SHEFFIELD AND ROTHERHAM CLEAN AIR ZONE FEASIBILITY STUDY

LOCAL PLAN AIR QUALITY MODELLING METHODOLOGY REPORT (AQ2)

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DOCUMENT CONTROL

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1.   INTRODUCTION

1.1   Context

1.1.1   The UK Government has named Sheffield and Rotherham as one of 28 areas in England which contains locations where the annual average concentrations of Nitrogen Dioxide (NO_2) exceed statutory EU Limit Values and are projected to continue to do so over and beyond the next 3-4 years.

1.1.2   Sheffield City Council (SCC) and Rotherham Metropolitan Borough Council (RMBC) have therefore been tasked with developing a joint strategy which will help ensure that their Council areas become compliant with the EU Limit Values 'in the shortest possible time'.

1.2   Overview of this Document

1.2.1   This document is the Air Quality Modelling Methodology Report (AQ2) which explains in detail how the model will be used to assess the air quality implications of the intervention options tested. This report provides information covering the key requirements as listed in the JAQU guidance for the "Evidence Package":

- A description of the methods used, including: the choice of model, the choice of modelling domain, the years modelled and details of the NO_2 from NOx calculations.
- Details locations and type of monitoring data (automatic and diffusion tubes) used for the model validation (provided in Supporting Document SD01).
- Details of how outputs from the transport model will feed into the air quality modelling.
- A description of the methods used to assess the impacts of changes in primary NO_2 emission fraction (f-NO_2) between the model base year, projection years and projection years with measures. f-NO_2 has been calculated for each road link for each relevant future year.

1.2.2   This report is part of the Initial Evidence Submission and will be updated in response to feedback from JAQU. The current version of this report has been written after the baseline (Business as Usual) modelling. It will be updated and resubmitted as part of the Outline Business Case and Full Business Case submissions.

1.3   Structure of this Document

1.3.1   The remainder of this document is structured as follows:

- Section 2 details the Air Quality Model including how NOx emissions data are calculated from the transport model and input to the Air Quality Model;
- Section 3 details the dispersion modelling for NOx;
- Section 4 describes the verification of the model;
- Section 5 describes the process by which f-NO_2 is calculated and forecast; and
- Section 6 provides a conclusion based on the information presented.

2. AIR QUALITY MODEL VERSION

2.1 Introduction

2.1.1 This section gives a description of the methods used, including: the choice of model, the choice of modelling domain, the years modelled and details of any NO_2 from NOx calculations.

2.2 Airviro

2.2.1 Air dispersion modelling of pollutants from a number of roads, points and diffuse sources within the Rotherham and Sheffield domain has been carried out using the Airviro v4.00.61_ct64® dispersion model (Estonian Environmental Research Centre (EERC), Eesti Keskkonnauuringute Keskus OU and Apertum IT AB**)**. The years modelled were 2017 and 2021 as well as other projected future years as required.

2.2.2 Airviro has been continuously developed since 1990 and has many users all over the world. It has been used in a number of intra-urban exposure studies in recent years (Korek et al., 2016; Jadaanet et al., 2016; Jerrett et al., 2004; Pierse et al., 2006). Its main advantage is being a web-based environmental management tool with embedded Geographical Information System (GIS) features which enables its application at urban and regional levels. In addition, it contains a dynamic emission database which allows for storage of static as well as dynamic emission characteristics for a large number of pollution sources, the latter is mainly used to characterise time-varying emissions from road, area and industrial sources. For example, Airviro calculates primary pollutant emissions for each road by utilising a database of updated information on the type of vehicle journeys, average daily traffic flows, speeds and vehicle mix.(SMHI, 2004).

2.2.3 SCC and RMBC have used the Airviro system for air quality modelling, time series data collection and validation continuously for over 18 years, in partnership with Doncaster and Barnsley Councils, therefore has become our model of choice.

2.2.4 Met data for all years from 1999 is stored as a time series for all the key parameters and this is used for the dispersion calculations. Most of the met data has been collected from a local weather mast within Sheffield. A meteorological pre-processor routine within the Airviro software tool analysed the local weather data obtained from the weather mast within Sheffield City, including the wind direction, velocity (see wind rose below) and vertical temperature profiles. These were used to determine the boundary layer scaling parameters – surface friction velocity and the Monin-Obukhov length. The wind fields were simulated using the diagnostic wind model available in the tool, which took into account the effects of topography, surface roughness and surface heating/cooling. Surface roughness describes the amount of near-ground turbulence that arises as a consequence of surface characteristics, such as land use (e.g., agriculture, lakes, urbanisation, woodland, open parkland, etc.). Farming areas may have a surface roughness of approximately 0.2m to 0.3m whereas built up cities, such as Sheffield and Rotherham, and woodlands may have a roughness of 1 to 1.5m. The wind field calculation is based on the concept first described by Danard (1976), "where mesoscale winds are generated by using:

- horizontal momentum equation

- pressure tendency equation

- first thermodynamic equation

This concept assumes that small-scale winds can be seen as a local adaptation of large scale winds (free winds) due to local fluxes of heat and momentum from the sea or earth surface. Any non-linear interaction between the scales is neglected. Danard assumes that the adaptation process is very fast, 1.5 hours for model resolutions of 10*10 km. It is also assumed that horizontal processes can be described by non-linear equations while the vertical processes can be parametrised as linear functions."[1]

The Gauss model cannot resolve buildings and other large elements. These elements, for example, an urban area with buildings and street canyons of many different length scales, are parameterised as increased surface roughness. The wind field generated has one unique resolution regardless of the size or scale of the dispersion area, which depends upon the input of topographic and physiographic information. The physiographic information used in the modelling generates a local wind field with a 100m x 100m grid. The topography data allows the wind field generated within the dispersion calculation to better reflect the impact of funnelling effects of land forms and greater resolution of the land use, including building heights on the surface roughness effects.
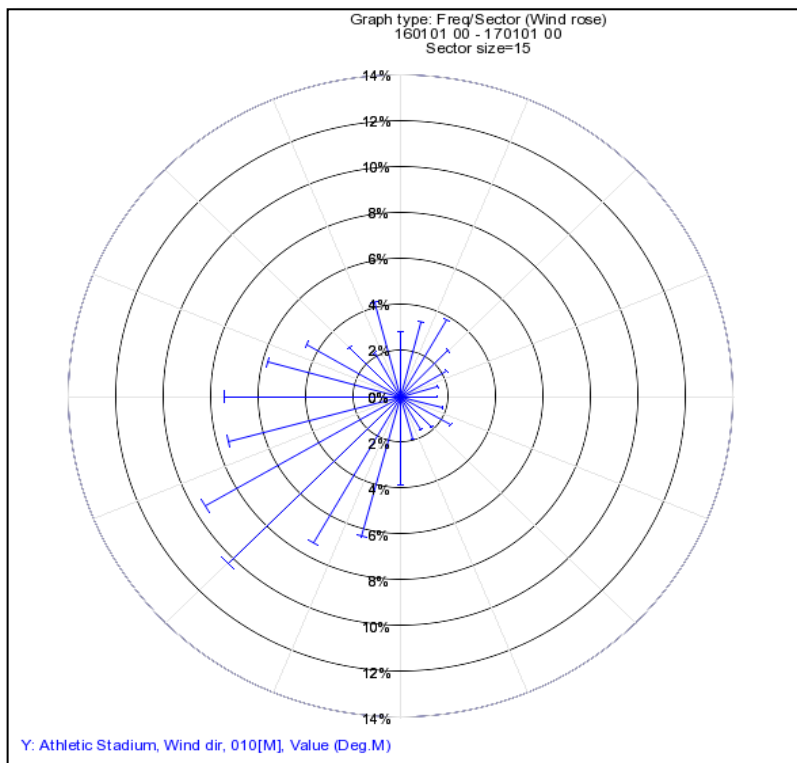

Figure 1 – Wind Rose for year 2016 Weather Data

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[1] Appendix 2A: The Wind Model - Calculation of the Wind Fields. Airviro User's Reference (Apertum): Working with the Dispersion Module
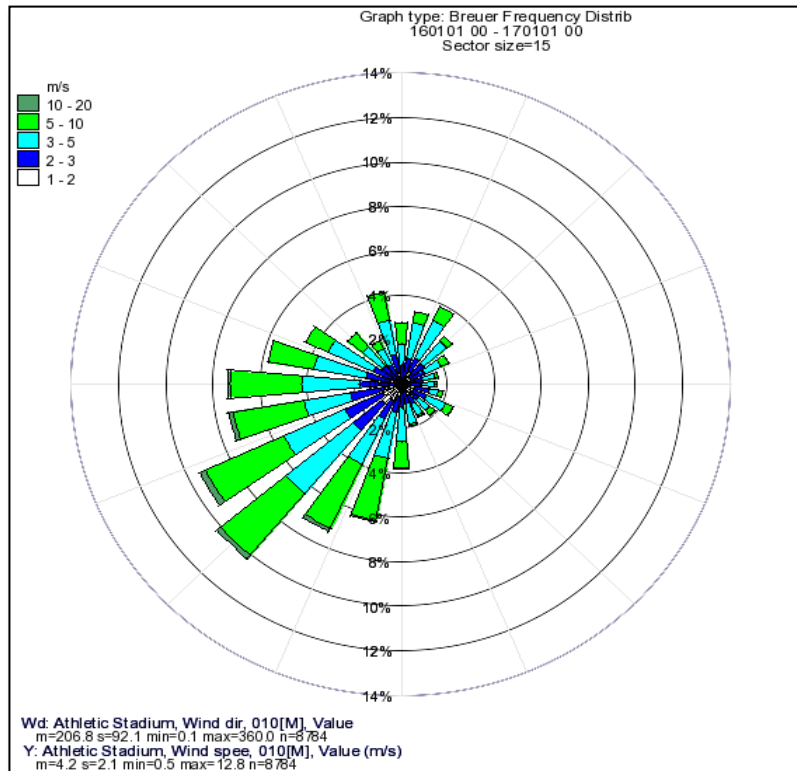
Figure 2 – Breuer Frequency Distribution (Wind Rose) for year 2016 Weather Data, with addition to sub-classes in each wind direction class

2.2.5 Rotherham and Sheffield Councils have used Airviro v4.00.61 dispersion model to simulate vehicle emissions of NOx from all major and minor road sources within the area, including, all the pollution climate mapping (PCM) road links as defined by Defra[2]. Emissions from industrial (point and area sources) domestic emissions (area sources) and background were also simulated in the same calculation. Each simulation run included the area-wide domain, and concentrations for NOx were estimated using Airviro's Gaussian model. The methodology adopted, to model vehicle emissions within Airviro adheres to the modelling criteria agreed with the Joint Air Quality Unit (JAQU) as per the Air Quality Tracking Table AQ1 (appended and previously submitted and agreed with JAQU).

2.2.6 The 2017 Base Year and 2021 Baseline projected vehicle fleet composition have been modelled for this work. The 2017 was based on current fleet from a full year of local Automatic Number Plate Recognition (ANPR)-based fleet profile data (Dec 2016 to Nov 2017). Data for the local bus fleet has been supplied by First Group and Stagecoach in Rotherham and Sheffield so represents a good data source for the majority of the fleet. This fleet composition was then forecast forward into the future using EFT-based 'Business as Usual' year on year proportional growth with new fleet types introduced in the relevant years they are expected to come on line. 'Do Something' Fleet Assumptions for the CAZ

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[2] Defra PCM data referred to in this document is based on '*2017 NO_2 projections data (2015 reference year)*', obtained from https://uk-air.defra.gov.uk/library/NO_2ten/2017-NO_2-projections-from-2015-data, accessed October 2017

scenarios have, in addition to the 'Business as Usual' forecasts, further changes to the fleet make-up as per JAQU Guidance.

2.2.7   Airviro models NOx sources across the whole domain. We used a similar methodology to one of those used by Leeds City Council for their CAZ Feasibility Study. The basic modelled grid size across the domain was a 250m x 250m grid (spatial resolution). This grid size was reduced to a 10m receptor grid when within 50m of a modelled road, point or line source emitting more than 0.000001g/s. This approach resulted in reasonable model run times.

To do this, the "Quad Grid" function within Airviro Dispersion module was used, with the threshold emissions value set to > 0.000001 or 1e-06g/(s*m) to ensure all road links with a noticeable emission rate are included

2.2.8   The road NOx output and that simulated for the domain NOx emissions from industrial (point and area sources) domestic emissions (area sources) and background concentrations in a separate calculation, can be combined for NOx to NO_2 conversion. Airviro can then be used to apply an empirical photochemical algorithm for conversion of NO_x to NO_2 concentrations (Derwent and Middleton). This algorithm utilises representative historical NO_x and NO_2 measurements from local monitoring stations and it is based on the statistical relation between the NO_2 / NO_x ratio to the absolute NO_x level, which considers the ratio to be normally higher for low NO_x concentration values (SMHI, 2004). However, for technical reasons, the Defra NOx to NO_2 calculator v6.1 was used for the conversion of NOx to NO_2.

2.3   Traffic Data for input to the air quality model

2.3.1   The annual average daily traffic (AADT) for each relevant year and scenario is derived from the Sheffield and Rotherham Transport Model, SRTM3B. This has a SATURN (Simulation and Assignment of Traffic to Urban Road Networks traffic model) based highway assignment module, which has been partially updated by SYSTRA for the CAZ Feasibility Study. The model outputs provide average weekday traffic volumes by vehicle class/purpose and speeds by road link for four periods covering the hours 0700-1900. For scenario modelling, Car, LGV and HGV user classes are split into compliant and non-compliant vehicles to allow any diversion impacts of a CAZ to be modelled. Buses, Black Cabs and PHV's are also modelled as fixed flows on each link and also split into compliant and non-compliant segments.

2.3.2   The subsequent traffic model outputs are vehicle flows on links which are converted to annual average daily volumes using locally derived annualisation factors (these are different in Sheffield, Rotherham and on the Parkway). For the purposes of the air quality modelling these were broken down into four time periods by vehicle class and compliance (cars, LGVs, HGVs and PSVs).

- AM Peak   0700 – 1000Hrs
- Inter-Peak   1000 – 1600Hrs
- PM Peak   1600 – 1900Hrs
- Off-Peak   1900 – 0700Hrs

2.3.3   The vehicle classes within SRTM3B were subsequently proportioned into fuel and body type sub classes based on data collected by classified traffic counts and the ANPR data across a number of representative sites within Sheffield and Rotherham. As we have collected 12 months ANPR data at most sites, we have a good understanding of the local vehicle fleet composition. As part of this process Black Cabs and private hire vehicles (PHV) were flagged

so we could identify them as separate from private cars (essential for any CAZ Feasibility Study which may target taxis).

2.3.4   In terms of the local bus fleet, as DVLA do not hold data on retrofitting and only provide the Euro standard based on first registration, we have obtained data from the South Yorkshire Passenger Transport Executive, who provide quarterly updates on the actual Euro classes of all buses operating in Sheffield and Rotherham. Both Rotherham and Sheffield have Voluntary Bus Partnerships setting Euro class standards, and several retrofitting schemes have successfully upgraded some of the Rotherham and Sheffield bus fleets.

2.4   Road Traffic Emission Calculations

2.4.1   The road emissions calculations are undertaken in ENEVAL[3]. ENEVAL takes outputs from a Highway traffic model (speeds, flows and link lengths) and uses the following inputs to convert these data into emissions:

- Emission Rate calculation coefficients – COPERT 5 (EEA, 2016);
- Emissions Factors for Alternative Vehicle Types (Ricardo 2013);
- Fuel Scaling parameters (NAEI 2014);
- Fleet split data (Ricardo 2017);
- Mileage Degradation Factors (TRL 2009);
- Catalytic Converter Failure rates (Ricardo 2013); and
- Tyre, break and abrasion emissions rates (Ricardo 2009).

2.4.2   These data sources are all consistent with the latest version of DEFRA's Emissions Factor Toolkit (EFTv8.0.1b)[4].

2.4.3   ENEVAL then outputs the following emission types:

- Oxides of Nitrogen – NOx;
- Particulate Matter – PM_{10};
- Fine Particulate Matter – $PM_{2.5}$;
- Hydrocarbons – HC;
- Carbon Dioxide- CO_2;

2.4.4   The ENEVAL program calculates these emissions for 778 different fleet types for which there are distinct emissions formulae[5], with different coefficients based on the inputs from COPERT 5.

2.4.5   ENEVAL also takes into consideration junction based queuing emissions. Junction delays are characterised by stop/start driving conditions, which have a different emission rate from either free-running, or stationary 'idling' vehicles. Since using idling engine emissions rates would underestimate the emissions, we use an assumption that stop start queuing has an average speed of the lowest speed at which a given link based function is valid. This is only undertaken where there are modelled junctions in SATURN.

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[3] ENEVAL (Environmental EVALuation) is SYSTRA's Environmental Analysis software which calculates tailpipe emissions from traffic models

[4] https://laqm.defra.gov.uk/documents/EFTv8-user-guide-v2.pdf

[5] Too many different formula to list here

2.4.6   The junction delay emission rate is then given by the formula below, using the min kph value for which a particular emissions formula is valid. It is divided by 3600 to convert the speed in kilometres per second.

Junction Delay Emission Rate (g/s) = 5kph Emission Factor (g/km per veh) x min (kph) / 3600

2.4.7   The total junction emissions are then calculated by multiplying this by the total junction delay in seconds, which is calculated by adding the times of all relevant vehicles at the junction.

2.4.8   So, as to not double count emissions the length of the link used for the calculation of link based emissions must be reduced by the length of the queue at the junction. This is, calculated as follows:

Queue (km) = (Total Junction Time(s) x min (kph) / 3600)/ No. of Lanes

2.4.9   It is assumed that any queuing cars are spread evenly over all lanes on the road.

2.4.10   In the case when the Queue is greater than the link length we assume the queuing occurs along the full length of the link and the length of the free flowing section of the link is therefore assumed to be zero.

2.4.11   The NOX emissions from links and junctions are then combined and it is these emissions which are input into the dispersal model, which is described in the next section.

3.   NOX EMISSIONS DISPERSION MODELLING

3.1   Introduction

3.1.1   The annual emissions of NOx calculated for each road-type and time period were linked to a georeferenced Shapefile representing the road centre lines of the network modelled within the Rotherham and Sheffield Transport Model. The georeferenced shapefile was then loaded in the Airviro model to ensure geospatial consistency between each model.

3.1.2   Airviro is set up to generate an emission database (EDB) which proportions the emissions calculated for each time period by the number of hours within each time period to create hourly emission rates (in g/s). The emission rates are also proportioned between weekdays, Saturdays and Sundays based on the relationship of traffic flows on these day-types compared with the AADT flows used to calculate the emissions.

Figure 1   Example of the Time and Day-type Variation in the Emissions Rate Allocation for Each Modelled Road Link

● Day type variation

	Mon-Thu	Fri	Sat	Sun
00 - 01	66	66	163	235
01 - 02	34	34	114	166
02 - 03	24	24	93	126
03 - 04	17	17	48	68
04 - 05	30	30	38	41
05 - 06	127	127	109	80
06 - 07	248	248	158	114
07 - 08	623	623	270	159
08 - 09	796	796	426	199
09 - 10	585	585	549	393
10 - 11	542	542	677	673
11 - 12	571	571	776	794
12 - 13	594	594	834	908
13 - 14	616	616	817	860
14 - 15	620	620	765	796

3.1.3   Model runs can be set up to apply meteorological data representing any calendar year to simulate the dispersion of the emissions and calculate the annual average concentration of NOx derived from the modelled road network. The meteorological data can be input as a time series covering every hour of any particular year. These model runs could be considered to be the closest representation of reality, however, they take about 14 day processing time. In order to run the number of scenarios required for this study, a 'scenario' of representative annual weather for Sheffield and Rotherham was created from our meteorological data for the baseline and scenario testing. Consequently, model runs have taken 2 days to be complete.

3.1.4   The Airviro model calculates the concentration of NOx at all locations within the modelled domain. Predicted concentrations of NOx calculated at some receptor points representing the locations of monitoring data collected in 2017 were used to validate the model, in accordance with LAQM TG16 guidance, and to generate modelled NOx values for output to the NOx to NO_2 calculator v6.1. As a large area (Sheffield and Rotherham) is modelled, on occasion, road NOx is factored for different road links and zones within the domain.

3.2 NO_2 Concentration Calculations

Industrial, commercial and domestic sources

3.2.1   Industrial, commercial and domestic sources for Rotherham and Sheffield are represented in Emission Data Bases in the South Yorkshire Airviro system. They include all known industrial emission sources such as biomass power plants, steel works, non-ferrous metal processes, and incinerators. As South Yorkshire is still an industrial area, it is important to include these sources in any modelling exercise. Many sources are represented as point sources within the system. The emissions data is derived from either the operator or the Environment Agency. Some sources which are more difficult to pin point in terms of exact position such as domestic heating and minor roads are entered as 1km x 1km grid squares.

3.2.2   Background NOx concentrations across Sheffield and Rotherham were derived from the DEFRA Background Maps.

3.2.3   The modelled NOx values calculated for the 2017 base year are compared with monitored data. The validation process confirmed the overall performance of the dispersion modelling and is described in AQ3. The factor for adjusting road NOx in particular were applied to future scenario and future year model runs.

3.2.4   For future years, the transport emissions are calculated for each scenario and entered into a new EDB. Dispersion calculations are then run to predict future NOx concentrations. The NO_2 annual mean values for future years are calculated using Defra's NOx to NO_2 calculator v6.1. This is described more fully in AQ3.

4.   VERIFICATION

4.1.1   Prior to completion of the model verification exercise, the key data and information used within the verification study were subject to appropriate quality assurance in accordance with LAQM TG16 and the respective limitations identified in terms of their application within the air quality modelling. The key data and information include:

- Traffic data, comprising time period flows (AM, PM, inter-peak, off-peak) and average speeds
- Vehicle fleet composition
- Existing Sheffield and Rotherham roads configuration
- Sheffield and Rotherham monitoring locations and associated annual mean NOx / NO_2 concentration (see Supporting Document SD01)

5.   F-NO_2 CALCULATION AND FORECASTING

5.1.1   Nitrogen oxides (NOX) are emitted from combustion engines in two forms:

- Nitric Oxide (NO); and
- Nitrogen Dioxide (NO_2).

5.1.2   The fraction emitted directly as NO_2, known as f-NO_2, is of particular importance for air quality modelling. Different vehicle types emit different proportions of f- NO2, with diesel engines in particular producing higher levels of f-NO_2 compared with petrol vehicles.

5.1.3   The European Environment Agency published f-NO_2 proportions by vehicle type and Euro Class[6]. SYSTRA created a post-ENEVAL process to apply these proportions to the NO_X outputs in order to produce f-NO_2 for each link in the traffic model. [Note: As set out in the Air Quality Modelling Tracker Table Airviro will take NOx, derived within ENEVAL, as input.] The Airviro dispersion module will calculate the annual average NOx concentration throughout the modelled domain and specifically at each receptor.

5.1.4   Forecast levels of f-NO_2 can also be output using the outputs from ENEVAL using the same process described above, with future f-NO_2 changing as the vehicle fleet changes.

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[6] https://www.eea.europa.eu/publications/emep-eea-guidebook-2013/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-road-transport/view - This is consistent with the DEFRA NOx to NO2 tool version 5.1 released in June 2016.

5.1.5 The calculated or forecast f-NO$_2$ was then used in the NOx to NO$_2$ calculator v6.1 to calculate Total NO$_2$ at the identified receptor locations in the appropriate unit of micrograms per cubic metre (μg.m^{-3}).

6. CONCLUSION

6.1.1 This report has provided information covering the key requirements as listed in the JAQU guidance for the Initial Evidence Submission by providing an overview of the air quality modelling process, including a description of the methods used. This document also supplements the information provided in the Local Plan Air Quality Modelling Tracking Table (AQ1) and provides a detailed understanding of modelling processes undertaken.