050	Additional tCO_2 to Baseline over 60 year appraisal period	Total tCO_2 over 60 year appraisal period
Air travel	324,944	728,573	1,476,657	68,860,268	307,281,972
Ground movements component	19,862	48,030	92,317	4,353,561	12,742,794
Passenger surface access	28,782	71,474	139,519	6,555,448	25,096,949
Airport operations energy & fuel use	10,330	10,688	14,243	759,561	2,370,875
Total operational CO_2 emissions	**364,056**	**810,735**	**1,630,419**	**76,175,277**	**334,749,796**
Construction of airport facilities & SA infrastructure*	n/a	n/a	n/a	3,891,468	6,907,686

* Construction emissions are calculated as tCO_2e.

Table A3 - Carbon assessment findings for Gatwick 2R: change in central carbon value, (NPV) for emission sources

Area of Emissions	2030	2040	2050	Additional £ to Baseline over 60 year appraisal period	Total £ over 60 year appraisal period
Air travel	£14,553,941	£44,614,639	£113,054,844	£4,440,846,383	£18,976,782,119
Ground movements component	£889,634	£2,941,187	£7,067,947	£280,464,851	£793,664,032
Passenger surface access journeys	£1,032,207	£2,408,358	£7,310,279	£422,198,583	£844,397,166
Airport operations energy & fuel use	£462,688	£654,510	£1,090,501	£48,093,366	£145,264,621
Total operational CO_2 emissions	**£16,048,836**	**£47,677,507**	**£121,455,624**	**£4,911,138,333**	**£19,966,443,906**
Construction of airport facilities & SA infrastructure*	n/a	n/a	n/a	£146,587,376	£289,447,744

Air travel emissions

The level of emissions for air travel at Gatwick Airport under the Gatwick 2R proposal is expected to exceed the baseline level by approximately 68.9 $MtCO_2$ over the 60 year appraisal period, rising from 4.2 to 5.3 $MtCO_2$ per year over this period (the baseline remains around 3.9 $MtCO_2$ per year over this period). The carbon value of this change is estimated at £4.4 billion.

Ground movements (Component of air travel)

Airside ground movements at Gatwick Airport, strongly correlated with ATMs at the airport, are predicted to increase over the assessment period from 140,000 to 231,000 tCO_2 per year (the baseline rises from 134,000 to 138,000 tCO_2 per year), with a total increase of approximately 4.4 $MtCO_2$ over the assessment period. This is forecast to make up approximately 6.2% of the change in air travel emissions.

Departure & arrival route changes

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

Surface access transport emissions

Emissions due to non-aviation accessing Gatwick (surface access transport) are thought to increase from 318,000 tCO_2 to 448,000 tCO_2 per year between 2030 and 2050 (the baseline is around 300,000 tCO_2 per year increasing from 290,000 to 308,500 tCO_2), with a total increase over the assessment period of 6.5 $MtCO_2$. This increases the total emissions in this emissions area by 41% between 2030 and 2050 within the Do Something scenario, and an increase of 55% over the 2030 Do Minimum Scenario. There is a 52% increase in total passenger numbers between 2030 and 2050 Do Something scenario, with the proportion of total terminal passengers using surface access to Gatwick staying broadly around 95% (43,000,000 of 45,600,000 in 2030 and 66,600,000 of 69,400,000 in 2050). The slightly less than proportionate growth in surface access emissions and is related to reduced road surface access emission factors after 2030.

Emissions due to energy and fuel use during airport operations

In the baseline, the emissions due to energy use in operations are expected to continuously reduce through the study period due to the decarbonisation of the grid, decreasing from 44,000 tCO_2 to 24,000 tCO_2 per year. However, due to the expansion, including new terminal space, more flights and additional passengers, the emissions will only reduce to 42,000 tCO_2 per year, resulting in total additional emissions of 750,000 tCO_2 over the assessment period.

Construction of airport facilities & SA infrastructure

Embodied emissions associated with construction are not immediately comparable with operational emissions, but have been estimated to sum to an additional 3.9$MtCO_2e$ over the assessment period. Construction emissions occur early in the assessment period, when the forecast cost per tonne of CO_2 is low, the overall cost of carbon is lower than an equivalent volume of emissions released more evenly over the period of assessment.

Carbon Assessment – Heathrow Airport Northwest Runway

Analysis of the Heathrow North West Runway scheme carbon emissions is based on the Northwest runway masterplan submitted by HAL, and the AoN Carbon Capped passenger and ATM forecasts developed by the Airports Commission. This sees ATMs grow from around the 480,000 level in 2026, to 750,000 in 2040, which then stays broadly fixed through to 2050 with some annual variance. The operational cap of 740,000 is not adhered to in the AoN forecast, so ATMs and emissions reflect demand directly within the confines of the UK aviation system cap of 37.5Mt CO_2. There would be significant construction of infrastructure during the early years of the scheme, with new runway and new terminal and surface access infrastructure dominating.

The most significant volume of emissions are related to air travel, but these initially increase in line with ATMs but then decrease over the period, linked to capacity being reached in 2040 and then reflecting continued changes to the Heathrow fleet and improved fuel efficiency of aircraft present within that fleet. Surface access emissions remain the second largest source of CO_2 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 initially increase with new infrastructure but then reduce over time, most significantly due to the presumed decarbonisation of grid electricity.

Table A4 outlines the findings of the carbon assessment for Heathrow NWR in terms of the change in tonnes of carbon dioxide. Table A5 details the net present value (£) for the predicted change.

Table A4 - Carbon assessment findings for Heathrow NWR: change in tCO_2

Area of Emissions	2030	2040	2050	Additional tCO_2 to Baseline over 60 year appraisal period	Total tCO_2 over 60 year appraisal period
Air travel	3,101,660	4,576,552	3,912,629	236,659,012	1,313,372,945
Ground movements component	137,899	217,858	231,150	12,845,042	36,640,725
Passenger surface access journeys	63,145	96,193	103,764	5,698,857	32,748,026
Airport operations energy & fuel use	44,392	39,755	35,004	2,218,775	7,507,784
Total operational CO_2 emissions	**3,209,197**	**4,712,500**	**4,051,397**	**244,576,644**	**1,353,628,755**
Construction of airport facilities & SA infrastructure*	n/a	n/a	n/a	11,260,690	24,775,297

* Construction emissions are calculated as tCO_2e.

Table A5 - Carbon assessment findings for Heathrow NWR: change in central carbon value, (NPV) for emission sources

Area of Emissions	2030	2040	2050	Additional £ to Baseline over 60 year appraisal period	Total £ over 60 year appraisal period
Air travel	£138,920,479	£280,248,124	£299,556,133	£14,736,139,315	£79,922,168,410
Ground movements component	£6,176,372	£13,340,662	£17,697,130	£805,252,094	£2,260,432,982
Passenger surface access journeys	£2,828,191	£5,890,430	£7,944,295	£358,755,534	£2,030,426,713
Airport operations energy & fuel use	£1,988,261	£2,434,436	£2,679,964	£135,341,278	£455,439,720
Total operational CO_2 emissions	**£143,736,931**	**£288,572,990**	**£310,180,392**	**£15,230,236,127**	**£82,408,034,843**
Construction of airport facilities & SA infrastructure*	n/a	n/a	n/a	£253,048,272	£875,194,585

Air travel emissions

The level of emissions for air travel at Heathrow Airport under the Heathrow NWR proposal is expected to exceed the baseline level by approximately 237 $MtCO_2$ over the 60 year appraisal period, rising from 23.2 $MtCO_2$ per year in 2030 to 23.7 $MtCO_2$ per year in 2040, before falling to 20.5 $MtCO_2$ per year in 2050 (The baseline drops from 20.1 $MtCO_2$ to 16.6 $MtCO_2$ per year over this period). The carbon value of these additional emissions is estimated at £14.7 billion.

Ground movements (Component of air travel)

Airside ground movements at Heathrow Airport, strongly correlated with ATMs at the airport, are predicted to increase from 534,000 tCO_2 to 617,000 tCO_2 per year (the baseline is forecast to vary between 385,000 and 405,000 tCO_2 per year) over the assessment period, with a total increase of approximately 12.8 $MtCO_2$. This is forecast to make up approximately 5.4% of the change in air travel emissions.

Departure & arrival route changes (Component of air travel)

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 journeys

Emissions due to non-aviation accessing Heathrow (surface access transport) are thought to increase over the assessment period from 372,000 tCO_2 to 572,000 tCO_2 per year (the baseline is forecast to increase from 372,000 tCO_2 to 469,000 tCO_2 per year), with the total emissions over the assessment period increasing by 5.7 $MtCO_2$. This increases the total emissions in this emissions area by 17.5%. This is lower than the forecast increase in passengers, which is approximately 40% over the 60 year period, due to the proportion of passengers who do not make surface access journeys.

Emissions due to energy and fuel use during airport operations

In the baseline, the emissions due to energy use in operations are expected to reduce through the study period due to the decarbonisation of the grid, dropping from 141,000 tCO_2 to 81,000 tCO_2 per year. However, due to the expansion, including new terminal space, more flights and additional passengers, the emissions will only fall to 120,000 tCO_2 per year, resulting in over 2.2 $MtCO_2$ of additional emissions over the assessment period.

Construction of airport facilities & SA infrastructure

Embodied emissions associated with construction are not immediately comparable with operational emissions, but have been estimated to sum to an additional 11.3 $MtCO_2e$ over the assessment period. Construction emissions occur early in the assessment period, when the forecast cost per tonne of CO_2 is low, the overall cost of carbon is lower than an equivalent volume of emissions released more evenly over the period of assessment.

Carbon Assessment – Heathrow Airport Extended Northern Runway

Analysis of the Heathrow Extended Northern Runway carbon emissions is based on the Extended Northwest runway masterplan submitted by HH, and the AoN Carbon Capped passenger and ATM forecasts developed by the Airports Commission. This sees ATMs grow from around the 480,000 level in 2026, to 710,000 in 2040, which then stays broadly fixed through to 2050 with some annual variance. The operational cap of 700,000 is not adhered to in the AoN forecast, so ATMs and emissions reflect demand directly within the confines of the UK aviation system cap of 37.5Mt CO_2. There would be significant construction of infrastructure during the early years of the scheme, with new runway and new terminal and surface access infrastructure dominating.

The most significant volume of emissions are related to air travel, but these initially increase in line with ATMs but then decrease over the period, linked to capacity being reached in 2040 and then reflecting continued changes to the Heathrow fleet and improved fuel efficiency of aircraft present within that fleet. Surface access emissions remain the second largest source of CO_2 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 initially increase with new infrastructure but reduce over time, most significantly due to the presumed decarbonisation of grid electricity.

Table A6 outlines the findings of the carbon assessment for Heathrow ENR in terms of the change in tonnes of carbon dioxide. Table A7 details the net present value (£) for the predicted change.

Table A6 - Carbon assessment findings for Heathrow ENR: change in tCO_2

Area of Emissions	2030	2040	2050	Additional tCO_2 to Baseline over 60 year appraisal period	Total tCO_2 over 60 year appraisal period
Air travel	3,243,282	4,166,682	3,337,514	210,414,493	1,287,128,426
Ground movements component	139,761	184,137	196,357	11,186,687	34,982,369
Passenger surface access journeys	63,734	83,823	87,033	4,893,316	31,942,485
Airport operations energy & fuel use	38,777	32,171	27,543	1,784,204	7,073,214
Total operational CO_2 emissions	**3,345,793**	**4,282,676**	**3,452,090**	**217,092,013**	**1,326,144,125**
Construction of airport facilities & SA infrastructure*	n/a	n/a	n/a	10,124,262	23,638,870

* Construction emissions are calculated as tCO2e.

Table A7 - Carbon assessment findings for Heathrow ENR: change in central carbon value, (NPV) for emission sources

Area of Emissions	2030	2040	2050	Additional £ to Baseline over 60 year appraisal period	Total £ over 60 year appraisal period
Air travel	£145,263,597	£255,149,469	£255,524,556	£13,002,339,352	£78,188,368,446
Ground movements component	£6,259,758	£11,275,771	£15,033,365	£697,721,748	£2,152,902,636
Passenger surface access journeys	£2,854,593	£5,132,977	£6,663,374	£306,507,064	£1,978,178,243
Airport operations energy & fuel use	£1,736,795	£1,970,017	£2,108,742	£108,389,626	£428,488,069
Total operational CO_2 emissions	**£149,854,985**	**£262,252,463**	**£264,296,672**	**£13,417,236,042**	**£80,595,034,758**
Construction of airport facilities & SA infrastructure*	n/a	n/a	n/a	£229,550,861	£851,697,173

Air travel emissions

The level of emissions for air travel at Heathrow Airport under the Heathrow ENR proposal is expected to exceed the baseline level by approximately 210 $MtCO_2$ over the 60 year appraisal period, remaining at levels of 23.3 $MtCO_2$ per year in 2030 and 2040, before falling to 19.9 $MtCO_2$ per year in 2050 (The baseline drops from 20.1 $MtCO_2$ to 16.6 $MtCO_2$ per year over this period). The carbon value of this change is estimated at £13 billion.

Ground movements (Component of air travel)

Airside ground movements at Heathrow Airport, strongly correlated with ATMs at the airport, are predicted to increase from 449,000 tCO_2 to 582,000 tCO_2 per year (the baseline is forecast to vary between 385,000 and 405,000 tCO_2 per year) over the assessment period, with a total increase of approximately 11.2 $MtCO_2$. This is forecast to make up approximately 5.3% of the change in air travel emissions.

Departure & arrival route changes (Component of air travel)

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 journeys

Emissions due to non-aviation (surface access transport) are thought to increase over the assessment period from 383,000 tCO_2 to 556,000 tCO_2 per year (the baseline is forecast to increase from 372,000 tCO_2 to 469,000 tCO_2 per year), with the total emissions over the assessment period increasing by 4.9 $MtCO_2$. This increases the total emissions in this emissions area by 15.3%. This is lower than the forecast increase in passengers, which is approximately 36% over the 60 year period, due to the proportion of passengers who do not make surface access journeys.

Emissions due to energy and fuel use during airport operations

In the baseline, the emissions due to energy use in operations are expected to reduce through the study period due to the decarbonisation of the grid, dropping from 141,000 tCO_2 to 81,000 tCO_2 per year. However, due to the expansion, including new terminal space, more flights and additional passengers, the emissions will only fall to 113,000 tCO_2 per year resulting in 1.8 $MtCO_2$ over the assessment period.

Construction of airport facilities & SA infrastructure

Embodied emissions associated with construction are not immediately comparable with operational emissions, but have been estimated to sum to an additional 11.3 $MtCO_2e$ over the assessment period. Construction emissions occur early in the assessment period, when the forecast cost per tonne of CO_2 is low, the overall cost of carbon is lower than an equivalent volume of emissions released more evenly over the period of assessment.

1 Introduction

This section covers:

- Context for the report and scope of the assessment; and
- Details of the content of the assessment and the report.

1.1 Context and scope

This report has been prepared to provide evidence to support the Airports Commission's Appraisal Framework Module 8: Carbon, (Airports Commission, 2014). Under this module the objective is to minimise carbon emissions in airport construction and operation.

This report identifies the carbon dioxide emissions impact 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)
- Heathrow Airport Extended Northern Runway (Heathrow ENR) promoted by Heathrow Hub (HH).

The module as a whole considers estimates of baseline and future runway schemes' 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. The assessment utilises proposal information and other data sources, as detailed in the methodology.

In calculating the 60 year appraisal, schemes have a base date of 2025 (Gatwick 2R) and 2026 (Heathrow NWR & Heathrow ENR) in line with assumed opening dates of the developments, and corresponding end dates of 2085 / 2086. Results for the years 2030, 2040 and 2050 are considered.

Based on the United Nations Framework Convention on Climate Change (UNFCCC) approach[1] 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[2]. By this measure, aviation emissions account for about 6% of the greenhouse gas (GHG) emissions in the UK (Department for Transport, 2013a), 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).

[1] The accounting convention used by the UK to assess emissions from UK aviation is consistent with this UNFCCC approach

[2] Other mechanisms for allocating emissions have been discussed: see e.g. http://www.cate.mmu.ac.uk/projects/international-aviation-emissions-allocations/ and http://southgateaviation.files.wordpress.com/2013/05/final-allocation-paper.pdf

According to the Department for Transport's published data "Total greenhouse gas emissions from transport" for 2011 (Department for Transport, 2012a), 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[3].

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 (Department for Transport, 2011b) and the European Commission (European Commission, 2011), the Committee on Climate Change (Committee on Climate Change, 2013), the aviation industry (e.g. Sustainable Aviation, ACI and IATA (International Air Transport Association (IATA), 2014)) and environmental NGOs (Airportwatch, n.d.).

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 (Department for Transport, 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

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

Table 1.1 outlines where the elements of Appraisal Framework are addressed within this appraisal.

Table 1.1: Appraisal Framework topics within this report

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

2 Methodology and legislation

This section covers:

- Methodology;
- Assumptions and Limitations; and
- Legislation.

2.1 Methodology

This section provides a summary of the assessment methodology included as Appendix A.

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 carbon dioxide (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 (see Appendix B for full methodology).

- **total aircraft emissions from ATMs**, including cruise - have been estimated based on the methodology used by the UK Department for Transport (DfT) Aviation Forecasts as described in the DfT Aviation Forecast 2011 (Department for Transport, 2011a) and 2013 (Department for Transport, 2013c)
  - **departure and arrival route impacts** – are not presented in this assessment; there is currently insufficient input data available to support robust emissions calculation.
  - **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 (Gatwick Airport Limited, 2014a) and Heathrow (Heathrow Airport Limited, 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 2009 (Department for Transport, 2009), 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 the WRAP (2013), Archetype resource benchmarks for construction projects tool (WRAP, 2013), for embodied carbon emissions

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 Airports Commission Assessment of Need Forecast (carbon capped) (AoN Carbon Capped[4]) 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.

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

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 2009 (Department for Transport, 2009), 2011 (Department for Transport, 2011a) and 2013 (Department for Transport, 2013c).

The AoN carbon capped demand forecast model does not limit ATMs on an operational basis and has calculated carbon emissions from air travel up to a maxima of 476,000 ATMs for Gatwick 2R, 755,000 for Heathrow NWR and 716,000 for Heathrow ENR. The ATMs assumed for operational purposes reach maxima of 560,000 ATMs for Gatwick 2R, 740,000 for Heathrow NWR and for 700,000 Heathrow ENR leading to a conservative (i.e. higher) estimate of carbon emissions where the operational ATM cap is below that within the AoN carbon capped.

The Airports Commission Do Minimum (DM) and AoN carbon capped 2014 are used as the major source for baseline and scheme assessment (they provide passenger numbers, ATMs and carbon outputs). The AoN 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, p. 63):

- 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

[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 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.

- All international freighter aircraft departing UK airports
- All freighter aircraft while on the ground in the UK (e.g. taxi-ing)

2.1.2 Departure and arrival route impacts

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, 2009). 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 (Department for Transport, 2014a).

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), which is intended to improve efficiencies through information sharing and group decisions of airport operations; and procedures such as reduced engine taxi (Sustainable Aviation, 2012) and provision of Fixed Electrical Ground Power (FEGP), which reduces the use of on-board auxiliary power units (APUs).

The method used for this basic assessment uses historic reported emissions associated with Landing and Take-Off (LTO) from both Gatwick (Gatwick Airport Limited, 2014a) and Heathrow (Heathrow Airport Limited, 2014) and reported ATMs in those years in order to create a factor representing LTO emissions per ATM. The proportion of the LTO which is ground based is then determined using ICAO Times-in-Mode (TIM), a measurement of how long an aircraft spends in the different modes of an LTO cycle, which are approach, taxi, take-off and climb, and thrust settings, resulting in an ICAO-Times forecast (International Civil Aviation Organisation, 2011). 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.

The change in emissions is presented for the proposal airport only, though it is acknowledged that there may be impacts at other airports due to the proposal.

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 "*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 (Department for Transport, 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 (Department for Transport, 2013b) (private vehicle) or Defra 2014 (rail and coach) (DEFRA, 2014). 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).

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.

Emissions are presented as the total change across the modelled system and also as the change that occurs in emissions that occurs due to journeys associated with use of the proposal airport

2.1.5 Airport operations

These impacts have been assessed to provide data to understand the carbon effects of the second element of the Appraisal Framework's "*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 impacting 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 footprint 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) for long term emissions factors from energy generation (DECC IAG, 2014a).

For gas and fuel, the current values reported in the Defra Greenhouse Gas Conversion Factor Repository (DEFRA, 2014) were used and presumed to hold across the assessment period (in line with DfT Aviation Forecast 2009, Annex I).

The change in emissions is presented for the proposal airport only, though it is acknowledged that there may be impacts at other airports due to the proposal.

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 UK Ltd, 2014a), using benchmarks from the WRAP Resource use benchmarks tool (WRAP, 2013), for embodied carbon emissions.

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).

The change in emissions is presented for the proposal airport only.

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 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) (DECC IAG, 2014a). 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.

The presented values use the DECC Central forecast for the EU ETS carbon prices[6], although the range of Low to High values are presented for sensitivity.

Where a total is presented for a key year, or the total assessment period, this is made up of the monetised totals for:

- the net change in air travel;
- the changes in surface access journeys;
- the operation of the proposed airport; and
- the construction of facilities and infrastructure at the proposed airport.

2.2 Assumptions and Limitations

2.2.1 Total aircraft emissions from ATMs, including cruise

This appraisal uses ATMs, passenger and carbon data as generated by the Airports Commission Demand Forecast 2014. 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 2011 (Department for Transport, 2011a) and 2013 (Department for Transport, 2013c).

2.2.2 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.

2.2.3 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.

[6] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal Values are taken from MS Excel document “Data tables 1-20: supporting the toolkit and the guidance”, Table 3: Carbon prices and sensitivities 2008-2100 for appraisal, 2014 £/tCO2e

The first calculation uses the ICAO Simple Approach to calculation and a presumed ground movement factor derived from published information on LTO cycle at Gatwick and Heathrow Airport. 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 Airport 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.

2.2.4 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 Jacobs 2014 Surface Access analyses (Jacobs, 2014b). The assumptions made in the 2014 surface access analysis are presented within the relevant report. 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.

2.2.5 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.

2.2.6 Carbon emissions from infrastructure construction

The activity data for construction cost, phasing and footprints were taken from the Revenue and Cost Identification report (Jacobs UK Ltd, 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, 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. 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, as described in the methodology.

2.2.7 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.

2.2.8 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.

In order to not introduce cumulative rounding errors, all factors and calculated results have been used at their original level of precision. In order to aid the reader in following the derivation of the results, the emissions levels and value of emissions are currently presented at the nearest whole unit. This should not be taken as overconfidence in the results, and should be treated accordingly.

2.3 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 (Committee on Climate Change, 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 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 Airport 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 .

3 Gatwick Airport Second Runway Carbon Impact Assessment

This section covers the following for Gatwick Airport Second Runway and each emissions category:

- Jacobs assessment of impacts;
- Potential for mitigation (or limitations);
- Comment on the proposer's submission ; and
- Conclusions

3.1 Increased airport capacity leading to a net change in air travel

Impact Assessment

Table 3.1 presents the carbon emissions from the AoN Carbon Capped scenario for all departing flights from Gatwick Airport between 2025 and 2050, with two runways, alongside the total carbon emissions from all UK flights and the percentage of the UK total that occurs with flights from Gatwick. Table 3.2 details the change between the baseline scenario compared with the Gatwick 2R scenario emissions. Figure 3.1 presents the Gatwick 2R carbon emissions and the baseline assessment graphically.

Table 3.1 - Carbon emissions, carbon capped: Gatwick 2R, for 2025 – 2050

Year	Gatwick Airport, Number of passengers	Gatwick Airport, Numbers of ATMs	Gatwick Airport, tonnes CO_2	UK Aviation Total, tonnes CO_2	Gatwick as % of UK Total for aviation carbon emissions
2025	40,487,944	288,285	4,425,878	38,908,184	11.4
2030	45,599,168	318,909	4,218,239	39,232,048	10.8
2040	55,606,912	379,752	4,689,706	39,699,139	11.8
2050	69,414,512	475,932	5,337,549	37,538,815	14.2

Figure 3.1 - Carbon emissions from departing flights at Gatwick Airport, 2025 – 2050: baseline and Gatwick 2R scenarios, carbon capped

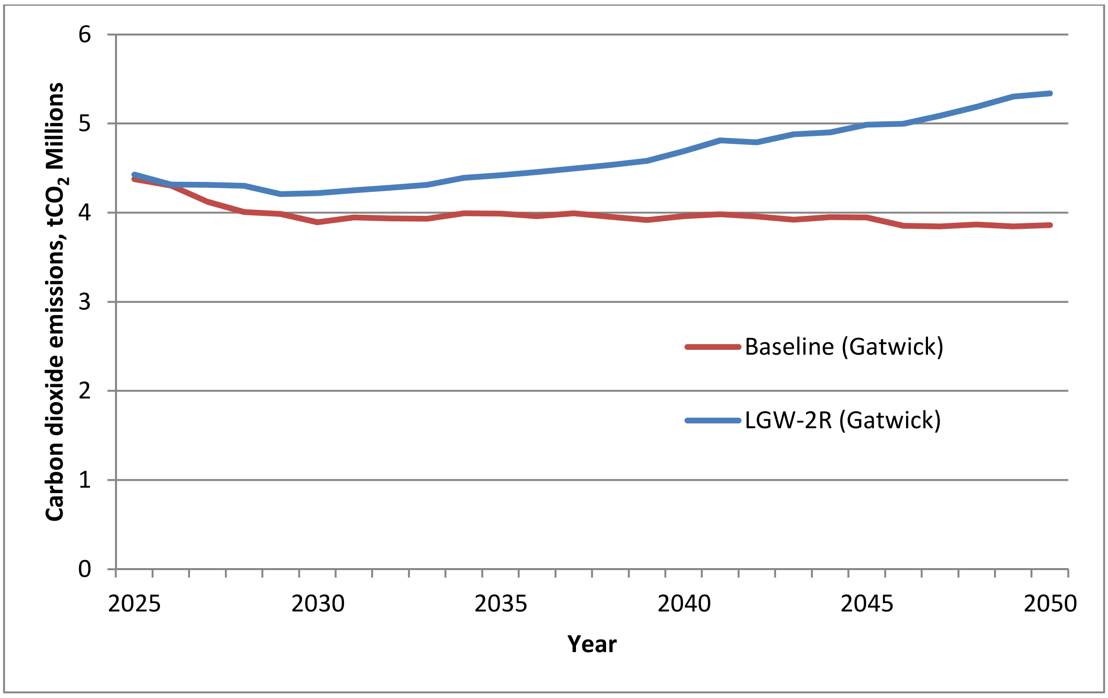


Table 3.2 - Comparison of the carbon emissions in 2030, 2040 and 2050 for the Gatwick Airport baseline and Gatwick 2R forecast scenarios

Year	Baseline tonnes CO_2	Gatwick 2R tonnes CO_2	Change (%)
2030	3,893,295	4,218,239	+8.3
2040	3,961,133	4,689,706	+18.4
2050	3,860,892	5,337,549	+38.2

With a second runway in use the carbon emissions associated with departing flights increase by 1.12 $MtCO_2$ or 26.5% over the period 2030 - 2050. This increase compares to the 'do minimum' (baseline) forecast that shows carbon emissions are almost flat. The carbon emissions in the 'do something' scenario are greater than in the 'do minimum' (baseline) scenario by 1.48 $MtCO_2$ or 38.2% in 2050.

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

- distances flown by aircraft;
- fuel efficiency of the aircraft fleet; and,
- type of fuel used.

Figure 3.2 shows the changes in ATMs during the period 2025 – 2050.

Figure 3.2 - Air transport movements (ATMs) during the period 2025 – 2050 at Gatwick Airport, baseline and Gatwick 2R scenarios, carbon capped

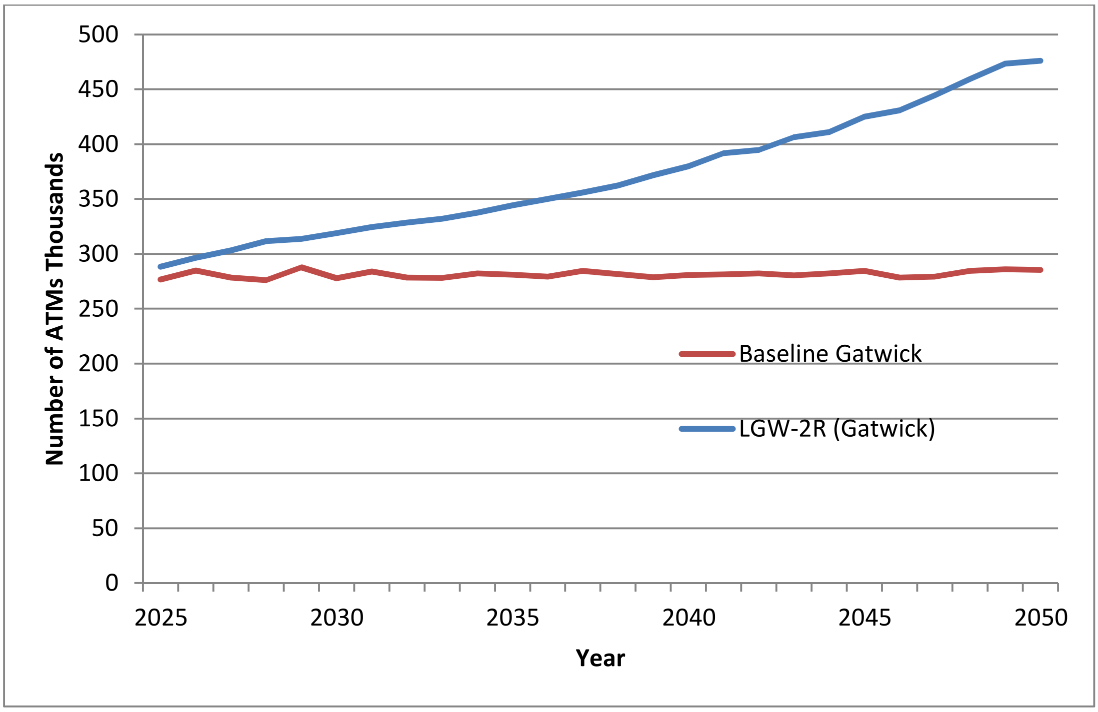


Figure 3.2 shows that the number of ATMs at Gatwick Airport, a key determinant of aviation carbon emissions, increases during the period 2030-2050. An increase in carbon emissions would be expected if ATMs were the only determinant of emissions. The increase in ATMs over the 2030-2050 period is 49.2% with the Gatwick 2R scheme compared with an increase of 26.5% in carbon emissions. There is therefore a reduction in carbon per ATM. This is due to a combination of aircraft fleet changes and alternative fuels, with the predicted fleet mix at Gatwick changing from the baseline estimation. The forecast 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 something (Gatwick R2)'. The forecast has not been made for a change in just one of these assumptions, therefore the magnitude, and the relative contributions of each, cannot be identified from the model output contained in the AoN Carbon Capped.

Carbon emissions from flights departing Gatwick Airport have not been modelled for the period 2050-2085. 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.

Mitigation

Mitigation that may impact this aspect of emissions includes the utilisation of mechanisms that would encourage the new demand to be utilised by the cleanest aircraft. Potential options for this include increased airport charges for older aircraft, or mandated "green slots" which require planes of a certain standard to take up the new capacity.

3.2 Airside ground movements

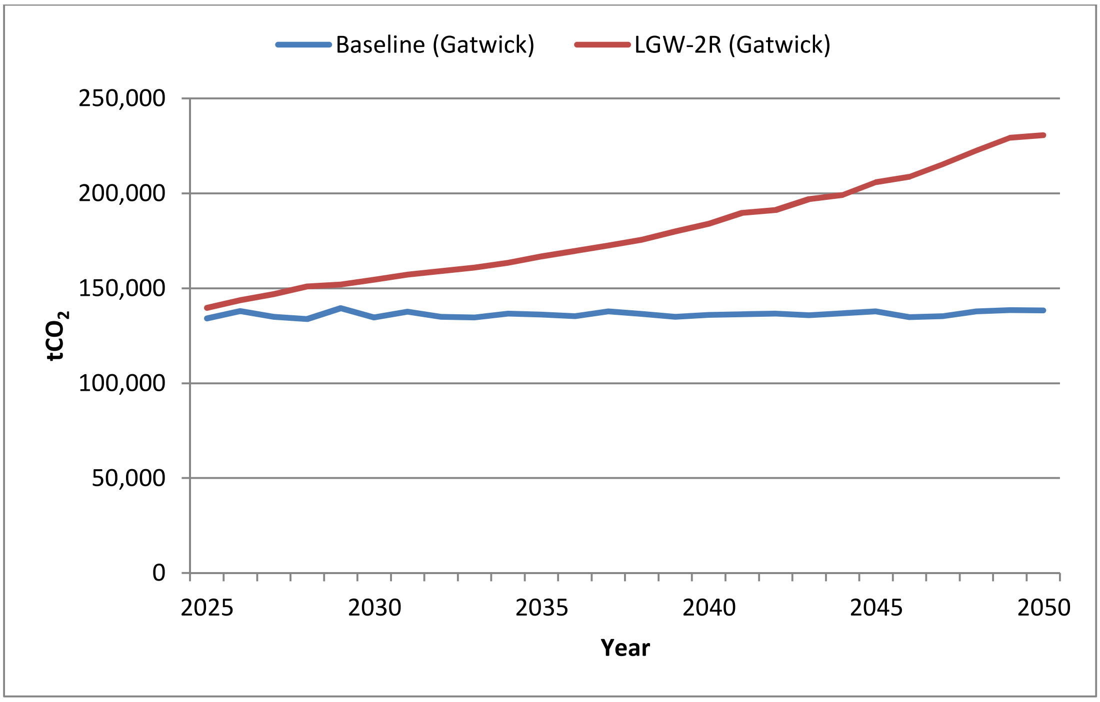
Impact Assessment

Table 3.3 presents a comparison of the carbon emissions over time for the baseline and Gatwick 2R forecast scenarios for airside ground movements, and shows both the ICAO-Times-in-mode and GAL-Reported Times-in-mode derived forecasts. It can be seen that due to the increase in ATMs in the Gatwick 2R scenario, the emissions associated with airside ground movements increase rapidly, diverging by more than 66% by 2050. This is also shown in Figure 3.3.

Table 3.3 - Comparison of the aircraft ground movement emissions 2025 – 2050 for the Gatwick Airport baseline and Gatwick 2R forecast scenarios

Year	Baseline, tCO_2	Gatwick 2R, tCO_2, ICAO-Times	Gatwick 2R, tCO_2, GAL-Reported Times
2025	134,085	139,696	133,949
2030	134,673	154,535	148,178
2040	135,988	184,019	176,448
2050	138,308	230,625	221,137

Figure 3.3 - Carbon emissions due to airside ground movements 2025 – 2050 for the baseline and Gatwick 2R forecast scenarios



It should be noted that in the Gatwick 2R proposed scheme it is not just ATMs at Gatwick which are expected to change, as additional capacity causes ATMs to shift between airports; as each airport will have its own level of emissions per ground movement, this means that a shift of ATMs to Gatwick or any airport with a higher level of emissions per LTO cycle, to Gatwick would reduce the overall impact of the additional ATMs at Gatwick.

Mitigation

The primary way in which to reduce the emissions associated with airside ground movements is through efficient runway and taxiway design and use. Airports have made advances in these areas, and it is recommended that best practice would be applied to any new designs. This should include:

- Use of airport terminal power and pre-conditioned air sources
    - This would reduce the burden on aircraft APUs and airport GPUs
- Reduce engine operation during taxing
    - By shutting down an engine during taxiing, both fuel use and emissions can be reduced.

3.3 Surface Access

Impact Assessment

For this assessment, the 2008 modal share was used to calculate emissions from surface access. Within this model, the rail, coach/bus and private vehicle shares differ according to Origin-Destination; the approximate overall mode share for Gatwick, was:

- Rail – 23%
- Coach/bus – 10%
- Private vehicle – 67%

Under Gatwick 2R there would be additional surface access requirements at Gatwick, which would lead to a change in the associated emissions. These can be seen in Table 3.4 and Figure 3.4, where the 45% increase over the 2025-2050 period can be seen.

Figure 3.4 - Emissions due to surface access for baseline and Gatwick 2R forecast scenarios

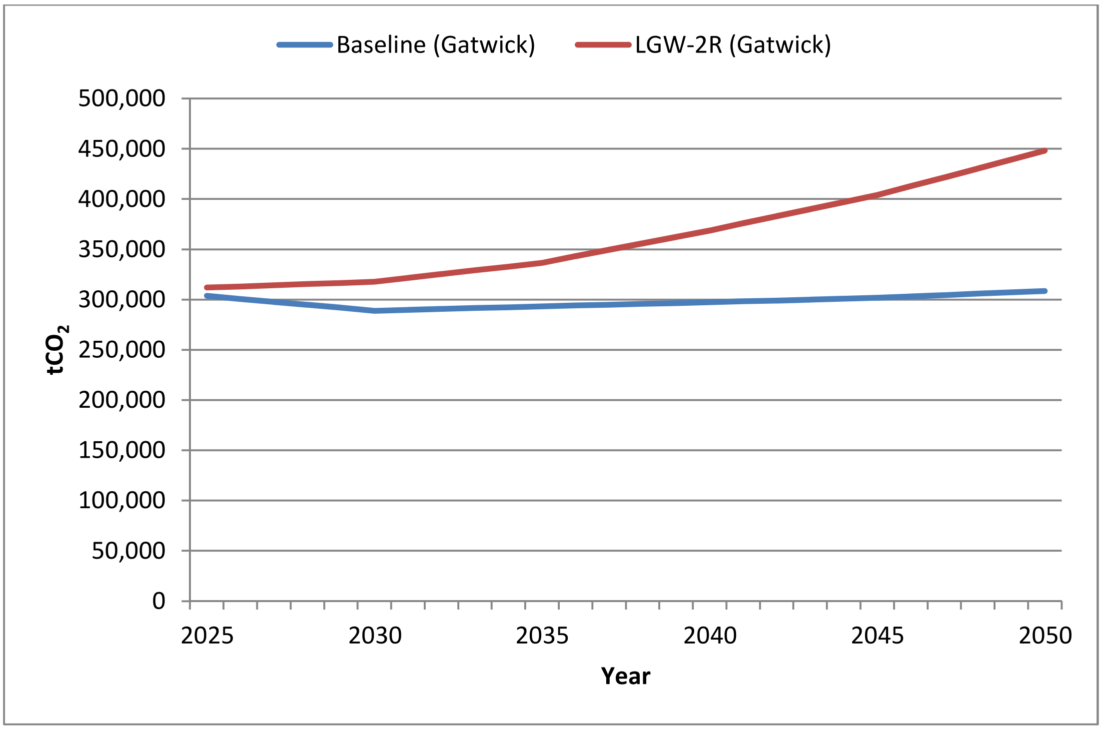


Table 3.4 - Emissions due to surface access for 2025 – 2050 for baseline and Gatwick 2R forecast scenarios

Year	Baseline emissions due to surface access to Gatwick Airport, tonnes CO_2	Gatwick 2R emissions due to surface access to Gatwick Airport, tonnes CO_2	Change from baseline (%)
2025	303,600	311,909	2.7%
2030	288,863	317,645	9.9%
2040	297,307	368,781	24.0%
2050	308,530	448,049	45.2%

Table 3.5 and Figure 3.5 present the combined total for the airports used in the National Surface Access model[7] under the Gatwick 2R proposal. It can be seen that the increase of passenger numbers at Gatwick 2R leads to a slight decrease in total surface access emissions. This is due to the fact that under the base model Gatwick has a higher public transport modal share than some other airports. This means that passengers substituting into an expanded Gatwick may do so from airports where their travel emissions would have been higher.

[7] The airports used are: Aberdeen, Birmingham, Bournemouth, Bristol, Cardiff, East Midlands, Edinburgh, Exeter, Gatwick, Glasgow, Heathrow, Humberside, Leeds/Bradford, Liverpool, London City, Luton, Manchester, Newcastle, Newquay, Norwich, Southend, Southampton, Stansted, Teesside, Blackpool, Doncaster Sheffield, Prestwick

Figure 3.5 - The emissions due to surface access across the UK airport system for baseline and Gatwick 2R forecast scenarios

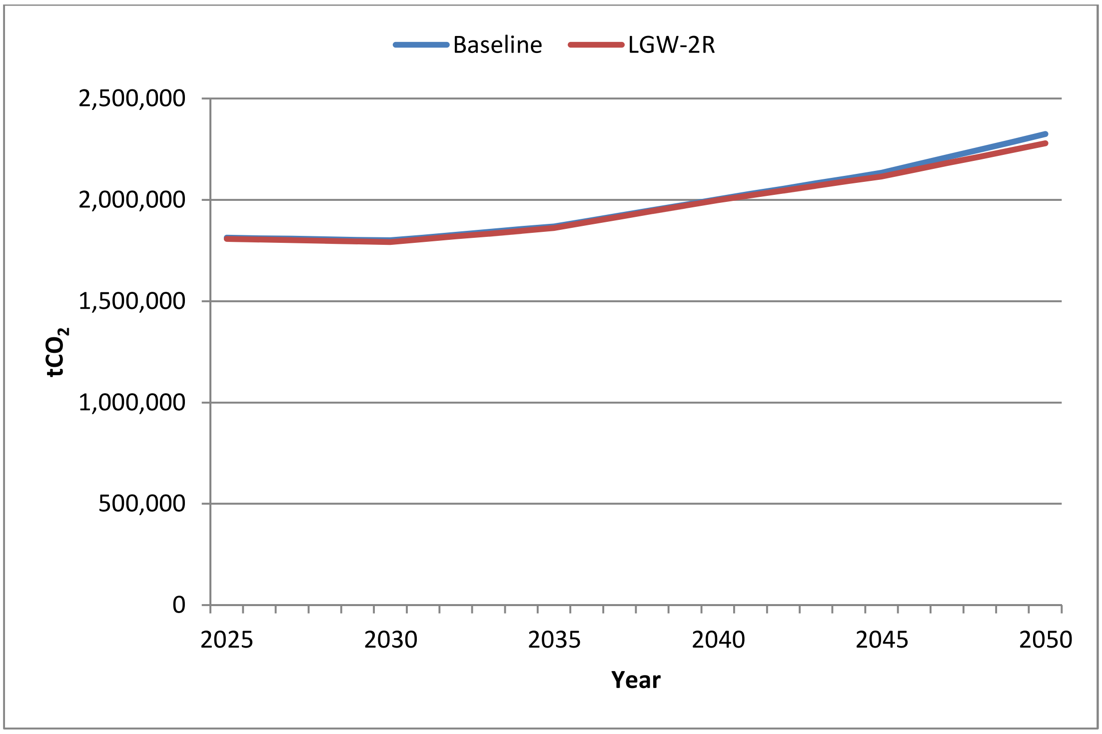


Table 3.5 - The emissions due to surface access across the UK airport system, 2025 – 2050 for baseline and Gatwick 2R forecast scenarios

Year	Baseline emissions due to surface access to UK airports[8], tonnes CO_2	Emissions due to surface access to UK airports with Gatwick 2R[9], tonnes CO_2	% change
2025	1,813,730	1,807,792	-0.3%
2030	1,800,361	1,791,654	-0.5%
2040	2,003,151	1,999,113	-0.2%
2050	2,324,692	2,278,623	-2.0%

Sensitivity: 2030 Modal split

A sensitivity scenario was developed in which the predicted Jacobs 2030 mode share was applied to the surface access for Gatwick. The forecast regional mode share for Gatwick in 2030 is shown in Table 3.6. The result of this can be seen in Table 3.7 and Figure 3.6. The primary difference is a reduction in absolute emissions; however the change over time is, in absolute terms, almost the same. This is due to the impact of additional passengers outweighing the positive impact of the reduction in road vehicle emissions.

[8] The airport set previously described.
[9] The airport set previously described.

Table 3.6 - 2030 Modal split for Gatwick Airport under Gatwick 2R scenario

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%
Yorkshire and the Humber	39%	13%	48%

Figure 3.6 - Emissions due to surface access at Gatwick, using a 2030 modal share for baseline and Gatwick 2R forecast scenarios

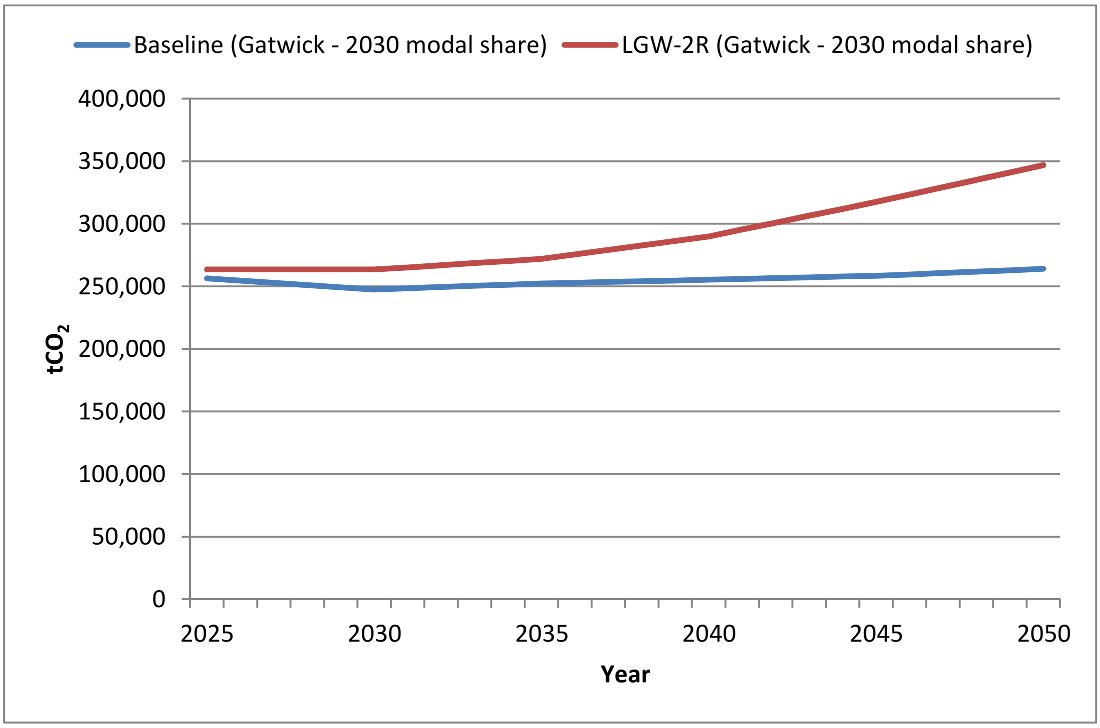


Table 3.7 – Emissions from Surface Access with 2030 Modal split for 2025 – 2050 for baseline and Gatwick 2R forecast scenarios

Year	Baseline emissions due to surface access to Gatwick Airport, tonnes CO_2	Gatwick 2R emissions due to surface access to Gatwick Airport, tonnes CO_2
2025	256,474	263,527
2030	247,490	272,052
2040	255,313	317,374
2050	264,012	384,292

Mitigation

In this section some ideas for improving emissions from surface access, without any specific construction of public transport infrastructure, are suggested. The suitability for application to the context of the proposal would need to be investigated to establish the benefits and costs. In addition, the extent to which some of these mitigations have been applied already is not considered.

The improvement of electric vehicle, and alternative fuelled vehicle, infrastructure, through provision of charging points, and similar, may help in encouraging a general shift towards these lower carbon vehicle types. In addition, this kind of provision may encourage vehicles that would otherwise have range concerns.

It may be desirable to allow for more preferential parking for zero- and low-emission vehicles, for similar reasons as above.

An avenue for improving emissions from surface access would be through agreements with suppliers and transport partners. By requiring a certain level of low emission vehicle provision from coach and freight operators that utilise the airport, the resultant emissions can be reduced.

3.4 Emissions due to energy and fuel use during airport operations

Impact Assessment

The construction and operation of an additional runway, and the associated infrastructure, is considered likely to result in changes to the operational energy requirements of the airport. Figure 3.7 identifies the estimated energy use from different sources at Gatwick Airport under the Gatwick 2R proposal. As may be expected with the doubling in size and capacity these energy usages tend to double over the course of the 2025 to 2050 period. In Table 3.8, the carbon emissions associated with these energy uses are shown.

Figure 3.7 - Energy use at Gatwick, by source, 2025 – 2050 for Gatwick 2R

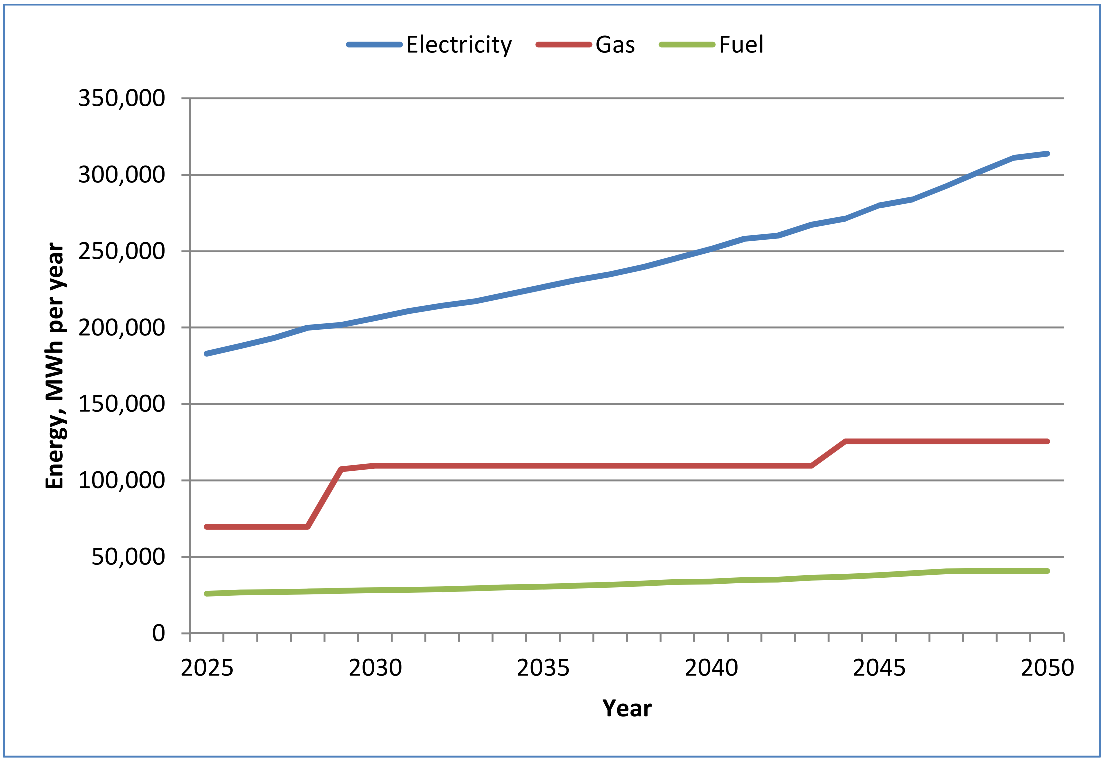
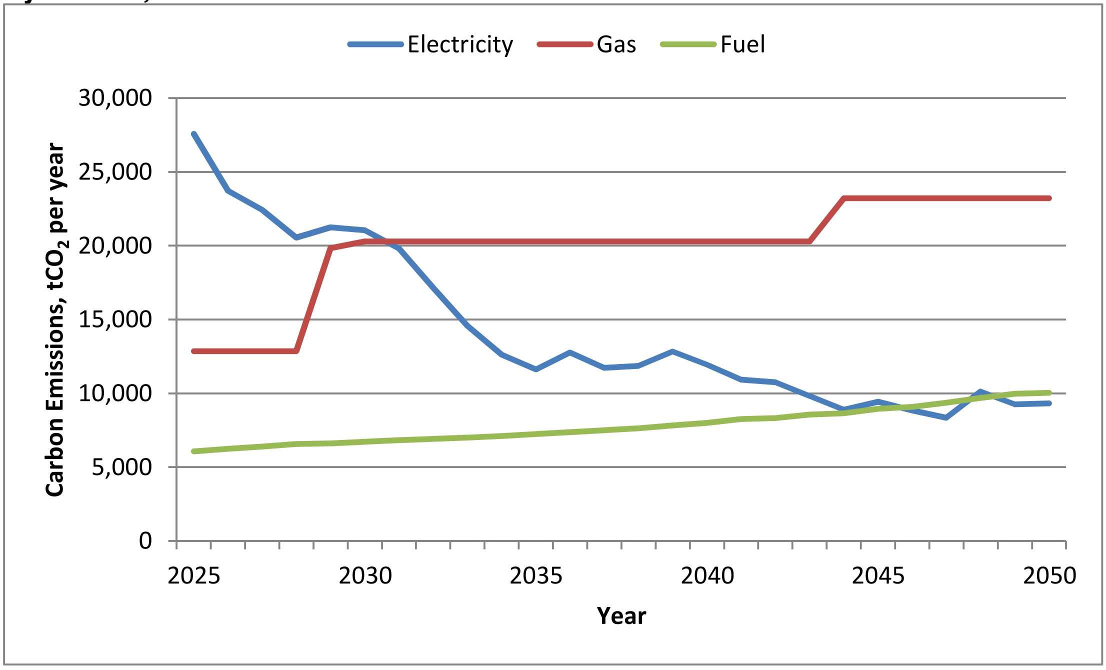


Table 3.8 - Carbon emissions due to airport operation at Gatwick, by source, 2025 – 2050 for Gatwick 2R forecast scenario

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	Total emissions due to airport operation at Gatwick Airport, tonnes CO_2
2025	27,578	12,865	6,075	46,518
2030	21,054	20,286	6,720	48,061
2040	11,955	20,286	8,003	40,244
2050	9,332	23,216	10,029	42,578

Figure 3.8 - Carbon emissions due to airport operation energy use at Gatwick, by source, 2025 – 2050 for Gatwick 2R forecast scenario



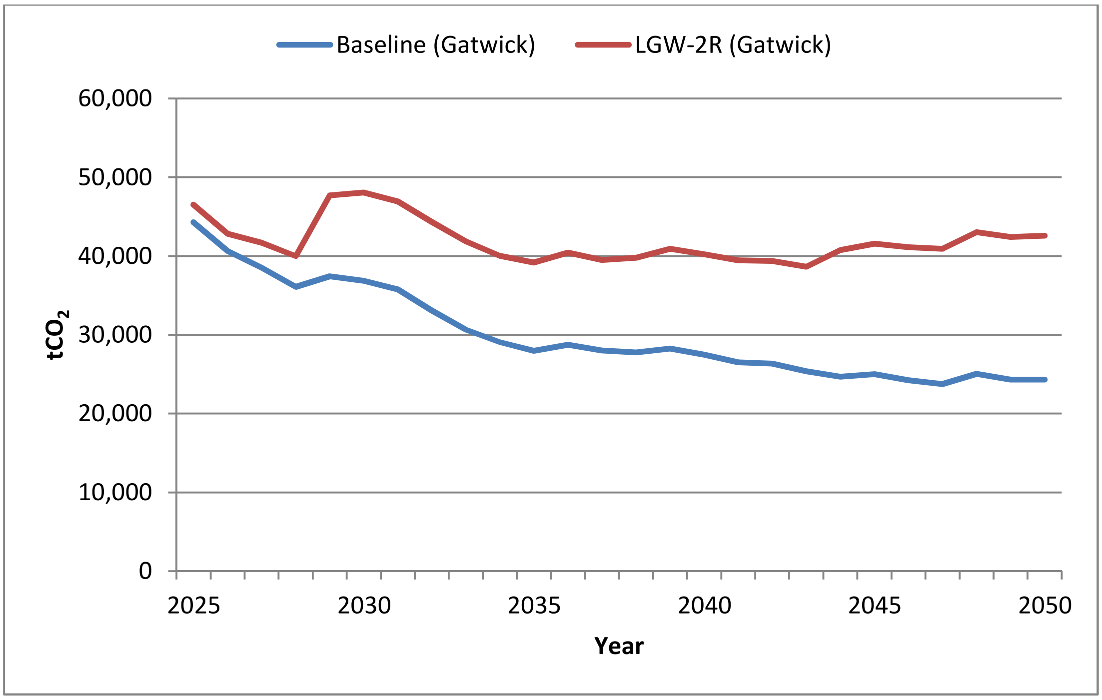
In Table 3.8 it can be seen that, despite the increase in energy use, the emissions associated with electricity fall over time. This is due to the predicted reduction in carbon emissions associated with grid electricity use. The emissions factors associated with gas and fuel uses are thought to remain stable, so the resultant emissions increase with the increase in usage, becoming a more substantial component on the total emissions.

Table 3.9 presents a comparison of the carbon emissions over time for the baseline and Gatwick 2R forecast scenarios. It can be seen that in the Gatwick 2R scenario, the emissions associated with airport operations increase rapidly compared with the baseline, diverging by more than 75% by 2050, and remaining relatively stable in absolute terms. This is due to the reductions seen in the baseline due to grid decarbonisation being offset by the increases in gas and fuel use. The emissions associated with airport use in the Gatwick 2R scenario remain little changed from 2025. This is depicted graphically in Figure 3.9.

Table 3.9 - Operational emissions due to energy and fuel at Gatwick, 2025 – 2050 for Gatwick 2R forecast scenario

Year	Baseline, tonnes CO_2	Gatwick 2R, tonnes CO_2	% Change
2025	44,291	46,518	5.0%
2030	36,867	48,061	30.4%
2040	27,467	40,244	46.5%
2050	24,320	42,578	75.1%

Figure 3.9 - Operational emissions due to energy and fuel at Gatwick, 2025 – 2050 for baseline and Gatwick 2R forecast scenarios



Mitigation
There are several avenues for development in terms of reducing the carbon emissions associated with operation, both of the existing facilities and any new construction.

Any new construction should make use of the latest developments in energy efficiency, allowing for a reduction in electricity use and required heating. As an example of these principles, Stockholm-Arlanda airport, having set a zero-carbon target for 2020, is involved in the following carbon mitigation strategies:

- Utilisation of renewable fuels, such as biogas, to power the ground vehicle fleet;
- New buildings that are constructed to a recognised environmental standard;
- A carbon emission inventory is regularly produced, and augmented, in order to target outstanding emissions sources;
- The use of biomass boilers, to replace fuel burning heat sources; and
- LED light sources, both in terminals and facilities, but also for aircraft parking stands and other areas with lighting requirements.

Other potential mitigating methods include the use of electric vehicles in addition to alternative fuel vehicles, the utilisation of local renewable generation where safe and feasible, and the utilisation of “loop-closing” technology, such as energy-from-waste.

It is noted from the Decade of Change documentation, that commitments and actions in line with those identified from Arlanda are already part of Gatwick’s approach to sustainability.

3.5 Construction of new facilities and infrastructure

Impact Assessment

Table 3.10 presents a comparison of the carbon emissions due to construction in terms of embodied carbon and expected fuel use. It can be seen that, due to the carbon intensity that has been assumed for airports, in particular the construction of airport terminal buildings, embodied carbon in airport infrastructure makes up approximately 90% of the estimated construction carbon footprint. While the proportion of emissions attributed to fuel use seems to be low, the magnitude is quite substantial (approximately equivalent to the use of 38 million litres of diesel fuel). In addition, the freighting of material to site will also increase the emissions associated with fuel use, with some indications that these emissions will be approximately equal to the emissions due to construction processes (The Strategic Forum for Construction , 2010). As noted in the cost report (Jacobs UK Ltd, 2014a), the third phase of Gatwick 2R construction is not expected to be required under the carbon capped demand scenario. Further, the construction that is expected to take place from 2019 to 2024 is included in this assessment, despite lying outside of the assessment period.

Table 3.10 - Carbon due to planned construction at Gatwick for Gatwick 2R

Year	Baseline	Additional construction carbon - Gatwick 2R
Embodied carbon in airport infrastructure	2,974,970	3,530,391
Embodied carbon in surface access infrastructure	0	264,353
Carbon emissions due to fuel use in construction	41,249	96,723

Mitigation

Mitigation for the emissions associated with construction are wide-ranging, and variously applicable. These include:

- Use of energy efficient site accommodation;
- Increased efficiency in use of construction plant, for example through no-idle policies;
- Construction site connection to grid electricity to avoid use of mobile generation, and smart energy management practices;
- Reduction of waste, and the transport of waste, for example through increasing on-site recycling;
- Select construction material to utilise low carbon options, such as carbon-negative cement; and
- Select construction material to minimise distance of transport, and increase recycling percentages of the material where appropriate.

3.6 Commentary on proposer's submission

3.6.1 Increased airport capacity leading to a net change in air travel

Gatwick Airport Limited (GAL) has reported carbon emissions for 2010 in its Master Plan 2012 (Gatwick Airport Limited, 2012). The calculated emissions are categorised according to the GHG Protocol (The Greenhouse Gas Protocol, 2012) into Scopes 1, 2 and 3. Scope 3 carbon emissions are those that GAL can influence at Gatwick Airport but do not own or have direct control. These include aircraft emissions within the LTO (the landing and take-off cycle refers to aircraft at an airport including approach and climb out up to 914 metres (3000 feet) above ground). Total flight emissions were not calculated. Carbon emissions were reported for 2010 as well as estimated emissions for a 40 million passenger per year Gatwick Airport (one runway) assumed to be in “2020 or soon after” for the LTO only.

Across the GAL proposal, several assumptions have been made regarding aircraft in the future (Gatwick Airport Limited, 2014a) which would impact any estimates they would make about total aircraft emissions. These are as follows:

- continuous upgrade of aircraft fleet would be implemented as outlined in the air traffic forecasts produced by the professional services company ICF International
- 10% reduction in emissions during the taxi-in phase due to expected common practice application of ‘engine off taxiing’ by 2040
- minimisation of the use of Auxiliary Power Units (APUs)
- a favourable runway layout and use strategy would minimise taxi and hold times.

3.6.2 Ground movements

The assumptions that Gatwick has made as regards aircraft also apply to this criterion. In particular, the assumptions about engine off taxiing, APU use and the airfield strategy and runway layouts are relevant. These seem to significantly impact the estimation made for aircraft emissions in 2050.

In the Gatwick 2R proposal estimations were made of flight emissions that take place near the airport, which included taxi in, taxi out, take-off, climb-out, and approach and landing (Gatwick Airport Limited, 2014a). The method utilised was to multiply the Time in Mode (TIM) with the ICAO performance data in order to produce CO_2 numbers. They incorporated hold times based on current and estimated future performance. The method is roughly analogous to that used in this report and described in the methodology section. The estimate made by GAL covers more than just the airside ground movements, but can be used for comparison purposes. This is shown in Table 3.11.

Table 3.11 - “Aircraft” emissions submitted by GAL (taxi in, taxi out, take-off, climb-out, and approach and landing)

Emission source	Year	GAL Baseline	GAL Gatwick 2R
Aircraft	2012	393,660	-
	2040	406,815	629,210
	2050	-	486,400

In Table 3.11, it can be seen that GAL predict an increase in the level of emissions associated with airside ground movements of approximately 50%. Their prediction for emissions related to the entire LTO cycle are at 629,210 tCO_2e; the estimations made above for the same year for just ground movements are 184,019, for which the proportion of taxi-in-taxi-out out of the whole LTO cycle was assumed to be approximately 33%. If similar assumptions were made with the GAL estimates then the airside ground movement emissions level in 2040 would be 207,000 tCO_2.

3.6.3 Passenger Surface Access Journeys

Under Gatwick 2R proposal there are several assumptions made about future surface access which affect the results reported in the proposal (Gatwick Airport Limited, 2014a).

- Committed schemes will be implemented.
- There will be a 20% efficiency improvement for rail emissions.
- The Gatwick 2R proposal will result in a 60% public transport share, made up of 50% rail and 10% bus/coach.
- A 40% public transport share will be delivered for staff commuting, made up of 20% rail and 20% bus/coach.

The surface access emissions reported by the GAL proposal are displayed in Table 3.12. It can be seen that the GAL baseline level in 2040 is significantly lower than the Airports Commission prediction for the same year, with the GAL baseline at 214,831 tCO_2e and the Airports Commission prediction at 297,307 tCO_2e. The Gatwick 2R emissions in 2040, as estimated by GAL are approximately 9.8% less than the emissions estimated in the assessment above; with the GAL at 332,695 tCO_2e and the Airports Commission estimate at 368,781 tCO_2e. The 2050 emissions are 15% lower than in the analysis above. The primary driver of the differences are likely to be the assumptions made over public transport modal share, particularly regarding any changes over time, and with the higher public transport share in the GAL proposal leading to lower emissions levels.

Table 3.12 - Surface access emissions forecasts submitted by GAL for baseline and Gatwick 2R scenarios

Emission source	Year	GAL Baseline (tCO_2e)	Gatwick 2R (tCO_2e)
Passenger surface access	2012	174,105.3	-
	2040	214,830.9	332,695.4
	2050	-	380,796.0
Staff commuting	2012	39,115.8	-
	2040	46,418.9	54,640.3
	2050	-	57,830.0

3.6.4 Airport Operations

In presenting the calculations of carbon associated with operational energy use at an expanded Gatwick, the GAL submission (Gatwick Airport Limited, 2014a) has made several assumptions.

- Energy
  - Efficiency improvements, such as new lighting, heat recovery and building management systems will be in place throughout Gatwick Airport by 2040.
  - Rather than purely grid electricity, new construction would also utilise a built capacity of 3MW of photovoltaics.
  - Gas and heat would be supplied by on-site biomass Combined Heat and Power (CHP) plant with up to 3MWe of capacity.
  - All new buildings to be constructed to high standards of energy efficiency.

- Fuels
  - Increase in the proportion of biofuel and hybrid vehicles, reflected as a decrease of 10% from baseline levels.

To calculate the emissions from grid electricity use, the Gatwick 2R proposal utilises emission factors produced by SAP (Department of Energy & Climate Change, 2014), rather than those published by DECC, and they have fitted a logarithmic trend line to extend this from 2027 to 2051. This has resulted in higher $kgCO_2e$ / kWh than that which has been used in the analysis above as detailed in Table 3.13.

Table 3.13 - Electricity intensity factors

Year	Electricity intensity factor used by GAL, $kgCO_2e$ / kWh	Electricity intensity factor used by Jacobs, $kgCO_2$ / kWh
2040	0.275	0.048
2050	0.220	0.030

In Table 3.14 the emissions estimated in the Gatwick 2R proposal have been shown, divided amongst emission sources. The main differences between this assessment and that made by the Airports Commission are the emissions from electricity and the emissions from gas. Emissions from electricity (both direct and third party consumption) in 2040 are approximately 3 times higher in the GAL estimation of the Gatwick 2R proposal. The differences in the electricity intensity factor used, if similar levels of electricity use were modelled, would lead to an expectation of almost 6 times the level assessed; the difference from what may be expected given the assumptions of electricity intensity factors may be due to the assumptions made by GAL in terms of the use of photovoltaics and improvements in building efficiency which were not used in the assessment. Gas use as estimated in the analysis above is expected to approximately double, with the doubling of Gatwick's terminal area. However, the figures used in the Gatwick 2R proposal indicate a halving in the emissions associated with gas use from a GAL baseline of 12,483 tCO_2e in 2040 to 6,232 tCO_2e in 2050, which may be in part derived from the assumed investment in an on-site biomass CHP.

Table 3.14 - Airport operational emissions submitted by GAL for baseline and Gatwick 2R forecast scenarios

Emission source	Year	Baseline (tCO_2e)	Gatwick 2R (tCO_2e)
Gas	2012	10,560.6	-
	2040	12,483.1	5,300.9
	2050	-	6,232.7
Fuel	2012	1,047.1	-
	2040	1,206.7	2,225.8
	2050	-	2,601.2
Electricity Consumption	2012	45,085.4	-
	2040	17,081.8	19,028.3
	2050	-	18,686.9
3rd Party Gas	2012	1,044.9	-
	2040	1,234.6	524.3
	2050	-	616.4
3rd Party Fuel	2012	5,114.8	-
	2040	5,881.5	10,848.1
	2050	-	12,677.9
3rd Party Electricity	2012	27,815.2	-
	2040	10,525.7	11,725.1
	2050	-	11,514.8
Total	**2040**	**48,413.4**	**49,652.5**

Table 3.15 - Comparison of airport operational emissions

Emission source	Year	GAL Proposal (tCO_2e)	Jacobs Assessment (tCO_2e)
Gas	2040	5825.2	20,286
	2050	6849.1	23,216
Fuel	2040	13,073.9	8,003
	2050	15,279.1	10,029
Electricity Consumption	2040	30,753.4	11,955
	2050	30,201.7	9,332
Total	**2040**	**49,652.5**	**40,244**
	2050	**52,329.9**	**42,578**

Also worth noting are the emissions that Gatwick has estimated based upon the use of refrigerants and water / wastewater, which impact upon total carbon emissions[10]. These are not estimated in the analysis above, and are repeated in Table 3.16.

[10] The gases used in refrigeration have high carbon equivalence factors, and so have a significant impact as they leak over time. Emissions due to water use occur due to the operation of pumps, which are not owned by the airport, in order to deliver the water.

Table 3.16 - Airport refrigerants and water / wastewater emissions submitted by GAL

Emission source	Year	Baseline (tCO_2e)	Gatwick 2R (tCO_2e)
Refrigerants	2012	1,587.8	-
	2040	1,879.7	3,467.0
	2050	-	4,051.7
Water / Wastewater	2012	665.8	-
	2040	813.7	1,377.6
	2050	-	1,241.9

3.6.5 Construction of new facilities and SA infrastructure

While the Gatwick 2R proposal does not make any quantitative estimates of carbon due to construction, there are several statements regarding how the proposal may differ from "typical" construction, including references to lowering their embodied carbon footprint through the use of sustainable materials and a sustainable materials strategy, which would include re-use of construction materials on-site. GAL provides the following list of assumptions and commentary on different aspects of the Gatwick proposal. (Gatwick Airport Limited, 2014a)

- Plant and machinery
  - A low quantity of complex engineering tasks, as it does not require relocation of major infrastructure.
  - Predominantly Greenfield, reducing requirements for construction, such as demolition of existing structures and preparation of ground.
- Site transport
  - Phased construction is thought to reduce on-site queuing of vehicles (reducing engine idle times).
- Accommodation
  - Use of energy efficient compounds, which reduce energy needs through efficient lighting and insulation.
- Freight transport
  - Emissions due to freighting are expected to be lower than average (per vehicle) due to the low congestion around the Gatwick site.
  - High likelihood of local sourcing of construction materials.
  - A dedicated railhead would reduce emissions associated with freighting construction materials.
- Commuting
  - Emissions due to commuting are expected to be lower than average (per vehicle) due to the low congestion around the Gatwick site.
  - Expectation that workers will make use of public transport.
- Waste removal
  - It is expected that construction and demolition waste arisings can be re-used or recycled on site, due to the Greenfield nature of the site. This is supported through past project track records.
- Off-site assembly
  - The sourcing of low-carbon materials is to be part of Gatwick's sustainable materials strategy.
- Office emissions
  - The proposal makes reference to the use of efficient and low energy solutions within office environments.

It can be seen that the Gatwick 2R proposal has considered several issues in depth under this section which were not factored into the values presented here by the Airports Commission; however the lack of quantification, of either the construction total or the benefits of their proposed interventions, makes comparison impossible.

3.7 Conclusions

Analysis of the Gatwick second runway scheme carbon emissions is based on the two runway masterplan submitted by GAL, and the AoN Carbon Capped passenger and ATM forecasts developed by the Airports Commission. This sees ATMs grow from around the 290,000 in 2025 to 476,000 in 2050, with a steady growth and some annual variance. There would be significant construction of infrastructure during the early years of the scheme, although new terminal capacity would not added until after new runway capacity. The most significant volume of emissions are related to air travel, and these would increase steadily over the period aligned with ATMs, but at a slower rate linked to improved fuel efficiency of airline fleets. Surface access emissions remain the second largest source of CO_2 and increase over the assessment period, linked to annual passenger numbers. Emissions from buildings and airport operations initially increase, but then reduce and remain steady as carbon intensity per passenger and per m^2 reduce over time, most significantly due to the presumed decarbonisation of grid electricity.

Table 3.17 - Carbon assessment findings for Gatwick 2R: change in tCO2

Area of Emissions	2030	2040	2050	Additional tCO_2 to baseline over 60 year appraisal period	Total tCO_2 over 60 year appraisal period
Air travel	324,944	728,573	1,476,657	68,860,268	307,281,972
Ground movements component	19,862	48,030	92,317	4,353,561	12,742,794
Passenger surface access journeys	28,782	71,474	139,519	6,555,448	25,096,949
Airport operations energy & fuel use	10,330	10,688	14,243	759,561	2,370,875
Total operational CO_2 emissions	**364,056**	**810,735**	**1,630,419**	**76,175,277**	**334,749,796**
Construction of airport facilities & SA infrastructure*	n/a	n/a	n/a	3,891,468	6,907,686

* Construction emissions are calculated as tCO_2e.

In terms of net change from baseline predicted levels, the emissions due to air travel are the largest proportion of the carbon emissions, both in terms of change and total emissions. Looking at the proportional change, the emissions area that will change the most is that of construction, more than doubling from the estimated baseline value.

3.8 Gatwick 2R Carbon Assessment Monetisation

In Table 3.18, the carbon results are displayed in a monetised format. This has been done for both the Net Present Value (NPV) of the additional carbon emissions enabled by the scheme, and also for particular assessment years in terms of £2014.

Table 3.18 - Gatwick Airport additional central carbon value (NPV) for Gatwick 2R forecast scenario

	Monetised value of carbon emissions
Total Additional Value (£)	£5,057,700,000
Snapshot 2030 (£)	£16,305,737
Snapshot 2040 (£)	£62,963,492
Snapshot 2050 (£)	£124,827,082
Snapshot 2060 (£)	£123,579,687

Table 3.19 displays the total additional carbon value divided amongst the identified emission areas that have been assessed. The key difference when reviewing these monetised results in contrast to the tCO_2 results is the impact that emission timing has on the value. Even though total change in emissions due to construction is similar to the change in emissions due to airside ground movements, the value for construction is lower, due to the fact that the emissions occur in the earlier parts of the assessment period where the price is lower.

Table 3.19: Additional and total central carbon value, (NPV) for emission sources for Gatwick 2R scenario

Area of Emissions	Monetised value of carbon emissions, additional £ over 60 year appraisal period	Monetised value of carbon emissions, total £ over 60 year appraisal period
Air travel	£4,440,846,383	£18,976,782,119
Ground movements component	£280,464,851	£793,664,032
Passenger surface access journeys	£422,198,583	£844,397,166
Airport operations energy & fuel use	£48,093,366	£145,264,621
Total operational CO_2 emissions	**£4,911,138,333**	**£19,966,443,906**
Construction of airport facilities & SA infrastructure*	£146,587,376	£289,447,744

In Table 3.20 and Table 3.21, the carbon results are displayed as the range from the low to high assumptions on carbon value. This has been done for both the Net Present Value (NPV) of the additional carbon emissions enabled by the scheme, and also for particular assessment years in terms of £ in 2014.

Table 3.20: Additional Low to High carbon value, (NPV) for Gatwick 2R forecast scenario

	Monetised value of carbon emissions
Total Additional Value (£million)	£2,231,100,000 - £7,916,700,000
Snapshot 2030 (£)	£8,152,868 - £24,458,605
Snapshot 2040 (£)	£31,481,746 - £94,445,238
Snapshot 2050 (£)	£62,413,541 - £187,240,623
Snapshot 2060 (£)	£55,610,859 - £191,548,514

Table 3.21: Additional Low to High carbon value, (NPV) for emission sources for Gatwick 2R forecast scenario

Area of Emissions	Monetised value of carbon emissions, additional £ over 60 year appraisal period
Air travel	£1,953,220,608 - £6,931,524,385
Ground movements component	£123,522,094 - £437,656,867
Passenger surface access journeys	£185,844,272 - £448,318,654
Airport operations energy & fuel use	£21,464,877 - £74,799,293
Construction of airport facilities & SA infrastructure*	£70,579,794 - £251,462,236

4 Heathrow Airport Northwest Runway

This section covers the following for Heathrow Airport Northwest Runway and each emissions category:

- Jacobs assessment of impacts;
- Potential for mitigation (or limitations);
- Comment on the proposer's submission ; and
- Conclusions.

4.1 Increased airport capacity leading to a net change in air travel

Impact Assessment

Table 4.1 presents the carbon emissions forecasts from the AoN Carbon Capped for all departing flights from Heathrow Airport between 2026 and 2050, with the NWR scheme (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 'do something' carbon emissions as shown in Table 4.1 in this assessment graphically.

Table 4.1- Carbon emissions, carbon capped: Heathrow NWR, for 2026 – 2050

Year	Heathrow Airport, Number of passengers	Heathrow Airport, Numbers of ATMs[11]	Heathrow Airport, tonnes CO_2	UK Aviation Total, tonnes CO_2	Heathrow as % of UK Total for carbon emissions
2026	91,709,424	552,887	21,615,342	38,510,990	56.1
2030	109,264,920	652,216	23,201,508	39,415,806	58.9
2040	127,879,384	750,498	23,760,857	39,962,754	59.5
2050	134,983,696	753,341	20,483,029	37,501,114	54.6

[11] The total number of ATMs based on demand forecasting is projected to exceed the operational cap of 740,000 ATMs. The Airports Commission economic analysis indicates that an equilibrium solution which satisfies capacity limits at all airports is computationally intensive and progressively more difficult to solve as demand mounts through the forecasting period. The solution is generally deemed to be found when over-capacity airports are within +/-1.5% of their input capacities. Runway capacity is regarded as a "harder" capacity than terminal capacity in the search for an equilibrium solution.

Figure 4.1 – Carbon emissions from departing flights at Heathrow Airport, 2026 – 2050: baseline and Heathrow NWR scenarios, carbon capped

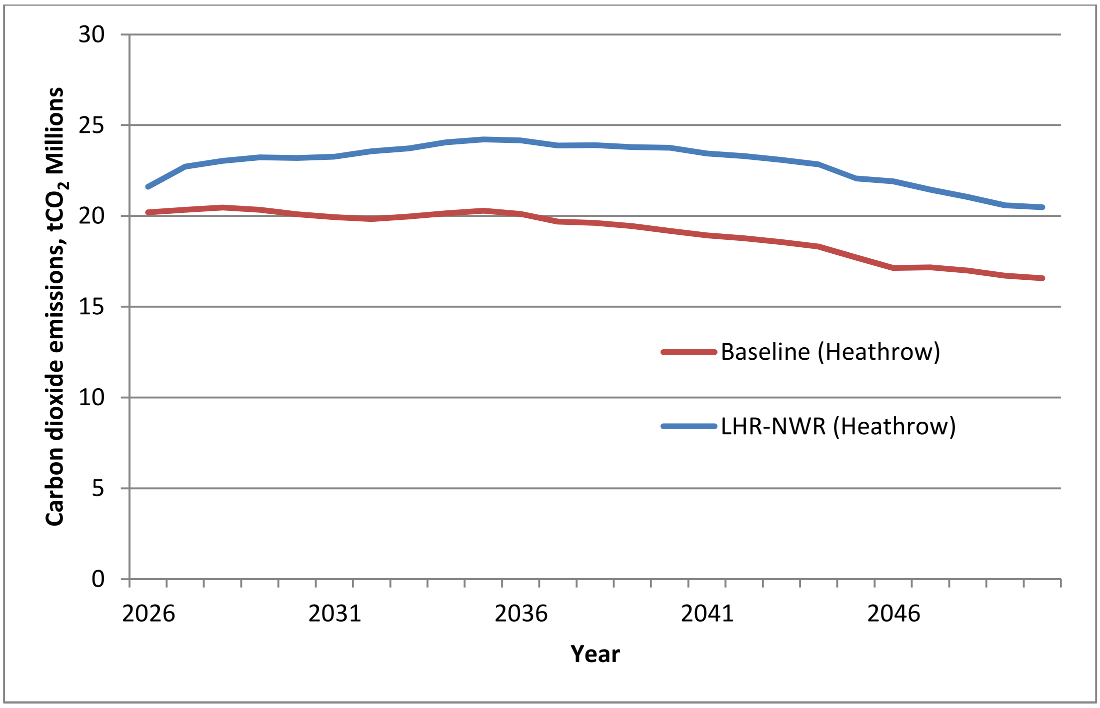


Table 4.2 presents a comparison of the carbon emissions in 2030, 2040 and 2050 for the 'do minimum' and 'do something' forecast scenarios.

Table 4.2 - Comparison of the carbon emissions in 2030, 2040 and 2050 for the Heathrow Airport baseline and Heathrow NWR forecast scenarios

Year	Baseline tonnes CO_2	Heathrow NWR tonnes CO_2	Change (%)
2030	20,099,848	23,201,508	+15.4
2040	19,184,305	23,760,857	+23.9
2050	16,570,400	20,483,029	+23.6

With a third runway in use the carbon emissions associated with departing flights decrease by 2.72 $MtCO_2$ or 11.7% over the period 2030 - 2050. This decrease is similar in its trend and magnitude to the decrease seen in the baseline forecast. However, the carbon emissions in the Heathrow NWR scenario are greater than in the baseline scenario by 3.91 $MtCO_2$ or 23.6% in 2050.

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

- distances flown by aircraft;
- fuel efficiency of the aircraft fleet; and,
- type of fuel used.

Figure 4.2 shows the changes in ATMs during the period 2026 – 2050.

Figure 4.2 - Air transport movements (ATMs) during the period 2026 – 2050 at Heathrow Airport, baseline and Heathrow NWR scenarios carbon capped

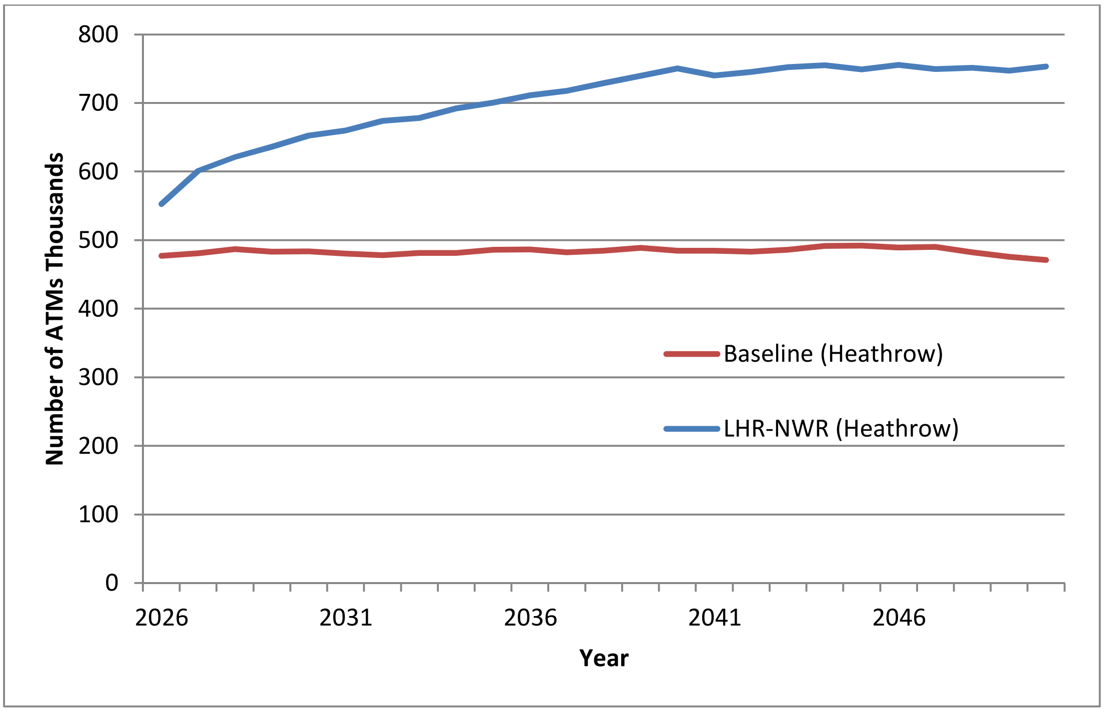


Figure 4.2 shows that the number of ATMs at Heathrow Airport, a key determinant of aviation carbon emissions, increases during the period 2030-2050. If emissions were linked just to the number of ATMs, an increase in carbon emissions would be expected. The increase in ATMs over the period 2030-2050 is 15.5%, while an 11.7% decrease in carbon emissions is observed. There is therefore a reduction in carbon per ATM. This is due to a combination of aircraft fleet changes and alternative fuels - these are the two assumptions that change in the central demand growth.

The change in biofuel use is a forecasted 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 Heathrow NWR forecast. The forecast has not been made for a change in just one of these assumptions, therefore the magnitude, and the relative contributions of each, cannot be identified from the model output contained in the AoN carbon Capped.

Carbon emissions from flights departing Heathrow Airport have not been modelled for the period 2050-2086. 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, as described in detail in Appendix A, 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.

Mitigation

Mitigation that may impact this aspect of emissions includes the utilisation of mechanisms that would encourage the new demand to be utilised by the cleanest aircraft. Potential options for this include increased airport charges for older aircraft, or mandated "green slots" which require planes of a certain standard to take up the new capacity.

4.2 Airside ground movements

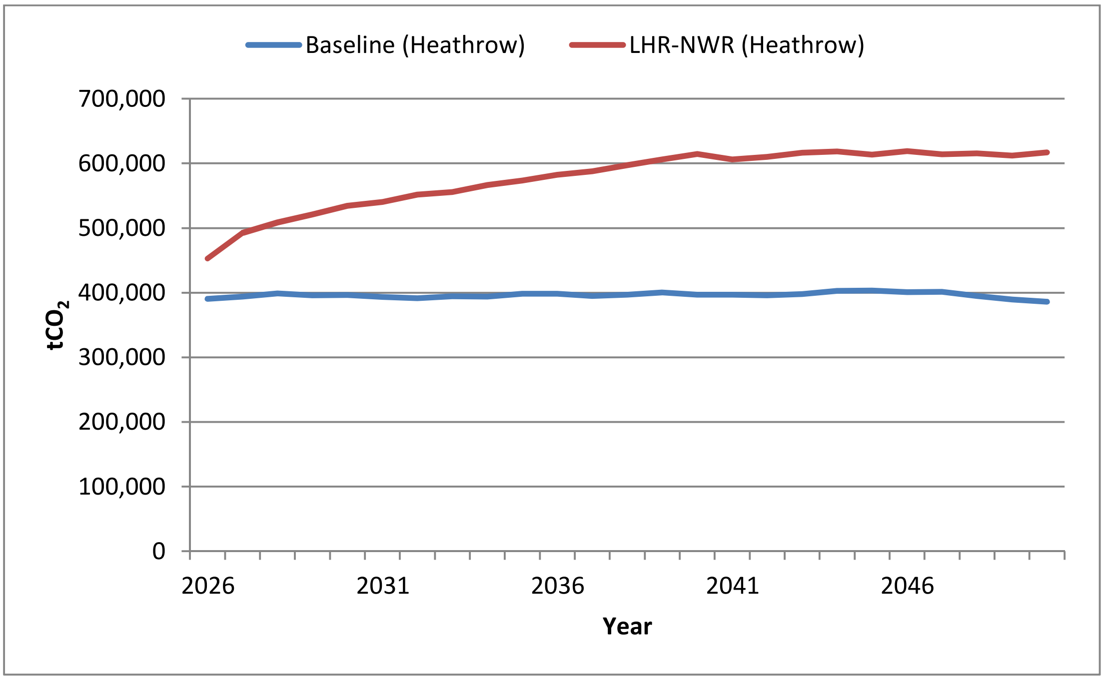
Impact Assessment

Table 4.3 and Figure 4.3 presents a comparison of the carbon emissions over time for the baseline and Heathrow NWR scenarios, and shows both the ICAO-Times and HAL-Reported Times derived forecasts. It can be seen that due to the increase in ATMs in the Heathrow NWR scenario, the emissions associated with airside ground movements increase rapidly, diverging by up to 60% by 2050.

Table 4.3- Comparison of the aircraft ground movement emissions 2026 – 2050 for the Heathrow Airport baseline and Heathrow NWR forecast scenarios

Year	Baseline, tonnes CO_2	Heathrow NWR, tonnes CO_2, ICAO-Times	Heathrow NWR, tonnes CO_2, HAL-Reported times
2026	390,677	452,855	358,936
2030	396,313	534,212	423,421
2040	396,855	614,712	487,226
2050	385,891	617,041	489,071

Figure 4.3 - Carbon emissions due to airside ground movements 2026 – 2050 for the baseline and Heathrow NWR forecast scenarios



It should be noted that in the Heathrow NWR proposal it is not just ATMs at Heathrow which are expected to change, as additional capacity causes ATMs to shift between airports. This may mean that over all airports, as each airport will have its own level of emissions per ground movement, a shift of ATMs to Heathrow could reduce the overall impact of the additional ATMs at Heathrow.

Mitigation

The primary way in which to reduce the emissions associated with airside ground movements is through efficient runway and taxiway design and use. Airports have made advances in these areas, and it is recommended that best practice would be applied to any new designs. This should include:

- Use of airport terminal power and pre-conditioned air sources
    - This would reduce the burden on aircraft APUs and airport GPUs
- Reduce engine operation during taxing
    - By shutting down an engine during taxiing, both fuel use and emissions can be reduced.

4.3 Surface Access

Impact Assessment

For this assessment, the 2008 modal share was used to calculate emissions from surface access. Within this model, the rail, coach/bus and private vehicle shares differ according to Destination; the approximate overall mode share for Heathrow was

- Rail – 20%
- Coach/bus – 18%
- Private vehicle – 62%

Under Heathrow NWR there would be additional surface access requirements at Heathrow, which would lead to an increase in the associated emissions. These can be seen in Table 4.4 and Figure 4.4.

Figure 4.4 - Emissions due to surface access for baseline and Heathrow NWR forecast scenarios

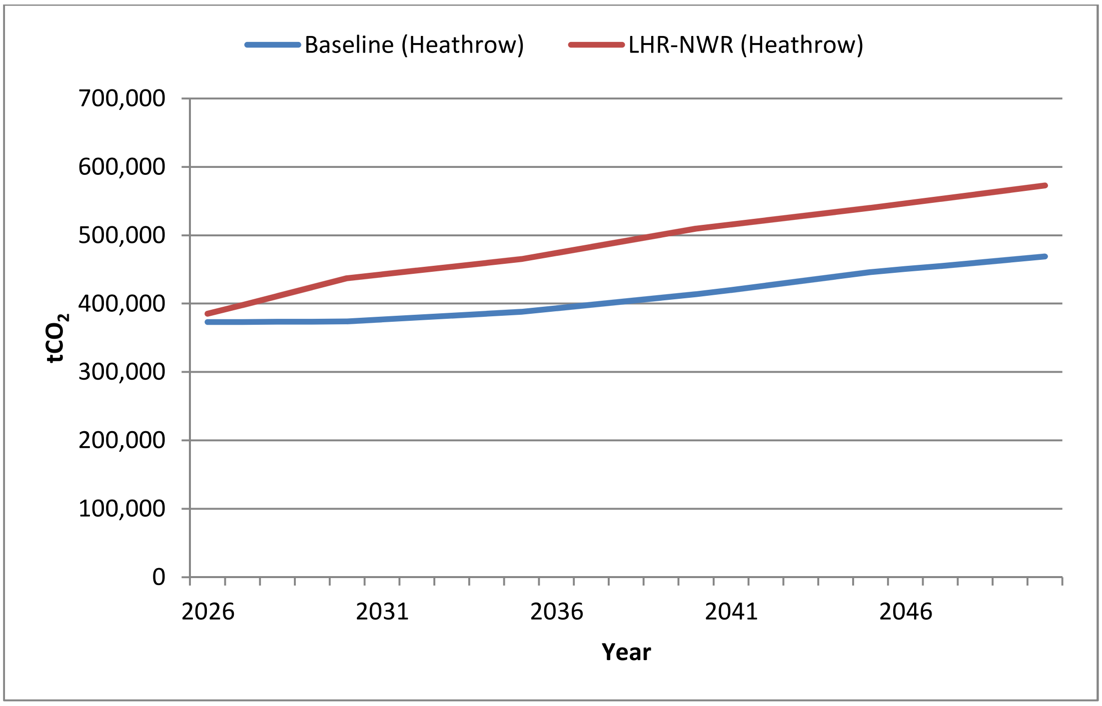


Table 4.4 - Emissions due to surface access for 2026 – 2050 for baseline and Heathrow NWR forecast scenarios

Year	Baseline emissions due to surface access to Heathrow Airport, tonnes CO_2	Heathrow NWR emissions due to surface access to Heathrow Airport, tonnes CO_2	% change
2026	384,112	385,099	0.3%
2030	373,888	437,033	16.9%
2040	413,575	509,768	23.3%
2050	469,066	572,830	22.1%

Figure 4.5 and Table 4.5 present the combined total for the airports used in the National Surface Access model[12] under the Heathrow NWR proposal. It can be seen that the transfer of passenger demand to Heathrow Airport in the Heathrow NWR scenario leads to a slight decrease in total surface access emissions. This is due to the fact that under the base model Heathrow has a higher public transport modal share than many other airports, and is predicted to maintain this mode share under expansion; passengers substituting into an expanded Heathrow will do so from airports where their travel emissions would have been higher.

[12] The airports used are: Aberdeen, Birmingham, Bournemouth, Bristol, Cardiff, East Midlands, Edinburgh, Exeter, Gatwick, Glasgow, Heathrow, Humberside, Leeds/Bradford, Liverpool, London City, Luton, Manchester, Newcastle, Newquay, Norwich, Southend, Southampton, Stansted, Teesside, Blackpool, Doncaster Sheffield, Prestwick

Figure 4.5 - The emissions due to surface access across the UK airport system for baseline and Heathrow NWR forecast scenarios

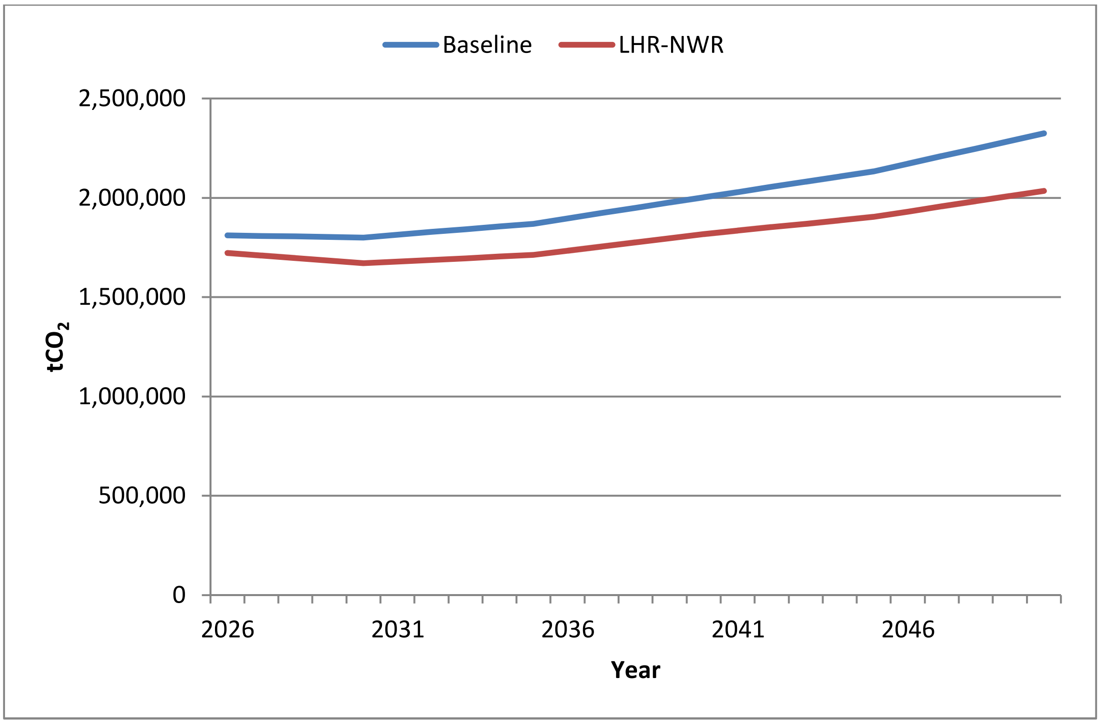


Table 4.5 - The emissions due to surface access across the UK airport system, 2026 – 2050 for baseline and Heathrow NWR forecast scenarios

Year	Baseline emissions due to surface access to UK airports[13], tonnes CO_2	Emissions due to surface access to UK airports with Heathrow NWR[14], tonnes CO_2	% change
2026	1,811,056	1,721,810	-4.9%
2030	1,800,361	1,671,184	-7.2%
2040	2,003,151	1,817,101	-9.3%
2050	2,324,692	2,035,495	-12.4%

Sensitivity: 2030 Modal split

A sensitivity scenario was developed in which the predicted 2030 mode share was applied to the surface access for Heathrow. The result of this can be seen in Table 4.7 and Figure 4.6. The primary difference is a reduction in absolute emissions.

For this assessment, the 2030 modal share was used to calculate emissions from surface access. Within this model, the rail, coach/bus and private vehicle shares differ according to Origin-Destination. The regional mode share is shown in Table 4.6.

[13] The previously referenced set.
[14] The previously referenced set.

Table 4.6 - 2030 Modal split for Heathrow Airport under Heathrow NWR scenario

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%

Figure 4.6 - Emissions due to surface access at Heathrow, using a 2030 modal share for baseline and Heathrow NWR forecast scenarios

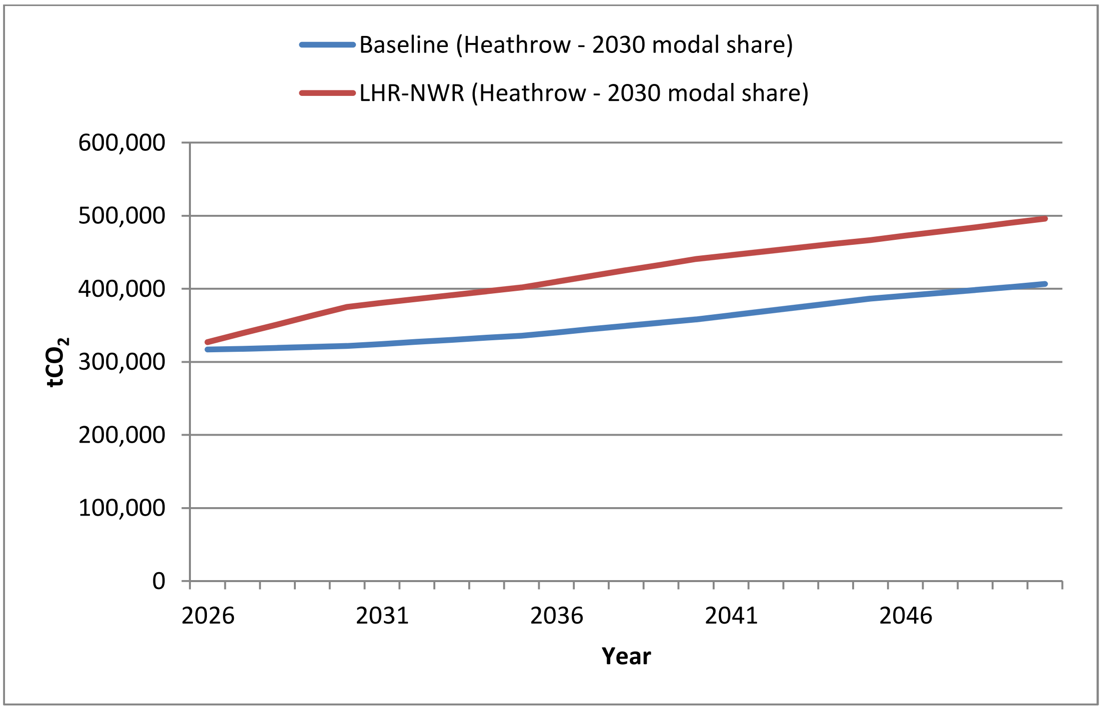


Table 4.7 - Emissions due to surface access at Heathrow, for 2026 – 2050 for baseline and Heathrow NWR forecast scenarios

Year	Baseline emissions due to surface access to Heathrow Airport, tonnes CO_2	Heathrow NWR emissions due to surface access to Heathrow Airport, tonnes CO_2
2026	316,763	327,027
2030	321,635	375,363
2040	358,267	440,861
2050	406,562	495,922

Mitigation

In this section some ideas for improving emissions from surface access, without any specific construction of public transport infrastructure, are suggested. The suitability for application to the context of the proposal would need to be investigated to establish the benefits and costs. In addition, the extent to which some of these mitigations have been applied already is not considered.

The improvement of electric vehicle, and alternative fuelled vehicle, infrastructure, through provision of charging points, and similar, may help in encouraging a general shift towards these lower carbon vehicle types. In addition, this kind of provision may encourage vehicles that would otherwise have range concerns.

It may be desirable to allow for more preferential parking for zero- and low-emission vehicles, for similar reasons as above.

An avenue for improving emissions from surface access would be through agreements with suppliers and transport partners. By requiring a certain level of low emission vehicle provision from coach and freight operators that utilise the airport, the resultant emissions can be reduced.

4.4 Emissions due to energy and fuel use during airport operations

Impact Assessment

The construction and operation of an additional runway, and the associated infrastructure, is considered likely to result in changes to the operational energy requirements of the airport. Figure 4.7 identifies the estimated energy use from different sources at Heathrow Airport under the Heathrow NWR proposal. Electricity use increases by approximately a third, due to the commensurate increase in passenger numbers in the 2026 to 2050 period, while gas use is modelled as significantly increasing due to the large increase in terminal area – much of this increase begins before 2026, with some terminal construction planned to complete in 2025. In Table 4.8 the carbon emissions associated with these energy uses are shown.

Figure 4.7 - Energy use at Heathrow, by source, 2026 – 2050 for Heathrow NWR

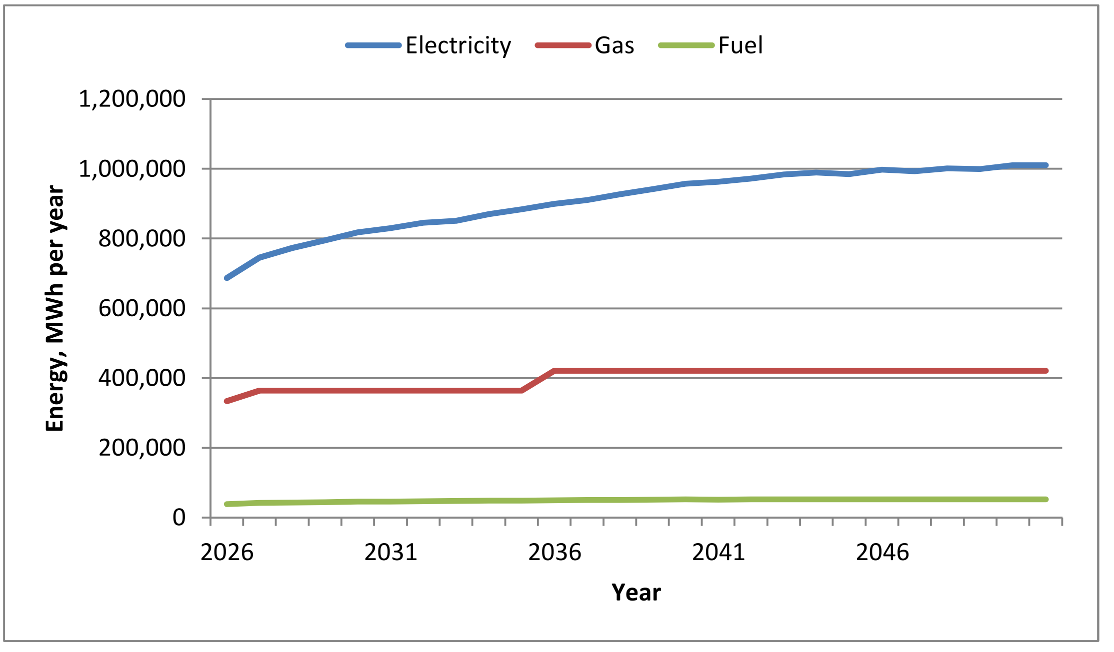
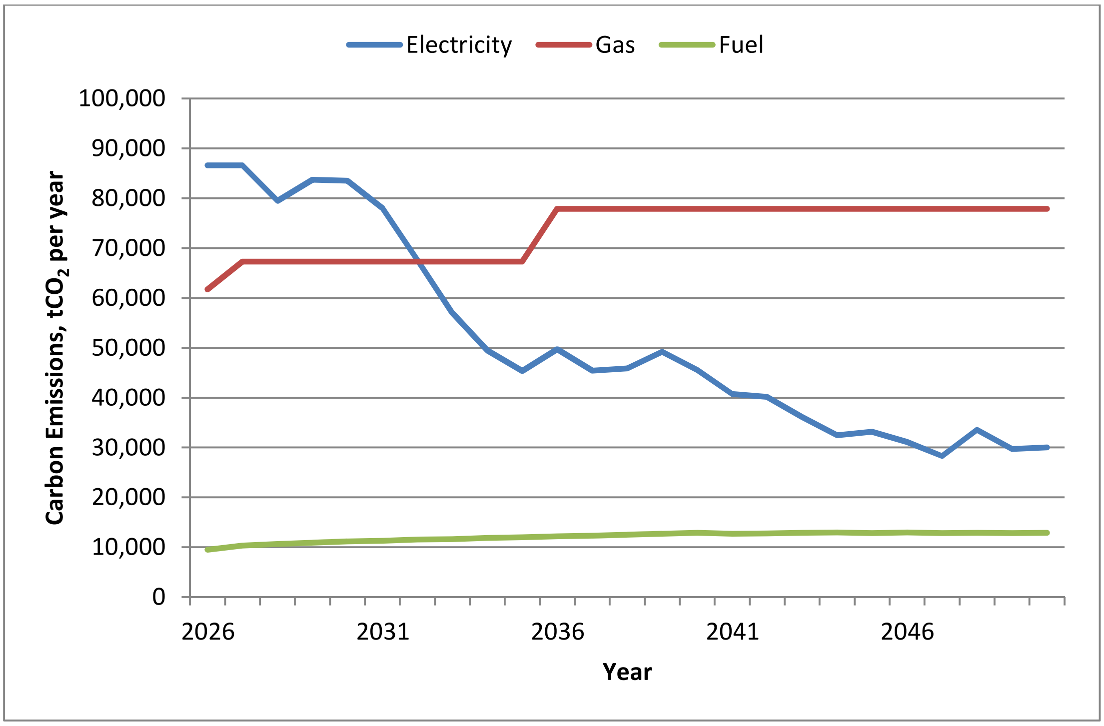


Table 4.8 – Carbon emissions due to airport operation energy use at Heathrow, by source 2026 – 2050 for Heathrow NWR forecast scenario

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	Total emissions due to airport operation at Heathrow Airport, tonnes CO_2
2026	101,765	61,717	9,483	157,788
2030	83,418	67,294	11,187	162,035
2040	44,827	77,874	12,872	136,279
2050	24,922	77,874	12,921	120,852

Figure 4.8 - Carbon emissions due to airport operation energy use at Heathrow, by source, 2026 – 2050 for Heathrow NWR forecast scenario



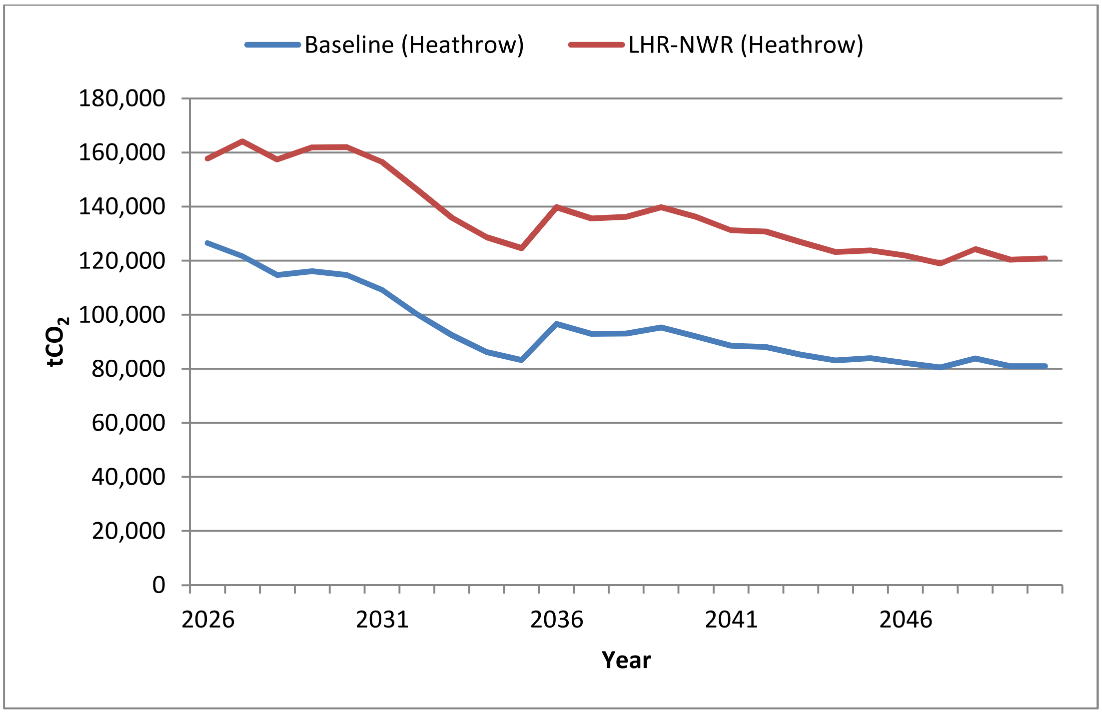
In Table 4.8, and the associated Figure 4.8, it can be seen that, despite an overall increase in energy use being predicted, the emissions associated with energy will fall over time. This is due to the predicted reduction in carbon emissions associated with grid electricity use. The emissions factors associated with gas and fuel uses are thought to remain stable, so the resultant emissions increase with the increase in usage that results from increased terminal space and additional flights, becoming a more substantial component of the total emissions.

Table 4.9 presents a comparison of the carbon emissions over time for the baseline and Heathrow NWR scenarios. It can be seen that in the Heathrow NWR scenario, the emissions associated with airport energy use fall far more slowly than in the baseline, diverging by more than 35% by 2050. The increase in terminal area, in this model, leads to an increase in gas fuel usage – the large amounts of additional terminal area offset the decarbonisation of grid electricity.

Table 4.9 - Operational emissions at Heathrow due to energy and fuel use, 2026 – 2050 for Heathrow NWR forecast scenario

Year	Baseline, tonnes CO_2	Heathrow NWR, tonnes CO_2	% Change
2026	126,509	157,788	24.7%
2030	114,756	162,035	41.2%
2040	91,962	136,279	48.2%
2050	81,007	120,852	49.2%

Figure 4.9 - Operational emissions due to fuel and energy use at Heathrow, 2026 – 2050 for baseline and Heathrow NWR forecast scenarios



It should be noted that in the Heathrow NWR proposed scheme it is not just operational emissions at Heathrow which are expected to change, as additional capacity at Heathrow will cause demand to shift from other airports.

Mitigation

There are several avenues for development in terms of reducing the carbon emissions associated with operation, both of the existing facilities and any new construction.

Any new construction should make use of the latest developments in energy efficiency, allowing for a reduction in electricity use and required heating. As an example of these principles, Stockholm-Arlanda airport, having set a zero CO2 emissions target from its own operations by 2020, is involved in the following carbon mitigation strategies:

- Utilisation of renewable fuels, such as biogas, to power the ground vehicle fleet;
- New buildings that are constructed are built to a recognised environmental standard;
- A carbon emission inventory is regularly produced, and augmented, in order to target outstanding emissions sources;
- The use of biomass boilers, to replace fuel burning heat sources; and
- LED light sources, both in terminals and facilities, but also for aircraft parking stands and other areas with lighting requirements.

Other potential mitigating methods include the use of electric vehicles in addition to alternative fuel vehicles, the utilisation of local renewable generation where safe and feasible, and the utilisation of “loop-closing” technology, such as energy-from-waste.

It is noted from Heathrow's published sustainability documentation, that commitments and actions broadly in line with those identified from Arlanda are already part of the airport's approach to sustainability.

4.5 Construction of new facilities and infrastructure

Impact Assessment

Table 4.10 presents a comparison of the carbon emissions due to construction at Heathrow for the baseline and the Heathrow NWR construction scenarios. It can be seen that, due to the carbon intensity that has been assumed for airports, in particular the construction of airport terminal buildings, embodied carbon from airport infrastructure makes up approximately 82% of the estimated carbon footprint. While the proportion of emissions attributed to fuel use seems to be low, the magnitude is quite substantial (equivalent to the use of over 100 million litres of diesel fuel). In addition, the freighting of material to site will also increase the emissions associated with fuel use, with some indications that these emissions will be approximately equal to the emissions due to construction processes (The Strategic Forum for Construction , 2010). The Phase 1 construction, expected to take place from 2019 to 2025, is included in this assessment, despite lying outside of the assessment period.

Table 4.10 - Carbon due to construction at Heathrow for Heathrow NWR

Year	Baseline	Additional construction emissions, Heathrow NWR
Embodied carbon due to airport infrastructure construction	13,325,975	9,313,475
Embodied carbon due to surface access construction	0	1,680,458
Carbon emissions due to fuel use in construction	188,633	266,757

Mitigation

Mitigation for the emissions associated with construction are wide-ranging, and variously applicable. These include:

- Use of energy efficient site accommodation;
- Increased efficiency in use of construction plant, for example through no-idle policies;
- Construction site connection to grid electricity to avoid use of mobile generation, and smart energy management practices;
- Reduction of waste, and the transport of waste, for example through increasing on-site recycling;
- Select construction material to utilise low carbon options, such as carbon-negative cement; and
- Select construction material to minimise distance of transport, and increase recycling percentages of the material where appropriate.

4.6 Commentary on proposer's submission

4.6.1 Increased airport capacity leading to a net change in air travel

Heathrow Airport Limited produces an annual carbon emissions inventory on a periodic basis, which includes Scope 3 carbon emissions. These carbon inventories include aircraft emissions within the LTO only and not the whole flight. Therefore, a comparison to this date for the 'do minimum' scenario could not be made.

However, Heathrow Airport Limited has released a report that focuses on the carbon emissions from flights departing Heathrow Airport (Heathrow Airport Limited, 2014d). The report contains calculated carbon emission forecasts up to 2050 assuming that a third runway opens in 2030 at Heathrow – Heathrow's North West Runway. The report presents its findings based on two sets of assumptions – those used by the CCC in a previous analysis ('Likely' forecast') (Committee on Climate Change , 2009) and a set of reduction figures produced by Sustainable Aviation in their 2012 CO_2 Roadmap (Sustainable Aviation, 2012). These two sets of assumptions, as they are reported in the Heathrow report, are presented below:

Sustainable Aviation assumptions for the period 2010 to 2050

- Air traffic management and operational practices: fuel efficiency could decrease emissions by 9%;
- Introduction of "imminent" generation and subsequent generation aircraft: combined improvement in fleet average fuel efficiency could decrease emissions by 39%; and
- Penetration of sustainable fuels into the global aviation fuel market with 60% life-cycle CO_2 saving per litre of fossil kerosene displaced. Assuming a 25-40% penetration, this is predicted to give an 18% reduction in CO_2 emissions from UK aviation.

The overall improvement forecast by Sustainable Aviation that could be achieved between 2010 and 2050 is, therefore, 54.5% (a carbon intensity reduction factor of 0.455).

The Committee on Climate Change assumptions for the period 2005 to 2050

- Improvement in fuel efficiency due to evolutionary airframe and engine technology innovation & improved efficiency of air traffic management and operations:
- Likely improvement in fleet fuel efficiency: -0.8% per annum (fleet averaged values on a seat-km basis).
- If funding increased and technology innovation accelerated: -1.5% per annum (fleet averaged values on a seat-km basis).
- Use of biofuels, assuming an average emissions saving of 50% relative to fossil fuels:
    - Likely: 10% penetration.
    - Optimistic: 20% penetration.
    - Speculative: 30% penetration.

The improvement forecast by the Committee on Climate Change that could be achieved between 2005 and 2050 is, therefore, 35% (likely), 45% (optimistic), 55% (speculative), corresponding to carbon intensity reduction factors of 0.65, 0.55 and 0.45 respectively.

The report uses DfT produced aviation carbon emissions for 2010 as its baseline (Department for Transport, 2013c). The stated purpose of this report is to establish whether a third runway at Heathrow is compatible with this UK target.

Table 4.11 presents the calculated carbon emissions from the Heathrow Airport Limited report alongside those in the AoN Carbon Capped.

Table 4.11 - Carbon emissions from departing flights at Heathrow Airport 2030 – 2050, for Heathrow NWR forecast scenario

	Heathrow NWR (Committee on Climate Change assumptions) tCO_2	Heathrow NWR (Sustainable Aviation assumptions)	AoN Carbon Capped tCO_2
2030	22,300,000 – 23,400,000	22,300,000 – 24,400,000	23,200,000
2050	25,000,000	17,600,000	20,500,000

The 2030 carbon emissions for Heathrow operating with three runways are similar for the three different methodologies. However, the differences in the methods and assumptions used to produce the 2050 carbon figures are apparent. The 17.6 $MtCO_2$ carbon figure, derived from the Sustainable Aviation assumptions, highlights the more optimistic set of assumptions used for aircraft fuel efficiency and biofuel use during the period to 2050

4.6.2 Airside ground movements

The submission by Heathrow Airport Limited provides an estimate of the emissions associated with the full LTO cycle (Heathrow Airport Limited, 2014). It has been calculated on the basis of fuel use, matching the methodology of the Air Quality Report (Heathrow Airport Limited, 2010). It makes use of the following assumptions when calculating the emissions associated with the full LTO cycle:

- Lower emission aircraft will be incentivised, through charges and “green slots”.
- Over time, the amount of time spent in LTO cycle will be reduced due to air traffic management.

In Table 4.12 the emissions submitted by Heathrow Airport limited for the LTO cycle are shown.

Table 4.12 - LTO emissions submitted by HAL for baseline and Heathrow NWR scenarios

Emission source	Year	Baseline, tCO_2	Heathrow NWR, tCO_2
LTO	2010	1,200,000	-
	2030	900,000	1,100,000
	2040	900,000	1,400,000

In Table 4.12 it can be seen that HAL would seem to predict an increase in LTO emissions of approximately 20% in the Heathrow NWR scenario. Their prediction for emissions related to the entire LTO cycle are at 1,100,000 tCO_2e in 2030 and 1,400,000 tCO_2e in 2040; the estimations made above for the same years for just ground movements are 534,000 tCO_2 and 615,000 tCO_2 for which the proportion of taxi-in-taxi-out out of the whole LTO cycle was assumed to be approximately 33%. If similar assumptions were made with the Heathrow Airport Limited estimates then the airside ground movement emissions level in 2030 would be approximately 367,000 tCO_2 and in 2040 it would be approximately 467,000 tCO_2. These lower estimates are likely to result from taking greater account for the use of lower emission planes over time, as described in the HAL Air Quality Report.

4.6.3 Surface access

The submission by Heathrow Airport Limited includes an assessment of the emissions associated with the transport of passengers and staff to Heathrow Airport. Transport emissions factors were taken from the relevant guidance and DfT forecasts (Defra / DECC, 2010).

The calculation of the future emissions under the Heathrow NWR proposal makes use of the following assumption:

- Additional public transport infrastructure will increase the public transport share to 50% in 2030 and 55% in 2040.

In Table 4.13 the emissions presented by Heathrow Airport Limited in its proposal are shown (Heathrow Airport Limited, 2014). It can be seen that the baseline levels in 2030 and 2040 are broadly similar to those presented in the analysis above; however, the numbers given by Heathrow Airport Limited include staff travel, so would be expected to be higher. Using the split in the presented distance travelled as a rough guide, the staff travel would seem to make up approximately 13% of the 2030 and 2040 baseline. The emissions presented for the Heathrow NWR proposal are consistently higher than those presented in the analysis above, as may be expected due to the inclusion of staff travel in the total.

Table 4.13 - Surface access emissions forecast submitted by HAL for baseline and Heathrow NWR scenarios

Emission source	Year	Baseline (tCO_2e)	Heathrow NWR (tCO_2e)
Travel to and from the airport	2010	700,000	-
	2030	400,000	500,000
	2040	400,000	600,000

4.6.4 Airport operations

The submission made by Heathrow Airport Limited considers energy use, but excludes the operation of ground support equipment as being of negligible significance.

Energy use is considered in detail as part of the proposal (Heathrow Airports Limited , 2014), with the following assumptions impacting the modelled results:

- A variety of energy generation technologies, such as photovoltaics and Energy from Waste (EfW).
- Efficiency measures, such as night time air purging, smart grid systems, and efficient baggage handling equipment.

Further, the submission uses the DECC emissions factors, with a +25% increase, up to the year 2030, where the submission assumes that the grid emission factor will flat-line.

In Table 4.14 the emissions estimated in the Heathrow NWR proposal have been shown. While the sources of emissions in this estimation are not fully described in the Carbon Footprint Report some indication can be made based on the reported energy supply sources. These are shown in Table 4.16.

Table 4.14 - Airport operational emissions submitted by HAL for baseline and Heathrow NWR forecast scenarios

Emission source	Year	Baseline (tCO_2e)	Heathrow NWR (tCO_2e)
Energy	2010	300,000	-
	2030	100,000	100,000
	2040	100,000	100,000

Table 4.15 – Comparison of airport operational emissions

Emission source	Year	HAL Proposal (tCO_2e)	Jacobs Assessment (tCO_2e)
Energy	2030	100,000	162,000
	2040	100,000	136,000

Table 4.16 - Energy supply submitted by HAL

Emission source	Year	Baseline (GWh/year, approx.)	Heathrow NWR (GWh/year, approx.)
Heating – Gas boilers	2010	180	-
	2020	190	-
	2030	-	0
Heating – Fuel boilers	2010	10	-
	2020	10	-
	2030	-	0
Heating – EfW	2010	0	-
	2020	50	-
	2030	-	220
Heating – Biomass CHP	2010	0	-
	2020	0	-
	2030	-	30
Electricity – Grid	2010	450	-
	2020	470	-
	2030	-	370
Electricity – Biomass CHP	2010	60	-
	2020	15	-
	2030	-	10
Electricity – EfW heat use	2010	0	-
	2020	0	-
	2030	-	120

In Table 4.15, we are able to compare the key differences between the assessments. Estimates made in this report place Heathrow's baseline electricity grid use at approximately 600 GWh/year in 2025, rising to 700 GWh/year in the period 2026-2051. The HAL submission, however, sees electricity demand fall, due to substitution with generation by the EfW plant. In addition, the profile submitted sees gas oil and fuel oil, at 190-200 GWh, phased out and completely replaced by EfW and biomass heating, which is not modelled in this assessment.

4.6.5 Construction of new facilities and infrastructure

Heathrow Airport Limited has made estimations of the potential embodied carbon that will result from the construction of the Heathrow NWR proposal and has also estimated plant, labour and commuting associated emissions (Heathrow Airport Limited, 2014).

These estimations have been based on a "Bill of Quantities" (Heathrow Airport Limited, 2014), which, due to the lack of specific material information, includes assumptions about the processes to be used and the associated level of activity. The labour, transport and energy use associated with construction are primarily calculated as a proportion of the embodied carbon.

The assumptions, which can be reviewed in detail in Table A1 of Heathrow's Carbon Footprint Assessment, are primarily factors from the following sources:

- Tunnelling factors - High Speed Two (HS2) (2013) London-West Midlands Statement: Volume 5: Technical Appendices
- Motorways and roads - Transport Scotland (2009) STAG Technical Database
- Terminal buildings - Heathrow Sustainability (n.d.) Embodied Carbon in Construction Materials Used on T2A and T2B
- Runways - SimaPro UK (2013) SimaPro 7.3.3 software and University of Bath (2011) Inventory of Carbon and Energy (ICE).
- Runway shoulders – 66% of the factor used for runway
- Taxiways, aprons, stands – 50% of the factor used for runways
- Buildings - Sansom and Pope (2012) A comparative embodied carbon assessment of commercial buildings. The Structural Engineer

In terms of particular factors, the types of embodied carbon factors utilised in the assessment above, which are based on tCO_2 / £100 k spend, preclude direct comparison.

The overall totals can be seen in Table 4.17. Under Heathrow Airport Limited's submission, the terminals, and their associated infrastructure, makes up 63.5% of the 3.2 $MtCO_2$ total. In the assessment above the terminal construction is thought to make up 65% of the 10.9 $MtCO_2$ total; even though the proportions are similar, the higher emissions factors for this type of construction likely drive the difference

Table 4.17 - Carbon due to construction at Heathrow

Year	Heathrow NWR submitted by Heathrow Airport Limited	Heathrow NWR calculated by Jacobs
Embodied Carbon	3,181,000	10,993,933
Carbon emissions due to fuel use in construction	388,000	266,757

4.7 Conclusions

Analysis of the Heathrow North West Runway scheme carbon emissions is based on the Northwest runway masterplan submitted by HAL, and the AoN Carbon Capped passenger and ATM forecasts developed by the Airports Commission. This sees ATMs grow from around the 480,000 level in 2026, to 750,000 in 2040, which then stays broadly fixed through to 2050 with some annual variance. The operational cap of 740,000 is not adhered to in the AoN forecasts, so ATMs and emissions reflect demand directly within the confines of the UK aviation system cap of 37.5Mt CO2. There would be significant construction of infrastructure during the early years of the scheme, with new runway and new terminal and surface access infrastructure dominating.

The most significant volume of emissions are related to air travel, but these initially increase in line with ATMs but then decrease over the period, linked to capacity being reached in 2040 and then reflecting continued changes to the Heathrow fleet and improved fuel efficiency of aircraft present within that fleet. Surface access emissions remain the second largest source of CO_2 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 initially increase with new infrastructure but then reduce over time, most significantly due to the presumed decarbonisation of grid electricity.

Table 4.18 - Carbon assessment findings for Heathrow NWR: change in tCO2

Area of Emissions	2030	2040	2050	Additional tCO_2 to baseline over 60 year appraisal period	Total tCO_2 over 60 year appraisal period
Air travel	3,101,660	4,576,552	3,912,629	236,659,012	1,313,372,945
Ground movements component	137,899	217,858	231,150	12,845,042	36,640,725
Passenger surface access journeys	63,145	96,193	103,764	5,698,857	32,748,026
Airport operations energy & fuel use	44,392	39,755	35,004	2,218,775	7,507,784
Total operational CO_2 emissions	**3,209,197**	**4,712,500**	**4,051,397**	**244,576,644**	**1,353,628,755**
Construction of airport facilities & SA infrastructure*	n/a	n/a	n/a	11,260,690	24,775,297

* Construction emissions are calculated as tCO_2e.

In terms of net change from baseline predicted levels, the emissions due to air travel are the largest proportion of the carbon emissions, both in terms of change and total emissions. Looking at the proportional change, the emissions area that will change the most is that of construction, increasing by 80% from the estimated baseline value.

4.8 Heathrow NWR Carbon Assessment Monetisation

In Table 4.19 and Table 4.20, the carbon results are displayed in a monetised format. This has been done for both the Net Present Value (NPV) of the additional carbon emissions enabled by the scheme, and also for particular assessment years in terms of £2014.

The key difference when reviewing these monetised results in contrast to the tCO_2 results is the impact that emission timing has on the value. For example, the emissions due to construction are approximately three times the emissions due to energy and fuel use however they are only double the value. This is because the construction emissions occur early in the assessment, while the energy emissions are spread through the full assessment period.

Table 4.19 – Heathrow Airport additional central carbon value (NPV) for the Heathrow NWR forecast scenario

	Monetised value of carbon emissions
Total Additional Value (£)	£15,483,300,000
Snapshot 2030 (£)	£145,886,720
Snapshot 2040 (£)	£288,572,990
Snapshot 2050 (£)	£310,180,392
Snapshot 2060 (£)	£307,080,764

Table 4.20 - Additional and total central carbon value, (NPV) for emission sources for the Heathrow NWR scenario

Area of Emissions	Additional £ over 60 year appraisal period	Total £ over 60 year appraisal period
Air travel	£14,736,139,315	£79,922,168,410
Ground movements component	£805,252,094	£2,260,432,982
Passenger surface access journeys	£358,755,534	£2,030,426,713
Airport operations energy & fuel use	£135,341,278	£455,439,720
Total operational CO_2 emissions	**£15,230,236,127**	**£82,408,034,843**
Construction of airport facilities & SA infrastructure*	£253,048,272	£875,194,585

In Table 4.21 and Table 4.22, the carbon results are displayed as the range from the low to high assumptions on carbon value. This has been done for both the Net Present Value (NPV) of the additional carbon emissions enabled by the scheme, and also for particular assessment years in terms of £ in 2014.

Table 4.21 - Additional Low to High carbon value, (NPV) for Heathrow NWR forecast scenario

	Monetised value of carbon emissions
Total Additional Value (£)	£6,962,900,000 – £24,192,100,000
Snapshot 2030 (£)	£72,943,360 - £218,830,080
Snapshot 2040 (£)	£144,286,495 - £432,859,485
Snapshot 2050 (£)	£155,090,196 - £465,270,587
Snapshot 2060 (£)	£138,186,344 - £475,975,183

Table 43 - Additional Low to High carbon value (NPV) for emission sources for Heathrow NWR forecast scenario

	Monetised value of carbon emissions, additional value
Increased airport capacity - net change in air travel	£6,629,362,836 - £22,881,107,988
Airside ground movements	£359,042,449 - £1,253,094,117
Passenger surface access journeys	£159,838,758 - £558,125,668
Airport operations	£61,031,144 - £210,325,510
Construction of new facilities & SA infrastructure	£112,638,461 - £542,514,962

5 Heathrow Airport Extended Northern Runway

This section covers the following for Heathrow Airport Extended Northern Runway and each emissions category:

- Jacobs assessment of impacts;
- Potential for mitigation (or limitations);
- Comment on the proposer's submission; and
- Conclusions,

5.1 Increased airport capacity leading to a net change in air travel

Impact Assessment

Table 5.1 presents the forecast carbon emissions from the AoN Carbon Capped for all departing flights from Heathrow Airport between 2026 and 2050, with the ENR scheme, alongside the total carbon emissions from all UK flights and the percentage of the UK total that occurs with flights from Heathrow.

Table 5.1 - Carbon emissions, carbon capped: Heathrow ENR, for 2026 – 2050

Year	Heathrow Airport, Number of passengers	Heathrow Airport, Numbers of ATMs[15]	Heathrow Airport, tonnes CO_2	UK Aviation Total, tonnes CO_2	Heathrow as % of UK Total for carbon emissions
2026	91,138,224	548,179	21,590,858	38,721,210	55.8
2030	109,824,896	654,489	23,343,130	39,816,192	58.6
2040	123,550,160	709,329	23,350,987	40,128,502	58.2
2050	128,614,152	710,863	19,907,914	37,518,909	53.1

Figure 5.1 presents the same carbon emissions as shown in Table 5.1 in this assessment graphically, where the impact of increased numbers of flights can be seen very clearly over the first decade, before emissions begin decreasing over the next two decades due to fleet changes and efficiency improvements.

[15] The total number of ATMs based on demand forecasting is projected to exceed the operational cap of 740,000 ATMs. The Airports Commission economic analysis indicates that an equilibrium solution which satisfies capacity limits at all airports is computationally intensive and progressively more difficult to solve as demand mounts through the forecasting period. The solution is generally deemed to be found when over-capacity airports are within +/-1.5% of their input capacities. Runway capacity is regarded as a "harder" capacity than terminal capacity in the search for an equilibrium solution.

Figure 5.1 – Carbon emissions from departing flights at Heathrow Airport, 2026 – 2050: baseline and Heathrow ENR scenarios, carbon capped

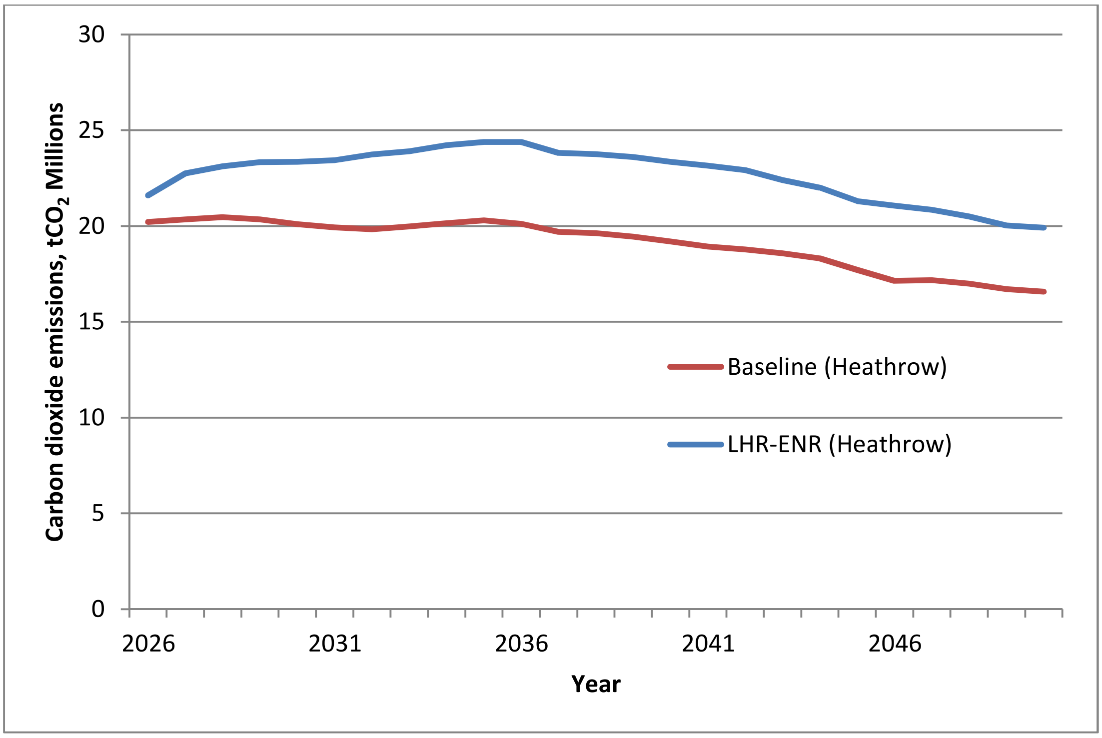


Table 5.2 presents a comparison of the carbon emissions in 2030, 2040 and 2050 for the baseline and Heathrow ENR forecast scenarios.

Table 5.2 - Comparison of the carbon emissions in 2030, 2040 and 2050 for the Heathrow Airport baseline and Heathrow ENR forecast scenarios

Year	Baseline tonnes CO_2	Heathrow ENR tonnes CO_2	Change (%)
2030	20,099,848	23,343,130	16.1
2040	19,184,305	23,350,987	21.7
2050	16,570,400	19,907,914	20.1

With a third runway in use the carbon emissions associated with departing flights decrease by 3.44 $MtCO_2$ or 14.7% over the period 2030 - 2050. This decrease is similar in its trend and magnitude to the decrease seen in the baseline forecast, which is derived from the conservative assumptions regarding improvements in aircraft type and fuel utilisation. However, the carbon emissions in the Heathrow ENR scenario are greater than in the baseline scenario by 3.34 $MtCO_2$ or 20.1% in 2050.

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

- distances flown by aircraft;
- fuel efficiency of the aircraft fleet; and,
- type of fuel used.

Figure 5.2 shows the changes in ATMs during the period 2026 – 2050.

Figure 5.2 - Air transport movements (ATMs) during the period 2026 – 2050 at Heathrow Airport, baseline and Heathrow ENR scenarios carbon capped

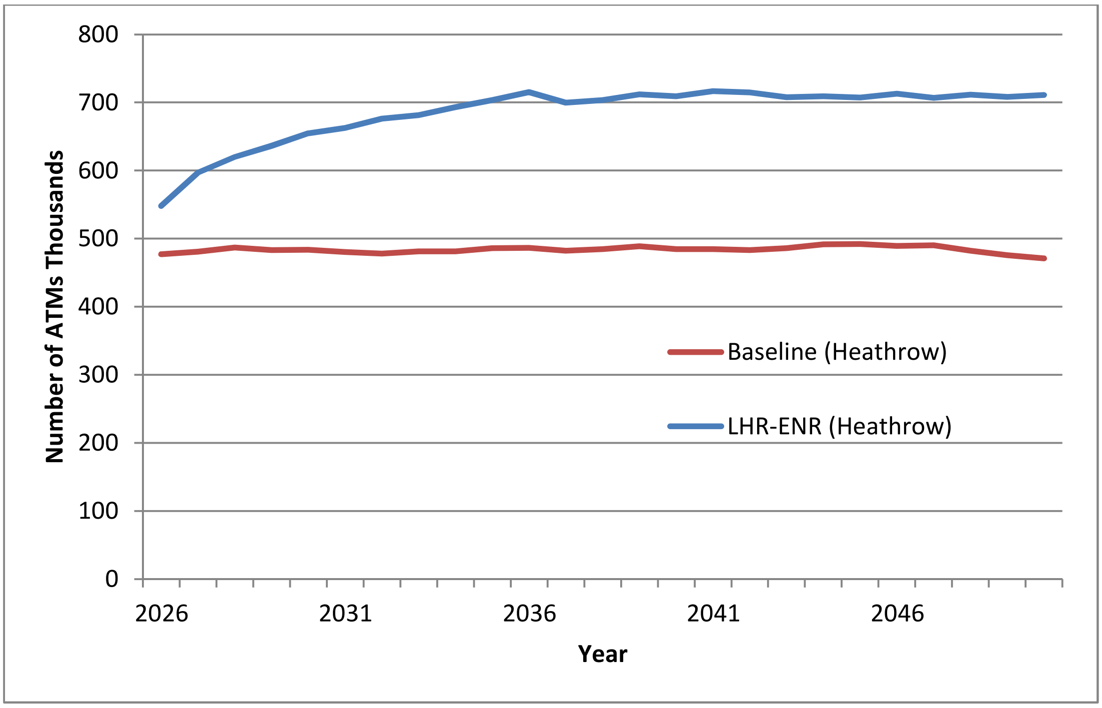


Figure 5.2 shows that the number of ATMs at Heathrow Airport, a key determinant of aviation carbon emissions, increase during the period 2026 – 2050 with the ENR scheme. An increase in carbon emissions would be expected if ATMs were the only determinant of emissions. The increase in ATMs over the period 2026 – 2050 is 8.6% compared with a 14.7% decrease in carbon emissions over this period. There is therefore a reduction in carbon per ATM. This is due to a combination of aircraft fleet changes and alternative fuels, with fleet changes at Heathrow changing from the baseline levels. 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 Heathrow ENR forecast. The forecast has not been made for a change in just one of these assumptions, therefore the magnitude, and the relative contributions of each, cannot be identified from the model output contained in the AoN Carbon Capped.

Carbon emissions from flights departing Heathrow Airport have not been modelled for the period 2050 - 2086. 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, as described in detail in Appendix A, 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.

Mitigation

Mitigation that may impact this aspect of emissions includes the utilisation of mechanisms that would encourage the new demand to be utilised by the cleanest aircraft. Potential options for this include increased airport charges for older aircraft, or mandated "green slots" which require planes of a certain standard to take up the new capacity.

Airside ground movements

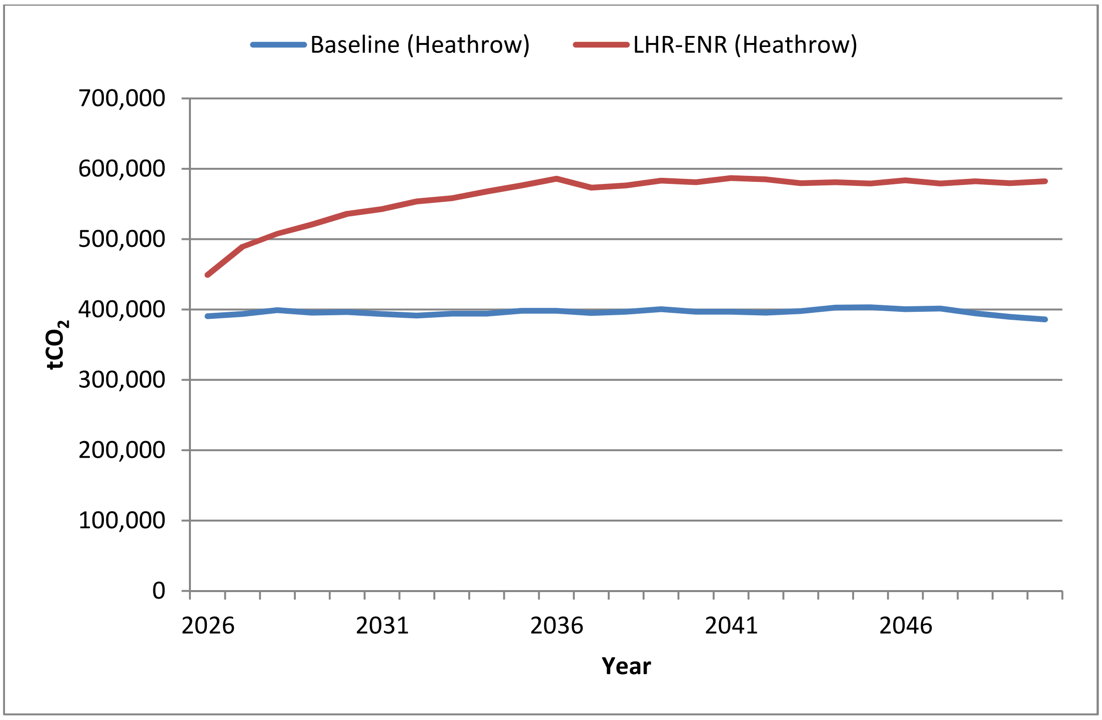
Impact Assessment

Table 5.3 and Figure 5.3 present a comparison of the carbon emissions at Heathrow over time for the baseline and Heathrow ENR scenarios. It can be seen that due to the increase in ATMs in the Heathrow ENR scenario, the emissions associated with airside ground movements increase rapidly, diverging by up to 50% by 2050.

Table 5.3 - Comparison of the aircraft ground movement emissions 2026 – 2050 for the Heathrow Airport baseline and Heathrow ENR forecast scenarios

Year	Baseline, tonnes CO_2	Heathrow ENR, tonnes CO_2, ICAO-Times	Heathrow ENR, tonnes CO_2, HAL-Reported times
2026	390,677	448,998	355,879
2030	396,313	536,074	424,896
2040	396,855	580,992	460,499
2050	385,891	582,248	461,494

Figure 5.3 - Carbon emissions due to airside ground movements 2026 – 2050 for the baseline and Heathrow ENR forecast scenarios ENR scenarios



It should be noted that in the Heathrow ENR proposal it is not just ATMs at Heathrow which are expected to change, as additional capacity causes demand and ATMs to shift between airports. As each airport will have its own level of emissions per ground movement, this means that a shift of ATMs to Heathrow, from any airport with a lower level of emissions per LTO cycle, could reduce the overall impact of the additional ATMs.

Mitigation

The primary way in which to reduce the emissions associated with airside ground movements is through efficient runway and taxiway design and use. Airports have made advances in these areas, and it is recommended that best practice would be applied to any new designs. This should include:

- Use of airport terminal power and pre-conditioned air sources
    - This would reduce the burden on aircraft APUs and airport GPUs
- Reduce engine operation during taxing
    - By shutting down an engine during taxiing, both fuel use and emissions can be reduced.

5.2 Arrival and departure route emissions

Impact Assessment

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.

Mitigation

UK airspace, together with that of the rest of Europe is subject to redesign for enhanced safety, efficiency and environmental reasons (CAA, 2009). 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 (Department for Transport, 2014a). Further assessment of carbon emissions impacts of departure and arrival routes must be undertaken when sufficient information is available.

5.3 Surface Access

Impact Assessment

For this assessment, the 2008 modal share was used to calculate emissions from surface access. Within this model, the rail, coach/bus and private vehicle shares differ according to Origin-Destination; the approximate overall mode share for Heathrow, was:
:

- Rail – 16%
- Coach/bus – 16%
- Private vehicle – 68%

Under Heathrow ENR there would be additional surface access requirements at Heathrow, which would lead to an increase in the associated emissions. These can be seen in Table 5.4 and Figure 5.4.

Figure 5.4 - Emissions due to surface access for baseline and Heathrow ENR forecast scenarios

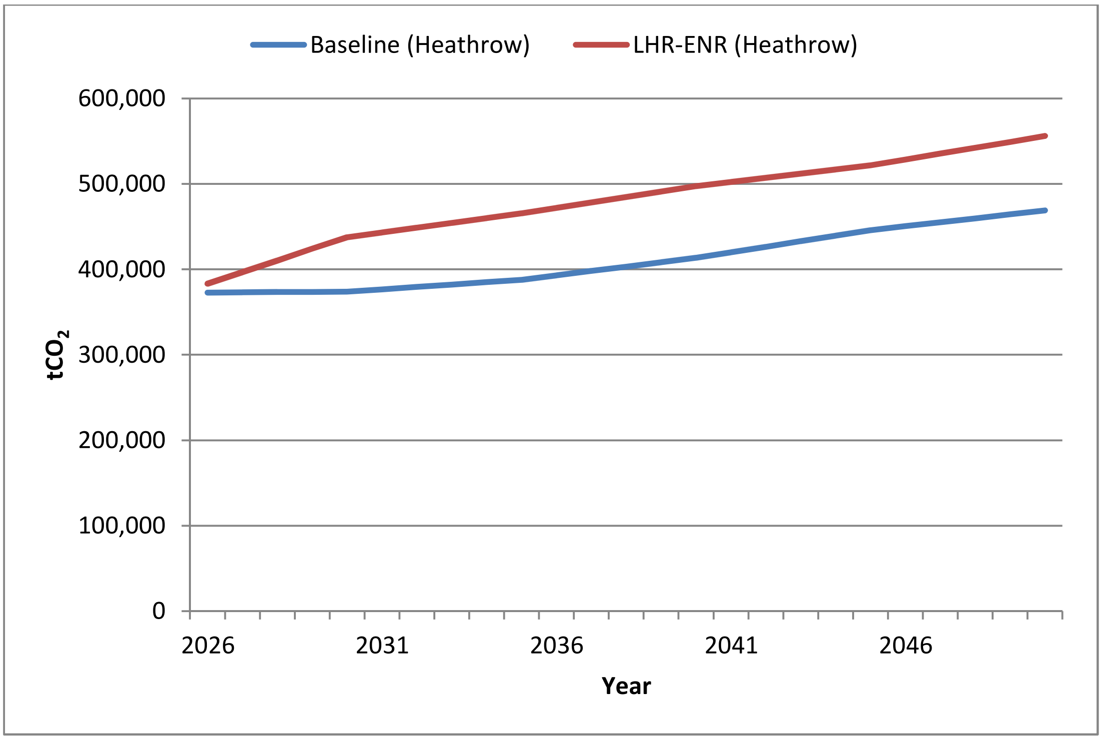


Table 5.4 - Emissions due to surface access for 2026 – 2050 for baseline and Heathrow ENR forecast scenarios

Year	Baseline emissions due to surface access to Heathrow Airport, tonnes CO_2	Heathrow ENR emissions due to surface access to Heathrow Airport, tonnes CO_2	% change
2026	372,947	383,247	2.8%
2030	373,888	437,622	17.0%
2040	413,575	497,398	20.3%
2050	469,066	556,099	18.6%

Figure 5.5 and Table 5.5 present the combined total for the airports used in the National Surface Access model[16] under the Heathrow ENR proposal. It can be seen that the transfer of passenger demand to Heathrow Airport in the Heathrow ENR scenario leads to a slight decrease in total surface access emissions. This is due to the fact that under the base model Heathrow has a higher public transport modal share than many other airports; passengers substituting into an expanded Heathrow will do so from airports where their travel emissions would have been higher.

[16] The airports used are: Aberdeen, Birmingham, Bournemouth, Bristol, Cardiff, East Midlands, Edinburgh, Exeter, Gatwick, Glasgow, Heathrow, Humberside, Leeds/Bradford, Liverpool, London City, Luton, Manchester, Newcastle, Newquay, Norwich, Southend, Southampton, Stansted, Teesside, Blackpool, Doncaster Sheffield, Prestwick

Figure 5.5 - The emissions due to surface access across the UK airport system for baseline and Heathrow ENR forecast scenarios

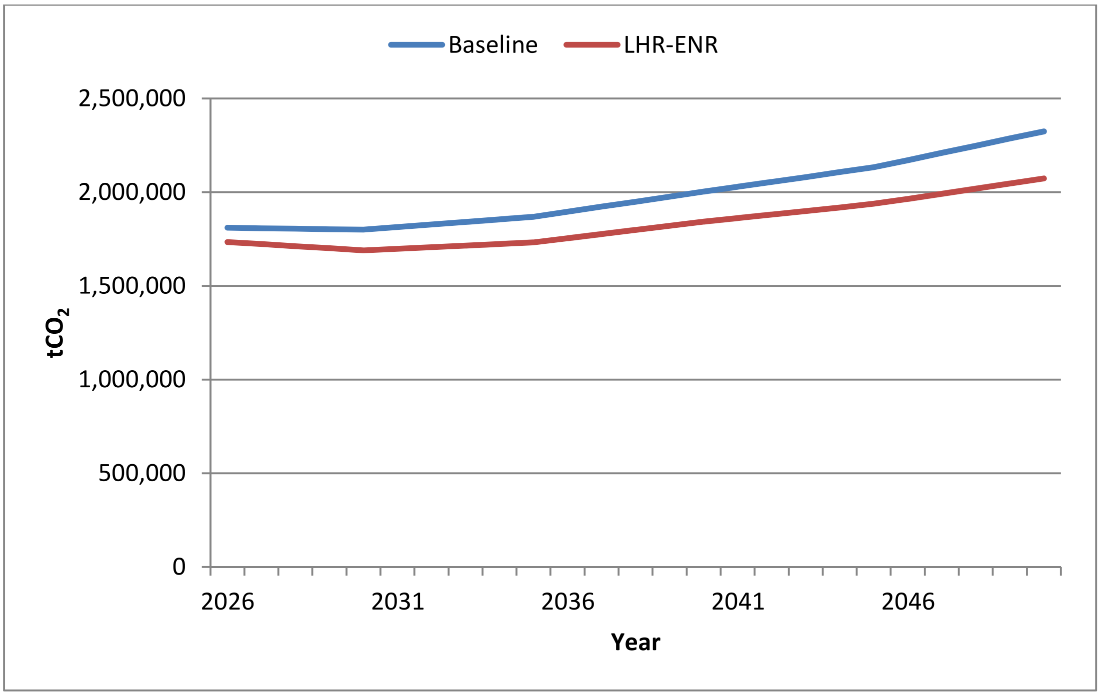


Table 5.5 - The emissions due to surface access across the UK airport system, 2026 – 2050 for baseline and Heathrow ENR forecast scenarios

Year	Baseline emissions due to surface access to UK airports[17], tonnes CO_2	Emissions due to surface access to UK airports with Heathrow ENR[18], tonnes CO_2	% change
2026	1,868,923	1,734,238	-4.2%
2030	1,800,361	1,690,625	-6.1%
2040	2,003,151	1,843,498	-8.0%
2050	2,324,692	2,073,791	-10.8%

Sensitivity: 2030 Modal split

A sensitivity scenario was developed in which the predicted 2030 mode share was applied to the surface access for Heathrow. The result of this can be seen in Table 5.7 and Figure 5.6. The primary difference is a reduction in absolute emissions.

For this assessment, the 2030 modal share was used to calculate emissions from surface access. The regional mode share is shown in Table 5.6.

[17] The previously referenced set.
[18] The previously referenced set.

Table 5.6 - 2030 Modal split for Heathrow Airport under Heathrow ENR scenario

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%

Figure 5.6 - Emissions due to surface access at Heathrow, using a 2030 modal share for baseline and Heathrow ENR forecast scenarios

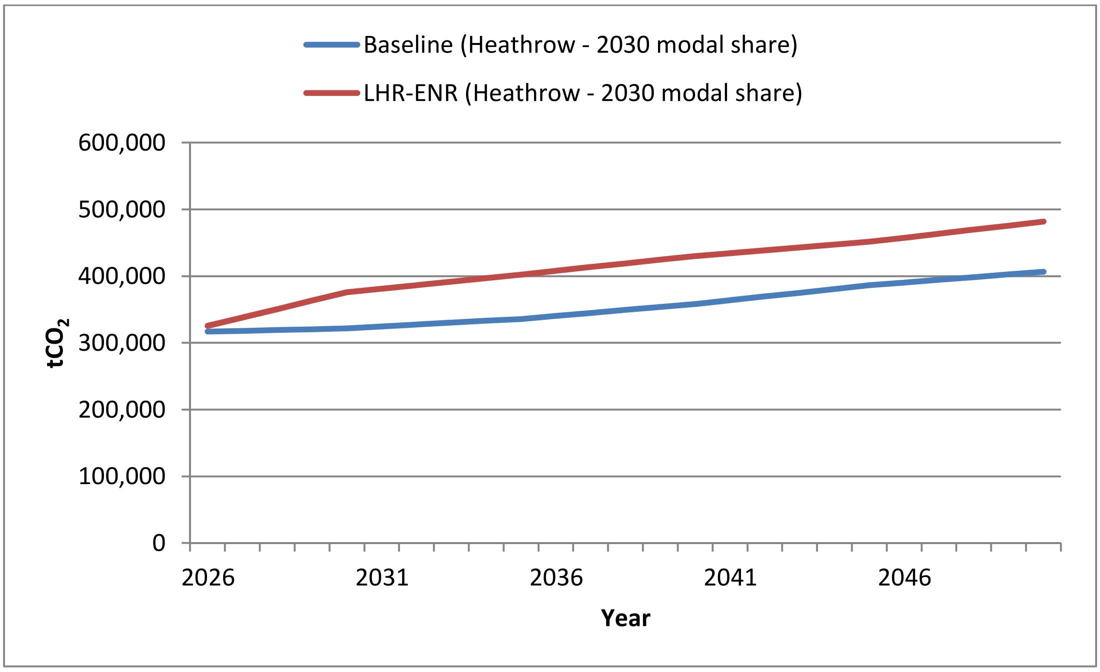


Table 5.7 - Emissions due to surface access at Heathrow, for 2026 – 2050 for baseline and Heathrow ENR forecast scenarios

Year	Baseline emissions due to surface access to Heathrow Airport, tonnes CO_2	Heathrow ENR emissions due to surface access to Heathrow Airport, tonnes CO_2
2026	316,763	325,442
2030	321,635	375,947
2040	358,267	430,153
2050	406,562	481,710

Mitigation

In this section some ideas for improving emissions from surface access, without any specific construction of public transport infrastructure, are suggested. The suitability for application to the context of the proposal would need to be investigated to establish the benefits and costs. In addition, the extent to which some of these mitigations have been applied already is not considered.

The improvement of electric vehicle, and alternative fuelled vehicle, infrastructure, through provision of charging points, and similar, may help in encouraging a general shift towards these lower carbon vehicle types. In addition, this kind of provision may encourage vehicles that would otherwise have range concerns.

It may be desirable to allow for more preferential parking for zero- and low-emission vehicles, for similar reasons as above.

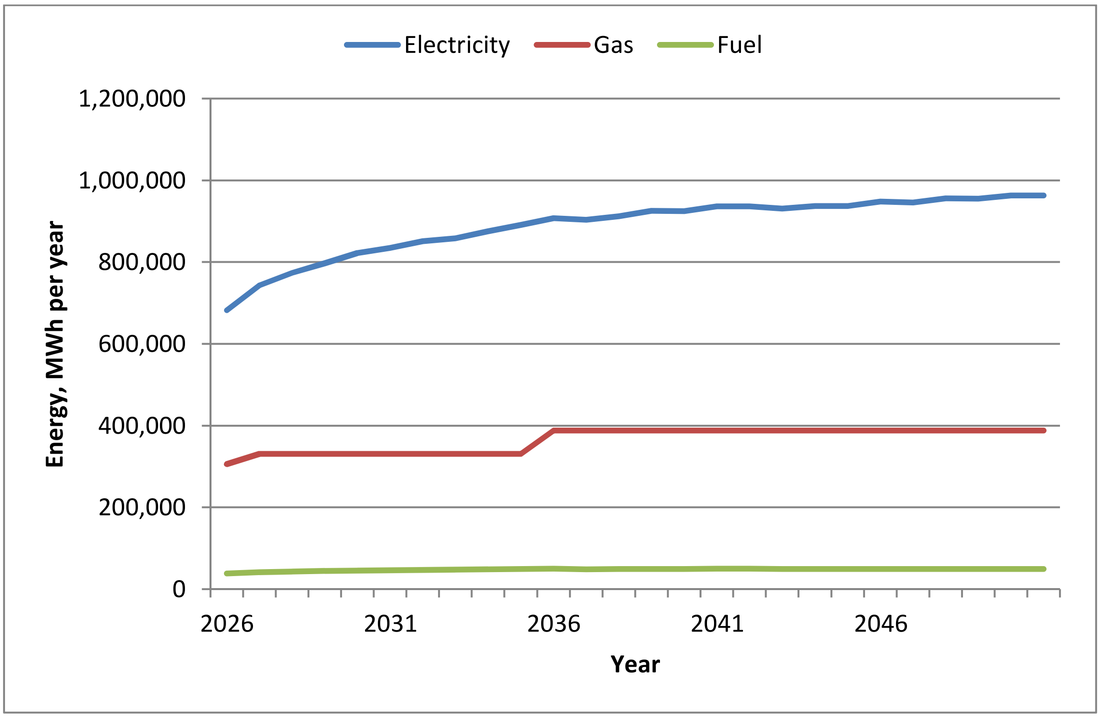
An avenue for improving emissions from surface access would be through agreements with suppliers and transport partners. By requiring a certain level of low emission vehicle provision from coach and freight operators that utilise the airport, the resultant emissions can be reduced.

5.4 Emissions due to energy and fuel use during airport operations

Impact Assessment

The construction and operation of an additional runway, and the associated infrastructure, is considered likely to result in changes to the operational energy requirements of the airport. Figure 5.7 identifies the estimated energy use from different sources at Heathrow Airport under the Heathrow-ENR proposal. Electricity use increases by approximately a third, due to the commensurate increase in passenger numbers in the 2026 to 2050 period, while gas use is modelled as significantly increasing due to the large increase in terminal area.

Figure 5.7 - Energy use at Heathrow, by source, 2026 – 2050 for Heathrow ENR



In Table 5.8 and Figure 5.8, the carbon emissions associated with these energy uses are shown. Despite an overall increase in energy use being predicted the emissions associated with energy will fall over time. This is due to the predicted reduction in carbon emissions associated with grid electricity use. The emissions factors associated with gas and fuel uses are thought to remain stable, so the resultant emissions increase with the increase in usage that results from increased terminal space and additional flights, becoming a more substantial component of the total emissions.

Table 5.8 – Carbon emissions due to airport operation energy use at Heathrow, by source 2026 – 2050 for Heathrow ENR forecast scenario

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
2026	86,049	56,635	9,402	152,086
2030	83,983	61,252	11,226	156,460
2040	43,991	71,831	12,166	127,989
2050	28,638	71,831	12,193	112,662

Figure 5.8 - Carbon emissions due to airport operation energy use at Heathrow, by source, 2026 – 2050 for Heathrow ENR forecast scenario

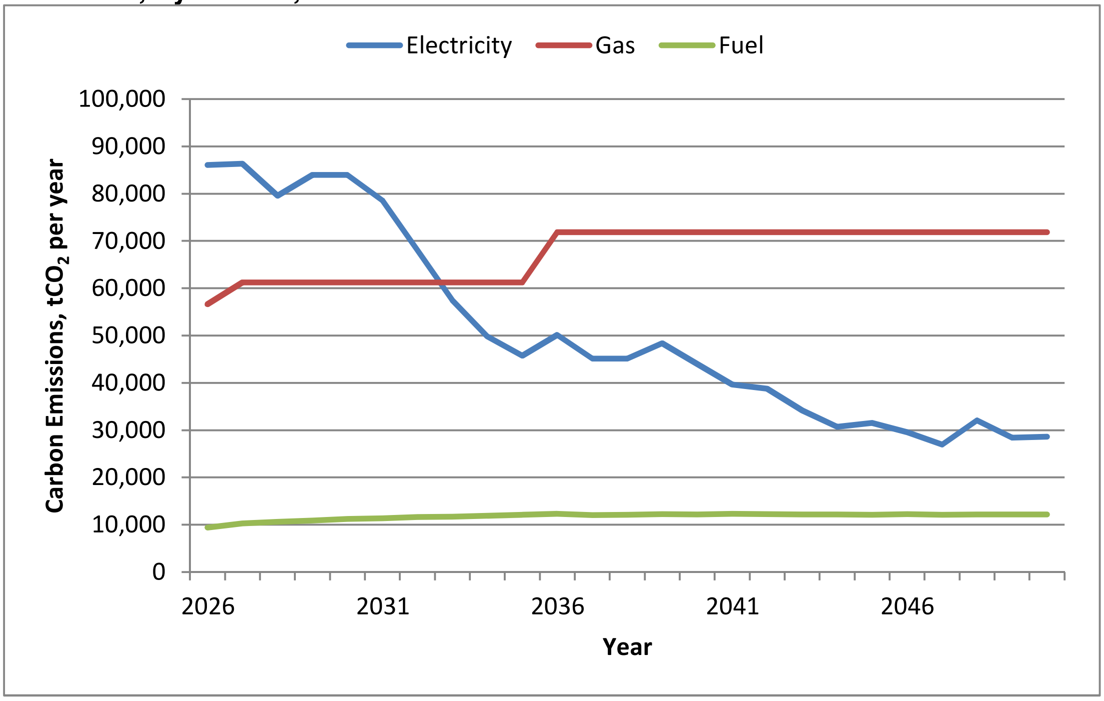
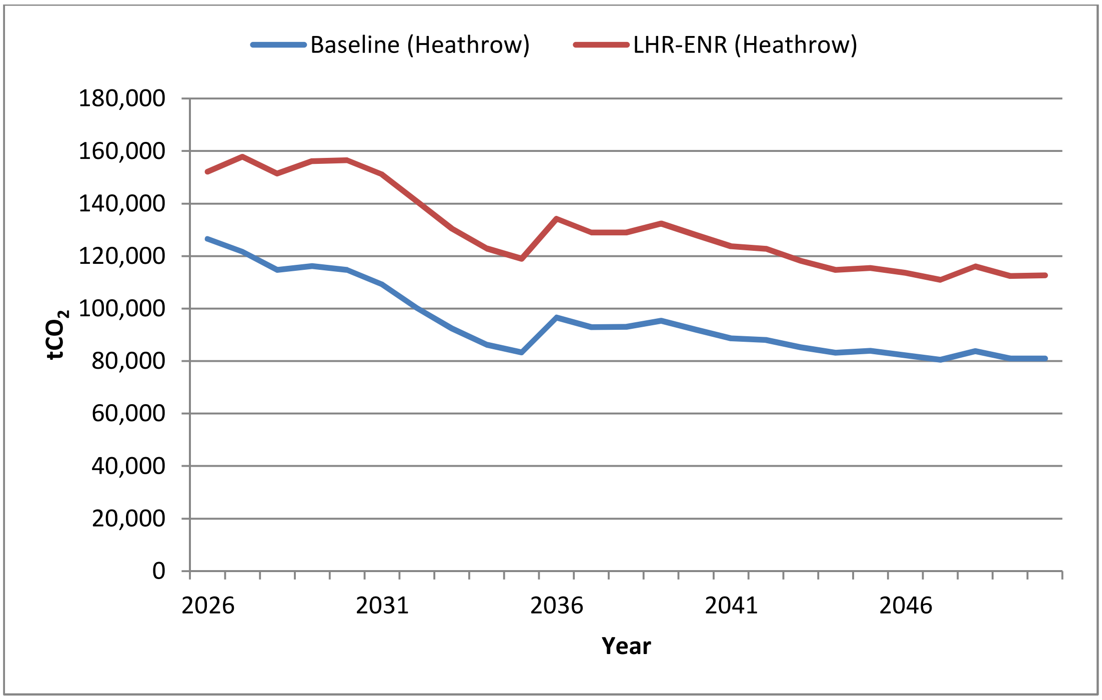


Table 5.9 presents a comparison of the carbon emissions over time for the baseline and Heathrow-ENR scenarios. It can be seen that in the Heathrow-ENR scenario, the emissions associated with airport energy use fall far slowly than in the baseline, being between 20% and 40% greater than the baseline over the course of 2026-2050. The significant increase in terminal area, in this model, leads to an increase in gas fuel usage, with emissions from this source increasing commensurately with terminal space. The large amounts of additional emissions due to gas use offset the decarbonisation of grid electricity.

Table 5.9 - Operational emissions due to energy and fuel use at Heathrow, 2026 – 2050 for Heathrow ENR forecast scenario

Year	Baseline, tonnes CO_2	Heathrow ENR, tonnes CO_2	% Change
2026	130,036	152,086	20.2%
2030	125,336	156,460	36.3%
2040	91,962	127,989	39.2%
2050	81,007	112,662	39.1%

Figure 5.9 - Operational emissions due to energy and fuel use at Heathrow 2026 – 2050 for Heathrow ENR



It should be noted that in the Heathrow-ENR proposal it is not just operational emissions at Heathrow which are expected to change, as additional capacity at Heathrow will cause demand to shift from other airports.

Mitigation

There are several avenues for development in terms of reducing the carbon emissions associated with operation, both of the existing facilities and any new construction.

Any new construction should make use of the latest developments in energy efficiency, allowing for a reduction in electricity use and required heating. As an example of these principles, Stockholm-Arlanda airport, having set a target of zero CO_2 emissions from its own operations by 2020, is involved in the following carbon mitigation strategies:

- Utilisation of renewable fuels, such as biogas, to power the ground vehicle fleet;
- New buildings that are constructed are built to a recognised environmental standard;
- A carbon emission inventory is regularly produced, and augmented, in order to target outstanding emissions sources;
- The use of biomass boilers, to replace fuel burning heat sources; and
- LED light sources, both in terminals and facilities, but also for aircraft parking stands and other areas with lighting requirements.

Other potential mitigating methods include the use of electric vehicles in addition to alternative fuel vehicles, the utilisation of local renewable generation where safe and feasible, and the utilisation of “loop-closing” technology, such as energy-from-waste.

It is noted from Heathrow's published sustainability documentation, that commitments and actions broadly in line with those identified from Arlanda are already part of the airport's approach to sustainability.

5.5 Construction of new facilities and infrastructure

Impact Assessment

Table 5.10 presents a comparison of the carbon emissions over time for the baseline and Heathrow-ENR forecast scenarios. It can be seen that, due to the carbon intensity that has been assumed for airports, in particular the construction of airport terminal buildings, embodied carbon due to airport infrastructure makes up approximately 80% of the measured carbon footprint. While the proportion of emissions attributed to fuel use seems to be low, the magnitude is quite substantial (equivalent to the use of 94 million litres of diesel fuel). In addition, the freighting of material to site will also increase the emissions associated with fuel use, with some indications that these emissions will be approximately equal to the emissions due to construction processes (The Strategic Forum for Construction , 2010). The Phase 1 construction, expected to take place from 2019 to 2025, is included in this assessment, despite lying outside of the assessment period.

Table 5.10 - Carbon due to construction at Heathrow for Heathrow ENR

Year	Baseline emissions, tonnes CO_2	Additional construction emissions, Heathrow ENR, tonnes CO_2
Embodied carbon due to airport infrastructure construction	13,325,975	8,234,415
Embodied carbon due to surface access construction	0	1,645,082
Carbon emissions due to fuel use in construction	188,633	244,766

Mitigation

Mitigation for the emissions associated with construction are wide-ranging, and variously applicable. These include:

- Use of energy efficient site accommodation;
- Increased efficiency in use of construction plant, for example through no-idle policies;
- Construction site connection to grid electricity to avoid use of mobile generation, and smart energy management practices;
- Reduction of waste, and the transport of waste, for example through increasing on-site recycling;
- Select construction material to utilise low carbon options, such as carbon-negative cement; and
- Select construction material to minimise distance of transport, and increase recycling percentages of the material where appropriate.

5.6 Commentary on proposer's submission

5.6.1 Increased airport capacity leading to a net change in air travel

A forecast for 2050 has not been made in the HH report. The report has calculated the CO_2 emissions per ATM for 2030 in the DfT forecast and then adjusted this to the ATM capacity provided by the addition of the third runway (northern runway extension). The report concludes that the third runway will therefore increase carbon emissions by 8.99 $MtCO_2$ on an undeclared baseline. The report also discusses using a 5% and 20% adjustment to take account of "policies and technology" but there is no discussion in the report to say how these percentage reduction have been used.

However, HH has produced a report which includes an assessment of the carbon emissions from flights (Runway Inovations Limited, Produced by URS, 2014). The report states that the baseline used in the calculation of increased carbon emissions due to the resulting increase in capacity of the proposed runway development is based on the DfT Aviation Forecasts 2013. However, the actual figure used for the baseline is not stated in the report i.e. whether the low, central or high forecast has been used. A comparison between the HH and AoN Carbon Capped has therefore not been made.

5.6.2 Airside ground movements

The initial submission by HH provides an estimate of the emissions from airport operations, including both operational emissions from energy and also airside ground movement emissions (Runway Innovations Limited, 2014). They calculated this by using the current reported operational emissions of Heathrow Airport, and factoring this up to the new ATM capacity. In addition, the submission made the assumption that efficiency improvements would reduce these emissions by 5% to 20%.

This was then provided in a format in which the component parts can be analysed separately.

In Table 5.11 the emissions submitted by HH for aircraft movements on the ground are shown.

Table 5.11 - Aircraft emissions submitted by HH

Emission source	Year	Baseline tonnes CO_2	Heathrow ENR tonnes CO_2
Aircraft movements on the ground	2012	585,000	-
	2030	-	683,000 – 854,000

In Table 5.11 it can be seen that HH would seem to predict a higher level of emissions associated with airside ground movements. Their prediction for emissions are at 683,000 – 854,000 tCO_2e in 2030; the estimation made above for the same year is 534,000. In the above analysis, the proportion of taxi-in-taxi-out out of the whole LTO cycle was assumed to be approximately 33% while the HH assessment used data that indicated that the proportion of emissions associated with groundside movements was 45%. This almost fully accounts for the difference in emissions estimates.

5.6.3 Surface access

The initial submission by HH provides an estimate of the emissions due to surface access (Runway Innovations Limited, 2014). They calculated this by using predicted traveller numbers from the surface access paper produced by May Associates in conjunction with emissions factors from Defra, and assumed travel distances for different categories of traveller. In addition, the submission made the assumption that efficiency improvements could reduce these emissions by up to 20%.

This was then provided in a format in which the component parts can be analysed separately (Runway Innovations Limited , 2014b).

In Table 5.12 the emissions submitted by HH for operational emissions sources are shown.

Table 5.12 - Operational emissions submitted by HH

Emission source	Year	Baseline tonnes CO_2	Heathrow ENR tonnes CO_2
Surface access	2012	823,000	-
	2030	-	1,167,000 – 1,253,000

The submission by HH for 2030 predicts emission levels due to surface access of approximately 3 times the levels predicted in the analysis above, using 2008 modal shares. If we consider the 2030 modal share sensitivity, the difference is greater. One reason for why this may be the case is the factors utilised for the emissions calculations. In addition to being from 2012, and so being at a higher rate than the current factors, they are also modelled as being static. In the analysis above, the emissions factor for road travel changes over time due to the DfT's predictions about fuel efficiency and electric vehicle uptake.

5.6.4 Airport operations

The initial submission by HH provides an estimate of the emissions airport operations, including both operation emissions from energy and also airside ground movement emissions (Runway Innovations Limited, 2014). They calculated this by using the current reported operational emissions of Heathrow Airport, and factoring this up to the new ATM capacity. In addition, the submission made the assumption that efficiency improvements would reduce these emissions by 5% to 20%.

This was then provided in a format in which the component parts can be analysed separately (Runway Innovations Limited , 2014b). In Table 5.13 the emissions submitted by HH for operational emissions sources are shown.

Table 5.13 - Operational emissions submitted by HH, tCO_2

Emission source	Year	Baseline	Heathrow ENR
Waste & water	2012	28,000	-
	2030	28,000	41,000
Refrigerants	2012	8,000	-
	2030	8,000	12,000
Other energy	2012	68,000	-
	2030	68,000	99,000
Electricity	2012	211,000	-
	2030	211,000	308,000
BAA Vehicles	2012	8,000	-
	2030	8,000	12,000

Table 5.14 - Operational emissions comparison tCO_2 for Heathrow ENR

Emission source	Year	Proposal	Jacobs Assessment
Other energy (Gas)	2030	99,000	61,252
Electricity	2030	308,000	83,983
BAA Vehicles	2030	12,000	11,226
Total	**2030**	**419,000**	**156,460**

In Table 5.13 it can be seen that HH have estimated waste & water and refrigerant emissions. A comparison is presented in Table 5.14. The “other energy” category, if taken to refer to gas use appears to estimate greater quantities of emissions related to this category than in the analysis above. The electricity category also reports much higher emissions levels in this submission. This is due to the methodology used, which does not take into account the predicted decarbonisation of the grid in any way. The method used for estimating fuel use (BAA vehicles), however, was highly comparable to the method used in the assessment above, and so returns very similar results. The minor differences appear to be due to the predicted level of ATMs in the year 2030, with HH estimating 700,000 ATMs in that year; this assessment used 655,000 ATMs for that year.

5.6.5 Construction of new facilities and infrastructure

HH have made estimations of the potential embodied carbon that will result from the construction of the Heathrow ENR proposal (Runway Innovations Limited, 2014). Within this calculation only the runway, including associated infrastructure such as taxiways, and additional major roads are included. Additional calculation is done for the emissions associated with the transport of material for this construction.

The factors used are derived from the following sources:

- Materials (Runways, roads) – SimaPro UK (2013) and University of Bath (2011) Inventory of Carbon and Energy (ICE).
- Material transport – DECC / Defra Greenhouse Gas Conversion Factor Repository

In terms of particular factors, the types of embodied carbon factors utilised in the assessment above, which are based on tCO_2 / £100 k spend, preclude direct comparison.

The overall totals can be seen in Table 5.15. The main differences appear to result from the calculation done for terminal construction by HH. Under HH submission, the terminals, and their associated infrastructure, are not included in the 381,000 to 484,000 tCO_2 total. In the assessment above, however, the terminal construction is thought to make up a large proportion of the 10.1 $MtCO_2$ total. If we limit the scope to just runways, highways, taxiways and stands, the assessment above returns a result of approximately 756,000 tCO_2 including associated plant fuel emissions, or 715,000 tCO_2 in just embodied carbon.

Table 5.15 - Carbon due to construction at Heathrow, tCO_2e for Heathrow ENR

Year	Heathrow ENR submitted by HH	Heathrow ENR calculated by Airports Commission
Embodied Carbon	270,000 – 374,000	10,548,098
Carbon emissions due to fuel use in construction	-	182,698
Carbon emissions due material transport	110,000	-

5.7 Conclusions

Analysis of the Heathrow Extended Northern Runway carbon emissions is based on the Extended Northwest runway masterplan submitted by HH, and the AoN Carbon Capped passenger and ATM forecasts developed by the Airports Commission. This sees ATMs grow from around the 480,000 level in 2026, to 710,000 in 2040, which then stays broadly fixed through to 2050 with some annual variance. The operational cap of 700,000 is not adhered to in the AoN forecast, so ATMs and emissions reflect demand directly within the confines of the UK aviation system cap of 37.5Mt CO_2. There would be significant construction of infrastructure during the early years of the scheme, with new runway and new terminal and surface access infrastructure dominating.

The most significant volume of emissions are related to air travel, but these initially increase in line with ATMs but then decrease over the period, linked to capacity being reached in 2040 and then reflecting continued changes to the Heathrow fleet and improved fuel efficiency of aircraft present within that fleet. Surface access emissions remain the second largest source of CO_2 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 initially increase with new infrastructure but reduce over time, most significantly due to the presumed decarbonisation of grid electricity.

Table 5.16 - Carbon assessment findings for Heathrow ENR: change in tCO_2

Area of Emissions	2030	2040	2050	Additional tCO_2 to baseline over 60 year appraisal period	Total tCO_2 over 60 year appraisal period
Air travel	3,243,282	4,166,682	3,337,514	210,414,493	1,287,128,426
Ground movements component	139,761	184,137	196,357	11,186,687	34,982,369
Passenger surface access journeys	63,734	83,823	87,033	4,893,316	31,942,485
Airport operations energy & fuel use	38,777	32,171	27,543	1,784,204	7,073,214
Total operational CO_2 emissions	**3,345,793**	**4,282,676**	**3,452,090**	**217,092,013**	**1,326,144,125**
Construction of airport facilities & SA infrastructure*	n/a	n/a	n/a	10,124,262	23,638,870

* Construction emissions are calculated as tCO_2e.

In terms of net change from baseline predicted levels, the emissions due to air travel are the largest proportion of the carbon emissions, both in terms of change and total emissions. Looking at the proportional change, the emissions area that will change the most is that of construction, increasing by 75% from the estimated baseline value.

5.8 Heathrow ENR Carbon Assessment Monetisation

In Table 5.17 and Table 5.18, the carbon results are displayed in a monetised format. This has been done for both the Net Present Value (NPV) of the additional carbon emissions enabled by the scheme, and also for particular assessment years in terms of £2014.

The key difference when reviewing these monetised results in contrast to the tCO_2 results is the impact that emission timing has on the value. For example, the emissions due to construction are approximately three times the emissions due to energy and fuel use however they are only double the value. This is because the construction emissions occur early in the assessment, while the energy emissions are spread through the full assessment period.

Table 5.17 - Heathrow Airport additional central carbon value (NPV) for the Heathrow ENR forecast scenario

	Monetised value of carbon emissions
Total Additional Value (£)	£13,646,800,000
Snapshot 2030 (£)	£152,004,773
Snapshot 2040 (£)	£262,252,463
Snapshot 2050 (£)	£264,296,671
Snapshot 2060 (£)	£261,655,558

Table 5.18 - Additional and total central carbon value, (NPV) for emission sources for the Heathrow ENR scenario

Area of Emissions	Additional £ over 60 year appraisal period	Total £ over 60 year appraisal period
Air travel	£13,002,339,352	£78,188,368,446
Ground movements component	£697,721,748	£2,152,902,636
Passenger surface access journeys	£306,507,064	£1,978,178,243
Airport operations energy & fuel use	£108,389,626	£428,488,069
Total operational CO_2 emissions	**£13,417,236,042**	£80,595,034,758
Construction of airport facilities & SA infrastructure*	£229,550,861	£851,697,173

In Table 5.19 and Table 5.20, the carbon results are displayed as the range from the low to high assumptions on carbon value. This has been done for both the Net Present Value (NPV) of the additional carbon emissions enabled by the scheme, and also for particular assessment years in terms of £ in 2014.

Table 5.19 - Additional Low to High carbon value, (NPV) for Heathrow ENR forecast scenario

	Monetised value of carbon emissions
Total Additional Value (£million)	£6,158,700,000 - £21,307,500,000
Snapshot 2030 (£)	£76,002,386 - £228,007,159
Snapshot 2040 (£)	£131,126,231 - £393,378,694
Snapshot 2050 (£)	£132,148,336 - £396,445,007
Snapshot 2060 (£)	£117,745,001 - £405,566,116

Table 5.20 - Additional Low to High carbon value (NPV) for emission sources for Heathrow ENR forecast scenario

	Monetised value of carbon emissions, additional value
Increased airport capacity - net change in air travel	£5,870,484,815 - £20,172,838,557
Airside ground movements	£311,819,457 - £1,085,205,746
Passenger surface access journeys	£136,860,363 - £476,583,730
Airport operations	£48,967,327 - £168,376,656
Construction of new facilities and infrastructure	£102,394,006 - £489,741,310

Glossary

AC	Airports Commission
ASAS	Airport Surface Access Strategy
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 per year
Carbon dioxide	A naturally occurring gas, and also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is 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
Collaborative Decision Making	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.
Carbon traded	The demand modelling scenario that presumes that air travel will fall within the European Union's Emissions Trading Scheme.
DEFRA	Department for Environment Food and Rural Affairs
DfT	Department for Transport
Embodied carbon	A development of the concept of embodied energy, embodied carbon represents the carbon emissions associated with the resource extraction, processing and delivery of physical products.
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 CO_2 - (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.
HAL	Heathrow Airport Limited
HH	Heathrow Hub
GAL	Gatwick Airport Limited
LCY	London City Airport
LGW	Gatwick Airport
LHR	Heathrow Airport
LTN	Luton Airport
NATS	The provider of air traffic control services at Gatwick
NO_2	Nitrogen Dioxide
NO_x	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
tCO_2	Tonnes of carbon dioxide
tCO_2e	Tonnes of carbon dioxide equivalent
TIM	Time in mode, the time in seconds spent in the different aircraft modes of approach, taxi, take-off and climb. Some alternative measurements of mode exist, but can also be placed into these broader groups.

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Appendix A Carbon assessment background

Background

This report has been prepared to provide evidence to support the Airports Commission's Appraisal Framework Module 8: Carbon. The objective under of this module is to minimise the carbon emissions associated with construction and with the day-to-day 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 (Gatwick 2R) promoted by Gatwick Airport Limited (GAL)
- Heathrow Airport Northwest Runway (Heathrow NWR) promoted by Heathrow Airport Limited (HAL)
- Heathrow Airport Extended Northern Runway (Heathrow ENR) promoted by Heathrow Hub (HH)

In establishing the baseline for a 60 year appraisal, the do minimum has a base date of 2025 (Gatwick 2R) and 2026 (both Heathrow schemes) in line with assumed opening dates of 'do something' development, and respective end dates 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, 2013c), 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 [19].

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 (Department for Transport, 2011b) and the European Commission (European Commission, 2011), the Committee on Climate Change (Committee on Climate Change, 2013), the

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

aviation industry (e.g. Sustainable Aviation, ACI and IATA (International Air Transport Association (IATA), 2014)) and environmental NGOs (Airportwatch, n.d.).

The future emissions from air travel are highly uncertain, however there are several sources that offer commentary. The Sustainable Aviation CO_2 Road Map[20] identifies a number of proven and planned technical and operational improvements that lead to incremental reductions in per passenger and per ATM carbon emissions. These include biofuel development, engine technology, airframe material and design optimisation, ground movement changes and airspace design. In addition the Road Map comments on a number of options with potential for greater savings, but that face a number of issues in realisation.

These include open rotor engine technology[21] (compared to today's turbo-fans in which the engine blades are contained within a nacelle), which although promising fuel efficiency gains (up to 30% per mission fuel burn - at the expense of only marginally increased journey times), faces challenges around noise, safety certification, accessibility and maintenance. However the Open Rotor concept is considered achievable as a development of next generation aircraft within the time period of assessment. More radical design issues developed by the major manufacturers such as Boeing and Airbus include blended wing bodies (where cabin space is integrated with a 'wing' lift surface) promise further fuel savings (up to 40% based on computer models[22]) but will need additional attention to be paid to airport design, and will present radically different cabin designs for the traveller, so are likely to take longer to be reflected in airline fleets. "Imminent" aircraft are those such as the Boeing 787 Dreamliner and 787-800 and Airbus 350 and 380. The subsequent aircraft "future" generation will build on the learning from airframe and engine design and materials innovations.

Full details of assumptions are found within the SA CO2 Road Map. The basic assumptions included are displayed in Tables A1, A2 and A3:

Table A1: Impact of measures to improve carbon efficiency of UK aviation, by 2030 and 2050

<table>
<tr><th colspan="2" rowspan="3">Measure</th><th colspan="4">Fleet Carbon Efficiency Benefit (%)</th></tr>
<tr><th colspan="2">2030</th><th colspan="2">2050</th></tr>
<tr><th>Potential</th><th>Assumed</th><th>Potential</th><th>Assumed</th></tr>
<tr><td colspan="2">ATM and Operations</td><td>7</td><td>4.5</td><td>13.5</td><td>9</td></tr>
<tr><td rowspan="2">Engine and Airframe</td><td>"Imminent" aircraft</td><td colspan="2">13</td><td colspan="2">17</td></tr>
<tr><td>"Future" aircraft</td><td colspan="2">1.5</td><td colspan="2">26</td></tr>
<tr><td colspan="2">Sustainable Fuels</td><td>10.5</td><td>7.5</td><td>24</td><td>18</td></tr>
<tr><td colspan="2">Total</td><td>28.5</td><td>24.5</td><td>59.5</td><td>54</td></tr>
</table>

[20] Sustainable Aviation, 2012, CO_2 Road Map, 2012
[21] Society of British Aerospace Companies, n.d., SBAC Aviation and Environment Briefing Papers: 3: Open Rotor Engines, http://www.sustainableaviation.co.uk/wp-content/uploads/open-rotor-engine-briefing-paper.pdf
[22] D'souza, Shilpa Isabella; An Analysis of the Developments in Blended Wing Body Aircraft for Sustainable Aviation https://essaylulu.s3.amazonaws.com/e6/ca7630272c11e4aecf575a442f9cfb/Final_Report.pdf

Table A2: Assumed fuel efficiency improvement of "imminent" (G1) aircraft types relative to their respective predecessors

Category	Single-Aisle	Twin-Aisle	Very-Large
Entry into service of aircraft type	2015	2011	2007
Fuel efficiency improvement relative to predecessor aircraft types	13%	20%	17%

Table A3: Assumed fuel efficiency improvement of "future" (G2) aircraft types relative to their respective predecessors

Category	Single-Aisle	Twin-Aisle	Very-Large
Entry into service of aircraft type	2025	2035	2040
Fuel efficiency improvement relative to equivalent G1 aircraft type	25%	38%	45%

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 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-CO_2 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 (The 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) (Airports Council International, 2009a) Europe, and through the ACI the Airports Carbon Accreditation Scheme (ACAS) (Airports Council International, 2009a). More detail can be found in Appendix A. 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 [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.

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 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 [23]:

- 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 $MtCO_2$). 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).

[23] Committee on Climate Change, 2013, Factsheet: Aviation http://www.theccc.org.uk/wp-content/uploads/2013/04/Aviation-factsheet.pdf

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 Airport 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 Methodology

Carbon dioxide (CO_2) emissions (often referred to as just carbon) from anthropogenic sources are contributing 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 carbon dioxide (CO_2) emissions considered in this 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 (Department for Transport, 2011a) and the DfT Aviation Forecast 2013 (Department for Transport, 2013c) and surface access as described in the DfT Aviation Forecast 2009 (Department for Transport, 2009) (with some adjustments to take account of indicated 2030 mode share). 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. 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 'with scheme' 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 (2013), Archetype resource benchmarks for construction projects tool (WRAP, 2013), for embodied carbon emissions.

Increased airport capacity leading to a net change in air travel

The UK National Atmospheric Emissions Inventory (NAEI) (NAEI, n.d.) provides annual carbon emissions for UK airports based on 'bunker' fuel sales i.e. jet fuel sold to aircraft operators. 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 and recently in 2011 (Department for Transport, 2011a) and 2013 (Department for Transport, 2013a).

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[24] scenarios. The AoN Carbon Capped, which uses DfT modelling, has been used because:

[24] For more detail, see report 8.Carbon: Baseline

- 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 has produced and which 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 Airports Commission Demand Forecast 2014 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;
- 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 B1 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 B1 presents the assumptions used for the central demand growth scenario.

Figure B1: UK aviation forecasting framework. Department for Transport, UK Aviation Forecasts 2011, August 2011, Figure 2.2 (Department for Transport, 2011a)

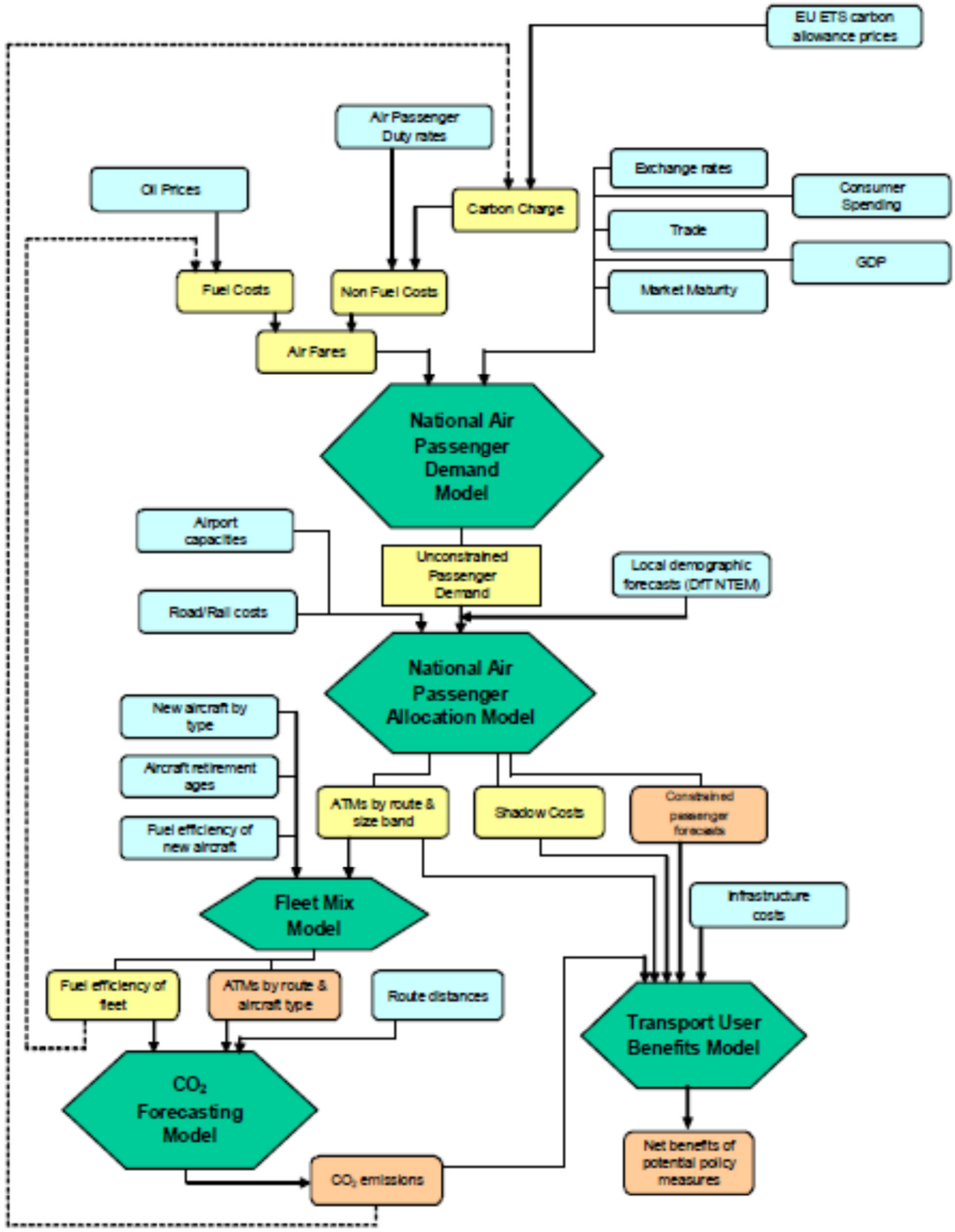

Table B1: Department for Transport, UK Aviation Forecasts 2013, January 2013, Table 3.12: CO_2 emissions variable range assumptions, Central: central demand growth +. (Department for Transport, 2013c)

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 B2 presents the assumptions made in the AoN Carbon Capped for the ATM capacity of new runways at Gatwick and Heathrow.

Table B2: Airports Commission: Appraisal Framework, April 2014 (Airports Commission, 2014)

Proposer	Descriptor	Assumption	Scenario reference
Gatwick Airport Limited	Gatwick Second Runway	Additional runway capacity of 260,000 ATMs is provided in 2025 (540,000 ATMs in total)	s06
Heathrow Airport Limited	Heathrow North West Runway	Additional runway capacity of 260,000 ATMs is provided in 2026 (740,000 ATMs in total)	s05
Heathrow Hub Ltd	Heathrow Extended Northern Runway	Additional runway capacity of 220,000 ATMs is provided in 2026 (700,000 ATMs in total)	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 (Department for Transport, 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[25]. 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[26]. The non-CO_2 effects of aircraft at high altitude are not included in the AoN Carbon Capped or in t
his assessment.

The assessment described in the assessment 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 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 historic reported emissions associated with Landing and Take-Off (LTO) from both Gatwick (Gatwick Airport Limited, 2014a) and Heathrow (Heathrow Airport Limited, 2014) and reported ATMs in those years in order to create a factor representing LTO emissions per 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 forecast (International Civil Aviation Organisation, 2011). 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.

The proportion of this LTO which can be attributed to ground movements must then be determined. Information from the International Civil Aviation Organization (ICAO) (International Civil Aviation Organisation, 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

[25] Lee et al (2010), ‘Transport impacts on atmosphere and climate: aviation’, *Atmospheric Environment*, 44, pp. 4678-4734.
[26] Airports Commission Discussion Paper 03: Aviation and Climate Change, April 2013.

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[27] 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 emissions per ATM are then multiplied by the ATMs per year as forecast for that proposal by 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, 2009). 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 [28].

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

[27] Heathrow Airport Response to the Airports Commission, Information Request 018 – Time in Mode data
[28] Guidance to the CAA on Environmental Objectives Relating to the Exercise of its Air Navigation Functions https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/269527/air-navigation-guidance.pdf

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 (Department for Transport, 2009)

The model makes use of forecasts of demand for travel to each of the UK's airports, from UK origin / destinations on a regional basis, and by using a 2008 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). 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[29] and HAL[30] 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.

[29] Gatwick Airports Limited, 2014, A Second Runway for Gatwick: Appendix: A32 Energy
[30] Heathrow Airport Limited, 2013, Responsible Heathrow 2013: 2013 Sustainability Performance Summary

Airports Council International (ACI) (Airports Council International, 2012) identifies a key environmental indicator of energy performance per m^2 of Terminal, and the related Airports Carbon Accreditation Scheme (Airports Council International, 2009a) 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 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 (DECC IAG, 2014a). 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 scheme promoters' 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 qualitatively 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[31], and/or the Defra Greenhouse Gas Conversion Factor Repository [32], or a bespoke tool that utilises these sources such as the Environment Agency Construction Carbon Calculator. 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 (WRAP, 2013) "Resource efficiency benchmarks for construction projects" 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

[31] University of Bath, 2011, Inventory of Carbon and Energy (ICE) v2.0
[32] Defra (2014), Defra Greenhouse Gas Conversion Factor Repository

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.

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, 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 B3.

Table B3: 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 proposals' construction, an estimate was made utilising the Gatwick 2R, Heathrow-NWR and Heathrow-ENR master plans (Jacobs UK Ltd, 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, n.d.).

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 IAG, 2014b) (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;
- Assumptions of the level of fuel burn by different aircraft types, derived from an adjusted "CORINAIR Emission Inventory Guidebook [33],[34];

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

[33] European Environment Agency, 2013, EMEP/EEA air pollutant emission inventory guidebook 2013; European Environment Agency, 2009, EMEP/EEA air pollutant emission inventory guidebook 2009

[34] see Aviation Forecast 2011 for further information'.

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 (Department for Transport, 2011a).

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, 2009). 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 (Department for Transport, 2014a). Further assessment of carbon emissions impacts of departure and arrival routes must be undertaken when sufficient information is available.

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 Simple Approach to calculation and a presumed ground movement factor derived from published information on LTO cycle at Gatwick and Heathrow Airport. 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 Airport 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.

Passenger surface access journeys
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 Jacobs 2014 Surface Access analyses, (Jacobs, 2014a, b and c). The assumptions made in the 2014 surface access analysis are presented within the relevant report. 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.

Airport operational emissions
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.

The relationships used are:

- 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 (the HH submission used emissions as reported by HAL), 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.

Emissions due to construction of airport facilities and SA infrastructure

The activity data for construction cost, phasing and footprints were taken from the Revenue and Cost Identification report[35].

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, 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. 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, as described in the methodology.

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 would require different carbon prices in order to deliver a similar net impact across a wider carbon market.

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.

[35] Jacobs 2014, Revenue and Cost Identification

In order to not introduce cumulative rounding errors, all factors and calculated results have been used at their original level of precision. In order to aid the reader in following the derivation of the results, the emissions levels and value of emissions are currently presented at the nearest whole unit. This should not be taken as overconfidence in the results, and should be treated accordingly.

Appendix C Full Tables

Gatwick Airport Second Runway Carbon Impact Assessment

Table C.1 - Carbon emissions, carbon capped;, Gatwick 2R, for 2025 – 2050

Year	Gatwick Airport, Number of passengers	Gatwick Airport, Numbers of ATMs	Gatwick Airport, tonnes CO_2	UK Aviation Total, tonnes CO_2	Gatwick as % of UK Total for aviation carbon emissions
2025	40,487,944	288,285	4,425,878	38,908,184	11.4
2026	41,600,196	296,576	4,313,705	38,861,597	11.1
2027	42,714,632	303,253	4,312,855	38,937,631	11.1
2028	44,207,964	311,690	4,302,311	39,108,475	11.0
2029	44,637,264	313,789	4,207,616	39,171,335	10.7
2030	45,599,168	318,909	4,218,239	39,232,048	10.8
2031	46,623,768	324,501	4,249,859	39,119,531	10.9
2032	47,414,008	328,378	4,279,155	39,248,101	10.9
2033	48,074,468	332,058	4,312,821	39,459,297	10.9
2034	49,104,848	337,422	4,390,403	40,047,822	11.0
2035	50,117,856	344,119	4,419,580	40,175,420	11.0
2036	51,112,920	350,099	4,454,774	40,018,604	11.1
2037	51,972,636	355,944	4,495,337	39,820,195	11.3
2038	53,016,524	362,267	4,535,191	39,894,154	11.4
2039	54,307,032	371,508	4,579,661	39,703,263	11.5
2040	55,606,912	379,752	4,689,706	39,699,139	11.8
2041	57,112,960	391,636	4,809,893	39,702,448	12.1
2042	57,540,932	394,592	4,790,186	39,692,073	12.1
2043	59,141,020	406,346	4,879,624	39,671,769	12.3
2044	59,997,152	410,861	4,901,632	39,484,571	12.4
2045	61,927,292	424,841	4,986,173	38,950,668	12.8
2046	62,805,216	430,681	4,998,624	38,459,014	13.0
2047	64,730,820	444,418	5,088,222	38,299,576	13.3
2048	66,824,964	459,406	5,185,654	37,721,443	13.7
2049	68,820,656	473,224	5,303,109	37,515,549	14.1
2050	69,414,512	475,932	5,337,549	37,538,815	14.2

Table C.3 - Comparison of the aircraft ground movement emissions 2025 – 2050 for the Gatwick Airport baseline and Gatwick 2R forecast scenarios

Year	Baseline, tCO_2	Gatwick 2R, tCO_2, ICAO-Times	Gatwick 2R, tCO_2, GAL-Reported Times
2025	134,085	139,696	133,949
2026	138,039	143,713	137,801
2027	134,935	146,949	140,903
2028	133,820	151,037	144,824
2029	139,482	152,054	145,799
2030	134,673	154,535	148,178
2031	137,595	157,245	150,776
2032	134,942	159,124	152,577
2033	134,704	160,907	154,287
2034	136,681	163,506	156,780
2035	136,191	166,752	159,891
2036	135,336	169,649	162,670
2037	137,837	172,482	165,386
2038	136,488	175,546	168,324
2039	135,009	180,024	172,617
2040	135,988	184,019	176,448
2041	136,309	189,777	181,970
2042	136,723	191,210	183,343
2043	135,845	196,905	188,804
2044	136,759	199,093	190,902
2045	137,878	205,868	197,398
2046	134,838	208,697	200,111
2047	135,332	215,354	206,494
2048	137,882	222,617	213,458
2049	138,570	229,313	219,879
2050	138,308	230,625	221,137

Table C.4 - Emissions due to surface access for 2025 – 2050 for baseline and Gatwick 2R forecast scenarios

Year	Baseline emissions due to surface access to Gatwick Airport, tonnes CO_2	Gatwick 2R emissions due to surface access to Gatwick Airport, tonnes CO_2	Change from baseline (%)
2025	303,600	311,909	2.7%
2026	300,652	313,056	4.1%
2027	297,705	314,204	5.5%
2028	294,758	315,351	7.0%
2029	291,811	316,498	8.5%
2030	288,863	317,645	10.0%
2031	289,751	321,443	10.9%
2032	290,639	325,242	11.9%
2033	291,527	329,040	12.9%
2034	292,415	332,838	13.8%
2035	293,302	336,636	14.8%
2036	294,103	343,065	16.6%
2037	294,904	349,494	18.5%
2038	295,705	355,923	20.4%
2039	296,506	362,352	22.2%
2040	297,307	368,781	24.0%
2041	298,214	375,827	26.0%
2042	299,120	382,874	28.0%
2043	300,027	389,920	30.0%
2044	300,934	396,966	31.9%
2045	301,840	404,013	33.8%
2046	303,178	412,820	36.2%
2047	304,516	421,627	38.5%
2048	305,854	430,434	40.7%
2049	307,192	439,241	43.0%
2050	308,530	448,049	45.2%

Table C.5 - The emissions due to surface access across the UK airport system, 2025 – 2050 for baseline and Gatwick 2R forecast scenarios

Year	Baseline emissions due to surface access to UK airports[36], tonnes CO_2	Emissions due to surface access to UK airports[37] with Gatwick 2R, tonnes CO_2	% change
2025	1,813,730	1,807,792	-0.3%
2026	1,811,056	1,804,564	-0.4%
2027	1,808,382	1,801,337	-0.4%
2028	1,805,708	1,798,109	-0.4%
2029	1,803,035	1,794,882	-0.5%
2030	1,800,361	1,791,654	-0.5%
2031	1,814,236	1,805,577	-0.5%
2032	1,828,111	1,819,500	-0.5%
2033	1,841,987	1,833,422	-0.5%
2034	1,855,862	1,847,345	-0.5%
2035	1,869,737	1,861,267	-0.5%
2036	1,896,420	1,888,836	-0.4%
2037	1,923,103	1,916,405	-0.3%
2038	1,949,785	1,943,975	-0.3%
2039	1,976,468	1,971,544	-0.2%
2040	2,003,151	1,999,113	-0.2%
2041	2,029,207	2,022,428	-0.3%
2042	2,055,263	2,045,744	-0.5%
2043	2,081,319	2,069,059	-0.6%
2044	2,107,375	2,092,375	-0.7%
2045	2,133,431	2,115,691	-0.8%
2046	2,171,683	2,148,277	-1.1%
2047	2,209,935	2,180,864	-1.3%
2048	2,248,187	2,213,450	-1.5%
2049	2,286,440	2,246,036	-1.8%
2050	2,324,692	2,278,623	-2.0%

[36] The airport set previously described.
[37] The airport set previously described.

Table C.7 – Emissions from Surface Access with 2030 Modal split for 2025 – 2050 for baseline and Gatwick 2R forecast scenarios

Year	Baseline emissions due to surface access to Gatwick Airport, tonnes CO_2	Gatwick 2R emissions due to surface access to Gatwick Airport, tonnes CO_2
2025	256,474	263,527
2026	254,678	265,232
2027	252,881	266,937
2028	251,084	268,642
2029	249,287	270,347
2030	247,490	272,052
2031	248,466	275,639
2032	249,441	279,227
2033	250,416	282,815
2034	251,392	286,402
2035	252,367	289,990
2036	252,956	295,467
2037	253,545	300,944
2038	254,134	306,421
2039	254,723	311,897
2040	255,313	317,374
2041	255,944	323,291
2042	256,575	329,208
2043	257,206	335,125
2044	257,838	341,042
2045	258,469	346,959
2046	259,578	354,425
2047	260,686	361,892
2048	261,795	369,359
2049	262,904	376,826
2050	264,012	384,292

Table C.8 - Carbon emissions due to airport operation at Gatwick, by source, 2025 – 2050 for Gatwick 2R forecast scenario

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	Total Emissions due to airport operation at Gatwick Airport, tonnes CO_2
2025	27,578	12,865	6,075	46,518
2026	23,715	12,865	6,250	42,830
2027	22,428	12,865	6,391	41,683
2028	20,547	12,865	6,568	39,979
2029	21,250	19,836	6,613	47,699
2030	21,054	20,286	6,720	48,061
2031	19,819	20,286	6,838	46,943
2032	17,141	20,286	6,920	44,347
2033	14,560	20,286	6,998	41,843
2034	12,618	20,286	7,111	40,015
2035	11,628	20,286	7,252	39,166
2036	12,768	20,286	7,378	40,432
2037	11,725	20,286	7,501	39,512
2038	11,850	20,286	7,634	39,771
2039	12,825	20,286	7,829	40,940
2040	11,955	20,286	8,003	40,244
2041	10,934	20,286	8,253	39,473
2042	10,758	20,286	8,315	39,360
2043	9,813	20,286	8,563	38,662
2044	8,888	23,216	8,658	40,762
2045	9,422	23,216	8,953	41,591
2046	8,851	23,216	9,076	41,143
2047	8,339	23,216	9,365	40,920
2048	10,131	23,216	9,681	43,028
2049	9,253	23,216	9,972	42,441
2050	9,332	23,216	10,029	42,578

Table C.9 - Operational emissions at Gatwick, 2025 – 2050 for Gatwick 2R forecast scenario

Year	Baseline, tonnes CO_2	Gatwick 2R, tonnes CO_2	% Change
2025	44,291	46,518	5.0%
2026	40,634	42,830	5.4%
2027	38,516	41,683	8.2%
2028	36,072	39,979	10.8%
2029	37,415	47,699	27.5%
2030	36,867	48,061	30.4%
2031	35,769	46,943	31.2%
2032	33,066	44,347	34.1%
2033	30,652	41,843	36.5%
2034	29,075	40,015	37.6%
2035	27,983	39,166	40.0%
2036	28,731	40,432	40.7%
2037	28,012	39,512	41.1%
2038	27,776	39,771	43.2%
2039	28,255	40,940	44.9%
2040	27,467	40,244	46.5%
2041	26,509	39,473	48.9%
2042	26,334	39,360	49.5%
2043	25,355	38,662	52.5%
2044	24,665	40,762	65.3%
2045	24,985	41,591	66.5%
2046	24,226	41,143	69.8%
2047	23,749	40,920	72.3%
2048	25,044	43,028	71.8%
2049	24,325	42,441	74.5%
2050	24,320	42,578	75.1%

Heathrow Airport North-West Runway (Heathrow-NWR) Carbon Impact Assessment

Table C.22 - Carbon emissions, carbon capped: Heathrow NWR, for 2026 – 2050

Year	Heathrow Airport, Number of passengers	Heathrow Airport, Numbers of ATMs	Heathrow Airport, tonnes CO_2	UK Aviation Total, tonnes CO_2	Heathrow as % of UK Total for carbon emissions
2026	91,709,424	552,887	21,615,342	38,510,990	56.1
2027	99,592,392	600,944	22,712,322	39,157,835	58.0
2028	103,235,256	621,140	23,034,704	39,421,190	58.4
2029	106,176,480	636,152	23,225,015	39,467,483	58.8
2030	109,264,920	652,216	23,201,508	39,415,806	58.9
2031	110,795,856	659,923	23,261,854	39,418,763	59.0
2032	112,923,952	673,729	23,565,112	39,619,646	59.5
2033	113,680,768	678,215	23,720,686	39,713,216	59.7
2034	116,269,520	691,852	24,055,426	40,181,981	59.9
2035	118,109,352	700,428	24,216,080	40,360,643	60.0
2036	120,132,992	711,133	24,159,047	40,358,076	59.9
2037	121,584,912	717,737	23,882,551	40,067,591	59.6
2038	123,825,512	729,033	23,892,609	40,092,949	59.6
2039	125,812,776	739,711	23,789,070	39,932,251	59.6
2040	127,879,384	750,498	23,760,857	39,962,754	59.5
2041	128,538,368	740,020	23,440,797	39,783,648	58.9
2042	129,771,920	745,099	23,298,957	39,656,943	58.8
2043	131,390,576	752,402	23,078,559	39,554,333	58.3
2044	132,198,208	755,224	22,837,613	39,406,242	58.0
2045	131,529,808	749,124	22,060,505	38,727,517	57.0
2046	133,207,280	755,503	21,914,429	38,622,342	56.7
2047	132,627,360	749,365	21,455,890	38,343,474	56.0
2048	133,711,152	751,498	21,040,463	37,891,897	55.5
2049	133,523,040	746,949	20,586,443	37,575,640	54.8
2050	134,983,696	753,341	20,483,029	37,501,114	54.6

Table C.24 - Comparison of the aircraft ground movement emissions 2026 – 2050 for the Heathrow Airport baseline and Heathrow NWR forecast scenarios

Year	Baseline, tonnes CO_2	Heathrow-NWR, tonnes CO_2, ICAO-Times	Heathrow-NWR, tonnes CO_2, HAL-Reported times
2026	390,677	452,855	358,936
2027	393,943	492,217	390,135
2028	398,981	508,759	403,246
2029	395,633	521,055	412,992
2030	396,313	534,212	423,421
2031	393,608	540,525	428,424
2032	391,449	551,833	437,387
2033	394,180	555,507	440,299
2034	394,120	566,677	449,152
2035	398,223	573,701	454,720
2036	398,324	582,470	461,670
2037	395,122	587,879	465,957
2038	396,846	597,131	473,290
2039	400,428	605,877	480,223
2040	396,855	614,712	487,226
2041	396,783	606,130	480,423
2042	395,674	610,290	483,721
2043	398,041	616,272	488,462
2044	402,804	618,583	490,294
2045	403,111	613,587	486,334
2046	400,652	618,812	490,475
2047	401,558	613,784	486,490
2048	394,845	615,531	487,875
2049	389,532	611,806	484,922
2050	385,891	617,041	489,071

Table C.25 - Emissions due to surface access for 2026 – 2050 for baseline and Heathrow NWR forecast scenarios

Year	Baseline emissions due to surface access to Heathrow Airport, tonnes CO_2	Heathrow-NWR emissions due to surface access to Heathrow Airport, tonnes CO_2	% change
2026	384,112	385,099	0.3%
2027	381,556	398,082	4.3%
2028	379,000	411,066	8.5%
2029	376,444	424,049	12.6%
2030	373,888	437,033	16.9%
2031	376,700	442,677	17.5%
2032	379,511	448,322	18.1%
2033	382,323	453,967	18.7%
2034	385,134	459,612	19.3%
2035	387,946	465,256	19.9%
2036	393,072	474,159	20.6%
2037	398,197	483,061	21.3%
2038	403,323	491,963	22.0%
2039	408,449	500,865	22.6%
2040	413,575	509,768	23.3%
2041	420,039	515,794	22.8%
2042	426,503	521,820	22.3%
2043	432,967	527,846	21.9%
2044	439,431	533,873	21.5%
2045	445,895	539,899	21.1%
2046	450,529	546,485	21.3%
2047	455,163	553,071	21.5%
2048	459,798	559,658	21.7%
2049	464,432	566,244	21.9%
2050	469,066	572,830	22.1%

Table C.26 - The emissions due to surface access across the UK airport system, 2026 – 2050 for baseline and Heathrow NWR forecast scenarios

Year	Baseline emissions due to surface access to UK airports[38], tonnes CO_2	Emissions due to surface access to UK airports with Heathrow-NWR[39], tonnes CO_2	% change
2026	1,868,923	1,721,810	-3.4%
2027	1,851,783	1,709,153	-2.7%
2028	1,834,642	1,696,497	-2.0%
2029	1,817,501	1,683,840	-1.2%
2030	1,800,361	1,671,184	-0.5%
2031	1,814,236	1,679,417	-0.5%
2032	1,828,111	1,687,650	-0.5%
2033	1,841,987	1,695,883	-0.5%
2034	1,855,862	1,704,116	-0.5%
2035	1,869,737	1,712,349	-0.5%
2036	1,896,420	1,733,299	-0.4%
2037	1,923,103	1,754,250	-0.3%
2038	1,949,785	1,775,200	-0.3%
2039	1,976,468	1,796,151	-0.2%
2040	2,003,151	1,817,101	-0.2%
2041	2,029,207	1,834,682	-0.3%
2042	2,055,263	1,852,262	-0.5%
2043	2,081,319	1,869,842	-0.6%
2044	2,107,375	1,887,422	-0.7%
2045	2,133,431	1,905,002	-0.8%
2046	2,171,683	1,931,101	-1.1%
2047	2,209,935	1,957,199	-1.3%
2048	2,248,187	1,983,298	-1.5%
2049	2,286,440	2,009,397	-1.8%
2050	2,324,692	2,035,495	-2.0%

[38] The previously referenced set.
[39] The previously referenced set.

Table C.28 - Emissions due to surface access at Heathrow, for 2026 – 2050 for baseline and Heathrow NWR forecast scenarios

Year	Baseline emissions due to surface access to Heathrow Airport, tonnes CO_2	Heathrow-NWR emissions due to surface access to Heathrow Airport, tonnes CO_2
2026	316,763	327,027
2027	317,981	339,111
2028	319,199	351,195
2029	320,417	363,279
2030	321,635	375,363
2031	324,479	380,694
2032	327,323	386,026
2033	330,167	391,357
2034	333,012	396,688
2035	335,856	402,020
2036	340,338	409,788
2037	344,820	417,556
2038	349,303	425,325
2039	353,785	433,093
2040	358,267	440,861
2041	363,884	446,061
2042	369,500	451,261
2043	375,117	456,461
2044	380,734	461,661
2045	386,350	466,860
2046	390,393	472,673
2047	394,435	478,485
2048	398,477	484,297
2049	402,519	490,110
2050	406,562	495,922

Table C.29 - Carbon emissions due to airport operation energy use at Heathrow, by source 2026 – 2050 for Heathrow NWR forecast scenario

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	Total Emissions due to airport operation at Heathrow Airport, tonnes CO_2
2026	101,765	61,717	9,483	157,788
2027	116,276	67,294	10,307	164,207
2028	106,941	67,294	10,654	157,414
2029	94,622	67,294	10,911	161,922
2030	83,418	67,294	11,187	162,035
2031	83,508	67,294	11,319	156,615
2032	75,415	67,294	11,556	146,462
2033	66,158	67,294	11,633	135,947
2034	59,456	67,294	11,867	128,642
2035	53,862	67,294	12,014	124,693
2036	53,876	77,874	12,197	139,773
2037	48,164	77,874	12,310	135,612
2038	46,882	77,874	12,504	136,218
2039	46,504	77,874	12,687	139,770
2040	44,827	77,874	12,872	136,279
2041	40,073	77,874	12,693	131,322
2042	41,186	77,874	12,780	130,838
2043	37,755	77,874	12,905	126,885
2044	32,009	77,874	12,953	123,263
2045	32,034	77,874	12,849	123,867
2046	29,381	77,874	12,958	121,923
2047	26,095	77,874	12,853	119,024
2048	25,978	77,874	12,890	124,337
2049	24,652	77,874	12,812	120,417
2050	24,922	77,874	12,921	120,852

Table C.30 - Operational emissions at Heathrow due to energy and fuel use, 2026 – 2050 for Heathrow NWR forecast scenario

Year	Baseline, tonnes CO_2	Heathrow-NWR, tonnes CO_2	% Change
2026	126,509	157,788	24.7%
2027	121,646	164,207	35.0%
2028	114,677	157,414	37.3%
2029	116,185	161,922	39.4%
2030	114,756	162,035	41.2%
2031	109,260	156,615	43.3%
2032	100,269	146,462	46.1%
2033	92,494	135,947	47.0%
2034	86,220	128,642	49.2%
2035	83,258	124,693	49.8%
2036	96,587	139,773	44.7%
2037	92,979	135,612	45.9%
2038	93,067	136,218	46.4%
2039	95,327	139,770	46.6%
2040	91,962	136,279	48.2%
2041	88,621	131,322	48.2%
2042	88,091	130,838	48.5%
2043	85,254	126,885	48.8%
2044	83,154	123,263	48.2%
2045	83,896	123,867	47.6%
2046	82,152	121,923	48.4%
2047	80,520	119,024	47.8%
2048	83,825	124,337	48.3%
2049	81,034	120,417	48.6%
2050	81,007	120,852	49.2%

Heathrow Airport Extended Northern Runway (Heathrow-ENR) Carbon Impact Assessment

Table C.44 - Carbon emissions, carbon capped: Heathrow ENR, for 2026 – 2050

Year	Heathrow Airport, Number of passengers	Heathrow Airport, Numbers of ATMs	Heathrow Airport, tonnes CO_2	UK Aviation Total, tonnes CO_2	Heathrow as % of UK Total for carbon emissions
2026	91,138,224	548,179	21,590,858	38,721,210	55.8
2027	99,292,520	597,012	22,740,300	39,431,930	57.7
2028	103,372,696	619,942	23,117,673	39,742,659	58.2
2029	106,500,704	636,362	23,333,670	39,830,443	58.6
2030	109,824,896	654,489	23,343,130	39,816,192	58.6
2031	111,546,008	662,814	23,430,542	39,845,834	58.8
2032	113,682,648	676,173	23,728,099	40,060,465	59.2
2033	114,595,056	681,398	23,901,969	40,187,303	59.5
2034	116,943,032	693,362	24,221,573	40,659,079	59.6
2035	119,001,200	703,632	24,390,899	40,855,383	59.7
2036	121,211,584	715,464	24,377,799	40,874,810	59.6
2037	120,719,368	699,906	23,817,825	40,426,037	58.9
2038	121,874,208	703,644	23,742,930	40,386,605	58.8
2039	123,620,816	712,012	23,591,867	40,231,265	58.6
2040	123,550,160	709,329	23,350,987	40,128,502	58.2
2041	125,088,736	716,680	23,143,986	40,093,782	57.7
2042	125,109,352	714,618	22,911,583	39,882,923	57.4
2043	124,330,512	707,649	22,389,746	39,591,686	56.6
2044	125,143,104	709,134	21,995,098	39,286,381	56.0
2045	125,210,776	707,244	21,302,386	38,681,988	55.1
2046	126,685,592	712,653	21,057,513	38,469,204	54.7
2047	126,299,248	706,871	20,851,088	38,408,833	54.3
2048	127,701,800	711,275	20,491,326	37,987,399	53.9
2049	127,545,992	707,952	20,017,728	37,659,403	53.2
2050	128,614,152	710,863	19,907,914	37,518,909	53.1

Table C.46 - Comparison of the aircraft ground movement emissions 2026 – 2050 for the Heathrow Airport baseline and Heathrow ENR forecast scenarios

Year	Baseline, tonnes CO_2	Heathrow-ENR, tonnes CO_2, ICAO-Times	Heathrow-ENR, tonnes CO_2, HAL-Reported times
2026	390,677	448,998	355,879
2027	393,943	488,996	387,582
2028	398,981	507,778	402,468
2029	395,633	521,227	413,128
2030	396,313	536,074	424,896
2031	393,608	542,893	430,301
2032	391,449	553,835	438,974
2033	394,180	558,114	442,366
2034	394,120	567,914	450,133
2035	398,223	576,326	456,800
2036	398,324	586,017	464,481
2037	395,122	573,274	454,381
2038	396,846	576,336	456,808
2039	400,428	583,190	462,240
2040	396,855	580,992	460,499
2041	396,783	587,013	465,271
2042	395,674	585,324	463,932
2043	398,041	579,616	459,408
2044	402,804	580,832	460,372
2045	403,111	579,284	459,145
2046	400,652	583,715	462,657
2047	401,558	578,979	458,903
2048	394,845	582,586	461,762
2049	389,532	579,864	459,605
2050	385,891	582,248	461,494

Table C.47 - Emissions due to surface access for 2026 – 2050 for baseline and Heathrow ENR forecast scenarios

Year	Baseline emissions due to surface access to Heathrow Airport, tonnes CO_2	Heathrow ENR emissions due to surface access to Heathrow Airport, tonnes CO_2	% change
2026	372,947	383,247	2.8%
2027	373,182	396,841	6.3%
2028	373,417	410,434	9.9%
2029	373,653	424,028	13.5%
2030	373,888	437,622	17.0%
2031	376,700	443,207	17.7%
2032	379,511	448,792	18.3%
2033	382,323	454,378	18.8%
2034	385,134	459,963	19.4%
2035	387,946	465,548	20.0%
2036	393,072	471,918	20.1%
2037	398,197	478,288	20.1%
2038	403,323	484,658	20.2%
2039	408,449	491,028	20.2%
2040	413,575	497,398	20.3%
2041	420,039	502,271	19.6%
2042	426,503	507,144	18.9%
2043	432,967	512,017	18.3%
2044	439,431	516,890	17.6%
2045	445,895	521,764	17.0%
2046	450,529	528,631	17.3%
2047	455,163	535,498	17.6%
2048	459,798	542,365	18.0%
2049	464,432	549,232	18.3%
2050	469,066	556,099	18.6%

Table C.48 - The emissions due to surface access across the UK airport system, 2026 – 2050 for baseline and Heathrow ENR forecast scenarios

Year	Baseline emissions due to surface access to UK airports[40], tonnes CO_2	Emissions due to surface access to UK airports with Heathrow - ENR[41], tonnes CO_2	% change
2026	1,811,056	1,734,238	-4.2%
2027	1,808,382	1,723,335	-4.7%
2028	1,805,708	1,712,431	-5.2%
2029	1,803,035	1,701,528	-5.6%
2030	1,800,361	1,690,625	-6.1%
2031	1,814,236	1,699,081	-6.3%
2032	1,828,111	1,707,536	-6.6%
2033	1,841,987	1,715,992	-6.8%
2034	1,855,862	1,724,447	-7.1%
2035	1,869,737	1,732,903	-7.3%
2036	1,896,420	1,755,022	-7.5%
2037	1,923,103	1,777,141	-7.6%
2038	1,949,785	1,799,260	-7.7%
2039	1,976,468	1,821,379	-7.8%
2040	2,003,151	1,843,498	-8.0%
2041	2,029,207	1,862,445	-8.2%
2042	2,055,263	1,881,392	-8.5%
2043	2,081,319	1,900,340	-8.7%
2044	2,107,375	1,919,287	-8.9%
2045	2,133,431	1,938,234	-9.1%
2046	2,171,683	1,965,346	-9.5%
2047	2,209,935	1,992,457	-9.8%
2048	2,248,187	2,019,568	-10.2%
2049	2,286,440	2,046,680	-10.5%
2050	2,324,692	2,073,791	-10.8%

[40] The previously referenced set.
[41] The previously referenced set.

Table C.50 - Emissions due to surface access at Heathrow, for 2026 – 2050 for baseline and Heathrow ENR forecast scenarios

Year	Baseline emissions due to surface access to Heathrow Airport, tonnes CO_2	Heathrow-ENR emissions due to surface access to Heathrow Airport, tonnes CO_2
2026	316,763	325,442
2027	317,981	338,068
2028	319,199	350,694
2029	320,417	363,320
2030	321,635	375,947
2031	324,479	381,241
2032	327,323	386,536
2033	330,167	391,831
2034	333,012	397,126
2035	335,856	402,421
2036	340,338	407,968
2037	344,820	413,514
2038	349,303	419,060
2039	353,785	424,607
2040	358,267	430,153
2041	363,884	434,431
2042	369,500	438,708
2043	375,117	442,985
2044	380,734	447,262
2045	386,350	451,540
2046	390,393	457,574
2047	394,435	463,608
2048	398,477	469,642
2049	402,519	475,676
2050	406,562	481,710

Table C.51 - Carbon emissions due to airport operation energy use at Heathrow, by source 2026 – 2050 for Heathrow ENR forecast scenario

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	Total Emissions due to airport operation at Heathrow Airport, tonnes CO_2
2026	86,049	56,635	9,402	152,086
2027	86,345	61,252	10,240	157,836
2028	79,572	61,252	10,633	151,456
2029	83,972	61,252	10,915	156,138
2030	83,983	61,252	11,226	156,460
2031	78,530	61,252	11,368	151,150
2032	68,066	61,252	11,598	140,916
2033	57,479	61,252	11,687	130,418
2034	49,768	61,252	11,892	122,912
2035	45,728	61,252	12,069	119,048
2036	50,148	71,831	12,272	134,251
2037	45,104	71,831	12,005	128,940
2038	45,118	71,831	12,069	129,018
2039	48,351	71,831	12,212	132,395
2040	43,991	71,831	12,166	127,989
2041	39,662	71,831	12,292	123,785
2042	38,740	71,831	12,257	122,829
2043	34,166	71,831	12,137	118,135
2044	30,704	71,831	12,163	114,699
2045	31,552	71,831	12,131	115,514
2046	29,569	71,831	12,223	113,623
2047	26,947	71,831	12,124	110,902
2048	32,065	71,831	12,200	116,095
2049	28,400	71,831	12,143	112,374
2050	28,638	71,831	12,193	112,662

Table C.52 - Operational emissions due to energy and fuel use at Heathrow, 2026 – 2050 for Heathrow ENR forecast scenario

Year	Baseline, tonnes CO_2	Heathrow-ENR, tonnes CO_2	% Change
2026	130,036	152,086	20.2%
2027	126,936	157,836	29.8%
2028	121,730	151,456	32.1%
2029	125,001	156,138	34.4%
2030	125,336	156,460	36.3%
2031	119,840	151,150	38.3%
2032	110,848	140,916	40.5%
2033	103,074	130,418	41.0%
2034	96,800	122,912	42.6%
2035	93,838	119,048	43.0%
2036	96,587	134,251	39.0%
2037	92,979	128,940	38.7%
2038	93,067	129,018	38.6%
2039	95,327	132,395	38.9%
2040	91,962	127,989	39.2%
2041	88,621	123,785	39.7%
2042	88,091	122,829	39.4%
2043	85,254	118,135	38.6%
2044	83,154	114,699	37.9%
2045	83,896	115,514	37.7%
2046	82,152	113,623	38.3%
2047	80,520	110,902	37.7%
2048	83,825	116,095	38.5%
2049	81,034	112,374	38.7%
2050	81,007	112,662	39.1%

Appendix D Data and factors

Defra energy and fuel use CO_2 factors		
Aviation turbine Fuel	3.150 tCO_2/t	Defra (2014), assumed to remain static 2014 - 2086
Natural Gas Carbon Factor	0.18497 $kgCO_2/kWh$	
Gasoil Carbon Factor	0.25359 $kgCO_2/kWh$	
Diesel Carbon Factor	0.24615 $kgCO_2/kWh$	
Webtag derived & Defra surface access CO_2 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 CO_{2e} 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 $MtCO_2$	2010: 477,000 ATMs Heathrow Expansion Carbon Footprint
Total LTO cycle emissions (Gatwick)	393,660 tCO_2	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 CO_2
Heathrow - Regulated Gas (MWh)	224,464	Heathrow (2013) Heathrow calculated from CO_2 split on total energy presented in proposal
Heathrow - Total Electricity (MWh)	519,596	Heathrow (2013) Heathrow calculated from CO_2 presented in proposal
Heathrow - Total Energy	744,060	Heathrow (2013)

Appendix E Aircraft Type Modelling

Introduction

This note outlines how the DfT aviation model forecasts:

- How forecasts of particular future ATMs by aircraft type are produced.
- How these future aircraft type forecasts are used to generate fuel burn forecasts.
- How these future aircraft type forecasts are used to generate CO_2 emissions forecasts.

These forecasts are only for passenger aircraft carrying passengers covered by the DfT model i.e. it does not include miscellaneous movements (such as positioning flights, diplomatic and military flights) and flights to non-modelled areas (e.g. domestic charters and flights to offshore locations such as the Isle of Man or oil rigs). These are counted as part of a CO_2 'residual' included in the final UK national CO_2 forecast. Freighter flights are generally considered outside the fleet modelling but included as a separate category for emissions modelling. The freighter treatment is described briefly at the end of this note.

This note draws on descriptions of the fleet and CO_2 modelling given by the Department for Transport (DfT). The last such description was published by the DfT in January 2013.[42] That methodology is largely unchanged from the more detailed account given in the DfT 2011 forecasts[43] which were produced to inform the Government response to the report by the Committee on Climate Change.[44] The methodology was also independently peer reviewed by Qinetiq in 2010 and the report from this process also provides much useful background on the modelling.[45]

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42 DfT *UK Aviation Forecasts*, January 2013, particularly chapter 2. https://www.gov.uk/government/publications/uk-aviation-forecasts-2013

43 See DfT *UK Aviation Forecasts, August 2011*, Chapter 3, https://www.gov.uk/government/publications/uk-aviation-forecasts-2011 for more information on this process.

44 Committee on Climate Change, Meeting the UK aviation target – options for reducing emissions to 2050, 2009, http://www.theccc.org.uk/reports/aviation-report

45 See *Future Aircraft Fuel Efficiencies – Review of Forecast Method*, QinetiQ on behalf of the DfT, March 2010 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/4515/future-aircraft-fuel-efficiency.pdf

ATM Forecasting Methodology

The ATM demand model

The ATM Demand Model translates passenger demand into ATM demand at each airport, to allow comparison of demand with both passenger and ATM capacity constraints.

The process begins with the National Air Passenger Demand Model, which forecasts unconstrained passenger demand (i.e. a demand for travel which is not constrained by airport capacity). The NAPAM passenger to airport allocation model then converts the national unconstrained passenger demand forecasts into forecasts of passenger and air traffic movement (ATM) throughput (constrained by airport capacity) for each UK airport, by route (or group of routes), aircraft 'seat band', and carrier type (scheduled, charter, or low-cost carrier).

Route viability and competition

During this process the ATM Demand Model also projects the availability of routes from each modelled airport. It is assumed that, in line with mainstream economic theory, supply will respond to demand, subject to airport capacity, so long as the market is commercially viable. Hence the supply of flights on routes is forecast to grow with demand, provided markets satisfy a minimum viability threshold. The ATM Demand Model simulates the introduction of new routes by testing in each forecast year whether sufficient demand exists to make new routes viable from each airport. The test is two-way, so routes can be both opened and withdrawn. Also, airports are tested jointly for new routes, allowing them to compete with each other.

Aircraft size by seat band

For each route at each airport, the ATM Demand Model forecasts the size of aircraft, load factor, and frequency of operation used to meet forecast passenger demand, by applying relationships between passenger demand, aircraft size and load factors, and flight frequency derived statistically from historical data – these are called 'Larame' graphs after a technique first developed by the CAA. These relationships indicate the stages of passenger demand growth that are likely to be accommodated by increases in frequency, and the points in the growth of demand at which a switch to operating larger aircraft can be expected.

Within NAPAM the Larame function converts forecast ATMs into one of 6 seat bands for each of the three airline types modelled (scheduled, low-cost and charter). An example of the ATM by seat band data provided by NAPAM used for association with specific future aircraft types is given in Figure 0.1.

Figure 0.1: Seat band output from NAPAM

2030	Origin: LHR	Seat	Scheduled (Excluding LCC)						
	Destination	Band	< 70	71-150	151-250	251-350	351-500	500+	Total
461	ABZ Aberdeen	Dom			13,316				13,316
462	BFS Belfast International	Dom		8					8
463	BHD Belfast City	Dom		7,280					7,280
464	BHX Birmingham	Dom							0
465	BOH Bournemouth	Dom							0
466	BRS Bristol	Dom							0
467	CWL Cardiff	Dom							0
468	EMA East Midlands	Dom							0
469	EDI Edinburgh	Dom			20,474				20,474
470	EXT Exeter	Dom							0
471	LGW Gatwick	Dom							0
472	GLA Glasgow	Dom			16,584				16,584
473	LHR Heathrow	Dom							0
474	HUY Humberside	Dom							0
475	INV Inverness	Dom		5,730					5,730
476	LBA Leeds/Bradford	Dom		1,784					1,784
477	LPL Liverpool	Dom							0
478	LCY London City	Dom							0
479	LTN Luton	Dom							0
480	MAN Manchester	Dom			19,334				19,334
481	NCL Newcastle	Dom			10,982				10,982
482	NQY Newquay	Dom							0
483	NWI Norwich	Dom							0
484	PLH Plymouth	Dom							0
485	SOU Southampton	Dom							0
486	STN Stansted	Dom							0
487	MME Teesside	Dom		2,748					2,748
488	XX1 New Site 1	Dom							0
489	XX2 New Site 2	Dom							0
490	XX3 New Site 3	Dom							0
491	SZD Sheffield	Dom							0
492	PIK Prestwick	Dom							0
501	LUX Belgium / Luxembourg	SH							0
502	YVR Canada West	US				2,225			2,225
503	YYZ Canada East	US			3,434	6,112			9,546
504	TFS Canary Islands	SH							0
505	LYS France	SH		7,856					7,856
506	TXL Germany	SH		19,062					19,062

At this stage, the fleet mix information is therefore fairly limited, representing aircraft type simply by size, using six seat band categories.

The six seat band sizes output by NAPAM are:

Class 1 0-70 seats
Class 2 71-150 seats
Class 3 151-250 seats
Class 4 251-350 seats
Class 5 351-500 seats
Class 6 501+ seats

The Fleet Mix Model (FMM)

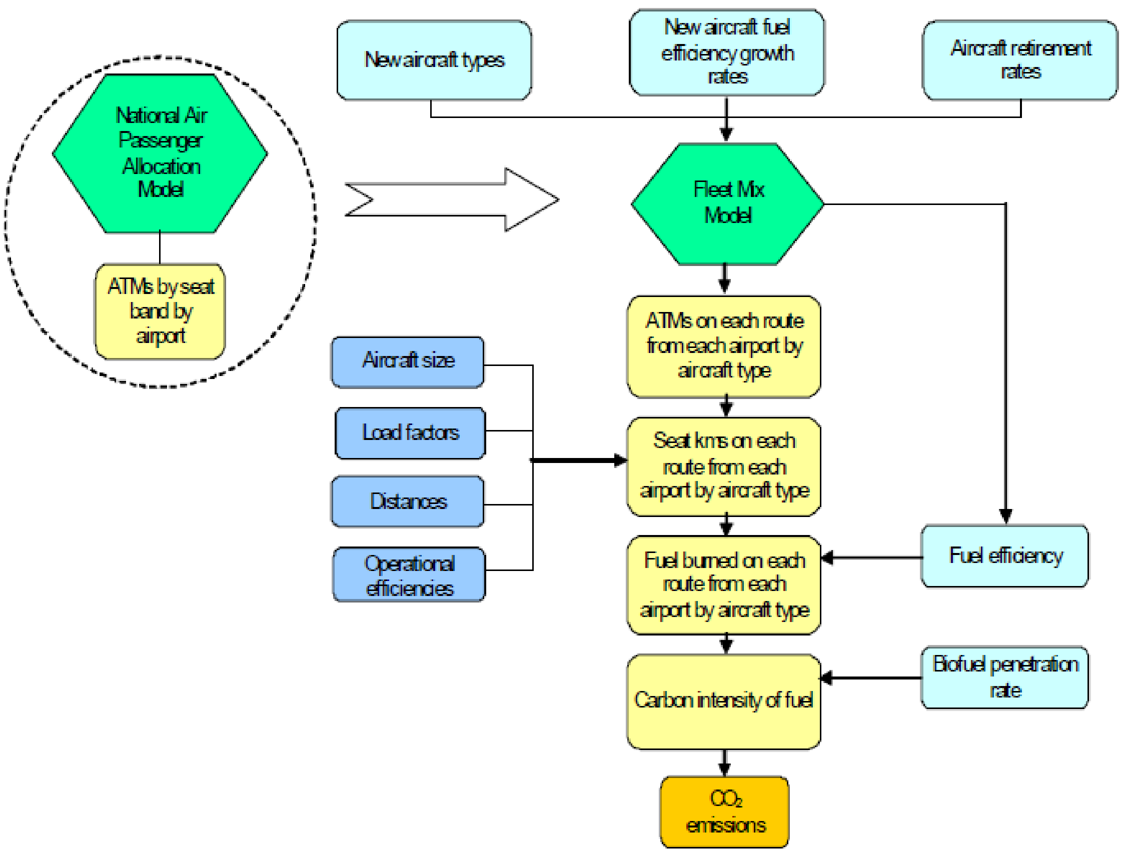
Overview

The National Air Passenger Allocation Model forecasts ATMs for each airport and route by 'seat-band' of aircraft (i.e. the seating capacity of the aircraft, split into six bands). This feeds into the Fleet Mix Model (FMM) which forecasts the particular composition of the aircraft fleet for each airport and route by specific aircraft type and age. It achieves this by taking the base year distribution of ATMs by aircraft type and age operating at all UK airports, and projects it forward using the forecast of ATM demand by seat band at each airport from the National Air Passenger Allocation Model, with assumptions about:

- the retirement age of each aircraft type; and,
- the split of new aircraft entering the fleet each year between specific aircraft types (by seat band and class of airline).

The relationship of the FMM with NAPAM, CO_2 emissions model and other input assumptions is shown below in Figure 0.2.

Figure 0.2: Fleet Mix Model



FMM Process

The FMM retires aircraft from the UK fleet as they reach the end of their serviceable life, typically 20-25 years, and replaces them with new aircraft. When an aircraft retires, it is assumed to be replaced by one of three types:

1. a new aircraft of the same type;
2. a new aircraft of an existing but different type; or,
3. a new aircraft of a new type

The FMM accounts for the considerable overlap between aircraft in the 6 NAPAM seat band categories resulting from the variability between cabin seating configurations between different airlines and carrier types. For example: in the base year bmi used to operate their A320s at 156 seats (seat band 3) while BA tended to operate at 149 seats (seat band 2); easyJet generally operate their A319s at 151 seats (seat band 3) while BA tend to operate at 123 seats; and Boeing 747s may be configured with anything between 290 and 450 seats.

The FMM has a base year population of the age of aircraft using all UK airports in 2008/9 by aircraft type using fleet airframe data and CAA data on ATMs by registration data. For each of the six ATM seat bands output by NAPAM for the scheduled, low-cost and charter airline types an age distribution of the type shown in Figure 0.3 is calculated.

Figure 0.3: Example of input ATM data

Seat Band	4						
Carrier type	Sch						
		Base Year Fleet Age Distribution Data					
	In service	0	1	2	3	4	5
Boeing 777-200	1	727	842	1233	1824	827	1340
Boeing 767-300	1	0	0	6	36	213	20
Airbus A340-600	1	965	4858	1768	1068	506	2367
Boeing 747-400	1	0	0	0	0	670	328
Airbus A340-300	1	0	595	484	288	144	0
Airbus A330-300	1	580	748	795	574	476	2
Airbus A330-200	1	999	2666	925	408	1663	2008
Airbus A300-600	1	0	0	0	0	0	0
Boeing 777-300 (ER)	1	2526	3420	2289	12	212	0
Airbus A310-300	1	0	0	0	0	0	0
Boeing 787 all pax models	0	0	0	0	0	0	0
Boeing 747-800	0	0	0	0	0	0	0
Airbus A350-900	0	0	0	0	0	0	0
ACARE Next-Gen CL4	0	0	0	0	0	0	0

For the first forecast year (2009), the FMM calculates the number of ATMs by seat band and carrier class from aircraft that have reached retirement age. This involves ‘aging’ the base year distribution of ATMs (by age, aircraft type, carrier type and seat band) by one year. This, combined with user assumptions about the retirement age of each aircraft type, defines the number of ATMs (by aircraft type, carrier type, and seat band) that are performed by aircraft at their retirement age and need to be re-allocated to new aircraft.

The reallocation of these ATMs between aircraft types is governed by user input assumptions about the 'supply pool'. This details for each forecast year (and carrier type and seat band) how 'retiring ATMs' from an aircraft type would be replaced by ATMs from available 'in-production' aircraft types for that year. For example, if the FMM identified that 100 ATMs were to be performed by 22 year old A340-300s, then it would identify these as due to retire[46], and reallocate their ATMs to a mixture of aircraft types (which could include new A340-300s).

Reflecting the variation in business models in the aviation industry, different fleet replacement assumptions are used in different sectors of the market, i.e. scheduled, charter and low cost airlines.

Figure 0.4: Definition of a supply pool for replacement aircraft model types (seat band 4 251-350 seats)

	Start Year		Phase Out												
		Retire Age	Year	In Prod	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
772	Boeing 777-200	22	2051	1	0.05	0.05	0.05	0.05	0.05	0.05					
763	Boeing 767-300	20	2031	0											
346	Airbus A340-600	22	2041	1											
744	Boeing 747-400	20	2031	0											
343	Airbus A340-300	22	2051	0											
333	Airbus A330-300	22	2031	0											
332	Airbus A330-200	22	2051	1	0.10										
AB6	Airbus A300-600	20	2021	0											
77W	Boeing 777-300 (ER)	22	2051	1	0.20	0.20	0.20	0.20	0.20	0.20	0.18	0.16	0.14	0.12	0.10
313	Airbus A310-300	20	2021	0											
787	Boeing 787 all pax models	22	2051	1	0.35	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.36
748	Boeing 747-800	22	2051	1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09
359	Airbus A350-900	22	2051	1	0.20	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.23
G14	New G1 CL4	22	2051	1							0.07	0.09	0.11	0.13	0.23
G24	New G2 Post 2030 CL4	22	2051	1											
G34	New G3 Post 2040 CL4	22	2051	1											

After the definition of the supply pools (these were audited by Qinetiq in 2010/2011) the following processes are made:

1. The first forecast year's number of ATMs by each aircraft type is then calculated as: base year ATMs – retired ATMs + replacement ATMs.

2. Subsequent forecast year fleet mixes are then calculated by the same process set out above, taking the previous forecast year as the base year.

3. The data thus generated are then used to assign specific aircraft types to the forecasts of ATMs.

   The final output is the percentage of UK ATMs by each aircraft type for each of the six seats bands for each of the 3 airline types.

[46] 22 years is the assumed retirement age for this aircraft type.

Figure 0.5: FMM output type percentages to apply to ATMs in each NAPAM seat band (seat band 4 251-350 seats)

Ac_Sch		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
772	Boeing 777-200	27.1%	27.3%	27.4%	27.2%	26.1%	24.7%	21.1%	18.5%	13.2%	8.6%	5.2%	4.6%	4.2%	3.4%	2.8%	2.4%
763	Boeing 767-300	6.4%	5.6%	4.4%	3.7%	2.9%	1.1%	0.7%	0.3%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
346	Airbus A340-600	17.8%	17.8%	17.8%	17.8%	17.8%	17.8%	17.8%	17.8%	17.8%	17.8%	16.4%	13.3%	12.6%	11.1%	8.8%	2.2%
744	Boeing 747-400	7.3%	6.2%	5.8%	5.1%	4.0%	2.3%	1.3%	1.2%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
343	Airbus A340-300	9.3%	8.3%	8.3%	7.6%	7.0%	5.8%	4.9%	2.7%	1.9%	1.3%	1.3%	1.3%	1.2%	0.9%	0.5%	0.0%
333	Airbus A330-300	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	8.5%	7.4%	5.5%	3.7%	3.7%	3.2%	2.5%	1.6%	0.7%
332	Airbus A330-200	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.3%	6.9%	5.8%	4.9%	4.1%	4.0%	3.5%	2.3%
AB6	Airbus A300-600	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
77W	Boeing 777-300 (ER)	8.2%	8.8%	9.1%	9.6%	10.4%	11.7%	12.7%	13.6%	14.8%	15.7%	16.5%	16.9%	16.9%	17.1%	16.0%	14.3%
313	Airbus A310-300	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
787	Boeing 787 all pax models	4.4%	5.6%	6.2%	7.2%	8.8%	11.3%	13.7%	15.8%	19.3%	22.4%	25.2%	26.7%	27.4%	28.3%	29.4%	31.2%
748	Boeing 747-800	1.3%	1.6%	1.7%	2.0%	2.4%	3.0%	3.6%	4.1%	5.0%	5.8%	6.5%	6.8%	7.0%	7.2%	7.5%	8.0%
359	Airbus A350-900	1.7%	2.4%	2.9%	3.5%	4.4%	6.0%	7.5%	8.9%	11.0%	12.9%	14.7%	15.7%	16.1%	16.6%	17.4%	18.5%
G14	New G1 CL4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.9%	1.9%	2.8%	4.6%	6.1%	7.2%	8.9%	12.5%	20.3%
G24	New G2 Post 2030 CL4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
G34	New G3 Post 2040 CL4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

These aircraft type ATM proportions are then used to calculate fuel burn and from the fuel burn the CO_2 emissions.

CO_2 emissions modelling

Seat-kilometres by aircraft type

The forecast number of ATMs by specific aircraft types at each airport are then converted into forecasts of seat-kilometres at the same level of detail, by applying projections of aircraft size (i.e. the number of seats per ATM), and the distance flown on each airport route. The latter is based on 'great circle' distances, which is a common metric for aviation purposes, and represents the shortest air travel distance between two airports taking account of the curvature of the earth. The actual distance flown is likely to be longer than the great circle distance in reality due to sub-optimal routeing and stacking at airports during periods of heavy congestion. An adjustment factor is therefore applied to uplift the distance flown by 8% for this “inefficiency”.

‘CORINAIR’

Current fuel burn rates by aircraft type measured in kilograms of fuel per aircraft for different distance bands flown, and for different stages of the flight are initially taken from the European Environment Agency's 'CORINAIR' Emission Inventory Guidebook[47]. This is an established and authoritative source of data on aircraft fuel burn rates, giving separate values for the different stages of the flight such as landing and take-off including taxiing and cruise emissions for different aircraft types[48].

[47] EMEP/CORINAIR Emission Inventory Guidebook - 2006, European Environment Agency http://reports.eea.europa.eu/EMEPCORINAIR4/en/page002.html

[48] It is assumed that fuel burn on a 100% loaded jet aircraft will be 5% higher than on a 70% loaded aircraft, due to the increased weight. See *An evaluation of aircraft emissions inventory methodology by comparisons with reported airline data*. Daggett, D. L., D. J. Sutkus Jr., D. P. DuPois, and S. L. Baughcum, 1999: NASA/CR-1999-209480.

In 2009, the DfT commissioned QinetiQ to re-assess the suitability of the current CORINAIR guidebook rates of fuel burnt by distance band for each CORINAIR aircraft type and for each aircraft type used in DfT modelling.[49] QinetiQ's study:

- reviewed the mapping of all aircraft types to the subset of mainly older types in the CORINAIR guidebook data;
- assessed the accuracy of the curve fits of projected fuel burnt by distance band flown in the CORINAIR data and the volume of fuel burnt at each distance by relating it to detailed operational data from the AERO2k project[50]; and
- reviewed the assumptions about the composition of the supply pool expected to replace retiring aircraft.

Improvements in fuel efficiency

Seat-kms per mass of fuel (i.e. seat-kms per tonne or kg of fuel) is the preferred metric for measuring aviation fuel efficiency in the model. It was widely used by the IPCC and the research on which the IPCC study drew.[51] There are in practice number of fuel efficiency measures. The value of this metric is that it is essentially unaffected by the assumed or modelled load factors.

The QinetiQ study made recommendations on mapping of specific aircraft types to CORINAIR types, adjusting burn rates for existing aircraft, improving the form of the fuel burn over distance curves and extrapolating CORINAIR burn rates over longer flight distances. QinetiQ also provided advice on more precise rates for recent aircraft not well represented in the CORINAIR guidebook such as extended range versions of the B777 and the A380. Finally, the study also made recommendations on the burn rates to assume for aircraft due to enter service in the next few years such as Boeing 787s, Airbus A350s and the Bombardier C Series[52] and then the subsequent generations of new aircraft from 2020s onwards.

Gains in the fuel efficiency of air travel on the metric of seat-kms delivered per tonne of fuel can be split into two sources[53]:

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49 *Future Aircraft Fuel Efficiencies – Review of Forecast Method*, QinetiQ, March 2010.

50 The QinetiQ AERO2k greenhouse gas model, is one of the models approved for CAEP (the Committee for Aviation Environmental Protection). It uses a huge range of operational data from missions flown. It was possible to create CORINAIR style burn rates using the PIANO aircraft design software and actual operational data rather than the standardised operational settings used in the CORINAIR guidebook.

51 *Aviation and the Global Atmosphere*, Inter-governmental Panel on Climate Change, 1999

52 See *Future Aircraft Fuel Efficiencies – Review of Forecast Method*, QinetiQ on behalf of the DfT, March 2010, Chapter 6.

53 Fuel efficiency is defined in DfT modelling as seat-km per tonne of fuel. It is therefore independent of load factors, which are accounted for elsewhere in the forecasting. A key issue is that a specific load factor can then be assumed, so a seat-km implies a certain tonne-km. This is helpful for making assumptions transparent when defining industry standards.

- **Air traffic management and operational efficiencies**: through better co-ordinating and controlling air transport movements, or eliminating non-essential weight, optimising aircraft speed, limiting the use of auxiliary power etc, less fuel will be needed for a given number of seat-kms flown.
- **Aircraft efficiency**: as new, more efficient aircraft replace older aircraft, the average efficiency of the fleet will rise. Improvements in new aircraft efficiency can be driven by better engine or airframe technology. These gains could take the form of new types of aircraft entering production (e.g. Boeing 787, Airbus A380 and A350) or incremental improvements to existing types of aircraft. It is also possible for certain existing aircraft to become more efficient through retrofitting of the latest engine technology or the fitting of aerodynamic devices such as winglets and riblets.

The central forecasts are based on the assumption that future net gains in ATM fuel efficiency from SESAR and other programmes are offset by an increase in traffic. In producing the forecast range a net +1% improvement by 2050 (i.e. a 1% reduction in actual distances flown) is assumed to define the lower bound and a net 4% deterioration (i.e. an increase in flight distance) defines the upper bound.

In producing the forecast range some allowance has been made for changes in airline operational practices (e.g. optimised payloads, flying speeds and altitudes) to deliver fuel efficiency gains. No additional improvement has been assumed in producing the central forecast, but +/- 0.25% efficiency improvement relative to the central forecast has been assumed in producing the lower/upper bound of the range.

The primary source of fuel efficiency gains is likely to come from the retirement of less efficient current aircraft types and their replacement by newer more fuel efficient types. As explained above, the Fleet Mix Model (FMM) forecasts the distribution of the future fleet by aircraft type, based on the retirement of old aircraft and the entry into the fleet of new aircraft. To project gains in the fleet's efficiency due to the replacement of older aircraft with newer, more efficient models, it is therefore necessary to project the efficiency of the aircraft that will enter service in the years to 2050, and feed that into the FMM. The fuel efficiency assumptions made impact on the whole fleet.

Projecting fuel efficiency of new aircraft

In general the forecasts are based on the assumption that there will be gradual improvements relative to conventional technologies. They are expected to reduce the weight of the engines and airframe through the increased use of new materials, improve various airframe efficiency metrics such as the reduction of aero-dynamic drag and increase both the thermo-dynamic and propulsive efficiency of engines. The forecasts do not reflect more radical departures such as the blended wing body aircraft or open rotor engines. The limited introduction of biofuels into the central and high baselines also has an impact on the emissions forecasts, although this assumption is independent of aircraft type.

It was noted above that aircraft entering service in a future year could be of an existing type, a known new type (i.e. aircraft not yet in service but which are on order such as the Boeing 787, Airbus A350 and the Bombardier C Series) or a completely new type. The efficiency of new types of aircraft expected in the near future can be projected using manufacturers' specifications for their aircraft and PIANO aircraft design and performance software[54].

Fuel efficiency assumptions

Efficiency of new aircraft types in the near future

Manufacturers' data and the PIANO aircraft design and performance model are used to project the fuel burn rates of new aircraft types expected to enter service in the near future. For example, the next generation of Boeing 737s and Airbus A320s are assumed to burn 15% less fuel than the current types. Boeing 787s are assumed to burn 5% less fuel than the B767s they will often replace. Airbus A350s are assumed to burn 7% more fuel than a B767, but their potential larger seating capacities mean that significant efficiencies can be delivered to the efficiency metric of seat-kms per tonne of fuel. The Airbus A380 is assumed to burn 15% more fuel than a Boeing 747-400, but could deliver efficiencies of up to 12% in terms of seat-kms per tonne of fuel depending on the seating configurations of each type. These updated rates are applied to the CORINAIR data of the respective existing aircraft types to project burn rates for the new types. An adjustment is also made to reflect the potential variation in seating configurations of the new aircraft.

No great technological change is assumed before 2020 beyond aircraft already in development. Mid-generation upgraded and re-engined Airbus A320 and B737 aircraft are assumed to enter service from around 2016. The introduction of Boeing 787s, Airbus A350s and Bombardier C Series aircraft are also assumed to improve on the types they replace. The forecasts do not assume any fuel efficiency gains are delivered through retrofitting because these gains are likely to be relatively small and limited to a relatively narrow range of aircraft currently in service.

Next generation aircraft (late 2020s onwards)

The development of new aircraft types tends to follow a product cycle over many years, and it is probable that future generations of aircraft types will enter production and the fleet during the 2020s with further waves in the 2030s and 2040s. However, their introduction will vary by size classes and the position of aircraft of that class in the approximate 20 year production and

[54] PIANO-X Aircraft performance and emissions software. Lissys Ltd. http://www.piano.aero/.

development cycles in the FMM described above. For example it is assumed that there will be relatively few new types to replace 120-200 seat narrow-bodied types in seat band class 2 & 3 in the 2020s because of the potential introduction of re-engined new generation B737s and A320s after 2016. New 2020 generation 500+ seat aircraft are not assumed to enter the replacement pools until late in the decade because of the current development of the A380 and B747-800.

Earlier DfT emissions forecasts assumed that future generations of aircraft introduced in 2020 and beyond would be influenced to some degree by the Advisory Council for Aeronautics Research in Europe (ACARE) target for fuel efficiency[55]. The ACARE 2020 vision was that aircraft manufacturer R&D, operational efficiency and air traffic management combine to deliver a 50% improvement in fuel burnt per seat-km by new aircraft entering service compared with their equivalents of 2000.[56] NASA has similar expectations for the future American aircraft fleet. It is not now assumed that future generations of aircraft coming into service beyond 2020 are uniformly "ACARE compliant".

This judgment is because forecasts since 2010 have gone a step further in reflecting expert industry advice on:

- the effectiveness of economic motives driving fuel cost reduction;
- the ICAO/CAEP expert review of fuel burn reduction technology in 2010 with more detailed analysis becoming available;[57]
- the willingness of manufacturers to anticipate agreements on ICAO/CAEP CO_2 standards; and
- the willingness of airlines to rollover their fleets more responsively to fuel costs and to anticipate potential new regulatory standards.

So although attainment of fuel burn goals remains an important part of the view of future aircraft efficiency, the availability of more detailed analysis of the specific factors driving aircraft technological development emerging from the analysis in 2010 in the Government's response to the CCC removed the need to make efficiency forecasts in line with ACARE aspirations. Allowance is also now made for the different development cycles for different size classes of aircraft.

Table 0.1 below shows what is assumed to be the fuel efficiency gains for the future generation ('FG') (or 'new generation') of aircraft introduced in the 2020s, 2030s and 2040s.

55 See *The Challenge of the Environment, Strategic Research Agenda*, Advisory Council for Aeronautics Research (ACARE), Volume 2, October 2002, (http://www.acare4europe.org/docs/es-volume1-2/volume2-03-environment.pdf)

56 *A Strategy Towards the Development of Sustainable Aviation*, Sustainable Aviation, 2005

57 ICAO/CAEP: *Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction From Technology, 2010* (Doc 9963)

Table 0.1: Fuel efficiency gains of future generation (FG) aircraft

		Base "2000" aircraft TYPE	Fuel Efficiency Gain: Central Case 2020s FG	2030s FG	2040s FG
Class1	0-70 seats	ATR42-320	21.5%	24.5%	31.5%
Class2	71-150 seats	B737-400	21.5%	24.5%	31.5%
Class3	151-250 seats	B757-200	21.5%	24.5%	31.5%
Class4	251-350 seats	B777-200	17.5%	27.5%	29.5%
Class5	351-500 seats	B777/A340-200	17.5%	27.5%	29.5%
Class6	500+ seats	A380	17.5%	27.5%	29.5%
Low case efficiency improvement on central			2.0%	4.0%	5.5%
High case efficiency improvement on central			-2.0%	-4.0%	-5.5%

Alternative fuels

The industry has been investigating keenly the potential for alternative fuels for some time. Test flights have shown that some forms of biofuel can successfully be mixed with kerosene. All recent ‘central carbon’ scenario forecasts assume that biofuels are gradually introduced in the 2020s and only make up 2.5% of all aviation fuel burnt by aircraft departing UK airports in 2050.

Once the above method has forecast the amount of fuel that is burned on flights departing each airport on each route by aircraft type, this is converted into CO_2 emissions on the basis that 1.00 kg of kerosene emits 3.15 kg of CO_2.[58] Where biofuel uptake is assumed, this average carbon intensity factor is reduced on the assumption that biofuels are accounted for in the transport sector as having zero emissions.[59] For example, in the central case in 2050 with 2.5% biofuel take up, it is assumed that across the entire fleet 1.00kg of fuel emits 3.07kg of CO_2.

CO_2 Model outputs

The CO_2 model at its most disaggregate output tabulates aircraft types modelled by the FMM at each airport for each international and domestic route together with supporting statistics on ATM, passenger and seat-kms. This data is available for every year NAPAM is run – normally 2011-2050.

4.1

[58] Each 1 kg of kerosene contains 858 g of carbon. Each 1kg of carbon is equivalent to 44/12 or 3.67 kg of CO_2.

[59] In practise, different biofuel feedstocks have different levels of life-cycle emissions and biofuels use in aviation is expected to result in lower emissions, but not reduce emissions to zero. The approach taken here is consistent with the accounting of biofuel use in the UK’s carbon budget and in the EU ETS, and latest guidance from the International Panel for Climate Change (IPCC).

Figure 0.6 provides an example of the CO_2 and FMM database output and gives an indication of the scope and detail of these models.

Figure 0.6: Example fleet model and CO_2 model database output

Run_Labe	Year	SCL	Airport_c	iSPASM	jSPASM	ac_IATA	ac_Name	ac_NETCEN	ATMs	ATM-kms	ATM-Hrs	CO2_Tot	CO2_LTO	CO2_Cruise	MTOW	NOx_LTO_	Size	Seats	Seat-Kms
s02_c0	2040	S	LGW	471	546	734	Boeing 737-400	B734	0.0	0	0	0.000	0.825	-0.825	65.033	8.3	146.9	0	0
s02_c0	2040	S	LGW	471	546	735	Boeing 737-500	B734	0.0	0	0	0.000	0.825	-0.825	54.475	8.3	111.7	0	0
s02_c0	2040	S	LGW	471	546	73G	Boeing 737-700	B737	0.0	0	0	0.000	0.784	-0.784	67.528	8.3	138.9	0	0
s02_c0	2040	S	LGW	471	546	CRC	Bombardier C Series	CRC	0.4	749	1	3.084	0.642	2.442	23.595	4.2	110.0	48	82,410
s02_c0	2040	S	LGW	471	546	DH4	Bombardier DHC-8 Q400	DASH8	5.0	8,527	12	23.822	0.188	23.633	28.866	1.9	77.9	389	664,230
s02_c0	2040	S	LGW	471	546	E90	Embraer 190	F100	0.2	281	0	1.334	0.744	0.590	51.593	4.2	98.0	16	27,533
s02_c0	2040	S	LGW	471	546	E95	Embraer 195	146	0.3	468	1	2.294	0.570	1.724	48.800	4.2	117.0	32	54,784
s02_c0	2040	S	LGW	471	546	N19	Post 2016 G2 Airbus A319	A319G2	2.2	3,746	5	16.380	0.682	15.698	68.524	10.8	126.4	278	473,430
s02_c0	2040	S	LGW	471	546	N20	Post 2016 G2 Airbus A320	A320G2	3.8	6,555	9	29.869	0.711	29.158	74.541	10.8	152.9	588	1,002,602
s02_c0	2040	S	LGW	471	546	N36	New Gen Post 2016 B737-60(	B736G2	0.2	375	1	1.546	0.616	0.930	59.610	8.3	111.3	24	41,695
s02_c0	2040	S	LGW	471	546	N37	New Gen Post 2016 B737-70(	B737G2	1.6	2,809	4	12.544	0.666	11.878	67.528	8.3	138.9	229	390,302
s02_c0	2040	S	LGW	471	546	G12	New G1 CL2	ACG1C2	9.0	15,291	22	66.370	0.648	65.722	65.033	8.3	125.0	1,121	1,911,330
s02_c0	2040	S	LGW	471	546	G22	New G2 Post 2030 CL2	ACG2C2	2.2	3,835	6	16.011	0.623	15.387	65.033	8.3	125.0	281	479,392
s02_c0	2040	C	LGW	471	503	350	Airbus A350 pax	A350	3.4	20,850	27	205.450	1.851	203.599	245.000	19.7	310.0	1,049	6,463,403
s02_c0	2040	C	LGW	471	503	762	Boeing 767-200	B763	0.0	0	0	0.000	1.730	-1.730	154.546	26.0	288.8	0	0
s02_c0	2040	C	LGW	471	503	763	Boeing 767-300	B763	0.0	0	0	0.000	1.730	-1.730	173.687	26.0	305.0	0	0
s02_c0	2040	C	LGW	471	503	787	Boeing 787 all pax models	B787	3.4	20,850	27	172.340	1.541	170.799	214.417	26.4	290.0	982	6,046,409
s02_c0	2040	C	LGW	471	503	G14	New G1 CL4	ACG1C4	1.9	11,799	15	121.264	2.114	119.149	277.786	53.6	300.0	575	3,539,791
s02_c0	2040	C	LGW	471	503	G24	New G2 Post 2030 CL4	ACG2C4	0.3	1,937	3	15.660	1.858	13.802	277.786	53.6	300.0	94	581,143
s02_c0	2040	C	LGW	471	504	320	Airbus A320-100/200	A320	71.2	223,049	241	1123.550	0.836	1122.714	74.541	10.8	177.0	12,610	39,483,172
s02_c0	2040	C	LGW	471	504	321	Airbus A321	A321	30.5	95,593	103	557.770	0.968	556.802	88.413	10.8	214.6	6,552	20,515,271
s02_c0	2040	C	LGW	471	504	738	Boeing 737-800	A320	101.8	318,642	344	1605.072	0.836	1604.236	76.796	8.3	187.8	19,113	59,842,164
s02_c0	2040	C	LGW	471	504	N20	Post 2016 G2 Airbus A320	A320G2	1246.8	3,903,687	4,214	16714.194	0.711	16713.483	74.541	10.8	177.0	220,697	691,012,705
s02_c0	2040	C	LGW	471	504	N21	Post 2016 G2 Airbus A321	A321G2	534.3	1,673,009	1,806	8297.518	0.823	8296.695	88.413	10.8	214.6	114,673	359,046,963
s02_c0	2040	C	LGW	471	504	N38	New Gen Post 2016 B737-80(	A320G2	1781.1	5,576,696	6,020	23877.420	0.711	23876.709	76.796	8.3	187.8	334,497	1,047,324,555
s02_c0	2040	C	LGW	471	504	G13	New G1 CL3	ACG1C3	751.2	2,351,985	2,539	12425.163	0.984	12424.180	109.154	19.7	190.0	142,725	446,877,101
s02_c0	2040	C	LGW	471	504	G23	New G2 Post 2030 CL3	ACG2C3	15.1	47,235	51	240.118	0.946	239.172	109.154	19.7	190.0	2,866	8,974,630
s02_c0	2040	C	LGW	471	505	320	Airbus A320-100/200	A320	20.1	16,025	38	114.046	0.836	113.210	74.541	10.8	177.0	3,564	2,836,653
s02_c0	2040	C	LGW	471	505	321	Airbus A321	A321	8.6	6,868	16	56.616	0.968	55.648	88.413	10.8	214.6	1,852	1,473,912
s02_c0	2040	C	LGW	471	505	738	Boeing 737-800	A320	28.8	22,893	54	162.923	0.836	162.086	76.796	8.3	187.8	5,402	4,299,337
s02_c0	2040	C	LGW	471	505	N20	Post 2016 G2 Airbus A320	A320G2	352.4	280,459	658	1696.572	0.711	1695.861	74.541	10.8	177.0	62,382	49,645,538
s02_c0	2040	C	LGW	471	505	N21	Post 2016 G2 Airbus A321	A321G2	151.0	120,197	282	842.238	0.823	841.415	88.413	10.8	214.6	32,413	25,795,589
s02_c0	2040	C	LGW	471	505	N38	New Gen Post 2016 B737-80(	A320G2	503.4	400,656	939	2423.674	0.711	2422.964	76.796	8.3	187.8	94,548	75,244,624
s02_c0	2040	C	LGW	471	505	G13	New G1 CL3	ACG1C3	212.3	168,977	396	1233.251	0.984	1232.268	109.154	19.7	190.0	40,342	32,105,711
s02_c0	2040	C	LGW	471	505	G23	New G2 Post 2030 CL3	ACG2C3	4.3	3,394	8	23.747	0.946	22.801	109.154	19.7	190.0	810	644,779
s02_c0	2040	C	LGW	471	506	318	Airbus A318	A319	0.4	446	1	2.781	0.802	1.979	64.570	10.8	123.0	55	54,885
s02_c0	2040	C	LGW	471	506	319	Airbus A319	A319	0.0	0	0	0.000	0.802	-0.802	68.524	10.8	151.0	0	0
s02_c0	2040	C	LGW	471	506	143	Bae 146-300	146	0.0	0	0	0.000	0.570	-0.570	43.076	4.2	106.6	0	0
s02_c0	2040	C	LGW	471	506	732	Boeing 737-200	B731	0.0	0	0	0.000	0.920	-0.920	52.688	8.0	128.3	0	0
s02_c0	2040	C	LGW	471	506	733	Boeing 737-300	B731	0.0	0	0	0.000	0.920	-0.920	60.631	8.0	144.5	0	0
s02_c0	2040	C	LGW	471	506	73G	Boeing 737-700	B737	0.4	446	1	2.579	0.784	1.795	67.528	8.3	147.4	66	65,764

The fields and therefore output variables above which are not self-explanatory are shown below in Table 0.2.

Table 0.2: FMM/CO2 model output fields

SCL	Scheduled, Charter of Low Cost
Airport_code	IATA Code
iSPASM	Origin Airport SPASM Number
jSPASM	Destination Airport SPASM Number
ac_IATA	Aircraft IATA Code
ac_Name	Aircraft name
ac_NETCEN	Corinair mapping type
ATMs	Air Transport Movements
CO2_Tot	Total CO2 for flight
CO2_LTO	Landing, takin-off cycle CO2
CO2_Cruise	Cruise CO2
MTOW	Maximum take of weight
NOx_LTO_kg	LTO Nox

Freighters

For freighters, a similar approach is taken by forecasting at the national level using the constrained forecast of freighter ATMs. Emissions are projected to grow by combining the freighter ATMs, average trip length, and fuel efficiency projections. Trip length is projected to grow at a decreasing rate, and fuel efficiency is assumed to follow a similar path to that of other passenger aircraft. A similar method is used for 'other' ATMs to mainly unmodelled domestic destinations at modelled airports (such as Isle of Man and oil rigs).