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Module 6: Air Quality Local Assessment

Detailed Emissions Inventory and Dispersion Modelling

Prepared for the
Airports Commission

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Jacobs U.K. Limited

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Executive Summary

The Airports Commission's Appraisal Framework considers the air quality implications of airport schemes at both a local and national level. The stated objective for the Air Quality Appraisal Module is *"to improve air quality consistent with EU standards and local planning policy requirements."*

This report quantifies the likely air quality effects of the three shortlisted Schemes, which are:

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

A first stage report, Air Quality National and Local Impacts: Assessment, was published in November 2014. At the time this report was published, surface access information was not sufficiently detailed to allow the meaningful prediction of pollutant concentrations and subsequent assessment of the impacts on sensitive receptors. This Addendum provides the second stage of the assessment to meet the required outputs of the Appraisal Framework. This report includes a detailed assessment of the change in airport and associated surface access emissions associated with each Scheme. The assessment of each Scheme has been carried out for 2030; this restriction is imposed through the limitations in surface access forecasts. A consistent baseline year of 2009 has been used to verify the model against monitoring data.

The Appraisal Framework sets out the recommended methods, guidance documents and datasets to facilitate the assessment. The specific outputs of the 'local assessment' are to quantify pollutant concentrations at locations substantially affected by the Scheme; to quantify the changes in pollutant concentrations between the Commission's "Do-Minimum" and "With Scheme" options, and assess where concentrations improve, worsen, or remain unchanged; and to assess potential mitigation measures, including those proposed by the Scheme Promoters. The specific outputs of the 'national assessment' are to quantify the changes in national pollutant emissions between the Commission's "Do-Minimum" and "With Scheme" options and to monetise the health impacts and environmental damage.

The principal focus for the local assessment is on the concentrations of nitrogen oxides (NOx) and nitrogen dioxide (NO_2). NOx concentrations are important in terms of the potential impacts on sensitive ecosystems, whilst NO_2 is important in terms of potential impacts on human health. Sensitive ecosystems may also be affected by nitrogen deposition which is directly related to concentrations of NO_2. Previous studies have demonstrated that airports have little impact on fine particulate matter (PM_{10} or $PM_{2.5}$) concentrations. Emissions and concentrations of (PM_{10}) have been quantified to inform the national assessment.

The assessment includes the detailed quantification of emissions from operations on the airport and those associated with surface-access emissions, i.e. road traffic; these emissions data have been input to a dispersion model (ADMS-Airport) to predict ground-level pollutant concentrations and nitrogen deposition rates at sensitive receptors. The assessment has considered changes within a "Principal

Study Area", which encompasses a 2km radius around each Scheme boundary, and a "Wider Study Area", which includes all roads for which a significant change in traffic has been forecast. The assessment of total emissions has considered emissions from all modelled roads within the "Traffic Model Simulation Area". The outputs of the emissions inventories have also been used to assess the impacts of each Scheme in relation to national emissions ceilings, and to monetise the health impacts and environmental damage.

Gatwick Airport Second Runway Scheme (Gatwick 2R)

The Gatwick 2R Scheme is predicted to increase emissions of NOx from the Traffic Model Simulation Area by 1,897 te/yr (28.0%) from 6,775 te/yr to 8,672 te/yr. The PM_{10} emissions increase by 66.0 te/yr, from 921.3 te/yr to 987.3 te/yr (an increase of 7.2%) and emissions of $PM_{2.5}$ increase by 64.0 te/yr, from 547.5 te/yr to 611.5 te/yr (an increase of 11.7%).

The Scheme would not affect compliance with the current National Emissions Ceiling Directive (NECD) and Gothenburg Protocol obligations[1]. If the NECD is tightened in line with current proposals, the UK would exceed the obligations with or without Gatwick 2R. The incremental change to emissions associated with Gatwick 2R represents only a very small fraction of the proposed obligations.

The total damage costs of the incremental increases in NOx and PM_{10} emissions over the 60 year appraisal period, based on the unmitigated change in mass emissions with the Gatwick 2R Scheme are £73.6m and £247m respectively, based on Defra's Green Book central estimate (a total damage cost of £320.5m). The total damage costs range between £250.7m (Green Book low estimate) to £962.7m (European Environment Agency (EEA) High, Value of a Statistical Life).

Changes in local air quality have been modelled for the assessment year, 2030. The maximum predicted annual mean NO_2 concentration with the Gatwick 2R Scheme is 38.6 $\mu g/m^3$ and occurs to the south east of the airport; the incremental change above Do-Minimum is 4.6 $\mu g/m^3$. The maximum predicted incremental change (13.1 $\mu g/m^3$) occurs at the south-eastern boundary of the new southern runway, where the predicted concentration for the Gatwick 2R Scheme is 30.7 $\mu g/m^3$. There are no predicted exceedences of the air quality objective at any receptor location with Gatwick 2R.

There are 20,985 properties where annual mean NO_2 concentrations within the Principal Study Area are predicted to be higher (on average by 2.1 $\mu g/m^3$), with 51,328 people affected. There are 62 "at risk" properties (>32 $\mu g/m^3$) that would experience an increase in NO_2 concentrations.

The Scheme would not cause any exceedences of the annual mean NO_2 concentration at which the EU Limit Value is set, and would not delay Defra in achieving compliance in the relevant zone. The proposals for the A23 in the Gatwick 2R Scheme are to realign the road to the east, but it is not possible to replicate Defra's Pollution Climate Mapping (PCM)[2] model predictions at this realigned link, nor is it possible to confirm whether this new link would be included in the PCM model (due to lack of public exposure) and no further assessment can be provided.

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[1] These are obligations on the UK to keep national pollutant emissions below specified targets.

[2] PCM is the national model used by Defra to determine exceedences of the EU Limit Value.

With respect to the protection of ecosystems, the Scheme would not cause any new exceedences of the Critical Level (for NOx) or the lower band of the Critical Load (for nitrogen deposition), at any designated habitat. The Scheme would increase NOx concentrations in locations where the value of the Critical Level is already exceeded (but as noted in Chapter 2, Defra's interpretation of the Directive is that the Critical Level does not strictly apply at these sites.

Heathrow Airport Northwest Runway Scheme (Heathrow NWR)

The Heathrow NWR Scheme is predicted to increase emissions of NOx from the Traffic Model Simulation Area by 2,526 te/yr (26.2%), from 9,643 te/yr to 12,169 te/yr. The PM_{10} emissions increase by 119 te/yr, from 759 te/yr to 878 te/yr (an increase of 15.7%) and emissions of $PM_{2.5}$ increase by 116 te/yr, from 512 te/yr to 628 te/yr (an increase of 22.7%).

The Scheme would not affect compliance with the current NECD and Gothenburg Protocol obligations. If the NECD is tightened in line with current proposals, the UK would exceed the obligations with or without Heathrow NWR. The incremental change to emissions associated with Heathrow NWR represents only a very small fraction of the proposed obligations.

The total damage costs of the incremental increases in NOx and PM_{10} emissions over the 60 year appraisal period, based on the unmitigated change in mass emissions with the Heathrow NWR Scheme are £94.2m and £863.5m respectively, based on Defra's Green Book central estimate (a total of £957.8m). The total damage costs range between £470.7m (EEA Low, Value of Life Year) and £1,299.5m (EEA High, Value of a Statistical Life).

Changes in local air quality have been modelled for the assessment year, 2030. The maximum predicted annual mean NO_2 concentration with the Heathrow NWR Scheme is 34.7 $\mu g/m^3$ and occurs to the north-east of the airport, at Bath Road (A4); the incremental change above Do-Minimum is 0.4 $\mu g/m^3$. The maximum predicted incremental change (10.8 $\mu g/m^3$) occurs to the north-west, adjacent to the new third runway, where the predicted concentration for the Heathrow NWR Scheme is 32.9 $\mu g/m^3$. There are no predicted exceedences of the air quality objective at any receptor location, in either the Do-Minimum or Heathrow NWR scenarios.

There are 47,063 properties where annual mean NO_2 concentrations within the Principal Study Area are predicted to be higher (on average by 0.9 $\mu g/m^3$), with 121,377 people affected. There are 14 "at risk" properties (>32 $\mu g/m^3$) that would experience an increase in annual mean NO_2 concentrations.

The Scheme would not cause any new exceedences of the annual mean NO_2 concentration at which the EU Limit Value is set. However, the incremental change associated with the unmitigated Heathrow NWR Scheme would cause the retained Bath Road (A4) sector PCM road link to have a marginally higher concentration in 2030 (48.7 $\mu g/m^3$) than the Maximum PCM Predicted Concentration in the Greater London Agglomeration (which is 48.6 $\mu g/m^3$ and occurs at Marylebone Road). The unmitigated Heathrow NWR Scheme would thus delay Defra in achieving compliance with the Limit Value. Potential mitigation measures to offset this impact have been investigated (including those proposed by the Promoter). If some of these mitigation measures were incorporated, a reduction in NO_2 concentrations at the Bath Road PCM receptor could be achieved, which might be sufficient to avoid delaying compliance.

The proposals for the A4 Bath Road in the Heathrow NWR scenario are to realign the road northwards to run around the northern boundary of the airport, but it is not possible to replicate Defra's PCM predictions at these realigned links, nor is it possible to confirm whether these new links would be included in the PCM model (due to lack of public exposure) and no further assessment can be provided.

With respect to the protection of ecosystems, the Scheme would cause a new exceedence of the Critical Level for NOx at the South West London Waterbodies RAMSAR/SPA and Wraysbury Reservoir SSSI. However, the UK Government's interpretation is that the Critical Level does not strictly apply at this location. The Scheme would not cause any exceedences of the lower band of the Critical Load (for nitrogen deposition) at any designated habitat.

Heathrow Airport Extended Northern Runway Scheme (Heathrow ENR)

The Heathrow ENR Scheme is predicted to increase emissions of NOx from the Traffic Model Simulation Area by 1,970 te/yr (20.4%), from 9,643 te/yr to 11,613 te/yr. The PM_{10} emissions increase by 91 te/yr, from 759 te/yr to 850 te/yr (an increase of 12.0%) and emissions of $PM_{2.5}$ increase by 86 te/yr, from 512 te/yr to 598 te/yr (an increase of 16.9%).

The Scheme would not affect compliance with the current NECD and Gothenburg Protocol obligations. If the NECD is tightened in line with current proposals, the UK would exceed the obligations with or without Heathrow ENR. The incremental change to emissions associated with Heathrow ENR represents only a very small fraction of the proposed obligations.

The total damage costs of the incremental increases in NOx and PM_{10} over the 60 year appraisal period, based on the unmitigated change in mass emissions with the unmitigated Heathrow ENR Scheme in place, are £69.6m and £618.7m respectively, based on Defra's Green Book central estimate (a total damage cost of £688.3m). The total damage costs range between £351,6m (EEA Low, Value of Life Year) and £971.3m (EEA High, Value of a Statistical Life).

The maximum predicted annual mean NO_2 concentration with the Heathrow ENR Scheme is 37.2 µg/m^3 and occurs to the north of the new extended runway, close to the A3044; the incremental change above Do-Minimum is 9.8 µg/m^3. The maximum predicted incremental change (14.0 µg/m^3) occurs to the north of the new extended runway, close to the realigned M25, where the predicted concentration for the Heathrow ENR Scheme is 37.1 µg/m^3. There are no predicted exceedences of the air quality objective at any receptor location, in either the Do-Minimum or Heathrow ENR scenarios.

There are 38,656 properties where annual mean NO_2 concentrations within the Principal Study Area are predicted to be higher (on average by 0.7 µg/m^3), with 100,389 people affected. There are 113 "at risk" properties (>32 µg/m^3) that would experience an increase in annual mean NO_2 concentrations.

The Scheme would not cause any new exceedences of the annual mean NO_2 concentration at which the EU Limit Value is set. However, the incremental change associated with the unmitigated Heathrow ENR Scheme would cause one of the Bath Road (A4) sector PCM road links to have a higher concentration in 2030 (55.8 µg/m^3) than the Maximum PCM Predicted Concentration in the Greater London Agglomeration (which is 48.6 µg/m^3). The unmitigated Heathrow ENR Scheme would thus delay Defra in achieving compliance with the Limit Value. Potential mitigation measures to offset this impact have been investigated (including those proposed by the Promoter). If all of these mitigation measures were incorporated, a reduction in NO_2 concentrations at the Bath Road PCM receptor could be achieved, but may not be sufficient to avoid delaying compliance.

With respect to the protection of ecosystems, the Scheme would cause a new exceedence of the NOx Critical Level at the South West London Waterbodies RAMSAR/SPA and Wraysbury Reservoir SSSI. However, the UK Government's interpretation is that the Critical Level does not strictly apply at this location. The Scheme would not cause any exceedences of the lower band of the Critical Load (for nitrogen deposition) at any designated habitat.

1 Introduction

This Chapter covers:

- The Airports Commission's Appraisal Framework requirements for air quality assessment;
- The purpose of this report, as the second stage of a two-stage assessment of the potential impacts of the airport expansion schemes;
- The scope of the assessment with regard to each Scheme; and
- An outline of the approach taken and how the report is structured.

1.1 Context and Scope

1.1.1 Purpose of Assessment

This report has been prepared to provide evidence to the Airports Commission's Appraisal Framework Module 6: Air Quality. The stated objective for the Air Quality Appraisal Module is *"to improve air quality consistent with EU standards and local planning policy requirements."*

A first stage report, *Air Quality National and Local Impacts: Assessment*, was published in November 2014 (Jacobs, 2014a). At the time this report was published, surface access information was only available from a static traffic model. These data were not sufficiently detailed for use in a dispersion model, or to allow the meaningful prediction of pollutant concentrations and subsequent assessment of the impacts on sensitive receptors. As such, a two-stage process was proposed.

This Addendum provides the second stage of the assessment to meet the required outputs of the Appraisal Framework. This report includes a more detailed assessment of each Scheme's airport and associated surface access emissions, as modelled for 2030. This year is coincident with the availability of surface access forecasts to provide the required emissions data.

1.1.2 Appraisal Framework Requirements

The Airports Commission's Appraisal Framework (April 2014) sets out the requirements for the assessment of the schemes identified for the Phase 2 air quality appraisal. The Appraisal Framework requires that two specific components are addressed, relating to the local and national assessment.

For the **local assessment**, the air quality implications of each Scheme need to be considered with regard to:

- Changes in emissions arising from the operational impacts of the Scheme, including those related to airport operations and associated surface access;
- Predictions of ground-level pollutant concentrations associated with these emissions;
- Potential impacts upon human health, sensitive ecosystems, and exceedences of the EU limit values; and

- Changes in exposure to pollutant concentrations in terms of the number of properties and populations affected.

The specific **outputs** of the local assessment are:

- Air quality pollutant concentration maps at all locations substantially influenced by the Scheme;
- The number of properties and population where air pollutant concentrations improve, worsen or stay the same;
- The changes in local pollutant concentrations between the Commission's "Do-Minimum" (i.e. Without Scheme) and With Scheme options;
- The monetisation of health impacts and environmental damage;
- Assessment against the stated sustainability objective; and
- Assessment of other potential air quality mitigation measures proposed by Scheme Promoters in their updated Scheme designs.

For the **national assessment**, the air quality implications of each Scheme need to be considered with regard to:

- Environmental damage costs based on calculations of population exposure per unit emission for different source categories of Particulate Matter and oxides of nitrogen (NOx); and
- Potential breaches of the UK national emissions ceilings.

The specific ***outputs*** of the national assessment are:

- The changes in national pollutant emissions between the Commission's "Do-Minimum" and With Scheme options;
- Monetisation of health impacts and environmental damage; and
- Assessment against the stated sustainability objective.

1.1.3 Scope of Air Quality Assessment

The air quality assessment has considered the likely air quality impacts associated with each of the schemes to deliver the required outputs for the local and national assessments as specified in the Appraisal Framework. The assessment includes the quantification of both airport related and associated surface access emissions; these emissions data have been input to a dispersion model to predict ground-level pollutant concentrations and nitrogen deposition rates at sensitive receptors. Emissions inventories have been compiled using different emissions toolkits[3], and the dispersion modelling carried out using ADMS-Airport software[4] from Cambridge Environmental Research Consultants (CERC). The output of the emissions inventories has also been used to assess the impact of each Scheme in relation to national emissions ceilings, and to monetise the health impacts and environmental damage.

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[3] For the Airport sources, the inventory has been compiled within an Excel tool primarily developed using ICAO Emissions Databank, the FOI Turboprop Emissions Databank, ACRP 64, the EMEP/EEA Database and the Defra Emissions Factor Toolkit; For Surface Access this is via the Defra Emissions Factors Toolkit

[4] http://www.cerc.co.uk/environmental-software/ADMS-Airport-model.html

The emissions inventories that have been compiled are based on detailed airport and surface access activity data, as compared to the *"simple ICAO"* and static traffic model approach that was used in the November 2014 report.

In line with the Appraisal Framework, the assessment focuses on the operational air quality impacts of each Scheme. In terms of the potential construction impacts, a high level review has been carried out which identifies the proximity of sensitive receptors within different distance bands in order to provide an indication of the potential for dust (i.e. soiling) and Particulate Matter impacts to arise. A review of best-practice mitigation measures related to the control of air pollutant emissions from construction works has also been conducted.

Key Pollutants

The Appraisal Framework requires that consideration be given to NOx [5] (nitrogen oxides), NO_2 (nitrogen dioxide) and fine particulate matter of less than 10 and 2.5 micrometres in diameter (PM_{10} and $PM_{2.5}$, respectively). The emissions inventories offer a modelled estimate of the overall mass emissions of NOx and PM_{10}. This allows a calculation of overall damage costs (health and environmental) in accordance with the cost per unit mass values specified by Defra.

The principal focus for the local assessment is on concentrations of NOx and NO_2. NOx concentrations are important in terms of the potential impacts on sensitive ecosystems, whilst NO_2 is important in terms of potential impacts on human health. Sensitive ecosystems may also be affected by nitrogen deposition, which is directly related to concentrations of NO_2.

Previous studies have demonstrated that airports have little impact on PM_{10} or $PM_{2.5}$ concentrations (DfT, 2006). Concentrations of these two pollutants across the Study Areas for each Scheme (see Section 3.2) are generally below the relevant air quality criteria and there is no risk that the schemes would cause exceedences to occur. However, in order to inform the health impact pathway assessment, PM_{10} concentrations have been quantified in terms of the incremental changes (between the Do-Minimum and With Scheme options) at sensitive receptors.

Assessment Scenarios

Do-Minimum and With Scheme air quality modelling has been undertaken for 2030. Consideration has been given to the three Schemes shortlisted by the Airports Commission: Gatwick Second Runway ("Gatwick 2R"), Heathrow Airport – North West Runway ("Heathrow NWR") and Heathrow Airport – Extended Northern Runway ("Heathrow ENR").

Assessments have also been carried out for a Baseline year (2009) primarily to test the performance of the model through verification against available monitoring data; this process is discussed in greater detail in Chapter 3 of this report.

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[5] NOx is the sum of nitrogen dioxide (NO_2) and nitric oxide (NO) and is expressed in terms of NO_2 mass equivalent concentrations

1.1.4 Overview of Approach

Pollutant emissions from airport sources and road transport arise principally from the combustion of fuel, although some fugitive emissions also arise (e.g. from. brake and tyre wear) and these have also been taken into account.

Detailed emissions inventories have been compiled for each of the scenarios described above, taking into account activity data (e.g. numbers and types of aircraft movements, traffic flows and composition) and other information such as fuel consumption. These emissions have then been assigned both spatially and temporally (e.g. by Terminal Stand location and season / hour of the day) and input into the ADMS-Airport dispersion model. The ADMS-Airport model is widely used in the UK for the assessment of airports, and was selected by DFT's Panel for the Sustainable Development of Heathrow (PSDH) for use in assessing expansion at Heathrow Airport, following a detailed model review and evaluation process (DfT, 2006). The model simulates the dispersion and dilution of emissions released into the atmosphere when combined with meteorological data (which describe wind speed, direction and atmospheric stability). The model has been used to predict ground-level concentrations of NOx, NO_2 and PM_{10} at a number of specific receptors. Nitrogen deposition rates at sensitive ecosystem receptors have been calculated from the NO_2 concentrations.

The model only takes account of those sources that are explicitly included within the emissions inventory. In order to account for emissions arising from other sources, both within and outside of the Study Areas, the background pollution contribution has also been taken into account using Defra Pollution Climate Model (PCM) generated year-specific 1x1km maps of background pollutant concentrations across the UK

The total annual emissions of NOx and PM_{10} have been derived from the inventories for comparison with the National Emissions Ceiling (NEC)[6], and have also been used to quantify (health and environmental) damage costs

Sensitivities and Sensitivity Tests

The assessment has included consideration of a number sensitivities and sensitivity tests to support the assumptions that have been made, and to take account of future uncertainties in the data; these are set out in Appendix H. Source apportionment of the various airport and road traffic contributions has been carried out to assist in this exercise and to identify specific areas for further consideration and analysis. These results are described in Chapters 4, 5 and 6 for each Scheme.

1.1.5 Report Structure

This report has been structured to address each of the outputs required for the local and national assessments, as follows:

- Chapter 2: Legislation and Policy Context
    - An introduction to the principal air quality issues;

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[6] A European obligation on the UK to not exceed nationally-established emissions limits

  - An overview of the principal policy context; and
  - A summary of the assessment criteria against which the impacts of the schemes are to be judged.

- Chapter 3: Assessment Methodology
  - Summary of the methodology that has been used to quantify the local and national air quality impacts of the schemes;
  - Summary of the tests that have been incorporated into the assessment to evaluate the sensitivity of key input data;
  - Future mitigation;
  - The limitations and assumptions of the assessment;
  - Summary of the assessment outputs that are provided;
  - Consideration of the Promoters' submissions; and
  - The approach taken to evaluate construction impacts.

- Chapter 4: Gatwick Second Runway
  - Key elements of the Scheme;
  - Current baseline position;
  - Emissions Inventory and Source Apportionment
  - Pollutant concentrations at all locations substantially affected by the Scheme and changes between Do-Minimum and With Scheme;
  - Number of properties and population where pollutant concentrations improve, worsen or stay the same;
  - Compliance with EU limit values;
  - Monetisation of health impacts and environmental damage;
  - Compliance with national emissions ceilings;
  - Impacts of the construction works;
  - Mitigation measures proposed by the Scheme Promoter; and
  - Commentary on the Promoter's submission.

- Chapter 5: Heathrow North West Runway
  - Key elements of the Scheme;
  - Current baseline position;
  - Emissions Inventory and Source Apportionment
  - Pollutant concentrations at all locations substantially affected by the Scheme and changes between Do-Minimum and With Scheme;
  - Number of properties and population where pollutant concentrations improve, worsen or stay the same;
  - Compliance with EU limit values;
  - Monetisation of health impacts and environmental damage;
  - Compliance with national emissions ceilings;
  - Impacts of the construction works;
  - Mitigation measures proposed by the Scheme Promoter; and
  - Commentary on the Promoter's submission.

- Chapter 6: Heathrow Extended Northern Runway
  - Key elements of the Scheme;
  - Current baseline position;
  - Emissions Inventory and Source Apportionment
  - Pollutant concentrations at all locations substantially affected by the Scheme and changes between Do-Minimum and With Scheme;
  - Number of properties and population where pollutant concentrations improve, worsen or stay the same;

  - Compliance with EU limit values;
  - Monetisation of health impacts and environmental damage;
  - Compliance with national emissions ceilings;
  - Impacts of the construction works;
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  - Appendix I: Highways Agency Compliance Risk Tool
  - Appendix J: Average Day Forecasting Methodology

2 Legislation and Policy Context

This Chapter covers:

- An introduction to the principal air quality issues;
- An overview of the policy context; and
- A summary of the assessment criteria against which the air quality impacts of the schemes will be assessed.

2.1 Introduction to Air Quality Issues

Air pollution can have serious effects on people's health. Exposure to air pollution is linked to both long and short-term effects on human health. Long-term exposure to air pollution is associated with premature mortality due to cardiovascular and pulmonary effects, whilst short-term exposure to high pollution episodes can cause increased hospital admissions and affects vulnerable members of the population by exacerbating symptoms such as asthma.

In the UK it has been estimated that the mortality burden associated with long-term exposure to particulate matter ($PM_{2.5}$) in 2008 was equivalent to 29,000 premature deaths in those individuals aged 30 years or older (COMEAP, 2010); this includes both primary $PM_{2.5}$ from direct emissions and secondary particulate matter formed from the chemical transformation of gaseous precursors including NOx. The economic cost from the impacts of air pollution in the UK is estimated at between £9-19 billion each year. Nitrogen dioxide also plays an important and independent role from $PM_{2.5}$, in exacerbating asthma, bronchial symptoms, lung inflammation and reduced lung function, through short-term exposure. Recent evidence published by the World Health Organisation (WHO, 2014) has strengthened the connection between exposure to NO_2 and health impacts, including chronic effects. The strength of this association is such that the effects may be comparable to those of $PM_{2.5}$, but only above a threshold annual mean concentration of 20 $\mu g/m^3$. This is currently under review by COMEAP, but is not yet included in the Defra damage costs.

Pollutant emissions are also associated with damage to built infrastructure and sensitive ecosystems. Nitrogen oxides (NOx) impacts on sensitive habitats and vegetation as it has the potential to alter nutrient availability and cause acid rain. NOx emissions are chemically transformed to NO_2 in the atmosphere, which leads to increased nitrogen deposition which may affect sensitive ecosystems.

2.2 Policy Context

2.2.1 European Union Ambient Air Quality and Clean Air for Europe, 2008

Directive 2008/50/EC Ambient Air Quality and Cleaner Air for Europe (Official Journal, 2008) entered into force on 11 June 2008, with Member States required to incorporate the provisions into National legislation before 11 June 2010.

The Air Quality Standards Regulations 2010 (Stationery Office, 2010) implement the requirements of the Directive into UK legislation. Compliance with the Regulations is a national obligation rather than a local one; in the UK, only monitoring and modelling carried out by the UK Government meets the data quality objectives that are required to assess compliance with the Limit Values.

The principal aim of the Directive is to protect human health and the environment by:

- avoiding, reducing or preventing harmful concentrations of air pollutants;
- the establishment of limit values;
- the assessment of air quality in a uniform manner;
- making air quality information available to the public; and
- setting out plans and programmes to maintain or improve ambient air quality conditions.

The Limit Values relevant to this assessment, as defined in the 2010 Regulations, are set out in Table 2.1.

Table 2.1 European Directive Limit Values

Pollutant	Concentration Measured As	Obligation	To Be Achieved By
Human Health			
Nitrogen dioxide (NO_2)	Annual mean	40 µg/m^3	2010
	1 hour mean	200 µg/m^3, no more than 18 occurrences each year	2010
Particulate Matter (PM_{10})	Annual mean	40 µg/m^3	2005
	Daily mean	50 µg/m^3, no more than 35 occurrences each year	2005
Particulate Matter ($PM_{2.5}$)	Annual mean	Target value of 25 µg/m^3	2010
	Annual mean	Limit value of 25 µg/m^3	2015
	Annual mean	Stage 2 indicative Limit value of 20 µg/m^3	2020
Ecosystems			
Nitrogen oxides (NOx)	Annual mean	30 µg/m^3	01 January 2005

Note: The macroscale siting criteria in the Directive states that sampling points for the protection of vegetation and ecosystems should be sited a) more than 20 km from an agglomeration (about 250,000 people), and b) more than 5 km from Part A industrial sources, motorways and built up areas of more than 5,000 people. The UK Government interprets this to infer that the critical level for NOx does not apply within these areas.

2.2.2 National Emissions Ceiling Directive

The 2001 National Emissions Ceiling Directive (NECD) (Official Journal, 2001) sets binding limits on Member States for the national emissions of four pollutants (NOx, sulphur dioxide, ammonia and non-volatile organic compounds), to be achieved by 2010 and not to be exceeded thereafter. The UK target for NOx in 2010 was 1,167 kt. The revision of the NECD is part of the implementation of the

Thematic Strategy on Air Pollution. The proposal to amend the NECD is still under preparation but is expected to set emission ceilings to be respected by 2030 for the four, already-regulated substances and for primary emissions of particulate matter ($PM_{2.5}$). The proposed ceilings are relative – that is, they are set as percentage reductions relative to emissions in 2005. For the UK, the proposals represent a 73% reduction for NOx, and a 47% reduction for $PM_{2.5}$ by 2030 (EC, 2013). A recent study published by IIASA[7] (IIASA, 2015) has re-run the GAINS[8] model resulting in a new set of proposed emissions ceilings (the “WPE2014 scenario”). For the UK, this implies a ceiling in 2030 of 414 kt of NOx (as compared to 430 kt for the original 73% reduction target) and 43.7 kt $PM_{2.5}$ (as compared to 49.3 kt for the original 47% reduction target). These proposals are currently under negotiation; for the purpose of this assessment, a 2030 NOx ceiling in the range of 410 to 440 kt, and a $PM_{2.5}$ ceiling in the range of 44 to 50 kt, has been assumed.

The Gothenburg Protocol is part of the Convention on Long-Range Transboundary Air Pollution (CLRTAP). The agreement covers Europe, North America and countries of Eastern Europe, Caucus and Central Asia.

The protocol is a multi-pollutant protocol designed to reduce acidification, eutrophication and ground-level ozone by setting emissions ceilings for sulphur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs) and ammonia (NH_3) which were to be met by 2010. In 2012, signatories to the Protocol, including the UK, agreed a set of revisions to reduce targets for national emissions of the four pollutants, along with Particulate Matter ($PM_{2.5}$), for 2020 and beyond. The UK has agreed to reduce its NOx emissions relative to 2005 (1,580 Kt) by 55% in 2020 (to 711 Kt), similarly $PM_{2.5}$ (81 Kt) emissions will be reduced by 30% (to 57 Kt).

2.2.3 Habitats Directive

European Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (the “Habitats Directive”) (Official Journal, 1992) requires member states to introduce a range of measures for the protection of habitats and species. The Conservation of Habitats and Species Regulations (The Air Quality Standards Regulations (No. 1001), 2010), transposes the Directive into law in England and Wales. The Regulations require the Secretary of State to provide the European Commission with a list of sites which are important for the habitats or species listed in the Directive. The Commission then designates worthy sites as Special Areas of Conservation (SACs). The Regulations also require the compilation and maintenance of a register of European sites, to include SACs and Special Protection Areas (SPAs); with the latter classified under the Council Directive 79/409/EEC on the Conservation of Wild Birds (Directive 2009/147/EC of the European Parliament and of the Council, 2009). These sites form a network termed “Natura 2000”. For further detail, please see the Module 7 Biodiversity: Assessment (Jacobs, 2014b).

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[7] International Institute for Applied Systems Analysis

[8] **G**reenhouse Gas and **A**ir Pollution **In**teractions and **S**ynergies model – used by the EC to establish a consistent framework for the analysis of co-benefits reduction strategies from air pollution and greenhouse gas sources.

2.2.4 UK Air Quality Strategy

The Air Quality Strategy published by the Department for Environment, Food, and Rural Affairs (Defra) provides the policy framework (Defra, 2007) for air quality management and assessment in the UK. It provides air quality standards and objectives for key air pollutants, which are designed to protect human health and the environment. It also sets out how the different sectors: industry, transport and local government, can contribute to achieving the air quality objectives. Local authorities are seen to play a particularly important role. The strategy describes the Local Air Quality Management (LAQM) regime that has been established, whereby every authority has to carry out regular reviews and assessments of air quality in its area to identify whether the objectives have been, or will be, achieved at relevant locations, by the applicable date. If this is not the case, the authority must declare an Air Quality Management Area (AQMA) and prepare an action plan which identifies appropriate measures that will be introduced in pursuit of the objectives.

The Air Quality Strategy sets out air quality objectives to protect human health and the environment. The objectives for use by local authorities are prescribed within the Air Quality Regulations 2000 (HMSO, 2000) and the Air Quality (Amendment) Regulations 2002 (HMSO, 2002). The objectives apply at locations where members of the public are likely to be regularly present and are likely to be exposed over the averaging period of the objective. Defra explains where these objectives should apply in LAQM Technical Guidance TG(09) (Defra, 2009). For the annual mean objectives, relevant locations are the facades of residential properties, schools, hospitals, care homes etc.

The air quality objectives relevant to this assessment are set out in Table 2.2.

Table 2.2 UK Air Quality Objectives

Pollutant	Concentration Measured As	Obligation	To Be Achieved By
Human Health			
Nitrogen dioxide (NO_2)	Annual Mean	40 µg/m^3	31 December 2005
	1 hour mean	200 µg/m^3, no more than 18 occurrences each year	31 December 2005
Particulate Matter (PM_{10})	Annual mean	40 µg/m^3	31 December 2004
	Daily mean	50 µg/m^3, no more than 35 occurrences each year	31 December 2004
Particulate Matter ($PM_{2.5}$)	Annual mean	25 µg/m^3	2020
Ecosystems			
Nitrogen oxides (NOx)	Annual mean	30 µg/m^3	01 January 2005

Note: The Air Quality Strategy (2007) states that the objective for NOx only applies a) more than 20 km from an agglomeration (about 250,000 people), and b) more than 5 km from Part A industrial sources, motorways and built up areas of more than 5,000 people. The NOx objective is not included in Regulations for LAQM.

2.2.5 National Planning Policy Framework

The National Planning Policy Framework (NPPF) (DCLG, 2012) sets out planning policy for England. It places a general presumption in favour of sustainable development, stressing the importance of local development plans, and states that the planning system should perform an environmental role to minimise pollution. One of the twelve core planning principles notes that planning should *"contribute to…reducing pollution"*. To prevent unacceptable risks from air pollution, planning decisions should ensure that new development is appropriate for its location. The NPPF states that the effects of pollution on health and the sensitivity of the area and the development should be taken into account.

The NPPF states that: *"Planning policies should sustain compliance with and contribute towards EU limit values or national objectives for pollutants, taking into account the presence of Air Quality Management Areas and the cumulative impacts on air quality from individual sites in local areas. Planning decisions should ensure that any new development in Air Quality Management Areas is consistent with the local air quality action plan"*.

The NPPF is supported by Planning Practice Guidance (PPG) (DCLG, 2014), which includes guiding principles on how planning can take account of the impacts of new development on air quality. The PPG states that *"Defra carries out an* *annual national assessment of air quality using modelling and monitoring to determine compliance with EU Limit Values"* and *"It is important that the potential impact of new development on air quality is taken into account … where the national assessment indicates that relevant limits have been exceeded or are near the limit"*. The role of the local authorities is covered by the LAQM regime, with the PPG stating that local authority Air Quality Action Plans *"identify measures that will be introduced in pursuit of the objectives"*. The PPG makes clear that *"Air quality can also affect biodiversity and may therefore impact on our international obligation under the Habitats Directive"*.

The PPG states that *"Whether or not air quality is relevant to a planning decision will depend on the proposed development and its location. Concerns could arise if the development is likely to generate air quality impact in an area where air quality is known to be poor. They could also arise where the development is likely to adversely impact upon the implementation of air quality strategies and action plans and/or, in particular, lead to a breach of EU legislation (including that applicable to wildlife)"*.

2.2.6 National Policy Statement for National Networks

The National Networks National Policy Statement (NN NPS) (DfT, 2014) sets out Government's policies on the development of nationally significant infrastructure projects on the national road and rail networks in England. With regard to air quality impacts and the decision making process, the NN NPS states:

"The Secretary of State must give air quality considerations substantial weight where, after taking into account mitigation, a project would lead to a significant air quality impact in relation to EIA and/or where they lead to a deterioration in air quality in a zone/agglomeration" (Para 5.12); and

"The Secretary of State should refuse consent where, after taking into account mitigation, the air quality impacts of the scheme will:

- *result in a zone/agglomeration which is currently reported as being compliant with the Air Quality Directive becoming non-compliant; or*
- *affect the ability of a non-compliant area to achieve compliance within the most recent timescales reported to the European Commission at the time of the decision."* (Para 5.13).

2.2.7 Countryside and Rights of Way Act, 2000

Sites of national importance may be designated as Sites of Special Scientific Interest (SSSIs). Originally notified under the National Parks and Access to the Countryside Act (1949), SSSIs have been re-notified under the Wildlife and Countryside Act (1981). Improved provisions for the protection and management of SSSIs (in England and Wales) were introduced by the Countryside and Rights of Way Act (2000) (the "CRoW" act) (HMSO, 2000). If a development is "likely to damage" a SSSI, the CROW act requires that a relevant conservation body (i.e. Natural England) is consulted. The CRoW act also provides protection to local nature conservation sites, which can be particularly important in providing 'stepping stones' or 'buffers' to SSSIs and European sites. In addition, the Environment Act (1995) and the Natural Environment and Rural Communities Act (2006) both require the conservation of biodiversity.

2.2.8 Critical Loads

Critical loads are the deposition fluxes (rates) below which significant harmful effects to sensitive ecosystems are unlikely to occur. Typically, the potential for exceedences of the critical loads is considered in the context of the level of protection afforded to the ecological site as a whole. Empirical critical loads for nutrient nitrogen are set under the CLRTAP. They are based on empirical evidence, mainly observations from experiments and gradient studies. Critical loads are assigned to habitat classes of the European Nature Information System (EUNIS) to enable consistency of habitat terminology and understanding across Europe. Critical loads are given as ranges (e.g. 10-20 kgN/ha/yr). These ranges reflect variation in ecosystem response across Europe. The Air Pollution Information System (APIS) website has provided a table of critical loads to use in impact assessments (APIS, 2015). It should be noted that the critical loads are derived from empirical or steady-state mass balance methods which are used to determine long-term critical loads for systems at steady state; thus, current exceedence of the critical load does not necessarily equate with ecosystem damage[9].

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[9] http://cldm.defra.gov.uk/crit_load_exceed_htm

3 Assessment Methodology

This Chapter covers:

- A summary of the methodology that has been used to quantify the air quality impacts of the schemes;
- Sensitivity tests;
- The limitations and assumptions of the assessment;
- Future mitigation;
- Assessment outputs;
- Consideration of the Promoter's submissions; and
- Construction impacts.

3.1 General Summary of Approach

This section describes the overall approach that has been adopted to quantify the air quality impacts of the schemes in terms of the specific outputs identified in the Appraisal Framework. The study has been founded on a detailed inventory of emissions, including both airport and surface access sources, for each scenario. These emissions have then been input to a model (ADMS-Airport) which calculates the dispersion and dilution of the pollutants (taking account of source strength, spatial distribution and meteorological variables including wind speed, wind direction and atmospheric stability) and predicts ground-level concentrations.

An important component of this process is model verification. Whilst the ADMS-Airport model has undergone detailed, peer-reviewed validation trials, it is important to demonstrate that the performance of the model within this study complies with recognised criteria. This has been accomplished by comparing measured values with modelled values. In undertaking this verification exercise, ideally all data (monitoring, emissions and meteorological) should originate from the same time period (year).

The baseline emissions inventories submitted by two of the Promoters are for different years, i.e. Heathrow (April 2008 - March 2009) and Gatwick (2010). This prevents adopting a consistent approach between the Schemes, for the following reasons:

- The choice of verification year influences the choice of meteorological year that may be used for the future year (2030) modelling predictions;
- 2010 is widely recognised as a *"high pollution"* year, due to the high background contribution; and
- Airport operations in 2010 were severely disrupted by the volcanic eruption in Iceland.

For this reason, the 2008/09 and 2010 inventories provided by the Promoters have been adjusted to a common calendar year (2009). A detailed description of this process is provided in subsequent sections.

3.1.1 National Compliance vs. Local Air Quality Management

It is important to recognise the difference between the EU Limit Values (for which compliance is determined at a national level by Government) and the air quality objectives (for which compliance is determined at a local level by local authorities under the LAQM regime). Whilst the Limit Value and air quality objective for the critical pollutant (NO_2) is set at the same concentration value (e.g. 40 µg/m^3, as an annual mean) the means of determining compliance are fundamentally different, and they must be considered separately.

Article 3 of the EU Directive requires Member States to nominate the competent authority for the assessment of air quality (which in the UK is the Secretary of State for the Environment) and it may be interpreted that only the competent authority can determine compliance with the Limit Values. Compliance is determined via the national monitoring network and national model (the Pollution Climate Mapping (PCM) model), and there are a number of important differences between this and the monitoring/modelling carried out by local authorities to determine compliance with the objectives. Some of these differences are summarised in Table 3.1.

Table 3.1 Comparison Between National and Local Compliance Approaches

	National Compliance	Local Compliance
Relevant exposure	Limit Values apply everywhere there is public access	Annual mean objectives only apply at locations where public exposure is relevant to the averaging period, e.g. at residential building facades
Treatment of junctions	Monitoring is not carried out with 25 metres of a junction and the same constraint is applied to the modelling	Junctions are specifically considered in both monitoring and modelling
Microscale	Excludes micro-environments and focuses on locations representative of 100m lengths of roads	Focuses on *“hot-spot”* locations
Roadside	Modelled concentrations apply to a distance of 4m from kerbside of the national road network. Local roads are excluded from the model	Focus is on concentrations at the building façade, whatever distance from the kerb and alongside any road.
Monitoring	Restricted to monitoring stations in the national network, operated to meet the Data Quality Objectives of the Directive	Principally based on local authority monitoring, including both automatic and passive diffusion samplers

Because of these differences, there are many locations across the UK where the national compliance with the Limit Values, and local compliance with the objectives, are not in agreement. For the purpose of this assessment, they are treated separately. This is consistent with the advice in the Planning Practice Guidance (see section 2.2.5).

The potential impact of each Scheme on the UK’s compliance with the EU Limit Values has been considered in the light of guidance set out in the National Policy Statement for National Networks (DfT, 2014).

Defra reports the compliance of a zone/agglomeration based on the maximum concentration modelled by the PCM model at any road link in that zone/agglomeration. The methodology defined in the Highways Agency’s Interim Advice Note IAN175/13 (HA, 2013) has been used to determine whether the Scheme would alter the date of compliance of a zone/agglomeration as reported to the European Commission by Defra[10]. The road network included in the compliance risk assessment for each Scheme is defined by overlaying the road network from this assessment onto the road network included in the PCM model. Where the two networks intersect, this is used to define the Compliance Risk Road Network.

3.2 Study Areas

Three distinct study areas have been considered for each Scheme.

The contribution of airport emissions to ground-level pollutant concentrations falls off rapidly with increasing distance from the airport boundary, and is very small beyond a distance of a few kilometres. The “Principal Study Area” for each Scheme has been selected to focus on sensitive properties and habitats likely to be substantially affected by the Scheme and encompasses a 2km radius around each Scheme boundary.

In addition, a “Wider Study Area” has been defined for the assessment of potential exceedences of the EU Limit Values (based on Defra future projections) and for the potential impacts on sensitive ecosystems. This Wider Study Area includes all roads for which a substantial change in traffic characteristics has been forecast in the 2030 With Scheme scenario, and has been based on criteria in the Highways Agency Guidance Design Manual for Roads and Bridges guidance (HA207/07 Air Quality) and the Airports Commission’s traffic change criteria set out within the Appraisal Framework. The combined criteria that have been applied to define the Wider Study Area are summarised in Table 3.2.

Finally, a “Traffic Model Simulation Area” has been used as the basis for the calculation of total surface access emissions. This area includes all roads that were considered in the traffic simulation model.

Table 3.2 Traffic Changes to Identify Wider Study Area

Traffic Characteristic	DMRB HA207/07	Airports Commission: Appraisal Framework	Deviations
Number of motor vehicles	+/- 1000 annual average daily traffic (AADT)	+/- 5% AADT or +/- 10% peak hours	+/- 500 AADT within or on the periphery of air quality management areas (AQMAs) Any change in traffic within 200m of internationally or nationally Designated Sites (ecosystems)
Average speed of traffic	+/- 10 kph AADT, or +/- 20 kph peak hours	No criteria	n/a

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[10] This is determined by the scheme resulting in a concentration higher than the existing maximum value in the zone/agglomeration, with the assumption that levels will reduce in future years across the zone/agglomeration, in a uniform manner.

Traffic Characteristic	DMRB HA207/07	Airports Commission: Appraisal Framework	Deviations
Heavy duty vehicles (HDVs)	+/- 200 AADT	No criteria	+/- 100 AADT (based on known sensitivities of road traffic emissions to HDV changes)

Note: Roads with low daily flows (<5,000 vehicles/day) have been excluded from the wider study area

3.3 Baseline Conditions

3.3.1 Monitoring Data

Information on Baseline (2009) conditions has been derived by collating the results of monitoring carried out by Government, the local authorities and the airport operators within each Study Area. To provide context on current air quality conditions, monitoring data have also been collated for all years up until 2014. All monitoring site types (e.g. roadside, background etc.) have been taken into account.

3.3.2 Mapped Background Concentrations

Information on background pollutant concentrations has been derived from the national maps prepared by Defra on a 1x1km grid square basis across the UK (Defra, 2015a). The background maps are based on a 2011 base year (in which the maps were calibrated against monitoring data). The 2011 background concentrations have been adjusted to 2009 using local monitoring data within each Study Area. The 2030 background concentrations have been derived directly from the maps for that year. A more detailed description of how these background maps have been interpolated is provided in Appendix A.

To avoid double-counting of source contributions, the 2009 and 2030 background concentrations input to the modelling study have been adjusted to remove the relevant sector contributions (which are explicitly included in the modelling study), based on guidance issued by Defra (Defra 2014). This has involved the removal of “in-square” source sector contributions for motorways, trunk roads, primary A roads and aircraft. For the background NO_2 concentrations, it is also necessary to adjust the concentrations in proportion to the reductions of NOx as a result of removing the specific source sectors. This has been achieved using the “NO_2 Adjustment for NOx Sector Removal Tool” (v4.0, 19 June 2014) (Defra, 2015a).

Whilst the existing contribution from minor road emissions is accounted for in this approach (as they remain included in the 1x1 km background values), it does not explicitly account for any incremental changes to traffic flows on these minor roads associated with the Schemes, as there is no way to estimate what these changes might be. In practice, the flows on the minor roads (some of which are cul-de-sacs) would not be expected to change to any large extent with the Schemes, so this omission is not expected to have had a significant impact on the assessment.

The out-of-square background values provide the contributions from baseline road traffic outside of the Principal Study Areas. In order to address the incremental effects of the Schemes on these contributions, the annual mean NOx and PM_{10} emissions from all roads within the Simulation Areas but outside of the Principal Study Areas have been aggregated into 1x1km grid squares. These grid squares have been included in the dispersion model as area sources and used to predict the concentrations at the centre of each background grid within the Principal Study Area. The incremental change (between Do-Minimum and With Scheme) has been added to each 1x1km adjusted background concentration.

3.3.3 National Compliance with EU Limit Values

Compliance with the annual mean EU limit value for NO_2 in 2009 and 2030 has been identified using the maps of roadside concentrations provided by Defra; these are derived using the Pollution Climate Mapping (PCM) model. These maps are used by the UK Government, together with the results from national Automatic Urban and Rural Network (AURN) monitoring sites that operate to EU data quality standards, to report exceedences of the limit value to the European Commission.

The PCM model includes all urban motorways and A-roads, but links can be excluded where there is no public access (e.g. where there are no adjacent buildings or pavements).

3.3.4 Air Quality Management Areas (AQMAs)

The locations of all AQMAs within the Principal Study Areas have been derived from the interactive maps published by Defra (Defra 2015b). This dataset contains information provided by the local authorities, and is correct as of January 2015. It is not practicable to derive the AQMA datasets for 2009 (as they are no longer available) but all the AQMAs shown were designated pre-2009, and there have been no changes over this time period.

It is important to note that the presence of an AQMA does not necessarily denote an exceedence of an air quality objective across the entire designated area. Many local authorities have chosen to designate whole-authority AQMAs, or AQMAs that cover much wider geographical areas than indicated by exceedences; this has been for administrative purposes, or to assist in the implementation of their action plans.

3.4 Sensitive Receptors

All sensitive receptors for human health and statutory designated nature conservation sites have been identified within the Principal Study Areas.

The selection of sensitive receptors for human health with regard to the air quality objectives has been undertaken in accordance with LAQM.TG(09). This states that the air quality objectives should be assessed in relation to "*the quality of the air at locations which are situated outside of buildings or other natural or man-made structures, above or below ground, and where members of the public are regularly present*". As described in Section 2.2.4, the annual mean objective for NO_2 thus applies at locations such as residential properties, schools, hospitals and care homes. Relevant locations have been identified using Ordnance Survey Address Base Plus mapping datasets. All health-based receptors were set at 1.5 metres height, at the address point location.

Statutory designated sites of nature conservation interest include Special Areas of Conservation (SACs), Special Protection Areas (SPAs), Ramsar sites, and Sites of Special Scientific Interest (SSSIs). This information has been derived from the Joint Nature Conservation Committee (JNCC, 2015). All identified sites within the Principal Study Areas have been reviewed to identify sensitivity to changes in air pollution, using the Air Pollution Information System (APIS). In addition, Natural England's Aviation Sensitivity Maps, provided in Jacobs' Module, 7 Biodiversity:

Assessment (Jacobs, 2014b), have been reviewed and any additional, potentially sensitive sites taken into account.

The selection of sensitive receptors for statutory designated nature conservation sites has been undertaken in accordance with the Design Manual for Roads and Bridges (HA207/07). Worst-case (typically roadside) locations within national, European and internationally-designated sites that lie within 200m of an affected road have been included, where the habitat associated with the primary reason for designation is determined to be nitrogen (N) sensitive. All receptors for nature conservation sites were set at 1.5 metres height.

The selection of receptors with regard to potential exceedences of the EU Limit Values has been based on the PCM roadside maps, described in Section 3.3.3, and covers the Wider Study Areas. Receptor locations have been placed at 4m from the kerbside (consistent with Defra's PCM mapping) at all locations within the Wider Study Area where Defra predicts that the Limit Value for NO_2 is exceeded, or is at risk of being exceeded in 2030. As a precautionary approach, a risk of exceedence has been taken to be any road link with a concentration of >32 $\mu g/m^3$.

3.5 Assessment Scenarios

Consideration has been given to the three Schemes shortlisted by the Airports Commission:

- Gatwick Second Runway (Gatwick 2R, with End-Around Taxiways), promoted by Gatwick Airport Limited (scenario: "Gatwick 2R").
- Heathrow Airport – North West Runway (NWR), promoted by Heathrow Airport Limited (HAL) (scenario: "Heathrow NWR");
- Heathrow Airport – Extended Northern Runway (ENR), promoted by Heathrow Hub Limited (HHL) (scenario: "Heathrow ENR"); and

The assessments have been carried out for a Baseline year (2009), primarily undertaken to test the performance of the model through verification against monitoring data. Do-Minimum and With Scheme assessments have been carried out for 2030 based upon the Airport Commission's demand model that results in the greatest likely air quality impact consistent with the Promoters' preferred business model. This means that the assessment is based on Carbon Traded Global Growth (CT GG) for Heathrow NWR and Heathrow ENR, and the Carbon Traded Low Cost is King (CT LCK) scenario for Gatwick 2R. The scenarios considered in this assessment are set out in Table 3.3 below.

Table 3.3 Assessment Scenarios

Scheme	Scenarios
Gatwick Baseline Heathrow Baseline	2009 Baseline (for model verification)
Gatwick 2R	2030 Do-Minimum 2030 With Scheme
Heathrow NWR	2030 Do-Minimum 2030 With Scheme
Heathrow ENR	2030 Do-Minimum 2030 With Scheme

3.6 Assessment Criteria

The principal criteria that have been used for the assessment of Scheme impacts are set out in Table 3.4, and have been derived from relevant policies and legislation described in Chapter 2.

Table 3.4: Assessment Criteria

Pollutant	Criteria	Averaging Period
Human Health		
Nitrogen Dioxide	40 µg/m^3	Calendar Year
Ecosystems		
Nitrogen oxides	30 µg/m^3	Calendar Year
Nutrient N Deposition	Site specific kg-N/ha/yr	Calendar Year

The 1-hour mean Limit Value/objective for NO_2 that is cited in Tables 2.1 and 2.2 has not been explicitly considered. It is extremely challenging to predict 1-hour mean concentrations with any certainty, and the annual mean limit value/objective is more stringent. Reliance is thus widely placed on an empirical relationship between the two metrics, whereby if the annual mean NO_2 concentration is less than 60 µg/m^3, there is little risk of exceeding the 1-hour mean criteria.

3.7 Compilation of Emissions Inventories and Dispersion Modelling

Inventories of emissions associated with each of the scenarios described in Table 3.3 have been compiled, taking into account the following sources:

- Aircraft engines during the Landing and Take-Off (LTO) cycle; this describes emissions during four modes of operation (taxiing, take-off, climbout and approach) representing different engine thrust settings, up to a height of 3,000 feet (915 metres);
- Aircraft Auxiliary Power Units (APUs);
- Ground Support Equipment, including airside vehicles and other plant such as Ground Power Units (GPUs);
- Airport heating plant; and
- Airport and non-Airport related road vehicles on the local road network

Emissions from the airport car parks, fire training grounds and aircraft engine ground-running have not been included, as they only make a minor contribution to ground-level concentrations for the pollutants of interest. In addition, the assignment of these sources in a consistent manner across the three schemes in 2030 would have been extremely difficult.

A description of the approach used to compile the airport and surface access emissions inventories, and to undertake the dispersion modelling study, is provided in this section, with further details provided in Appendix B and Appendix C respectively.

3.7.1 Airport Source Emission

Aircraft Emissions

Information on 2009 aircraft movements, types and engine assignments was provided by Heathrow Airport. Similar information was provided by Gatwick Airport, but for 2010; the 2009 aircraft movements for Gatwick were derived from the CAA UK Airport Statistics database (CAA, 2015). It was assumed that the aircraft types (fleet mix) operating in 2009 was unchanged from that in 2010.

For 2030, the aircraft movements and types for each Scheme have been based on the Airports Commission's Do-Minimum and Low Cost is King (carbon traded) and Global Growth (carbon traded) forecasts and conservative fleet mix assumptions, as appropriate.

Aircraft engine emissions during each mode of the LTO Cycle were derived from the International Civil Aviation Organisation (ICAO) E*ngine Exhaust Emissions Data Bank* (EASA, 2015) and the Federal Aviation Administration *Emissions and Dispersion Modelling System* (EDMS) v5.1.4.1 (FAA, 2015), based on the ICAO standard thrust settings for take-off (100%), climbout (85%), approach (30%) and idle/taxi (7%). Emissions for intermediate thrust settings were calculated using the advanced approach in the ICAO *Airport Air Quality Manual*. For the small number of turboprops in use at Gatwick Airport, emissions data were derived from the FOI database (FOI, 2015)[11]. As the latter only contains emissions data for NOx, PM emissions for turboprop engines were derived from the average ratio of NOx:PM emissions for turbofan engines.

The dispersion model takes account of the characteristics of the individual aircraft engines including their pollutant emission rates and their buoyancy flux (described in terms of the engine exhaust velocity and temperature, and the diameter of the engine exhaust). The exhaust buoyancy flux has been calculated from the jet engine thrust rating and the bypass ratio using the approach described in the ADMS-Airport model user guide (CERC, 2014). Other issues, such as the number of engines and their mounting position, are also important within the dispersion model. It is impractical to treat each airframe/engine combination separately, and so the aircraft were assigned into a number of "modelling categories" (MCATs), with "lead aircraft" selected to represent all aircraft within the individual MCATs. These lead aircraft were selected so as to be broadly representative of the other aircraft in the group, taking account of the most critical emission parameters (principally the buoyancy flux and NOx emission rate), but also taking account of overall ATMs (such that an uncommon airframe/engine combination was not selected as the lead aircraft in any MCAT).

To account for seasonal variations in airport activity, annual forecast aircraft movements were apportioned into quarterly (3-month) periods to represent variations in ATMs during different periods of the year. To account for fluctuations in airport and runway activity across the day, hour-by-hour diurnal profiles of aircraft departures and arrivals were determined for both Heathrow and Gatwick. For each airport, diurnal profiles for four 'typical' days were determined to represent activity during each of the quarterly periods of the year. For each of the four typical days, a separate diurnal profile was produced for each MCAT included in the dispersion model, as well as a total airport activity profile to apply to other airport emissions (e.g. APU and GSE) activities.

For 2030, airframe/engine assignments have been based on the Airport Commission's Passenger Demand Forecasts and known current airframe and common engine allocations from Air Transport Movement Data. Future aircraft have used proxy engine assignments based on known similarities and estimated CAEP

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[11] FOI is the Swedish Defence Research Agency

improvement trajectories. For the 2030 scenarios, MCATs have been determined for future aircraft/engine combinations using the same method as for 2009, by taking account of engine exhaust buoyancy flux and NOx emissions, as well as the forecast proportion of total annual airport ATMs.

There are, however, expected to be a number of new aircraft in operation by 2030, which are expected to be equipped with engines that have not yet been certified. These include:

- NEO Airbus A319, A320 and A321 – expected to be fitted with the PW1100G series of engines;
- New generation Boeing 737 series – expected to be fitted with the CFM-LEAP-1B engine;
- New generation Boeing 777 series – expected to be fitted with the GE9X engine; and
- Bombardier C100 series – expected to be fitted with PW1524G engine.

For MCATs with uncertified engine types, engine emissions and exhaust buoyancy flux characteristics (velocity, temperature and diameter) have been estimated, from an assessment carried out by LeighFisher, and based on information provided by the manufacturers, Pratt & Whitney, CFM International and General Electric. Information on the PW1524G engine was derived from published data provided by Bombardier.

No improvements to emissions associated with engine rollover to existing air frames was assumed, as it was deemed unrealistic within the timeframes under consideration (i.e. up until 2030).

Assumptions on aircraft times-in-mode (TIMs) for the 2009 baseline were based on information provided by the Promoters. For the 2030 Do-Minimum scenario at Gatwick, TIMs were assumed to be unchanged from the 2009 baseline, with the exception of minor adjustments to take-off and climbout times to account for new aircraft types that were not operational in 2009 (e.g. Boeing 787 and Airbus A350), and to account for a 3.2 degree glide slope on approach. For the Heathrow 2030 Do-Minimum scenario, take-off and climbout times were also adjusted to account for new aircraft types, and approach times to account for the changed glide slope; in addition, the taxi times were adjusted to account for the proposed new central airfield layout that will be operational at Heathrow by 2030. For the 2030 With Scheme scenarios (Heathrow - NWR and ENR, and Gatwick 2R), the TIMs for take-off, climbout and approach were assumed to be unchanged from the 2030 Do-Minimum scenarios; taxi-in and taxi-out times were adjusted to take account of the new apron and runway layouts, based on an historically-derived analysis of average taxi speeds.

Average aircraft hold times at runway ends have been provided by the Promoters for 2009. These represent the average length of time than an aircraft is queueing or held at idle waiting to access the main runway. Emissions from aircraft on hold at runway end have been determined based on the average hold time, assuming that the main engines run at idle thrust setting (7%). Delay times in 2030 have been assumed to be unchanged from 2009.

Engine thrust settings during take-off were provided for different aircraft types by the Promoters for 2009. The take-off thrust setting for each MCAT has been based on the typical take-off thrust setting for the lead aircraft in each MCAT. For 2030, thrust settings during take-off were assumed to be the same as for 2009. For new MCATs, a take-off thrust setting of 85% was assumed.

APU Emissions

The Auxiliary Power Units (APUs) are small gas turbines fitted to the aircraft which are used to provide power (e.g. for cabin conditioning) at times when the main engines are not running. It was assumed that APUs operate in the Environmental Control Systems (ECS) mode, with separate running times for wide and narrow-bodied aircraft, based on information provided by the Promoters. No changes to APU running times were assumed for any of the 2030 scenarios. Emissions data were derived from the ACRP Report 64 (ACRP, 2012).

Ground Support Equipment

Ground Support Equipment (GSE) includes vehicles and plant located airside, which are used to support the aircraft operations. These include vehicles used by caterers and fuel handlers, buses, Ground Power Units, and specialist vehicles (tugs, runway maintenance equipment etc.)

Emissions from GSE have been estimated from information on annual fuel consumption, for a variety of road and non-road engine types. Emission indices for road vehicle engines were derived from data presented in the Heathrow 2008/09 emissions inventory, calculated using emissions factors published by Defra in the Emissions Factor Toolkit (v6.0.2). For non-road mobile machinery (NRMM), emissions indices have been derived from the European Environment Agency (EEA)/EMEP) air pollutant emissions inventory guidebook (EMEP, 2013). The proportions of fuel used by GSE of different engine types (e.g. Euro V diesel HGVs, Euro 4 petrol cars, Stage II NRMM etc.) were provided for 2009 by Heathrow Airport and for 2010 by Gatwick Airport. It was assumed that the GSE fleet and fuel use in 2009 at Gatwick was the same as in 2010. Total annual GSE fuel use was obtained from the 2008/09 Heathrow Airport and 2010 Gatwick Airport emissions inventories.

For the 2030 scenarios, the fleet mix for road vehicle GSE was assumed to have the same age profile and proportion of Ultra-Low Emissions Vehicles (ULEVs) as in 2009, but projected forwards by 21 years. The 2030 activity data (i.e. fuel use by the different vehicle categories) was assumed to increase in proportion to the ratio of passenger numbers.

Heating and Energy Plant

Information on heating and energy plant at Heathrow was provided by the Promoter for 2008/09; this included release conditions for the major sources which were explicitly input to the ADMS-Airport model. For the minor sources, a conservative assumption was made on release height and conditions based on professional experience of gas-fired combustion sources.

For Gatwick, total annual NOx emissions from heating plant were obtained from the 2010 emissions inventory and assumed to be representative of emissions in 2009. Two key emissions points were identified for Gatwick at the North and South Terminal energy centres. The total NOx emissions were divided equally between these two points. Release conditions were estimated, based on professional experience.

For the 2030 scenarios, it has been assumed that all heating and energy plant at Heathrow are located within the main T2 and T5 energy centres. NOx emissions for

2030 have been calculated based on predicted energy consumption, assuming a NOx emission rate of 40 mg/kWh, which is typical of modern gas-fired heating plant. For Gatwick, a similar approach has been applied, assuming that both the North and South Terminal energy centres remain as the only heating and energy plant emission points at the airport.

PM_{10} and $PM_{2.5}$

Emissions of Particulate Matter (PM) from aircraft engines were based on the First Order Approximation v3.0, as recommended by ICAO. An adjustment to the emissions was applied to account for potential underestimates of organic and black carbon. All PM emissions from aircraft engines, APU use and GSE were assumed to be represented as both PM_{10} and $PM_{2.5}$.

Emissions from aircraft brake and tyre wear have been based on the recommended approach in the PSDH report (Curran, 2006).

Spatial and Temporal Assignments

Emissions from moving aircraft (during all modes) were represented in the model as “moving jet” sources. Emissions during take-off have been assumed to occur over the length of the runway between start of roll and wheels off, assuming a constant emission rate and uniform rate of acceleration. Initial climb-out and approach trajectories were assumed to follow straight-line pathways in the direction of the runways.

The choice of runways for the 2009 baseline year was based on information provided by the Promoters. For Heathrow Airport, the information was extracted from the (Business Objective Search System) BOSS database that was provided; for Gatwick Airport, runway use was allocated based on the wind direction threshold advised by the Promoter.

For the 2030 Do-Minimum scenarios, the forecast ATMs across each hour of the day have been allocated to runways using the same assumptions on wind directions. In the case of Heathrow Airport, the layout was assumed to be unchanged, but with full alternation in easterly operations.

For 2030 With Scheme scenarios, the allocation of aircraft at groups of aprons has been based on a high level analysis of the numbers of stands per terminal and their capacity to accommodate different types of aircraft (e.g. Code C, D or E). For the Heathrow NWR Scheme, runway assignments were based on the assumption that the four modes of operation (MDL, MLD, DLM and LDM) are used equally often. For the Heathrow ENR Scheme, runway assignments were based on the assumption that the two northern runways operate in single mode and the southern runway in mixed-mode, and that these are used equally often. For the Gatwick 2R Scheme, operations were assumed to be split equally in mixed-mode operation between the two runways.

In all cases, the choice of easterly or westerly operations has been based on the same meteorological thresholds as applied in 2009.

3.7.2 Roads (Surface Access) Sources

The proposed schemes have the potential to generate traffic, and influence traffic flows and routing on the surrounding road network. These changes to traffic behaviour and the associated vehicle emissions have the potential to impact on local air quality and to contribute to national emissions.

Traffic data for the modelling of each proposed Scheme were produced by Jacobs, as inputs for the air quality modelling of road vehicle emissions. The traffic model covered three scenarios:

- Base Year (2009): Used for model verification, against existing air quality monitoring data;
- Do Minimum (2030): This scenario represents traffic conditions without the airport expansion Schemes in place, but includes other committed development due to be in place before 2030; and
- With Scheme (2030): This scenario adds the traffic from the proposed airport Scheme to the Do-Minimum.

Traffic conditions on a section of road vary over the course of the day. Traffic data which represent the average conditions occurring in specific time periods were provided from the traffic model for the periods specified in Table 3.5.

Peak-hour spreading is a phenomenon that describes drivers electing to travel earlier or later to avoid travelling in ‘rush hour’, when journey times increase because a road or junction is over-capacity. Peak-hour spreading has been accounted for by incorporating the over-capacity flows within the three-hour wide Peak-Period calculations. This allows for the modelling to account for increased traffic during the peak periods in the With Scheme scenarios.

Table 3.5: Annual Average Weekday Time Periods used in the Assessment

Traffic Period	Time Period
Annual Average Daily Traffic (AADT)	00:00 – 24:00
Annual Average Weekday Traffic (AAWT)	00:00 – 24:00
AAWT AM Peak (AM)	07:00 – 10:00
AAWT Inter-Peak (IP)	10:00 – 16:00
AAWT PM Peak (PM)	16:00 – 19:00
AAWT Off Peak (OP)	19:00 – 07:00

For each time period, the following traffic data parameters were provided:

- Total traffic flow, defined as vehicles/hour;
- Percentage heavy duty vehicles (HDV); and
- Vehicle speed, in kilometres per hour (kph).

These data have been used in this assessment to calculate emissions from surface access associated with each Scheme.

The emissions of NOx and PM_{10} from road traffic sources have been derived from Defra’s Emission Factor Toolkit (EFT, version 6.0.2) issued in June 2014 (Defra, 2015b). There are a number of variables in the EFT that affect the emissions characteristic for the area; these include the type of road, the traffic flows and speeds across different periods of the day, and the fleet composition (the proportion of Heavy Duty and Light Duty Vehicles).

The vehicle emission factors in the EFT are speed-related; both queuing and congestion can affect vehicle emissions by reducing traffic speeds. Congested traffic conditions have been accounted for within the air quality modelling, by using the traffic speed output which includes trip delays, for each period.

The daily road traffic emissions for each modelled road link have been calculated by summing the time-weighted emissions from each traffic time period (as shown in Table 3.5), to incorporate the temporal variation in vehicle emissions. This time-weighted emission rate was modelled as a constant emission rate over the period of the day.

All road sources have been represented as line sources, aligned to the centreline of each road. Major roads, such as motorways and dualled A-roads, have been represented as separate line sources for each carriageway. The integrated traffic network (ITN) developed by the Ordnance Survey (OS) has been used to geo-reference road alignments within the dispersion model. The typical road width for each link has been derived from OS MasterMap 1:1,250.

It has been assumed that the Do-Minimum scenarios in 2030 will have the same road alignments as those given in the ITN layer. Where new roads, or changes in road alignments, are included within the Promoters' submissions, in the absence of confirmed alignments these have been included in the dispersion model using straight-line geometry derived from the traffic model. Thus, while the emissions from these new roads have been calculated in detail, the position and alignment of the new roads can only be broadly indicative at this time. The alignment of new roads will, in practice, be different from those simulated in the dispersion model.

Both the Heathrow NWR and ENR Schemes would require existing sections of road to be tunnelled. For both Schemes, this includes the M25 London orbital road which would run beneath the new runways. To account for emissions from road vehicles within these tunnels, the tunnel-end portals have been explicitly included in the dispersion modelling. These tunnel-end portals have been characterised as volume sources in the model, and assigned a width equivalent to that of the road/carriageway, a length of 20-30m extending from the end of the tunnel, and a depth of 5 m to account for the ceiling height of the portals. Total emissions from the tunnel sections have been calculated from the EFT (v6.0.2) based on the volume of traffic within each section, the average vehicle speed and the tunnel section length. These total emissions have been used to calculate volume source emission rates.

The proposed new roads could pass close to, or through, existing properties, based on the modelled straight-line routes. Modelled pollutant concentrations are highly dependent on the distance between the road and the property. Therefore, the predicted With Scheme scenario concentrations along the potential new route corridors can only be indicative, and should be treated with caution. To minimise the risk of receptors being assigned to unrealistic positions with respect to these indicative road alignments, existing properties within 10 m of these alignments have been excluded from the analysis. Properties within 200m of the new modelled roads have been identified within the appropriate Figures, but concentrations are not shown in the Figures, as they cannot be taken to be realistic. All modelled receptors within this 200m boundary (apart from those within 10m of the road) have, nevertheless, been included in the property counts to represent overall Scheme impacts.

3.7.3 Future Mitigation

Assessments for the Gatwick 2R, Heathrow NWR and Heathrow ENR scenarios have explicitly taken into account any 'mitigation by design' brought about by the re-alignment of airport access roads, physical changes in surface access, and physical alignments of the airport infrastructure (e.g. runway and apron layouts). These mitigation measures are included in the results.

Consideration has also been given to the more specific mitigation measures, set out by the Promoters, based on a qualitative or semi-quantitative approach, depending on the expected viability of the measure and the level of detail available. An assessment on the impact of these additional mitigation measures is provided in Chapters 4, 5 and 6.

3.8 Dispersion Modelling

The ADMS-Airport v3.4 model was used for the assessment (CERC, 2014). This is an advanced dispersion model that takes account of the latest understanding of the boundary layer structure, using advanced algorithms for the height-dependence of wind speed, turbulence and stability. It also makes use of the ADMS jet model for the assessment of aircraft exhausts, capturing the effect of the movement of the jet engine source in reducing the effective buoyancy of the exhaust. The model is able to incorporate a wide range of emissions sources, including those related to all airport and surface access activities, and this allows surface access and airport operational sources to be combined.

The airport and surface access sources were considered separately to predict annual mean NOx concentrations at the geo-referenced receptor locations. The two outputs were then added to produce combined annual mean NOx concentrations for post-processing to give NO_2 concentrations.

The ADMS-Airport model requires the user to input a number of variables related to the interpretation and use of the meteorological data. These key parameters include the latitude of the study area, and the surface roughness of both the study area and meteorological measurement site. The minimum Monin-Obukhov length (L_{MO}) was also defined. Other advanced settings, such as the surface albedo and Priestly-Taylor number, were left at their default settings. A summary of the model settings is provided in Table 3.6.

Table 3.6: Meteorological Input Parameters

Scheme	Met Site	Latitude (º)	Surface Roughness		L_{MO} (m)	
			Met Site	Dispersion Site	Met Site	Dispersion Site
Gatwick 2R	Gatwick Airport	51.15	0.2	0.75	30	30
Heathrow NWR	Heathrow Airport	51.50	0.2	1.00	30	30
Heathrow ENR	Heathrow Airport	51.50	0.2	1.00	30	30

3.8.1 NOx to NO_2 Conversion

The emissions from all combustion sources (including aircraft and road traffic) are predominantly in the form of nitric oxide (NO), although varying proportions of primary NO_2 are emitted from all sources. Nitric oxide is transformed to NO_2 in the atmosphere via a complex series of oxidative reactions. It is therefore necessary to convert the predicted NOx concentrations to NO_2, taking account of a number of factors that influence the relationship

The ADMS-Airport model includes a chemistry module that can be used to derive NO_2 from NOx, and which requires all NOx emission sources to be included in the same model run. As this assessment has necessarily been based on the separate treatment of airport and surface access sources (which have then been combined), the use of the chemistry module was precluded.

The calculations have therefore been based on the NOx:NO_2 calculation tool provided by Defra (Defra 2015c). A full description of the approach taken is set out in Appendix D.

3.8.2 Model Verification

The outputs from the airport, landside road network and background contributions have been combined to generate total annual mean pollutant concentrations. A comparison of the predicted versus measured 2009 concentrations has been undertaken to evaluate the model performance based on criteria in LAQM.TG(09) for correlation coefficient, root mean square error (RMSE) and Fractional Bias. The monitoring data used in model verification are described in Appendix E and the verification process itself is described in Appendix F.

3.8.3 Calculation of Nitrogen Deposition Rates

Nitrogen deposition rates have been calculated from the predicted ground-level NO_2 concentrations using the deposition velocities of 0.0015 m/s (grassland) or 0.003 m/s (forest) based on guidance provided by the Environment Agency in AQTAG06 (Environment Agency, 2011). The deposition velocities have been applied by multiplying the NO_2 concentration ($\mu g/m^3$) by the deposition velocity (m/s) to predict a deposition flux ($\mu g/m^2/s$). Subsequent calculations required to present the data as kg/ha/yr of nitrogen follow basic mathematical rules.

Wet deposition of nitrogen has been discounted. The low solubility of NO_2 means that any scavenging will be a negligible factor.

3.8.4 Population exposure

The population within the Study Areas in 2030 has been estimated using CACI datasets[12]. Population data attributed to postcode areas have been overlain on the Study Areas, and “clipped” to the Study Area extents. It has been assumed that the population is evenly distributed across the postcode area; those areas that overlay the Study Areas have been assigned a population based on the proportional area matched. Changes in pollutant concentrations predicted at each sensitive receptor, within each overlapping postcode area, have been averaged and multiplied by the estimated population attributed to that area. Population exposure to changes in air quality has therefore been estimated at a scale of micrograms per cubic metre per person per postcode.

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[12] CACI is a professional services and information technology company providing market intelligence, including population forecasts, based on census and other data www.caci.co.uk

3.9 Monetisation

The overall approach to Air Quality Impact monetisation follows the procedure set out in the Valuing impacts on air quality: Supplementary Green Book guidance (Defra, 2013).

The damage cost approach is used to estimate the size of the total air quality impacts through Health and Environmental damage. 'Environmental damage' is further subdivided into two categories: built environment and designated habitats. Defra's central estimates have been used to calculate damage costs, with sensitivity provided with reference to central-low and central-high figures. Reference is also made to the EEA values related to "value of a life year" (VOLY[1]) and "value of a statistical life" (VSL[2]) which give higher costs (EEA, 2014) related to health.

Damage costs are estimates of the cost to society of the likely impacts of changes in emissions, and they assume an average impact on an average population affected by changes in air quality. The steps are:

1. Calculate the changes in emissions; and then
2. Apply the damage costs (in £/tonne) which are provided in the Green Book guidance;

The Green Book guidance states that the 'impact pathway approach' should be considered where the environmental damage costs are more than £50 million. The impact pathway approach (Defra, 2013) is a detailed way to value air quality changes. A Partial Impact Pathway approach has been applied as a second stage monetisation, and has been based on the concentration response coefficients provided by the Defra impact pathway guidance[13], and applied to the predicted incremental changes to pollutant concentrations to calculate the effects on health of exposure, based on estimated populations derived from CACI population forecasts and spatial distribution. These health impacts have been monetised using the Interdepartmental Group on Costs and Benefits (IGCB) recommended values, converted to 2014 prices.

A more detailed consideration of the monetisation methodology is provided in Appendix G.

3.10 Limitations and Assumptions

The assessment has been carried out following the general processes and practices specified in Defra's LAQM.TG(09) Technical Guidance, although it is recognised that this document is not specifically aimed at airport studies. Wherever possible, the assessment has followed the "sophisticated" or "advanced" approach defined in the *Airport Air Quality Manual* published by the International Civil Aviation Organisation (ICAO) (ICAO, 2009); however, as the guidance in this document is

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[1] Value of a life year: An estimate of damage costs based upon the loss of life expectancy (expressed as potential years of life lost, or YOLLs). This takes in to account the age at which deaths occur by giving greater weight to deaths at younger age and lower weight to deaths at older age

[2] Value of statistical life (VSL): an estimate of damage costs based on how much people are willing to pay for a reduction in their risk of dying from adverse health conditions

[13] The Green Book is to be updated taking account of more recent findings such as the Health Risks of Air Pollution in Europe (HRAPIE) report (available at www.euro.wo.int), and revision of economic parameters, and it is recognised that the Green Book valuation based on emissions of NOx, does not include the direct effects of local NO_2 exposure.

founded on the assessment of existing airport operations, it has been necessary to make other assumptions on likely, future operations. Consideration has also been given, wherever practicable, to the recommendations within DfT's Project for the Sustainable Development of Heathrow (PSDH) report (DfT, 2006).

There are many components that contribute to the uncertainty of modelling predictions. Many of the inputs will have inherent uncertainties associated with them including the:

- Demand forecasts provided by the Airports Commission;
- Detailed aircraft movement data provided by LeighFisher; and
- Detailed traffic forecasts provided by Jacobs.

There are then additional uncertainties, as the model is required to simplify real-world conditions into a series of algorithms. An important stage in the process is model verification, which involves comparing the model output with measured concentrations. Because the model has been verified and adjusted as necessary, there can be reasonable confidence in the prediction of 2009 Baseline concentrations.

Predicting pollutant concentrations in a future year will always be subject to greater uncertainty. For obvious reasons, the model cannot be verified in the future, and it is necessary to rely on a series of projections and assumptions as to what will happen to aircraft movements and types, road traffic volumes, background pollutant concentrations, and aircraft engine and vehicle emissions.

Exceedences, and potential exceedences of the Limit Values in 2030, have been based on the PCM model forecasts published by Defra. These forecasts are based on vehicle emissions data in COPERT4v10, and do not take into account the potential benefits that may arise from the second phase of Euro 6 diesel cars and vans (the so-called "Euro 6c"), which are expected to become available around 2018. Euro 6c diesels are expected to have lower NOx emissions than the first phase of Euro 6 (Euro 6a/b), due to improved abatement and testing of real-world driving emissions. There are no Euro 6c vehicles to test at present and estimates of their performance can only be based on a prognosis of likely technologies; at present the best estimate is that NOx emissions for Euro 6c may be about 45% lower than Euro 6a/b. However, there is also the possibility that Euro 6c vehicles may have higher emissions of primary-NO_2 (which could increase roadside NO_2 concentrations) at least in the short to medium-term until emissions standards to limit this effect are agreed.

Revised emission factors that account for Euro 6c are included in COPERT4v11. These are currently being reviewed by Defra, and will be taken into account in future revisions to the PCM maps, but there is no robust manner in which to judge, at this time, what changes may occur. A sensitivity test regarding Euro 6 emissions has been carried out (Appendix H) but this cannot be reliably used to adjust the PCM maps. There is thus additional uncertainty associated with potential exceedences of the Limit Values in 2030.

The addition of the Scheme emissions to the national emissions to compare with national obligations is based on the assumption that Defra's 2030 forecasts do not include any allowance for new airport runways in south-east England. Defra's 2030 emission forecasts are thus assumed to be consistent with the Do-Minimum scenarios considered in this assessment.

3.11 Sensitivities and Sensitivity Tests

A number of sensitivities have been considered in the assessment to assist in the evaluation of some of the key assumptions. The potential influence of different meteorological years for dispersion modelling, and the potential effects of climate change have been considered. In addition, sensitivity tests have been carried out to quantify:

- The potential effects of higher primary NO_2 emissions from Euro 6c light duty vehicles in 2030; and
- The potential effects of lower NOx emissions from Euro 6c light duty vehicles in 2030.

The outcome of these sensitivities and sensitivity tests, and how they have informed the assessment, is provided in Appendix H.

Additional sensitivity tests have been carried out to inform the potential benefits of mitigation measures. These are described in Sections 4.6.3, 5.6.3 and 6.6.3 for each Scheme.

3.12 Source Apportionment

In addition to the source apportionment that has been provided in the tabulated results, a more detailed analysis has been carried out for receptors alongside a number of selected road links. This specifically takes account of any locations that are at risk of exceeding, or are predicted to exceed the objective or limit value. This analysis identifies the detailed contributions to NOx concentrations along these road links, specifically separating airport and road traffic sources.

3.13 Promoters' Submissions

The Promoters' submissions to the Airports Commission have been reviewed with respect to:

- the requirements of Appraisal Framework Module 6: Air Quality;
- their stated air quality impacts with regard to changes to pollutant concentrations at human health and ecosystem receptors, and compliance with the air quality objectives and limit values;
- their comparisons of emission changes with national emissions ceilings; and
- proposed measures to mitigate air quality impacts.

3.14 Construction Impacts

Air quality impacts associated with the construction of the proposed schemes have not been included in the detailed assessment. A high-level review of land take associated with the schemes, and the number of sensitive receptors within different distance bands has been undertaken to provide an indicative overview of the potential for dust nuisance. This includes distance banding based upon the Institute of Air Quality Management's (IAQM) Construction Dust Guidance (IAQM, 2014). For health-based impacts, this considers the number of receptors within 350m of the site boundary; for ecological receptors, this is based on any site within 50m of the site boundary.

For those schemes within Greater London (Heathrow NWR and ENR) consideration has also been given to guidance issued by the Greater London Authority (GLA, 2014).

Consideration has also been given to the mitigation measures described by the Promoter (where available), and the best-practice measures that should be employed, based on the IAQM and GLA guidance.

4 Gatwick Airport Second Runway

This Section focuses on the Gatwick 2R Scheme and

- Summarises the key elements of the Scheme insofar as they are pertinent to air quality impacts;
- Summarises the current baseline monitoring data;
- Describes the air quality impacts of the Scheme based on the ADMS-Airport modelling;
- Summarises the pollutant concentrations at all locations substantially affected by the Scheme;
- Identifies the number of properties and populations where pollutant concentrations improve, worsen or stay the same between the Do-Minimum and Gatwick 2R option;
- Quantifies the monetisation of health impacts and environmental damage;
- Identifies the effect of the Scheme with regard to compliance with national emissions ceilings;
- Describes the high level impacts of the construction works;
- Describes the likely effects of mitigation measures proposed by the Scheme Promoter; and
- Provides commentary on the Promoter’s submission.

4.1 Scheme Description

The key elements of the Scheme with regard to air quality impacts are:

- The construction of a new, parallel 3,400 metre runway to the south of Gatwick Airport; and
- The construction of a new midfield apron and terminal buildings, with associated aircraft movement areas and taxiways;

The Low Cost is King, Carbon Traded demand scenario of the Airports Commission’s forecast represents an additional 200,000 ATMs per annum with the Gatwick 2R Scheme, to give a total; of approximately 480,000 ATMs by 2030. In terms of operation, the two-runway airport would operate in simultaneous, independent mixed-mode operation. It has been assumed within this assessment that end-around taxiways would be provided to allow aircraft using the new runway to taxi around the existing runway, as opposed to taxiing across it.

4.2 Study Area

The Principal Study Area for the Gatwick 2R assessment is shown in Figure 4.1. This indicates the layout of the proposed Scheme and a 2km radius around the Scheme boundary.

The Wider Study Area indicating the full extent of the affected road network is shown in Figure 4.2. The Traffic Simulation Area used for the calculation of total surface access emissions is shown in Figure 4.3

4.2.1 Baseline Conditions

Air quality monitoring data across the study area are summarised in Appendix E, for the period 2009 to 2014. There are five continuous monitoring stations in the immediate vicinity of Gatwick Airport. Sites RG1 and RG2 lie to the north-east of the Airport within Horley, Site RG3 is to the south of the Airport, while Site CR1 is to the east. LGW3 is on the Airport, close to the eastern end of the runway and to the A23. All of these sites are classified as urban background, suburban, rural or airport, and there are no roadside or kerbside monitoring sites. Measured annual mean concentrations of NO_2 have generally been well below the air quality objective, although a marginal exceedence (41.1 µg/m^3) was recorded at the Gatwick East (CR1) site in 2014. PM_{10} concentrations are measured at two of these sites, RG1 and LGW3; the annual mean concentrations (18-23 µg/m^3) are well below the objective (40 µg/m^3), and the surrogate value for the daily mean objective (31.5 µg/m^3)[14]. There are no continuous monitoring stations measuring $PM_{2.5}$ in the vicinity of the Airport, but given that $PM_{2.5}$ levels are typically 75% of PM_{10} within this part of England (SNIFFER, 2010), it can be concluded that $PM_{2.5}$ concentrations are highly unlikely to exceed any relevant criteria.

The Scheme lies within the administrative area of Crawley Borough Council. The Borough has not declared any AQMAs, although an area adjacent to the A2011 has been identified as exceeding the annual mean objective for NO_2, and the local authority has concluded that an AQMA should be declared; this is pending approval by Defra. An AQMA for exceedences of the annual mean objective for NO_2 has been declared by Reigate and Banstead Borough Council, and which encompasses the south-west quadrant of Horley, immediately to the north-east of the Airport.

The location of the AQMA is shown in Figure 4.1

The Defra PCM maps indicate exceedences of the annual mean EU limit value for NO_2 in 2009 along the A23T (53.3 µg/m^3) to the south of Horley and along the A23 London Road (42.0 µg/m^3). This is illustrated in Figure 4.4.

The locations of internationally and nationally-designated statutory conservation sites within the Wider Study Area, are shown in Figure 4.5. These sites are also listed in Table 4.1, which also summarises the current background nitrogen deposition rates and NOx concentrations at these sites is shown in Table 4.1.

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[14] This is the surrogate threshold value applied by Defra in its assessments of national compliance

Table 4.1: Estimated Annual Mean Nitrogen Deposition Rates and NOx Concentrations (www.apis.ac.uk)

Site Name	Designation	Habitat Type	Critical Load (kgN/ha/yr)	Current N Deposition kgN/ha/yr	Current NOx Conc µg/m^3
Mole Gap to Reigate Escarpment	SAC and SSSI	Broad-leaved and mixed yew woodland	5-15	30.7	15.4
		Acid grassland	8-15		
		Dwarf shrub heath	10-20	16.7	
		Calcareous grassland	15-25		
		Mixed	N/A		
Thames Basin Heaths	SPA	Coniferous woodland	5-15	27.6	15.2
		Dwarf shrub heath	10-20	14.9	
Glovers Wood	SSSI	Broad-leaved, mixed and yew woodland	15-20	34.2	12.8
		Invertebrate assemblage	N/A	14.1	
Buchan Hill Ponds	SSSI	Broad-leaved, mixed and yew woodland	10-20	27.7	12.5
West Thurrock Lagoon & Marshes	SSSI	Littoral sediments	20-30	16.0	29.3
Lullingstone Park	SSSI	Broad-leaved, mixed and yew woodland	10-20	35.0	16.7
		Invertebrate assemblage	N/A	16.8	
Westerham Wood	SSSI	Broad-leaved, mixed and yew woodland	15-20	36.1	15.6
		Mixed scrub woodland	N/A	17.4	
Titsey Woods	SSSI	Broad-leaved, mixed and yew woodland	15-20	34.6	16.3
		Assemblage	N/A	16.9	
Epsom & Ashtead Commons	SSSI	Broad-leaved, mixed and yew woodland	10-15	28.9	19.1
		Lowland damp grassland	N/A	14.9	
Ockham & Wisley Commons	SSSI	Fen, marsh and swamp	10-15	14.8	18.4
		Dwarf scrub heath	10-20	14.8	

The current N deposition rates and NOx concentrations are the average values across the site, and represent the average value over a 3 year period, 2009-2011.

Current site-average nitrogen deposition rates exceed the upper range of the Critical Load at all sites; as set out in Section 2.2.7, this does not necessarily infer ecosystem damage.. Current site-average NOx concentrations are below the Critical Level and air quality objective.

4.3 Air Quality Assessment

The assessment for the Gatwick 2R Scheme has been carried out using the methodology described in Chapter 3. Specific input assumptions related to aircraft movements etc. are set out in detail in Appendix B.

4.4 Assessment Outputs

4.4.1 Emissions Inventory

A summary of the forecast emissions from the Do-Minimum and Gatwick 2R scenarios for each pollutant in 2030, and the incremental changes between them, is provided in Tables 4.2 and 4.3 respectively.

Table 4.2: Pollutant Emissions (te/yr) in 2030 for Do-Minimum (DM) and Gatwick 2R (2R) Scenarios – Traffic Simulation Area

Source Category		NOx (te/yr)		PM$_{10}$ (te/yr)		PM$_{2.5}$ (te/yr)	
		DM	2R	DM	2R	DM	2R
Aircraft	Take-off	232.8	509.6	7.9	12.3	7.9	12.3
	Initial Climb	293.7	630.9	10.4	15.7	10.4	15.7
	Climbout	458.5	985.1	16.3	24.5	16.3	24.5
	Approach	235.0	521.6	15.8	34.2	15.8	34.2
	Landing Roll (incl brake & tyre wear)	17.5	38.5	7.6	15.3	7.6	15.3
	Taxi + Hold	134.9	371.6	15.3	28.3	15.3	28.3
APU		116.5	272.1	3.0	6.2	3.0	6.2
GSE		50.4	73.2	3.2	4.5	3.2	4.5
Stationary sources (heating +boiler)		6.5	11.0	0	0	0	0
Airport sources (sub-total)		***1,545.8***	***3,413.7***	***79.6***	***140.9***	***79.6***	***140.9***
Surface Access Sources (sub-total) [1]		***5,228.9***	***5,257.8***	***841.7***	***846.4***	***467.9***	***470.6***
TOTAL		**6,774.7**	**8,671.5**	**921.3**	**987.3**	**547.5**	**611.5**

[1] These emissions are for all the roads in the Traffic Model Simulation Area, and include airport and non-airport related traffic.

Table 4.3: Incremental Change to Pollutant Emissions (te/yr) in 2030 between Do-Minimum (DM) and Gatwick 2R (2R) Scenarios

Source Category		Difference (te/yr)			Percentage Change		
		NOx	PM$_{10}$	PM$_{2.5}$	NOx	PM$_{10}$	PM$_{2.5}$
Aircraft	Take-off	276.8	4.4	4.4	118.9%	55.7%	55.7%
	Initial Climb	337.3	5.3	5.3	114.8%	51.0%	51.0%
	Climbout	526.6	8.2	8.2	114.9%	50.3%	50.3%
	Approach	286.6	18.4	18.4	122.0%	116.5%	116.5%
	Landing Roll (incl brake and tyre wear)	21.0	7.6	7.6	120.0%	101.3%	101.3%
	Taxi + Hold	236.7	13.0	13.0	175.5%	85.0%	85.0%
APU		155.6	3.2	3.2	133.6%	106.7%	106.7%
GSE		22.8	1.3	1.3	45.2%	40.6%	40.6%
Stationary sources (heating +boiler)		4.5	-	-	69.2%	-	-
Airport sources (sub-total)		***1,867.9***	***61.3***	***61.3***	***120.8%***	***77.0%***	***77.0%***
Surface Access Sources (sub-total) [1]		***28.9***	***4.7***	***2.7***	***0.6%***	***0.6%***	***0.6%***
TOTAL		**1896.8**	**66.0**	**64.0**	**28.0%**	**7.2%**	**11.7%**

[1] These emissions are for all the roads in the Traffic Model Simulation Area, and include airport and non-airport related traffic.

In 2030, the Gatwick 2R Scheme would increase emissions of NOx from 6,775 te/yr to 8,672 te/yr, an increase of 1,897 te/yr (28.0%) above the Do-Minimum. The increase is predominantly associated with the net change in aircraft emissions, and largely with non-ground operations (e.g. initial climb, climbout and approach). The incremental change associated with ground-based operations (airport and surface access) is 620 te/yr.

Emissions of PM$_{10}$ increase by 66.0 te/yr, from 921.3 te/yr to 987.3 te/yr (an increase of 7.2%) and emissions of PM$_{2.5}$ increase by 64.0 te/yr, from 547.5 te/yr to

611.5 te/yr (an increase of 11.7%). As described in Appendix B, emissions of PM_{10} and $PM_{2.5}$ have been assumed to be equivalent from airport sources.

4.4.2 Comparison with Emissions Ceilings

The National Atmospheric Emissions Inventory (NAEI) projections have been used to report the UK's status on compliance with the National Emissions Ceilings Directive and Gothenburg Protocol targets in 2030 (EIONET, 2015). The incremental change to NO_x and $PM_{2.5}$ emissions associated with the Gatwick 2R operations are presented in Table 4.4; these do not take account of the mitigation measures discussed in Section 4.5. There are no NAEI projections for PM_{10} as this pollutant is not prescribed under the NECD or Gothenburg Protocols.

Table 4.4: NAEI NO_x and $PM_{2.5}$ Emission Projections (kt/yr) for the UK

	NOx (kt/yr)	$PM_{2.5}$ (kt/yr)
NECD 2010 emission target	1,167	N/A
NECD 2030 emission target (proposed range)	410 - 440	44 - 50
Gothenburg Protocol 2020 emission targets	714	67
NAEI emission projections (2030)	585.7	50.7
NAEI emission projection + change associated with Gatwick 2R	587.6	50.8

The 2010 NECD target for NOx is 1,167 kt/yr, whilst the 2020 Gothenburg Protocol target is 714 kt/yr. The latest projections estimate that emissions will be well below these targets in 2030 (585.7 kt/yr). The incremental change to NOx emissions associated with the Gatwick 2R Scheme is 1.9 kt/yr, and would not cause the NECD or Gothenburg Protocol targets to be exceeded. As discussed in Chapter 3, the NECD targets are currently being revised, and the outcome of the negotiations is not yet known; an assumed target range of 410-440 kt/yr has been based on current proposals. If a target within this range were adopted, the UK would fail to meet compliance based on current forecasts, whether the Gatwick 2R Scheme were developed or not. The incremental change only represents about 0.46% of the lower range of the target.

The 2020 Gothenburg Protocol target for $PM_{2.5}$ is 67 kt/yr. The latest projections estimate that emissions will be below this target in 2030 (50.7 kt/yr). The incremental change to $PM_{2.5}$ emissions associated with the Gatwick 2R Scheme is 0.06 kt/yr, and would not cause the Gothenburg Protocol target to be exceeded. As discussed in Chapter 3, the NECD targets are currently being revised, and the outcome of the negotiations is not yet known; an assumed target range of 44-50 kt/yr has been based on current proposals. If a target within this range were adopted, the UK would fail to meet compliance based on current forecasts, whether the Gatwick 2R Scheme were developed or not. The incremental change only represents about 0.14% of the lower range of the target.

4.4.3 Predicted Concentrations at Health-Based Receptors

The predicted annual mean concentrations of NO_2 at the identified sensitive receptors are shown in Figure 4.6 and 4.7 for the Do-Minimum and Gatwick 2R scenarios respectively. The incremental change to annual mean NO_2 concentrations at each receptor is shown in Figure 4.8. The predicted concentrations, and the source contributions, are also set out in Table 4.5 for the Gatwick 2R scenario, for a selected number of receptors; these receptor locations are shown in Figure 4.9. These receptors are not necessarily intended to represent worst-case concentrations, but rather receptors at which airport and road-NOx contributions are important.

Table 4.5: Predicted Annual Mean NO_2 Concentrations (µg/m^3) at Selected Receptor Locations in 2030, with Gatwick 2R

Receptor ID	OS Grid Ref		Airport NOx	Road NOx	Backgnd NOx	Total NO_2
2R-A	524053	138409	5.7	1.1	10.9	11.8
2R-B	524115	139275	7.0	5.3	10.8	14.3
2R-C	524272	141041	3.8	9.9	11.5	15.2
2R-D	525135	138437	6.6	12.7	12.1	18.4
2R-E	525540	138486	5.6	2.9	12.7	13.9
2R-F	526287	138514	4.6	2.8	15.6	15.3
2R-G	526547	141906	7.2	6.3	13.8	16.8
2R-H	526989	138345	3.6	18.2	26.0	27.6
2R-I	527063	142274	9.9	7.0	14.6	18.8
2R-J	527682	142615	11.6	23.3	16.5	27.4
2R-K	528449	138089	2.7	35.2	35.4	38.6
2R-L	528600	141770	26.4	10.9	21.7	31.4
2R-M	528774	143258	9.2	12.0	21.0	24.6
2R-N	529150	139637	8.9	9.4	18.9	22.3
2R-O	529266	141996	13.8	13.8	18.5	25.7
2R-P	529706	139501	5.8	15.9	16.8	22.7
2R-Q	529722	140815	8.7	15.4	16.1	22.8
2R-R	529742	138570	3.8	22.6	19.7	26.1
2R-S	530378	140496	5.2	30.9	15.4	27.3
2R-T	530894	142808	5.1	32.6	14.5	27.4

There are no predicted exceedences of the air quality objective at any receptor location, in either the Do-Minimum or Gatwick 2R scenarios. The maximum predicted annual mean NO_2 concentration at any receptor location with the Gatwick 2R Scheme is 38.6 µg/m^3 and occurs to the south of the airport, close to the A2011 in Crawley, where the background concentration is higher; the incremental change above Do-Minimum is 4.6 µg/m^3. The maximum predicted incremental change (13.1 µg/m^3) occurs at the south-eastern boundary of the airport, where the predicted NO_2 concentration for the 2R Scheme is 30.7 µg/m^3.

The numbers of properties and the associated population where annual mean NO_2 concentrations are predicted to improve, worsen, or remain unchanged, are summarised in Table 4.6. The analysis excludes properties that lie within the Scheme boundary or within 10m of any new road link. The analysis considers the change with respect to "zero" (≤ ±0.05 µg/m^3) and within the concentration bands shown in Figure 4.8. For NO_2, a separate description is also provided for properties and populations “at risk” of exceeding the objective (i.e. greater than 32 µg/m^3).

Table 4.6 Properties and Populations Affected by Changes to Annual Mean NO_2 Concentrations within the Principal Study Area

Change in Concentration (µg/m^3)	Figure 4.8 Key	Properties Affected			Estimated Population Affected		
		NO_2		PM_{10}	NO_2		PM_{10}
		Absolute NO_2 <32µg/m^3	Absolute NO_2 >32µg/m^3		Absolute NO_2 <32µg/m^3	Absolute NO_2 >32µg/m^3	
>+12	●	5	0	0	12	0	0
+10 – +12	●	0	0	0	0	0	0
+8 – +10	●	5	0	0	12	0	0
+6 – +8	●	75	1	0	183	2	0
+4 – +6	●	1,217	4	0	2,977	10	0
+2 – +4	●	6,728	25	8	16,457	61	20
+0.05 – +2	●	12,893	32	20,975	31,536	78	51,303
+0.05 - -0.05	○	0	0	2	0	0	5
-0.05 – -2	●	0	0	0	0	0	0
-2 – -4	●	0	0	0	0	0	0
-4 – -6	●	0	0	0	0	0	0
<-6	○	0	0	0	0	0	0

The term “properties” refers to buildings with relevant exposure at ground level.

More properties experience an increase than a decrease or no change. As can be seen from Figure 4.8, the highest incremental changes occur close to main roads, and are concentrated in the area to the north-east of the Gatwick 2R boundary, in Horley. The average increase to annual mean NO_2 concentrations at affected properties is 2.1 µg/m^3. There are 62 “at risk” properties (>32 µg/m^3) that would experience an increase in NO_2 concentrations

Figures 4.10, 4.11 and 4.12 show the predicted annual mean PM_{10} concentrations for Do-Minimum, Gatwick 2R and Incremental Change respectively. The average change is an increase of 0.4 µg/m^3. These data are utilised in the Partial Impact Pathway assessment (Appendix G).

4.4.4 National Compliance

Table 4.7 sets out the results for the two Defra PCM modelled road links with NO_2 concentrations greater than 32 µg/m^3 in 2030. The links are also shown in Figure 4.13. If the Gatwick 2R Scheme is implemented, both links shown in Table 4.7 would be realigned and would become incorporated into the Scheme. It is, therefore not realistic to predict the incremental change to NO_2 concentrations at these links. On this basis, the Gatwick 2R Scheme would not alter Defra’s reported position on UK compliance with the Air Quality Directive.

Table 4.7: National Compliance – Predicted Annual Mean NO_2 Concentrations ($\mu g/m^3$) in 2030 with Gatwick 2R

Road Link	Maximum PCM Predicted Concentration in Defra Zone [1]	PCM Predicted Concentration for Link	Predicted 2R Incremental Change	Total NO_2 Concentration
Airport Way, A23	35.9	35.9	N/A [2]	N/A
London Road, A23	35.9	35.9	N/A	N/A

1. This value is the maximum predicted concentration by the PCM model in 2030 at any location within the South East Zone (31).
2. N/A = not applicable (see text)

The proposals for the A23 in the Gatwick 2R scenario are to realign the road several hundred metres to the east. The road would then re-join the existing A23 to the north-east of the existing North Terminal, where alterations would be made to the A23/Airport Way junction. It is not possible to replicate what Defra's PCM calculations of concentrations alongside this new road link would be, nor is it possible to confirm whether this link would be included in the PCM model (as it may be excluded due to lack of public exposure, as described in Chapter 3 of this report).

The PCM model does not predict any exceedences of the PM_{10} Limit Values.

4.4.5 Monetisation of Health Impacts and Environmental damage

The total damage costs for the Gatwick 2R (Low Cost is King) Scenario are set out in Table 4.8.

Table 4.8: Total Damage Costs – Gatwick 2R

2014 prices £ million	Green Book Central Estimate	Green Book Central – Low	Green Book Central - High	EEA – Low VOLY 1	EEA – High VSL 2
Total Present Value Damage - PM_{10}	£246.9m	£193.3m	£280.6m	£83.0m	£240.8m
Total Present Value Damage - NO_X	£73.6m	£57.4m	£83.7m	£266.6m	£721.9m
Total Air Quality Damage Costs over 60 Years	£320.5m	£250.7m	£364.2m	£349.6m	£962.7
Snapshot 2030	£4.2m	£3.3m	£4.7m	£5.9m	£16.3m
Snapshot 2040	£5.9m	£4.6m	£6.7m	£7.0m	£19.2m
Snapshot 2050	£6.1m	£4.8m	£6.9m	£6.1m	£16.8m
Snapshot 2060	£5.6m	4.4m	£6.4m	£5.6m	£15.6m

1. VOLY = Value of a life year
2. VSL = Value of a statistical life

The total costs of NOx and PM_{10} over the 60 year appraisal period, based on the unmitigated change in mass emissions with the Gatwick 2R Scheme in place, are £73.6m and £246.9m respectively (based on central estimate).

The Impact Pathway values for hospital admissions with the WHO Health Risks of Air Pollution in Europe (HRAPIE) concentration-response coefficients are reported in Appendix G

4.4.6 Nitrogen Deposition at Sensitive Ecosystems

The maximum predicted annual mean concentrations of nitrogen oxides and nitrogen deposition fluxes to each of the designated conservation sites identified in Table 4.1 are set out in Table 4.9 and Table 4.10.

Table 4.9: Maximum Nitrogen Oxides Concentrations (µg/m^3) at Designated Habitats for Do-Minimum (DM) and Change due to Gatwick 2R in 2030

Site Name	OS Grid Ref of Receptor		DM	Change Due to 2R
Mole Gap to Reigate Escarpment SAC and SSSI	524347	152422	56.8	3.4
Thames Basin Heaths SPA (W) Ockham & Wisley Commons SSSI	507989	159235	101.6	0.3
	507335	159467	127.0	2.1
Ockham & Wisley Commons SSSI	508033	159351	140.8	0.3
	507226	159522	166.2	1.9
Glovers Wood SSSI	523335	140920	12.3	1.5
	523161	141617	11.7	1.2
Buchan Hill Ponds SSSI	524506	134774	58.3	1.6
	524549	134518	43.1	-2.7
	524385	134511	32.0	-1.3
West Thurrock Lagoon & Marshes SSSI	557230	176669	47.8	0.6
Lullingstone Park SSSI	550403	164163	25.3	0.4
Westerham Wood SSSI	543909	154680	113.1	1.6
	543955	154641	84.4	1.3
Titsey Woods SSSI	541772	154434	133.9	2.2
	541783	154385	92.6	0.0
Epsom & Ashtead Commons SSSI	516465	158756	75.8	0.5
Critical Level			30	

The receptor for Mole Gap to Reigate Escarpment SAC and SSSI is inside the SSSI but nearer to the road than the SAC.

The Gatwick 2R Scheme would not cause any new exceedences of the Critical Level. The greatest incremental change occurs at the Mole Gap to Reigate Escarpment SAC and SSSI (3.4 µg/m^3) representing a 6% increase. A reduction in NOx concentrations is predicted to occur at the Buchan Hill Ponds SSSI (of up to 2.7 µg/m^3).

Table 4.10: Maximum Nutrient Nitrogen Deposition Fluxes (kgN/ha/yr) at Designated Habitats for Do-Minimum and Change due to Gatwick 2R in 2030

Site Name	OS Grid Ref of Receptor		DM	Change Due to 2R	Critical Load
Mole Gap to Reigate Escarpment SAC and SSSI (W)	524347	152422	23.3	0.4	5-15
Thames Basin Heaths SPA (W) Ockham & Wisley Commons SSSI (W)	507989	159235	25.1	<0.1	5-15
	507335	159467	26.9	0.1	
Ockham & Wisley Commons SSSI (G)	508033	159351	14.5	<0.1	10-15
	507226	159522	15.3	0.1	
Glovers Wood SSSI (W)	523335	140920	20.6	<0.1	15-20
	523161	141617	20.5	0.3	
Buchan Hill Ponds SSSI (W)	524506	134774	22.1	0.2	10-20
	524549	134518	20.5	-0.3	
	524385	134511	19.2	-0.2	
West Thurrock Lagoon & Marshes SSSI (G)	557230	176669	11.2	<0.1	20-30
Lullingstone Park SSSI (W)	550403	164163	22.1	0.1	10-20
Westerham Wood SSSI (W)	543909	154680	31.5	0.1	15-20
	543955	154641	29.2	0.1	
Titsey Woods SSSI (W)	541772	154434	32.0	0.2	15-20
	541783	154385	28.9	<0.1	
Epsom & Ashtead Commons SSSI (W)	516465	158756	23.6	<0.1	10-15

Where more than one Critical Load range applies within a site, the most stringent range has been used. Those sites with a letter (G) shown in parenthesis have been modelled using a deposition velocity of 0.0015 m/s which is typical for grassland. Those sites with a letter (W) shown in parentheses have been modelled using a deposition velocity of 0.003 m/s which is typical of woodland. The deposition velocity has been based on the habitat to which the most stringent Critical Load refers. The receptor for Mole Gap to Reigate Escarpment SAC and SSSI is inside the SSSI but nearer to the road than the SAC.

The Gatwick 2R Scheme would not cause any new exceedences of the lower or upper bounds of the Critical Loads. The greatest incremental change occurs at the Mole Gap to Reigate Escarpment SAC and SSSI (0.4 kgN/ha/yr) representing a 1.7% increase. A reduction in nitrogen deposition is predicted to occur at the Buchan Hill Ponds SSSI (of up to 0.3 kgN/ha/yr).

4.5 Construction Impacts

There are insufficient details available at this stage to undertake any quantitative assessment of the construction impacts. A qualitative assessment has been carried out, based on IAQM guidance, which assigns a risk category to construction sites based on the scale of the works and the proximity of sensitive receptors.

An analysis of the numbers of sensitive properties within different distance band categories cited within the IAQM guidance has been undertaken. As set out in Chapter 3, the precise alignment of new road links is not known at this stage, and so the analysis has been based solely on the Scheme boundary. The number of sensitive receptors within different distance bands is provided in Table 4.11.

Table 4.11: Numbers of Sensitive Receptors Within 350m of Scheme Boundary

Less than 100m	100 to 200m	200 to 350m	Total within 350m
160	253	564	977

There are no ecological receptors within 50m of the Gatwick 2R Scheme boundary, and any potential impacts can be discounted. The Scheme boundary is within a relatively rural setting, but given the size of the expected works, it is likely that the construction works will be classified as High Risk.

It is the view of IAQM that dust impacts (which may give rise to soiling nuisance and/or elevated PM_{10} levels) from construction sites can be mitigated, and that the residual impact should be insignificant in most cases. During the detailed design of the Scheme, a Construction Environmental Management Plan (CEMP) should be prepared which sets out in detail the best practice mitigation measures that will be applied, and how they will be managed. Guidance on best-practice measures is set out in the IAQM document.

There is evidence that effective mitigation can adequately control dust impacts from large construction projects. During the course of the Heathrow Terminal 5 construction works, a detailed dust monitoring network was established. The study concluded that there was no significant impact in the local area due to dust impacts (Entec, 2006).

With regard to emissions from on-site plant and construction traffic, impacts can be controlled by mitigation and use of low-emission plant and vehicles. The use of Stage IV emissions Non Road Mobile Machinery (NRMM) and Euro VI HGVs will minimise any impacts. Construction Logistics Plans allow site deliveries and removals to be managed so that they are made at times when they are most needed and when they will contribute least to local road network congestion.

4.6 Commentary on Promoter's Submission

This section focuses on the Promoter's predicted air quality impacts of the Scheme.

4.6.1 Information Provided by the Promoter

The Promoter has carried out a detailed air quality assessment to quantify the air quality impacts of the proposed Gatwick 2R in comparison with the Do-Minimum option. The Promoter has completed the assessments for 2040 and 2050.

The Promoter's submission describes air quality conditions in 2040 with respect to annual mean concentrations of NO_2, PM_{10} and $PM_{2.5}$, and the number of days exceedence of the daily mean PM_{10} objective. Although the Promoter states that exceedences of the EU Limit Values have been evaluated, this is not the case as no consideration has been given to national compliance (as predicted by Defra).

A comparison with the national emissions ceiling for NOx in 2040 is provided, together with an analysis of the damage costs based on the Supplementary Green Book guidance.

There are no specific mitigation measures set out that are included in the assessment, other than mitigation by design (e.g. achieving high public transport and congestion-free road access, and concentrating future airfield activities in the midfield area which is remote from sensitive receptors). Mitigation measures during construction include the use of low emissions vehicles, and during operation, encouraging airlines to shut down an engine during taxiing.

The assessment was carried out using the ADMS-Airport model, based on the 2010 emissions inventory. Key assumptions within the study are:

- The forecast aircraft fleet data were derived from information provided by Gatwick Airport, including diurnal profiles;
- For the future scenarios, the 2010 airframe/engine split was used in conjunction with the age profile of the global fleet and a fleet rollover model to derive future airframe/engine combinations. Future engine variants were included taking into account tighter NOx emissions standards;
- APU run times were based on Managing Director's Instructions[15] for 2011. APU emissions were assumed to be unchanged in future years;
- The GSE fleet emissions in 2040 were scaled up from 2010 based on passenger numbers and accounting for improved emissions;
- Road vehicle emissions were calculated using COPERT4v8.1 emission factors and fleet vehicle projections in the 2010 NAEI;
- Meteorological data for 2005/06 were used in conjunction with the 2010 emissions inventory;
- A detailed modelling evaluation study was undertaken in the 2005/06 assessment and a re-evaluation in the 2010 assessment. Both studies showed the model to be performing well and no adjustment was applied to the predicted concentrations (although the 2010 emissions inventory and air quality modelling report notes that an apron scaling factor had been applied to the 2005/06 results);
- An assessment of the air quality impacts during construction was carried out citing IAQM guidance; and
- Damage costs were calculated on the basis of £955 per tonne NOx (central estimate at 2010 prices) and £48,517 per tonne PM_{10} (central estimate at 2010 prices, based on "Transport Average" costs).

The principal conclusions of the Promoter's submission (with EATs) are:

- The Scheme would increase overall NOx emissions from 1,764 to 2,663 tonnes per annum in 2040 (principally associated with aircraft emissions). PM_{10} emissions are predicted to increase from 80 to 104 tonnes/annum, and $PM_{2.5}$ emissions from 47 to 64 tonnes per annum. The study area used for the quantification of emissions is not precisely stated, but the modelling grid was 6x8km;
- The total airport-related NOx emission in 2040, with the Gatwick 2R scenario, is 2,830 tonnes/annum, an increase of 1,070 tonnes above Do-Minimum. This is compared with a 2030 national emissions forecast of 589,000 tonnes;
- The maximum predicted annual mean NO_2 concentration in 2040 With Scheme (in the Horley AQMA), is 30.8 $\mu g/m^3$ (an increase of 0.6 $\mu g/m^3$ above Do-Minimum);
- There are no predicted exceedences of the annual mean limit value or air quality objective for NO_2 at locations that are relevant in terms of exposure;

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[15] Managing Directors Instructions are included in Airport's Conditions of Use and are to be complied with by all operators.

- The maximum predicted incremental change to annual mean PM_{10} concentrations (in the Horley AQMA) is 0.2 µg/m^3; there is stated to be no predicted exceedence of the EU limit value or air quality objective;
- The maximum predicted incremental change to annual mean $PM_{2.5}$ concentrations is 0.1 µg/m^3; there is stated to be no predicted exceedence of the EU limit value;
- Construction impacts are judged to be insignificant, taking into account proposed mitigation measures, although the risk-based approach set out in the IAQM guidance has not been strictly carried out; and
- The annual damage costs associated with NOx and PM_{10} emissions in 2040 are calculated to be £975,055 and £1,200,000 respectively.

4.6.2 Comparison with Promoter's Submission

Any direct comparison between this assessment for the Airports Commission and the Promoter's submission is confounded by the fact that two different assessment years have been used. This assessment has focussed on 2030, whereas the Promoter provides an assessment for 2040 and 2050. As many of the underlying assumptions on vehicle emissions and background concentrations will be substantially different between these years, direct comparison is not practicable. Added to this, different assumptions on the aircraft fleet and movements, passenger numbers, and associated surface access have been made.

It is noted that the model evaluation study did not include a comparison with any roadside monitoring sites, thus no road traffic adjustment was applied, as has been the case in this study. The road traffic increments of NOx concentrations may therefore have been underestimated.

The Promoter concludes that the Gatwick 2R Scheme would not cause any exceedences of the air quality objectives or EU Limit Values; the maximum predicted 2040 annual mean NO_2 concentration is 30.8 µg/m^3 in Horley (an incremental change of 0.6 above Do-Minimum). This assessment has shown a maximum predicted annual mean NO_2 concentration with Gatwick 2R, of 38.6 µg/m^3 in Crawley in 2030.

Whilst the Promoter compares predicted concentrations with the EU Limit Value this cannot strictly be done, as no consideration was given to Defra's PCM modelled concentrations (although Defra predictions are not available beyond 2030). The Promoter's assessment concludes that there would be no exceedences of the Limit Value with the Gatwick 2R Scheme.

The Promoter estimates that NOx emissions would increase from 1,764 to 2,663 te/yr in 2040, PM_{10} emissions from 80 to 104 te/yr, and $PM_{2.5}$ emissions from 47 to 64 te/yr. The incremental changes identified by the Promoter are about 50% lower than those determined in this study; this is predominantly associated with assumptions of aircraft emissions. The total emissions within the assessments cannot be compared, as substantially different study areas over which the emissions have been calculated were assumed (e.g. the Promoter estimates NOx emissions from surface access to be about 240 tonnes in 2040 with the Gatwick 2R Scheme, whereas this assessment estimates NOx emissions in 2030 to be 5,258 tonnes; this is, in part, related to the different scales of study area assumed). The Promoter concludes that the Gatwick 2R Scheme could be accommodated within the NECD and Gothenburg Protocol, which is consistent with this assessment.

The damage costs estimated by the Promoter are lower than calculated for this assessment, i.e. the Promoter estimates annual damage costs for 2040 to be about £2.2m compared with £5.9m for 200 in this assessment (Table 4.8).

4.6.3 Commentary on Promoter's Mitigation

An evaluation of the principal mitigation measures set out by the Promoter is provided below:

Measure 1: Achieving high public transport access and congestion-free road access.

The Surface Access Strategy sets out a vision for a high level of public transport access, but it is not clear whether this is deliverable. The surface access modal share and traffic volumes assumed in this Airports Commission assessment have been built into the dynamic modelling.

Reducing congestion has the potential to reduce emissions, which tend to increase as a result of stop-start driving. It is difficult to quantify how much the reduction would be without a detailed assessment, which could take the form of using instantaneous emissions with a microsimulation traffic model.

Measure 2: Concentrating future aircraft activities in the midfield area which is remote from populated areas.

The layout of the Gatwick 2R Scheme has been incorporated into this assessment, and this mitigation measure has been fully accounted for in the modelling study.

Measure 3: Encouraging airlines to shut down an engine during taxiing.

It is not clear to what extent shutting down one engine during taxiing is used by the airlines. The PSDH report (paragraph 109) notes that *"there are a number of reasons why engines cannot be shut down, such as the requirement for a cooling-down period (especially after having used reverse thrust above idle) and the difficulty of having to turn an aircraft on the taxiway against the live engine. This, coupled with advice from one manufacturer that NOx emissions may not benefit from this technique, has dissuaded some operators from pursuing its use more thoroughly"*.

In contrast, a study funded by NASA Ames (Kumar et al, 2014) concluded that single engine taxi-out procedures have the potential to reduce taxi-out NOx emissions by 27% at Orlando (MCO) Airport and by 45% at New York La Guardia (LGA). If implemented effectively, a potential reduction in taxi-out NOx emissions of approximately 25% for the Gatwick 2R Scheme might be achievable.

Measure 4: Supporting ongoing technological developments and innovation, including industry research into the use of alternative fuels for aircraft.

The feasibility for the uptake of alternative fuels (biofuels) into commercial airline operations is increasing; this is primarily driven by targets to reduce the carbon footprint, rather than to reduce emissions of pollutants such as NOx and fine particulate matter. Whilst a number of technical and economic challenges remain, it is anticipated that sustainable biofuels will represent an appreciable proportion of the global jet fuel supply in the future.

The International Air Transport Association (IATA) report on alternative fuel use for aviation (IATA, 2013) briefly discusses non-CO_2 emissions from biofuel use in aviation. The report cites evidence that the use of some certified biofuels can reduce emissions of ultrafine particles due to the lower fraction of aromatics and impurities in the fuel; however, the effects on reducing NOx emissions are less pronounced. The report further notes that *"significant research efforts are needed to better understand the issues related to non-CO_2 emissions"*.

The formation of NOx during the combustion of aviation fuel arises primarily from the oxidation of atmospheric nitrogen in high temperature flame regions within the turbine engine. For a given engine, the rate of NOx formation is dependent on many variables, which include the physical and chemical properties of the fuel in use. Biofuels are usually blended with standard Jet A/A1 kerosene in variable proportions to balance cost, availability and performance. Taking into account the uncertainty in economic feasibility and the possible range of fuel blends, it is not possible to quantify what, if any effect, the future uptake of biofuels would have on reducing NOx emissions from aircraft associated with the Gatwick 2R Scheme.

4.6.4 Additional Mitigation Measures

There are a number of additional mitigation measures, not specifically highlighted by the Promoter, which could be implemented. Commentary on these is provided below.

NOx emissions charging to encourage airlines to use the cleanest aircraft.

A NOx emissions charging scheme has been in operation at Gatwick Airport since 2004. There is no clear evidence that this measure has influenced airlines to select airframe/engine combinations with lower NOx emissions when the other economic and environmental factors are also taken into consideration. A recent review of the NOx emissions charging scheme (CAA, 2013) notes that *"the engines on 60% of British Airways' fleet of Boeing 747-400s were modified, possibly as a consequence of the NOx charge"*, but *"as airport charges are typically a small proportion of an airline's total costs, so the associated incentives for airlines to use aircraft with best-in-class NOx performance may be small compared to other drivers"*.

NOx emissions from aircraft engines are limited by the CAEP standards and this is the main driver to change; however, because of the desire to deliver improved fuel performance (with associated, higher Overall Pressure Ratios) there is limited evidence that the CAEP standards have significantly reduced emissions from aircraft engines when expressed in terms of kgNOx/second. The aircraft movements and fleet mix assumed for the Gatwick 2R Scheme have been based on the Airports Commission's Low Cost is King (Carbon Traded) scenario, and it would not be appropriate to adjust this assumption within the assessment.

Operate 2R airport with a steeper glide slope to reduce the impact of aircraft approach emissions at ground level.

A steeper glide slope of 3.2 degrees has been assumed for the Gatwick 2R Scheme. However, emissions during approach make very little contribution to ground-level concentrations (as the emissions are principally at altitude). This is confirmed in the report which was published by the Government's Air Quality Expert

Group (AQEG)[16], which noted that *“aircraft emissions between 100m and 1000m contribute little to ground-level concentrations”*.

Introduce a management process designed to improve airport efficiency and reduce hold times and delays through cooperation of pilots, airlines, ground crew and air traffic control.

Busy airports experience delays to departing aircraft between the push back from the stand and the start of take-off roll on the runway. The typical delay time (2 minutes) was provided by the Promoter of the Gatwick 2R Scheme for the 2009 baseline, and has been represented in the model as runway-end hold queues. For the 2030 Gatwick 2R scenario, departure delay times (runway hold times) were assumed to be unchanged from 2009 as no robust indication of future hold times was provided by the Promoter.

A UK runway resilience study, published in 2008 (SH&E, 2008) used electronic flight processing system (EFPS) data to analyse taxi times at Gatwick Airport to identify departure delay times. The delay times were calculated as the difference between the actual stand-to-runway taxi time and the unimpeded stand-to-runway taxi time. The resilience study concluded that average departure delay (i.e. runway hold times) at Gatwick was around 9 minutes, and thus substantially higher than that suggested by the Promoter.

A sensitivity test for increased departure delay times has been carried out to consider the potential impact in terms of NOx emissions, as described below.

In order to estimate possible delay times for Gatwick in 2030, departure delay curves have been provided by LeighFisher (LeighFisher, 2012). These allow typical delay times to be determined depending on the capacity ratio of the airport. Capacity ratios for the Gatwick 2R scenario, split into summer and winter, have been provided by LeighFisher.

To estimate an annual average delay time the following approach has been applied.

$$\text{DelayAA} = ((\text{DelaySMR} \times \text{ATMSMR}) + (\text{DelayWTR} \times \text{ATMWTR})) / \text{ATMA}$$

Where:

DelayAA = Annual Average Delay Time;
DelaySMR = Summer Average Delay Time (obtained from the summer delay curve using the summer capacity ratio);
ATMSMR = Total ATMs in the summer period;
DelayWTR = Winter Average Delay Time (obtained from the winter delay curve using the winter capacity ratio);
ATMWTR = Total ATMs in the winter period.
ATMA = Total Annual ATMs

Table 4.12 shows the calculation of the annual average departure delay times (DelayAA) for Gatwick 2R in 2030 using the summer and winter delay curves and capacity ratios provided by LeighFisher.

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[16] AQEG (2009) Nitrogen Dioxide in the United Kingdom

Table 4.12: Calculation of Annual Average Departure Delay Times

Scenario	Summer Capacity Ratio	Summer ATMs	Winter Capacity Ratio	Winter ATMs	Annual Average Delay Time ($Delay_{AA}$)
Gatwick 2R	0.9360	307,262	0.7458	172,745	9.21 mins

Using the annual average departure delay time in Table 4.12, a sensitivity test for total annual NOx emissions has been carried out for runway hold queues for the Gatwick 2R 2030 scenario. The results of the sensitivity test include a comparison with the total annual NOx emissions from runway hold queues assumed in the dispersion modelling study, and are shown in Table 4.13.

Table 4.13: Hold Time NOx Emission Sensitivity Test Results

Scenario	Hold Time Assumed in Model (mins)	Total Annual NOx from Hold Queues (t/yr)	Hold Time Assumed for Sensitivity Test (mins)	Total Annual NOx from Hold Queues (t/yr)	% Difference
Gatwick 2R	1.77	14.6	9.21	75.9	420%

The data in Table 4.13 suggest that the underestimate of NOx emissions associated with departure delay times in the model would be of the order of 420% if this approach was used. The potential to reduce average delay times below those assumed within the model appears infeasible and has not been explored in greater detail.

Install Fixed Electrical ground Power (FEGP) and Pre Conditioned Air (PCA) to all future aircraft stands to reduce the need for APU usage.

The Airports Commission assessment has been founded on information provided by the Gatwick 2R Promoter, and assumes full compliance with the Managing Directors Instruction (MDI) on maximum APU run times. However, there is no evidence that full compliance is achieved in practice. Uptake of greater FEGP use is sensitive to the cost incurred by airlines, and provision is no guarantee that it will be used. Should FEGP be made cost-advantageous to airlines over APU by the Promoter, then greater uptake is likely.

There are examples in Europe of international airport operators that enforce strict rules regarding the use of APU for commercial aircraft on both arrival and departure, for example at Faro Airport in Portugal, and Barcelona and Madrid Airports in Spain. The policy employed at Barcelona Airport has been published by Boeing (Boeing 2015), and states:

"*At Stands in contact with terminal: It is obligatory to use the 400 Hz facilities. The use of the air-conditioning facilities will be obligatory when the aircraft air conditioning is needed. The use of the aircraft APU is forbidden in these stands in the period between 2 minutes after blocks for the arrivals and 5 minutes before off-blocks for departure. The aircraft APU will only be able to be used when the fixed units are not operative and the mobile units are not available.*

At Remote Stands: The use of APU is forbidden except for 10 minutes after blocks for the arrival and 10 minutes before off-blocks for the departure except for wide bodied aircraft that may be allowed to use it 50 minutes before departure and 15 minutes after arrival."

In the Gatwick 2R Scheme, the ratio of remote stands to contact stands is approximately 20-25%. In terms of operation, the airport will preferentially use contact stands, and remote stand use is likely be much less than 20%. It is anticipated that the vast majority of aircraft will utilise contact stands and will have access to FEGP and PCA. As a sensitivity test for APU run times, NOx emissions have been calculated assuming that the Barcelona Airport APU usage times for contact stands are enforced with the Gatwick 2R Scheme. This represents a feasible minimum. The results of the sensitivity test are presented in Table 4.14.

Table 4.14: APU NOx Emission Sensitivity Test Results

Scenario	APU Run Time (used in dispersion model)	Total Annual NOx Emissions from APU (t/yr)	Sensitivity Test APU Run Time	Total Annual NOx Emissions from APU (t/yr)
2R	Arrival: 20 minutes for wide body and 15 minutes for narrow body aircraft. Departure: 89 minutes for wide body and 36 minutes for narrow body aircraft.	272.1	Arrival: 2 minutes for all aircraft. Departure: 5 minutes for all aircraft.	24.8

The results indicate an approximate 90% reduction in annual NOx emissions from APUs could be achievable if stringent regulations on APU run times were introduced and enforced in 2030, at all stands.

Improve the infrastructure for Ultra Low Emission Vehicles (ULEV) such as electric charging points and hydrogen fuel stations, both airside and landside.

It is not possible to forecast the uptake of ULEVs by airside operators or by visitors to the airport. The assessment has included a rollover model for road-vehicle GSE, such that the vast majority of vehicles will be Euro 6/VI by 2030. As non-road vehicles and plant are replaced less frequently, no rollover has been assumed but all new vehicles and plant have been assumed to comply with Stage IIIA emissions.

A substantial proportion of NOx emission from GSE in 2030 comes from the Non-Road Mobile Machinery (NRMM); this includes aircraft tugs, ground power units (GPUs), baggage tugs, belt loaders, cargo tractors and carts.

A feasibility study on extremely low emission technology GSE at Los Angeles (LAX) airport (Smith, 2013) sets out the 2013 GSE fleet at LAX, by fuel use. For almost all types of NRMM, there are electric-powered variants in operation, and for certain types, the proportion of electric variants operating at LAX in 2013 was between 45 and 95%, with a commitment to introduce more electric vehicles to the GSE fleet.

A sensitivity test for the introduction of a higher proportion of non-road GSE for the Gatwick 2R Scheme has been based on an assumption that 80% of the diesel NRMM is replaced with electric variants by 2030. This is based on 100% removal of GPUs due to extended coverage of FEGP across all aircraft stands, and evidence from LAX that operating with up to 95% electric NRMM is possible.

The results of the sensitivity test are set out in Table 4.15. The results suggest that the use of 80% electric NRMM within the GSE fleet could lead to reductions in total annual NOx emissions of around 43 te/yr, equivalent to a 60% decrease.

Table 4.15: Non-Road GSE NOx Emission Sensitivity Test Results – Gatwick 2R 2030

Total Annual NOx Emissions (te/yr)				% Difference
Non-Road GSE	All GSE	Non-Road GSE (80% Electric NRMM)	All GSE (80% Electric NRMM)	
54.2	73.2	10.8	29.9	-59.2%

The reduction in NOx emissions is founded on the simple assumption that replacement of 80% of the NRMM GSE with electric variants would reduce fuel use and NOx by an equivalent amount.

Introduce an airport congestion charge for people travelling to the airport. Possible exemptions for the greenest vehicles.

It is not clear how effective a congestion charge could be for the Gatwick 2R Scheme. An assessment on demand management measures in reducing car use at Heathrow Airport has been carried out for Appraisal Framework Module 4 (Jacobs 2015). Whilst the outcome of this assessment cannot be directly transferred to a different airport, the overall conclusions that the imposition of additional charges on car users could have a significant impact on car mode share and overall traffic demand, remain valid. Depending on the scale of charge imposed, and the extent of the scheme (i.e. whether it targets passengers, employees and/or taxis), it is possible that traffic generation with the Gatwick 2R Scheme could be reduced to 2013 levels.

4.7 Conclusions

The principal conclusions of this assessment with respect to the Gatwick 2R Scheme are:

- The Scheme would not affect compliance with the current NECD and Gothenburg Protocol obligations. If the NECD obligation is tightened in line with current proposals, the UK would exceed the obligation with or without Gatwick 2R. The incremental emissions associated with Gatwick 2R represent a very small fraction of the proposed obligations;
- The Scheme would not cause any exceedences of the Limit Value or air quality objective for NO_2, and would not delay Defra achieving compliance with the Limit Value in the relevant zone. The proposals for the Gatwick 2R Scheme include realignment of the A23 to the east, but it is not possible to replicate Defra's PCM predictions at this realigned link, nor is it possible to confirm whether this new link would be included in the PCM model (due to lack of public exposure) and no further assessment can be provided;
- The Scheme would not cause any new exceedences of the Critical Level (for NOx) or the lower band of the Critical Load (for nitrogen deposition), at any designated habitat. The Scheme would increase NOx concentrations in locations where the Critical Level is already exceeded (but as noted in Chapter 2, Defra's interpretation of the Directive is that the Critical Level does not strictly apply at these sites;
- The Scheme would worsen air quality (in terms of annual mean NO_2 concentrations) at about 21,000 properties;
- The total costs of the increases in NOx and PM_{10} emissions over the 60 year appraisal period, based on the unmitigated change in mass emissions with the Gatwick 2R Scheme in place, are £73.6m and £246.9m respectively.

4.7.1 Summary of Additional Mitigation

This assessment has taken into account mitigation by design, but has not included the mitigation measures proposed by the Promoter, or additional mitigation measures, as described in Section 4.6. A summary of all measures is provided in Table 4.16. It should also be noted (as described in Appendix H) that if the Euro 6c emissions standard for diesel cars and LGVs delivers the reduction in emissions as expected, then NOx emissions from road traffic could be 7% lower than has been assumed in this assessment.

Table 4.16: Summary of Mitigation Measures for Gatwick 2R

Mitigation Measure	Commentary
Achieving high public transport access and congestion-free road access	Reducing congestion has the potential to reduce emissions, which tend to increase as a result of stop-start driving. It is difficult to quantify how much the reduction would be without a detailed assessment, which could take the form of using instantaneous emissions with a microsimulation traffic model.
Concentrating future aircraft activities in the midfield area	The layout of the Gatwick 2R Scheme has been incorporated into this assessment, and this mitigation measure has been fully accounted for in the modelling study.
Encouraging airlines to shut down an engine during taxiing	It is not clear to what extent shutting down one engine during taxiing is used by the airlines, but has the potential to reduce taxi-out emissions by approximately 25%.
Technological developments and innovation, such as alternative fuels	Taking into account the uncertainty in economic feasibility and the possible range of fuel blends, it is not possible to quantify what, if any effect, the future uptake of biofuels would have on reducing NOx emissions from aircraft associated with the Gatwick 2R Scheme.
NOx emissions charging	A NOx emissions charging scheme has been in operation at Gatwick Airport since 2004. There is no clear evidence that this measure has influenced airlines to select airframe/engine combinations with lower NOx emissions, when the other economic and environmental factors are also taken into consideration. The aircraft movements and fleet mix assumed for the Gatwick 2R Scheme have been based on the Airports Commission's Low Cost is King (Carbon Traded) scenario, and it would not be appropriate to adjust this assumption within the assessment.
Steeper Glide Slope	A steeper glide slope of 3.2 degrees has been assumed for the Gatwick 2R Scheme. However, emissions during approach make very little contribution to ground-level concentrations (as the emissions are principally at altitude).
Improved Airport Efficiency	Hold times used in the modelling are likely to have been under-predicted, and thus a sensitivity test has been carried out to consider a more realistic scenario. The results of this test suggest that the NOx emissions underestimate associated with departure delay times in the model could be of the order of 420%. The potential to reduce average delay times below those assumed within the model appears infeasible and has not been explored in greater detail.
FEGP and PCA for all future aircraft stands	Uptake of greater FEGP use is sensitive to the cost incurred by airlines, and provision is no guarantee that it will be used. Should FEGP be made cost-advantageous to airlines over APU by the Promoter, then greater uptake is likely. There are examples in Europe of international airport operators that enforce strict rules regarding the use of APU for commercial aircraft on both arrival and departure. A sensitivity test has been undertaken

Mitigation Measure	Commentary
	that follows these rules, whereby APUs are only allowed to run for a maximum of 2 minutes on arrival and 5 minutes on departure. The results indicate an approximate 90% reduction in annual NOx emissions (approximately 25 te/annum) from APUs could be achievable if stringent regulations on APU run times were introduced and enforced in 2030, at all stands.
Infrastructure for ULEVs	It is not possible to forecast the uptake of ULEVs by airside operators or by visitors to the airport. A sensitivity test for the introduction of a higher proportion of non-road GSE for the Gatwick 2R Scheme has been based on an assumption that 80% of the diesel NRMM is replaced with electric variants by 2030. The results suggest that the use of 80% electric NRMM within the GSE fleet could lead to reductions in total annual NOx emissions of around 43 te/yr, equivalent to a 60% decrease.
Congestion Charging	It is not clear how effective a congestion charge would be with the Gatwick 2R Scheme. Depending on the charging scheme imposed, overall traffic demand could potentially be reduced to 2013 levels.

5 Heathrow Airport Northwest Runway

This Chapter focuses on the Heathrow NWR Scheme and:

- Summarises the key elements of the Scheme insofar as they are pertinent to air quality impacts;
- Summarises the current baseline monitoring data;
- Describes the air quality impacts of the Scheme based on the ADMS-Airport modelling;
- Summarises the pollutant concentrations at all locations substantially affected by the Scheme;
- Identifies the number of properties and population where pollutant concentrations improve, worsen or stay the same, between the Do-minimum and Heathrow NWR option;
- Quantifies the monetisation of health impacts and environmental damage;
- Identifies the effect of the Scheme with regard to compliance with national emissions ceilings;
- Describes the high level impacts of the construction works;
- Describes the likely effects of mitigation measures proposed by the Scheme Promoter; and
- Provides commentary on the Promoter’s submission.

5.1 Scheme Description

The key elements of the Scheme with regard to air quality impacts are:

- The construction of a new 3,500 metre runway to the north-west of Heathrow Airport; and
- The construction of two new terminal buildings, with associated aircraft stands, aircraft movement areas and taxiways;

The Global Growth, Carbon Traded demand scenario of the Airports Commission’s forecast, represents an additional 242,000 ATMs per annum with the Heathrow NWR Scheme, to give a total of approximately 722,000 ATMs per annum in 2030. In terms of operation, the three-runway airport would operate in four modes as summarised below. As each operating mode delivers the same capacity, it has been assumed that these modes occur in equal amounts over the year; this means approximately one-third of all departures and arrivals go to each runway.

Runway	Mode 1	Mode 2	Mode 3	Mode 4
North West	Mixed-mode	Mixed-mode	Landing	Departure
Centre	Landing	Departure	Departure	Landing
Southerly	Departure	Landing	Mixed-mode	Mixed-mode

5.2 Study Area

The Principal Study Area for the Heathrow NWR assessment is shown in Figure 5.1. This indicates the layout of the proposed Scheme and a 2km radius around the Scheme boundary.

The Wider Study Area indicating the full extent of the affected road network is shown in Figure 5.2. The Traffic Simulation Area, used for the calculation of total surface access emissions, is shown in Figure 5.3.

5.2.1 Baseline Conditions

Air quality monitoring data across the study area are summarised in Appendix E, for the period 2009 to 2014. Annual mean NO_2 concentrations are below the air quality objective at background sites, but exceedences have been consistently recorded at the monitoring station close to the north-west boundary of the airport (LH2 – approximately 190m to the north-west of the existing northern main runway) and at other sites close to busy roads across the Principal Study Area (e.g. the M4 motorway (HI0) and Oxford Avenue (HI3)). Measured annual mean concentrations of PM_{10} and $PM_{2.5}$ are well below the objectives.

The Scheme lies within the London Borough of Hillingdon. The Borough has declared an AQMA for exceedences of the annual mean objective for NO_2. The AQMA boundary encompasses the southern part of the Borough, including Heathrow Airport. AQMAs have also been declared by the neighbouring local authorities as follows:

- London Borough of Hounslow – whole-borough AQMA for exceedences of the annual mean objective for NO_2;
- Spelthorne Borough Council - whole-borough AQMA for exceedences of the annual mean objective for NO_2.

Slough Borough Council has also declared an AQMA, but it is not within the Principal Study Area.

The locations of the AQMAs are shown in Figure 5.1.

The Defra PCM maps indicate exceedences of the annual mean EU Limit Value for NO_2 in 2009 along a number of roads in the vicinity of Heathrow Airport, including:

- A4 Bath Road – 61.5 $\mu g/m^3$
- A312 – 63.1 $\mu g/m^3$
- A316 – 64.6 $\mu g/m^3$
- A3044 – 53.1 $\mu g/m^3$

There are further 2009 exceedences of the Limit Value within the Wider Study Area to the east, including along Chiswick High Road (75.8 $\mu g/m^3$). These exceedence areas are shown in Figure 5.4.

The locations of internationally and nationally-designated statutory conservation sites within, or immediately adjacent to the Wider Study Area, are shown in Figure 5.5. These sites are listed in Table 5.1, which also summarises current background nitrogen deposition rates and NOx concentrations.

Table 5.1: Estimated Annual Mean Nitrogen Deposition Rates and NOx Concentrations (www.apis.ac.uk)

Site Name	Designation	Habitat Type	Critical Load (kgN/ha/yr)	Current N Deposition kgN/ha/yr	Current NOx Conc µg/m^3
South West London Waterbodies	RAMSAR/SPA	Neutral grassland	20-30	16.5	25.8
		Standing open water	N/A	13.3	
Staines Moor	SSSI	Neutral grassland	20-30	16.4	26.0
		Standing open water	N/A	13.3	
		Littoral sediments	20-30	16.4	
		Fen, marsh and swamp	N/A	16.4	
		Vascular plant assemblage	N/A	13.3	
Wraysbury Reservoir	SSSI	Neutral grassland	20-30	17.6	26.8
		Standing open water	N/A	13.4	
		Littoral sediments	20-30	17.6	
		Superlittoral rock	N/A	17.6	
Kingcup Meadows & Oldhouse Wood	SSSI	Broad-leaved, mixed and yew woodland	10-20	38.2	25.1
		Fen, marsh and swamp	15-25	19.9	
		Neutral grassland	20-30	19.9	
Thorpe Park No. 1 Gravel Pit	SSSI	Standing open water	N/A	13.2	24.1
Wraysbury No. 1 Gravel Pit	SSSI	Standing open water	N/A	13.4	26.6
Langham Pond	SSSI	Neutral grassland	20-30	16.7	23.8
		Woodland	N/A	13.4	
Fray's Farm Meadow	SSSI	Fen, marsh and swamp	N/A	18.5	20.3
Wraysbury & Hythe End Gravel Pit	SSSI	Littoral sediments	20-30	16.7	25.5
		Standing open water	N/A	13.3	
		Lowland open water	N/A	13.3	
Dumsey Meadow SSSI	SSSI	Crested dog's-tail	20-30	15.3	20.3
Bushy Park and Home Park SSSI	SSSI	Acid grassland	10-15	15.4	23.9
		Veteran trees	N/A		
		Invertebrate assemblage	N/A		

The current N deposition rates and NOx concentrations are the average values across the site, and represent the average value over a 3 year period, 2009-2011.

Current site-average nitrogen deposition rates are below the lower range of the Critical Load at most sites, but above at two sites; as set out in Section 2.2.7, being above the Critical Load does not necessarily infer ecosystem damage. Current site-average NOx concentrations are below the Critical Level and air quality objective.

5.3 Air Quality Assessment

The assessment for the Heathrow NWR Scheme has been carried out using the methodology described in Chapter 3. Specific input assumptions related to aircraft movements etc. are set out in detail in Appendix B.

5.4 Assessment Outputs

5.4.1 Emissions Inventory

A summary of the forecast emissions from the Do-Minimum and Heathrow NWR scenarios for each pollutant in 2030, and the incremental changes between them, is provided in Tables 5.2 and 5.3 respectively.

Table 5.2: Pollutant Emissions (te/yr) in 2030 for Do-Minimum (DM) and Heathrow NWR (NWR) Scenarios – Traffic Simulation Area

Source Category		NOx (te/yr)		PM$_{10}$ (te/yr)		PM$_{2.5}$ (te/yr)	
		DM	NWR	DM	NWR	DM	NWR
Aircraft	Take-off	948.5	1,274.0	19.2	27.3	19.2	27.3
	Initial Climb	1,269.1	1,699.1	25.9	36.8	25.9	36.8
	Climbout	1,684.9	2,259.5	34.3	49.1	34.3	49.1
	Approach	738.8	994.5	43.7	62.1	43.7	62.1
	Landing Roll (incl brake & tyre wear)	58.3	78.6	22.8	31.4	22.8	31.4
	Taxi + Hold	610.2	1,301.0	33.4	80.1	33.4	80.1
APU		284.7	398.2	5.7	8.2	5.7	8.1
GSE		170.0	216.3	11.0	13.7	11.0	13.7
Stationary sources (heating +boiler)		85.8	100.6	0	0	0	0
Airport sources (sub-total)		***5,850.2***	***8,321.8***	***195.9***	***308.7***	***195.9***	***308.7***
Surface Access Sources (sub-total)[1]		***3,792.6***	***3,847.2***	***563.2***	***569.4***	***316.0***	***319.5***
TOTAL		**9,642.8**	**12,169.0**	**759.1**	**878.1**	**511.9**	**628.2**

[1] These emissions are for all the roads in the Traffic Model Simulation Area, and include airport and non-airport related traffic.

Table 5.3: Incremental Change to Pollutant Emissions (te/yr) in 2030

Source Category		Difference (te/yr)			Percentage Change		
		NOx	PM$_{10}$	PM$_{2.5}$	NOx	PM$_{10}$	PM$_{2.5}$
Aircraft	Take-off	325.5	8.1	8.1	34.3%	42.2%	42.2%
	Initial Climb	430.0	10.9	10.9	33.9%	42.1%	42.1%
	Climbout	574.6	14.8	14.8	34.1%	43.1%	43.1%
	Approach	255.7	18.4	18.4	34.6%	42.1%	42.1%
	Landing Roll	20.3	8.6	8.6	34.8%	37.7%	37.7%
	Taxi + Hold	690.8	46.7	46.7	113.2%	139.8%	139.8%
APU		113.5	2.5	2.5	39.9%	43.9%	43.9%
GSE		46.3	2.7	2.7	27.2%	24.5%	24.5%
Stationary sources (heating +boiler)		14.8	0.0	0.0	17.3%	0.0%	0.0%
Airport sources (sub-total)		***2,471.6***	***112.8***	***112.8***	***42.2%***	***57.6%***	***57.6%***
Surface Access Sources (sub-total)[1]		***54.6***	***6.2***	***3.5***	***1.4%***	***1.1%***	***1.1%***
TOTAL		**2,526.2**	**119.0**	**116.3**	**26.2%**	**15.7%**	**22.7%**

[1] These emissions are for all the roads in the Traffic Model Simulation Area, and include airport and non-airport related traffic.

In 2030, the Heathrow NWR Scheme would increase emissions of NOx from 9,643 te/yr to 12,169 te/yr, an increase of 2,526 te/yr (26.2%) above the Do-Minimum. The increase is predominantly associated with the net change in aircraft emissions, and largely with non-ground operations (e.g. initial climb, climbout and approach).

Emissions of PM_{10} increase by 119 te/yr, from 759 te/yr to 878 te/yr (an increase of 15.7%) and emissions of $PM_{2.5}$ increase by 116 te/yr, from 512 te/yr to 628 te/yr (an increase of 22.7%). As described in Appendix B, emissions of PM_{10} and $PM_{2.5}$ have been assumed to be equivalent from airport sources.

5.4.2 Comparison with Emissions Ceilings

The National Atmospheric Emissions Inventory (NAEI) projections have been used to report the UK's status on compliance with the National Emissions Ceilings Directive and Gothenburg Protocol targets in 2030 (EIONET, 2015). The incremental change to NO_x and $PM_{2.5}$ emissions associated with the Heathrow NWR unmitigated operations are presented in Table 5.4. There are no NAEI projections for PM_{10} as this pollutant is not prescribed under the NECD or Gothenburg Protocols.

Table 5.4: NAEI NO_x and $PM_{2.5}$ emission projections (kt/yr) for the UK

	NOx (kt/yr)	$PM_{2.5}$ (kt/yr)
NECD 2010 emission target	1,167	N/A
NECD 2030 emission target (proposed range)	410 - 440	44 - 50
Gothenburg Protocol 2020 emission targets	714	67
NAEI emission projections (2030)	585.7	50.7
NAEI emission projection + change associated with Heathrow NWR	588.2	50.8

The 2010 NECD target for NOx is 1,167 kt/yr, whilst the 2020 Gothenburg Protocol target is 714 kt/yr. The latest projections estimate that emissions will be well below these targets in 2030 (585.7 kt/yr). The incremental change to NOx emissions associated with the Heathrow NWR Scheme is 2.5 kt/yr, and would not cause the NECD or Gothenburg Protocol targets to be exceeded. As discussed in Chapter 3, the NECD targets are currently being revised, and the outcome of the negotiations is not yet known; an assumed target range of 410-440 kt/yr has been based on current proposals. If a target within this range were adopted, the UK would fail to meet compliance based on current forecasts, whether the Heathrow NWR Scheme were developed or not. The incremental change only represents about 0.61% of the lower range of the target.

The 2020 Gothenburg Protocol target for $PM_{2.5}$ is 67 kt/yr. The latest projections estimate that emissions will be below this target in 2030 (50.7 kt/yr). The incremental change to $PM_{2.5}$ emissions associated with the Heathrow NWR Scheme is 0.12 kt/yr, and would not cause the Gothenburg Protocol target to be exceeded. As discussed in Chapter 3, the NECD targets are currently being revised, and the outcome of the negotiations is not yet known; an assumed target range of 44-50 kt/yr has been based on current proposals. If a target within this range were adopted, the UK would fail to meet compliance based on current forecasts, whether the Heathrow NWR Scheme were developed or not. The incremental change only represents about 0.26% of the lower range of the target.

5.4.3 Predicted Concentrations at Health-Based Receptors

The predicted annual mean concentrations of NO_2 at the identified sensitive receptors are shown in Figure 5.6 and 5.7 for the Do-Minimum and Heathrow NWR scenarios respectively. The incremental change to annual mean NO_2 concentrations at each receptor is shown in Figure 5.8. The predicted concentrations, and the source contributions, are also set out in Table 5.5 for the Heathrow NWR scenario for a selected number of receptors; these receptor locations are shown in Figure 5.9. These receptors are not necessarily intended to represent worst-case concentrations, but rather receptors at which airport and road-NOx contributions are important.

The maximum predicted annual mean NO_2 concentration with the Heathrow NWR Scheme is 34.7 $\mu g/m^3$ and occurs to the north-east of the airport, at Bath Road (A4); the incremental change above Do-Minimum is 0.4 $\mu g/m^3$. The maximum predicted incremental change (10.8 $\mu g/m^3$) occurs to the north-west, adjacent to the new third runway, where the predicted concentration for the Heathrow NWR Scheme is 32.9 $\mu g/m^3$. There are no predicted exceedences of the air quality objective at any receptor location, in either the Do-Minimum or Heathrow NWR scenarios.

Table 5.5: Predicted Annual Mean NO_2 Concentrations ($\mu g/m^3$) at Selected Receptor Locations in 2030, with Heathrow NWR

Receptor ID	OS Grid Ref		Airport NOx	Road NOx	Backgnd NOx	Total NO_2
NWR-A	501268	178074	2.2	6.4	23.3	20.2
NWR-B	501352	176386	2.7	2.1	19.0	15.6
NWR-C	502602	173280	4.0	33.8	20.2	30.1
NWR-D	502777	177055	5.5	33.3	23.9	32.6
NWR-E	503422	178761	5.5	4.3	26.8	22.4
NWR-F	504209	174945	12.4	6.8	20.5	23.0
NWR-G	505210	178469	11.4	14.5	25.3	28.4
NWR-H	505953	174022	9.3	2.7	20.2	19.6
NWR-I	506490	179566	5.5	5.0	31.3	25.1
NWR-J	507132	177938	13.6	6.0	23.0	24.9
NWR-K	507561	170562	2.3	10.0	18.3	18.6
NWR-L	507989	177031	19.2	4.9	23.6	27.1
NWR-M	509121	177076	22.5	3.4	23.3	27.7
NWR-N	509640	175229	17.1	3.7	22.5	25.3
NWR-O	509640	175229	15.8	6.2	23.8	26.2
NWR-P	510183	178361	6.5	14.1	24.4	25.9
NWR-Q	510223	176477	11.3	2.7	23.1	22.6
NWR-R	511058	173420	4.4	14.0	21.9	23.6
NWR-S	511517	176330	6.3	14.0	23.3	25.3
NWR-T	512517	174604	3.7	1.7	21.4	17.4

The numbers of properties and the associated population where annual mean NO_2 concentrations are predicted to improve, worsen, or remain unchanged, are summarised in Table 5.6. The analysis excludes properties that lie within the Scheme boundary or within 10m of any new road link. The analysis considers the change with respect to "no change" (≤ ±0.05 $\mu g/m^3$) and within the concentration bands described in Figure 5.8. For NO_2, a separate description is provided for properties and populations “at risk” of exceeding the objective (i.e. greater than 32 µg/m^3).

Table 5.6 Properties and Populations Affected by Changes to Annual Mean NO_2 Concentrations within the Principal Study Area

Change in Concentration (µg/m^3)	Figure 5.8 Key	Properties Affected			Estimated Population Affected		
		NO_2			NO_2		
		Absolute NO_2 <32µg/m^3	Absolute NO_2 >32µg/m^3	PM_{10}	Absolute NO_2 <32µg/m^3	Absolute NO_2 >32µg/m^3	PM_{10}
>+12	●	0	0	0	0	0	0
+10 – +12	●	0	7	0	0	18	0
+8 – +10	●	34	0	0	88	0	0
+6 – +8	●	72	1	0	186	3	0
+4 – +6	●	640	1	7	1,651	3	18
+2 – +4	●	2,386	3	45	6,153	8	116
+0.05 – +2	●	43,917	2	46,898	113,262	5	120,951
+0.05 - -0.05	○	19	0	160	49	0	413
-0.05 – -2	●	145	0	117	374	0	302
-2 – -4	●	0	0	0	0	0	0
-4 – -6	●	0	0	0	0	0	0
<-6	○	0	0	0	0	0	0

The term “properties” refers to buildings with relevant exposure at ground level.

As can be seen from Figure 5.8, the highest incremental changes take place to the east (Colnbrook) and west (Sipson) of the new runway, as well as to the north of the new airport boundary. The changes near the ends of the new runway are predominantly driven by aircraft taking-off. More properties experience an increase than a decrease or no change. The average increase to annual mean NO_2 concentrations at affected properties is 0.9 µg/m^3. There are 14 “at risk” properties (>32 µg/m^3) that would experience an increase in NO_2 concentrations.

Figures 5.10, 5.11 and 5.12 show the predicted annual mean PM_{10} concentrations for Do-Minimum, Heathrow NWR and Incremental Change respectively. The average change is an increase of 0.2 µg/m^3. These data are utilised in the Simplified Impact Pathway assessment (Appendix G).

5.4.4 National Compliance

Table 5.7 sets out Defra’s PCM modelled road links with NO_2 concentrations for greater than 32 µg/m^3 in 2030. The forecasts are also shown in Figure 5.13. The incremental changes to annual mean NO_2 concentrations in 2030, associated with the Heathrow NWR Scheme at these locations, are also shown in Table 5.7.

It is important to note that there is a predicted reduction in traffic on Bath Road (A4) associated with the Heathrow NWR Scheme; this is due to the rerouting of the A4/Colnbrook bypass and severance of the Bath Road crossing of the M25. In addition, the existing western link of Bath Road falls within the Heathrow NWR red line boundary and is effectively removed.

Table 5.7: National Compliance – Predicted Annual Mean NO_2 Concentrations ($\mu g/m^3$) in 2030

Road Sector	Maximum PCM Predicted Concentration in Defra Zone [1]	PCM Predicted Concentration for Road Sector [2]	Predicted NWR Incremental Change [3]	Total NO_2 Concentration [4]
Bath Road, A4 (junction A437 to west of Newbury Road)	48.6	47.4	1.3	48.7
A4 (junction of Fulham Palace Road to Earls Court Road)	48.6	37.4 – 44.9	0.5 – 0.6	38.0 – 45.4
A312	48.6	32.1 – 33.9	0.6 – 1.2	32.9 – 33.3
A40 Western Avenue (junction A406 to east of A219)	48.6	37.8 – 44.3	0.2 – 0.4	37.2 – 44.5
Junction of Kew Rd/ Gunnersbury Ave extending east along A4 to Chiswick Lane	48.6	33.7 – 33.9	0.6 – 3.7	34.5 – 37.4
M4 (Windmill Rd) extending west along Great West Road	48.6	33.3	n/a	33.3

1. This value is the maximum predicted concentration by the PCM model in 2030 at any location within the Greater London agglomeration.
2. The PCM predicted concentration indicates the range across all individual links in the identified road sector
3. The predicted Heathrow NWR incremental change is the maximum predicted increment at any location along the individual road links (at a distance of 4m from the kerbside)
4. The total concentration has been calculated for each link by adding the PCM Predicted Concentration to the maximum Heathrow NWR incremental change. The values shown are the recalculated ranges across the individual links.

Defra's PCM model forecasts exceedences of the Limit Value along Bath Road (junction A437 to west of Newbury Road), the A4 (junction of Fulham Palace Road to Earls Court Road) and A40 (junction A406 to east of A219) in 2030 for the Do-Minimum scenario. The unmitigated NWR Scheme would increase annual mean NO_2 concentrations along the Bath Road (A4) sector by up to 1.3 $\mu g/m^3$, resulting in a total concentration[17] of 48.7 $\mu g/m^3$. Along the A4 (Fulham Palace Road to Earls Court Road) concentrations are predicted to increase by 0.5 to 0.6 $\mu g/m^3$, with total concentrations up to 45.4 $\mu g/m^3$. Along the A40 Western Avenue, concentrations are predicted to increase by 0.2 to 0.4 $\mu g/m^3$ (less than 1% of the Limit Value), with total concentrations up to 44.5 $\mu g/m^3$. There are no predicted exceedences of the Limit Value at any other PCM-modelled road link considered in this assessment. Further details of the EU Air Quality Directive compliance risk assessment are provided in Appendix I

The incremental change associated with the unmitigated Heathrow NWR would cause the retained Bath Road (A4) sector PCM road link to have a marginally higher concentration in 2030 (48.7 $\mu g/m^3$) than the Maximum PCM Predicted Concentration in the Greater London Agglomeration (which is 48.6 $\mu g/m^3$ and occurs at Marylebone Road) identified in the current Defra compliance assessment. This means there is a risk that the unmitigated Heathrow NWR Scheme would delay

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[17] In approximate terms, the airport contribution to this concentration is 32% whilst the road contribution is 29%; the remaining 39% contribution is related to the background.

compliance with the Limit Value. The implications of this are discussed in Section 3.1.1.

The proposals for the A4 Bath Road in the Heathrow NWR scenario are to realign the road northwards to the east of the M4 Spur, then over the M4 Spur and around the eastern and northern boundary of the airport. It is not possible to replicate Defra's PCM calculations of concentrations alongside these new road links, nor is it possible to confirm whether these links would be included in the PCM model (as they may be excluded due to lack of public exposure, as described in Chapter 3 of this report).

The PCM model does not predict any exceedences of the PM_{10} limit values.

The impacts identified above should also be considered in the light of the uncertainties of the PCM model predictions, set out in Section 3.10. In particular, if Euro 6c vehicles perform as currently expected, then the PCM model predictions in 2030 would be lower than shown. In addition, the incremental change due to the Heathrow NWR Scheme would also be lower (see Appendix H).

The impacts identified above include mitigation-by-design, but do not take account of additional mitigation measures, a number of which have been suggested by the Promoter. The potential impact of these additional mitigation measures is discussed in Section 5.7.1.

5.4.5 Monetisation of Health Impacts and Environmental damage

The total damage costs for the Heathrow NWR (Global Growth) Scenario are set out in Table 5.8.

Table 5.8: Total Damage Costs – Heathrow NWR (GG)

2014 prices £ million	Green Book Central Estimate	Green Book Central – Low	Green Book Central - High	EEA – Low VOLY [1]	EEA – High VSL [2]
Total Present Value Damage - PM_{10}	£863.5m	£676.1m	£981.3m	£129.5m	£375.6m
Total Present Value Damage - NO_X	£94.2m	£73.4m	£107.1m	£341.2m	£923.9m
Total Air Quality Damage Costs over 60 Years	£957.8m	£749.5m	£1,088.4m	£470.7m	£1,299.5m
Snapshot 2030	£15.1m	£11.8m	£17.1m	£8.4m	£23.0m
Snapshot 2040	£14.8m	£11.5m	£16.8m	£7.2m	£19.8m
Snapshot 2050	£18.3m	£14.3m	£20.7m	£8.8m	£24.2m
Snapshot 2060	£16.9m	£13.2m	£19.2m	£8.1m	£22.4m

1. VOLY = Value of a life year
2. VSL = Value of a statistical life

The total costs of NOx and PM_{10} over the 60 year appraisal period, based on the unmitigated change in mass emissions with the Heathrow NWR Scheme in place, are £94.2m and £863.5m respectively (based on the central estimate).

The Impact Pathway values for 2030 for hospital admissions with the WHO HRAPIE concentration-response coefficients are reported in Appendix G.

5.4.6 Nitrogen Deposition at Sensitive Ecosystems

The predicted annual mean concentrations of nitrogen oxides and nitrogen deposition fluxes to each of the designated conservation sites identified in Table 5.1 are set out in Table 5.9 and Table 5.10.

Table 5.9: Maximum Nitrogen Oxides Concentrations (µg/m^3) at Designated Habitats for Do-Minimum (DM) and Change due to Heathrow NWR in 2030

Site Name	OS Grid Ref of Receptor		DM	Change Due to NWR
South West London Waterbodies RAMSAR/SPA and Staines Moor SSSI	504757	174224	44.0	1.4
	506009	172602	38.7	-0.6
	504420	172274	39.4	0.6
	504557	172428	42.4	0.4
South West London Waterbodies RAMSAR/SPA and Wraysbury Reservoir SSSI	502365	175609	23.7	2.0
	502958	175624	27.5	3.9
	502955	174298	45.3	8.0
	503179	175195	28.6	3.8
Staines Moor SSSI	503445	175476	33.7	8.9
	503544	175364	39.6	20.3
	503254	174851	48.9	8.7
	504731	174245	41.8	2.5
	503523	172352	52.5	<0.1
	504677	172028	46.5	1.2
	504436	171918	53.3	0.3
	504464	171838	41.7	0.9
	504734	171710	39.1	0.9
Kingcup Meadows & Oldhouse Wood SSSI	502516	185332	29.1	0.5
Fray's Farm Meadows SSSI	505680	185651	53.2	0.9
Langham Pond SSSI	500744	171577	35.6	2.0
Wraysbury & Hythe End Gravel Pit SSSI	501814	172745	34.2	1.4
	500564	173427	25.9	1.4
Critical Level			30	

Where designated sites overlap (e.g. Staines Moor SSSI and South West London Bodies RAMSAR/SPA) they are shown more than once.

The Heathrow NWR Scheme would cause a new exceedence of the NOx Critical Level at the South West London Waterbodies RAMSAR/SPA and Wraysbury Reservoir SSSI (a total concentration of up to 32.4 µg/m^3). However, as set out in Table 2.1, the UK Government's interpretation is that the Critical Level does not strictly apply at this location. The greatest incremental change occurs at the Staines Moor SSSI (20.3 µg/m^3) representing a 51% increase. A minor reduction in NOx concentration is predicted to occur at the South West London Waterbodies RAMSAR/SPA and Staines Moor SSSI (0.6 µg/m^3).

Table 5.10: Maximum Nutrient Nitrogen Deposition Fluxes at Designated Habitats for Do-Minimum (DM) and Change due to Heathrow NWR in 2030

Site Name	OS Grid Ref of Receptor		DM	Change Due to NWR	Critical Load
South West London Waterbodies RAMSAR/SPA and Staines Moor SSSI (G)	504757	174224	10.8	0.1	20 - 30
	506009	172602	10.7	<0.1	
	504420	172274	10.7	<0.1	
	504557	172428	11.0	<0.1	
South West London Waterbodies RAMSAR/SPA and Wraysbury No. 1 Gravel Pit SSSI (G)	500732	174279	10.0	0.1	20 - 30
South West London Waterbodies RAMSAR/SPA and Wraysbury Reservoir SSSI (G)	502365	175609	10.7	0.1	20 - 30
	502958	175624	10.5	0.3	
	502955	174298	11.7	0.5	
	503179	175195	10.5	0.3	
Staines Moor SSSI (G)	503445	175476	9.8	0.6	20 - 30
	503544	175364	10.2	1.2	
	503254	174851	11.0	0.5	
	504731	174245	10.6	0.2	
	503523	172352	11.2	<0.1	
	504677	172028	11.2	0.1	
	504436	171918	11.4	<0.1	
	504464	171838	10.8	0.1	
	504734	171710	10.7	0.1	
Kingcup Meadows & Oldhouse Wood SSSI (W)	502516	185332	11.8	0.1	10 - 20
Fray's Farm Meadows SSSI (G)	505680	185651	12.7	0.1	N/A
Langham Pond SSSI (G)	500744	171577	10.8	0.1	20 - 30
Wraysbury & Hythe End Gravel Pit SSSI (G)	501814	172745	10.3	0.1	20 - 30
	500564	173427	10.3	0.1	

Where designated sites overlap (e.g. Staines Moor SSSI and South West London Bodies RAMSAR/SPA) they are shown more than once.
Those sites with a letter (G) shown in parentheses have been modelled using a deposition velocity of 0.0015 m/s which is typical for grassland. Those sites with a letter (W) shown in parentheses have been modelled using a deposition velocity of 0.003 m/s which is typical of woodland. The deposition velocity has been based on the habitat to which the Critical Load refers.

The Heathrow NWR Scheme would not cause any new exceedences of the lower or upper bounds of the Critical Loads. The greatest incremental change occurs at the Staines Moor SSSI (1.2 kgN/ha/yr) representing a 11.8% increase.

5.5 Construction Impacts

There are insufficient details available at this stage to undertake any quantitative assessment of the construction impacts. A qualitative assessment has been carried out, based on IAQM guidance, which assigns a risk category to construction sites based on the scale of the works and the proximity of sensitive receptors.

An analysis of the numbers of sensitive properties within different distance band categories cited within the IAQM guidance has been undertaken. As set out in

Chapter 3, the precise alignment of new road links is not known at this stage, and so the analysis has been based solely on the Heathrow NWR Scheme boundary. The number of sensitive receptors within different distance bands is shown in Table 5.11.

Table 5.11: Numbers of Sensitive Receptors Within 350m of Scheme Boundary

Less than 100m	100 to 200m	200 to 350m	Total within 350m
998	1,121	2,029	4,148

There are no ecological receptors within 50m of the Scheme boundary, and any potential impacts can be discounted. Given the proximity of a large number of receptors to the Scheme boundary, and the size of the expected works, it is likely that the construction works will be classified as High Risk.

It is the view of IAQM that dust impacts (associated with soiling nuisance and/or increased PM_{10}) from construction sites can be mitigated, and that the residual impact should be insignificant in most cases. During the detailed design of the Scheme, a Construction Environmental Management Plan (CEMP) should be prepared which sets out in detail the best practice mitigation measures that will be applied, and how they will be managed. Guidance on best-practice measures is set out in both the IAQM and GLA documents.

There is evidence that effective mitigation can adequately control dust impacts from large construction projects. During the course of the Heathrow Terminal 5 construction works, a detailed dust monitoring network was established. The study concluded that there was no significant impact in the local area due to dust impacts (Entec, 2006).

With regard to emissions from on-site plant and construction traffic, impacts can be controlled by mitigation and use of low-emission plant and vehicles. The use of Stage IV emissions Non Road Mobile Machinery (NRMM) and Euro VI HGVs will minimise any impacts. Construction Logistics Plans allow site deliveries and removals to be managed so that they are made at times when they are most needed and when they will contribute least to local road network congestion.

5.6 Commentary on Promoter’s Submission

This section focuses on the Promoter’s predicted air quality impacts of the Scheme.

5.6.1 Information Provided by the Promoter

The Promoter has carried out a detailed air quality assessment to quantify the air quality impacts of the proposed Heathrow NWR in comparison with the Do-Minimum option. The study was founded on the assumption that Heathrow would achieve 570,000 ATMs in 2030 With Scheme, as opposed to 480,000 ATMs for the Do-Minimum.

The Promoter’s submission describes air quality conditions in 2030 with respect to annual mean concentrations of NO_2, PM_{10} and $PM_{2.5}$, and the number of days exceedence of the daily mean PM_{10} objective. Although the Promoter states that exceedences of the EU Limit Values have been evaluated, this is not the case as no consideration has been given to national compliance in 2030 (as predicted by Defra). The Promoter has assumed that all ecological sites in the vicinity of the airport are excluded from compliance with the objective and EU limit value, and no assessment has been undertaken. Nitrogen deposition rates at ecological receptors have been calculated, and their significance reported in the Biodiversity Assessment.

A comparison with the National Emissions Ceiling for NOx in 2030 is provided.

A key assumption is that the Scheme will generate no growth in airport-related traffic on the local road network (with respect to the current situation), and that this will be facilitated by the Airport Surface Access Strategy. Additional mitigation measures included in the assessment include:

- Cleaner aircraft technologies – there is an assumption that 98% of aircraft using a three-runway airport would achieve 98% compliance with CAEP/6. A rollover model has been used to assume new engines are introduced every eight years with improved (but unstated) improvements to NOx emissions;
- Cleaner aircraft operations in the sky – a three-runway airport will operate with displaced runway thresholds and steeper approach glide slopes;
- Cleaner aircraft operations on the ground – includes further rollout of the Airport Collaborative Decision Making (A-CDM) process to reduce hold and taxi times on the ground, and provision of Fixed Electrical Ground Power (FEGP) and Preconditioned Air (PCA) to all new stands to reduce APU run times; and
- Cleaner Airside Vehicles – the provision of fuel and charging infrastructure (electric charging points and hydrogen fuelling) to support the requirements of airside ultra-low emission vehicles (ULEV) and equipment.

The assessment was carried out using the ADMS-Airport model, based on model verification undertaken for the 2008/09 emissions inventory. Key assumptions within the study are:

- The forecast aircraft fleet in 2030 was based on whole-day flight schedules representative of a busy summer day’s operation for the Do-Minimum and With Scheme scenarios;
- Taxiing (and hold) times for the Do-Minimum scenario were based on 2013 data. For the Heathrow NWR scenario the changes to the airfield layout were incorporated from simulations undertaken by NATS;
- APU run times in 2030 were assumed to be unchanged from 2015 (which introduces a new instruction to reduce maximum permitted running times (20 minutes for narrow-bodied aircraft and 40 minutes for wide-bodied aircraft);
- For the Do-Minimum scenario, the two modes of operation (Landing-Departure and Departure-Landing on both runways) were assumed to be used equally often with full easterly alternation implemented. For the Heathrow NWR scenario, each of the four modes of operation (MDL, MLD, DLM and LDM) were assumed to be used equally often;
- The GSE fleet was assumed to retain the same age profile (and proportion of ULEVs) as current, with activity data scaled by the ratio of passenger numbers;
- Road vehicle emissions were calculated using COPERT4v8.1 emission factors and fleet vehicle projections in the Emissions Factor Toolkit v5.2;
- Changes to the configuration of the heating plant were made from the 2008/09 inventory, but no information on 2030 assumptions With Scheme were provided;

- The model verification carried out for the 2008/09 inventory recommended that a scaling factor of 1.21 be applied to the contribution from landside road NOx concentrations. No scaling factor was applied in the Promoter's assessment on the basis that the traffic data were changed and the revised vehicle emissions factors were believed to account for the previous underestimation; and
- Nitrogen deposition was calculated using a deposition velocity of 0.002 m/s. Total nitrogen deposition rates in 2030 were based on 2012 values.

The principal conclusions in the Promoter's submission are:

- The Scheme would increase overall NOx emissions from 4,074 to 4,923 tonnes per annum in 2030 (principally associated with aircraft emissions). PM_{10} emissions are predicted to increase from 267 to 283 tonnes/annum, and $PM_{2.5}$ emissions from 155 to 167 tonnes per annum;
- The total airport-related NOx emission (within the LTO cycle) in 2030, with the Scheme, is 3.99 kt per annum. This is compared with a national emissions ceiling of 6,519 kt/annum;
- The maximum predicted annual mean NO_2 concentration in 2030 with Heathrow NWR, is 31.6 $\mu g/m^3$ (an increase of 0.8 $\mu g/m^3$ above Do-Minimum). The maximum predicted incremental change (between Do-Minimum and Heathrow NWR) is 5.3 $\mu g/m^3$ (increasing from 24.2 $\mu g/m^3$ to 29.5 $\mu g/m^3$);
- There are no predicted exceedences of the annual mean limit value for NO_2 at locations that are relevant in terms of exposure.
- The maximum predicted incremental change to annual mean PM_{10} concentrations is 1.1 $\mu g/m^3$; there is stated to be no predicted exceedences of the EU limit value;
- The maximum predicted incremental change to annual mean $PM_{2.5}$ concentrations is 0.7 $\mu g/m^3$; there is stated to be no predicted exceedences of the EU limit value;
- The maximum predicted increase in nitrogen deposition rates at an ecological receptor is 4.5 kg/ha/year.

5.6.2 Comparison with Promoter's Submission

Any direct comparison between this assessment for the Airports Commission, and the Promoter's submission is confounded by the fact that different assumptions on the aircraft fleet and movements, passenger numbers, and associated surface access have been made.

The Promoter concludes that the Heathrow NWR Scheme would not cause any exceedences of the air quality objectives or EU Limit Values; the maximum predicted 2030 annual mean NO_2 concentration (which can be compared with the objective) is 31.6 $\mu g/m^3$ in Hatton (an incremental change of 0.8 $\mu g/m^3$ above Do-Minimum). This assessment predicts a maximum NO_2 concentration of 34.7 $\mu g/m^3$ along the Bath Road, with the Heathrow NWR in 2030 (an incremental change of 0.4 $\mu g/m^3$ above Do-Minimum)

Whilst the Promoter compares predicted concentrations with the EU Limit Value this cannot strictly be done, as no consideration was given to Defra's PCM modelled concentrations. This assessment concludes that the Scheme would not cause any new exceedences of the concentration at which the Limit Value for NO_2 is set; however, the incremental change associated with Heathrow NWR would cause the Bath Road (A4) sector PCM road links to have a marginally higher concentration in

2030 (48.7 µg/m^3) than the Maximum PCM Predicted Concentration in the Greater London Agglomeration (which is 48.6 µg/m^3). The unmitigated Heathrow NWR Scheme would thus delay Defra in achieving compliance with the Limit Value.

The Promoter estimates that NOx emissions would increase from 4,073 to 4,922 te/yr in 2030, PM_{10} emissions from 292 to 327 te/yr, and $PM_{2.5}$ emissions from 169 to 194 te/yr, with the Heathrow NWR Scheme. The incremental changes suggested by the Promoter are substantially lower than for this assessment, e.g. aircraft emissions increase by 790 tonnes, compared with an increase in this assessment of about 2,500 tonnes. This is due to different assumptions in the aircraft fleet mix, numbers of movements, and assumptions on future aircraft engine emissions.

The total emissions related to each Scheme cannot be compared as substantially different study areas were assumed (e.g. the Promoter estimates NOx emissions from non-airport surface access to be about 546 tonnes in 2030 with the Heathrow NWR Scheme, whereas this assessment estimates NOx emissions in 2030 to be 3,792 tonnes (airport and non-airport). The Promoter concludes that the Heathrow NWR Scheme could be accommodated within the NECD and Gothenburg Protocol, but has only included aircraft emissions (and has excluded other airport-related sources) within this assessment; in addition, the emissions have been compared with the emission ceiling set for the EU15 member states, and not that which applies to the UK alone.

The Promoter concludes that the maximum predicted increase in nitrogen deposition at an ecological receptor to be 4.50 kg/ha/yr. This figure is inconsistent with the Promoter’s Biodiversity Assessment which states the maximum increase to be 0,54 kg/ha/yr. The latter is broadly consistent with this assessment.

5.6.3 Commentary on the Promoter’s Mitigation

An evaluation of the principal mitigation measures set out by the Promoter is provided below:

Measure 1: Achieving an increase in public transport access from 40% to >50% to ensure total road passenger road vehicle trips to and from the airport do not increase relative to the baseline.

The Promoter’s Air Quality Assessment sets out a vision for high public transport access, but it is not clear whether this is deliverable. The surface access modal share and traffic volumes assumed in this Airports Commission assessment have been built into the dynamic modelling.

Measure 2: The airport is designed to minimise the distances that aircraft taxi between stands and runways.

The layout of the Heathrow NWR Scheme has been incorporated into this assessment, and this mitigation measure has been fully accounted for in the modelling study.

Measure 3: NOx emissions charging to encourage airlines to use the cleanest aircraft.

A NOx emissions charging scheme has been in operation at Heathrow Airport since 2004[18]. There is no clear evidence that this measure has influenced airlines to select airframe/engine combinations with lower NOx emissions when the other economic and environmental factors are also taken into consideration. A recent review of the NOx emissions charging scheme (CAA, 2013) notes that "the engines on 60% of British Airways' fleet of Boeing 747-400s were modified, possibly as a consequence of the NOx charge", but "as airport charges are typically a small proportion of an airline's total costs, so the associated incentives for airlines to use aircraft with best-in-class NOx performance may be small compared to other drivers".

NOx emissions from aircraft engines are limited by the CAEP standards and this is the main driver to change; however, because of the desire to deliver improved fuel performance (with associated, higher Overall Pressure Ratios) there is limited evidence that the CAEP standards have significantly reduced emissions from aircraft engines when expressed in terms of kgNOx/second. The aircraft movements and fleet mix assumed for the Heathrow NWR Scheme have been based on the Airports Commission's Global Growth (carbon traded) scenario, and it would not be appropriate to adjust this assumption within the assessment.

As a sensitivity test, a 20% reduction in aircraft emissions in 2030 has been assumed, based on expected, future engine improvements.

Measure 4: Operate 3R airport with a steeper glide slope to reduce the impact of aircraft approach emissions at ground level.

A steeper glide slope of 3.2 degrees has been assumed for the Heathrow NWR Scheme. However, emissions during approach make very little contribution to ground-level concentrations (as the emissions are principally at altitude). This is confirmed in the report which was published by the Government's Air Quality Expert Group (AQEG)[19], which noted that "aircraft emissions between 100m and 1000m contribute little to ground-level concentrations".

Measure 5: Airport Collaborative Decision Making (A-CDM) is a management process designed to improve airport efficiency and reduce hold times and delays through cooperation of pilots, airlines, ground crew and air traffic control.

Busy airports experience delays to departing aircraft between the push back from the stand and the start of take-off roll on the runway. The typical delay time (8 minutes) was provided by the Promoter of the Heathrow NWR Scheme for the 2009 baseline, and has been represented in the model as runway-end hold queues. For the 2030 NWR scenario, departure delay times (runway hold times) were assumed to be unchanged from 2009 as no robust indication of future hold times was provided by the Promoter.

A UK runway resilience study, published in 2008 (SH&E, 2008) used electronic flight processing system (EFPS) data to analyse taxi times at Heathrow Airport to identify departure delay times. The delay times were calculated as the difference between the actual stand-to-runway taxi time and the unimpeded stand-to-runway taxi time. The resilience study concluded that average departure delays (i.e. runway hold

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[18] Heathrow Airport Limited is currently consulting on NOx emissions charges, and proposes to increase the NOx charge from 15% of the total environmental charge to 20%. (Heathrow Airport Limited, 2015)

[19] AQEG (2009 Nitrogen Dioxide in the United Kingdom

times) at Heathrow were around 9 minutes, and thus slightly higher than that suggested by the Promoter.

A sensitivity test for increased departure delay times has been carried out to consider the potential impact in terms of NOx emissions.

In order to estimate possible delay times for Heathrow in 2030, departure delay curves have been provided by LeighFisher (LeighFisher, 2012). These allow typical delay times to be determined depending on the capacity ratio of the airport. Capacity ratios for the Heathrow NWR scenario, split into summer and winter, have been provided by LeighFisher.

To estimate an annual average delay time the following approach has been applied.

DelayAA = ((DelaySMR x ATMSMR) + (DelayWTR x ATMWTR)) / ATMA

Where:

DelayAA = Annual Average Delay Time;
DelaySMR = Summer Average Delay Time (obtained from the summer delay curve using the summer capacity ratio);
ATMSMR = Total ATMs in the summer period;
DelayWTR = Winter Average Delay Time (obtained from the winter delay curve using the winter capacity ratio);
ATMWTR = Total ATMs in the winter period.
ATMA = Total Annual ATMs

Table 5.12 shows the calculation of the annual average departure delay times (DelayAA) for NWR in 2030 using the summer and winter delay curves and capacity ratios provided by LeighFisher.

Table 5.12: Calculation of Annual Average Departure Delay Times

Scenario	Summer Capacity Ratio	Summer ATMs	Winter Capacity Ratio	Winter ATMs	Annual Average Delay Time (Delay_{AA})
Heathrow NWR	0.9786	424,492	0.9733	297,898	10.24 mins

Using the annual average departure delay times in Table 5.12, a sensitivity for total annual NOx emissions has been carried out for runway hold queues for the Heathrow NWR 2030 scenario. The results of the sensitivity test include a comparison with the total annual NOx emissions from runway hold queues assumed in the dispersion modelling study, and is shown in Table 5.13.

Table 5.13: Hold Time NOx Emission Sensitivity Test Results

Scenario	Hold Time Assumed in Model (mins)	Total Annual NOx from Hold Queues (t/yr)	Hold Time Assumed for Sensitivity Test (mins)	Total Annual NOx from Hold Queues (t/yr)	% Difference
Heathrow NWR	7.95	145.0	10.24	186.6	29%

The data in Table 5.13 suggest that the underestimate of NOx emissions associated with departure delay times in the model may be of the order of 30%. The use of A-CDM to *reduce* average delay times by a similar margin (e.g. from 8 minutes to 5.5 minutes) would be expected to deliver benefits of the same magnitude, but the feasibility of such a reduction in delay times is highly uncertain. It is also important to consider these data in the context of total airport ground-source emissions of NOx (i.e. excluding emissions at altitude in the initial climb, climbout and approach modes). For the 2030 Heathrow NWR scenario, total ground-source emissions are 3,368 te/yr. Emissions from hold times thus represent about 4.3% of the total (in the modelled assumption); a reduction of 2.5 minutes in average hold times would deliver an improvement of about 1.2%.

Measure 6: Install Fixed Electrical ground Power (FEGP) and Pre Conditioned Air (PCA) to all future aircraft stands to reduce the need for APU usage.

This Airports Commission assessment has been founded on information provided by the NWR Promoter, and assumes full compliance with the Managing Directors Instruction (MDI) on maximum APU run times. However, there is no evidence that full compliance is achieved in practice. Uptake of greater FEGP use is sensitive to the cost incurred by airlines, and provision is no guarantee that it will be used. Should the Promoter make FEGP cost-advantageous to airlines over APU use, then greater uptake is likely. To test this, an assumption has been made on APU run times.

There are examples in Europe of international airport operators that enforce strict rules regarding the use of APU for commercial aircraft on both arrival and departure, for example at Faro Airport in Portugal, and Barcelona and Madrid Airports in Spain. The policy employed at Barcelona Airport has been published by Boeing (Boeing 2015), and states:

"*At Stands in contact with terminal: It is obligatory to use the 400 Hz facilities. The use of the air-conditioning facilities will be obligatory when the aircraft air conditioning is needed. The use of the aircraft APU is forbidden in these stands in the period between 2 minutes after blocks for the arrivals and 5 minutes before off-blocks for departure. The aircraft APU will only be able to be used when the fixed units are not operative and the mobile units are not available.*

At Remote Stands: The use of APU is forbidden except for 10 minutes after blocks for the arrival and 10 minutes before off-blocks for the departure except for wide bodied aircraft that may be allowed to use it 50 minutes before departure and 15 minutes after arrival."

In the NWR Scheme, the ratio of remote stands to contact stands is approximately 20-25%. In terms of operation, the airport will preferentially use contact stands, and remote stand use is likely be much less than 20%. It is anticipated that the vast majority of aircraft will utilise contact stands and will have access to FEGP and PCA. As a sensitivity test for APU run times, NOx emissions have been calculated assuming that the Barcelona Airport contact stands APU usage times are enforced with the Heathrow NWR Scheme. This represents a feasible minimum. The results of the sensitivity test are presented in Table 5.14 below.

Table 5.14: APU NOx Emission Sensitivity Test Results

Scenario	APU Run Time (in dispersion model)	Total Annual NOx Emissions from APU (t/yr)	Sensitivity Test APU Run Time	Total Annual NOx Emissions from APU (t/yr)
NWR	Arrival: 40 minutes for wide body and 20 minutes for narrow body aircraft. Departure: 40 minutes for wide body and 20 minutes for narrow body aircraft.	390.2	Arrival: 2 minutes for all aircraft. Departure: 5 minutes for all aircraft.	42.0

The results indicate an approximate 90% reduction in annual NOx emissions from APUs which could be achievable if stringent regulations on APU run times were introduced and enforced in 2030, at all stands. A source apportionment study of modelled airport NOx concentrations suggests maximum off-airport contributions from APU emissions to NOx concentrations of around 1.1 µg/m^3 (based on model predictions at the Oaks Road (HOA) and Hatton Cross (HS7) monitoring sites).

Measure 7: Improve the infrastructure for Ultra Low Emission Vehicles (ULEV) such as electric charging points and hydrogen fuel stations, both airside and landside.

It is not possible to forecast the uptake of ULEVs by airside operators or by visitors to the airport. The assessment has included a rollover model for road-vehicle GSE, such that the vast majority of vehicles will be Euro 6/VI by 2030. As non-road vehicles and plant are replaced less frequently, no rollover has been assumed but all new vehicles and plant have been assumed to comply with Stage IIIA emissions.

A substantial proportion of NOx emission from GSE in 2030 comes from the Non-Road Mobile Machinery (NRMM); this includes aircraft tugs, ground power units (GPUs), baggage tugs, belt loaders, cargo tractors and carts.

A feasibility study on extremely low emission technology GSE at Los Angeles (LAX) airport (CDM Smith, 2013) sets out the 2013 GSE fleet at LAX, by fuel use. For almost all types of NRMM, there are electric-powered variants in operation, and for certain types, the proportion of electric variants operating at LAX in 2013 was between 45 and 95%, with a commitment to introduce more electric vehicles to the GSE fleet.

A sensitivity test for the introduction of a higher proportion of non-road GSE for the Heathrow NWR Scheme has been based on an assumption that 80% of the diesel NRMM is replaced with electric variants by 2030. This is based on 100% removal of GPUs due to extended coverage of FEGP across all aircraft stands, and evidence from LAX that operating with up to 95% electric NRMM is possible.

The results of the sensitivity test are set out in Table 5.15. The results suggest that the use of 80% electric NRMM within the GSE fleet could lead to reductions in total annual NOx emissions of around 106 te/yr, equivalent to a 60% decrease.

Table 5.15: Non-Road GSE NOx Emission Sensitivity Test Results Heathrow NWR 2030

Total Annual NOx Emissions (te/yr)				% Difference
Non-Road GSE	All GSE	Non-Road GSE (80% Electric NRMM)	All GSE (80% Electric NRMM)	
162.9	216.3	32.6	86.0	-60.3

The reduction in NOx emissions is founded on the simple assumption that replacement of 80% of the NRMM GSE with electric variants would reduce fuel use and NOx by an equivalent amount.

Measure 8: Introduce an airport congestion charge for people travelling to the airport. Possible exemptions for the greenest vehicles.

An assessment of demand management measures in reducing car use at Heathrow Airport has been carried out for Appraisal Framework Module 4 (Jacobs 2015). The overall conclusions are that the imposition of additional charges on car users could have a significant impact on car mode share and overall traffic demand. Depending on the scale of charge imposed, and the extent of the scheme (i.e. whether it targets passengers, employees and/or taxis), it is possible that traffic generation with the Heathrow NWR Scheme could be reduced to 2013 levels. However, as traffic levels on Bath Road are estimated to be lower With Scheme than for the Do-Minimum, no additional analysis has been undertaken.

5.6.4 Additional Mitigation Measures

There are a number of additional mitigation measures, not specifically highlighted by the Promoter that could be implemented. Commentary on these is provided below.

Encouraging airlines to shut down an engine during taxiing.

It is not clear to what extent shutting down one engine during taxiing is used by the airlines. The PSDH report (paragraph 109) notes that *“there are a number of reasons why engines cannot be shut down, such as the requirement for a cooling-down period (especially after having used reverse thrust above idle) and the difficulty of having to turn an aircraft on the taxiway against the live engine. This, coupled with advice from one manufacturer that NOx emissions may not benefit from this technique, has dissuaded some operators from pursuing its use more thoroughly”*.

In contrast, a study funded by NASA Ames (Kumar et al, 2014) concluded that single engine taxi-out procedures have the potential to reduce taxi-out NOx emissions by 27% at Orlando (MCO) Airport and by 45% at New York La Guardia (LGA). If implemented effectively, a potential reduction in taxi-out NOx emissions of 25% for the Heathrow NWR Scheme might be achievable.

Supporting ongoing technological developments and innovation, including industry research into the use of alternative fuels for aircraft.

The feasibility for the uptake of alternative fuels (biofuels) into commercial airline operations is increasing; this is primarily driven by targets to reduce the carbon footprint, rather than to reduce emissions of pollutants such as NOx and fine particulate matter. Whilst a number of technical and economic challenges remain, it is anticipated that sustainable biofuels will represent an appreciable proportion of the global jet fuel supply in the future.

The International Air Transport Association (IATA) report on alternative fuel use for aviation (IATA, 2013) briefly discusses non-CO_2 emissions from biofuel use in aviation. The report cites evidence that the use of some certified biofuels can reduce emissions of ultrafine particles due to the lower fraction of aromatics and impurities in the fuel; however, the effects on reducing NOx emissions are less pronounced. The report further notes that *"significant research efforts are needed to better understand the issues related to non-CO_2 emissions"*.

The formation of NOx during the combustion of aviation fuel arises primarily from the oxidation of atmospheric nitrogen in high temperature flame regions within the turbine engine. For a given engine, the rate of NOx formation is dependent on many variables which include the physical and chemical properties of the fuel in use. Biofuels are usually blended with standard Jet A/A1 kerosene in variable proportions to balance cost, availability and performance. Taking into account the uncertainty in economic feasibility and the possible range of fuel blends, it is not possible to quantify what, if any effect, the future uptake of biofuels would have on reducing NOx emissions from aircraft associated with the Heathrow NWR Scheme.

Implementation of an Ultra-Low Emissions Zone (ULEZ)

A ULEZ is currently being promoted by TfL for the central London area. A ULEZ scheme implemented in the Heathrow NWR area could potentially reduce NO_2 concentrations. It is not possible to accurately predict the impact of such a scheme on the PCM model results for the key link along the A4 Bath Road, as this will depend on the nature and geographic scope of the ULEZ and because it is not possible to accurately adjust the PCM background for the presence of a ULEZ. A sensitivity test has been carried out using a nominal scenario to indicate the potential impact of a ULEZ on the changes in concentrations as a result of the Heathrow NWR Scheme. There have been two parts to the sensitivity test: A) it has been assumed that all non-Euro VI and non-Euro 6 vehicles are replaced by Euro VI and Euro 6 vehicles, and B) it has been assumed that 30% of the light duty vehicles in the part (A) test are zero emission vehicles. The road traffic model NOx concentrations for the Do Minimum and With Scheme on this key link have been adjusted for this change in emissions. The reduction in the do-minimum NOx contribution has been subtracted from the PCM value, then the With Scheme increment has been added, to calculate the new road NOx value, which has then been converted into NO_2 using the standard approach. The difference between the original With Scheme PCM NO_2 concentration and the new NO_2 concentration is the effect of the ULEZ. The results of the sensitivity test would be to reduce the Heathrow NWR NO_2 concentration by 0.2 $\mu g/m^3$ for part (A) of the test and 0.8 $\mu g/m^3$ for part (B).

5.7 Conclusions

The principal conclusions of this assessment with respect to the NWR Scheme are:

- The Scheme would not affect compliance with the current NECD and Gothenburg Protocol obligations. If the NECD obligation is tightened in line with current proposals, the UK would exceed the obligation with or without Heathrow NWR. The incremental emissions associated with Heathrow NWR represent a very small fraction of the proposed obligations;
- The Scheme would not cause any new exceedences of the Limit Value or air quality objective for NO_2. However, the incremental change associated with Heathrow NWR would cause the Bath Road (A4) sector PCM road links to have

a marginally higher concentration in 2030 (48.7 µg/m^3) than the Maximum PCM Predicted Concentration in the Greater London Agglomeration (which is 48.6 µg/m^3 and occurs at Marylebone Road). The unmitigated Heathrow NWR Scheme would thus delay Defra's predicted date for achieving compliance with the Limit Value. The proposals for the A4 Bath Road in the Heathrow NWR scenario are to realign the road northwards and then to the east around the boundary of the airport, but it is not possible to replicate Defra's PCM predictions at these realigned links, nor is it possible to confirm whether these new links would be included in the PCM model (due to lack of public exposure) and no further assessment can be provided.

- The Scheme would cause a new exceedence of the Critical Level at the South West London Waterbodies RAMSAR/SPA and Wraysbury Reservoir SSSI. However, the UK Government's interpretation is that the Critical Level does not strictly apply at this location. The Scheme would not cause any exceedences of the lower band of the Critical Load (for nitrogen deposition) at any designated habitat;
- The Scheme would worsen air quality (in terms of annual mean NO_2 concentrations) at about 47,000 properties; and
- The total costs of NOx and PM_{10} over the 60 year appraisal period, based on the unmitigated change in mass emissions with the Heathrow NWR Scheme in place, are £94.2m and £863.5m respectively.

5.7.1 Assessment of Mitigation

This assessment has taken into account mitigation by design, but has not included the mitigation measures proposed by the Promoter, or additional mitigation measures, as described in Section 5.6. As it is concluded that the Heathrow NWR would delay compliance with the Limit Value, the potential benefits of these measures (in terms of changes to annual mean NO_2 concentrations) at the Bath Road link, where the PCM model predicts the highest concentration in 2030, are summarised in Table 5.16.

Quantification has been carried out, wherever possible, by calculating the ratio of the mitigated source-NOx emissions to the total source-NOx emissions (for each source in question). This fraction has then been applied to the source contribution at the relevant Bath Road PCM receptor, and Defra's NOx:NO_2 calculator used to estimate the NO_2 concentration.

In addition to these mitigation measures, the potential impacts of the sensitivity tests described in Appendix H should also be considered. If the Euro 6c emissions standard for vehicles were to deliver the stated improvement, then it is estimated that there could be an average reduction in road-NOx emissions of about 7%. It is difficult to determine the precise effect that this could have upon NO_2 concentrations at Bath Road, as both background and roadside levels would be affected, as well as concentrations at Marylebone Road.

If primary NO_2 emissions were to increase from 16.6% to 24.0%, annual mean NO_2 concentrations at Bath Road might be expected to increase by about 0.1 µg/m^3. This is a pessimistic assumption, and makes no allowance for possible future European legislation to control primary NO_2 emissions.

Table 5.16: Summary of Mitigation Measures for Heathrow NWR

Mitigation Measure	**Commentary**	**Indicative Impact (+/- $\mu g/m^3$ NO_2) at PCM Exceedence**
Achieving an increase in public transport access from 40% to >50%	The Promoter's Air Quality Assessment sets out a vision for high public transport access, but it is not clear whether this is deliverable. The surface access modal share and traffic volumes assumed in this Airports Commission assessment have been built into the dynamic modelling. However, traffic movements on Bath Road are predicted to decrease with Heathrow NWR, due to the proposed rerouting of the A4/Colnbrook bypass and severance of the Bath Road crossing of M25. No reduction in emissions above Do-Minimum can be quantified. Whilst a further reduction in surface access movements on Bath Road would be beneficial, this cannot be quantified.	N/A
The airport is designed to minimise the distances that aircraft taxi between stands and runways	The layout of the Heathrow NWR Scheme has been incorporated into this assessment, and this mitigation measure has been fully accounted for in the modelling study.	N/A
NOx emissions charging	A NOx emissions charging scheme has been in operation at Heathrow Airport since 2004. There is no clear evidence that this measure has influenced airlines to select airframe/engine combinations with lower NOx emissions when the other economic and environmental factors are also taken into consideration. The aircraft movements and fleet mix assumed for the Heathrow NWR Scheme have been based on the Airports Commission's Global Growth (Carbon Traded) scenario, and it would not be appropriate to adjust this assumption within the assessment. If a 20% reduction in aircraft NOx emissions were assumed, based on future engine improvements, a reduction in concentrations could be achieved.	-0.8 $\mu g/m^3$
Steeper Glide Slope	A steeper glide slope of 3.2 degrees has been assumed for the Heathrow NWR Scheme. However, emissions during approach make very little contribution to ground-level concentrations (as the emissions are principally at altitude).	N/A

Mitigation Measure	Commentary	Indicative Impact (+/- µg/m^3 NO$_2$) at PCM Exceedence
Airport Collaborative Decision Making	Hold times used in the modelling are likely to have been under-predicted slightly; a sensitivity test has been carried out to consider a more realistic scenario. The results suggest that the underestimate of NOx emissions associated with departure delay times in the model could be of the order of 29%, which would increase NO2 concentrations. The use of A-CDM to reduce average delay times by a similar margin could be expected to deliver benefits of the same magnitude, but the feasibility of such a reduction in delay times is highly uncertain.	N/A
FEGP and PCA for all future aircraft stands	Uptake of greater FEGP use is sensitive to the cost incurred by airlines, and provision is no guarantee that it will be used. Should FEGP be made cost-advantageous to airlines over APU by the Promoter, then greater uptake is likely. There are examples in Europe of international airport operators that enforce strict rules regarding the use of APU for commercial aircraft on both arrival and departure. A sensitivity test has been undertaken based on these rules, whereby APUs are only allowed to run for a maximum of 2 minutes on arrival and 5 minutes on departure. The results indicate an approximate 90% reduction in annual NOx emissions from APUs could be achievable if stringent regulations on APU run times were introduced and enforced in 2030, at all stands.	-0.6 µg/m^3
Infrastructure for ULEVs	It is not possible to forecast the uptake of ULEVs by airside operators or by visitors to the airport. A sensitivity test for the introduction of a higher proportion of non-road GSE for the Heathrow NWR Scheme has been based on an assumption that 80% of the diesel NRMM is replaced with electric variants by 2030. The results suggest that the use of 80% electric NRMM within the GSE fleet could lead to reductions in total annual NOx emissions of around 106 te/yr, equivalent to an approximate 60% decrease.	-0.25 µg/m^3
Congestion Charging	As traffic on Bath Road is assumed to reduce with the Heathrow NWR Scheme, further consideration to the benefits of a congestion charge zone at this link has not been considered.	N/A
Encouraging airlines to shut down an engine during taxiing.	It is not clear to what extent shutting down one engine during taxiing could be implemented by the airlines. Based on U.S. studies, potentially a 25% reduction in NOx emissions on taxi-out could be achieved.	-0.3 µg/m^3
Ultra-Low Emissions Zone	It is unclear what form a ULEZ would take. However, an indicative sensitivity test has been carried out assuming A) only Euro VI and Euro 6 vehicles are on Bath Road and B) in addition to (A) 30% of the light duty vehicles are zero emission.	A) -0.4 µg/m^3 B) -1.6 µg/m^3

Mitigation Measure	Commentary	Indicative Impact (+/- µg/m^3 NO$_2$) at PCM Exceedence
TOTAL	Total potential reduction in the change in NO$_2$ concentrations with NWR at the Bath Road PCM exceedence area, assuming all the sensitivity tests are additive. A reduction of 0.1 µg/m^3 is required to prevent the scheme from causing a delay to compliance with the annual mean NO$_2$ EU LV.	-2.4 µg/m^3 to -3.6 µg/m^3

6 Heathrow Airport Extended Northern Runway

This Chapter focuses on the Heathrow ENR covers:

- Summarises the key elements of the Scheme insofar as they are pertinent to air quality impacts;
- Summarises the current baseline monitoring;
- Describes the air quality impacts of the Scheme based on the ADMS-Airport modelling;
- Summarises the pollutant concentrations at all locations substantially affected by the Scheme;
- Identifies the number of properties and population where pollutant concentrations improve, worsen or stay the same between the Do-Minimum and Heathrow ENR options;
- Quantifies the monetisation of health impacts and environmental damage;
- Identifies the effect of the Scheme with regard to compliance with national emissions ceilings;
- Describes the high level impacts of the construction works;
- Describes the likely effects of mitigation measures proposed by the Scheme Promoter; and
- Provides commentary on the Promoter's submission.

6.1 Scheme Description

The key elements of the Scheme with regard to air quality impacts are:

- The construction of a new runway to the west of the existing northern runway to approximately double its current length, and with a safety area mid-way, allowing it to operate as two independent runways; and
- The construction of a new Terminal 6 to the west of the existing Terminal 5, together with apron areas and new taxiways.

The Global Growth, Carbon Traded demand scenario of the Airports Commission's forecast represents an additional 220,000 ATMs with the Heathrow ENR Scenario, to give an approximate total 700,000 ATMs per annum in 2030. In terms of operation, the three-runway airport would operate in single mode on the two northern runways, and mixed-mode on the existing southern runway.

6.2 Study Area

The Principal Study Area for the Heathrow ENR assessment is shown in Figure 6.1. This indicates the layout of the proposed Scheme, and a 2km radius around the Scheme boundary.

The Wider Study Area indicating the full extent of the affected road network is shown in Figure 6.2. The Traffic Simulation Area is shown in Figure 6.3, and has been used to calculate the total surface access emissions.

6.2.1 Baseline Conditions

Air quality monitoring data across the study area are summarised in Appendix E, for the period 2009 to 2014. Annual mean NO_2 concentrations are below the objective at background sites, but there have been consistently recorded exceedences at the monitoring station close to the north-west boundary of the airport (LHR2 – approximately 190m to the north-west of the existing northern main runway) and at other sites close to busy roads across the Principal Study Area (e.g. the M4 motorway (HI0) and Oxford Avenue (HI3)). Measured annual mean concentrations of PM_{10} and $PM_{2.5}$ are well below the objectives.

The Scheme lies within the London Borough of Hillingdon. The Borough has declared an AQMA for exceedences of the annual mean objective for NO_2. The AQMA boundary encompasses the southern part of the Borough, including Heathrow Airport. AQMAs have also been declared by the neighbouring local authorities as follows:

- London Borough of Hounslow – whole-borough AQMA for exceedences of the annual mean objective for NO_2;
- Spelthorne Borough Council - whole-borough AQMA for exceedences of the annual mean objective for NO_2.

The locations of the AQMAs are shown in Figure 6.1.

The Defra PCM maps indicate exceedences of the annual mean EU limit value for NO_2 in 2009 along a number of roads in the vicinity of Heathrow Airport, including:

- A4 Bath Road – 61.5 µg/m^3
- A312 – 63.1 µg/m^3
- A316 – 64.6 µg/m^3
- A3044 – 53.1 µg/m^3

There are widespread exceedences of the limit value within the Wider Study Area to the east, including Chiswick High Road (75.8 µg/m^3). This is illustrated in Figure 6.4.

The locations of internationally and nationally-designated statutory conservation sites within the Wider Study Area are shown in Figure 6.5. These sites are also listed in Table 6.1, which also provides a summary of the current background nitrogen deposition rates and NOx concentrations.

Table 6.1: Estimated Annual Mean Nitrogen Deposition Rates and NOx Concentrations

Site Name	Designation	Habitat Type	Critical Load (kgN/ha/yr)	Current N Deposition kgN/ha/yr	Current NOx Conc µg/m^3
South West London Waterbodies	RAMSAR/SPA	Neutral grassland	20-30	16.5	25.8
		Standing open water	N/A	13.3	
Staines Moor	SSSI	Neutral grassland	20-30	16.4	26.0
		Standing open water	N/A	13.3	
		Littoral sediments	20-30	16.4	
		Fen, marsh and swamp	N/A	16.4	
		Vascular plant assemblage	N/A	13.3	
Wraysbury Reservoir	SSSI	Neutral grassland	20-30	17.6	26.8
		Standing open water	N/A	13.4	
		Littoral sediments	20-30	17.6	
		Superlittoral rock	N/A	17.6	
Wraysbury No.1 Gravel Pit	SSSI	Standing open water	N/A	13.4	26.6
Wraysbury & Hythe End Gravel Pits	SSSI	Littoral sediments	20-30	16.7	25.5
		Standing open water	N/A	13.3	
		Lowland open waters	N/A	13.3	
Wraysbury No. 1 Gravel Pit	SSSI	Standing open water	N/A	13.4	26.6
Langham Pond	SSSI	Neutral grassland	20-30	16.7	23.8
		Woodland	N/A	13.4	
Fray's Farm Meadow	SSSI	Fen, marsh and swamp	N/A	18.5	20.3
Wraysbury & Hythe End Gravel Pit	SSSI	Littoral sediments	20-30	16.7	25.5
		Standing open water	N/A	13.3	
		Lowland open water	N/A	13.3	
Bushy Park and Home Park SSSI	SSSI	Acid grassland	10-15	15.4	23.9
		Veteran trees	N/A		
		Invertebrate assemblage	N/A		

The current N deposition rates and NOx concentrations are the average values across the site, and represent the average value over a 3 year period, 2009-2011.

Current site-average nitrogen deposition rates below the lower range of the Critical Load at most sites, but above at one site; as set out in Section 2.2.7, being above the Critical Load does not necessarily infer ecosystem damage. Current site-average NOx concentrations are below the Critical Level and air quality objective.

6.3 Air Quality Assessment

The assessment for the Heathrow ENR Scheme has been carried out using the methodology described in Chapter 3. Specific input assumptions related to aircraft movements etc. are set out in detail in Appendix B.

6.4 Assessment Outputs

6.4.1 Emissions Inventory

A summary of the forecast emissions from the Do-Minimum and Heathrow ENR scenarios for each pollutant in 2030, and the incremental changes between them, is provided in Tables 6.2 and 6.3 respectively.

Table 6.2: Pollutant Emissions (te/yr) in 2030 for Do-Minimum (DM) and Heathrow ENR (ENR) Scenarios – Traffic Model Simulation Area

Source Category		**NOx (te/yr)**		**PM_{10} (te/yr)**		**$PM_{2.5}$ (te/yr)**	
		DM	**ENR**	**DM**	**ENR**	**DM**	**ENR**
Aircraft	Take-off	948.5	1256.1	19.2	26.9	19.2	26.9
	Initial Climb	1,269.1	1674.1	25.9	36.2	25.9	36.2
	Climbout	1,684.9	2226.2	34.3	48.2	34.3	48.2
	Approach	738.8	978.6	43.7	61.1	43.7	61.1
	Landing Roll (incl brake & tyre wear)	58.3	78.0	22.8	30.9	22.8	30.9
	Taxi + Hold	610.2	856.7	33.4	52.3	33.4	52.3
APU		284.7	390.2	5.7	8.0	5.7	8.0
GSE		170.0	213.8	11.0	13.5	11.0	13.5
Stationary sources (heating +boiler)		85.8	91.6	0	0	0	0
Airport sources (sub-total)		***5,850.2***	***7,765.2***	***195.9***	***277.1***	***195.9***	***277.1***
Surface Access Sources (sub-total)[1]		***3,792.6***	***3,847.3***	***563.2***	***572.8***	***316.0***	***321.1***
TOTAL		**9,642.8**	**11,612.5**	**759.1**	**849.9**	**511.9**	**598.2**

[1] These emissions are for all the roads in the Traffic Model Simulation Area, and include airport and non-airport related traffic.

Table 6.3: Incremental Change to Pollutant Emissions (te/yr) in 2030

Source Category		**Difference (te/yr)**			**Percentage Change**		
		NOx	**PM_{10}**	**$PM_{2.5}$**	**NOx**	**PM_{10}**	**$PM_{2.5}$**
Aircraft	Take-off	307.6	7.7	7.7	32.4%	40.1%	40.1%
	Initial Climb	405.0	10.3	10.3	31.9%	39.8%	39.8%
	Climbout	541.3	13.9	13.9	32.1%	40.5%	40.5%
	Approach	239.8	17.4	17.3	32.5%	39.8%	39.8%
	Landing Roll	19.7	8.1	8.2	33.8%	35.5%	35.5%
	Taxi + Hold	246.5	18.9	18.9	40.4%	56.6%	56.6%
APU		105.5	2.3	2.3	37.1%	40.4%	40.5%
GSE		43.8	2.5	2.5	25.8%	22.7%	22.8%
Stationary sources (heating +boiler)		5.8	0	0	6.8%	0%	0%
Airport sources (sub-total)		***1,915.0***	***81.2***	***81.2***	***32.7%***	***41.4%***	***41.4%***
Surface Access Sources (sub-total)[1]		***54.7***	***9.6***	***5.1***	***1.4%***	***1.7%***	***1.6%***
TOTAL		**1,969.7**	**90.8**	**86.3**	**20.4%**	**12.0%**	**16.9%**

[1] These emissions are for all the roads in the Traffic Model Simulation Area, and include airport and non-airport related traffic.

In 2030, the Heathrow ENR Scheme would increase emissions of NOx from 9,643 te/yr to 11,613 te/yr, an increase of 1,970 te/yr (20.4%) above the Do-Minimum. The increase is predominantly associated with the net change in aircraft emissions, and largely with non-ground operations (e.g. initial climb, climbout and approach).

Emissions of PM_{10} increase by 90.8 te/yr, from 759 te/yr to 850 te/yr (an increase of 12.0%) and emissions of $PM_{2.5}$ increase by 86.3 te/yr, from 512 te/yr to 598 te/yr (an increase of 16.9%). As described in Appendix B, emissions of PM_{10} and $PM_{2.5}$ have been assumed to be equivalent from airport sources.

6.4.2 Comparison with Emissions Ceilings

The National Atmospheric Emissions Inventory (NAEI) projections have been used to report the UK's status on compliance with the National Emissions Ceilings Directive and Gothenburg Protocol targets in 2030 (EIONET, 2015). The incremental change to NO_x and $PM_{2.5}$ emissions associated with the Heathrow ENR unmitigated operations are presented in Table 6.4. There are no NAEI projections for PM_{10} as this pollutant is not prescribed under the NECD or Gothenburg Protocols.

Table 6.4 – NAEI NO_x and $PM_{2.5}$ emission projections (kt/yr) for the UK

	NOx (kt/yr)	$PM_{2.5}$ (kt/yr)
NECD 2010 emission target	1,167	-
NECD 2030 emission target (proposed range)	410 - 440	44 - 50
Gothenburg Protocol 2020 emission targets	714	67
NAEI emission projections (2030)	585.7	50.7
NAEI emission projection + change associated with Heathrow ENR	587.7	50.8

The 2010 NECD target for NOx is 1,167 kt/yr, whilst the 2020 Gothenburg Protocol target is 714 kt/yr. The latest projections estimate that emissions will be well below these targets in 2030 (585.7 kt/yr). The incremental change to NOx emissions associated with the ENR Scheme is 2.0 kt/yr, and would not cause the NECD or Gothenburg Protocol targets to be exceeded. As discussed in Chapter 3, the NECD targets are currently being revised, and the outcome of the negotiations is not yet known; an assumed target range of 410-440 kt/yr has been based on current proposals. If a target within this range were adopted, the UK would fail to meet compliance based on current forecasts, whether the ENR Scheme were developed or not. The incremental change only represents about 0.48% of the lower range of the target.

The 2020 Gothenburg Protocol target for $PM_{2.5}$ is 67 kt/yr. The latest projections estimate that emissions will be below this target in 2030 (50.7 kt/yr). The incremental change to $PM_{2.5}$ emissions associated with the ENT Scheme is 0.09 kt/yr, and would not cause the Gothenburg Protocol target to be exceeded. As discussed in Chapter 3, the NECD targets are currently being revised, and the outcome of the negotiations is not yet known; an assumed target range of 44-50 kt/yr has been based on current proposals. If a target within this range were adopted, the UK would fail to meet compliance based on current forecasts, whether the ENR Scheme were developed or not. The incremental change only represents about 0.20% of the lower range of the target.

6.4.3 Predicted Concentrations at Health-Based Receptors

The predicted annual mean concentrations of NO_2 at the identified sensitive receptors are shown in Figure 6.6 and 6.7 for the Do-Minimum and Heathrow ENR scenarios respectively. The incremental change to annual mean NO_2 concentrations at each receptor is shown in Figure 6.8. The predicted concentrations, and the source contributions, are also set out in Table 6.5 for the

ENR scenario, for a number of selected receptors; these receptor locations are shown in Figure 6.9. These receptors are not necessarily intended to represent worst-case concentrations, but rather receptors at which airport and road-NOx contributions are important.

The maximum predicted annual mean NO_2 concentration with the Heathrow ENR Scheme is 37.2 µg/m^3 and occurs to the north of the new extended runway, close to the A3044; the incremental change above Do-Minimum is 9.8 µg/m^3. The maximum predicted incremental change (14.0 µg/m^3) occurs to the north of the new extended runway, close to the realigned M25, where the predicted concentration for the Heathrow ENR Scheme is 37.1 µg/m^3. There are no predicted exceedences of the air quality objective at any receptor location, in either the Do-Minimum or Heathrow ENR scenarios.

Table 6.5: Predicted Annual Mean NO_2 Concentrations (µg/m^3) at Selected Receptor Locations in 2030, with Heathrow ENR

Receptor ID	OS Grid Ref		Airport NOx	Road NOx	Backgnd NOx	Total NO_2
ENR-A	501268	178074	2.0	8.3	23.3	20.9
ENR-B	501352	176386	2.4	3.0	19.0	15.8
ENR-C	502602	173280	3.6	27.7	20.3	27.6
ENR-D	502777	177055	4.8	17.6	23.9	26.2
ENR-E	503422	178761	3.9	4.3	26.8	21.6
ENR-F	504209	174945	14.3	5.6	20.5	23.2
ENR-G	505210	178469	8.4	13.8	25.3	26.8
ENR-H	505953	174022	10.7	2.7	20.2	20.2
ENR-I	506490	179566	4.7	5.0	31.3	24.7
ENR-J	507132	177938	8.7	6.8	23.0	23.0
ENR-K	507561	170562	2.6	11.3	18.3	19.3
ENR-L	507989	177031	13.5	5.9	23.6	24.9
ENR-M	509121	177076	9.7	3.7	23.3	22.2
ENR-N	509640	175229	15.7	4.0	22.5	24.6
ENR-O	509640	175229	13.6	6.9	23.8	25.5
ENR-P	510183	178361	4.4	13.5	24.4	24.7
ENR-Q	510223	176477	7.4	2.8	23.1	20.8
ENR-R	511058	173420	3.7	14.4	21.9	23.4
ENR-S	511517	176330	4.9	14.8	23.3	25.1
ENR-T	512517	174604	3.1	1.7	21.4	17.2

The numbers of properties and the associated population where annual mean NO_2 concentrations are predicted to improve, worsen, or remain unchanged, are summarised in Table 6.6. The analysis excludes properties that lie within the Scheme boundary or within 10m of any new road link. The analysis considers the change with respect to "zero" (≤ ±0.05 µg/m^3) and within the concentration bands described in Figure 6.8. For NO_2, a separate description is provided for those properties and populations "at risk" of exceeding the objective (i.e. greater than 32 µg/m^3).

Table 6.6 Properties and Populations Affected by Changes to Annual Mean NO_2 Concentrations within the Principal Study Area

Change in Concentration ($\mu g/m^3$)	Figure 6.8 Key	Properties Affected			Estimated Population Affected		
		NO_2		PM_{10}	NO_2		PM_{10}
		Absolute NO_2 <32µg/m^3	Absolute NO_2 >32µg/m^3		Absolute NO_2 <32µg/m^3	Absolute NO_2 >32µg/m^3	
>+12	●	0	6	0	0	16	0
+10 – +12	●	0	8	0	0	21	0
+8 – +10	●	51	59	0	132	153	0
+6 – +8	●	248	40	0	644	104	0
+4 – +6	●	508	0	1	1,319	0	3
+2 – +4	●	1,925	0	152	4,999	0	395
+0.05 – +2	●	35,811	0	38,151	93,001	0	99,076
+0.05 - -0.05	○	2,338	0	8,797	6,072	0	22,846
-0.05 – -2	●	6,319	0	469	16,410	0	1,218
-2 – -4	●	242	0	0	628	0	0
-4 – -6	●	13	0	0	34	0	0
<-6	○	2	0	0	5	0	0

The term “properties” refers to buildings with relevant exposure at ground level.

More properties experience an increase than a decrease or no change. As can be seen from Figure 6.8, the highest incremental changes occur immediately to the north of the eastern end of the new extended runway. This is associated with take-off emissions on the two northern runways; for operational reasons, take-offs from these runways are necessarily restricted to the centre of the airport (i.e. during westerly operations, take-offs would be on the new extended runway, whilst during easterly operations, take-offs would be on the existing northern runway). The average increase to annual mean NO_2 concentrations at affected properties is 0.7 µg/m^3. There are 113 “at risk” properties (>32 µg/m^3) that would experience an increase in NO_2 concentrations.

Figures 6.10, 6.11 and 6.12 show the predicted annual mean PM_{10} concentrations for Do-Minimum, Heathrow ENR and Incremental Change respectively. The average change is an increase of 0.1 µg/m^3. These data are utilised in the Partial Impact Pathway assessment (Appendix G).

6.4.4 National Compliance

Table 6.7 sets out Defra’s PCM modelled road links with NO_2 concentrations for 2030 greater than 32 µg/m^3. The forecasts are also shown in Figure 6.13. The incremental change to annual mean NO_2 concentrations in 2030, associated with the Heathrow ENR Scheme at these locations, is also shown in Table 6.7.

It is important to note that the Heathrow ENR Scheme is predicted to increase traffic flows on Bath Road (A4) and that the proposed Terminal 6 would be in close proximity to the western link of this road section.

Table 6.7: National Compliance – Predicted Annual Mean NO_2 Concentrations ($\mu g/m^3$) in 2030

Road Link	Maximum PCM Predicted Concentration in Defra Zone [1]	PCM Predicted Concentration [2]	Predicted ENR Incremental Change [3]	Total NO_2 Concentration [4]
Bath Road, A4 (junction A437 to west of Newbury Road)	48.6	47.4 – 47.6	2.8 – 8.2	50.3 – 55.8
A4 (junction of Fulham Palace Road to Earls Court Road)	48.6	37.4 – 44.9	0.4 – 0.5	37.9 – 45.3
A312	48.6	32.1 – 33.9	0.1 – 0.4	32.7 – 34.1
A40 Western Avenue (junction A406 to east of A219)	48.6	37.8 – 44.3	0.1 – 0.3	37.1 – 44.4
Junction of Kew Rd/ Gunnersbury Ave extending east along A4 to Chiswick Lane	48.6	33.7 – 33.9	0.5 – 3.3	34.4 – 37.1
M4 (Windmill Rd) extending west along Great West Road	48.6	33.3	0.5	33.8

1. This value is the maximum predicted concentration by the PCM model in 2030 at any location within the Greater London agglomeration.
2. The PCM Predicted Concentration indicates the range across all individual links in the identified road sector
3. The Predicted Heathrow ENR incremental change is the maximum predicted increment at any location along the individual road links (at a distance of 4m from the kerbside)
4. The total concentration has been calculated for each link by adding the PCM Predicted Concentration to the maximum Heathrow ENR incremental change. The values shown are the recalculated ranges across the individual links.

Defra's PCM model forecasts exceedences of the Limit Value along Bath Road (junction A437 to west of Newbury Road), the A4 (junction of Fulham Palace Road to Earls Court Road) and A40 (junction A406 to east of A219) in 2030 for the Do-Minimum scenario. The unmitigated Heathrow ENR Scheme would increase annual mean NO_2 concentrations along the Bath Road (A4) sector links by between 2.8 and 8.2 $\mu g/m^3$, resulting in total concentrations[20] of between 50.3 and 55.8 $\mu g/m^3$. Along the A4 (Fulham Palace Road to Earls Court Road) concentrations are predicted to increase by 0.4 to 0.5 $\mu g/m^3$, with total concentrations up to 45.3 $\mu g/m^3$. Along the A40 Western Avenue, concentrations are predicted to increase by 0.1 to 0.3 $\mu g/m^3$ (less than 1% of the Limit Value), with total concentrations up to 44.4 $\mu g/m^3$. There are no predicted exceedences of the Limit Value at any other PCM-modelled road link considered in this assessment. Further details of the EU Air Quality Directive compliance risk assessment are provided in Appendix I.

The incremental change associated with the unmitigated Heathrow ENR would cause the Bath Road (A4) sector PCM road links to have a higher concentration in 2030 (55.8 $\mu g/m^3$) than the Maximum PCM Predicted Concentration in the Greater London Agglomeration (which is 48.6 $\mu g/m^3$, and occurs at Marylebone Road)

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[20] The approximate contributions to concentrations at this link are 41% for airport sources and 31% from road traffic; the remaining 28% is related to the background contribution.

identified in the current Defra compliance assessment. The unmitigated Heathrow ENR Scheme would thus delay compliance with the Limit Value. The implications of this are discussed in Section 3.1.1.

The PCM model does not predict any exceedences of the PM_{10} limit values.

The impacts identified above should be considered in the light of the uncertainties of the PCM model predictions, set out in Section 3.10. In particular, if Euro 6c vehicles perform as currently expected, then the PCM model predictions in 2030 would be lower than shown. In addition, the incremental change due to the Heathrow ENR Scheme would also be lower (see Appendix H).

The impacts identified above include mitigation-by-design, but do not take account of additional mitigation measures, a number of which have been suggested by the Promoter. The potential impact of these additional mitigation measures is discussed in Section 6.7.1.

6.4.5 Monetisation of Health Impacts and Environmental damage

The total damage costs for the Heathrow ENR (Global Growth) Scenario are set out in Table 6.8.

Table 6.8: Total Damage Costs – Heathrow ENR (GG)

2014 prices £ million	Green Book Central Estimate	Green Book Central – Low	Green Book Central - High	EEA – Low VOLY [1]	EEA – High VSL [2]
Total Present Value Damage - PM_{10}	£618.7m	£484.4m	£703.1m	£99.5m	£288.6m
Total Present Value Damage - NO_X	£69.6m	£54.3m	£79.1m	£252.1m	£682.7m
Total Air Quality Damage Costs over 60 Years	£688.3m	£538.7m	£782.2m	£351.6m	£971.3m
Snapshot 2030	£11.0m	£8.6m	£12.5m	£6.4m	£17.6m
Snapshot 2040	£10.2m	£8.0m	£11.6m	£5.1m	£14.2m
Snapshot 2050	£13.2m	£10.3m	£15.0m	£6.6m	£18.2m
Snapshot 2060	£12.2m	£9.6m	£13.9m	£6.1m	£16.8m

1. VOLY = Value of a life year
2. VSL = Value of a statistical life

The total costs of NOx and PM_{10} over the 60 year appraisal period, based on the unmitigated change in mass emissions with the Heathrow ENR Scheme in place, are £69.6m and £618.7m respectively, based on the central estimate.

The Impact Pathway values for 2030, for hospital admissions with the WHO HRAPIE concentration-response coefficients are reported in Appendix G.

6.4.6 Nitrogen Deposition at Sensitive Ecosystems

The predicted annual mean concentrations of nitrogen oxides and nitrogen deposition fluxes at each of the designated conservation sites identified in Table 6.1 are set out in Table 6.9 and Table 6.10.

Table 6.9: Maximum Nitrogen Oxides Concentrations at Designated Habitats for Do-Minimum (DM) and Change due to Heathrow ENR in 2030

Site Name	OS Grid Ref of Receptor		DM	Change Due to ENR
South West London Waterbodies RAMSAR/SPA and Staines Moor SSSI	504757	174224	44.0	9.2
	506009	172602	38.7	5.4
	504420	172274	39.4	-0.3
	504557	172428	42.4	-1.2
South West London Waterbodies RAMSAR/SPA and Thorpe Park No. 1 Gravel Pit SSSI	502300	168043	38.3	0.5
South West London Waterbodies RAMSAR/SPA and Wraysbury No. 1 Gravel Pit SSSI	500732	174279	22.7	0.7
South West London Waterbodies RAMSAR/SPA and Wraysbury Reservoir SSSI	502365	175609	23.7	1.5
	502958	175624	27.5	5.9
	502955	174298	45.3	2.2
	503179	175195	28.6	22.7
Staines Moor SSSI	503445	175476	33.7	27.8
	503544	175364	39.6	13.9
	503254	174851	48.9	2.3
	504731	174245	41.8	34.7
	503523	172352	52.5	45.6
	504677	172028	46.5	4.5
	504436	171918	53.3	4.9
	504464	171838	41.7	2.6
	504734	171710	39.1	2.4
Fray's Farm Meadows SSSI	505680	185651	53.2	0.4
Langham Pond SSSI	500744	171577	35.6	0.2
Wraysbury & Hythe End Gravel Pit SSSI	501814	172745	34.2	0.4
	500564	173427	25.9	0.9
Dumsey Meadow SSSI	505855	166814	35.3	0.7
	505487	166611	35.4	0.9
Bushy Park and Home Park SSSI	514458	169350	50.8	1.1
	515077	168959	47.9	1.1
Critical Level			30	

Where designated sites overlap (e.g. Staines Moor SSSI and South West London Bodies RAMSAR/SPA) they are shown more than once.

The Heathrow ENR Scheme would cause a new exceedence of the NOx Critical Level at the South West London Waterbodies RAMSAR/SPA and Wraysbury Reservoir SSSI (a total concentration of up to 51.3 µg/m^3). However, as set out in Table 2.1, the UK Government's interpretation is that the Critical Level does not strictly apply at this location. The greatest incremental change occurs at the Staines Moor SSSI (45.6 µg/m^3) representing an 87% increase. A minor reduction in NOx concentration is predicted to occur at the South West London Waterbodies RAMSAR/SPA and Staines Moor SSSI (1.2 µg/m^3).

Table 6.10: Maximum Nutrient Nitrogen Deposition Fluxes at Designated Habitats for Do-Minimum and Change due to Heathrow ENR in 2030

Site Name	OS Grid Ref of Receptor		DM	Change Due to ENR	Critical Load
South West London Waterbodies RAMSAR/SPA and Staines Moor SSSI (G)	504757	174224	10.8	0.5	20 - 30
	506009	172602	10.7	0.3	
	504420	172274	10.7	<0.1	
	504557	172428	11.0	-0.1	
South West London Waterbodies RAMSAR/SPA and Thorpe Park No. 1 Gravel Pit SSSI (G)	502300	168043	10.8	<0.1	20 - 30
South West London Waterbodies RAMSAR/SPA and Wraysbury No. 1 Gravel Pit SSSI (G)	500732	174279	10.0	<0.1	20 - 30
South West London Waterbodies RAMSAR/SPA and Wraysbury Reservoir SSSI (G)	502365	175609	10.7	0.1	20 - 30
	502958	175624	10.5	0.4	
	502955	174298	11.7	0.1	
	503179	175195	10.5	1.4	
Staines Moor SSSI (G)	503445	175476	9.8	1.6	20 - 30
	503544	175364	10.2	0.8	
	503254	174851	11.0	0.1	
	504731	174245	10.6	1.8	
	503523	172352	11.2	2.2	
	504677	172028	11.2	0.3	
	504436	171918	11.4	0.3	
	504464	171838	10.8	0.2	
	504734	171710	10.7	0.1	
Fray's Farm Meadows SSSI (G)	505680	185651	12.7	<0.1	N/A
Langham Pond SSSI (G)	500744	171577	10.8	<0.1	20 - 30
Wraysbury & Hythe End Gravel Pit SSSI (G)	501814	172745	10.3	<0.1	20 - 30
	500564	173427	10.3	0.1	
Dumsey Meadow SSSI (G)	505855	166814	10.1	<0.1	20 - 30
	505487	166611	10.1	0.1	
Bushy Park and Home Park SSSI (G)	514458	169350	11.0	0.1	10 - 15
	515077	168959	10.8	0.1	

Where designated sites overlap (e.g. Staines Moor SSSI and South West London Bodies RAMSAR/SPA) they are shown more than once.
Those sites with a letter (G) shown in parenthesis have been modelled using a deposition velocity of 0.0015 m/s which is typical for grassland. Those sites with a letter (W) shown in parentheses have been modelled using a deposition velocity of 0.003 m/s which is typical of woodland. The deposition velocity has been set based on the habitat to which the Critical Load refers.

The Heathrow ENR Scheme would not cause any new exceedences of the lower or upper bounds of the Critical Loads. The greatest incremental change occurs at the Staines Moor SSSI (2.2 kgN/ha/yr) representing a 19.6% increase.

6.5 Construction Impacts

There are insufficient details available at this stage to undertake any quantitative assessment of the construction impacts. A qualitative assessment has been carried out, based on IAQM guidance, which assigns a risk category to construction sites based on the scale of the works and the proximity of sensitive receptors.

An analysis of the numbers of sensitive properties within different distance band categories cited within the IAQM guidance has been undertaken. As set out in Chapter 3, the precise alignment of new road links is not known at this stage, and so the analysis has been based solely on the Scheme boundary. The number of sensitive receptors within different distance bands is shown in Table 6.11.

Table 6.11: Numbers of Sensitive Receptors Within 350m of Scheme Boundary

Less than 100m	100 to 200m	200 to 350m	Total within 350m
526	1,231	1,913	3,760

The Heathrow ENR Scheme would remove part of the Staines Moor SSSI, with the remaining part of the site adjacent to the Heathrow ENR boundary. Given the proximity of a large number of receptors to the Scheme boundary, and the size of the expected works, it is likely that the construction works will be classified as High Risk.

It is the view of IAQM that dust impacts (associated with soiling nuisance and/or PM_{10}) from construction sites can be mitigated, and that the residual impact should be insignificant in most cases. During the detailed design of the Scheme, a Construction Environmental Management Plan (CEMP) should be prepared which sets out in detail the best practice mitigation measures that will be applied, and how they will be managed. Guidance on best-practice measures is set out in both the IAQM and GLA documents.

There is evidence that effective mitigation can adequately control dust impacts from large construction projects. During the course of the Heathrow Terminal 5 construction works, a detailed dust monitoring network was established. The study concluded that there was no significant impact in the local area due to dust impacts (Entec, 2006).

With regard to emissions from on-site plant and construction traffic, impacts can be controlled by mitigation and use of low-emission plant and vehicles. The use of Stage IV emissions Non Road Mobile Machinery (NRMM) and Euro VI HGVs will minimise any impacts. Construction Logistics Plans allow site deliveries and removals to be managed so that they are made at times when they are most needed and when they will contribute least to local road network congestion

6.6 Commentary on Promoter’s Submission

This section focuses on the Promoter’s predicted air quality impacts of the Scheme.

6.6.1 Information Provided by the Promoter

The Promoter has carried out a review of air quality constraints based on available baseline data. It was considered that sufficient data were not available to support a detailed dispersion modelling study to be carried out.

The Promoter's submission sets out the policy background and describes existing air quality conditions in terms of local monitoring data and the presence of AQMAs. General constraints have then been listed (assuming a Scheme opening year of 2023).

A list of embedded mitigation measures are provided including:

- An assumption that Heathrow Hub would promote a modal shift of approximately 38-50% of passengers moving from cars to public transport access to the airport;
- Adjusting the proposed infrastructure layout where possible to maximise the distance of new routes and car parking from sensitive receptors;
- Incorporating ventilation systems in the new M25 tunnel to reduce the build-up of emissions at the portals; and
- Through the use of the extended runway, reducing the number of take-offs from the existing boundary so that emissions are closest to the centre of the airport away from sensitive receptors.

Measures currently in place, and which the Promoter assumes will continue, include:

- Encouraging aircraft to have the lowest emissions and use of optimised thrust take-off settings;
- Minimising aircraft emissions through the development of take-off/landing and taxiing schedules to reduce hold times on apron and taxiway;
- Ensuring on-site emissions from GSE are minimised through the use of low emissions vehicles or electric vehicles;
- Ensuring additional emissions from heat and power generation plant are mitigated; and
- Providing FEGP and PCA on stand to reduce APU use.

The Promoter recognises that further work will be required at the detailed design stage to demonstrate the air quality impacts and to further refine the mitigation strategies as required. This will include targeted modelling of the key risk locations.

6.6.2 Comparison with Promoter's Submission

As the Promoter has provided no quantitative assessment of the air quality impacts of the Heathrow ENR Scheme, no comparison with this assessment can be made.

6.6.3 Commentary on the Promoter's Mitigation

An evaluation of the principal mitigation measures set out by the Promoter is provided below:

Measure 1: Modal shift of 38-50% of passengers from cars to public transport access to the airport.

The Stage 2 Submission from the Promoter sets out a vision for high public transport access, but it is not clear whether this is deliverable. The surface access modal share and traffic volumes assumed in this assessment have been built into the dynamic modelling.

Measure 2: Maximising distance between the new road sections, car parks and other key emissions sources from future sensitive receptors.

The layout of the Heathrow ENR Scheme has been incorporated into this assessment, and this mitigation measure has been accounted for in the modelling study. However, as set out in Chapter 3, precise alignments of the new roads are not available at this stage, and the predicted impact on sensitive receptors can only be indicative.

Measure 3: Incorporating ventilation systems within the M25 tunnel to reduce build-up of emissions at tunnel portals.

Ventilation systems within the tunnel will be required for safety reasons. However, such systems do not reduce the impact of emissions from the tunnel portal (as the mass emission is unchanged). A key characteristic of tunnel portal emissions is they rapidly disperse and concentrations are reduced to background levels within a relatively short distance. A summary of key research on tunnel portal emissions has been prepared by the New South Wales Government (NSW, 2014). This concludes that *"the impact of portal emissions on concentrations typically extends up to about 100 – 200m from the portal, and beyond this distance it is difficult to distinguish the impact of the portal from the surface road section"*. There are no sensitive receptor locations within 200m of the tunnel portals and no additional ventilation beyond that normally required is necessary.

The only effective mitigation measure that could be applied to reduce portal emissions would be to expel the tunnel air through a stack. Given the quantity of air that needs to be extracted, the size of the stack can be considerable. This is not considered to be a viable consideration given safety considerations and the proximity of the Heathrow ENR Scheme.

Measure 4: Use of the extended runway to allow a proportion of the take-off emissions (on the Heathrow ENR) to be well away from the airport boundary.

This assessment has assumed a two-thirds departure with Heathrow ENR during all westerly operations, and maximises the benefits of take-off emissions away from the airport boundary,

Measure 5: NOx emission charging to encourage airlines to use the cleanest aircraft and encouragement to use optimised thrust take-off techniques.

A NOx emissions charging scheme has been in operation at Heathrow Airport since 2004[21]. There is no clear evidence that this measure has influenced airlines to select airframe/engine combinations with lower NOx emissions when the other economic and environmental factors are also taken into consideration. A recent review of the NOx emissions charging scheme (CAA, 2013) notes that *"the engines on 60% of British Airways' fleet of Boeing 747-400s were modified, possibly as a consequence of the NOx charge",* but *"as airport charges are typically a small*

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[21] Heathrow Airport Limited is currently consulting on NOx emissions charges, and proposes to increase the NOx charge from 15% of the total environmental charge, to 20% (Heathrow Airport Limited, 2015).

proportion of an airline's total costs, so the associated incentives for airlines to use aircraft with best-in-class NOx performance may be small compared to other drivers".

NOx emissions from aircraft engines are limited by the CAEP standards and this is the main driver to change; however, because of the desire to deliver improved fuel performance (with associated, higher Overall Pressure Ratios) there is limited evidence that the CAEP standards have significantly reduced emissions from aircraft engines when expressed in terms of kgNOx/second. The aircraft movements and fleet mix assumed for the ENR Scheme have been based on the Airports Commission's Global Growth (carbon traded) scenario, and it would not be appropriate to adjust this assumption within the assessment.

The NOx charging scheme is based solely on a calculation of emissions in the standard ICAO LTO Cycle (which assumes 100% thrust on take-off) and no adjustment to the landing charge is applied to account for actual thrust settings. Even where airlines adopt a policy to use reduced thrust on take-off wherever possible, there are circumstances where higher (and 100%) thrust settings are dictated by the Limited Take-Off Weight, and environmental conditions such as ice on the runway and wind shear.

Measure 6: The provision of Fixed Electrical Ground Power (FEGP) and Pre-Conditioned Air (PCA) to reduce the need for APU usage.

The Airports Commission assessment has been founded on information provided by the ENR Promoter, and assumes full compliance with the Managing Directors Instruction (MDI) on maximum APU run times. However, there is no evidence that full compliance is currently achieved in practice. Uptake of greater FEGP use is sensitive to the cost incurred by airlines, and provision is no guarantee that it will be used. Should FEGP be made cost-advantageous to airlines over APU by the Promoter, then greater uptake is likely. To test this, an assumption has been made on APU run times.

There are examples in Europe of international airport operators that enforce strict rules regarding the use of APU for commercial aircraft on both arrival and departure, for example at Faro Airport in Portugal, and Barcelona and Madrid Airports in Spain. The policy employed at Barcelona Airport has been published by Boeing (Boeing 2015), and states:

"*At Stands in contact with terminal: It is obligatory to use the 400 Hz facilities. The use of the air-conditioning facilities will be obligatory when the aircraft air conditioning is needed. The use of the aircraft APU is forbidden in these stands in the period between 2 minutes after blocks for the arrivals and 5 minutes before off-blocks for departure. The aircraft APU will only be able to be used when the fixed units are not operative and the mobile units are not available.*

At Remote Stands: The use of APU is forbidden except for 10 minutes after blocks for the arrival and 10 minutes before off-blocks for the departure except for wide bodied aircraft that may be allowed to use it 50 minutes before departure and 15 minutes after arrival."

In the Heathrow ENR Scheme, the ratio of remote stands to contact stands is approximately 20-25%. In terms of operation, the airport will preferentially use contact stands, and remote stand use is likely be much less than 20%. It is anticipated that the vast majority of aircraft will utilise contact stands and will have access to FEGP and PCA. As a sensitivity test for APU run times, NOx emissions have been calculated assuming that the Barcelona Airport contact stands APU usage times are enforced with the Heathrow ENR Scheme. This represents a feasible minimum. The results of the sensitivity test are presented in Table 6.12 below.

Table 6.12: APU NOx Emission Sensitivity Test Results

Scenario	APU Run Time (in dispersion model)	Total Annual NOx Emissions from APU (t/yr)	Sensitivity Test APU Run Time	Total Annual NOx Emissions from APU (t/yr)
ENR	Arrival: 40 minutes for wide body and 20 minutes for narrow body aircraft. Departure: 40 minutes for wide body and 20 minutes for narrow body aircraft.	390.2	Arrival: 2 minutes for all aircraft. Departure: 5 minutes for all aircraft.	43.2

The results indicate an approximate 90% reduction in annual NOx emissions from APUs which could be achievable if stringent regulations on APU run times were introduced and enforced in 2030, on all stands. A source apportionment study of modelled airport NOx concentrations suggests maximum off-airport contributions from APU emissions to NOx concentrations of around 1.1 µg/m^3 (based on model predictions at the Oaks Road (HOA) and Hatton Cross (HS7) monitoring sites). This indicates a potential for reductions of up to 1 µg/m^3 of NOx at sensitive receptor locations resulting from the implementation of this measure.

Measure 7: Improve infrastructure for Ultra Low Emission Vehicles (ULEVs) such as electrical charge points and hydrogen fuel stations, both airside and landside.

It is not possible to forecast the uptake of ULEVs by airside operators or by visitors to the airport. The assessment has included a rollover model for road-vehicle GSE, such that the vast majority of vehicles will be Euro 6/VI by 2030. As non-road vehicles and plant are replaced less frequently, no rollover has been assumed but all new vehicles and plant have been assumed to comply with Stage IIIA emissions.

A substantial proportion NOx emission from GSE in 2030 comes from the Non-Road Mobile Machinery (NRMM), which includes all ground support vehicles and equipment which are not road registered; this includes aircraft tugs, ground power units (GPUs), baggage tugs, belt loaders, cargo tractors and carts.

A feasibility study on extremely low emission technology GSE at Los Angeles (LAX) airport (Smith, 2013) sets out the 2013 GSE fleet at LAX, by fuel use. For almost all types of NRMM, there are electric-powered variants in operation, and for certain types, the proportion of electric variants operating at LAX in 2013 was between 45 and 95%, with a commitment to introduce more electric vehicles to the GSE fleet.

A sensitivity test for the introduction of a higher proportion of non-road GSE for the Heathrow ENR Scheme has been based on an assumption that 80% of the diesel NRMM is replaced with electric variants by 2030. This is based on 100% removal of GPUs due to extended coverage of FEGP across all aircraft stands, and evidence from LAX that operating with up to 95% electric NRMM is possible.

The results of the sensitivity test on are set out in Table 6.13 below. The results suggest that the use of 80% electric NRMM within the GSE fleet could lead to reductions in total annual NOx emissions of around 106 te/yr, equivalent to a 60% decrease.

Table 6.13: Non-Road GSE NOx Emission Sensitivity Test Results Heathrow ENR 2030

Total Annual NOx Emissions (te/yr)				% Difference
Non-Road GSE	All GSE	Non-Road GSE (80% Electric NRMM)	All GSE (80% Electric NRMM)	
161.3	213.8	32.3	84.8	-60.3

The reduction in NOx emissions is founded on the simple assumption that replacement of 80% of the NRMM GSE with electric variants would reduce fuel use and NOx by an equivalent amount.

Measure 8: Minimising aircraft emissions through the development of take-off/landing and taxiing schedules to reduce hold times on the apron and taxiway.

Busy airports experience delays to departing aircraft between the push back from the stand and the start of take-off roll on the runway. The typical delay time (8 minutes) was provided by the Promoter of the Heathrow ENR Scheme for the 2009 baseline, and has been represented in the model as runway-end hold queues. For the 2030 Heathrow ENR scenario, departure delay times (runway hold times) were assumed to be unchanged from 2009 as no robust indication of future hold times was provided by the Promoter.

A UK runway resilience study, published in 2008 (SH&E, 2008) used electronic flight processing system (EFPS) data to analyse taxi times at Heathrow Airport to identify departure delay times. The delay times were calculated as the difference between the actual stand-to-runway taxi time and the unimpeded stand-to-runway taxi time. The resilience study concluded that average departure delays (i.e. runway hold times) at Heathrow were around 9 minutes, and thus slightly higher than that suggested by the Promoter.

A sensitivity test for increased departure delay times has been carried out to consider the potential impact in terms of NOx emissions.

In order to estimate possible delay times for Heathrow in 2030, departure delay curves have been provided by LeighFisher (LeighFisher, 2012). These allow typical delay times to be determined depending on the capacity ratio of the airport. Capacity ratios for the Heathrow ENR scenario, split into summer and winter, have been provided by LeighFisher.

To estimate an annual average delay time the following approach has been applied.

$$\text{DelayAA} = ((\text{DelaySMR} \times \text{ATMSMR}) + (\text{DelayWTR} \times \text{ATMWTR})) / \text{ATMA}$$

Where:

DelayAA = Annual Average Delay Time;
DelaySMR = Summer Average Delay Time (obtained from the summer delay curve using the summer capacity ratio);
ATMSMR = Total ATMs in the summer period;
DelayWTR = Winter Average Delay Time (obtained from the winter delay curve using the winter capacity ratio);
ATMWTR = Total ATMs in the winter period.
ATMA = Total Annual ATMs

Table 6.14 shows the calculation of the annual average departure delay times (DelayAA) for Heathrow ENR in 2030 using the summer and winter delay curves and capacity ratios provided by LeighFisher.

Table 6.14: Calculation of Annual Average Departure Delay Times

Scenario	Summer Capacity Ratio	Summer ATMs	Winter Capacity Ratio	Winter ATMs	Annual Average Delay Time ($Delay_{AA}$)
Heathrow ENR	1.0012	410,948	0.9962	288,522	10.42 mins

Using the annual average departure delay times in Table 6.14, a sensitivity for total annual NOx emissions has been carried out for runway hold queues for the Heathrow ENR 2030 scenario. The results of the sensitivity test include a comparison with the total annual NOx emissions from runway hold queues assumed in the dispersion modelling study, and is shown in Table 6.15.

Table 6.15: Hold Time NOx Emission Sensitivity Test Results

Scenario	Hold Time Assumed in Model (mins)	Total Annual NOx from Hold Queues (t/yr)	Hold Time Assumed for Sensitivity Test (mins)	Total Annual NOx from Hold Queues (t/yr)	% Difference
Heathrow ENR	7.95	142.1	10.42	186.0	31%

The data in Table 6.15 suggest that the underestimate of NOx emissions associated with departure delay times in the model may be of the order of 30%. The use of a management system to *reduce* average delay times by a similar margin (e.g. from 8 minutes to 5.5 minutes) would be expected to deliver benefits of the same magnitude, but the feasibility of such a reduction in delay times is highly uncertain. It is also important to consider these data in the context of total airport ground-source emissions of NOx (i.e. excluding emissions at altitude in the initial climb, climbout and approach modes). For the 2030 Heathrow ENR scenario, total ground-source emissions are 2,886 te/yr. Emissions from hold times thus represent about 4.9% of the total (in the modelled assumption); a reduction of 2.5 minutes in average hold times would deliver an improvement of about 1.5%.

Measure 9: Ensuring additional emissions from heat and power generation plant are mitigated.

For the Heathrow ENR scenario, it has been assumed that all heating and energy plant at Heathrow are located within the main T2 and T5 energy centres. NOx emissions for 2030 have been calculated based on predicted energy consumption, assuming a NOx emission rate of 40 mg/kWh, which represents an ultra-low NOx standard. Mitigation for heat and power sources has therefore been included within the assessment.

6.6.4 Additional Mitigation Measures

There are a number of additional mitigation measures, not specifically highlighted by the Promoter, which could be implemented. Commentary on these is provided below.

Encouraging airlines to shut down an engine during taxiing.

It is not clear to what extent shutting down one engine during taxiing is used by the airlines. The PSDH report (paragraph 109) notes that *"there are a number of reasons why engines cannot be shut down, such as the requirement for a cooling-down period (especially after having used reverse thrust above idle) and the difficulty of having to turn an aircraft on the taxiway against the live engine. This, coupled with advice from one manufacturer that NOx emissions may not benefit from this technique, has dissuaded some operators from pursuing its use more thoroughly"*.

In contrast, a study funded by NASA Ames (Kumar et al, 2014) concluded that single engine taxi-out procedures have the potential to reduce taxi-out NOx emissions by 27% at Orlando (MCO) Airport and by 45% at New York La Guardia (LGA). If implemented effectively, a potential reduction in taxi-out NOx emissions for the Gatwick 2R Scheme might be achievable.

Supporting ongoing technological developments and innovation, including industry research into the use of alternative fuels for aircraft.

The feasibility for the uptake of alternative fuels (biofuels) into commercial airline operations is increasing; this is primarily driven by targets to reduce the carbon footprint, rather than to reduce emissions of pollutants such as NOx and fine particulate matter. Whilst a number of technical and economic challenges remain, it is anticipated that sustainable biofuels will represent an appreciable proportion of the global jet fuel supply in the future.

The International Air Transport Association (IATA) report on alternative fuel use for aviation (IATA, 2013) briefly discusses non-CO_2 emissions from biofuel use in aviation. The report cites evidence that the use of some certified biofuels can reduce emissions of ultrafine particles due to the lower fraction of aromatics and impurities in the fuel; however, the effects on reducing NOx emissions are less pronounced. The report further notes that *"significant research efforts are needed to better understand the issues related to non-CO_2 emissions"*.

The formation of NOx during the combustion of aviation fuel arises primarily from the oxidation of atmospheric nitrogen in high temperature flame regions within the turbine engine. For a given engine, the rate of NOx formation is dependent on many variables which include the physical and chemical properties of the fuel in use. Biofuels are usually blended with standard Jet A/A1 kerosene in variable proportions to balance cost, availability and performance. Taking into account the uncertainty in economic feasibility and the possible range of fuel blends, it is not possible to quantify what, if any effect, the future uptake of biofuels would have on reducing NOx emissions from aircraft associated with the Heathrow ENR Scheme.

Operate ENR with a steeper glide slope to reduce the impact of aircraft approach emissions at ground level.

A steeper glide slope of 3.2 degrees has been assumed for the Heathrow ENR Scheme. However, emissions during approach make very little contribution to ground-level concentrations (as the emissions are principally at altitude). This is confirmed in the report which was published by the Government's Air Quality Expert

Group (AQEG)[22], which noted that “aircraft emissions between 100m and 1000m contribute little to ground-level concentrations”.

Introduce an airport congestion charge for people travelling to the airport, with possible exemptions for the greenest vehicles.

An assessment on demand management measures in reducing car use at Heathrow Airport has been carried out for Appraisal Framework Module 4 (Jacobs 2015). The overall conclusions are that the imposition of additional charges on car users could have a significant impact on car mode share and overall traffic demand. Depending on the scale of charge imposed, and the extent of the scheme (i.e. whether it targets passengers, employees and/or taxis), it is possible that traffic generation with the Heathrow ENR Scheme could be reduced to 2013 levels. An evaluation of Measure 1 (see above) assumes no increase in traffic levels above Do-Minimum, and no further analysis was considered necessary.

Implementation of an Ultra-Low Emissions Zone

A ULEZ is currently being promoted by TfL for the central London area. A ULEZ scheme implemented in the Heathrow ENR area could potentially reduce NO_2 concentrations. It is not possible to accurately predict the impact of such a scheme on the PCM model results for the key link along the A4 Bath Road, as this will depend on the nature and geographic scope of the ULEZ and because it is not possible to accurately adjust the PCM background for the presence of a ULEZ. A sensitivity test has been carried out using a nominal scenario to indicate the potential impact of a ULEZ on the changes in concentrations as a result of the Heathrow ENR Scheme. There have been two parts to the sensitivity test: A) it has been assumed that all non-Euro VI and non-Euro 6 vehicles are replaced by Euro VI and Euro 6 vehicles, and B) it has been assumed that 30% of the light duty vehicles in the part (A) test are zero emission vehicles. The road traffic model NOx concentrations for the Do Minimum and With Scheme on this key link have been adjusted for this change in emissions. The reduction in the do-minimum NOx contribution has been subtracted from the PCM value, then the With Scheme increment has been added, to calculate the new road NOx value, which has then been converted into NO_2 using the standard approach. The difference between the original With Scheme PCM NO_2 concentration and the new NO_2 concentration is the effect of the ULEZ. The results of the sensitivity test would be to reduce the Heathrow ENR NO_2 concentration by 0.3 $\mu g/m^3$ for part (A) of the test and 1.1 $\mu g/m^3$ for part (B).

6.7 Conclusions

The principal conclusions of this assessment with respect to the ENR Scheme are:

- The Scheme would not affect compliance with the current NECD and Gothenburg Protocol obligations. If the NECD obligation is tightened in line with current proposals, the UK would exceed the obligation with or without Heathrow ENR. The incremental emissions associated with Heathrow ENR represent a very small fraction of the proposed obligations;
- The Scheme would not cause any new exceedences of the concentration at which the Limit Value is set, or any exceedences of the air quality objective for NO_2. However, the incremental change associated with the unmitigated

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[22] AQEG (2009) Nitrogen Dioxide in the United Kingdom

Heathrow ENR would cause the Bath Road (A4) sector PCM road links to have a higher concentration in 2030 (55.8 µg/m^3) than the Maximum PCM Predicted Concentration in the Greater London Agglomeration (which is 48.6 µg/m^3). The unmitigated Heathrow ENR Scheme would thus delay Defra in achieving compliance with the Limit Value;

- The Scheme would cause a new exceedence of the Critical Level at the South West London Waterbodies RAMSAR/SPA and Wraysbury Reservoir SSSI. However, the UK Government's interpretation is that the Critical Level does not strictly apply at this location. The Scheme would not cause any exceedences of the lower band of the Critical Load (for nitrogen deposition) at any designated habitat;
- The Scheme would worsen air quality (in terms of annual mean NO_2 concentrations) at about 39,000 properties, but would improve air quality at about 6,600 properties; and
- The total costs of NOx and PM_{10} over the 60 year appraisal period, based on the unmitigated change in mass emissions with the Heathrow ENR Scheme in place, are £69.6m and £618.7m respectively.

6.7.1 Assessment of Additional Mitigation

This assessment has taken into account mitigation by design, but has not included the mitigation measures proposed by the Promoter, or additional mitigation measures, as described in Section 6.6. As it is concluded that the unmitigated Heathrow ENR would delay compliance with the Limit Value, the potential benefits of these measures (in terms of changes to annual mean NO_2 concentrations) at the Bath Road link where the PCM model predicts the highest concentration in 2030, are summarised in Table 6.16.

Quantification has been carried out, wherever possible, by calculating the ratio of the mitigated source-NOx emissions to the total source-NOx emissions (for each source in question). This fraction has then been applied to the source contribution at the relevant Bath Road PCM receptor, and Defra's NOx:NO_2 calculator used to estimate the NO_2 concentration.

In addition to these mitigation measures, the potential impacts of the sensitivity tests described in Appendix H should also be considered. If the Euro 6c emissions standard for vehicles were to deliver the stated improvement, then it is estimated that there could be an average reduction in road-NOx emissions of about 7%. It is difficult to determine the precise effect that this could have upon NO_2 concentrations at Bath Road, as both background and roadside levels would be affected, as well as concentrations at Marylebone Road.

If primary NO_2 emissions were to increase from 16.6% to 24.0%, annual mean NO_2 concentrations at Bath Road might be expected to increase by about 0.2 µg/m^3. This is a pessimistic assumption, and makes no allowance for future European legislation to control primary NO_2 emissions.

Table 6.16: Summary of Mitigation Measures for Heathrow ENR

Mitigation Measure	Commentary	Indicative Impact on PCM Exceedence
Modal shift of 38-50% of passengers from cars to public transport access to the airport	The Stage 2 Submission from the Promoter sets out a vision for high public transport access, but it is not clear whether this is deliverable. The surface access modal share and traffic volumes assumed in this Airports Commission assessment have been built into the dynamic modelling. The potential benefits of reducing surface access movements have been considered by assuming the Do-Minimum road-NOx contribution on Bath Road for the Heathrow ENR Scheme.	-2 µg/m^3
Maximising distance between the new road sections, car parks and other key emissions sources from future sensitive receptors	The layout of the Heathrow ENR Scheme has been incorporated into this assessment, and this mitigation measure has been accounted for in the modelling study. However, as set out in Chapter 3, precise alignments of the new roads are not available at this stage, and the predicted impact on sensitive receptors can only be indicative.	N/A
Incorporating ventilation systems within the M25 tunnel	Ventilation systems within the tunnel will be required for safety reasons. However, such systems do not reduce the impact of emissions from the tunnel portal (as the mass emission is unchanged). A key characteristic of tunnel portal emissions is they rapidly disperse and concentrations are reduced to background levels within a relatively short distance. The only effective mitigation measure that could be applied to reduce portal emissions would be to expel the tunnel air through a stack. Given the quantity of air that needs to be extracted, the size of the stack can be considerable. This is not considered to be a viable consideration given safety considerations and the proximity of the Heathrow ENR Scheme.	N/A
Use of the extended runway to allow a proportion of the take-off emissions (on the Heathrow ENR) to be well away from the airport boundary	This assessment has assumed a two-thirds departure with Heathrow ENR during all westerly operations, and maximises the benefits of take-off emissions away from the airport boundary,	N/A

Mitigation Measure	Commentary	Indicative Impact on PCM Exceedence
NOx emissions charging	A NOx emissions charging scheme has been in operation at Heathrow Airport since 2004. There is no clear evidence that this measure has influenced airlines to select airframe/engine combinations with lower NOx emissions when the other economic and environmental factors are also taken into consideration. The aircraft movements and fleet mix assumed for the Heathrow ENR Scheme have been based on the Airports Commission's Global Growth (carbon traded) scenario, and it would not be appropriate to adjust this assumption within the assessment. If a 20% reduction in aircraft NOx emissions were assumed, based on future engine improvements, a reduction in NO_2 concentrations could be achieved.	-1.2 µg/m^3
FEGP and PCA for all future aircraft stands	Uptake of greater FEGP use is sensitive to the cost incurred by airlines, and provision is no guarantee that it will be used. Should FEGP be made cost-advantageous to airlines over APU by the Promoter, then greater uptake is likely. There are examples in Europe of international airport operators that enforce strict rules regarding the use of APU for commercial aircraft on both arrival and departure. A sensitivity test has been undertaken based on these rules, whereby APUs are only allowed to run for a maximum of 2 minutes on arrival and 5 minutes on departure. The results indicate an approximate 90% reduction in annual NOx emissions from APUs could be achievable if stringent regulations on APU run times were introduced and enforced in 2030, at all stands.	-0.4 µg/m^3
Infrastructure for ULEVs	It is not possible to forecast the uptake of ULEVs by airside operators or by visitors to the airport. A sensitivity test for the introduction of a higher proportion of non-road GSE for the Heathrow ENR Scheme has been based on an assumption that 80% of the diesel NRMM is replaced with electric variants by 2030. The results suggest that the use of 80% electric NRMM within the GSE fleet could lead to reductions in total annual NOx emissions of around 106 te/yr, equivalent to a 60% decrease.	-0.2 µg/m^3
Minimising aircraft emissions through the development of take-off/landing and taxiing schedules to reduce hold times on the apron and taxiway	Hold times used in the modelling are likely to have been under-predicted, and thus a sensitivity test has been carried out to consider a more realistic scenario. The results of the sensitivity test suggest that the underestimate of NOx emissions associated with departure delay times in the model would be of the order of 31%. The potential to reduce average delay times below those assumed within the model appears infeasible and has not been explored in greater detail.	N/A

Mitigation Measure	**Commentary**	**Indicative Impact on PCM Exceedence**
Ensuring additional emissions from heat and power generation plant are mitigated.	For the Heathrow ENR scenario, it has been assumed that all heating and energy plant at Heathrow are located within the main T2 and T5 energy centres. NOx emissions for 2030 have been calculated based on predicted energy consumption, assuming a NOx emission rate of 40 mg/kWh, which represents an ultra-low NOx standard. Mitigation for heat and power sources has therefore been included within the assessment.	N/A
Encouraging airlines to shut down an engine during taxiing	It is not clear to what extent shutting down one engine during taxiing is used by the airlines. Based on U.S studies, potentially a 25% reduction in NOx emissions on taxi-out could be achieved.	-0.25 µg/m^3
Technological developments and innovation, such as alternative fuels	Taking into account the uncertainty in economic feasibility and the possible range of fuel blends, it is not possible to quantify what, if any effect, the future uptake of biofuels would have on reducing NOx emissions from aircraft associated with the Heathrow ENR Scheme.	N/A
Steeper Glide Slope	A steeper glide slope of 3.2 degrees has been assumed for the Heathrow ENR Scheme. However, emissions during approach make very little contribution to ground-level concentrations (as the emissions are principally at altitude).	N/A
Congestion Charging	An evaluation of Measure 1 (see above) assumes no increase in traffic levels above Do-Minimum, and no further analysis was considered necessary.	N/A
Ultra-Low Emissions Zone	It is unclear what form a ULEZ would take. However, an indicative sensitivity test has been carried out assuming A) only Euro VI and Euro 6 vehicles are on Bath Road and B) in addition to (A) 30% of the light duty vehicles are zero emission.	A) -0.4 µg/m^3 B) -1.6 µg/m^3
TOTAL	Total potential reduction in the change in NO_2 concentrations with ENR at the Bath Road PCM exceedence area, assuming all the sensitivity tests are additive. A reduction of 7.2 µg/m^3 is required to prevent the Scheme from causing a delay to compliance with the annual mean NO_2 EU LV.	-2.5 µg/m^3 to -3.9 µg/m^3

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Glossary and Abbreviations

ADMS-Airport	Atmospheric Dispersion Modelling System; model developed specifically for the assessment of airports
APIS	Air Pollution Information System
APU	Auxiliary Power Unit
AQMA	Air Quality Management Area
ATM	Air Transport Movement
CAEP	Committee on Aviation Environmental Protection
COPERT4	COmputer Programme to calculate Emissions from Road Transport
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
EEA	European Environment Agency
FEGP	Fixed Electrical Ground Power
FOI	Swedish Defence Research Agency
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies Model
GPU	Ground Power Unit
GSE	Ground Support Equipment
HDV	Heavy Duty Vehicles
IIASA	International Institute for Applied Systems Analysis
ICAO	International Civil Aviation Organisation
LDV	Light Duty Vehicles
LTO	Landing and Take Off Cycle
MARS	Multiple Aircraft Receiving Stands
MDI	Managing Directors Instruction – included in Airports Conditions of Use, and are to be complied with by all operators.
MGPU	Mobile Ground Power Unit
NAEI	National Atmospheric Emissions Inventory
NECD	National Emissions Ceiling Directive
PCM	Pollution Climate Mapping model

PSDH	Project for the Sustainable Development of Heathrow
SAC	Special Area of Conservation
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
ULEV	Ultra Low Emission Vehicles

Appendix A: Background Concentrations

The background concentrations across the Study Areas have been defined using the national pollution maps published by Defra (2015a). These cover the whole country on a 1x1 km grid and are published for each year from 2011 until 2030. The maps currently in use were verified against measurements made during 2011 at a large number of automatic monitoring stations. These 2011 background concentrations have been adjusted to the 2009 baseline year using the approach described below. Background concentrations for each of the relevant 1 km x 1km grid squares have been extracted from the Pollution Climate Mapping (PCM) model maps for 2011. Surfer[23] was then used to interpolate concentrations between the centre points of each 1 km x 1km square to create a high resolution (50m x 50m) grid. Interpolated PCM mapped concentrations were then extracted for a number of background monitoring stations across the Study Areas and compared with the monitored values in 2009.

A1 Background NOx Concentrations

Table A1 describes the monitoring sites that were selected, and shows the comparison between the 2011 mapped annual mean NOx concentration and the 2009 measured concentrations. The data are also shown in Figure A1. The data indicate that the 2011 mapped values are marginally lower than 2009 measured values. The summary statistics from this comparison are:

Root Mean Square Error (RMSE) – 5.30
Correlation coefficient – 0.91
Fractional bias – 0.02

Table A1: Comparison of 2011 Mapped and 2009 Measured Annual Mean NOx Concentrations (µg/m^3)

Monitoring Site	x	y	NOx Concentration	
			2011 Mapped	2009 Measured
Poles Lane Pumping Station- Crawley	526420	139638	28.9	25.6
Gatwick East CRI	529411	141493	42.7	48.6
Hounslow 2 - Cranford	510370	177195	54.7	52.8
Heathrow - Oaks Road	505729	174496	52.1	55.9
Hounslow Hatton Cross	509355	174989	68.6	67.7
Slough Colnbrook	503542	176827	53.8	57.8
Slough Lakeside 2	503569	177385	51.7	65.3
London Teddington	515545	170416	32.8	34.4
London Harlington	508295	177800	64.3	68.1
Horley	528206	142331	47.8	42.6
Ealing Southall	511677	180071	55.3	49.7
Richmond Nat Phys Lab	515115	170778	34.5	34.4
RG1 - Horley	528204	142330	47.9	42.3

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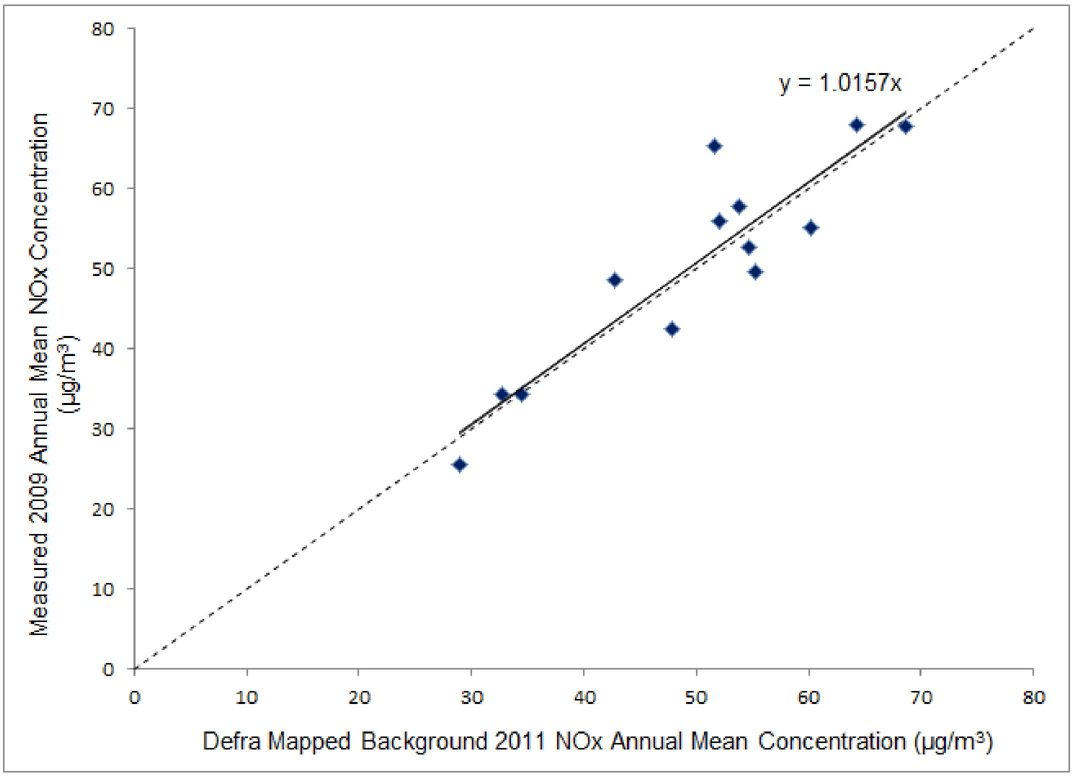
[23] Surfer is a software programme that allows the interpolation of concentrations between a grid of discrete points using a variety of processes, the approach known as “kriging” was used.

Monitoring Site	x	y	NOx Concentration	
			2011 Mapped	2009 Measured
RG2 - Horley South	528552	141855	60.3	55.2

Figure A1: Comparison of 2011 Mapped and 2009 Measured Annual Mean NOx Concentrations (µg/m^3)



The data presented in Table A1 and Figure A1 show the close relationship between the total 2011 mapped NOx concentrations and the 2009 measured values. While it would be possible to adjust the 2011 values by a factor of 1.0157 to represent better the 2009 values, this is not considered appropriate. This is because the mapped background concentrations used in assessment have been manipulated to remove the airport and in-square motorway, primary and trunk road components, to avoid double counting, as these sources are explicitly modelled within each Study Area. It is not known which specific NOx sources in the mapped background concentrations (roads, airport, rural, domestic, industrial, rail, point or other sources) might be responsible for the small difference between the 2011 mapped and 2009 measured background NOx concentrations, therefore it is deemed inappropriate to adjust the manipulated mapped background concentrations in case difference is being driven by components of airport or road NOx that are being removed from the background concentrations used in the assessment. Overall, and without adjustment, the 2011 mapped background NOx concentrations show a good agreement with 2009 measured NOx concentrations. It is therefore considered appropriate to use the 2011 mapped background NOx concentrations to represent 2009 values, without any adjustment.

A2 Background NO_2 Concentrations

Table A2 shows the comparison between the 2011 mapped annual mean NO_2 concentrations and the 2009 measured concentrations. The data are also shown in Figure A2. The data indicate that the 2011 mapped values are slightly higher than the 2009 measured values.

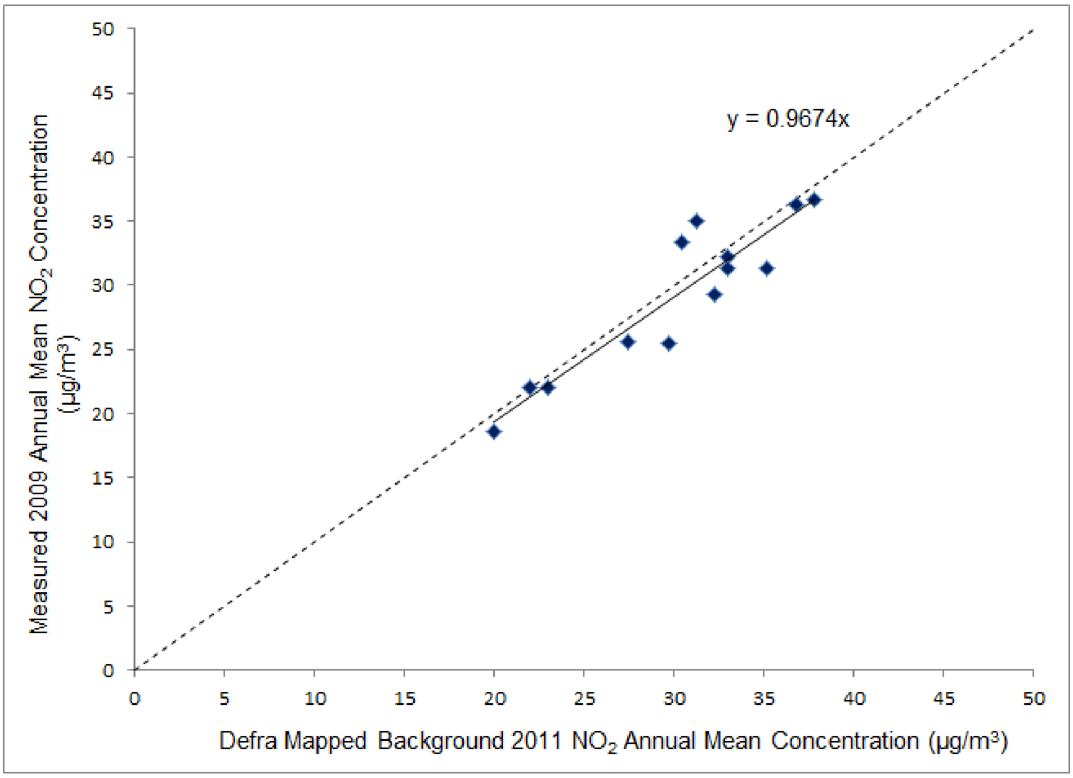
The summary statistics from this comparison are:

RMSE – 2.41
Correlation coefficient – 0.92
Fractional bias – -0.03

Table A2: Comparison of 2011 Mapped and 2009 Measured Annual Mean NO_2 Concentrations (µg/m^3)

Monitoring Site	x	y	NO_2 Concentration	
			2011 Mapped	2009 Measured
Poles Lane Pumping Station- Crawley	526420	139638	20.0	18.6
Gatwick East CRI	529411	141493	27.4	25.6
Hounslow 2 - Cranford	510370	177195	33.0	32.3
Heathrow - Oaks Road	505729	174496	30.5	33.4
Hounslow Hatton Cross	509355	174989	37.9	36.6
Slough Colnbrook	503542	176827	32.3	29.3
Slough Lakeside 2	503569	177385	31.2	35.0
London Teddington	515545	170416	22.0	22.0
London Harlington	508295	177800	36.8	36.3
Horley	528206	142331	29.8	25.5
Ealing Southall	511677	180071	33.0	31.3
Richmond Nat Phys Lab	515115	170778	23.0	22.0
RG1 - Horley	528204	142330	29.8	25.3
RG2 - Horley South	528552	141855	35.2	31.4

Figure A2: Comparison of 2011 Mapped and 2009 Measured Annual Mean NO_2 Concentrations (µg/m^3)



The data presented in Table A2 and Figure A2 show the close relationship between the total 2011 mapped NO_2 concentrations and the 2009 measured values. While it would be possible to adjust the 2011 values by a factor of 0.9674 to represent better the 2009 values, this is not considered appropriate. This is because the mapped background concentrations used in assessment have been manipulated to remove the airport and in-square motorway, primary and trunk road components, to avoid double counting, as these sources are explicitly modelled within each Study Area. It is not know which specific sources in the mapped background concentrations might be responsible for the small difference shown in Figure A2 and therefore it is deemed inappropriate to adjust the manipulated mapped background concentrations in case the trend is being driven by airport or road components that are being removed from the background concentrations used in the assessment. Overall, without adjustment, the 2011 mapped background NO_2 concentrations show a good agreement with 2009 measured NO_2 concentrations. It is therefore considered appropriate to use the 2011 mapped background NO_2 concentrations to represent 2009 values, without any adjustment.

A3 Background PM_{10} Concentrations

Table A3 shows the comparison between the 2011 mapped annual mean PM_{10} concentrations and the 2009 measured concentrations. The data are also shown in Figure A3. The data indicate that the 2011 mapped values are slightly higher than the 2009 measured values.

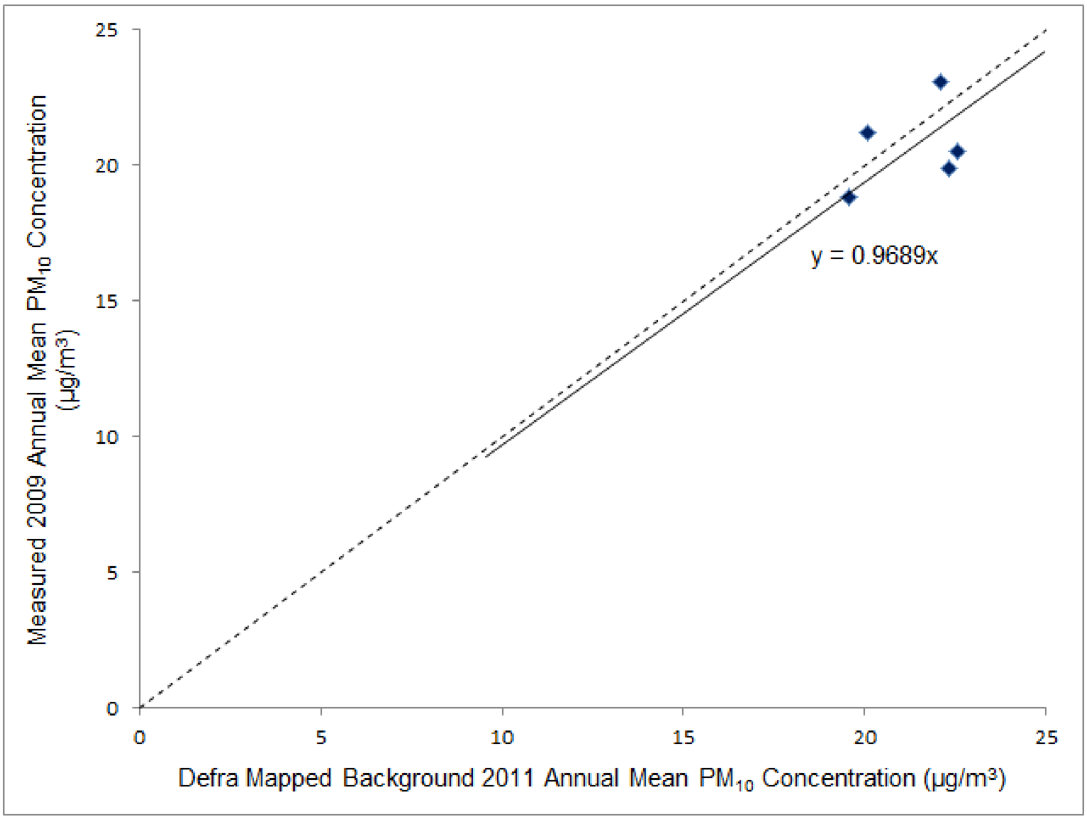
The summary statistics from this comparison are:

RMSE – 1.62
Correlation coefficient – 0.39
Fractional bias – -0.03

Table A3: Comparison of 2011 Mapped and 2009 Measured Annual Mean PM_{10} Concentrations (µg/m^3)

Monitoring Site	x	y	NO_2 Concentration	
			2011 Mapped	2009 Measured
Heathrow Oaks Road	505729	174496	20.1	21.2
Slough Colnbrook	503542	176827	22.6	20.5
Slough Lakeside 2	503569	177385	22.1	23.1
RG1 - Horley	528204	142330	19.5	18.8
EA7 -Ealing Southall	511677	180071	22.4	19.9

Figure A3: Comparison of 2011 Adjusted Mapped and 2009 Measured Annual Mean PM_{10} Concentrations (µg/m^3)



The data presented in Table A3 and Figure A3 show the relationship between the total 2011 mapped PM_{10} concentrations and the 2009 measured values. While it would be possible to adjust the 2011 values by a factor of 0.9689 to represent better the 2009 values, this is not considered appropriate. This is because the mapped background concentrations used in assessment have been manipulated to remove the airport and in-square motorway, primary and trunk road components, as these sources are explicitly modelled within each Study Area. It is not know which specific sources in the mapped background concentrations might be responsible for the small difference shown in Figure A3 and therefore it is deemed inappropriate to adjust the manipulated mapped background concentrations in case the trend is being driven by airport or road components that are being removed from the background concentrations used in the assessment. Overall, without adjustment, the 2011 mapped background PM_{10} concentrations show a good correlation to 2009 measured PM_{10} concentrations. It is therefore considered appropriate to use the 2011 mapped background PM_{10} concentrations to represent 2009 values, without any adjustment.

Appendix B: Airport Emissions Representation

B1 Aircraft Operations – Landing and Take-off Cycle

The emissions arising from aircraft movements have been calculated for each part of the LTO Cycle. The following phases of the LTO Cycle have been represented in the emissions inventories:

- Taxi-out (from stand to runway, including hold);
- Take-off roll (from start-of-roll to wheels-off);
- Initial climb to 1500 ft (457m);
- Climbout from 1500 ft to 3000 ft (457m to 915m);
- Approach from 3000 ft (915m) to touch-down;
- Landing roll (including reverse thrust above idle); and
- Taxi-in (from runway to stand).

Aircraft Movements and Fleet Composition

Records of 2009 aircraft movements at Heathrow Airport were provided by the NWR Promoter from the BOSS (Business Objective Search System) database. The database contains a detailed summary of all departures and arrivals during the year, including aircraft types and engine assignments. BOSS data for 2010 were made available by the Promoter for Gatwick 2R Scheme; to adjust these data to a 2009 calendar year, total annual ATMs for 2009 were obtained from the CAA UK Airport Statistics database (CAA, 2015) and used to factor the 2010 data, assuming the same proportion of aircraft types and engine assignments operated at Gatwick in both 2009 and 2010. The 2009 aircraft movements for Heathrow and Gatwick airports are summarised in Tables B1 and B2 respectively.

Table B1: Aircraft Movements in 2009 (Heathrow)

Aircraft	Engine[a]	ATMs
Airbus 319	V2522-A5	81,489
Airbus 320-100, 200	V2527-A5	97,049
Airbus 321-100, 200	V2533-A5	46,511
Airbus 330/340-200, 300	CFM56-5C4Trent 772	18,936
Airbus 340-500, 600	Trent 556-61	14,203
Airbus 380	Trent 970-84	2,476
Boeing 737-300, 400, 500, 600, 700, 800, 900	CFM56-3-B1 CFM56-3C-1 CFM56-3-B1	25,418
Boeing 747-400	RB211-524G	37,683
Boeing 757-200	RB211-535E4	14,270
Boeing 767-300, 300ER/F, 400	RB211-524H	27,304
Boeing 777-200, 200ER, 300, 300-ER	GE90-85B GE90-115B	52,289
Embraer RJ Series, Canadair Regional Jet	AE3007A1/1	13,167
MD81, 82, 90	JT8D-217	7,416
Other		28,182
Total Movements		**466,393**

(a) The most common engine type(s) is shown

Table B2: Aircraft Movements in 2009 (Gatwick)

Aircraft	Engine[a]	ATMs
Aerospatiale ATR-72	PW127M	3,393
Airbus A319	CFM56-5B5/P	73,358
Airbus A320-100, 200	CFM56-5B4/3, CFM56-5B4/P	27,701
Airbus A321-100, 200	V2533-A5	9,637
Airbus A330-200, 300	Trent 772B-60	5,063
Airbus A300-600	CF6-80C2A5	1,770
Boeing 737-300, 400, 500, 700, 700 (winglets)	CFM56-3C1	42,614
Boeing 737-800, 800 (winglets)	CFM56-7B26	16,693
Boeing 747-400	CF6-80C2B1F	4,194
Boeing 757-200, 300	RB211-535E4	15,897
Boeing 767-300	CF6-80C2B7F	3,152
Boeing 777-200, 300ER	GE90-85B	7,023
Dash-8 Q400, Q300	PW150A	19,546
Canadair Regional Jet 100, 200	CF34-3A1, CF34-3B1	1,581
Embraer 190, 195	CF34-10E7	9,422
Other		10,832
Total Movements		**251,879**

(a) The most common engine type(s) is shown
(b) 2009 ATMs have been estimated based on 2010 BOSS data

For the 2030 scenarios (both Do-Minimum and With Scheme), the forecasts of aircraft movements and fleet mix have been based on the Airports Commission's Demand Forecast 2014 for passenger numbers Low Cost is King Carbon Traded (Gatwick 2R) and Global Growth Carbon Traded (Heathrow NWR and ENR). These figures were translated into average day schedules by LeighFisher; the methodology used is provided in Appendix J. Where the forecast ATMs exceed the assumed capacity limit, the ATMs were capped at the limit.

The forecast ATMs by quarter in 2030 are shown for each scenario in Table B3.

Table B3: Forecast ATMs Per Quarter in 2030[a,b]

Period	Gatwick Do-Min	Heathrow Do-Min	Gatwick 2R	Heathrow ENR	Heathrow NWR
Q1	57,873	117,909	105,629	172,822	177,590
Q2	76,100	122,544	127,341	175,610	180,535
Q3	84,990	124,534	138,041	177,593	182,579
Q4	60,562	119,164	109,615	176,870	181,769
Total	279,525	484,151	480,626	702,895	722,473

a) Totals are annual totals and may not agree with the sum of the individual quarters due to rounding
b) Where the demand scenario predicts more than the capacity limit (for Heathrow Do-Minimum and Heathrow ENR, the movements have been capped as stated above

Emission Factors

Aircraft engines with a rated power greater than 26.7 kN are certified by the International Civil Aviation Organisation (ICAO) for emissions of NOx and Smoke Number. For each type of aircraft, emissions per aircraft movement have been calculated using emission factors in grammes of pollutant per kilogram of fuel burnt, together with fuel flow in kilogrammes per second, based on the following equation:

$$E_{ij} = \sum (TIM_{jk}*60) * (FF_{jk}) * (EI_{jk}) * (NE_{j}) \qquad \text{Equation [1]}$$

Where:

E*ij* = Emissions of pollutant *i* in grammes, produced by aircraft type *j* for each LTO cycle;
TIM*jk* = Time-in-mode for mode *k* (e.g. idle, approach, climb-out or take-off) in minutes for aircraft type *j*;
FF*jk* = Fuel flow for mode k (e.g. idle, approach, climb-out or take-off) in kg/sec for each engine on aircraft type *j*;
EI*jk* = Emissions index for each pollutant *i* in grammes per kilogram of fuel, in mode k, for each engine used on aircraft type *j*; and
NE*j* = Number of engines on aircraft type *j*.

The emissions indices have been derived from the International Civil Aviation Organisation (ICAO) *Engine Exhaust Emissions Data Bank* (EASA, 2015). The database includes emission indices for all high-bypass turbofan jet engines currently in use by commercial aircraft. Engine assignments for aircraft currently operating at Heathrow and Gatwick airports were based on actual data provided by the Promoters.

Emissions factors for turboprop engines are not included in the ICAO database. Turboprop aircraft in use at Heathrow Airport in 2009 represent a very small proportion (<1%) of total aircraft movements, and emissions from these aircraft were not calculated explicitly, but have been based on emissions indices for similar small aircraft operating with high-bypass turbofan engines. At Gatwick Airport, turboprop aircraft represented a much higher proportion of movements in 2009, and NOx emission factors for turboprop engines were derived from the FOI database (FOI, 2015). The FOI database does not contain any data on smoke number or PM emissions. PM emissions were derived from the average ratio of NOx:PM emissions from all turbofan engines operating at Gatwick Airport; this ratio was then applied to the NOx emissions from the PW150A engine (which is the principal engine in use at Gatwick Airport), derived from the FOI database. An alternative approach, based on average PM emissions (expressed as g/kg fuel), provided a very similar answer. The estimate of PM emissions from turboprops is open to additional uncertainty, but due to the small number of aircraft movements involved, this will have a negligible impact on the assessment.

B1.1 Thrust Settings

The International Civil Aviation Organisation (ICAO) has defined a specific LTO cycle with four modal phases, extending to a ceiling height of 3,000 feet (915 metres). Emission factors are provided for ‘take-off’ (100% thrust), ‘climbout’ (85% thrust), ‘approach’ (30% thrust) and ‘idle’ (7% thrust). In reality, aircraft rarely take-off at 100% thrust - the actual take-off thrust used being dependent on a combination of factors including take-off weight and weather conditions.

Typical take-off thrust settings for a number of common aircraft types in operation at Heathrow and Gatwick Airports were provided by the Promoters. These typical thrust settings were used for the 2009 baseline inventories (see Tables B4 and B5).

The ICAO certification does not include fuel flow data and emission indices for intermediate thrust settings. The ICAO *Airport Air Quality Manual* suggests an advanced approach to calculate emissions for intermediate thrust settings based on a twin quadratic equation to calculate fuel flow at the required thrust, and then applying the corresponding emissions indices calculated using the Boeing Fuel Flow Model *v*2 (BFFM2) curve fitting methodology (BBFM2, 2006). However, the BFFM2 approach is typically used to calculate emissions from aircraft throughout the entire flight envelope (when the engine is operating in substantially different conditions from that used for certification, i.e. sea-level and static). The BFFM2 approach notes that NOx emissions increase “somewhat linearly” with increasing power. Therefore, for the purpose of this assessment, a hybrid approach has been adopted. The fuel flow for intermediate thrust settings has been derived from the twin quadratic equation based on the 7%, 30%, 85% and 100% thrusts and associated fuel flow points. Emissions were then assumed to be linear between the thrust settings in order to obtain representative indices (in g/kg fuel) for the required thrust setting. The pollutant emission rate was then calculated using the approach set out in Equation [1] above.

Emission factors within the EDMS and ICAO databases are stated for new engines. Based on PSDH recommendations to account for engine deterioration, NOx emissions have been increased by 4.5% while, for PM, the fuel flow and subsequent calculation of emissions has been increased by 4.3%.

Table B4: Thrust Settings Applied to Each MCAT Group and Mode 2009 (Heathrow)

MCAT	Lead Aircraft	Lead Engine	Thrust Settings		
			TO	IC	CO
1	Embraer RJ145	AE3007A1/1	78%	78%	78%
2	Airbus A320	V2527-A5	78%	78%	78%
3	Airbus A321	V2533-A5	76%	76%	76%
4	Boeing 757-200	RB211-535E4B	76%	76%	76%
5	Boeing 777-200	TRENT 892	79%	79%	79%
6	Airbus A340-300	CFM56-5C4	86%	86%	86%
7	Airbus A340-600	TRENT 556-61	86%	86%	86%
8	Boeing 747-400	RB211-524H-T	83%	83%	83%
9	Boeing 747-400	RB211-524G	83%	83%	83%
10	Airbus A380	TRENT 970-84	87%	87%	87%

TO (start of roll to wheels off); IC (initial climb to 1500 feet); CO (climbout to 3000 feet)

Table B5: Thrust Settings Applied to Each MCAT Group and Mode 2009 (Gatwick)

MCAT	Lead Aircraft	Lead Engine	Thrust Settings		
			TO	IC	CO
1	Dash-8 Q400	PW150A	87%	87%	87%
2	Airbus A319	CFM56-5B5/P	88%	88%	88%
3	Airbus A320	CFM56-5B4/P	89%	89%	89%
4	Airbus A321	V2533-A5	86%	86%	86%
5	Boeing 767-300	CF6-80C2B7F	90%	90%	90%
6	Airbus A330-200	TRENT 772B-60	90%	90%	90%
7	Boeing 777-200	TRENT 895	87%	87%	87%
8	Boeing 747-400	CF6-80C2B1F	78%	78%	78%

TO (start of roll to wheels off); IC (initial climb to 1500 feet); CO (climbout to 3000)

B1.2 Future Aircraft and Engine Assignments

There are expected to be a number of new aircraft in operation by 2030, all of which are expected to be equipped with engines that have not yet been certified by ICAO. These include:

- NEO Airbus A319, A320 and A321 – expected to be fitted with the PW1100G series of engines;
- New generation Boeing 737 series – expected to be fitted with the CFM-LEAP-1B engine;
- New generation Boeing 777 series – expected to be fitted with the GE9X engine; and
- Bombardier C100 series – expected to be fitted with the PW1524G engine.

Emissions associated with the PW1524G engine have been derived from published information provided by Bombardier (London City Airport, 2014). An assessment of the emissions associated with the other new engines has been carried out by LeighFisher, and is described below.

Methodology

Forecasts were developed for six engine type variants: four variants of the PW1100G (1124, 1127, 1133, and 1135, which represent models with different maximum thrust capabilities) and one variant each for the CFM-LEAP-1B and GE9X.

For each of the engine type variants, references to, or estimations of the following values, were derived:

- Overall maximum engine thrust (kN), engine bypass ratio (%) and fuel flow (kg/s); and
- NOx emission factor (g/kg), and smoke number for each of the standard engine thrust settings (100%, 80%, 35%, and 7%, representing take-off (T/O), climbout (C/O), approach, and taxi/Idle).

Maximum thrust settings

For the PW1100G variant and the CFM-LEAP-1B, maximum thrust settings for the engines were taken from the most recently available public statements from the manufacturers' websites. In each case, the manufacturer reported thrust in pound-force (lbf), which was converted to kilo-Newtons (kN).

For the GE9X engine, the maximum thrust capability was derived from personal communication with the manufacturer (General Electric).

Fuel flow

For each of the six engine type variants, fuel flow for the four thrust settings was estimated by scaling the fuel flow from an existing, ICAO certified engine, using the thrust and percentage fuel savings claimed by the manufacturer. For example, for the PW1124G, it was assumed that a similar engine would be the CFM56-59B/2B; this has a rated thrust of 120.1 kN, as compared to the estimated thrust of 116.8 kN for the 1124G. To estimate the fuel flow for the 1124G, the ratio of rated thrusts (120.1/116.8) was multiplied by the manufacturers' claimed fuel efficiency (85%) and then applied to the fuel flow numbers for the CFM56.

“Similar” engines were chosen based upon public statements from the manufacturer, or other sources; if more than one engine met this criterion, one was selected based upon the most similar rated thrust and, if still inconclusive, the lowest NOx T/O emissions factor. The other engines selected were the CFM56-5B4/2P (for the 1127G); the CFM56-5B2/3 (for the 1133G); the CFM56-5B3/3 (for the 1135G); the CFM56-7B27E (for the LEAP-1B); and the GE90-115B (for the GE9X).

The “claimed fuel efficiency” was calculated as “1 – any claimed fuel savings”; these were 17% for the PW variant, 15% for the LEAP-1B, and 10% for the GE9X.

NOx emissions indices (EI NOx)

For each of the six engine type variants, EI NOx values were estimated by taking the manufacturers’ claims regarding engine performance and the margin to the CAEP standard (e.g. CAEP6 minus 50%), and then applying the ICAO standards methodology in reverse. For example, for the 1124G, the manufacturer claimed that the engine would have a 50% margin to the CAEP/6 standard. The standard was estimated by applying the best available estimates of engine compression pressure ratio and maximum thrust, and then subtracting the claimed margin to result in the estimated engine NOx characteristic. The characteristic was scaled (as per ICAO methodology) assuming that the manufacturer would offer three test engines, and then multiplied by the maximum thrust to yield the expected NOx (g) per LTO Cycle. ICAO defines this value as *“the total mass of oxides of nitrogen emitted during the LTO cycle (sum of Time in Mode x fuel flow x average EI at each of the four power settings)”*. The estimated EI NOx for each mode was then derived using ICAO’s standard Times In Mode, the estimated fuel flow factors, and an assumption that engine thrust settings for the four modes would be 100%, 85%, 30%, and 7%.

Smoke Number

For each of the six engine type variants, the smoke number was assumed to be identical to the similar engine from the ICAO certification database. PM emission factors were derived from the Smoke Number using the FOAv3 approach.

The estimated emission indices assumed are shown in Table B.6.

Table B6: Estimated Emissions Indices for New Engines

Engine	Fuel Flow (kg/s)				EI NOx (g/kg)				Smoke No.			
	TO	CO	AP	ID	TO	CO	AP	ID	TO	CO	AP	ID
PW1124G	0.96	0.80	0.30	0.11	11.90	10.11	3.57	0.83	0.30	0.30	6.60	1.70
PW1127G	1.14	0.95	0.34	0.12	11.27	9.58	3.38	0.79	0.30	0.30	0.50	2.00
PW1133G	1.39	1.11	0.36	0.11	12.01	10.21	3.60	0.84	15.50	13.10	2.10	2.10
PW1135G	1.46	1.15	0.37	0.11	12.56	10.68	3.77	0.88	16.00	13.40	2.10	2.10
PW1524G	-	-	-	-	21.50	14.00	2.29	0.47	2.8	-	-	-
CFM-LEAP-1B	1.29	1.03	0.34	0.11	13.61	11.57	4.08	0.95	13.40	11.20	2.10	2.10
GE9X	4.69	3.67	1.13	0.38	8.02	6.82	2.41	0.56	4.10	2.50	1.45	0.87

The PW1127G variant was selected to represent engines on the NEO Airbus A319, A320 and A321; it is the engine identified by Airbus for the A320, which is the most common aircraft in operation in 2030, across all Schemes.

B1.3 Modelling Categories

The ADMS-Airport model takes into account the heat and momentum flux, and the pollutant emission rate, which varies for each certified engine. It is impractical to treat each airframe/engine combination separately, and so the aircraft have been assigned into a number of “modelling categories” (MCATs).

For the 2009 Baseline Year, the aircraft were assigned into MCATs of similar characteristics (e.g. jet plume buoyancy, numbers of engines, engine types, engine mounting, wake category and NOx emission rate) with a “lead” aircraft selected to represent each group. The emissions, and input parameters for the ADMS-Airport model, were then based on the assumption that the total number of movements within each MCAT was represented by the lead aircraft. The lead aircraft/engine combination in each MCAT was selected based on the frequency of use (number of ATMs), the buoyancy flux and the NOx emission rate (as compared to the MCAT average). For the 2030 scenarios, MCATs have been determined for future aircraft/engine combinations using the same method as for 2009, by taking account of engine exhaust buoyancy flux and NOx emissions, as well as the forecast proportion of total annual airport ATMs.

As a check, a comparison between the NOx emission rate for the lead aircraft in each MCAT group was compared with the average, weighted NOx emission of all aircraft/engine combinations in that group. This analysis is shown in Tables B7 to B10 for the Heathrow and Gatwick 2009 Baseline, and the 2030 Do-Minimum, Gatwick 2R, Heathrow NWR and Heathrow ENR scenarios. The data are also shown in Figures B1 to B4; in each case the distribution of individual aircraft parameters (NOx emission, ATMs and buoyancy flux) is shown, with the lead aircraft shown as the shaded bar. The aircraft ID corresponds with that given in Tables B7 to B10.

A summary of the MCAT assignments for 2009 and 2030 is shown in Tables B.11 to B.14.

Table B7: Heathrow MCAT Assignments 2009. The "lead aircraft" in each MCAT is shown in the shaded box.

ID	Airframe	Engine	ATMS	Buoyancy Flux (@100%)	MCAT Assignment	Number of Engines	NOx (g/s per engine)	NOx (g/s per aircraft)	Weighted Average NOx in Group
1	Embraer RJ135	AE3007A3	528	80.7	1	2	6.6	13.3	
2	Embraer RJ145 Amazon	AE3007A	641	81.5	1	2	7.7	15.5	
3	**Embraer RJ145 Amazon**	**AE3007A1/1**	**7694**	**84.8**	**1**	**2**	**7.4**	**14.9**	**15.2**
4	Embraer RJ145 Amazon	AE3007A1	1140	85.2	1	2	7.5	15.0	
5	Canadair Regional Jet 700	CF34-8C1	1464	136.5	1	2	8.9	17.7	
6	Fokker 100	TAY MK650-15	1030	169.8	2	2	17.3	34.6	
7	Boeing 737-300 pax	CFM56-3-B1	4084	216.6	2	2	16.7	33.5	
8	Boeing 737-500 pax	CFM56-3-B1	2800	216.6	2	2	16.7	33.5	
9	Boeing 737-600 pax	CFM56-7B20/2	1400	220.4	2	2	12.0	23.9	
10	Boeing 737-700 pax	CFM56-7B20/2	628	220.4	2	2	12.0	23.9	
11	Airbus A319	CFM56-5B5/P	2468	232.3	2	2	19.5	39.0	
12	Boeing 737-400 pax	CFM56-3B-2	1302	238.2	2	2	20.5	41.0	
13	McDonnell Douglas MD81	JT8D-217 SERIES	3266	238.8	2	2	33.9	67.8	
14	McDonnell Douglas MD82	JT8D-217 SERIES	2682	238.8	2	2	33.9	67.8	
15	McDonnell Douglas MD82	JT8D-217A	589	238.8	2	2	23.2	46.3	
16	McDonnell Douglas MD82	JT8D-217C	696	238.9	2	2	21.1	42.3	
17	Airbus A319	CFM56-5B6/P	2144	247.4	2	2	22.7	45.4	
18	Airbus A319	CFM56-5A5	1385	247.4	2	2	24.1	48.2	
19	McDonnell Douglas MD82	JT8D-219	1239	248.7	2	2	36.6	73.1	
20	Airbus A319	V2522-A5	76134	250.0	2	2	23.8	47.6	
21	Boeing 737-300 pax	CFM56-3C-1	2484	253.5	2	2	23.9	47.8	
22	Boeing 737-400 pax	CFM56-3C-1	4405	253.5	2	2	23.9	47.8	
23	Boeing 737-500 pax	CFM56-3C-1	2459	253.5	2	2	23.9	47.8	
24	Boeing 737-700 pax	CFM56-7B24	618	260.2	2	2	27.9	55.8	
25	Boeing 737-800 pax	CFM56-7B24	2142	260.2	2	2	27.9	55.8	
26	Airbus A320-100/200	CFM56-5-A1	15121	263.1	2	2	25.9	51.7	
27	**Airbus A320-100/200**	**V2527-A5**	**54135**	**271.2**	**2**	**2**	**27.9**	**55.8**	**51.0**
28	McDonnell Douglas MD90	V2525-D5	714	271.2	2	2	27.9	55.8	
29	Airbus A320-100/200	CFM56-5A3	602	278.9	2	2	29.9	59.7	
30	Airbus A320-100/200	CFM56-5B4	2032	279.8	2	2	33.5	66.9	
31	Airbus A320-100/200	CFM56-5B4/2	3174	281.3	2	2	19.6	39.2	
32	Boeing 737-800 pax	CFM56-7B26/2	1720	283.5	2	2	23.1	46.2	
33	Boeing 737-800 pax	CFM56-7B26	1305	283.5	2	2	35.2	70.3	
34	Boeing 737-900 pax	CFM56-7B26	740	283.5	2	2	35.2	70.3	

ID	Airframe	Engine	ATMS	Buoyancy Flux (@100%)	MCAT Assignment	Number of Engines	NOx (g/s per engine)	NOx (g/s per aircraft)	Weighted Average NOx in Group
35	Airbus A320-100/200	CFM56-5B4/2P	2991	285.0	2	2	21.0	42.0	
36	Airbus A321-100/200	CFM56-5B4/2P	950	285.0	2	2	21.0	42.0	
37	Airbus A320-100/200	CFM56-5B4/P	11752	285.0	2	2	31.7	63.4	
38	Airbus A321-100/200	CFM56-5B1/2P	1246	318.6	3	2	30.8	61.5	
39	Airbus A321-100/200	V2530-A5	4092	327.4	3	2	45.0	90.0	
40	Airbus A321-100/200	CFM56-5B2/P	3992	329.9	3	2	47.8	95.5	
41	Airbus A321-100/200	CFM56-5B3/P	14307	340.6	3	2	53.3	106.7	
42	Airbus A321-100/200	CFM56-5B3/2P	1884	340.7	3	2	47.0	94.1	
43	**Airbus A321-100/200**	**V2533-A5**	**26409**	**345.5**	**3**	**2**	**52.0**	**104.0**	**101.6**
44	Airbus A340-300	CFM56-5C2	2251	320.2	8	4	42.6	170.6	
45	Airbus A340-200	CFM56-5C3	504	334.7	8	4	47.6	190.6	
46	Airbus A340-300	CFM56-5C3	534	334.7	8	4	47.6	190.6	
47	**Airbus A340-300**	**CFM56-5C4**	**5532**	**351.3**	**8**	**4**	**54.8**	**219.4**	**203.5**
48	**Boeing 757-200 pax**	**RB211-535E4**	**16990**	**441.8**	**4**	**2**	**83.5**	**167.0**	**163.5**
49	Boeing 757-200 pax	RB211-535E4B	561	474.8	4	2	113.3	226.6	
50	Boeing 767-200 pax	CF6-80C2B2	598	559.9	4	2	46.8	93.5	
51	Airbus A310-300 pax	CF6-80C2A2	646	565.4	4	2	59.1	118.3	
52	Airbus Industrie A300B2/B4/C4 pax	CF6-50C2	860	568.3	4	2	68.4	136.8	
53	**Airbus A340-600**	**TRENT 556-61**	**14641**	**593.1**	**9**	**4**	**100.3**	**401.1**	**399.6**
54	Boeing 747-400 pax	CF6-80C2B1F	4516	616.1	9	4	60.4	241.6	
55	Boeing 747-400 Freighter	PW4056	506	617.3	9	4	79.6	318.4	
56	Boeing 747-400 pax	PW4056	5540	617.3	9	4	79.6	318.4	
57	Boeing 747-400 pax	RB211-524G-T	18054	624.7	9	4	74.5	297.9	
58	Boeing 747-400 pax	RB211-524G	14228	624.7	9	4	153.8	615.3	
59	Boeing 747-400 pax	CF6-80C2B5F	531	660.4	9	4	76.7	306.9	
60	BOEING 767-300ER/F	PW4056	1631	617.3	5	2	79.6	159.2	
61	BOEING 767-200ER	CF6-80C2B4F	813	617.4	5	2	67.8	135.5	
62	**Boeing 767-300 pax**	**RB211-524G**	**3033**	**624.7**	**5**	**2**	**153.8**	**307.6**	**259.3**
63	Boeing 767-300 pax	CF6-80C2B6F	604	647.0	5	2	71.0	142.0	
64	BOEING 767-300ER/F	CF6-80C2B6F	2405	647.0	5	2	71.0	142.0	
65	BOEING 767-300ER/F	CF6-80C2B6	2007	647.4	5	2	73.7	147.4	
66	Boeing 767-300 pax	PW4060	548	652.7	5	2	81.5	163.0	
67	BOEING 767-300ER/F	PW4060	4467	652.7	5	2	81.5	163.0	
68	Boeing 767-300 pax	RB211-524H	3008	653.5	5	2	179.7	359.5	
69	BOEING 767-300ER/F	RB211-524H	8748	653.5	5	2	179.7	359.5	

ID	Airframe	Engine	ATMS	Buoyancy Flux (@100%)	MCAT Assignment	Number of Engines	NOx (g/s per engine)	NOx (g/s per aircraft)	Weighted Average NOx in Group
70	Airbus A330-200	PW4168A	1120	732.9	6	2	120.2	240.4	
71	Airbus A330-300	PW4168A TALON II	1208	733.0	6	2	77.6	155.2	
72	Airbus A330-200	CF6-80E1A3	1823	738.5	6	2	136.4	272.8	
73	**Airbus A330-200**	**TRENT 772**	**4898**	**767.7**	**6**	**2**	**110.0**	**220.0**	**224.9**
74	Airbus A330-300	TRENT 772	2590	767.7	6	2	110.0	220.0	
75	Boeing 777-200 pax	GE90-76B	1945	771.9	6	2	112.4	224.8	
76	BOEING 777-200ER	PW4077	1030	794.1	6	2	120.2	240.3	
77	**Airbus A380 pax**	**TRENT 970-84**	**1242**	**752.2**	**10**	**4**	**96.7**	**386.9**	**386.9**
78	BOEING 777-200ER	GE90-85B	10746	851.6	7	2	147.2	294.4	
79	BOEING 777-200ER	GE90-90B	1916	903.1	7	2	175.7	351.4	
80	BOEING 777-200ER	GE90-92B	1434	923.1	7	2	196.5	393.0	
81	BOEING 777-200ER	GE90-94B	582	936.3	7	2	198.2	396.4	
82	BOEING 777-300ER	GE90-94B	1416	936.3	7	2	198.2	396.4	
83	Boeing 777-200 pax	PW4090	702	966.2	7	2	225.8	451.6	
84	BOEING 777-200ER	PW4090	3846	966.2	7	2	225.8	451.6	
85	Boeing 777-200 pax	TRENT 892	1104	981.9	7	2	178.7	357.4	
86	BOEING 777-200ER	TRENT 892	10515	981.9	7	2	178.7	357.4	
87	Boeing 777-300 pax	TRENT 892	1190	981.9	7	2	178.7	357.4	
88	**BOEING 777-200ER**	**TRENT 895**	**8270**	**985.6**	**7**	**2**	**192.6**	**385.2**	**375.8**
89	BOEING 777-300ER	GE90-115B	6922	1173.9	7	2	236.1	472.2	

Table B8: Gatwick MCAT Group Assignments 2009. The "lead aircraft" in each MCAT is shown in the shaded box.

ID	Airframe	Engine	ATMS	Buoyancy Flux (@100%)	MCAT Assignment	Number of Engines	NOx (g/s per engine)	NOx (g/s per aircraft)	Weighted Average NOx in Group
1	**De Havilland Canada DHC-8-400 Dash 8Q**	**PW150A**	**15933**	**n/a**	**1**	**2**	**5.7**	**11.3**	**9.8**
2	De Havilland Canada DHC-8-300 Dash 8 / 8Q	PW123	2730	n/a	1	2	2.6	5.3	
3	Aerospatiale/Alenia ATR 72	PW127M	2628	n/a	1	2	3.2	6.4	
4	Aerospatiale/Alenia ATR 72	PW124B	612	n/a	1	2	2.7	5.3	
5	Canadair Regional Jet 100	CF34-3A1	766	78.4	1	2	4.7	9.5	
6	Canadair Regional Jet 200	CF34-3B1	744	78.4	1	2	4.5	9.0	
7	EMBRAER 190/195	CF34-10E7	8996	168.1	2	2	17.1	34.2	
8	Boeing 737-700 pax	CFM56-7B20	812	181.8	2	2	18.7	37.4	
9	Airbus A319	CFM56-5B5/3	19750	189.3	2	2	14.7	29.4	
10	**Airbus A319**	**CFM56-5B5/P**	**44043**	**190.1**	**2**	**2**	**19.5**	**39.0**	**40.2**
11	Boeing 737-300 pax	CFM56-3B2	1083	197.4	2	2	20.5	41.0	
12	Boeing 737-700 (winglets) pax	CFM56-7B22	836	201.2	2	2	23.6	47.2	
13	Airbus A319	CFM56-5B6/2P	1199	202.0	2	2	13.8	27.5	
14	Airbus A319	CFM56-5B6/P	711	202.1	2	2	22.7	45.4	
15	Airbus A319	V2522-A5	4341	207.9	2	2	23.8	47.6	
16	Boeing 737-400 pax	CFM56-3C1	31989	210.0	2	2	23.9	47.8	
17	Boeing 737-300 pax	CFM56-3C1	2738	210.0	2	2	23.9	47.8	
18	Boeing 737-300 pax	CFM56-3C1	1300	210.0	2	2	23.9	47.8	
19	Boeing 737-500 pax	CFM56-3C1	721	210.0	2	2	23.9	47.8	
20	Boeing 737-700 (winglets) pax	CFM56-7B24	1210	215.3	2	2	27.9	55.8	
21	Airbus A320-100/200	V2500-A1	872	221.5	3	2	41.3	82.7	
22	Airbus A320-100/200	V2527-A5	3302	225.7	3	2	27.9	55.8	
23	Airbus A320-100/200	CFM56-5A3	1019	227.9	3	2	29.9	59.7	
24	**Airbus A320-100/200**	**CFM56-5B4/P**	**9843**	**233.3**	**3**	**2**	**31.7**	**63.4**	**59.7**
25	Boeing 737-800 (winglets) pax	CFM56-7B26	6354	234.9	3	2	35.2	70.3	
26	Boeing 737-800 pax	CFM56-7B26	556	234.9	3	2	35.2	70.3	
27	Boeing 737-800 (winglets) pax	CFM56-7B26/3	6134	234.9	3	2	26.4	52.9	
28	Airbus A320-100/200	CFM56-5B4/3	11414	235.3	3	2	24.6	49.3	
29	Boeing 737-800 (winglets) pax	CFM56-7B27/3	706	243.8	3	2	31.0	61.9	
30	Boeing 737-800 (winglets) pax	CFM56-7B27	2189	244.8	3	2	39.7	79.4	

ID	Airframe	Engine	ATMS	Buoyancy Flux (@100%)	MCAT Assignment	Number of Engines	NOx (g/s per engine)	NOx (g/s per aircraft)	Weighted Average NOx in Group
31	Airbus A321-100/200	CFM56-5B3/P	1731	280.1	4	2	53.3	106.7	
32	**Airbus A321-100/200**	**V2533-A5**	**7471**	**288.9**	**4**	**2**	**52.0**	**104.0**	**93.2**
33	Boeing 757-200 pax	RB211-535E4	10913	371.2	4	2	41.3	82.5	
34	BOEING 757-200 WINGLETS	RB211-535E4	1916	371.2	4	2	41.3	82.5	
35	Boeing 757-300 pax	RB211-535E4-B	1210	398.8	4	2	53.6	107.1	
36	Boeing 757-200 pax	RB211-535E4-B	1140	398.8	4	2	53.6	107.1	
37	**Boeing 747-400 pax**	**CF6-80C2B1F**	**4005**	**510.6**	**8**	**4**	**60.4**	**241.6**	**241.6**
38	**Boeing 767-300 pax**	**CF6-80C2B7F**	**1404**	**536.2**	**5**	**2**	**71.0**	**142.0**	**144.0**
39	Boeing 767-300 pax	CF6-80C2B6F	936	536.2	5	2	71.0	142.0	
40	Boeing 767-300 pax	CF6-80C2B7F	670	536.2	5	2	71.0	142.0	
41	Airbus Industrie A300-600 pax	CF6-80C2A5	1690	536.8	5	2	73.7	147.4	
42	Airbus A330-200	CF6-80E1A4B	678	597.3	6	2	90.8	181.7	
43	Airbus A330-300	PW4168A	918	607.4	6	2	77.6	155.2	
44	**Airbus A330-200**	**Trent 772B-60**	**3238**	**636.8**	**6**	**2**	**110.0**	**220.0**	**202.3**
45	Boeing 777-200 pax	GE90-85B	3967	661.0	7	2	147.2	294.4	
46	**Boeing 777-200 pax**	**Trent 895**	**1289**	**809.3**	**7**	**2**	**192.6**	**385.2**	**350.3**
47	Boeing 777-300ER (ER)	GE90-115BL2	1450	940.0	7	2	236.1	472.2	

Table B9: Heathrow MCAT Assignments 2030 (Do-Minimum, NWR and ENR). The “lead aircraft” in each MCAT is shown in the shaded box.

ID	Fleet	ATMs Assumed for Group	Engine	Number of Engines	NOx (g/s per engine)	NOx (g/s per aircraft)	Buoyancy Flux (@100%)	MCAT Assignment	Weighted Average NOx in Group
1	**Bombardier C Series**	**2,090**	**PW1524G**	**2**	**21.6**	**43.1**	**99.3**	**1**	**43.1**
2	Embraer E170	19,253	CF34-8E5A1	2	10.9	21.8	125.3	2	
3	Embraer 190	1,959	CF34-10E5A1	2	18.0	36.1	168.1	2	
4	Embraer 195	4,950	CF34-10E5A1	2	18.0	36.1	168.1	2	
5	Airbus A319	8,035	V2522-A5	2	23.8	47.6	207.9	2	
6	Airbus A318	595	PW6124A	2	24.6	49.2	215.0	2	
7	Boeing 737-700	3,889	CFM56-7B24	2	27.9	55.8	215.3	2	
8	**Airbus A320-100/200**	**19,216**	**V2527-A5**	**2**	**27.9**	**55.8**	**225.7**	**2**	**53.0**
9	Boeing 737-800	7,904	CFM56-7B26	2	35.2	70.3	234.9	2	
10	Airbus A321	10,960	V2533-A5	2	52.0	104.0	288.9	2	
23	Post 2016 G2 Airbus A319	15,050	PW1127G	2	12.8	25.7	93.2	3	
24	**Post 2016 G2 Airbus A320**	**41,888**	**PW1127G**	**2**	**12.8**	**25.7**	**93.2**	**3**	**25.7**
25	Post 2016 G2 Airbus A321	34,558	PW1127G	2	12.8	25.7	93.2	3	
26	New Gen Post 2016 B737-600	814	CFM-LEAP-1B	2	17.6	35.2	197.9	4	
27	New Gen Post 2016 B737-700	6,104	CFM-LEAP-1B	2	17.6	35.2	197.9	4	
28	**New Gen Post 2016 B737-800**	**27,647**	**CFM-LEAP-1B**	**2**	**17.6**	**35.2**	**197.9**	**4**	**35.2**
29	New Gen Post 2016 B737-900	6,912	CFM-LEAP-1B	2	17.6	35.2	197.9	4	
11	Airbus A350-800	17,634	Trent XWB-75	2	88.2	176.4	516.5	5	
12	Airbus A350-900	22,327	Trent XWB-84	2	128.2	256.4	601.8	5	221.0
18	Airbus A330-200	5,617	Trent 772	2	110.0	220.0	636.8	5	
19	Airbus A330-300	820	Trent 772	2	110.0	220.0	636.8	5	
13	**Boeing 787 (Trent)**	**32,753**	**Trent 1000-J2**	**2**	**154.6**	**309.1**	**555.6**	**6**	**309.1**
14	**Boeing 787 (GEnx)**	**32,753**	**GEnx-1B70**	**2**	**84.9**	**169.9**	**520.5**	**7**	**169.9**
20	Boeing 777-200	6,439	GE90-115B	2	236.1	472.2	940.0	8	
21	Boeing 777-300	3,230	GE90-115B	2	236.1	472.2	940.0	8	
22	**Boeing 777-300 (ER)**	**40,292**	**GE90-115B**	**2**	**236.1**	**472.2**	**940.0**	**8**	**472.2**
30	**Boeing 777X**	**8,414**	**GE9X**	**2**	**37.6**	**75.3**	**639.0**	**9**	**75.3**
15	Boeing 747-800	20,208	GEnx-1B70	4	84.9	339.8	520.5	10	
16	Airbus A340-600	2,668	Trent 556-61	4	100.3	401.1	470.6	10	
17	**Airbus A380 pax**	**11,999**	**Trent 970-84**	**4**	**96.7**	**386.9**	**596.9**	**10**	**360.7**

Table B10: Gatwick MCAT Assignments 2030 (Do-Minimum, 2R). The "lead aircraft" in each MCAT is shown in the shaded box.

ID	Airframe	ATMs Assumed for Group	Engine	Number of Engines	NOx (g/s per engine)	NOx (g/s per aircraft)	Buoyancy Flux (@100%)	MCAT Assignment	Weighted Average NOx in Group
1	EMB-ERJ145	593	AE3007A1	2	7.5	15.0	71.0	1	
2	Executive Jet Chapter 3	347	CF34-3A1	2	4.7	9.5	78.4	1	
4	Embraer 170	1290	CF34-8E5A1	2	10.9	21.8	125.3	1	
5	**Embraer 170-2**	**11282**	**CF34-8E5A1**	**2**	**10.9**	**21.8**	**125.3**	**1**	**24.7**
6	Embraer 190	1194	CF34-10E5A1	2	18.0	36.1	168.1	1	
7	Embraer 195	2887	CF34-10E5A1	2	18.0	36.1	168.1	1	
3	**Bombardier C Series**	**2015**	**PW1524G**	**2**	**28.0**	**56.0**	**99.3**	**2**	**56.0**
8	Airbus A319	8859	CFM56-5B5/P	2	19.5	39.0	190.1	3	
9	Airbus A318	699	PW6124A	2	24.6	49.2	215.0	3	
10	Boeing 737-700	5333	CFM56-7B24	2	27.9	55.8	215.3	3	
11	**Airbus A320-100/200**	**9087**	**CFM56-5B4/P**	**2**	**31.7**	**63.4**	**233.3**	**3**	**62.0**
12	Boeing 737-800	10306	CFM56-7B26	2	35.2	70.3	234.9	3	
13	Airbus A321	3173	V2533-A5	2	52.0	104.0	288.9	3	
14	Boeing 757-200	700	RB211-535E4	2	41.3	82.5	371.2	3	
15	Boeing 767-200	14	CF6-80C2B2	2	46.8	93.5	464.0	3	
30	Post 2016 G2 Airbus A319	10986	PW1127G	2	12.8	25.7	93.2	4	
31	**Post 2016 G2 Airbus A320**	**29146**	**PW1127G**	**2**	**12.8**	**25.7**	**93.2**	**4**	**25.7**
32	Post 2016 G2 Airbus A321	19676	PW1127G	2	12.8	25.7	93.2	4	
33	New Gen Post 2016 B737-600	1321	CFM-LEAP-1B	2	17.6	35.2	197.9	5	
34	New Gen Post 2016 B737-700	10972	CFM-LEAP-1B	2	17.6	35.2	197.9	5	
35	**New Gen Post 2016 B737-800**	**34281**	**CFM-LEAP-1B**	**2**	**17.6**	**35.2**	**197.9**	**5**	**35.2**
36	New Gen Post 2016 B737-900	3958	CFM-LEAP-1B	2	17.6	35.2	197.9	5	
19	Airbus A350 pax	1773	TRENT XWB-75	2	88.2	176.4	516.5	6	
20	Airbus A350-800	4645	TRENT XWB-75	2	88.2	176.4	516.5	6	
21	**Airbus A350-900**	**4925**	**TRENT XWB-84**	**2**	**128.2**	**256.4**	**601.8**	**6**	**205.7**
22	Boeing 767-300	58	CF6-80C2B7F	2	71.0	142.0	536.2	6	
23	Airbus A330-200	1968	CF6-80E1A4	2	90.8	181.7	597.3	6	
24	Airbus A330-300	212	PW4168A	2	77.6	155.2	607.4	6	
26	**Boeing 787 (Trent)**	**9337.5**	**Trent 1000-J2**	**2**	**154.6**	**309.1**	**555.6**	**7**	**309.1**
25	**Boeing 787 (GEnx)**	**9337.5**	**GEnx-1B70**	**2**	**84.9**	**169.9**	**520.5**	**8**	**169.9**
27	Boeing 777-200	1025	GE90-115B	2	236.1	472.2	940.0	9	
28	Boeing 777-300	214	GE90-115B	2	236.1	472.2	940.0	9	
29	**Boeing 777-300 (ER)**	**5707**	**GE90-115B**	**2**	**236.1**	**472.2**	**940.0**	**9**	**472.2**

ID	Fleet	ATMs Assumed for Group	Engine	Number of Engines	NOx (g/s per engine)	NOx (g/s per aircraft)	Buoyancy Flux (@100%)	MCAT Assignment	Weighted Average NOx in Group
37	**Boeing 777X**	**1028**	**GE9X**	**2**	**37.6**	**75.3**	**639.0**	**10**	**75.3**
16	Airbus A340-600	589	Trent 556-61	4	100.3	401.1	470.6	11	
17	**Boeing 747-800**	**3344**	**GEnx-1B70**	**4**	**84.9**	**339.8**	**520.5**	**11**	**355.3**
18	Airbus A380 pax	795	Trent 970-84	4	96.7	386.9	596.9	11	

Table B10: MCAT Assignments 2009 (Heathrow)

MCAT	Number Engines	Buoyancy Flux Range (@100%)	Lead Aircraft	Lead Engine	ATMs	Lead Aircraft NOx Emission	Weighted Average NOx Emission
1	2	<150	Embraer RJ145	AE3007A1/1	14,592	14.9	15.2
2	2	150-300	Airbus A320	V2527-A5	224,761	55.8	51.0
3	2	300-400	Airbus A321	V2533-A5	48,672	104.0	101.6
4	2	400-600	Boeing 757-200	RB211-535E4	45,490	167.0	163.5
5	2	600-700	Boeing 767-300	RB211-524G	67,367	307.6	259.3
6	2	700-850	Airbus A330-200	TRENT 772	7,994	220.0	224.9
7	2	>850	Boeing 777-200ER	TRENT 895	15,028	385.2	375.8
8	4	<400	Airbus A340-300	CFM56-5C4	24,391	219.4	203.5
9	4	400-750	Airbus A340-600	TRENT 556-61	15,479	401.1	399.6
10	4	>750	Airbus A380	TRENT 970-84	2,619	386.9	386.9

Table B11: MCAT Assignments 2009 (Gatwick)

MCAT	Number Engines	Buoyancy Flux Range (@100%)	Lead Aircraft	Lead Engine	ATMs	Lead Aircraft NOx Emission	Weighted Average NOx Emission
1	2	<150	Dash-8 Q400	PW150A	25,623	11.3	9.8
2	2	150-200	Airbus A319	CFM56-5B5/P	131,029	39.0	40.2
3	2	200-220	Airbus A320	CFM56-5B4/P	46,390	63.4	59.7
4	2	220-250	Airbus A321	V2533-A5	26,682	104.0	93.2
5	2	250-500	Boeing 767-300	CF6-80C2B7F	5,144	142.0	144.0
6	2	500-550	Airbus A330-200	TRENT 772B-60	5,290	220.0	202.3
7	2	550-650	Boeing 777-200	TRENT 895	7,339	385.2	350.3
8	2	>650	Boeing 747-400	CF6-80C2B1F	4,382	241.6	241.6

Table B12: MCAT Assignments 2030 (Heathrow Do-Minimum, NWR and ENR)

MCAT	Number Engines	Buoyancy Flux Range (@100%)	Lead Aircraft	Lead Engine	ATM			Lead Aircraft NOx Emission	Weighted Average NOx Emission (DM)
					DM	NWR	ENR		
1	2	99	Bombardier C Series	PW1524G	13,496	16,492	15,831	43.1	43.1
2	2	100-300	Airbus A320-100/200	V2527-A5	77,330	120,843	109,420	55.8	53.0
3	2	93	Post 2016 G2 Airbus A320	PW1127G	105,389	177,748	174,574	25.7	25.7
4	2	180	New Gen Post 2016 B737-800	CFM-LEAP-1B	55,371	95,257	93,727	35.2	35.2
5	2	500-650	Airbus A350-900	TRENT XWB-84	58,684	84,920	83,967	256.4	221.0
6	2	556	Boeing 787 (Trent)	Trent 1000-J2	38,895	56,415	55,780	309.1	309.1
7	2	521	Boeing 787 (GEnx)	GEnx-1B70	38,895	56,415	55,780	169.9	169.9
8	2	>900	Boeing 777-300	GE90-115B	49,961	60,398	59,936	472.2	472.2

MCAT	Number Engines	Buoyancy Flux Range (@100%)	Lead Aircraft	Lead Engine	ATM			Lead Aircraft NOx Emission	Weighted Average NOx Emission (DM)
					DM	NWR	ENR		
			(ER)						
9	2	600-700	Boeing 777X	GE9X	8,414	9,521	9,465	75.3	75.3
10	4	450-600	Airbus A380 pax	Trent 970-84	37,716	44,464	44,415	386.9	360.7

Table B13: MCAT Assignments 2030 (Gatwick Do-Minimum, 2R)

MCAT	Number Engines	Buoyancy Flux Range (@100%)	Lead Aircraft	Lead Engine	ATM		Lead Aircraft NOx Emission	Weighted Average NOx Emission
					DM	2R		
1	2	<170	Embraer 170-2	CF34-8E5A1	21,583	67,660	21.8	24.7
2	2	99	Bombardier C Series	PW1524G	10,094	30,462	56.0	56.0
3	2	190-500	Airbus A320-100/200	CFM56-5B4/P	38,225	71,719	63.4	62.0
4	2	93	Post 2016 G2 Airbus A320	PW1127G	83,208	119,056	25.7	25.7
5	2	198	New Gen Post 2016 B737-800	CFM-LEAP-1B	73,932	61,321	35.2	35.2
6	2	500-650	Airbus A350-900	TRENT XWB-84	17,188	37,281	256.4	205.7
7	2	556	Boeing 787 (Trent)	Trent 1000-J2	11,170	25,028	309.1	309.1
8	2	521	Boeing 787 (GEnx)	GEnx-1B70	11,170	25,028	169.9	169.9
9	2	>900	Boeing 777-300 (ER)	GE90-115B	7,004	22,820	472.2	472.2
10	2	639	Boeing 777X	GE9X	1,028	4,199	75.3	75.3
11	4	450-600	Boeing 747-800	GEnx-1B70	4,925	16,053	339.8	355.3

B1.4 Seasonal and Diurnal Variations

To account for seasonal variations in airport activity, annual forecast aircraft movements were apportioned into quarterly (3-month) periods to represent variations in ATMs during different periods of the year. For Gatwick Airport, the 2010 Q2 average day was adjusted to exclude 15-19 April (the period affected by the volcanic eruption in Iceland).

To account for fluctuations in airport and runway activity across the day, hour-by-hour diurnal profiles of aircraft departures and arrivals were determined for both Heathrow and Gatwick. For each airport, diurnal profiles for four 'typical' days were determined to represent activity during each of the quarterly periods of the year. For each of the four typical days, a separate diurnal profile was produced for each MCAT included in the dispersion model, as well as a total airport activity profile to apply to other airport emissions (e.g. APU and GSE) activities.

B1.5 Times in Mode

Taxiing

Times in Mode (TIMs) for taxi-in and taxi-out for the 2009 scenarios have been directly based on information provided by the Promoters. Information on the distances of taxi routes was derived from airport layouts, and then used to calculate average speeds. A summary of the 2009 data is provided in Tables B14 and B15.

Table B14: Taxi Times in Mode – Heathrow 2009

Taxi Route (Taxi-In/Out, Runway, Apron Area)	Distance (m)	Time (s)	Average Speed (m/s)
TO 27R - T5B	3390.0	700	4.8
TO 27L - T5B	3322.9	652	5.1
TO 09R - T5B	1703.1	574	3.0
TO 09L - T5B	1825.8	626	2.9
TI 27R - T5B	1072.9	373	2.9
TI 27L - T5B	1151.2	329	3.5
TI 09R - T5B	2668.5	518	5.2
TI 09L - T5B	2207.6	505	4.4
TO 27R - T5A	4062.8	792	5.1
TO 27L - T5A	4127.9	780	5.3
TO 09R - T5A	948.1	525	1.8
TO 09L - T5A	1106.6	583	1.9
TI 27R - T5A	1745.7	429	4.1
TI 27L - T5A	1956.2	448	4.4
TI 09R - T5A	3473.5	650	5.3
TI 09L - T5A	2880.4	508	5.7
TO 27R - T4A	2688.5	491	5.5
TO 27L - T4A	1415.2	502	2.8
TO 09R - T4A	3059.8	622	4.9
TO 09L - T4A	4406.8	838	5.3
TI 27R - T4A	3109.3	738	4.2
TI 27L - T4A	1805.0	407	4.4
TI 09R - T4A	718.0	320	2.2
TI 09L - T4A	3715.5	807	4.6
TO 27R - T3A	3306.4	711	4.7
TO 27L - T3A	3396.2	633	5.4
TO 09R - T3A	2446.2	606	4.0
TO 09L - T3A	2286.7	820	2.8
TI 27R - T3A	989.3	336	2.9
TI 27L - T3A	1243.4	327	3.8
TI 09R - T3A	2741.8	448	6.1
TI 09L - T3A	2124.0	409	5.2
TO 27R - T2A	1087.7	561	1.9
TO 27L - T2A	1048.9	617	1.7
TO 09R - T2A	4002.2	912	4.4
TO 09L - T2A	4105.2	933	4.4
TI 27R - T2A	2807.7	418	6.7
TI 27L - T2A	2799.4	602	4.7
TI 09R - T2A	1214.5	492	2.5
TI 09L - T2A	1452.2	338	4.3

Table B15: Taxi Times in Mode - Gatwick 2009

Taxi Route (Taxi-In/Out, Runway, Apron Area)	Distance (m)	Time (s)	Average Speed (m/s)
TI 08R - NTA	1688.9	330	5.1
TI 08R - NTB	1266.0	283	4.5
TI 08R - STA	1558.7	363	4.3
TI 08R - STB	1327.5	298	4.5
TI 26L - NTA	3449.7	427	8.1
TI 26L - NTB	2927.6	393	7.5
TI 26L - STA	3743.4	511	7.3
TI 26L - STB	3500.8	424	8.3
TO 08R - NTA	3710.9	805	4.6
TO 08R - NTB	3188.8	806	4.0
TO 08R - STA	3993.2	933	4.3

Taxi Route (Taxi-In/Out, Runway, Apron Area)	Distance (m)	Time (s)	Average Speed (m/s)
TO 08R - STB	3762.1	834	4.5
TO 26L - NTA	2120.8	673	3.2
TO 26L - NTB	1280.5	574	2.2
TO 26L - STA	1400.4	640	2.2
TO 26L - STB	405.7	468	0.9
TO 26L - CTB	2159.9	570	3.8
TI 08R - CTB	1529.3	272	5.6
TI 26L - CTB	2480.6	366	6.8
TX 08R - CTB	2706.9	701	3.9

The rotation velocity for the lead aircraft in each MCAT was estimated from published information on typical rotation velocities for commercial aircraft[24], and based on calculations using FAA Electronic Code of Federal Regulations data (FAA, 2015). These Regulations require that the lift-off speed for commercial aircraft must conform to the following rules:

- Vr is greater than V1;
- Vr is 5% greater than Vmc; and
- Vr is sufficient to ensure the aircraft reaches V2 before an altitude of 35 feet.

Where: Vr = rotation velocity; V1 = one engine inoperative (OEI) decision speed; Vmc = minimum control speed with OEI; and, V2 = take-off climb speed at 35 feet (which must be greater than 10% of Vmc.

Take-off roll times provided by the Promoters were used to assign an appropriate time to each MCAT based on the lead aircraft. Take-off roll length was based on an assumption of linear acceleration from start-of–roll to rotation velocity, taking account of the take-off roll times.

Climbout times to 1,500 and 3,000 feet were based on information provided by the Promoters. Climbout speeds were assumed to be 210 knots at 1,500 feet (FAA, 2015), and then increased to 250 knots at 3,000 feet. Climb angles were assumed to be constant and have been calculated assuming linear acceleration between rotation velocity and 210 knots at 1,500 feet, and between 210 knots at 1,500 feet to 250 knots at 3,000 feet.

Landing-roll distances have been based on runway touchdown marks and an assumed runway exit point for each MCAT. The proportion of aircraft using reverse thrust above idle has been based on information provided by the Promoters. It has been assumed that all aircraft using reverse thrust above idle use a thrust setting of 30%, in line with PSDH.

For the 2030 Do-Minimum scenario at Gatwick, TIMs were assumed to be unchanged from the 2009 baseline, with the exception of minor adjustments to take-off and climbout times to account for new aircraft types that were not operational in 2009 (e.g. Boeing 787 and Airbus A350), and to account for a 3.2 degree glide slope on approach. For the Heathrow 2030 Do-Minimum scenario, take-off and climbout times were also adjusted to account for new aircraft types, and approach times to account for the changed glide slope; in addition, the taxi times were adjusted to account for the proposed new central airfield layout that will be operational at Heathrow by 2030. For the 2030 With Scheme scenarios (Heathrow - NWR and ENR, and Gatwick 2R), the TIMs for take-off, climbout and approach were assumed

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[24] Derived from www.aerospaceweb.org/question/performance/q0088.shtml

to be unchanged from the 2030 Do-Minimum scenarios. Taxi-in and taxi-out times were for the With Scheme scenarios were derived from regression analyses between taxi times and taxi distances for the current airport layouts. A best-fit polynomial was applied to this relationship and used to assign future taxi times based on future design distances between stands and runway.

Average aircraft hold times at runway ends have been provided by the Promoters for 2009. These represent the average length of time than an aircraft is queueing or held at idle waiting to access the main runway. Hold times provided for Gatwick Airport indicate identical hold times for both runways (easterly and westerly use). For Heathrow Airport, individual, average hold times were provided for the four runways (easterly and westerly use). Emissions from aircraft on hold at runway end have been determined based on the average hold time, assuming that the main engines run at idle thrust setting (7%).

For the 2030 scenarios at Gatwick Airport, runway hold times were assumed to be unchanged from the 2009 baseline. For Heathrow Airport (Do-Minimum, NWR and ENR), average runway hold times were calculated by averaging the 2009 hold times provided by the NWR Promotor

B1.6 Apron Allocations in 2030

For the future scenarios (Do-Minimum and With Scheme) it is necessary to estimate the proportion of aircraft that will use different aprons across the year. This is important as it influences the movements of aircraft on departure or arrival to the main runway, and the taxi routes that will be used.

Information for 2030 is not available to describe the fleet mix of different airlines at each terminal and the associated stand facilities. The allocations have been based on a high level analysis of the number of stands at each terminal.

For the Gatwick 2R Scheme, this information was provided by the Promoter, and included a detailed breakdown of ICAO Code C, D, E and Multiple Aircraft Receiving Stands (MARS) stands. As the MARS stands can accommodate two Code C aircraft, or one Code E aircraft, an analysis was based on the minimum and maximum numbers of aircraft at a given apron. An average between these two extremes was used as the basis for the credible average use of an apron over the period of a year.

A small number of stands are not pier-served, but are remote; on the basis of information provided by the Promoter this was assumed to represent no more than 5%. The derived allocation figures were adjusted to reflect the preference for the use of pier-served stands.

The outcome of the assessment was verified from the capacity of each terminal (in terms of mppa) and what the resulting apron apportionment would be.

For the Gatwick 2R Scheme, it was assumed that the third phase of midfield terminal and satellite will not be operational in 2030; to reflect this, only the eastern half of the midfield satellite was assumed to be operational with a capacity of 30 mppa. Further information on the capacity and phasing is provided in the Jacobs Appraisal Framework Module 13: Cost and Commercial Viability, and Appraisal Framework Module 14: Operational Efficiency.

For both the Heathrow NWR and ENR schemes, most stands are MARS. The number of aircraft at each apron can thus vary largely, depending on the airline mix at each terminal. Aircraft movements were allocated based on the capacity of each terminal (T2, T4, T5 and T6). Further information on the capacity and phasing is provided in the Jacobs Appraisal Framework Module 13: Cost and Commercial Viability, and Appraisal Framework Module 14: Operational Efficiency.

The assumed apron block allocations for each scenario are shown in Table B16.

Table B16: Apron Allocations – 2030

Do-Minimum			
Heathrow		NWR/ENR	
Apron Block	Allocation	Apron	Allocation
T1A	18%	T1A	13%
T2A	18%	T2A	13%
T3A	18%	T3A	13%
T4A	11%	T4A	8%
T5A	18%	T5A	13%
T5B	18%	T5B	13%
		T6A	27%
Gatwick		2R	
STA	27%	STA	17%
STB	29%	STB	18%
NTA	22%	NTA	14%
NTB	17%	NTB	11%
CTB	5%	CTB	3%
ATB	-	ATB	9%
ATC	-	ATC	9%
ATD	-	ATD	10%
ATE	-	ATE	10%

B1.7 Particulate Matter Emissions

The approach used for the estimation of PM emissions arising from aircraft engines has undergone development in recent years. The original approach, based on the ICAO reported maximum Smoke Number, only estimated the non-volatile fraction of PM. To address this problem, the contribution of PM emissions from the volatile fraction was considered by a CAEP Working Group, and a First Order Approximation (FOA) method was derived; this approach estimates the non-volatile portion using the ICAO Smoke Number, but also estimates the volatile portion associated with the fuel sulphur content, fuel-based organics and lube oil. Version 3 of the FOA is now available (FOAv3.0) and is the approach recommended in the ICAO *Airport Air Quality Manual*. The FOAv3.0 approach has been used to calculate PM emissions from the Smoke Number data obtained for each MCAT lead engine, based on the ICAO databank.

Recent research comparing the FOA*v*3.0 approach with measurements has identified a discrepancy in both the organic carbon and black carbon emissions indices (Stettler et al, 2011). Combined, these discrepancies result in a 3.4 factor underestimate of total $PM_{2.5}$ emissions. To remove this bias, the FOA v3.0 emissions indices for PM have been multiplied by 3.4.

Virtually all of the mass emission of PM from aircraft engines will be associated with $PM_{2.5}$. It has been assumed that emissions are represented as both PM_{10} and $PM_{2.5}$.

B1.8 Brake & Tyre Wear

An allowance has also been made for PM emissions arising from brake and tyre wear based on a methodology developed during the PSDH work. For brake wear, an emission factor of 2.51 x 10^{-7} kg PM_{10} per kg MTOW[25] was assumed. For tyre wear, the following relationship was used:

PM (kg) per landing = 2.23 x 10^{-6} x (MTOW kg) – 0.0874 kg   Equation [2]

Emissions were calculated for all large aircraft. The relationship is not applicable to smaller aircraft, below 55,000 kg, and it has been assumed the PM emissions from tyre wear follow a linear relationship between MTOW and PM, intersecting at zero.

Based on the PSDH work, the PM_{10} fraction of total tyre wear PM was assumed to be 10%. It has been assumed that $PM_{2.5}$ emissions from these fugitive sources are equal to PM_{10}. This is likely to be a conservative assumption for this source.

B2 Auxiliary Power Units

Emissions for APUs have been calculated on the basis of normal running Environmental Control System (ECS) mode. The assumed APU running times are summarised in Table B17.

Table B17: APU Running Times

Scenario	Wide Body Aircraft	Narrow Body Aircraft
Heathrow 2009 Baseline Heathrow NWR Heathrow ENR	80 minutes per LTO Cycle	40 minutes per LTO Cycle
Gatwick 2009 Baseline Gatwick 2R	110 minutes per LTO Cycle	50 minutes per LTO Cycle

Wide Body applies to both Wide and Jumbo-wide aircraft. Narrow body applies to all other aircraft types

APU fuel and emissions indices have been derived from the ACPR Report 6464 (ACRP, 2012), and are summarised in Table B18.

Table B18: APU Fuel Use and Emissions Indices for ECS Mode

Aircraft Category	Fuel Flow (kg/s)	EI NOx (g/kg fuel)
Narrow Body	0.033	5.72
Wide Body	0.052	7.55
Jumbo-wide Body	0.061	7.41
Regional Jet	0.019	6.14
Turbo Prop	0.019	6.14

The ACRP Report does not provide information on PM emissions from APU operations. Emission rates for PM have been based on a function of the corresponding NOx emission factor (AEA, 2008) as set out in Table B.19.

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[25] Maximum Take Off Weight

Table B.19: APU PM Emissions Rates

Aircraft Type	PM emission rate (kg/hr) as function of NOx emission rate (kg/hr)
All types, except those below	$PM=0.0233*NOx^{0.0934}$
Business jets, BAE146, ERJ 135/145, CRJ, CRJ700	$PM=0.379*NOx^{2.642}$
B752-2, B767-2, B767-3, A300, A310	$PM=0.0630*NOx^{0.173}$

The aircraft categories have been assigned to each MCAT as shown in Table B.20.

Table B.20: APU Assignments BY MCAT

MCAT	Lead Aircraft	APU Aircraft Category
Heathrow 2009 Baseline		
MCAT01	Embraer RJ145	Regional Jet
MCAT02	Airbus A320	Narrow Body
MCAT03	Airbus A321	Narrow Body
MCAT04	Boeing 757-200	Narrow Body
MCAT05	Boeing 777-200	Wide Body
MCAT06	Airbus A340-300	Jumbo Wide Body
MCAT07	Airbus A340-600	Jumbo Wide Body
MCAT08	Boeing 747-400	Jumbo Wide Body
MCAT09	Boeing 747-400	Jumbo Wide Body
MCAT10	Airbus A380	Jumbo Wide Body
Heathrow 2030 Do-Minimum, NWR, ENR		
MCAT01	Bombardier C Series	Narrow Body
MCAT02	Airbus A320-100/200	Narrow Body
MCAT03	Post 2016 G2 Airbus A320	Narrow Body
MCAT04	New Gen Post 2016 B737-800	Narrow Body
MCAT05	Airbus A350-900	Wide Body
MCAT06	Boeing 787 (Trent)	Wide Body
MCAT07	Boeing 787 (GENX)	Wide Body
MCAT08	Boeing 777-300 (ER)	Wide Body
MCAT09	Boeing 777X	Wide Body
MCAT10	Airbus A380 pax	Jumbo Wide Body
Gatwick 2009 Baseline		
MCAT01	Dash-8 Q400	Turboprop
MCAT02	Airbus A319	Narrow Body
MCAT03	Airbus A320	Narrow Body
MCAT04	Airbus A321	Narrow Body
MCAT05	Boeing 767-300	Wide Body
MCAT06	Airbus A330-200	Wide Body
MCAT07	Boeing 777-200	Wide Body
MCAT08	Boeing 747-400	Jumbo Wide Body
Gatwick 2030 Do-Minimum, 2R		
MCAT01	Embraer 170	Narrow Body
MCAT02	Bombardier C Series	Narrow Body
MCAT03	Airbus A320-100/200	Narrow Body
MCAT04	Post 2016 G2 Airbus A320	Narrow Body
MCAT05	New Gen Post 2016 B737-800	Narrow Body
MCAT06	Airbus A350-900	Wide Body
MCAT07	Boeing 787 (Trent)	Wide Body
MCAT08	Boeing 787 (GEnx)	Wide Body

MCAT	Lead Aircraft	APU Aircraft Category
MCAT09	Boeing 777-300 (ER)	Wide Body
MCAT10	Boeing 777X	Wide Body
MCAT11	Boeing 747-800	Jumbo Wide Body

B3 Ground Support Equipment

Emissions arising from GSE have been calculated using emissions factors based on annual fuel use for road and non-road GSE. A breakdown of the fraction of total annual fuel use by type of vehicle/GSE for 2009 was provided by the Heathrow NWR and Gatwick 2R Promoters (Table B.21). For Heathrow, total annual fuel use was obtained from Table 2.14 of the 08/09 Heathrow Airport emissions inventory (AEA, 2010). For Gatwick, total annual fuel use was obtained from Table 3.5 of the 2010 Gatwick Airport emissions inventory report (Ricardo-AEA, 2012). No adjustments have been made for 2009, and it has been assumed that GSE fuel use for 08/09 at Heathrow and 2010 at Gatwick are representative of GSE fuel use in 2009 at each airport.

Table B.21: 2009 GSE Fuel Use[a]

Vehicle	Fuel Type	Emission Standard	Fraction of Airside Fuel Used	
			Heathrow	Gatwick
Artic HGV	Diesel	Euro I	0.12%	4.31%
Artic HGV	Diesel	Euro II	0.26%	2.13%
Artic HGV	Diesel	Euro III	0.22%	3.26%
Artic HGV	Diesel	Euro IV	0.30%	n/a
Artic HGV	Diesel	Pre-Euro I	0.05%	0.16%
Artic HGV	Diesel	Unknown	0.32%	n/a
Artic HGV	LPG	Pre-Euro I	0.02%	n/a
Bus	Diesel	Euro I	n/a	4.13%
Bus	Diesel	Euro II	0.18%	0.11%
Bus	Diesel	Euro III	0.55%	n/a
Bus	Diesel	Euro IV	1.62%	n/a
Bus	Diesel	Unknown	0.22%	n/a
Bus	Petrol	Pre-Euro I	0.04%	n/a
Bus	LPG	Euro I	n/a	12.63%
Car	Diesel	Euro 1	0.76%	0.08%
Car	Diesel	Euro 2	1.31%	0.20%
Car	Diesel	Euro 3	5.00%	1.58%
Car	Diesel	Euro 4	5.84%	4.16%
Car	Diesel	Euro 5	n/a	0.03%
Car	Diesel	Pre-Euro 1	0.04%	0.08%
Car	Diesel	Unknown	4.26%	n/a
Car	LPG	Euro 1	n/a	0.0002%
Car	LPG	Euro 2	0.02%	0.001%
Car	LPG	Euro 3	0.10%	0.01%
Car	LPG	Euro 4	0.06%	0.01%
Car	LPG	Pre-Euro 1	0.00%	0.001%
Car	LPG	Unknown	0.04%	n/a
Car	Petrol	Euro 1	0.08%	0.001%
Car	Petrol	Euro 2	0.64%	0.03%
Car	Petrol	Euro 3	1.67%	0.07%
Car	Petrol	Euro 4	0.74%	0.07%
Car	Unleaded	Euro 5	n/a	0.0002%
Car	Unleaded	Pre-Euro 1	n/a	0.01%
Car	Petrol	Unknown	0.72%	n/a
Coach	Diesel	Euro I	1.27%	1.27%
Coach	Diesel	Euro II	0.10%	3.07%

Vehicle	Fuel Type	Emission Standard	Fraction of Airside Fuel Used	
			Heathrow	Gatwick
Coach	Diesel	Euro III	0.21%	0.92%
Coach	Diesel	Euro IV	0.17%	n/a
Coach	Diesel	Pre-Euro I	0.00%	0.01%
Coach	Diesel	Unknown	0.12%	n/a
Coach	LPG	Euro I	n/a	2.95%
Coach	LPG	Euro II	n/a	9.13%
Coach	LPG	Euro III	n/a	2.47%
Coach	LPG	Pre-Euro I	n/a	0.02%
LGV	Diesel	Euro 1	1.25%	0.07%
LGV	Diesel	Euro 2	4.56%	2.20%
LGV	Diesel	Euro 3	11.93%	5.45%
LGV	Diesel	Euro 4	8.09%	4.42%
LGV	Diesel	Pre-Euro 1	0.52%	1.21%
LGV	Diesel	Unknown	6.61%	0.00%
LGV	LPG	Euro 1	n/a	0.00002%
LGV	LPG	Euro 2	0.04%	0.001%
LGV	LPG	Euro 3	0.42%	0.53%
LGV	LPG	Euro 4	0.12%	0.10%
LGV	LPG	Pre-Euro 1	n/a	0.0004%
LGV	LPG	Unknown	0.06%	n/a
LGV	Petrol	Euro 1	0.06%	0.001%
LGV	Petrol	Euro 2	0.36%	0.04%
LGV	Petrol	Euro 3	0.36%	0.30%
LGV	Petrol	Euro 4	0.08%	0.20%
LGV	Unleaded	Pre-Euro 1	n/a	0.003%
LGV	Petrol	Unknown	0.44%	n/a
Rigid HGV	Diesel	Euro I	0.58%	1.78%
Rigid HGV	Diesel	Euro II	3.75%	0.19%
Rigid HGV	Diesel	Euro III	6.87%	4.17%
Rigid HGV	Diesel	Euro VI	1.95%	n/a
Rigid HGV	Diesel	Pre 1988	0.11%	n/a
Rigid HGV	Diesel	Pre-Euro I	0.44%	0.01%
Rigid HGV	Diesel	Unknown	3.62%	n/a
Rigid HGV	LPG	Pre-Euro I	0.04%	n/a
Rigid HGV	Petrol	Pre-Euro I	0.08%	n/a
Rigid HGV	Petrol	Unknown	0.06%	n/a
Specialist; 130-560	Diesel	Stage I	0.48%	1.08%
Specialist; 130-560	Diesel	Stage II	0.48%	5.53%
Specialist; 130-560	Diesel	Stage IIIa	0.40%	4.15%
Specialist; 130-560	Diesel	Uncontrolled	1.55%	9.96%
Specialist; 130-560	Diesel	Unknown	1.02%	n/a
Specialist; 130-560	Petrol	Uncontrolled	0.04%	n/a
Specialist; 37-75	Petrol	Unknown	0.02%	n/a
Specialist; 37-75	Diesel	Stage I	3.51%	0.96%
Specialist; 37-75	Diesel	Stage II	4.14%	1.23%
Specialist; 37-75	Diesel	Stage IIIa	0.04%	0.41%
Specialist; 37-75	Diesel	Uncontrolled	5.26%	0.97%
Specialist; 37-75	Diesel	Unknown	1.99%	n/a
Specialist; 37-75	LPG	Uncontrolled	0.66%	n/a
Specialist; 37-75	LPG	Unknown	0.14%	n/a
Specialist; 37-75	Petrol	Uncontrolled	0.12%	n/a
Specialist; 75-130	Petrol	Unknown	0.06%	n/a
Specialist; 75-130	Diesel	Stage I	0.42%	0.33%
Specialist; 75-130	Diesel	Stage II	0.52%	0.79%
Specialist; 75-130	Diesel	Stage IIIa	0.12%	0.65%
Specialist; 75-130	Diesel	Uncontrolled	0.32%	0.36%
Specialist; 75-130	Diesel	Unknown	0.52%	n/a
Specialist; 75-130	Petrol	Uncontrolled	0.02%	n/a
Specialist; 75-130	Petrol	Unknown	0.02%	n/a

[a] Data for Heathrow are for April 08-April 09 and data for Gatwick are for 2010. Both have been assumed to be representative of GSE fuel use in 2009.

NOx and PM_{10} emissions factors for GSE have been obtained from two sources. For road-GSE, emission factors have been taken from Tables 2.17 and 2.19 of the Heathrow Airport 08/09 emissions inventory report. For non-road GSE, emission factors have been obtained from Tables 3-1 and 3-2 of the EMEP/EEA emissions inventory guidebook (EMEP, 2013).

The GSE emissions factors used in the assessment are presented in Table B22 and Table B23. For all vehicles with ‘unknown’ emissions standards, emissions factors for either Euro 1/I or Pre-Euro 1/I vehicles have been used.

Table B22: Road GSE Emission Factors

Vehicle Type	Emission Standard	Emission Factors (g/kg_{fuel})	
		NOx	PM_{10}
Diesel Car	Pre-Euro 1	14.51	3.77
	Euro 1	19.86	1.44
	Euro 2	18.25	0.65
	Euro 3	9.80	0.64
	Euro 4	8.36	0.44
	Euro 5	8.57	0.18
	Euro 6	3.59	0.21
Diesel LGV	Pre-Euro 1	26.79	5.34
	Euro 1	22.96	1.23
	Euro 2	17.02	0.80
	Euro 3	7.23	0.81
	Euro 4	5.56	0.54
	Euro 5	6.84	0.29
	Euro 6	2.39	0.29
Rigid HGV	Pre-Euro I	35.64	3.23
	Euro I	30.91	1.92
	Euro II	35.69	0.68
	Euro III	30.88	0.83
	Euro IV	17.86	0.20
	Euro V	10.94	0.20
	Euro VI	1.54	0.15
Artic HGV	Pre-Euro I	35.64	1.89
	Euro I	29.24	1.83
	Euro II	32.60	0.61
	Euro III	29.80	0.78
	Euro IV	18.40	0.18
	Euro V	11.15	0.18
	Euro VI	1.17	0.11
Bus	Pre-Euro I	37.84	2.28
	Euro I	30.48	1.44
	Euro II	36.44	0.63
	Euro III	30.76	0.50
	Euro IV	18.53	0.19
	Euro V	11.59	0.18
	Euro VI	1.80	0.12
Coach	Pre-1988	36.54	1.94
	Pre-Euro I	36.54	1.94
	Euro I	32.98	1.68
	Euro II	37.85	0.68
	Euro III	34.89	0.79
	Euro IV	19.90	0.21
	Euro V	12.37	0.21
	Euro VI	1.80	0.12
Petrol car	Pre-Euro 1	15.58	0.05
	Euro 1	9.89	0.05
	Euro 2	9.24	0.04
	Euro 3	3.95	0.04

Vehicle Type	Emission Standard	Emission Factors (g/kg_{fuel})	
		NOx	PM_{10}
	Euro 4	3.03	0.04
	Euro 5	2.34	0.04
	Euro 6	2.34	0.04
Petrol LGV	Pre-Euro 1	19.61	0.06
	Euro 1	9.56	0.06
	Euro 2	7.44	0.04
	Euro 3	4.44	0.02
	Euro 4	2.97	0.02
	Euro 5	1.54	0.02
	Euro 6	1.54	0.02
LPG Car	Pre Euro 1	22.84	0.07
	Euro 1	29.77	0.05
	Euro 2	6.49	0.03
	Euro 3	5.91	0.03
	Euro 4	4.38	0.03
	Euro 5	3.31	0.03
	Euro 6	3.31	0.03
LPG LGV	Pre Euro 1	28.74	0.09
	Euro 1	32.83	0.05
	Euro 2	7.50	0.03
	Euro 3	6.45	0.03
	Euro 4	4.29	0.03
	Euro 5	5.28	0.03
	Euro 6	3.36	0.02

Table B23: Non-Road GSE Emission Factors

Fuel Type	Technology	Emission Factors (g/kg_{fuel})	
		NOx	PM_{10}
Diesel	Uncontrolled	43.62	3.55
	Stage I	31.11	0.97
	Stage II	22.09	1.03
	Stage IIIA	16.36	0.96
Petrol	Uncontrolled/Unknown	33.58	0.16

For all road-GSE, it has been assumed that the average operating speed of vehicles on the airfield (for both Heathrow and Gatwick) is 20 mph (32 kph), which is the airside speed limit for Heathrow.

For 2030, GSE annual fuel use has been scaled up from 2009, based on the ratio of passenger numbers (mppa) for each scenario. A summary of the total annual GSE fuel use for all model scenarios is shown in Table B24.

Table B24: Total Annual GSE Fuel Use

Airport	Scenario	mppa	Annual GSE Fuel Use (t/yr)	
			Road	Non-Road
Heathrow	2009 Baseline	65,907,900	7,328	3,231
	2030 Do Minimum	87,452,728	9,723	4,287
	2030 NWR	125,153,056	13,915	6,135
	2030 ENR	123,120,616	13,689	6,036
Gatwick	2009 Baseline	31,348,100	2,892	1,038
	2030 Do Minimum	43,720,928	4,033	1,448
	2030 2R	72,025,032	6,644	2,385

In order to estimate the GSE fleet mix in 2030, a rollover approach has been used. All 2009 non-road GSE have been assumed to remain operational in 2030, and all new non-road GSE, assumed to be Stage IIIa. To estimate the new non-road GSE, all additional non-road fuel use in each 2030 scenario (compared to the 2009 baseline) has been assumed to be utilised by new, non-road GSE, operating to Stage IIIa emissions standards. For road-GSE, it has been assumed that all new vehicles in 2030 will be Euro 6/VI compliant. For existing road-GSE it has been assumed that all vehicles will have been replaced by 2030, with all vehicles currently compliant to Euro 2/II up to Euro 5/V being replaced with Euro 6/VI compliant vehicles, and all vehicles Euro 1/I, pre-Euro 1/I or unknown emission standard will have been replaced with Euro 5/V compliant vehicles by 2030.

Euro 6/VI emission factors in g/kg_{fuel} have been estimated by obtaining emission rates for Euro 5/V and Euro 6/VI vehicles in g/km/s from Defra's EFT (assuming a vehicle speed of 32 kph) and applying the ratios between the relevant Euro 5/V and Euro 6/VI emission rates to the Euro 5/V emission factors shown above.

B4 Heating and Energy Plant

Emissions of NOx and PM_{10} from heating plant in 2009 were provided for Heathrow Airport by the NWR Promoter. These data include the location and release conditions (stack height and diameter, efflux velocity and flue gas temperature) of major heating and energy plant sources at the Airport, and seasonal (monthly) emissions profiles for each source. For minor heating and energy sources, the location and emissions were provided, but no release conditions were given. For these sources a standard set of release conditions has been assumed (stack height 10m, stack diameter 0.5m, efflux velocity 5m/s and efflux temperature 353K).

For Gatwick Airport, no information on heating and energy plant was provided by the 2R Promoter. NOx and PM_{10} emissions were calculated using the total annual emissions presented in the Gatwick Airport 2010 emissions inventory (Ricardo-AEA, 2013). It was assumed that heating and energy plant emissions at Gatwick in 2009 were the same as those reported for 2010. The two major heating and energy plant sources included in the 2010 emissions inventory (the north and south terminal energy centres) were identified, and included in the model; it was assumed that each source represented 50% of the total annual NOx and PM_{10} emissions. Release conditions were estimated, based on data provided for Heathrow Airport and previous experience of modelling emissions from large gas-fired combustion plant. The stack heights were estimated from observations (15m); other assumed release conditions were: stack diameter 0.9m (north) and 1.0 (south), efflux velocity 10m/s and efflux temperature 353K. A seasonal profile of emissions was obtained from the data provided for Heathrow Airport and applied to the Gatwick Airport heating and energy plant sources to account for variations in heating demand throughout the year.

For 2030, it was assumed that complete replacement of heating and energy plant will occur for all future scenarios. Energy plant sources have been retained in the 2030 modelling at two key locations at Heathrow Airport (the T2 and T5 energy centres) for the Do-Minimum, NWR and ENR Schemes. NOx emission estimates for heating and energy plant were provided by the Heathrow NWR Promoter and were assumed to be split equally between the T2 and T5 energy centres. Release conditions for these sources have been assumed to be the same as for the baseline.

For Gatwick, a reduction in total annual heating and energy plant NOx emissions (in terms of mg/NOx per kWh of gas combustion) has been estimated based on the predicted reduction in NOx emissions at Heathrow between 2009 and 2030. Heating and energy plant emissions have been retained at the two locations included in the 2009 baseline (the north and south terminal energy centres), with NOx emissions split equally between each source. Release conditions were assumed to be the same as for the baseline scenario.

B5 Spatial and Temporal Representation of Emissions

Emissions occur at different locations and over different time periods. The spatial representation of sources has been undertaken using a combination of line and volume sources.

All aircraft emissions, including take-off, initial climb to 1,500ft, climbout to 3,000ft, approach, landing roll and taxiing have been represented in the ADMS-Airport model “Airfile”. Each aircraft movement between spatial nodes has been included as a separate line in the airfile. ADMS-Airport then treats each source as a series of fixed jet sources between each node point. Each line of the airfile has been assigned an “NT number”, which is the number of fixed jet sources along its length. For each part of the LTO cycle, there is a maximum jet source spacing, which has been used to calculate NT (NT = distance between aircraft start and end points / max jet-source spacing).

The airfile contains information on the geometry of individual aircraft, the engine exhaust parameters (exit velocity, temperature and diameter), the geometry of the LTO Cycle (e.g. taxiway start and end points, take-off start and end points, approach start and end points etc.), the times in mode, and the aircraft emissions.

The emission rates contained within the airfile are annual average emission rates based on the number of movements of a particular aircraft or group of aircraft, on a particular runway or taxiway.

Due to the significant number of taxiway sources required within the model, it is impractical, in terms of model size and run time, to assign specific taxiing emissions for each group of modelled aircraft. It is therefore common practice to use a single taxiing emission rate for all aircraft within an airport scenario. To account for the variation in taxiing emissions between different aircraft engines, the approach to determining a single representative taxiing emission rate for all aircraft is to calculate an airport average taxiing emission rate that is weighted by annual air traffic movements (ATMs) for each aircraft engine type (based on the chosen lead aircraft and engine in each group). The calculation is as follows:

$$ER_A = ((ER_{G1} \text{ x } ATM_{G1}) + (ER_{G2} \text{ x } ATM_{G2}) + (ERG_3 \text{ x } ATM_{G3})) / ATM_T$$

Where:

ER_A = Average taxiing emission rate, ER_{G1} = Taxiing emission rate for Group 1 lead aircraft, ATM_{G1} = number of ATMs for aircraft in Group 1, ER_{G2} = taxiing emission rate for Group 2 lead aircraft, ATM_{G2} = number of ATMs for aircraft in Group 2, ER_{G3} = taxiing emission rate for Group 3 lead aircraft, ATM_{G3} = number of ATMs for aircraft in Group 3, ATM_T = total airport ATMs.

The total annual APU emissions have been calculated for each scenario and apportioned across the key apron areas based on the proportions of aircraft movements using each apron area (see Table B.16). To account for the initial release height (5m for a narrow body aircraft up to 12m for a jumbo-wide body aircraft) and initial plume buoyancy, the APU emissions have been treated as volume sources with a source centre height of 10m and a mixing depth of 10m.

All GSE sources have been represented as volume sources with an assigned centre height of 1m and a mixing depth of 2m.

Aircraft hold queues at the runway end have been modelled as volume sources with a centre height of 3.5 m and a mixing depth of 5 m. This is to account for the initial plume buoyancy of the hot exhaust emissions, taking account of the variations in jet engine exhaust height (1.6 m to 3.3 m for the 2009 LHR MCAT lead aircraft and 1.6 m to 3.0 m for the 2009 LGW MCAT lead aircraft).

B5.1 Cargo and Maintenance Aprons

Emissions from the BA Maintenance Hub at Heathrow Airport, and the designated cargo and maintenance apron areas at Gatwick Airport, have been excluded from the model. These areas are generally located well away from the airport boundary and are only serviced by a very small number of aircraft movements. All designated cargo and maintenance aircraft movements have been included in the ADMS-Airport model, but the on-stand emissions (APU and GSE) and taxiway emissions have been assigned to the commercial aircraft apron areas.

On-stand emissions (APU and GSE) from designated cargo apron areas at Heathrow Airport (to the south of the southern runway and the west of T4) have been included as volume sources, as these apron areas are close to the Airport boundary. Due to the limited number of movements of these aircraft, taxiways from runway ends, to and from the cargo apron areas, have not been included in the model and the emissions from designated cargo aircraft taxiing across the airfield have been assigned to other taxiways serving the commercial apron areas.

Appendix C: Surface Access Emissions Representation

This appendix provides details of the surface access emissions and modelling, focussing on limitations that have arisen.

C1 Vehicle Fleet Compositions

Vehicle fleet compositions have been assigned based on the location of the mid-point of each road link. As the M25 does not delineate the outer boundary of the London Outer zone, as defined in the London Atmospheric Emissions Inventory (LAEI), parts of it lie inside and outside of this zone. Consequently, the composition of the fleet between contiguous sections of the M25 changes at a number of locations.

Whilst this does not represent a situation that occurs in the real-world, where no changes to the road links are proposed, the fleet compositions remain consistent across the scenarios. This issue will therefore not have significantly affected the comparisons between the various Schemes and their respective baselines. Where new road links are proposed, however, or where links are re-aligned due to a specific Scheme, there is the potential for the fleet composition to vary on equivalent links between the Do-Minimum and With Scheme scenarios if they move in or out of the London Outer zone. This has been corrected in the total emissions calculations, and dealt with by way of a sensitivity test for the dispersion modelling.

This sensitivity test indicates that for the Heathrow NWR Scheme, impacts at 24 properties south of Wraysbury Reservoir, close to (within 200m) Junction 13 of the M25, may have been underestimated by a small amount of between 0.1 and 3.1 $\mu g/m^3$ NOx; fourteen of these properties change from small reductions in concentrations of 0.1 to 2.1 $\mu g/m^3$, to small increases of 0.3 to 0.9 $\mu g/m^3$. Impacts at 13 properties may be overestimated at other locations close to sections of the M25 that change in fleet composition between contiguous links, by small amounts of between 0.1 and 0.4 $\mu g/m^3$ NOx.

For the Heathrow ENR Scheme, the sensitivity test indicates that impacts may be underestimated by small amounts at up to 20 properties close to sections of the M25 that change in fleet composition between contiguous links (by being in or out of the Outer London zone), by between 0.3 and 3.1 $\mu g/m^3$ NOx. No predicted impacts change from being increases to reductions, or vice versa.

The effect of the changes in fleet composition between contiguous M25 links is negligible (0.0 to -0.1 $\mu g/m^3$) for PM_{10} in both the Heathrow NWR and ENR Schemes.

C2 Vehicle Fleet Splits

The vehicle fleet split provided in the traffic data outputs included Light Goods Vehicles (LGV) and Heavy Goods Vehicles (HGV). The standard fleet mix defined in the Emission Factor Toolkit (v6.0.2) was used to determine the emissions from specific vehicle types and Euro classes on each road. The fleet splits contained in the EFT were used to determine the fractions of the fleet for a sensitivity test into Euro 6 primary-NO_2 emissions (see Appendix H).

C3 Weekday average vs annual average traffic volumes

Total emissions were calculated using the annual average weekday traffic (AAWT) values output from the traffic model, which were subsequently adjusted by the ratio of annual average daily traffic (AADT) volumes / AAWT volumes. It was not possible to account for the difference in fleet composition, speeds and routing that might occur at weekends, as weekends were not included within the traffic model.

C4 Airport-related surface access emissions apportionment

Apportionment of surface access emissions into airport and non-airport related categories was not possible as outputs of the traffic model for airport related traffic were in a format incompatible with those of the outputs for total traffic on the network. As such, it has not been possible to attribute the proportion of impacts caused by changes in traffic emissions to airport-related surface access.

C5 Meteorology: Wind Directions

The surface access dispersion modelling was setup with wind directions at specific 10˚ angles, rather than distributed over 10˚ sectors as was used in the model runs for the airport sources. Sensitivity tests subsequently showed that the differences were negligible, with model outputs only affected by up to 0.2%, and that the effect was non-systematic.

C6 Road Source Geometry

In the process of allocating traffic emissions to road centrelines for inclusion in the dispersion model, there were a small number of instances where emissions from a nearby link, rather than the correct link, have been used. This only occurred over very short sections of road some considerable distance from any sensitive receptor, or was associated with opposite carriageways of dualled road links being switched. In either case, the effects on the results will be imperceptible.

There have also been some isolated locations in the model network where gaps have occurred between modelled roads, or where slightly different alignments were used for existing roads across the different scenarios. None of these instances occurred close to sensitive receptors and the effects on the results will be imperceptible.

C7 Airport access road to Heathrow Central Terminal Area

The airport access road to the Heathrow Central Terminal Area (CTA) has been excluded from the surface access dispersion modelling. The section of road on the CTA-side of the tunnel is unlikely to give rise to any measureable off-site contribution, due to its distance from the nearest receptors and its relatively low emissions footprint relative to the aircraft aprons of Terminal 2 and Terminal 3 which surround it, and the existing northern runway which separates it from sensitive receptors. At the northern portal, a sensitivity test was carried out which estimates a maximum NOx concentration at Bath Road of less than 0.15 µg/m^3 of NOx, and can be disregarded.

C8 Vertical alignment of roads and receptors

All road links were modelled at ground level, with receptors at 1.5 m height, representing typical breathing height.

Roads with canyon-like features can increase concentrations of pollutants within the canyon environment. ADMS can represent canyon effects, but this feature was not applied as it was considered impractical to implement consistently across the extent of the Study Areas.

Appendix D: NOx to NO_2 Conversion

The approach taken for the conversion of NOx to NO_2 for the airport air quality assessments at LHR and LGW has been to use Defra's NOx:NO_2 calculation tool, Version 4.1[26].

The NO_x:NO_2 calculation tool (which is based on the Jenkin approach) requires the user to input, as a minimum, the source NO_x contribution (labelled "*Road increment* NO_x" in the calculator), and the background NO_2 concentration. The tool uses in-built default primary NO_2 (fNO_2) fractions for road traffic (based on one of 6 default vehicle fleet mixes) specific to the year of conversion (2008 – 2030), but also allows the user to overwrite the default fNO_2 fractions by inserting receptor specific values (in a column labelled "*Fraction emitted as* NO_2").

For the purpose of this assessment, the "*Road increment* NO_x" at each receptor represents the road-NO_x + airport-NO_x contribution (predicted using the ADMS-Airport model), receptor-specific background NO_2 (from the PCM maps with relevant source components removed to avoid double counting), and receptor-specific fNO_2 fractions calculated from the individual source contributions of road-NO_x and airport-NO_x at each receptor.

The receptor-specific fNO_2 equation is:

$$fNO_{2receptor} = ((Road\text{-}NO_x \times fNO_{2road}) + (Airport\text{-}NO_x \times fNO_{2airport})) / (Road\text{-}NO_x + Airport\text{-}NO_x)$$

Where:
$fNO_{2receptor}$ = the receptor-specific fNO_2 fraction.
Road-NO_x = the predicted contribution of NO_x from road traffic at the receptor.
fNO_{2road} = the fNO_2 fraction from road traffic emissions.
Airport-NO_x = the predicted contribution of NO_x from airside sources at the receptor.
$fNO_{2airport}$ = the fNO_2 fraction from airport emissions sources.

Calculating the fNO_2 from road traffic emissions (fNO_{2road})

The default year-specific fNO_2 fractions for 'all London traffic', which are presented in Defra's NOx:NO_2 calculator tool have been used.

Calculating the fNO_2 from airport emissions ($fNO_{2airport}$)

To calculate the fNO_2 from the airport emissions, an approach based on calculating an average airport fNO_2 has been used; this is weighted by the relative annual airport NOx emissions of various different airside sources with varying fNO_2 fractions. Emissions during climb out and approach have been discounted as these contribute very little to ground level concentrations. The approach is summarised in the table below, which uses approximate total NOx emissions, but uses the default fNO_2 fractions for each source, which are based on the NAEI publication, which includes data compiled for the PSDH study[27].

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[26] Available to download at: http://laqm.defra.gov.uk/review-and-assessment/tools

[27] http://naei.defra.gov.uk/resources/3_9_324_136262_primary_no2_emission_factors_for_aviation_and_other_transport_sources_2010naei_v1.pdf

Table D.1: Calculation of Airport fNO_2

Source	fNO_2	Total Annual NO_x Emission (kg)	Total Annual NO_2 Emission (kg)
Aircraft at take-off (90%+ thrust)	0.045	100,000	4,500
Aircraft at idle/taxi (7% thrust)	0.375	30,000	11,250
GSE	0.15	7,500	1,125
Other sources	0.05	2,500	125
TOTAL Annual Emissions (kg)		**140,000**	**17,000**
Average Airport fNO_2	**= (NO_2/NOx) = (17,000/140,000) = 0.1214**		

Selection of Local Authority

One of the inputs into Defra’s NOx:NO_2 calculator is the local authority in which the study area or specific receptor location exists. This allows the calculator to determine the regional background ozone (O_3) concentration.

As the NWR/ENR and 2R Study Areas are large, and cover multiple local authorities, this potentially requires:

- the relevant local authority to be identified for every single receptor location; and
- the NOx:NO_2 tool to be used repeatedly to process receptors in each local authority area separately.

In order to reduce this post-processing requirement, the NOx:NO_2 calculator has been assessed to test the influence of the ‘local authority’ setting on the output NO_2 concentrations.

The NOx:NO_2 calculator has been run to predict total NO_2 concentrations for 2009, using three separate background NO_2 settings (20 µg/m^3, 25 µg/m^3 and 30 µg/m^3), and for road-NOx concentrations of 1-50 µg/m^3 at 1 µg/m^3 increments. This has been repeated with the NOx:NO_2 tool set to five different local authorities within the Heathrow NWR/ENR Study Area and five different local authorities in within the Gatwick 2R Study Area. These are:

Heathrow NWR/ENR	Gatwick 2R
Hillingdon	Crawley
Hounslow	Mid Sussex
Slough	Mole Valley
Spelthorne	Reigate & Banstead
Windsor & Maidenhead	Tandridge

The results of calculations are shown in Figure D.1 and Figure D.2. A randomly selected sample of the results is also presented in Table 1 and Table 2 to show the range in the values (compare values along rows and not down columns).

The results show very little variance in total NO_2 concentrations with variations in local authority setting within the NOx:NO_2 calculator tool (typically <0.2µg/m^3).

For the purposes of results processing Hillingdon has been selected as the local authority setting for all receptors in the Heathrow NWR and ENR Study Areas, and Crawley for all receptors in the Gatwick 2R study area.

Figure D.1: Comparison of Defra's NOx:NO_2 calculator outputs for a range of road-NOx contributions and background NO_2 concentrations in five local authorities around Heathrow Airport (note that all data points overlap)

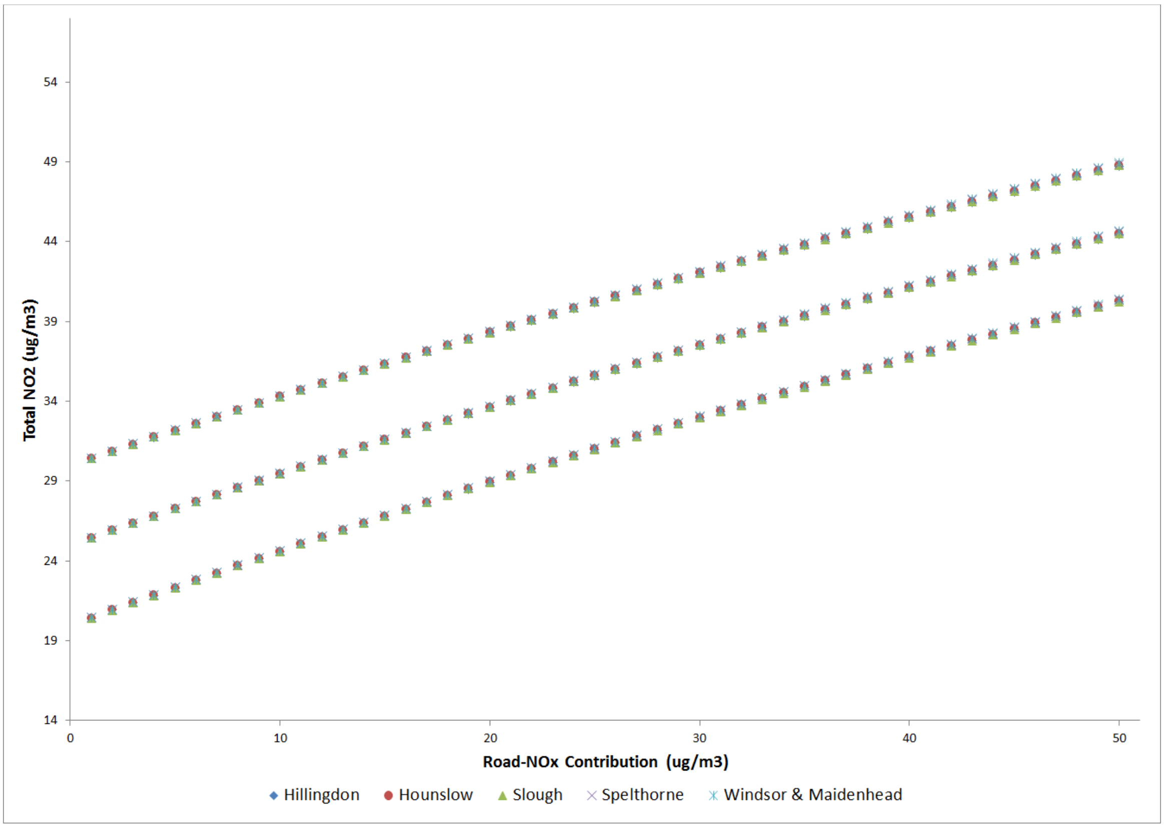

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Table D2 – Data Sample from the NOx:NO_2 Calculator Sensitivity Test for LHR (µg/m^3)

Background NO_2	Road-NOx Contribution	Final Total NO_2				
		Hillingdon	Hounslow	Slough	Spelthorne	Windsor & Maidenhead
20	5	22.32	22.32	22.32	22.36	22.36
20	20	28.93	28.95	28.94	28.99	29.01
25	7	28.16	28.17	28.16	28.17	28.18
25	43	42.13	42.18	42.17	42.25	42.31
30	18	37.52	37.54	37.53	37.56	37.58
30	50	48.72	48.78	48.78	48.87	48.95

Figure D.2: Comparison of Defra's NOx:NO_2 calculator outputs for a range of road-NOx contributions and background NO_2 concentrations in five local authorities around London Gatwick Airport (note that all data points overlap)

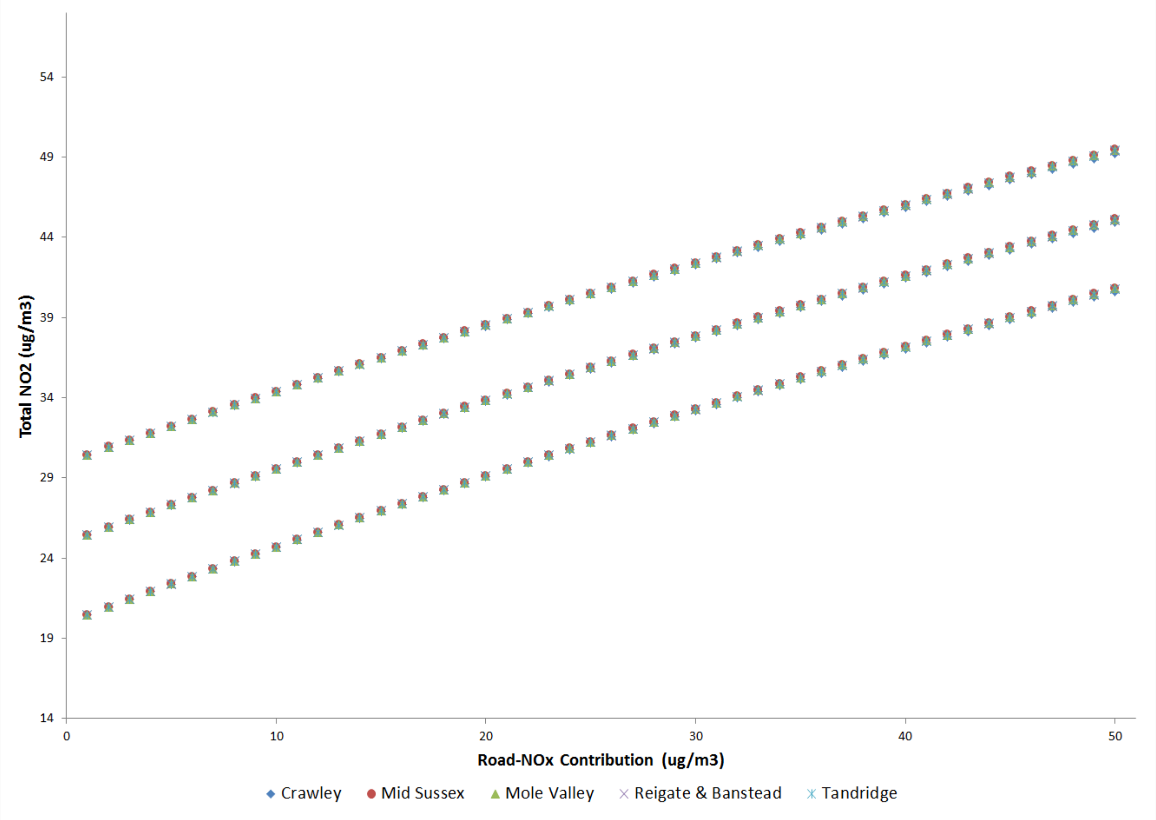


Table D3 – Data Sample from the NOx:NO_2 Calculator Sensitivity Test for LGW (µg/m^3)

Background NO_2	Road-NOx Contribution	Final Total NO_2				
		Crawley	Mid Sussex	Mole Valley	Reigate & Banstead	Tandridge
20	5	22.39	22.40	22.40	22.39	22.40
20	20	29.09	29.15	29.15	29.14	29.14
25	7	28.21	28.23	28.23	28.23	28.23
25	43	42.52	42.71	42.69	42.65	42.67
30	18	37.67	37.74	37.74	37.72	37.73
30	50	49.23	49.47	49.45	49.39	49.42

Appendix E: Monitoring Data

Monitoring data have been collated across the Study Areas, primarily for the purpose of model verification, i.e. to assess the performance of the model in predicting pollutant concentrations at sensitive receptor locations. This has been achieved by comparing modelled and measured concentrations at a number of representative sites.

The monitoring sites have been identified to include locations that are influenced by airport source emissions (i.e. sites that are within close proximity to the airport boundaries), and sites that are influenced by road traffic emissions across the road network affected by airport-related surface access movements.

The verification studies have been carried out for the Baseline Year of 2009 (the year for which the Baseline emissions inventories have been compiled). Monitoring data over the period 2009 to 2014 are provided for completeness, and to provide context for current baseline conditions across the Study Areas.

The assessment has been based on data from continuous monitoring sites. The local authorities within the Study Areas operate large networks of passive NO_2 samplers. These provide valuable information of the spatial distribution of concentrations that could not be achieved through the use of automatic monitoring stations, but the data are of lower precision, and they do not provide information on NOx concentrations (which plays an important role in the verification process). For these reasons, the verification has been founded on the automatic sites.

All of the automatic monitoring stations are operated to a high standard of quality assurance/quality control checks, and are part of the Automatic Urban and Rural Network or the London Air Quality Network, or fall within the Calibration Club operated by Ricardo-AEA.

All data have been reported, but where data capture is below 90% in 2009, the site has been excluded for the model verification purposes.

E1. Gatwick 2R Study Area

The automatic monitoring sites considered in the Gatwick 2R Study Area are set out in Table E1. The monitoring data over the period 2009 to 2014 are then set out in Tables E2 to E4.

Table E1: Monitoring Site Information

Site ID	Monitoring Site	Grid Ref	Site Type	Data Source
LGW3	Gatwick LGW3	528627, 140809	Airport	www.crawley.gov.uk
CR1	Gatwick East CR1	529411, 141493	Urban Background	www.sussex-air.net
RG1	Horley RG1	528207, 142331	Suburban	www.sussex-air.net
RG2	Horley South RG2	528555, 141854	Suburban	www.sussex-air.net
RG3	Poles Lane RG3	526422, 139639	Rural	www.sussex-air.net

Table E2: Annual Mean NOx Concentrations, µg/m^3 (2009-2014)

Monitoring Site	Year					
	2009	2010	2011	2012	2013	2014
Gatwick LGW3	59.2	73.7	-	-	-	-
Gatwick East CR1	54.2	67.1	42.6	52.0	51.3	54.3
Horley RG1	42.3	45.9	31.6	38.3	34.3	34.3
Horley South RG2	55.2	52.4	47.3	53.3	46.5	49.2
Poles Lane RG3	25.6	28.0	25.0	41.5	26.8	27.9

Shaded cells indicate data capture <90%

Table E3: Annual Mean NO_2 Concentrations, µg/m^3 (2009-2014)

Monitoring Site	Year					
	2009	2010	2011	2012	2013	2014
Gatwick LGW3	34.3	36.8	32.3	33.4	32	-
Gatwick East CR1	28.6	38.2	25.8	27.7	30.8	41.1
Horley RG1	25.4	28.8	21.0	22.6	21.8	21.8
Horley South RG2	31.4	31.3	28.8	31.2	28.5	28.5
Poles Lane RG3	18.6	20.5	17.8	23.2	19.4	17.5

Shaded cells indicate data capture <90%

Table E4: Annual Mean PM_{10} Concentrations, µg/m^3 (2009-2014)

Monitoring Site	Year					
	2009	2010	2011	2012	2013	2014
Gatwick LGW3	20.9	21.3	23.0	-	-	-
Gatwick East CR1	-	-	-	-	-	-
Horley RG1	18.8	19.5	21.7	20.1	20.4	18.7
Horley South RG2	-	-	-	-	-	-
Poles Lane RG3	-	-	-	-	-	-

Shaded cells indicate data capture <90%

E2. Monitoring Data – Heathrow NWR and ENR Study Areas

The automatic monitoring sites considered in the Heathrow NWR and ENR Study Areas are set out in Table E5. The monitoring data over the period 2009 to 2014 are then set out in Tables E6 to E9.

Table E5: Automatic Monitoring Site Information

Site ID	Monitoring Site	Grid Ref	Site Type	Data Source
LH2	Heathrow LHR2	508392, 176743	Airport	www.heathrowairwatch.org.uk
SIPS	Hillingdon Sipson	507328, 177289	Urban Background	www.heathrowairwatch.org.uk
HGG	Heathrow Green Gates	505184, 176922	Urban Background	www.heathrowairwatch.org.uk
H10	London Hillingdon	506945, 178609	Urban Background	www.heathrowairwatch.org.uk
HIL1	Hillingdon Harmondsworth	505563, 177660	Urban Background	www.airqualityengland.co.uk
HOA	Heathrow Oaks Road	505734, 174493	Urban Background	www.heathrowairwatch.org.uk
HS7	Hounslow Hatton Cross	509334, 174999	Roadside	www.heathrowairwatch.org.uk
LH0	London Harlington	508295, 177799	Airport	www.heathrowairwatch.org.uk
HI3	Hillingdon 3 – Oxford Avenue	509554, 176977	Urban Centre	www.heathrowairwatch.org.uk
SLH8	Slough Lakeside 2	503569, 177385	Urban Background	http://sloughair.aeat.com
SLH6	Slough Colnbrook (Pippins)	503536, 176825	Urban Background	http://sloughair.aeat.com

Table E6: Annual Mean NOx Concentrations, µg/m^3 (2009-2014)

Monitoring Site	Year					
	2009	2010	2011	2012	2013	2014
Heathrow LHR2	109.6	121.9	107.4	104.9	105.7	102.2
Hillingdon Sipson	68.8	65.3	62.2	61.6	62.6	61.5
Heathrow Green Gates	67.0	71.1	58.1	63.2	63.4	63.6
London Hillingdon	116.3	114.5	117.5	118.3	107.5	121.6
Hillingdon Harmondsworth	60.9	55.8	53.1	57.2	55.2	53.1
Heathrow Oaks Road	55.9	63.9	51.2	51.8	58.1	57.9
Hounslow Hatton Cross	65.9	71.4	61.5	61.6	70.1	52.5
London Harlington	68.1	62.0	56.0	61.6	65.7	63.3
Hillingdon 3 – Oxford Avenue	82.1	80.8	83.4	78.4	75.6	66.9
Slough Lakeside 2	65.3	75.0	65.4	58.9	59.8	62.7
Slough Colnbrook (Pippins)	57.8	54.6	53.6	53.6	51.1	54.1

Shaded cells indicate data capture <90%

Table E7: Annual Mean NO_2 Concentrations µg/m^3 (2009-2014)

Monitoring Site	Year					
	2009	2010	2011	2012	2013	2014
Heathrow LHR2	49.8	49.6	50.4	47.1	47.9	46.4
Hillingdon Sipson	39.0	38.3	37.0	35.3	36.5	36.6
Heathrow Green Gates	37.5	41.2	34.8	33.5	33.5	35.2
London Hillingdon	54.0	53.6	55.2	57.2	52.8	57.4
Hillingdon Harmondsworth	33.4	31.0	31.5	31.8	30.3	29.6
Heathrow Oaks Road	33.4	37.2	30.5	30.4	34.2	32.6
Hounslow Hatton Cross	35.1	38.4	34.5	31.7	37.2	31.1
London Harlington	36.3	34.5	33.7	34.6	37.5	36.5
Hillingdon 3 – Oxford Avenue	43.8	41.8	44.4	44.1	39.2	35.1
Slough Lakeside 2	35.0	38.8	34.8	31.2	32.5	33.9
Slough Colnbrook (Pippins)	29.3	29.5	30.1	29.5	29.6	30.7

Shaded cells indicate data capture <90%

Table E8: Annual Mean PM_{10} Concentrations µg/m^3 (2009-2014)

Monitoring Site	Year					
	2009	2010	2011	2012	2013	2014
Heathrow LHR2	25.2	24.4	25.0	24.3	26.1	18.7
Heathrow Green Gates	17.6	18.2	20.4	19.4	20.7	17.0
Hillingdon Harmondsworth	27.7	20.1	21.3	19.6	22.0	20.9
Heathrow Oaks Road	21.2	20.7	24.1	20.1	21.6	18.2
Hounslow Hatton Cross	18.5	16.3	16.5	19.6	20.9	20.9
London Harlington	16.2	14.4	19.3	17.7	19.9	19.7
Hillingdon 3 – Oxford Avenue	20.1	21.5	26.9	-	-	-
Slough Lakeside 2	27.8	22.0	30.0	23.7	24.6	19.4
Slough Colnbrook (Pippins)	15.8	14.3	14.8	15.1	14.5	14.7

Shaded cells indicate data capture <90%

Table E9: Annual Mean $PM_{2.5}$ Concentrations µg/m^3 (2009-2014)

Monitoring Site	Year					
	2009	2010	2011	2012	2013	2014
Heathrow LHR2	-	11.3	11.4	10.6	10.9	9.9
Heathrow Green Gates	10.0	9.9	10.2	9.9	10.1	10.0
Hillingdon Harmondsworth	9.7	7.3	13.0	5.3	8.2	6.9
Heathrow Oaks Road	10.3	10.6	10.4	9.7	10.0	10.3
London Harlington	10.3	13.5	15.7	13.4	13.8	14.0

Shaded cells indicate data capture <90%

Appendix F: Model Verification

The process of model verification refers to a comparison between the predicted and measured concentrations. The verification allows model performance to be evaluated. It also allows adjustments to model outputs to improve overall model performance, where consistent under or over-estimation of pollutant concentrations are identified.

The model verification undertaken in this assessment has been carried out in four steps:

Step 1: verification of background pollutant concentrations;
Step 2: verification of airport model outputs;
Step 3: verification of road traffic model outputs; and
Step 4: final model comparison study.

The model verification has been carried out using the 2009 baseline model outputs and corresponding 2009 measured pollutant concentrations.

Step 1: Verification of background pollutant concentrations

The verification and validation of the Defra mapped background pollutant concentrations is described in detail in Appendix A of this report. The conclusions of the verification of background pollutant concentrations were that Defra mapped background NOx and NO_2 concentrations obtained from 2011 maps were comparable to 2009 measured background pollutant concentrations at background monitoring sites within the wider study area and as such, no adjustment to Defra mapped background concentrations is required.

Step 2: Verification of airport model outputs

The verification of the Heathrow and Gatwick 2009 baseline dispersion model outputs has been undertaken by comparing modelled concentrations of NOx to measured concentrations at the Heathrow LHR2 and Gatwick LGW3 monitoring sites. These sites are located at sensitive locations on each airport airfield (LHR2 is just to the north of Heathrow runway 27R, around 135 m from the edge of the runway, and LGW3 just to the east of the Gatwick 26L runway, around 270 m from the end of the runway).

The predicted (modelled) contributions of NOx at these monitors have been compared to the measured concentrations in 2009 as well as the predicted airport contributions published in the 08/09 Heathrow emissions inventory report and the Gatwick 2010 emissions inventory report. A summary of this comparison is presented in Table F1. It should be noted that each monitor will receive a contribution from road traffic which is not included in the table.

Table F1: Comparison Between 2009 Predicted and Measured Annual Mean Airport NOx Contributions at LHR2 and LGW3 (µg/m^3)

Site ID	NOx Comparison				
	Measured NOx (2009)	LHR/LGW Airport Model NOx [a]	2009 Baseline Model Results		
			Airport Model NOx	Background NOx	Total Airport + Background NOx
LH2	109.6	33.0	31.6	49.9	81.5
LGW3	59.2	42.8[b]	25.9	35.7	61.6

[a] LHR and LGW airport model NOx contributions obtained from the 08/09 Heathrow Airport emissions inventory and 2010 Gatwick Airport emissions inventory reports.
[b] Predicted concentration is for 2010 not 2009, but is used for comparison.

The data presented in Table F1 demonstrate that, for Heathrow (LHR2), the airport model is not likely to be significantly over-predicting the airport-related concentrations of NOx, because total predicted 2009 airport + background concentrations are less than the measured 2009 concentration (which allows for some additional contribution from local road traffic emissions), and the modelled airport contribution align well with that presented in the 08/09 Heathrow Airport emissions inventory report. It is judged that the performance of the Heathrow airport dispersion model is good, and no adjustment of airport model NOx concentrations is required.

For Gatwick (LGW3), the modelled airport + background NOx concentrations slightly exceed the measured 2009 NOx concentration. The LGW3 monitor is likely to be influenced by some additional local road traffic emissions, principally from the airport perimeter road and the A23. The predicted 2009 airport model NOx contribution at LGW3 is, however, much lower than that predicted in the 2010 Gatwick Airport emissions inventory report. Based on this evidence, it is acknowledged that the airport model performance is slightly uncertain, but there is no strong case for a downward adjustment to the model results. It is judged that the performance of the Gatwick airport dispersion model is adequate and no adjustment of airport model NOx concentrations is required.

Step 3: Verification of road traffic model outputs

In order to verify the road traffic model, the modelled road NOx contributions at selected automatic roadside monitoring sites within the Heathrow Study Area have been compared to measured NOx concentrations at these sites. There are no automatic monitoring sites close to roads within the Gatwick Study Area and therefore the road model verification is based on monitoring sites at Heathrow only. There are, however, 5 non-roadside automatic monitoring sites within the Gatwick Study Area which have been included in the final model comparison study in Step 4.

Table F2 provides a comparison of the modelled and measured road-NOx concentrations at 7 monitoring sites within the Heathrow Study Area. In order to calculate the measured road-NOx concentrations, the modelled airport-NOx and background NOx contributions at each monitoring site have been subtracted from the measured totals. Table F2 also presents the calculation of the model road-NOx adjustment factor.

Table F2: Calculation of the Model Road-NOx Adjustment Factor

Site ID	Measured NOx	Modelled NOx Concentrations			Measured Road-NOx [a]	Road-NOx Ratio [b]	Model Road-NOx Adjustment Factor [c]
		Airport	Background	Road			
HI0	116.3	3.6	41.9	38.3	70.7	1.85	**1.808**
HI3	82.1	14.5	41.4	10.9	26.2	2.41	
LH2	109.6	31.6	49.9	9.3	28.1	3.04	
LH0	68.1	7.5	41.5	8.2	19.1	2.33	
HGG	67.0	6.1	43.8	13.2	17.0	1.29	
SLH8	65.3	2.5	42.7	12.7	20.1	1.58	
SLH6	57.8	2.7	42.0	13.1	13.0	1.00	

[a] Measured road-NOx is calculated by subtracting modelled airport NOx and background NOx from the total measured road-NOx concentration (Measured Road-NOx = Measured NOx – (Airport + Background NOx). Values based on unrounded numbers.

[b] The road-NOx ratio is the ratio between the measured road-NOx and the modelled road-NOx contribution.

[c] The model road-NOx adjustment factor is calculated from the best-fit linear trend line of a graph of measured road-NOx vs model road-NOx, forced through zero. It is not an average of the road-NOx ratios.

The verification of model road-NOx concentrations has identified an underestimate of road-NOx contributions at roadside monitors in the Heathrow Study Area. Under-prediction of the road traffic NOx component in dispersion models is commonly experienced and therefore this is not unexpected. The calculated model road-NOx adjustment factor of 1.808 has been applied to all 2030 modelled road-NOx concentrations for all 2030 model scenarios, including at Gatwick. Although the verification of model road-NOx concentrations was based on monitors at Heathrow only, it is important to maintain a consistent approach to modelling of all schemes.

Step 4: Final model comparison study

A final model comparison study for NOx and NO_2 has been undertaken to compare the final predicted concentrations (airport contribution + adjusted road-NOx contribution + background contribution) to total measured NOx and NO_2 concentrations at a number of local automatic monitoring sites within the Heathrow and Gatwick Study Areas. The final model comparison study includes the calculation of a final NO_2 adjustment factor, which is a factor applied to the modelled total NO_2 concentrations to improve their overall correlation with the measured NO_2 concentrations and improve the overall accuracy of the model results.

The final 2009 modelled NOx comparison against measured concentrations is presented in Table F3. The calculation of the final NO_2 adjustment factor, and comparison of final modelled NO_2 concentrations to measured NO_2 concentrations is presented in Table F4. A graph showing the final modelled NO_2 concentrations compared to the 2009 measured NO_2 concentrations is presented in Figure F1.

Table F3: Comparison Between 2009 Predicted and Measured Annual Mean NOx Concentrations (µg/m^3)

Site ID	Site	Modelled Annual Mean NOx Concentrations				Measured NOx
		Airport Sources	Road Sources[a]	Background	Total	
HI0	London Hillingdon	3.6	69.3	41.9	114.8	116.3
HI3	Hillingdon Oxford Avenue	14.5	19.6	41.4	75.6	82.1
LH2	Heathrow LHR2	31.6	16.7	49.9	98.3	109.6
HS7	Hounslow Hatton Cross	16.6	17.4	42.4	76.5	65.9
LH0	London Harlington	7.5	14.8	41.5	63.8	68.1
HGG	Heathrow Green Gates	6.1	23.8	43.8	73.8	67.0
SLH8	Slough Lakeside 2	2.5	23.0	42.7	68.2	65.3
SLH6	Slough Colnbrook (Pippins)	2.7	23.6	42.0	68.4	57.8

Site ID	Site	Modelled Annual Mean NOx Concentrations				Measured NOx
		Airport Sources	Road Sources[a]	Background	Total	
SIPS	Hillingdon Sipson	9.4	15.4	44.2	69.0	68.8
HOA	Heathrow Oaks Road	10.3	12.7	35.5	58.5	55.9
HIL1	Hillingdon Harmondsworth	4.1	20.0	43.3	67.3	60.9
RG3	Poles Lane	2.6	6.4	22.5	31.4	25.6
RG2	Horley South	14.8	22.3	36.4	73.5	55.2
RG1	Horley	9.6	14.5	31.6	55.6	42.3
LGW 3	Gatwick LGW3	25.9	24.3	35.7	85.9	59.2
CA2	Gatwick East	5.8	29.0	29.1	63.8	54.2

N.B. White cells represent sites within the Heathrow Study Area; shaded cells represent sites within the Gatwick Study Area.

[a] Road NOx concentrations are post-model adjustment (factor = 1.808)

Table F4: Calculation of Final Model NO_2 Adjustment Factor and Comparison Between 2009 Predicted and Measured Annual Mean NO_2 Concentrations (µg/m^3)

Site ID	Airport + Road NOx [a]	Background NO_2	fNO_2 [b]	Total Modelled NO_2	Final Model NO_2 Adjustment Factor [c]	Final Modelled NO_2	Measured NO_2
HI0	72.9	26.6	0.181	52.7	0.931	49.1	54.0
HI3	34.2	26.3	0.175	40.1		37.3	43.8
LH2	48.4	30.2	0.171	48.0		44.7	49.8
HS7	34.0	26.6	0.174	40.3		37.5	35.1
LH0	22.3	26.4	0.176	35.8		33.3	36.3
HGG	29.9	27.5	0.179	39.7		36.9	37.5
SLH8	25.5	26.9	0.180	37.5		34.9	35.0
SLH6	26.4	26.5	0.180	37.5		34.9	29.3
SIPS	24.8	27.5	0.176	37.8		35.2	39.0
HOA	23.0	23.0	0.174	33.1		30.8	33.4
HIL1	24.1	27.4	0.179	37.4		34.8	33.4
RG3	9.0	16.3	0.177	20.6		19.2	18.6
RG2	37.1	24.1	0.175	39.3		36.6	31.4
RG1	24.0	21.6	0.175	32.1		29.9	25.4
LGW 3	50.2	23.7	0.173	43.4		40.4	34.3
CR1	34.7	20.1	0.179	35.0		32.6	28.6

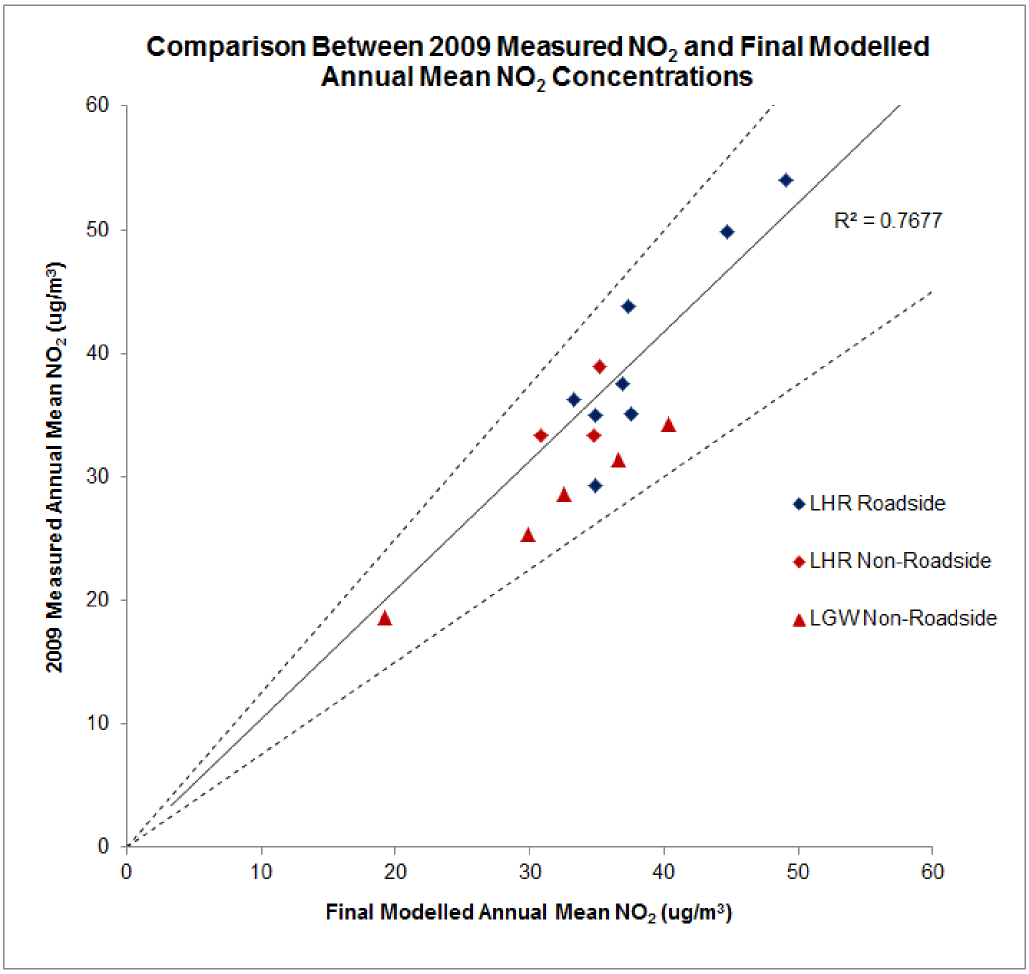
N.B. White cells represent sites within the Heathrow Study Area; shaded cells represent sites within the Gatwick Study Area.

[a] Road NOx concentrations are post-model adjustment (factor = 1.808)

[b] fNO2 calculated using the methodology described in Appendix D.

[c] The final model NO_2 adjustment factor is calculated from the best-fit linear trend line of a graph of measured NO_2 vs Total Modelled NO_2, forced through zero.

Figure F1: Comparison Between 2009 Predicted and Measured Annual Mean NO_2 Concentrations (µg/m³)



In order to assess the overall performance of the modelling in terms of NO_2, it is typical to calculate the Root Mean Square Error (RMSE), correlation coefficient and fractional bias of the data and compare them to ideal values. The statistics for the data presented in Figure F1 are set out in Table E5.

Table F5: Summary of Modelled NO_2 Statistics

Sites	Final NO_2 Adjustment? [a]	Root Mean Square Error	Correlation Coefficient	Fractional Bias
Roadside Sites	Prior to application of final model NO_2 adjustment	3.71	0.92	-0.02
	After application of final model NO_2 adjustment	4.16	0.90	0.04
All Sites	Prior to application of final model NO_2 adjustment	4.84	0.89	-0.08
	After application of final model NO_2 adjustment	4.04	0.89	-0.01
Ideal Values [b]		**<4**	**1**	**0**

N.B. Values in shaded cells represent the final adjusted model NO_2 comparison.

[a] Final model NO_2 adjustment factor = 0.931 as shown in Table E4.

[b] Ideally, values should be within these criteria as described in Defra technical guidance TG(09).

Overall, the data presented in Tables F3 and F4 and Figure F1 show a good correlation between final modelled NOx and NO_2 concentrations and measured NOx and NO_2 concentrations in the Heathrow and Gatwick Study Areas. The RMSE, correlation coefficient and fractional bias of the final modelled NO_2 concentrations are close to ideal values.

Verification of PM_{10}

A comparison of the 2009 measured annual mean PM_{10} concentrations and modelled annual mean PM_{10} concentrations at a number of automatic monitoring sites in the Heathrow and Gatwick Study Areas is set out in Table F6 and shown in Figure F2.

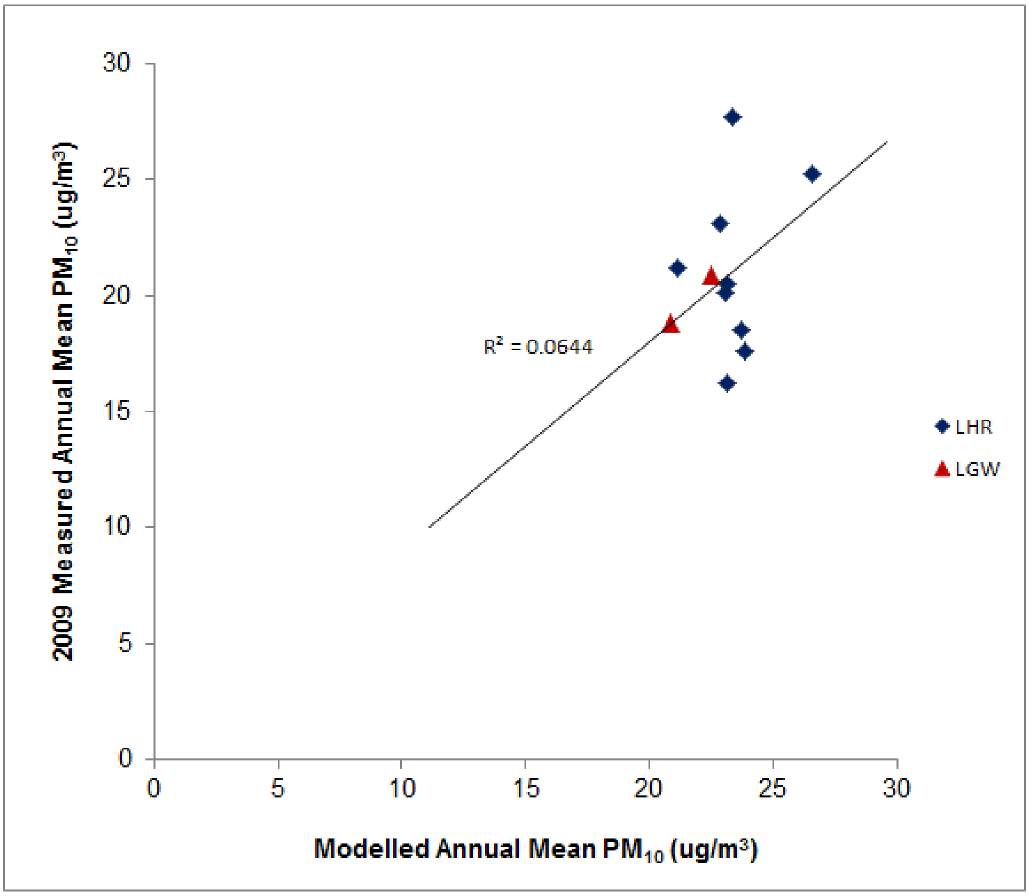
Table F6: Comparison Between 2009 Predicted and Measured Annual Mean NOx Concentrations (µg/m^3)

Site ID	Site	Modelled Annual Mean PM_{10} Concentrations				Measured PM_{10}
		Airport Sources	Road Sources	Background	Total [a]	
HI3	Hillingdon Oxford Avenue	0.7	0.9	21.5	23.1	20.1
LH2	Heathrow LHR2	2.6	0.7	23.3	26.6	25.2
HS7	Hounslow Hatton Cross	0.9	0.8	22.0	23.7	18.5
LH0	London Harlington	0.6	0.6	22.0	23.1	16.2
HGG	Heathrow Green Gates	0.4	0.8	22.6	23.9	17.6
SLH8	Slough Lakeside 2	0.1	0.8	21.9	22.9	23.1
SLH6	Slough Colnbrook (Pippins)	0.2	0.7	22.3	23.2	20.5
HOA	Heathrow Oaks Road	0.6	0.5	20.1	21.1	21.2
HIL1	Hillingdon Harmondsworth	0.4	0.7	22.3	23.4	27.7
RG1	Horley	0.5	0.9	19.5	20.9	18.8
LGW3	Gatwick LGW3	0.6	1.5	20.3	22.5	20.9

N.B. White cells represent sites within the Heathrow Study Area; shaded cells represent sites within the Gatwick Study Area.

[a] Calculated using unrounded modelled airport, road and background contributions.

Figure F2: Comparison Between 2009 Predicted and Measured Annual Mean PM_{10} Concentrations (µg/m^3)



The model performance is poor for PM_{10}, but there is no clear overestimation or underestimation of PM_{10} concentrations and therefore no model adjustment has been applied. The poor correlation is driven by high background contributions and low airport and road-PM_{10} contributions at the monitoring sites used in the verification, as shown in Table F6. The statistics for the graph presented in Figure E2 are as follows:

RMSE = 3.78
Correlation Coefficient = 0.33
Fractional Bias = -0.1

Appendix G: Monetisation Methodology

Monetisation of damage costs has been undertaken on a mass emissions basis, following the Air Quality Appraisal – Damage Cost methodology published by Defra and the Interdepartmental Group on Costs and Benefits (IGCB), Air Quality Subject Group.

A Partial Impact Pathway approach analysis has also been undertaken to quantify the health impacts of changes in concentrations of various pollutants.

G1. Airport Emissions

Total airport emissions have been estimated for 2030, 2040 and 2050; the following total emissions scenario tests have been run:

- Gatwick 2R: Low Cost is King Carbon Traded (LCIK);
- Heathrow NWR and ENR: Global Growth Carbon Traded.

For each scenario, predicted aircraft fleet mix data were provided by LeighFisher based on the Airport Commission Demand Forecasts. AC Fleet Mix data were assigned to the 2030 Aircraft Model Category (MCAT) groups and linked to data describing times in mode (derived from promoter submissions) and emission factors (derived from ICAO), together with assumptions regarding future airframe and engine types. Together with assumptions regarding ground support equipment and fixed asset combustion, this resulted in airport emissions inventories. The inventories were used to estimate total emissions for each scenario.

G2 Surface Access Emissions

Surface access emissions have been estimated from dynamic traffic models and the application of DfT Emissions Factor Toolkit for 2030, resulting in mass emissions across the wider network for both Do Minimum and With Scheme Options. The forecast in surface access emissions beyond 2030 were estimated based on predicted annual passenger numbers. The passenger numbers (in mppa) for each scenario have been provided by LeighFisher. The ratio between the mppa for each test scenario and the mppa for the 2030 Do-Minimum scenario (LCIK for Gatwick 2R and GG for Heathrow NWR and ENR) has been applied to the mppa-weighted incremental change in NOx and PM10 between the 2030 With Scheme and Do-Minimum scenarios (LCIK for Gatwick 2R and GG for Heathrow NWR and ENR). This provides an mppa-weighted incremental change for each test scenario, which is applied to the Do-Minimum NOx and PM10 total emissions to estimate a With Scheme total emissions value for each scenario.

An example of the calculation for NOx is described below:

1) $\mathrm{NOx}_{(IC)} = \mathrm{NOx}_{(DS)} - \mathrm{NOx}_{(DM)}$

2) $\mathrm{NOx{:}mppa}_{(DM:DS)} = \mathrm{NOx}_{(IC)} / (\mathrm{mppa}_{(DS)} / \mathrm{mppa}_{(DM)})$

3) $\mathrm{NOx}_{(Scenario\text{-}A)} = \mathrm{NOx}_{(DM)} + (\mathrm{NOx{:}mppa}_{(DM:DS)} \times (\mathrm{mppa}_{(Scenario\text{-}A)} / \mathrm{mppa}_{(DM)}))$

Where:

$\mathrm{NOx}_{(IC)}$ = Incremental change in NOx between 2030 Do Minimum and 2030 Do Something (LCIK/GG);

NOx(DS) = Total NOx emissions in 2030 Do Something scenario (LCIK/GG);

NOx(DM) = Total NOx emissions in 2030 Do Minimum scenario (LCIK/GG);

NOx:mppa$_{(DM:DS)}$ = Ratio between incremental change in NOx and incremental change in mppa between the 2030 Do Minimum and Do Something scenarios (LCIK/GG);

mppa$_{(DS)}$ = Million passengers per annum in the 2030 Do Something scenario (LCIK/GG);

mppa$_{(DM)}$ = Million passengers per annum in the 2030 Do Minimum scenario (LCIK/GG);

NOx$_{(Scenario\text{-}A)}$ = Total NOx emissions from surface access in the test scenario (2030, 2040, or 2050 - LKIC/GG/)

mppa$_{(Scenario\text{-}A)}$ = Million passengers per annum in the test scenario (2030, 2040, or 2050 - LKIC/GG/).

The total emissions from airports and surface access have then been combined for each test scenario to provide totals for monetisation.

G3 Damage costs

Defra's damage cost estimates for a tonne of NOx provides a fixed unit value across all areas of the UK and remain the same for all emissions sources. The central estimate for a tonne of NOx published by Defra has been used to calculate the damage costs, with sensitivity provided by using Defra's central-low and central-high figures. Defra's figures are published in 2010 prices and have been uplifted to 2014 prices using a Gross Domestic Product (GDP) deflator.

Within Defra's guidance for the economic analysis of impacts on air quality, the cost placed on a tonne of PM$_{10}$ is dependent on where the pollutant is being emitted within the UK and the source of the pollutant. The central estimate for a tonne of PM$_{10}$ published by Defra has been used to calculate the damage costs, with sensitivity provided by using Defra's central-low and central-high figures. Defra's figures are published in 2010 prices and have been uplifted to 2014 prices using a GDP deflator.

Damage costs for PM (Transport) are at a UK-wide level, with disaggregated damage costs split by National Transport Model area:

- For the Heathrow NWR and ENR Schemes, outer London PM Transport values were used (as the Schemes lie within the London Borough of Hillingdon);
- For the Gatwick 2R Scheme, medium urban PM Transport values were used (as the Scheme is close to Crawley); and
- For surface access, PM Transport average values were used as people would be travelling from all over the UK to each Scheme.

Some of the Green Book damage costs figures are considered by some commentators to be low in comparison to other sources. Values have also been published by the European Environment Agency (EEA) and the Organisation for Economic Cooperation and Development (OECD). The EEA[28] has produced a report which provides some detail on costing health effects and provides damage costs per tonne figures for a number of pollutants, across Europe. The EEA uses

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[28] http://www.eea.europa.eu/publications/costs-of-air-pollution-2008-2012

two contrasting but complementary approaches for valuing health damage – the value of a life year (VOLY) and a (higher) value of statistical life (VSL) – which both provide higher values than most of Defra's damage cost estimates. These are provided for NOx and PM_{10} only and, as they have been calculated to be applicable across Europe, the values do not vary by the area within the UK or source of pollutant.

The EEA figures were published in Euros, in 2005 prices. These have been converted to Sterling using the Bank of England's Euro-Sterling Spot Exchange rate and uplifted to 2014 prices using a GDP deflator.

Discounting

There is significant evidence to show that people prefer to consume goods and services now, rather than in the future i.e. even after adjusting for inflation, people would generally prefer to have £1 now, rather than £1 in 60 years' time. This phenomenon is known as "social time preference" and needs to be taken account of when costs and benefits are presented in monetised terms.

This adjustment to reflect people's preference for current consumption over future consumption is made by discounting. A "discount rate" represents the extent to which people prefer current over future consumption and it is applied to convert future costs and benefits to their "present value". This is the equivalent value of a cost or benefit in the future occurring today. The present value of a stream of monetary values can be calculated by discounting the values and then summing the stream of discount values.

The discount rate is 3.5% for the first 30 years and 3% for the remaining 30 years of the 60-year appraisal period.

Discounting is separate from the process of adjusting for inflation, which accounts for the reduction in what £1 can purchase over time.

Table G1 below shows the range of values which have been used to produce damage costs over the 60-year appraisal period.

Table G1: Damage Cost Values (per tonne)

2014 prices	Central Estimate	Central – Low	Central - High	EEA – Low VOLY	EEA – High VSL
NO_x	£1,037	£808	£1,178	£3,754	£10,166
PM Transport Outer London	£161,737	£126,633	£183,793		
PM Transport Urban Medium	£60,059	£47,023	£68,249		
PM Transport Average	£52,682	£41,248	£59,866		
PM_{10}				£19,531	£56,665

G4 Partial Impact Pathway

The Green Book guidance states that if damage costs are greater than £50m then the Impact Pathway approach should be considered. The Impact Pathway approach would include the following steps:

- Set the appropriate baseline;
- Quantify the changes in air quality;
- Model how pollutants are dispersed;
- Estimate health (both morbidity and mortality) and non-health impacts (building soiling and the impact on materials); and
- Monetisation of impacts using values derived from a contingent valuation study

The damage cost analysis (Section 4.4.5, Section 5.4.5 and Section 6.4.5) identified air quality related damage costs greater than £50m for all Schemes, but it has not been possible at this stage to undertake a comprehensive Impact Pathway Assessment due to the level of detail available on future pollution concentrations and the difficulty predicting mortality rates of the relevant populations from 2030 to 2050 and beyond.

The monetisation of health impacts (discrete from those that dominate the damage cost assessment) was, therefore, limited to a 2030 snapshot of morbidity impacts through the increase in respiratory and cardiovascular related hospital admissions. This partial assessment of one component of health costs, as estimated from concentration changes on a given population, supports the broader conclusions drawn from the damage cost assessment.

The concentration of NO_2 and PM_{10} was calculated for 2030 both for Do-Minimum and With Scheme. It is the health impact of these changes in concentration that has been monetised, using the concentration-response coefficients provided in Defra's guidance[29] which were applied to a spatial distribution of the projected 2030 population derived from CACI forecasts.

These concentration-response coefficients capture the change in the number of hospital admissions from the baseline as a result of the change in concentrations of various pollutants and can be used to quantify the effects of short term exposure.

The evidence used to calculate the coefficient for nitrogen dioxide is considered less robust than those for the other pollutants. It is therefore suggested that the quantification of the effects of nitrogen dioxide are included for sensitivity analysis only, and that it is not used for central estimates.

Following more detailed air quality analysis which is anticipated for any chosen scheme, a full Impact Pathway Assessment would be required and further discussion with Defra would be expected.

Table G2 shows the relevant concentration-response coefficients in the Defra guidance.

Table G2: Concentration-Response Coefficients

Pollutant	Health outcome	Concentration-response coefficient
PM_{10}	Respiratory hospital admissions Cardiovascular hospital admissions	+0.8% per 10µgm^{-3} (24 hour mean) +0.8% per 10µgm^{-3} (24 hour mean)

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[29] Impact pathway guidance for valuing changes in air quality. https://www.gov.uk/government/publications/air-quality-impact-pathway-guidance

Pollutant	Health outcome	Concentration-response coefficient
Nitrogen dioxide	Respiratory hospital admissions	+0.5% per 10µgm^{-3} (8 hour mean)

The World Health Organisation's Health Risks of Air Pollution in Europe (HRAPIE) project produced "Recommendations for concentration-response functions for cost-benefit analysis of particulate matter, ozone and nitrogen dioxide"[30]. These WHO concentration-response functions for NO_2, as set out in Table G3, are provided to show the range of potential health effects of NO_2 and have not been used in the Partial Impact Pathway analysis.

Table G3: WHO Concentration-Response Coefficients for NO_2

Pollutant	Health outcome	Concentration-response coefficient
Nitrogen dioxide	Respiratory hospital admissions Respiratory hospital admissions	+0.15% per 10µgm^{-3} (1 hour mean) +1.80% per 10µgm^{-3} (24 hour mean)

Population projections from CACI and spatial distribution analysis were used to provide estimates of the population that would be affected by changes in air quality as a result of the three schemes in 2030.

A baseline number of hospital admissions around Heathrow and Gatwick airports for 2030 were calculated using hospital admissions data by specialty, published by the Health & Social Care Information Centre[31]. Cardiology and Respiratory Medicine hospital admissions data for the London and Surrey and Sussex NHS Local Area Trusts for 2013/2014 were assigned proportionally using the population within the three Scheme footprints, and population growth rates were applied to give an estimated baseline of hospital admissions in 2030.

The concentration-response coefficients were used to quantify the effects of the expected change in the annual mean concentrations of PM_{10} and nitrogen dioxide in 2030 in terms of additional hospital admissions.

These additional hospital admissions in 2030 were valued using the IGCB recommended health values provided in Defra's Impact Pathway guidance as set out in Table G4.

Table G4: IGCB Recommended Health Values

Health effect	Form of measurement valuations apply to	Central value (2012 prices)
Respiratory hospital admissions	Case of hospital admission, of average duration 8 days	£2,600 - £10,700

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[30] http://www.euro.who.int/__data/assets/pdf_file/0006/238956/Health-risks-of-air-pollution-in-Europe-HRAPIE-project,-Recommendations-for-concentrationresponse-functions-for-costbenefit-analysis-of-particulate-matter,-ozone-and-nitrogen-dioxide.pdf?ua=1

[31] http://www.hscic.gov.uk/searchcatalogue?productid=17192&q=title%3a%22Hospital+Episode+Statistics%3a+Admitted+patient+care%22&sort=Relevance&size=10&page=1#top

Health effect	**Form of measurement valuations apply to**	**Central value (2012 prices)**
Cardiovascular hospital admissions	Case of hospital admission, of average duration 9 days	£3,000 - £9,900

These values were uplifted to 2014 prices using a GDP deflator as set out in Table G5.

Table G5: 2014 Prices

£ million **2014 prices**	**Impact Pathway Central value**	**Impact Pathway Central value NO_2 sensitivity**
Gatwick 2R	£0.5m - £2.0m	£1.0m - £4.0m
Heathrow NWR	£1.4m - £5.2m	£2.8m - £10.8m
Heathrow ENR	£0.7m - £2.5m	£1.1m - £4.2m

Appendix H: Sensitivity Tests

H1. Meteorology and Climate Change

H1.1 Sensitivity to Meteorology

The air quality model (ADMS-Airport) calculates the dispersion and dilution of the pollutant emissions from the different sources that are included (e.g. aircraft operations, surface access traffic etc.) in order to predict ground-level pollutant concentrations. It does this by considering the source strengths, release conditions, and geographical locations of each individual source, in combination with meteorological data. In simple terms, the meteorological data describe hour-by-hour conditions across an entire year (8760 hours) in terms of wind speed and wind direction. This generates annual mean concentrations.

Modelling has been carried out using meteorological data collected in 2009. This year was chosen as it most closely aligns with the baseline concentration data for Heathrow and Gatwick. This year has then also been used to model 2030 scenarios (both Do Minimum and With Scheme) for all schemes. Probably the largest effect on concentrations that could arise from using different meteorological years would be from the variability in easterly and westerly winds, which will affect the runway use and hence have an effect on the distribution of emissions associated with taxiing, take-off and landing. The effect is unlikely to be significant beyond those receptors near to the runways, and will have a minimal impact on emissions.

Figures H1 to H20 show the variability in meteorological conditions at Heathrow and Gatwick over five years. The figures show that 2009 was not atypical of other years. Furthermore, Defra (in LAQM.TG(09)) notes that: “*In the case of annual mean concentrations, the choice of one [meteorological] year against another usually has only a small effect on modelled concentrations from local sources, and can largely be ignored.*” (Paragraph 6.14 of LAQM.TG(09)).

It is thus considered that the results would not have been significantly different had different data from different recent years been used.

Defra goes on to note that “*Meteorological conditions generally have a more significant impact on background concentrations than local concentrations, especially in the case of particulate matter (PM), where an increase in easterly winds bringing air from northern Europe can significantly increase the background*”.

As explained in Appendix A, background concentrations have been derived from Defra, and have not been calculated within the dispersion model. These represent future-year concentrations projected from conditions in 2011.

H1.2 Sensitivity to Climate Change

Predicting meteorological conditions in the future is difficult, particularly taking account of the effects of climate change. While indicative projections as to the effects of climate change exist (e.g. Table H1) they do not extend to the level of detail required for ADMS.

Even with respect to regional-level air quality, Defra’s Air Quality Expert Group (AQEG) notes that: “*It is difficult to use output from current climate models to investigate the effects of climate change on regional air quality. Improvements in the temporal resolution are needed to examine processes with daily variations, and* *seasonal changes in emissions from natural sources; shorter timescales (for example to 2020 – 2030) are also needed. Both surface temperature and soil dryness are keys to understanding the likely severity of future summer pollution episodes*".

Ground-level Ozone

An important effect of climate change may be to increase the formation of ground level ozone (O_3), which forms as a result of emissions of primary pollutants through processes that are influenced by sunlight and temperature. Heal et al. (2012), note that "*current indications are that until at least mid-century the net additional impact of climate change on the health burden associated with ground level* O_3 *will be smaller than the impact from changes in future anthropogenic emissions*."

NO_2 and PM

In terms of NO_2, there is an argument that increases in ground-level O_3 concentrations may increase the near-source formation of NO_2 from emitted NO. In practice, emissions from airport sources tend to be so well-mixed at the airport boundary that this will have little effect.

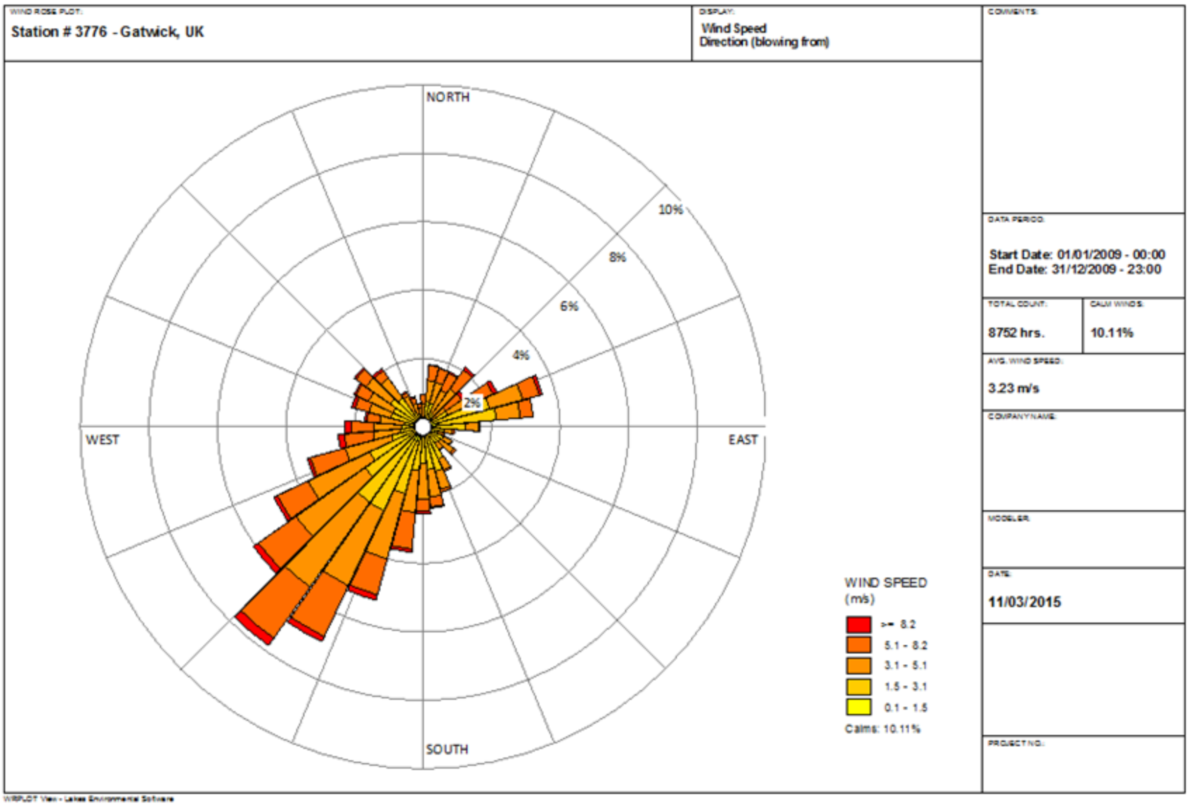
In terms of PM_{10}, if a future UK climate is drier than the current climate, PM emissions may be enhanced; since PM is raised by wind blowing across dry surfaces. Furthermore, secondary PM formation may be enhanced during photo-chemically active periods and by increased emissions of isoprene from vegetation.

Heal et al (2012) note that: "*the biggest influence on future UK concentrations of … particulate matter (PM) and* NO_2*, will be the trends in the anthropogenic primary and precursor emissions in the UK and regionally*".

Conclusions

- Climate change, especially towards the end of century will impact air quality and related health effects, but it is not currently possible to indicate the scale of such impacts due to uncertainties, feedbacks and confounding factors (such as behavioural change).
- More specifically for the dispersion modelling exercise, although air quality is highly influenced by weather, it is simply not possible to suggest a more typical weather year for 2030, especially for wind speed / direction and boundary layer height, which are the key meteorological variables affecting air quality issues.
- Whilst 2009 will not be fully representative of 2030 meteorology, 2009-2013 data and UKCP09 central scenario forecasts suggest it is not an unreasonable dataset to have used. Furthermore it has been applied evenly to all scenarios so comparison of do minimum and do something directly reflects activity change rather than possible weather effects.
- It is expected that the biggest influence on future UK concentrations of ambient air pollutants including particulate matter (PM) and NO_2, will be the trends in the anthropogenic primary and precursor emissions, rather than climate change effects on weather

Figure H1: Wind Speed and Direction at Gatwick in 2009



WIND ROSE PLOT:
Station # 3776 - Gatwick, UK

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:

DATA PERIOD:
Start Date: 01/01/2009 - 00:00
End Date: 31/12/2009 - 23:00

TOTAL COUNT:
8752 hrs.

CALM WINDS:
10.11%

AVG. WIND SPEED:
3.23 m/s

COMPANY NAME:

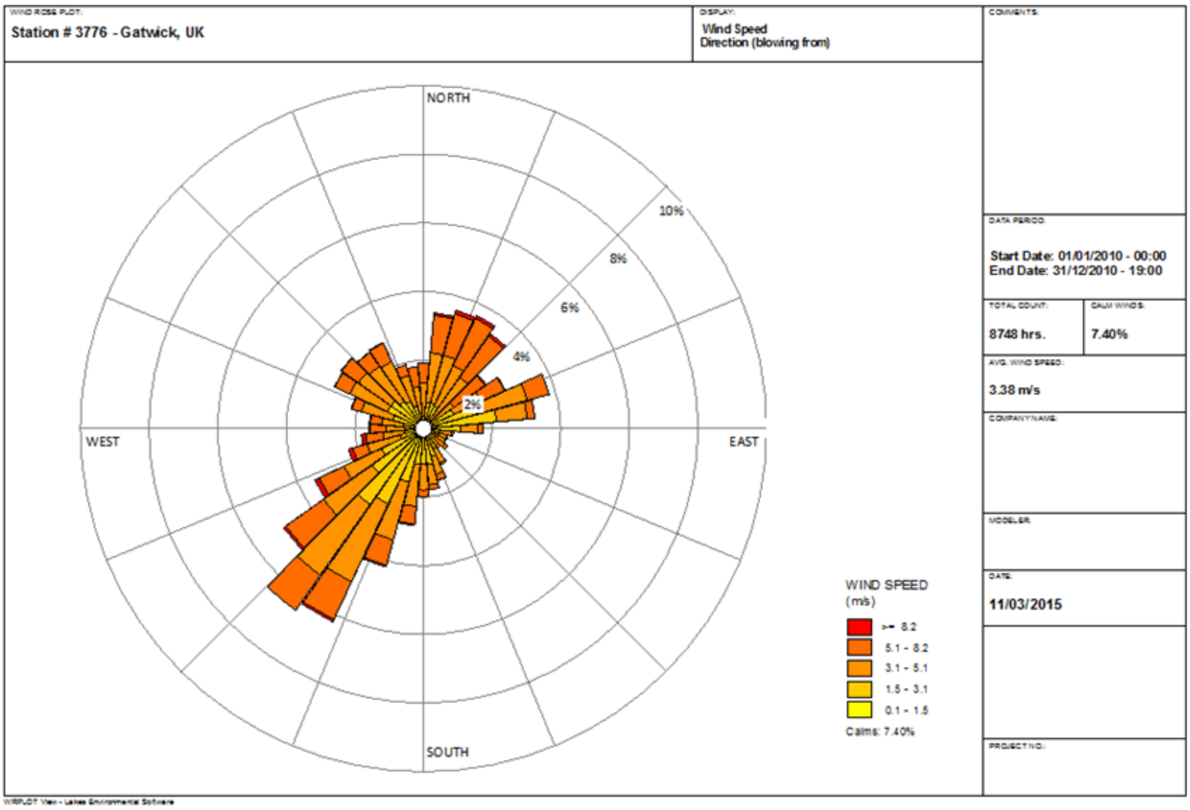
MODELER:

DATE:
11/03/2015

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure H2: Wind Speed and Direction at Gatwick in 2010



WIND ROSE PLOT:
Station # 3776 - Gatwick, UK

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:

DATA PERIOD:
Start Date: 01/01/2010 - 00:00
End Date: 31/12/2010 - 19:00

TOTAL COUNT:
8748 hrs.

CALM WINDS:
7.40%

AVG. WIND SPEED:
3.38 m/s

COMPANY NAME:

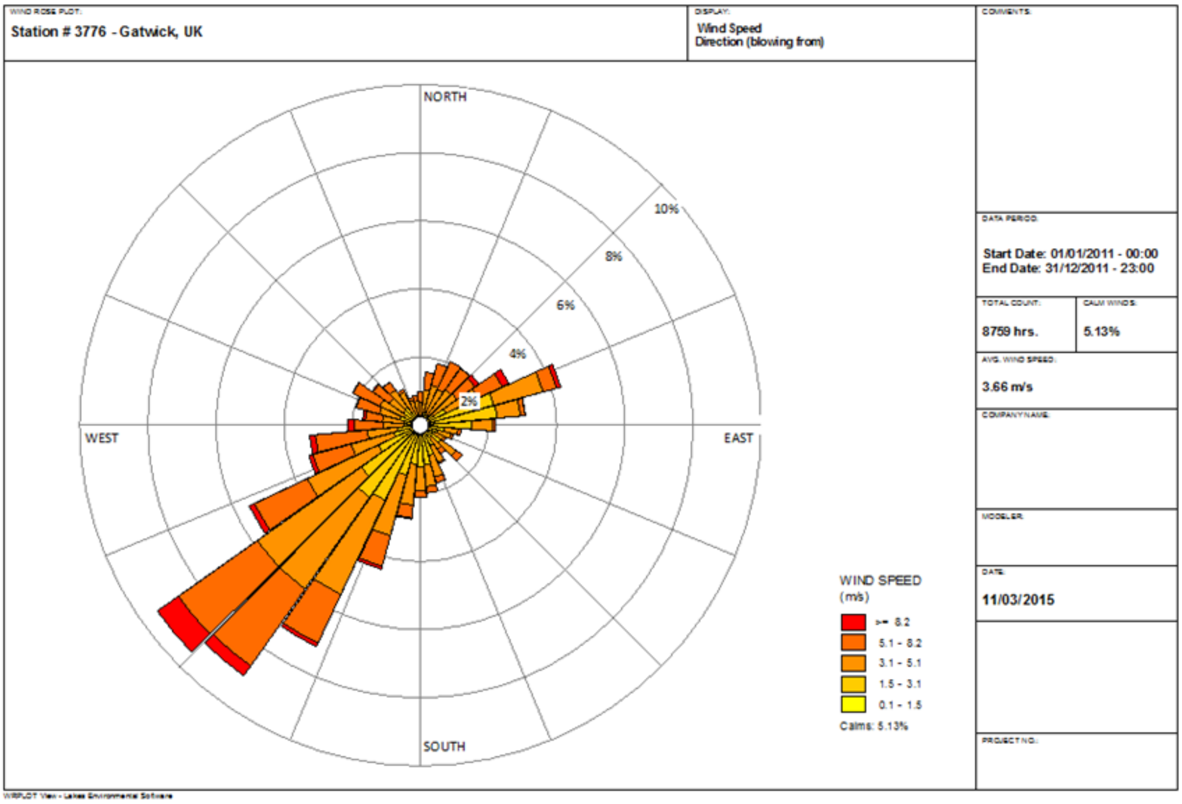
MODELER:

DATE:
11/03/2015

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure H3: Wind Speed and Direction at Gatwick in 2011



WIND ROSE PLOT:
Station # 3776 - Gatwick, UK

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:

DATA PERIOD:
Start Date: 01/01/2011 - 00:00
End Date: 31/12/2011 - 23:00

TOTAL COUNT:
8759 hrs.

CALM WINDS:
5.13%

AVG. WIND SPEED:
3.66 m/s

COMPANY NAME:

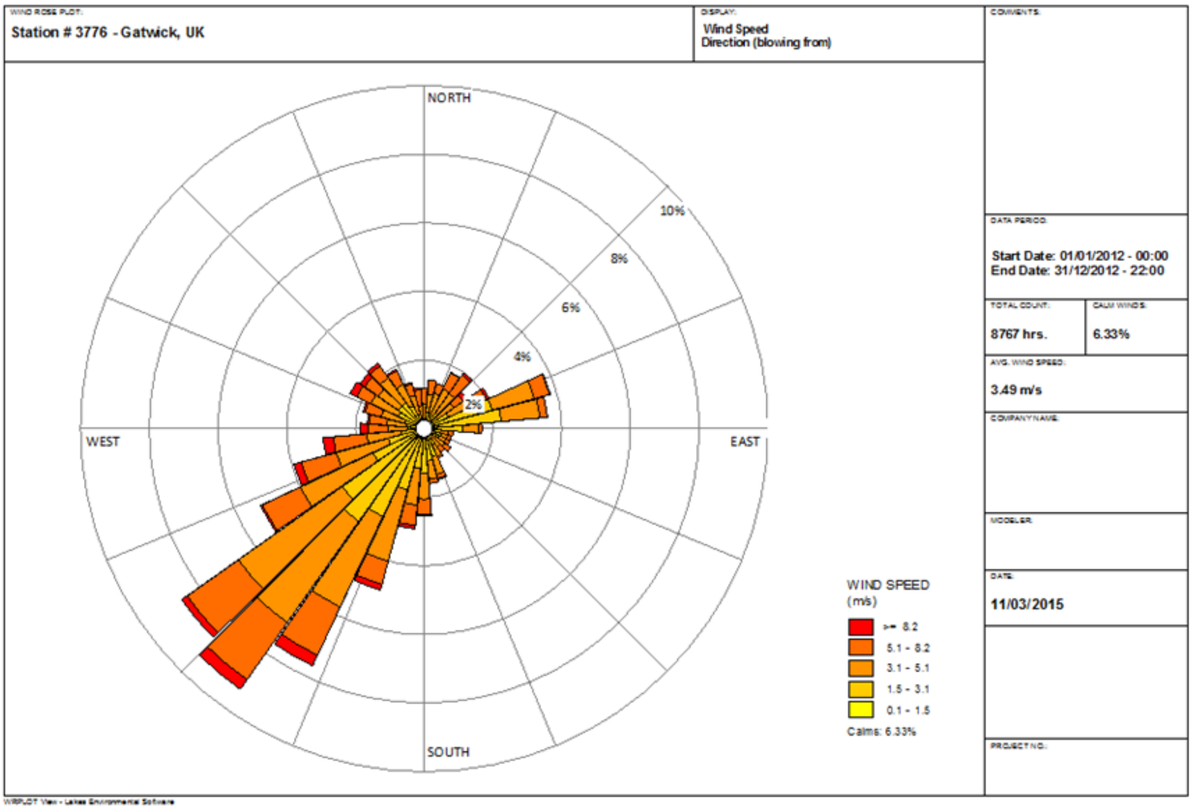
MODELER:

DATE:
11/03/2015

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure H4: Wind Speed and Direction at Gatwick in 2012



WIND ROSE PLOT:
Station # 3776 - Gatwick, UK

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:

DATA PERIOD:
Start Date: 01/01/2012 - 00:00
End Date: 31/12/2012 - 22:00

TOTAL COUNT:
8767 hrs.

CALM WINDS:
6.33%

AVG. WIND SPEED:
3.49 m/s

COMPANY NAME:

MODELER:

DATE:
11/03/2015

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure H5: Wind Speed and Direction at Gatwick in 2013

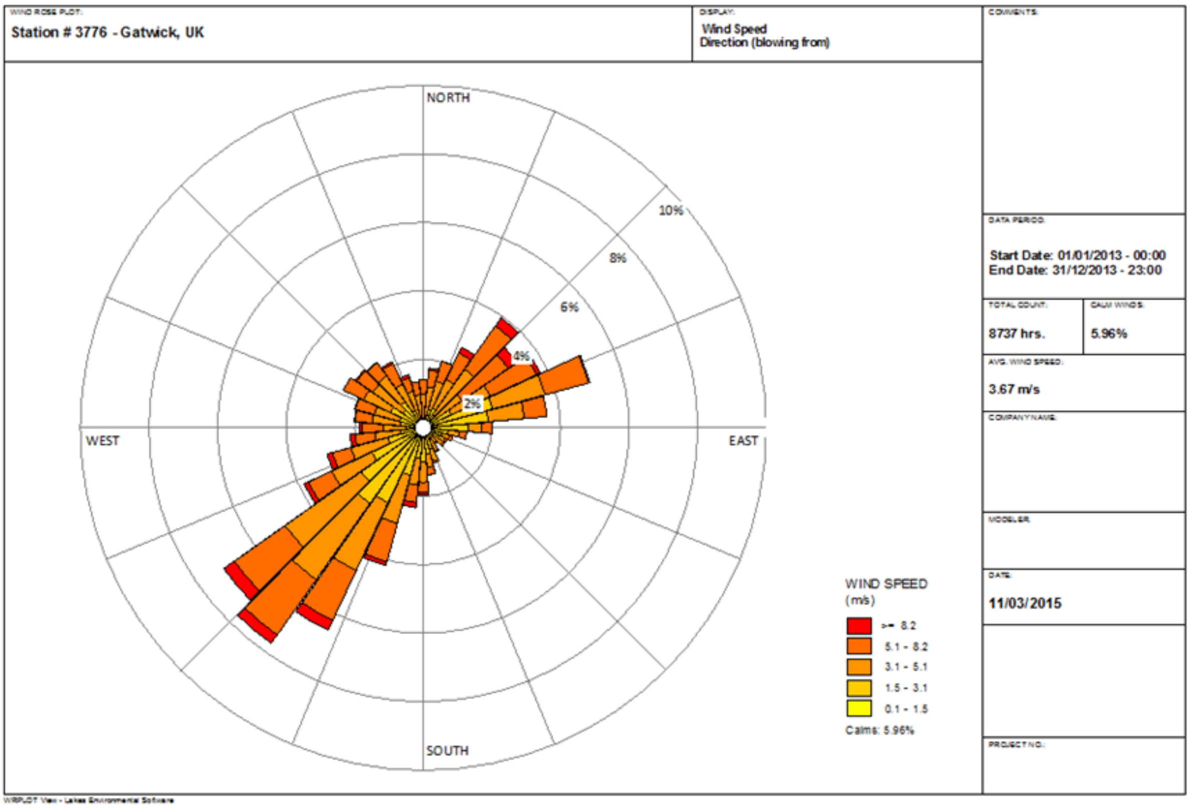


Figure H6: Ambient Temperature by Month at Gatwick in 2009

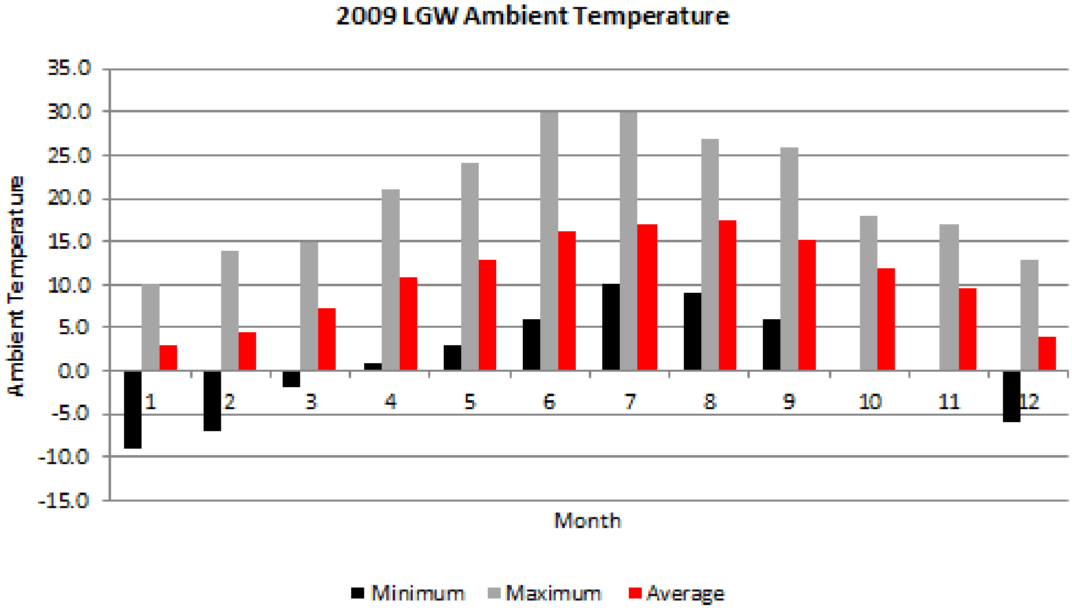


Figure H7: Ambient Temperature by Month at Gatwick in 2010

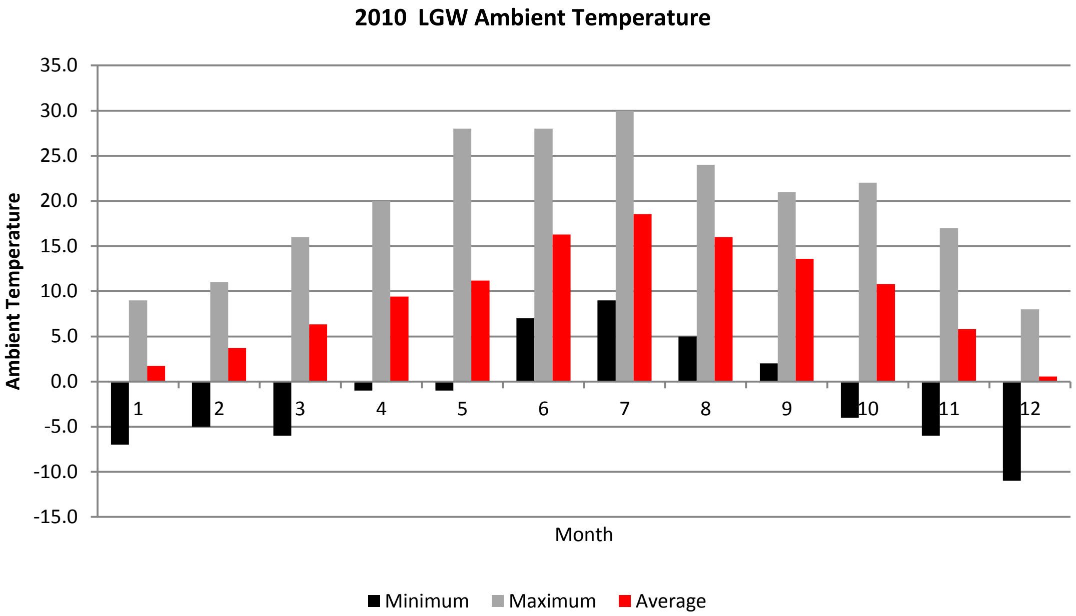


Figure H8: Ambient Temperature by Month at Gatwick in 2011

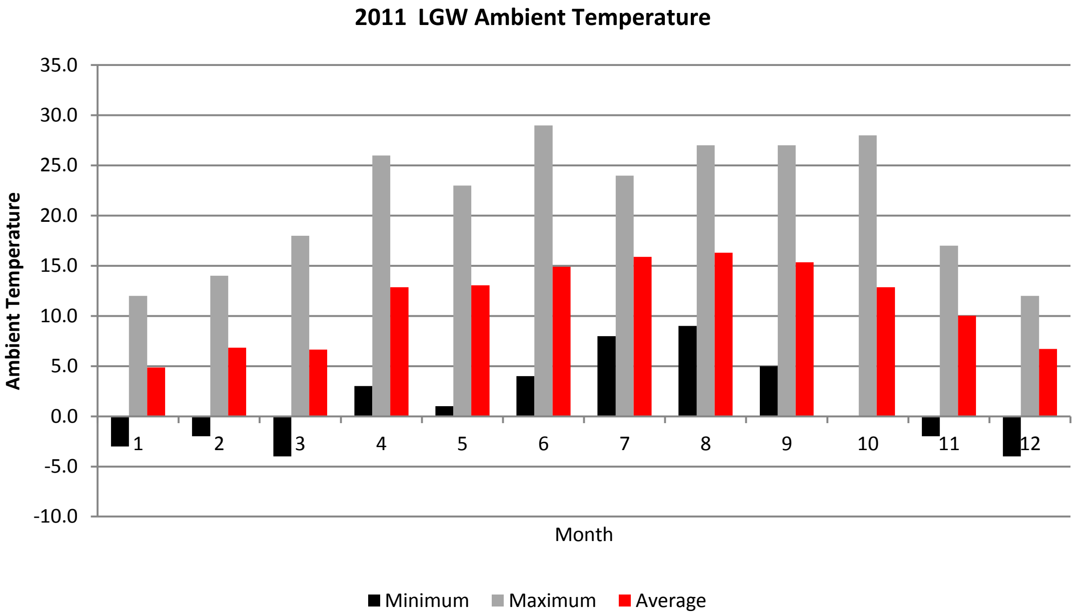


Figure H9: Ambient Temperature by Month at Gatwick in 2012

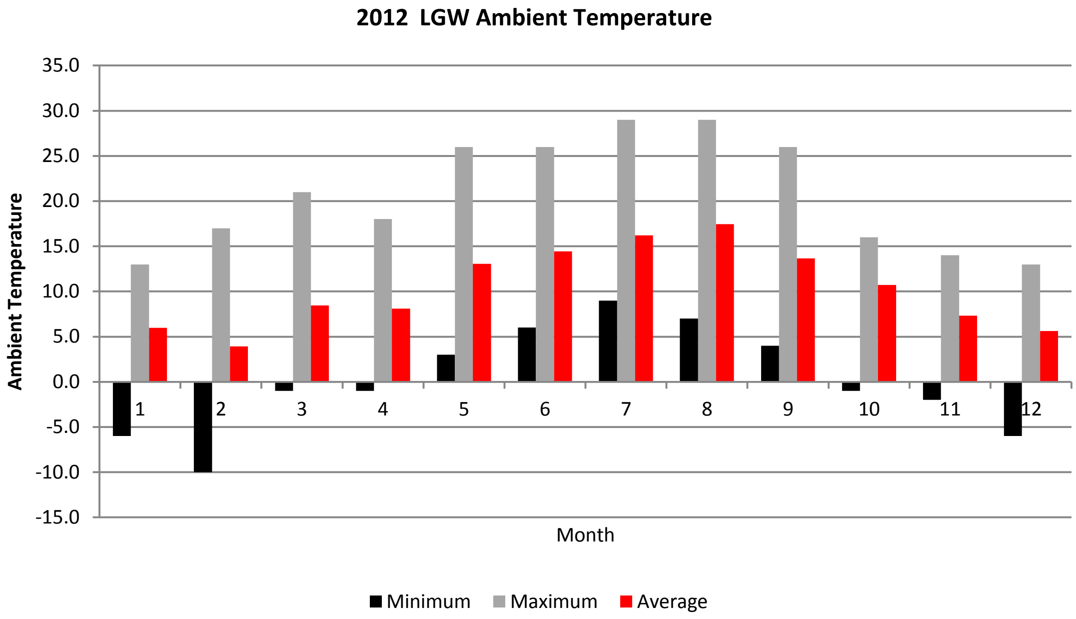


Figure H10: Ambient Temperature by Month at Gatwick in 2013

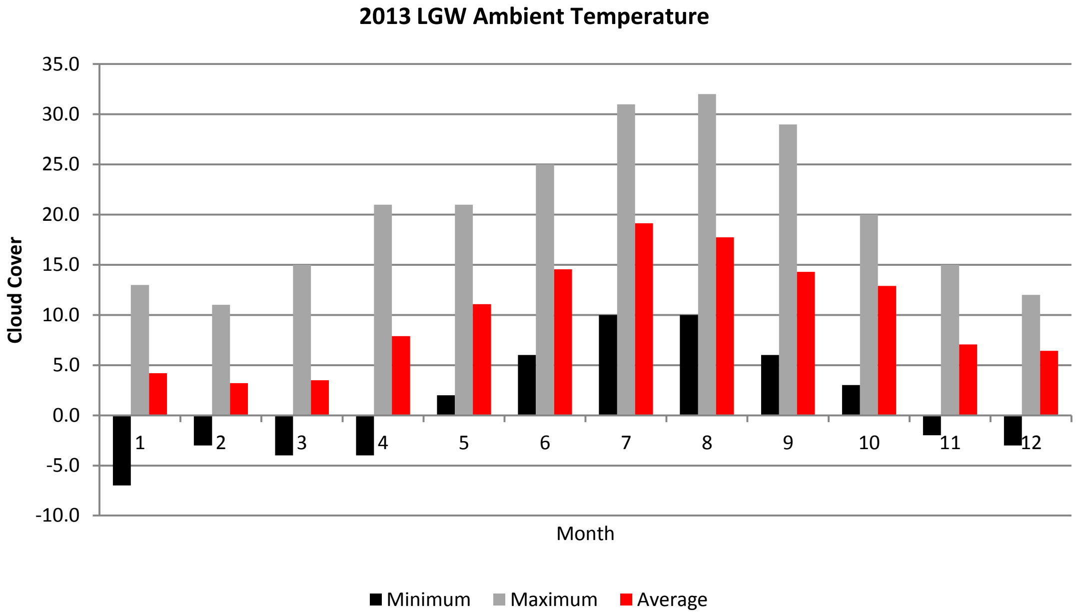


Figure H11: Wind Speed and Direction at Heathrow in 2009

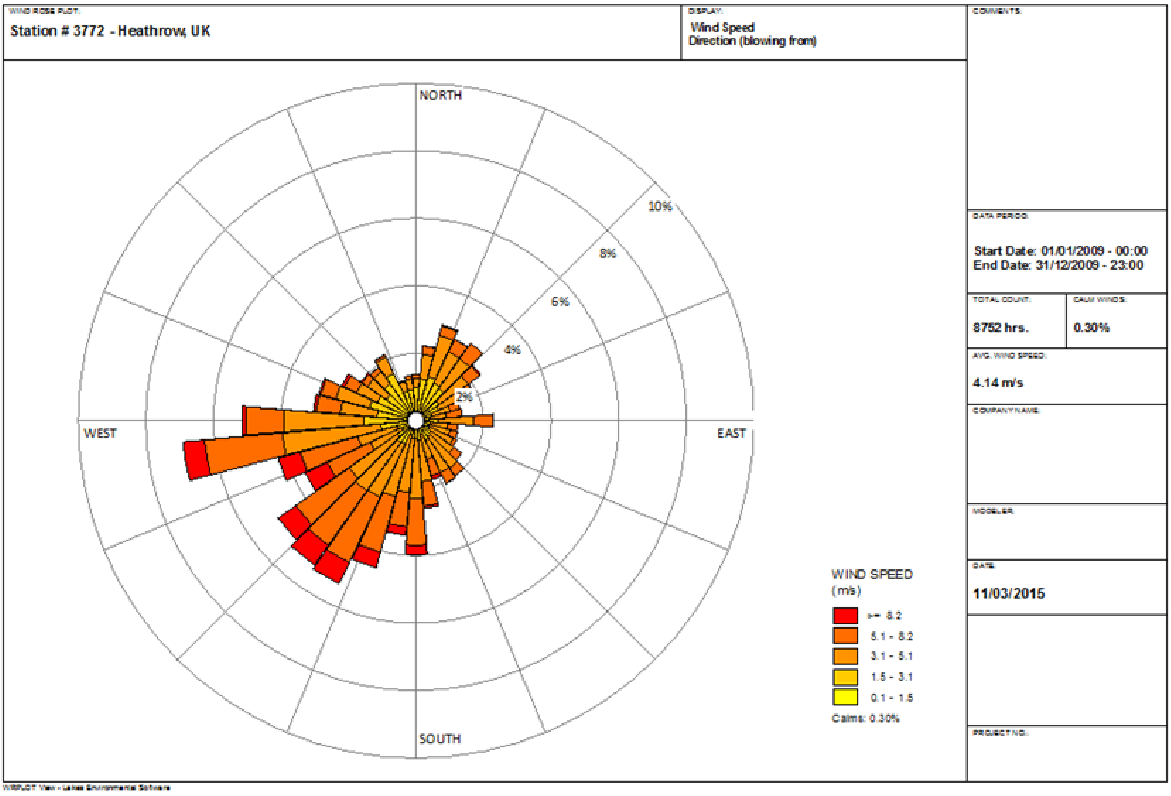


Figure H12: Wind Speed and Direction at Heathrow in 2010

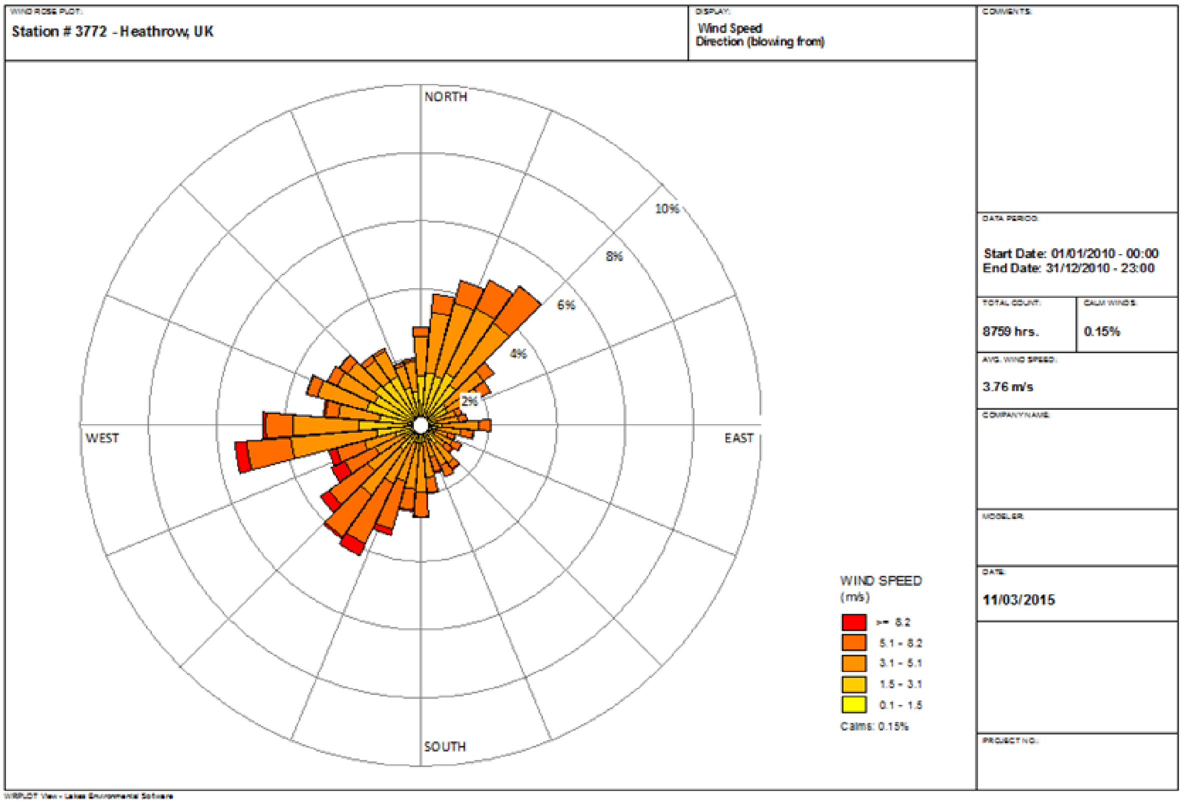
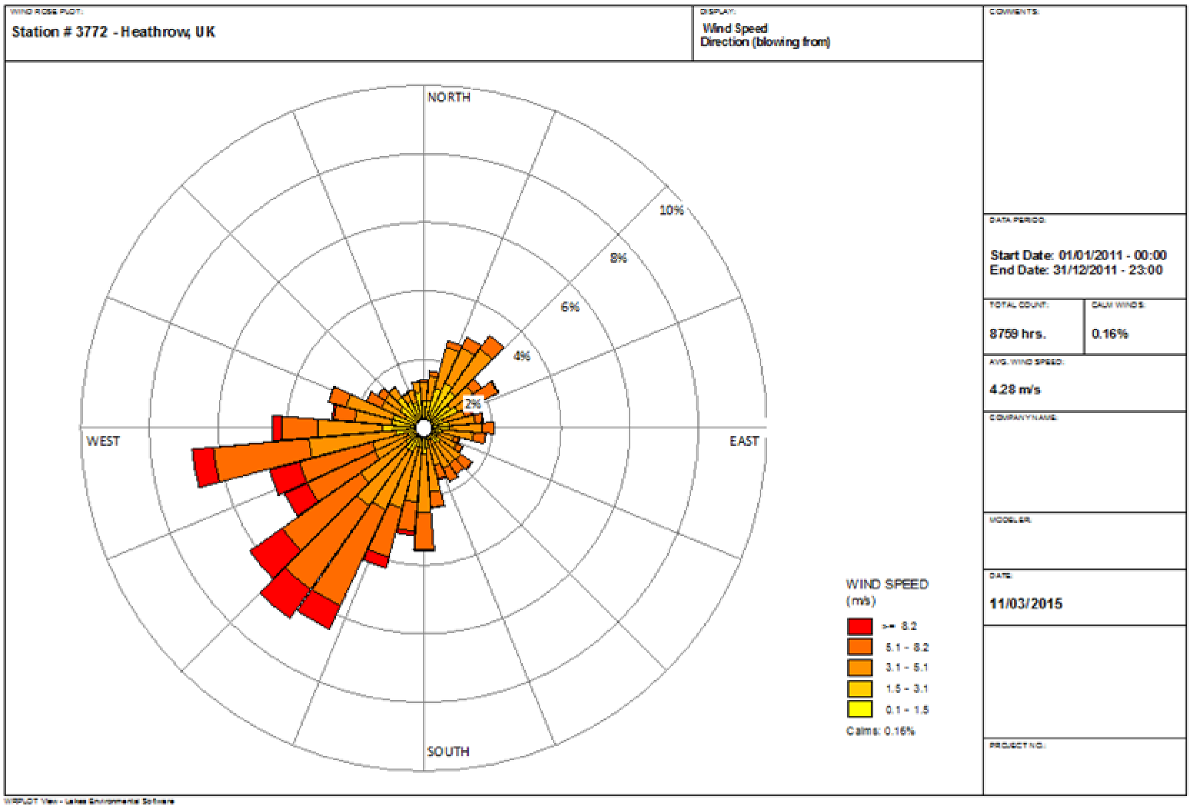


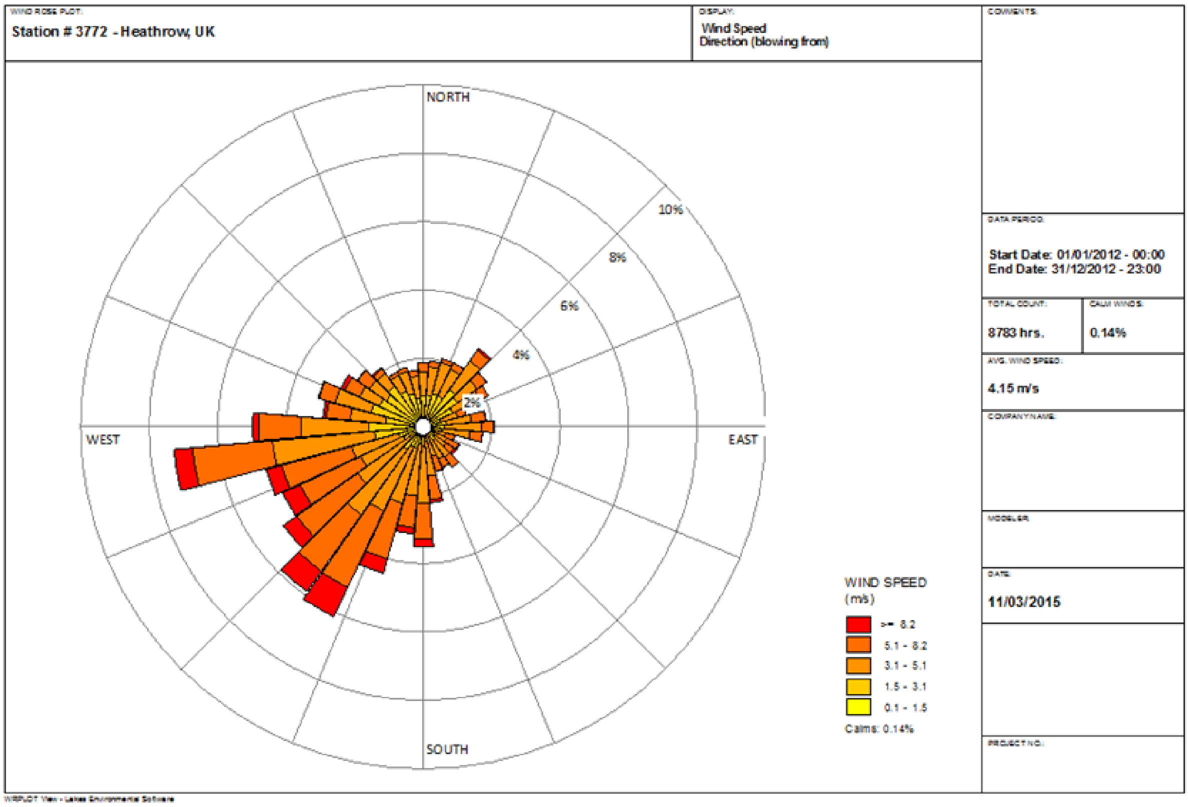
Figure H13: Wind Speed and Direction at Heathrow in 2011



WIND ROSE PLOT: Station # 3772 - Heathrow, UK
DISPLAY: Wind Speed Direction (blowing from)
COMMENTS:
DATA PERIOD: Start Date: 01/01/2011 - 00:00 End Date: 31/12/2011 - 23:00
TOTAL COUNT: 8759 hrs.
CALM WINDS: 0.16%
AVG. WIND SPEED: 4.28 m/s
COMPANY NAME:
MODELER:
DATE: 11/03/2015
PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure H14: Wind Speed and Direction at Heathrow in 2012



WIND ROSE PLOT: Station # 3772 - Heathrow, UK
DISPLAY: Wind Speed Direction (blowing from)
COMMENTS:
DATA PERIOD: Start Date: 01/01/2012 - 00:00 End Date: 31/12/2012 - 23:00
TOTAL COUNT: 8783 hrs.
CALM WINDS: 0.14%
AVG. WIND SPEED: 4.15 m/s
COMPANY NAME:
MODELER:
DATE: 11/03/2015
PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure H15: Wind Speed and Direction at Heathrow in 2013

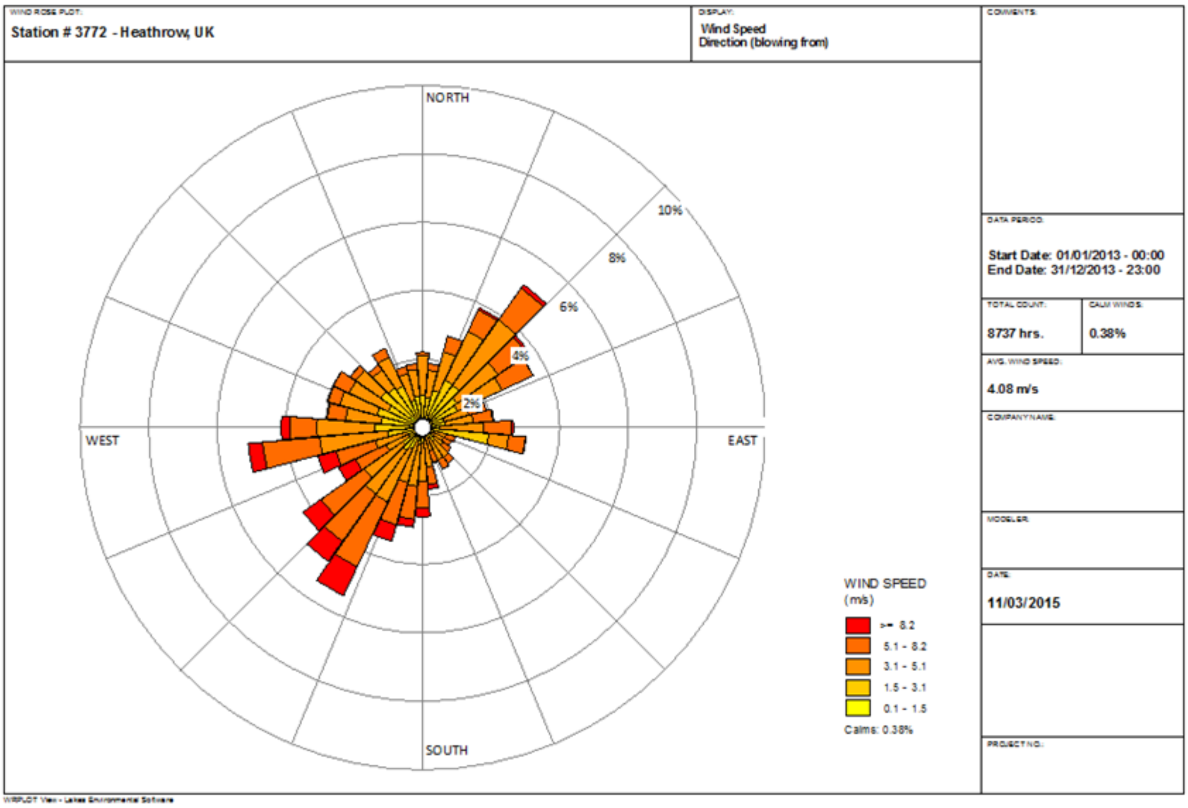


Figure H16: Ambient Temperature by Month at Heathrow in 2009

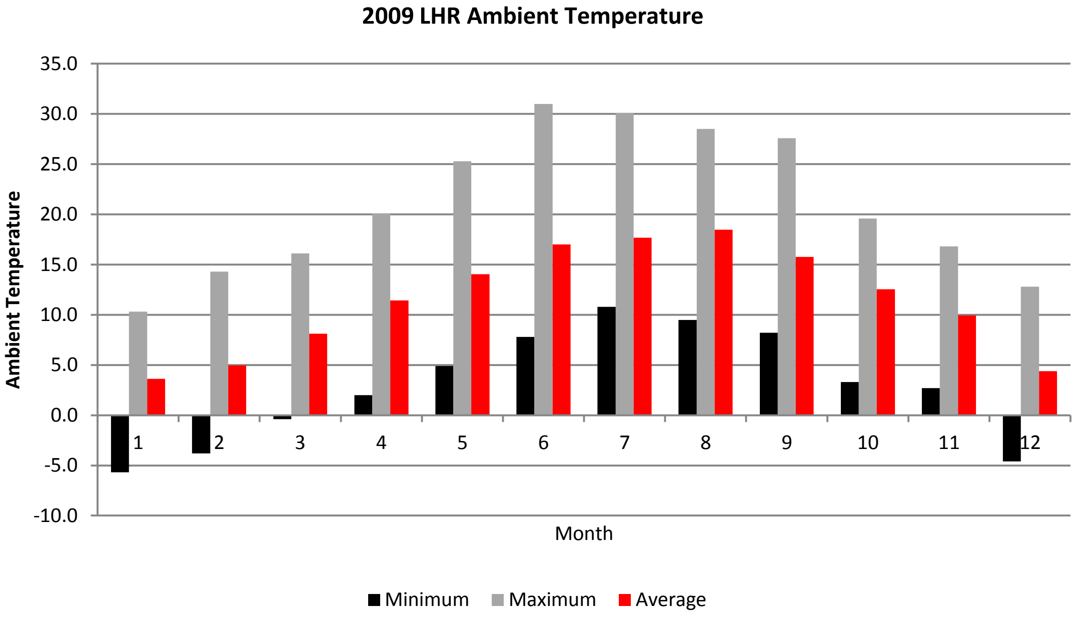


Figure H17: Ambient Temperature by Month at Heathrow in 2010

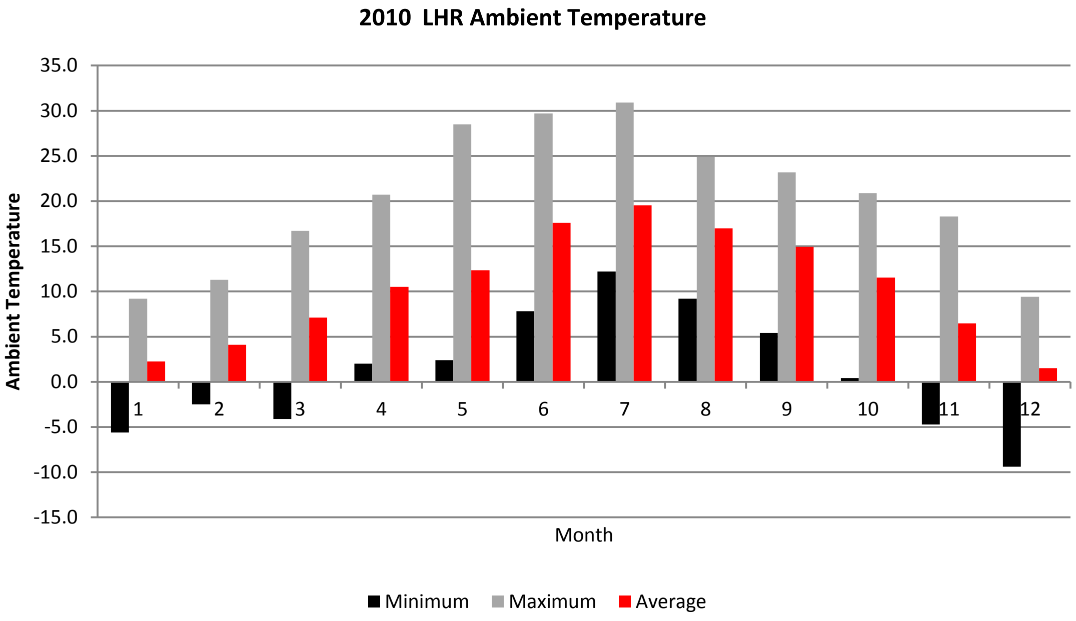


Figure H18: Ambient Temperature by Month at Heathrow in 2011

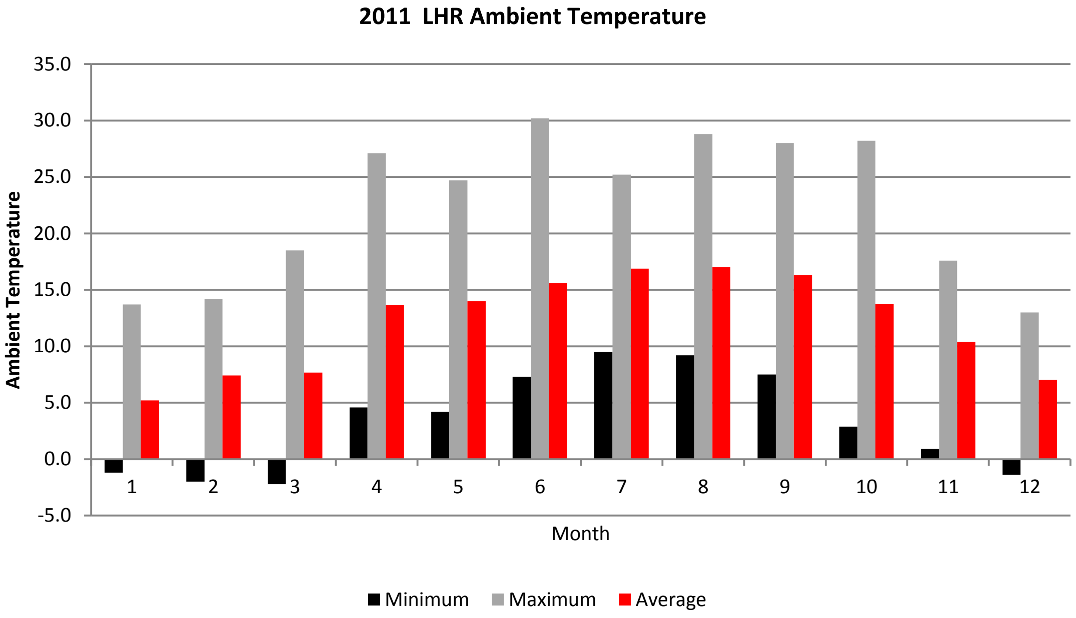


Figure H19: Ambient Temperature by Month at Heathrow in 2012

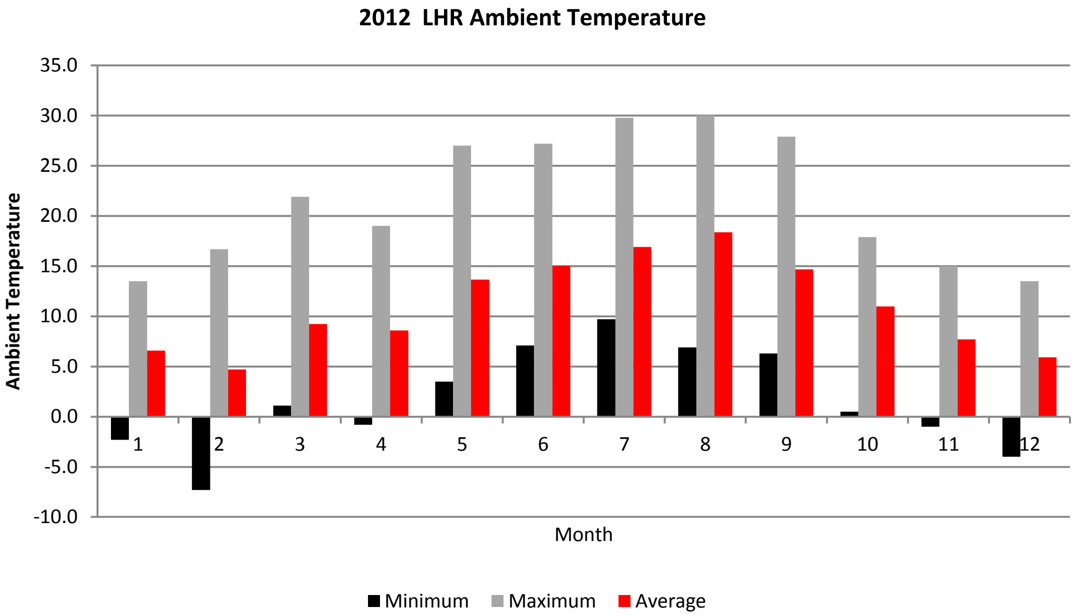


Figure H20: Ambient Temperature by Month at Heathrow in 2013

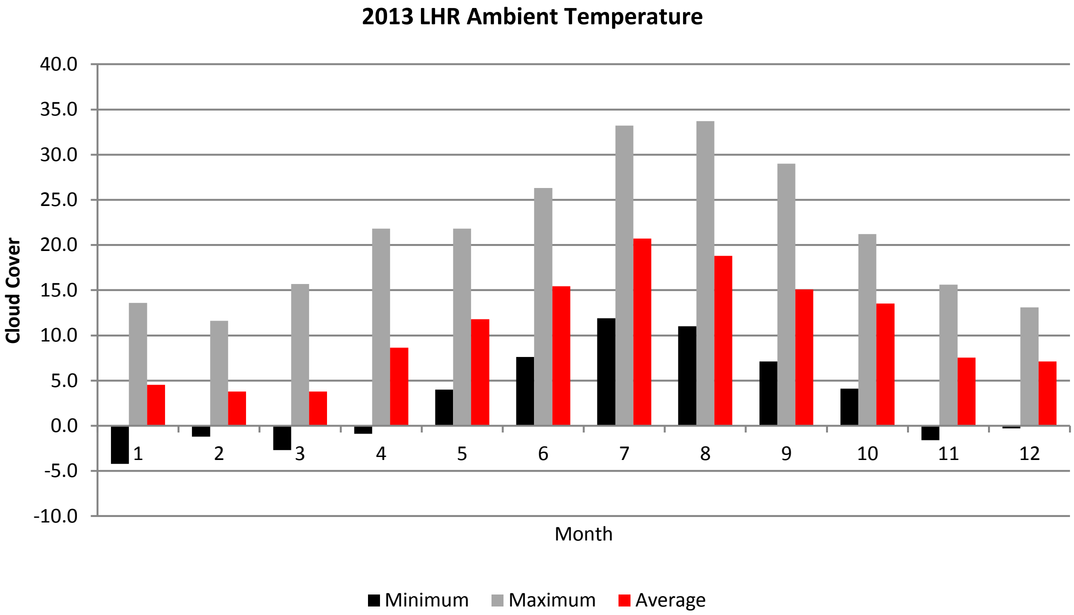


Table H1: Key Findings for London & South East England from UKCP09[32]

	Projected Change relative to 1961-1990 Baseline			
	London		South East	
Variable	2020s	2050s	2020s	2050s
Mean winter temperature (ºC)	1.3	2.2	1.3	2.2
Mean summer temperature (ºC)	1.6	2.7	1.6	2.8
Mean winter precipitation (mm) and change (%)	6	14	6	16
Mean summer precipitation (mm) and change (%)	-7	-19	-8	-19
(50% Probability Estimate, Medium Emissions Scenario) © Crown Copyright 2009. The UK Climate Projections (UKCP09) have been made available by the Department for Environment, Food and Rural Affairs (Defra) and the Department of Energy and Climate Change (DECC) under licence from the Met Office, UKCIP, British Atmospheric Data Centre, Newcastle University, University of East Anglia, Environment Agency, Tyndall Centre and Proudman Oceanographic Laboratory. These organisations give no warranties, express or implied, as to the accuracy of the UKCP09 and do not accept any liability for loss or damage, which may arise from reliance upon the UKCP09 and any use of the UKCP09 is undertaken entirely at the users risk.				

H2. Road Transport Emissions

Consideration has been given to address the evidence that on-road diesel vehicles have not, to date, delivered the emission reductions expected from the tightening Euro standards, at least up to Euro 5 for cars and vans and Euro V for lorries and buses (Carslaw et al, 2011). While Euro 6 and Euro VI standards[33] are expected to deliver improvements to NOx emissions, it is uncertain, given recent experience, that the full improvements will be delivered. The emissions standard for Euro 6 diesel vehicles is being delivered in two stages; the current Euro 6 diesel vehicles (often referred to as "Euro 6a/b", and Euro 6c, which will become available from about 2018. The Euro 6 emission standard is unchanged between Euro 6a/b and Euro 6c, but the test procedure is different. The latter will be based on PEMS (Portable Emissions Measurement Systems) to ensure a reduction in emissions under real-world driving conditions.

The emission factors for Euro 6a/b vehicles are incorporated into the latest version of the Defra Emissions Factor Toolkit (v6.0.2) which has been used in this study; the emission factors are based on COPERT4v10[34], which was released in November 2012. This assumes that Euro 6 diesel cars and Light Goods Vehicles (LGVs) have NOx emissions 65% lower than Euro 5, and represents a Conformity Factor[35] of 2.8 (APRIL, 2015).

The COPERT4v11 report was released in September 2014 and contains updated emissions factors for Euro 5/V and Euro 6/VI vehicles. This confirms that the current assumption for Euro 6a/b within EFT6.0.2 is correct, and that NOx emissions from Euro 6c vehicles are expected to be lower than Euro 6a/b, although this is necessarily based on a prognosis of likely technologies to be used (as there are

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[32] UK Climate Projections - http://ukclimateprojections.metoffice.gov.uk/21678

[33] The Euro 6 standards relate to Light Duty Vehicles whilst the Euro VI standards relate to Heavy Duty Vehicles.

[34] COPERT4 is a programme used to calculate emissions from the road transport sector. It is internationally recognised and is used by many European countries for reporting official emissions data.

[35] The Conformity Factor (CF) is the ratio between the emissions during real-world driving conditions and the Type Approval Limit Value, i.e. a CF of 2.8 indicates that real-world emissions are 2.8 times higher than the standard.

currently no in-service Euro 6c vehicles available). The evidence indicates that Euro 6c vehicles may be expected to deliver a Conformity Factor of about 1.5.

By 2030, there is expected to be a high penetration of Euro 6c vehicles. As all Euro 6 diesel vehicles in 2030 are represented by Euro 6a/b emission factors (as these are within EFTv6.0.2), the predicted emissions and concentrations are expected to be conservative.

There is also an additional concern that Euro 6c diesel cars and vans may significantly increase the proportion of primary NO_2 (f-NO_2) that is emitted. This is due to the preferred abatement train to reduce NOx and PM emissions, which is likely to be based on Selective Catalytic Reduction (SCR) followed by a catalytic Diesel Particle Filter (DPF). At this stage, COPERT4v11 anticipates that there is likely to be a 70% take-up of this abatement option, and that this may increase f-NO_2 emissions from 30% (as assumed in EFTv6.0.2) to something closer to 50%. There is a possibility that an emissions limit for f-NO_2 may be introduced which would minimise this effect, but there is no certainty.

Two sensitivity tests have been carried out, to assess the broader implications of these issues:

1. An assumption has been made that Euro 6c vehicles will deliver lower NOx emissions when they become available after 2018. Diesel cars and LGVs registered after 2018 have been assumed to achieve lower NOx emissions than those within EFT6.0.2, adjusted by the ratio of the Conformity Factors (i.e. 1.5/2.8); and
2. To take account of the potential increase in primary NO_2 emissions, the f-NO_{2road} factor has been increased from the default value of 16.6%, which is a fleet-weighted average that includes 30% f-NO_2 from Euro 6 diesel cars, to 24.0%, which is an estimate of the fleet-weighted average if f-NO_2 from these Euro 6c vehicles were 50%.

H2.1 Effect of Lower Euro 6c Emissions

As the model has been run for total NOx emissions from all road traffic components combined (as opposed to separately for each vehicle type), the contribution of Euro 6 vehicles (6a/b and 6c) to concentrations cannot be derived easily. Instead, the sensitivity test has been based on the average emissions from those roads which are expected to most significantly affect concentrations at the receptors used for the National Compliance assessment. As explained in Chapter 3 all road traffic emissions were calculated for each vehicle type separately before being aggregated for inclusion in the dispersion model and the total emissions calculations. For this sensitivity test, the calculated emissions from diesel cars and LGVs were further apportioned to those from Euro 6c vehicles only. This was based on the default fleet proportions in the EFT, as well as the projected penetration of these vehicles 12 years after introduction; again as set out in the EFT. Emissions from these Euro 6c diesel cars and LGVs were then multiplied by 1.5/2.8 to account for the improved Conformity Factor. Applying this adjustment resulted in an average reduction in total NOx emissions of approximately 7% from the relevant roads.

H2.2 Increased Primary NO_2 Emissions

The f-NO_2 factor for road traffic has been increased from 16.6% to 24.0%. Total f-NO_2 at each receptor, which takes account of f-NO_2 from airport sources, has then been recalculated. NO_2 concentrations have then been recalculated as described in

Appendix D. The results are presented for those receptors set out in Table 4.5, 5.5, and 6.5 and the revised results are set out in Table H1 and Table H2. The results show that the increase to primary NO_2 emissions would have generally have no significant effect on the predicted concentrations. In the case of the Gatwick 2R Scheme, an increase in primary NO_2 emissions is shown to cause a marginal exceedence of the objective at Receptor 2R-K, but this is based on a worst-case assumption regarding increased primary NO_2 emissions.

Table H1: Annual Mean NO_2 Concentrations at Representative Heathrow Do-Minimum, NWR and ENR Receptors under Two f-NO_2 Assumptions (µg/m^3)

	Do Minimum		NWR		ENR	
Receptor	16.6% Road f-NO_2	24.0% Road f-NO_2	16.6% Road f-NO_2	24.0% Road f-NO_2	16.6% Road f-NO_2	24.0% Road f-NO_2
NWR/ENR-A	19.7	19.8	20.2	20.3	20.9	21.0
NWR/ENR-B	14.9	14.9	15.6	15.6	15.8	15.9
NWR/ENR-C	29.5	30.8	30.1	31.5	27.6	28.6
NWR/ENR-D	22.2	22.5	32.6	33.9	26.2	26.8
NWR/ENR-E	20.9	21.0	22.4	22.5	21.6	21.7
NWR/ENR-F	20.3	20.4	23.0	23.3	23.2	23.4
NWR/ENR-G	24.9	25.3	28.4	28.9	26.8	27.2
NWR/ENR-H	18.3	18.4	19.6	19.7	20.2	20.3
NWR/ENR-I	23.5	23.6	25.1	25.2	24.7	24.8
NWR/ENR-J	20.8	20.9	24.9	25.1	23.0	23.2
NWR/ENR-K	18.1	18.3	18.6	18.8	19.3	19.6
NWR/ENR-L	25.1	25.2	27.1	27.2	24.9	25.1
NWR/ENR-M	26.8	27.0	27.7	27.8	22.2	22.3
NWR/ENR-N	24.7	24.8	25.3	25.4	24.6	24.8
NWR/ENR-O	25.7	25.9	26.2	26.4	25.5	25.7
NWR/ENR-P	24.9	25.3	25.9	26.3	24.7	25.0
NWR/ENR-Q	21.9	22.0	22.6	22.7	20.8	20.9
NWR/ENR-R	22.9	23.3	23.6	24.0	23.4	23.8
NWR/ENR-S	24.7	25.1	25.3	25.8	25.1	25.5
NWR/ENR-T	17.0	17.1	17.4	17.5	17.2	17.2

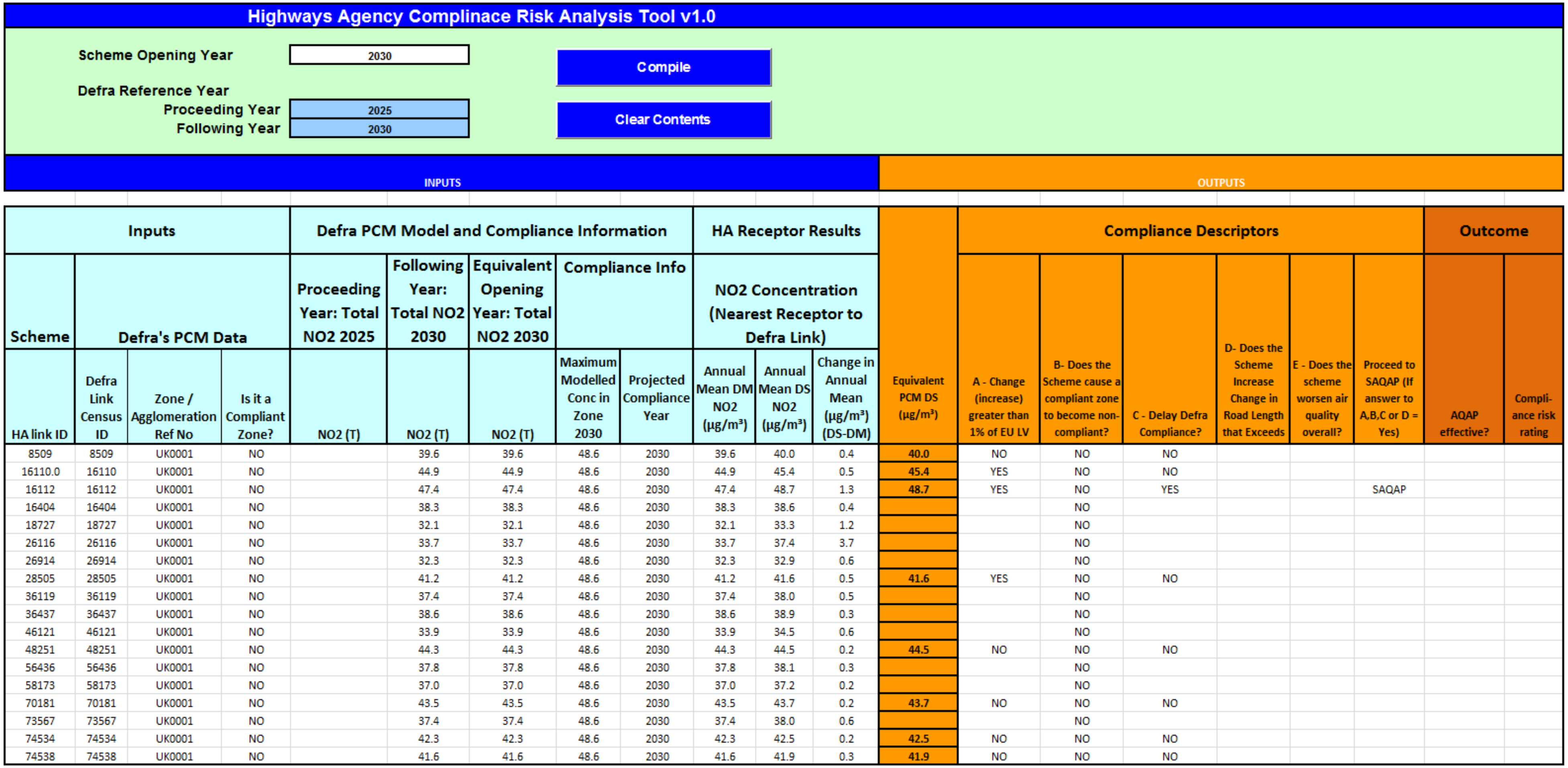
Table H2: Annual Mean NO_2 Concentrations at Representative Gatwick Do-Minimum and 2RW Receptors under Two f-NO_2 Assumptions (µg/m^3)

	Do Minimum		2RW	
Receptor	16% Road f-NO_2	24% Road f-NO_2	16% Road f-NO_2	24% Road f-NO_2
2R-A	10.0	10.0	11.8	11.8
2R-B	10.8	10.9	14.3	14.5
2R-C	11.2	11.3	15.2	15.6
2R-D	12.7	12.8	18.4	18.8
2R-E	11.0	11.0	13.9	13.9
2R-F	13.1	13.1	15.3	15.3
2R-G	13.6	13.7	16.8	16.9
2R-H	22.5	22.7	27.6	28.2
2R-I	15.3	15.4	18.8	19.0
2R-J	22.2	22.7	27.4	28.3
2R-K	34.0	34.9	38.6	40.1
2R-L	25.3	25.6	31.4	31.8
2R-M	19.7	19.8	24.6	25.0
2R-N	16.9	17.0	22.3	22.6
2R-O	20.1	20.3	25.7	26.2
2R-P	17.6	17.8	22.7	23.2
2R-Q	15.9	16.0	22.8	23.4
2R-R	22.1	22.6	26.1	26.9
2R-S	23.6	24.5	27.3	28.5
2R-T	25.2	26.3	27.5	28.8

Appendix I: Air Quality Directive Compliance Risk Assessment

The following are the outputs from the Highways Agency spreadsheet accompanying Interim Advice Note 175/13.

Table I1 Output for Heathrow NWR.



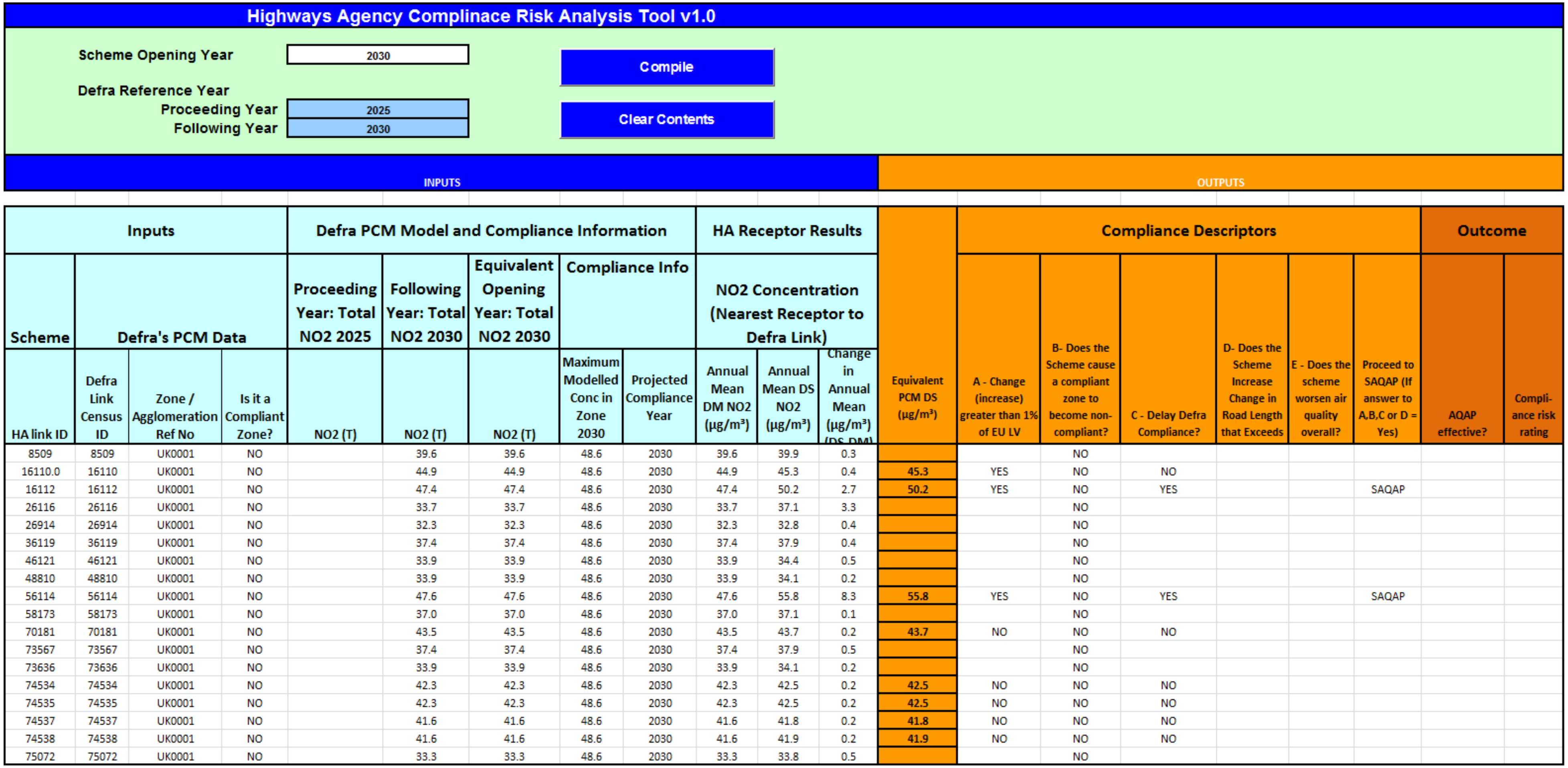
Highways Agency Complinace Risk Analysis Tool v1.0

Scheme Opening Year: 2030

Defra Reference Year
Proceeding Year: 2025
Following Year: 2030

Inputs				Defra PCM Model and Compliance Information					HA Receptor Results				Compliance Descriptors						Outcome	
Scheme	Defra's PCM Data			Proceeding Year: Total NO2 2025	Following Year: Total NO2 2030	Equivalent Opening Year: Total NO2 2030	Compliance Info		NO2 Concentration (Nearest Receptor to Defra Link)											
HA link ID	Defra Link Census ID	Zone / Agglomeration Ref No	Is it a Compliant Zone?	NO2 (T)	NO2 (T)	NO2 (T)	Maximum Modelled Conc in Zone 2030	Projected Compliance Year	Annual Mean DM NO2 (µg/m³)	Annual Mean DS NO2 (µg/m³)	Change in Annual Mean (µg/m³) (DS-DM)	Equivalent PCM DS (µg/m³)	A - Change (increase) greater than 1% of EU LV	B- Does the Scheme cause a compliant zone to become non-compliant?	C - Delay Defra Compliance?	D- Does the Scheme Increase Change in Road Length that Exceeds	E - Does the scheme worsen air quality overall?	Proceed to SAQAP (If answer to A,B,C or D = Yes)	AQAP effective?	Compli-ance risk rating
8509	8509	UK0001	NO		39.6	39.6	48.6	2030	39.6	40.0	0.4	40.0	NO	NO	NO					
16110.0	16110	UK0001	NO		44.9	44.9	48.6	2030	44.9	45.4	0.5	45.4	YES	NO	NO					
16112	16112	UK0001	NO		47.4	47.4	48.6	2030	47.4	48.7	1.3	48.7	YES	NO	YES			SAQAP		
16404	16404	UK0001	NO		38.3	38.3	48.6	2030	38.3	38.6	0.4			NO						
18727	18727	UK0001	NO		32.1	32.1	48.6	2030	32.1	33.3	1.2			NO						
26116	26116	UK0001	NO		33.7	33.7	48.6	2030	33.7	37.4	3.7			NO						
26914	26914	UK0001	NO		32.3	32.3	48.6	2030	32.3	32.9	0.6			NO						
28505	28505	UK0001	NO		41.2	41.2	48.6	2030	41.2	41.6	0.5	41.6	YES	NO	NO					
36119	36119	UK0001	NO		37.4	37.4	48.6	2030	37.4	38.0	0.5			NO						
36437	36437	UK0001	NO		38.6	38.6	48.6	2030	38.6	38.9	0.3			NO						
46121	46121	UK0001	NO		33.9	33.9	48.6	2030	33.9	34.5	0.6			NO						
48251	48251	UK0001	NO		44.3	44.3	48.6	2030	44.3	44.5	0.2	44.5	NO	NO	NO					
56436	56436	UK0001	NO		37.8	37.8	48.6	2030	37.8	38.1	0.3			NO						
58173	58173	UK0001	NO		37.0	37.0	48.6	2030	37.0	37.2	0.2			NO						
70181	70181	UK0001	NO		43.5	43.5	48.6	2030	43.5	43.7	0.2	43.7	NO	NO	NO					
73567	73567	UK0001	NO		37.4	37.4	48.6	2030	37.4	38.0	0.6			NO						
74534	74534	UK0001	NO		42.3	42.3	48.6	2030	42.3	42.5	0.2	42.5	NO	NO	NO					
74538	74538	UK0001	NO		41.6	41.6	48.6	2030	41.6	41.9	0.3	41.9	NO	NO	NO					

Table I2 Output for Heathrow ENR.



Highways Agency Complinace Risk Analysis Tool v1.0

Scheme Opening Year	2030
Defra Reference Year	
Proceeding Year	2025
Following Year	2030

Compile

Clear Contents

INPUTS

OUTPUTS

Inputs				Defra PCM Model and Compliance Information					HA Receptor Results				Compliance Descriptors						Outcome	
Scheme	Defra's PCM Data			Proceeding Year: Total NO2 2025	Following Year: Total NO2 2030	Equivalent Opening Year: Total NO2 2030	Compliance Info		NO2 Concentration (Nearest Receptor to Defra Link)											
HA link ID	Defra Link Census ID	Zone / Agglomeration Ref No	Is it a Compliant Zone?	NO2 (T)	NO2 (T)	NO2 (T)	Maximum Modelled Conc in Zone 2030	Projected Compliance Year	Annual Mean DM NO2 (µg/m³)	Annual Mean DS NO2 (µg/m³)	Change in Annual Mean (µg/m³) (DS DM)	Equivalent PCM DS (µg/m³)	A - Change (increase) greater than 1% of EU LV	B- Does the Scheme cause a compliant zone to become non-compliant?	C - Delay Defra Compliance?	D- Does the Scheme Increase Change in Road Length that Exceeds	E - Does the scheme worsen air quality overall?	Proceed to SAQAP (If answer to A,B,C or D = Yes)	AQAP effective?	Compli-ance risk rating
8509	8509	UK0001	NO		39.6	39.6	48.6	2030	39.6	39.9	0.3			NO						
16110.0	16110	UK0001	NO		44.9	44.9	48.6	2030	44.9	45.3	0.4	45.3	YES	NO	NO					
16112	16112	UK0001	NO		47.4	47.4	48.6	2030	47.4	50.2	2.7	50.2	YES	NO	YES			SAQAP		
26116	26116	UK0001	NO		33.7	33.7	48.6	2030	33.7	37.1	3.3			NO						
26914	26914	UK0001	NO		32.3	32.3	48.6	2030	32.3	32.8	0.4			NO						
36119	36119	UK0001	NO		37.4	37.4	48.6	2030	37.4	37.9	0.4			NO						
46121	46121	UK0001	NO		33.9	33.9	48.6	2030	33.9	34.4	0.5			NO						
48810	48810	UK0001	NO		33.9	33.9	48.6	2030	33.9	34.1	0.2			NO						
56114	56114	UK0001	NO		47.6	47.6	48.6	2030	47.6	55.8	8.3	55.8	YES	NO	YES			SAQAP		
58173	58173	UK0001	NO		37.0	37.0	48.6	2030	37.0	37.1	0.1			NO						
70181	70181	UK0001	NO		43.5	43.5	48.6	2030	43.5	43.7	0.2	43.7	NO	NO	NO					
73567	73567	UK0001	NO		37.4	37.4	48.6	2030	37.4	37.9	0.5			NO						
73636	73636	UK0001	NO		33.9	33.9	48.6	2030	33.9	34.1	0.2			NO						
74534	74534	UK0001	NO		42.3	42.3	48.6	2030	42.3	42.5	0.2	42.5	NO	NO	NO					
74535	74535	UK0001	NO		42.3	42.3	48.6	2030	42.3	42.5	0.2	42.5	NO	NO	NO					
74537	74537	UK0001	NO		41.6	41.6	48.6	2030	41.6	41.8	0.2	41.8	NO	NO	NO					
74538	74538	UK0001	NO		41.6	41.6	48.6	2030	41.6	41.9	0.2	41.9	NO	NO	NO					
75072	75072	UK0001	NO		33.3	33.3	48.6	2030	33.3	33.8	0.5			NO						

Appendix J: LeighFisher Average Day Forecasting Methodology

Leigh|Fisher

APPRAISAL MODULE 6: AIR QUALITY

AVERAGE DAY FORECASTING METHODOLOGY

Prepared for

Airports Commission

9th March 2015

Leigh|Fisher

Document control sheet

Client: Airports Commission
Document Title: Average Day Forecasting Methodology

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1. INTRODUCTION

As part of the Airports Commission's appraisal process set forward in its Appraisal Framework Module 6: Air Quality, Jacobs and Air Quality Consultants undertook dispersion modelling to assess the impact of each airport Scheme on air quality.

To conduct this dispersion modelling it is necessary to know the daily profile of aircraft movements at the airport in question. As the Airports Commission's demand scenarios are expressed in terms of annual aircraft movements, LeighFisher was retained to transform these forecast annual aircraft movements into day schedules. This report describes the methodology behind the development of those day schedules.

As average day schedules had been produced previously, as part of the analysis for Appraisal Framework Module 5: Noise, for consistency these schedules were used as the starting point and developed to the level of detail required for this air quality analysis.

2. DEMAND SCENARIOS

Table 1 summarises the modelled demand scenarios and their forecast annual air traffic movements (ATMs). Note that when the forecast ATMs exceed the assumed capacity limit, we adopted the capacity limit itself and reduced all ATMs equally. The assumed capacity limits are:

- Do minimum
    - Gatwick Airport: 280,000 ATMs
    - Heathrow Airport: 480,000 ATMs
- Do something
    - Gatwick Airport Second Runway (2R): 560,000 ATMs
    - Heathrow Airport Extended Northern Runway (ENR): 700,000 ATMs
    - Heathrow Airport North West Runway (NWR): 740,000 ATMs

Table 1 - Overview of demand scenarios and forecast annual ATMs

	2R Low Cost Is King Carbon Traded	ENR Global Growth Carbon Traded	NWR Global Growth Carbon Traded
Do minimum	279,525	484,150*	
Do something	480,623	702,893*	722,472

*Demand scenario predicts more than the capacity limit; therefore, the movements were limited as noted previously.

3. METHODOLOGY

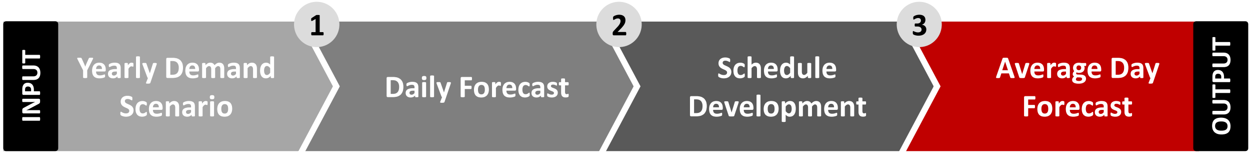
We had previously developed average day schedules as part of the noise appraisal framework module. These schedules were detailed only into day, evening and night periods. The methodology specific to this air quality analysis translated those schedules into hourly ATMs. Furthermore, the noise analysis required only one average day representative of the year and another of the average summer day, whereas the air quality assessment used four average days: each one representative of a quarter of the year. This ensures a more robust representation of the year taking seasonal variations into account. The latter is important as weather has an effect on the behaviour of airport related emissions and, therefore, those emissions need to reflect seasonal variations.

OVERVIEW

Starting with the demand scenarios expressed in annual ATMs, we followed three major steps to develop daily schedules as depicted in **Figure 1**:

1. **Daily Forecast**: The annual movements of a demand scenario were allocated into daily movements using the profile of demand observed in 2011 as a base, respecting the daily capacity in terms of aircraft movements for each Scheme. This required an understanding of the seasonal, weekly and daily variations occurring over the year. Each airport had provided four representative days in 2011 to be used as a basis for the development of the forecasts. Based on the seasonal variations, a certain number of forecast movements were added to these four days, each representing a quarter of the year.
2. **Schedule Development**: Taking the movements for those four days, the movements were divided across markets, or regions in the world, reflective of the Airports Commission's demand scenario market splits. Next, an aircraft type was assigned to each flight respecting the demand scenario's fleet mix, recognising that the fleet mix differs depending on the market being served. The last factor is the time of day a flight departs or lands. This again was determined per market and driven by the 2011 schedule taking into account the movement limits for each hour of the day.
3. **Average Day Forecast**: Taking the output of the previous step, we carried out several checks to ensure each day respected the fleet mix, market split, and hourly limits on departures and arrivals.

Figure 1 - General principles and major steps behind the methodology.



- Input: annual ATMs

- Daily ATM capacity
- Seasonal variations

- Market split
- Hourly limits
- Fleet mix

DAILY FORECAST

This section describes how the demand scenario in terms of annual movements was translated into daily movements.

Daily ATM Capacity

With reference to Chapter 2, five scenarios were modelled: two without development ("do minimum") and three with development ("do something"). For the "do minimum" scenarios, the movements capacity was taken from the slot coordination declaration for summer 2014 and winter 2014[36], the latest available data at the time of modelling. For the "do something" scenarios, the daily limit was based on the submissions by the Scheme Promoters, ensuring that the total number of forecast movements respected the assumed capacity limit for the particular Scheme. **Table 2** shows these daily capacity limits.

Table 2 - Daily capacity limits for the different scenarios

[movements]	2R	ENR	NWR
Do minimum	Winter: 753 Summer: 949	Winter: 1,334 Summer: 1,368	
Do something	1,634	1,945	2,053

In the "do minimum" scenarios there is a split between winter and summer. As these scenarios describe each of the airports without development they are comparable to the airports today. The difference between the seasons is limited at Heathrow Airport, but at Gatwick Airport a significant seasonal variation can be observed.

Current restrictions to the number of night flights were preserved insofar as possible. For Gatwick Airport the number of night movements in the "do minimum" scenario was limited to the actual number of night flights in the 2011 schedules. However, the Gatwick Airport "do something" scenario and all Heathrow Airport scenarios forced a limited number of arrivals, from certain markets, into the night period as demand exceeded capacity in the first few hours of operation. These flights went into the shoulder periods and not the core time of the night quota.

As the "do something" scenarios change the characteristics of the airport in terms of daily capacity completely, it was not practical to create these schedules to the same level of detail as the "do minimum" scenarios. A constant hourly capacity limit was adopted throughout the whole year which reflected the hourly movements as proposed by the Scheme Promoters as closely as possible. These limits were relatively increased or decreased so that the daily movements summed over an entire year to the annual capacity limits as discussed in Chapter 2.

Seasonal Variations

The schedule for the base year, 2011, was retrieved from OAG for both Gatwick and Heathrow airports to analyse how the aircraft movements were spread across the year[37]. **Figure 2** shows how the traffic at Heathrow Airport is relatively flat throughout the year: weekly trends are more visible than seasonal differences. Gatwick Airport shows weekly trends, but it is clear that the difference between summer and winter is significant. Note that both airports have a low volume of flights through the Christmas and New Year period.

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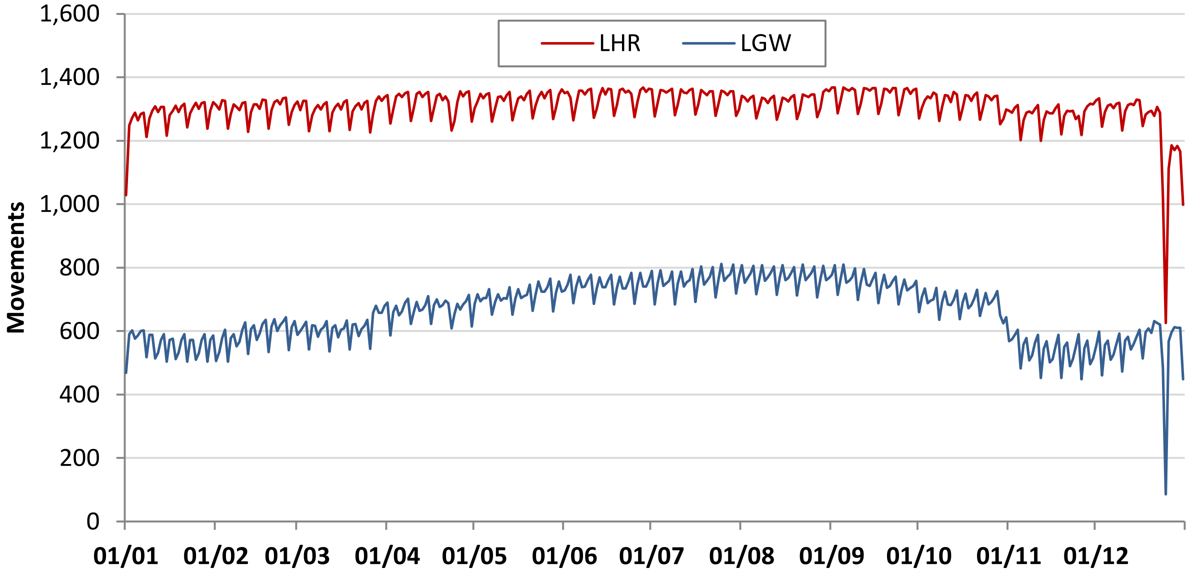
[36] Airport Coordination Limited (ACL) UK – Retrieved from http://www.acl-uk.org on 10th February 2015

[37] Based on 2011 data extracted from OAG Analyser, OAG Aviation Worldwide Ltd. - Data retrieved on 16th June 2014

Figure 2 - 2011 daily movements for London Heathrow (LHR) and London Gatwick (LGW)[37].



As it is important to reflect the seasonal variations in the forecasts, Gatwick Airport Ltd (GAL) and Heathrow Airport Ltd (HAL) were asked to provide four days equally spread in 2011 representing the seasons. Each day served as a starting point for its three month period in the forecast schedule and, therefore, as an indication of the market splits and aircraft types flown typically during that period. The number of movements on those particular 2011 days mattered less for the output as each day was weighed in the overall forecast of the year in order to match the annual ATMs forecast. The days that were submitted and used for the remainder of the methodology are shown in **Table 3** below.

Table 3 - 2011 schedule days as submitted by GAL and HAL

	GAL	HAL
Winter	19/02	16/03
Spring	20/05	15/06
Summer	19/08	14/09
Autumn	18/11	14/12

There is a difference between the number of scheduled flights reported by OAG and the schedules as submitted by the Promoter. However, as mentioned previously, the number of movements on the particular day was scaled up or down according to the yearly demand scenario such that the total number of annual ATMs matched the Airports Commission's demand scenarios.

The following method was applied to the total number of movements for each day to reflect both seasonal and day of the week variations:

- The daily movements in 2011 were expressed as a percentage of the daily limit for the applicable scenario.
- The highest percentage across the whole year represented the busiest day and vice-versa for the lowest percentage. Assuming that the busy days are more likely to be favoured by airlines and will therefore continue to be popular, most growth was assigned to the higher percentage days.

By means of a quadratic formula, growth was assigned more to those busy days and as such, the balance between busy and quiet days was maintained and, indeed, slightly increased.

- If an airport was forecast with such significant growth that the quadratic formula would create a large difference between the busiest and the quietest day of the year, part of the annual growth was uniformly distributed over the year and the remaining growth was assigned using the quadratic formula.
- In this way, the difference between e.g. a Friday in August and a Friday in December was maintained, but equally so was the difference between a Sunday and a Friday in August.
- By checking the annual total of ATMs and altering the distribution in the quadratic formula between the highest and lowest day (the Christmas and New Year period was excluded as being exceptional), the annual ATMs forecast was respected.
- After assigning the growth to each day, daily throughput was tested against the daily capacity as discussed in Section 3. If the growth exceeded capacity for a particular day, it was assumed to be displaced to the two days on each side. This would represent an airline wishing to fly on, for example, a Friday but not being able to and therefore opting for a slot on the Thursday or Saturday instead. Although this behaviour might not always exactly represent reality, at this level of modelling it was considered to be a valid assumption.
- As such, the forecast ATMs are distributed across the year for each of the scenarios in 2030.
- The forecast number of ATMs over each three month period was divided by the number of days in the three month period to generate the ‘average’ day. This exercise was repeated for all five demand scenarios.

SCHEDULE DEVELOPMENT

This section describes the steps and assumptions that led to the development of each schedule.

Market Splits

With the growth assigned to each of the four days mentioned previously, the total number of flights was matched to the market splits of the Airports Commission’s demand scenarios. This required adding flights to certain markets and removing some from others. The global markets or regions that were used were:

- Africa
- Americas
- Australasia
- Europe
- Far East
- Middle East

These regions retain consistency with the noise forecast schedules and were important for allocating traffic across the day.

Time of operation

Based on the 2011 schedule and the demand scenario’s market splits, we determined in which hour a flight to, for example, Europe is most likely to operate during the day. Once each future flight had been allocated to an hour, the hourly capacity limits were checked. If the capacity was exceeded, we allocated those flights to the remaining hours with spare capacity, whilst continually respecting the day/evening/night periods as developed previously for the noise appraisal framework module.

If, for example, a schedule required three additional flights to Europe and one of the flights departs during the 09:00 hour, one departs during the 15:00 hour, and one departs during the 19:00 hour, then the following situation may occur:

- Adding a flight to the 19:00 hour breaches the capacity during these hours by one flight.
- Therefore, this flight was assigned to the next hour, in order to maintain the hourly capacity limit and to respect the day/evening/night split as 19:00 and 20:00 both fall in the evening period.

Fleet Mix

The Airports Commission’s demand scenarios detail the fleet mix by aircraft type by market (as defined in section 3.). As part of the dispersion modelling, these aircraft types were divided into Model Categories (MCATs) by Air Quality Consultants (as described in Appendix B). Per scenario, we allocated a MCAT to each ATM within every market respecting the Airports Commission’s demand scenario.

We carried out several checks to ensure all parameters influencing the daily schedule were respected:

- Market split
- Annual ATMs per MCAT
- Hourly capacity limits of the airport
- Number of departures and arrivals (both by market as by MCAT)

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