Southampton Clean Air Zone – Air Quality Modelling Methodology Report (AQ2)

Report for Southampton City Council

ED 10107 | Issue Number 5 | Date 17/12/2018

Customer:

Southampton City Council

Customer reference:

Southampton CAZ Feasibility Study

Confidentiality, copyright & reproduction:

Contact:

Guy Hitchcock

Ricardo Energy & Environment

Gemini Building, Harwell, Didcot, OX11 0QR, United Kingdom

t: +44 (0) 1235 75 3327
e: guy.hitchcock@ricardo.com

Ricardo-AEA Ltd is certificated to ISO9001 and ISO14001

Authors:

Guy Hitchcock, Andy Lewin, Tim Scarbrough, Nicola Masey

Approved By:

David Birchby

Date:

17 December 2018

Ricardo Energy & Environment reference:

Ref: ED10107- Issue Number 5

Table of contents

Appendices

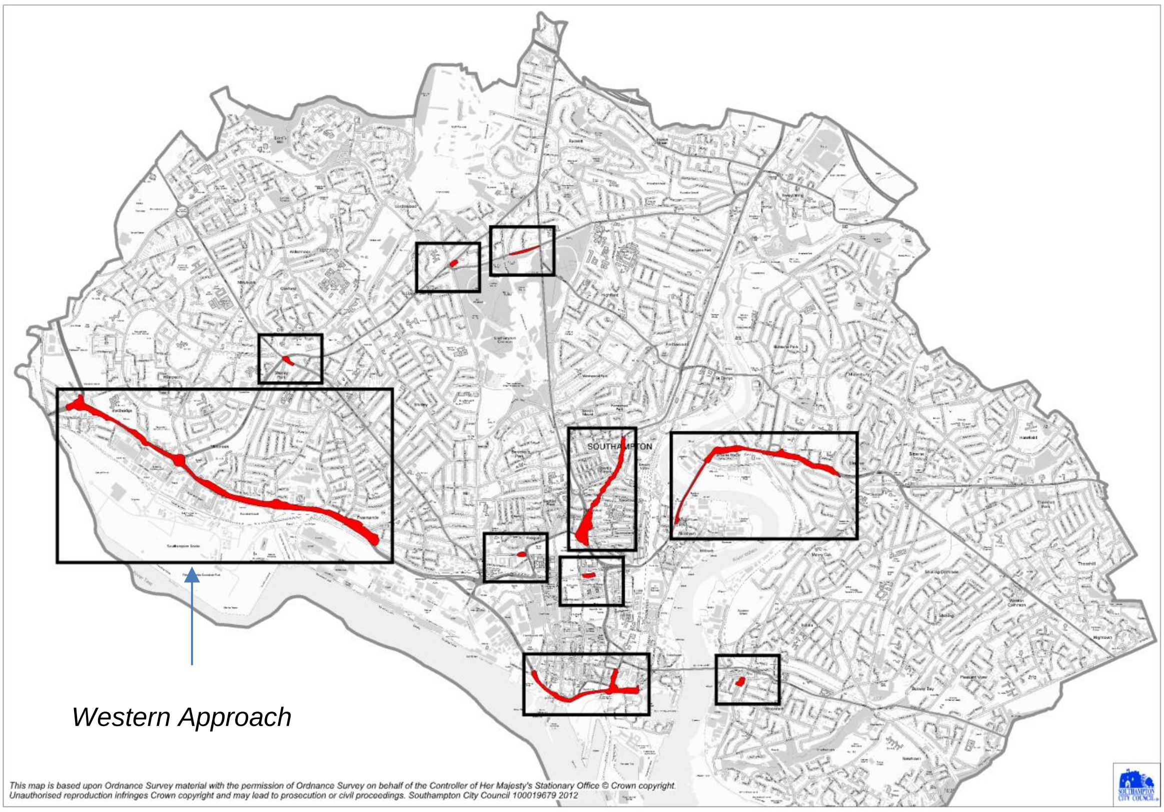
1 Introduction and outline modelling scope

Southampton City Council is one of the initial five cities ('first wave') that were required to carry out a Clean Air Zone (CAZ) Feasibility Study by the Government for non-compliance with the NO_2 limit values. This report sets out the Air Quality modelling methodology used for this study. It is an update on the version of this report provided with the Outline Business Case (OBC) and reflects any changes that have been made in the air quality assessment used for the Final Business Case (FBC).

1.1 Background

Southampton like many other urban areas, has elevated levels of Nitrogen Dioxide (NO_2) due mainly to road transport emissions. Emissions from the port related activity also contribute to pollution concentrations in key locations such as the Western Approaches into the city. As such Southampton City Council (SCC) has designated 10 Air Quality Management Areas (AQMA) across the City where concentrations of NO_2 breach Government, health-based air quality objectives as shown in Figure 1.

Figure 1 Southampton Air Quality Management Areas (AQMA)



At the national level the EU has commenced infraction proceedings against the UK Government and Devolved Administrations for their failure to meet the EU Limit Value for NO_2. In 2015, the Supreme Court ordered the Government to consult on new air pollution plans that had to be submitted to the European Commission no later than 31 December 2015. As such DEFRA released plans[1] to improve air quality, specifically tackling NO_2, in December 2015. The Plans identify 5 cities outside London,

[1] https://www.gov.uk/government/publications/air-quality-in-the-uk-plan-to-reduce-nitrogen-dioxide-emissions

including Southampton, where the EU Limit Value for NO_2 are not expected to be met by 2020. The Plans state that each of the cities identified could be legally required to introduce a formal charging-based Clean Air Zone (CAZ) for specified classes of vehicles and European Vehicle Emission Standards (Euro Standards) as soon as practical but no later than 2020.

The key area identified by the DEFRA plan that was forecast to exceed the limit value in 2020 is the Western Approaches AQMA. This area was the focus of a study on a Low Emission Zone undertaken by Southampton City Council in 2014[2]. The study showed that road transport emissions accounted for between a third and two thirds of modelled levels of NOx in certain locations and port activities contributed up to a third of levels at Millbrook.

Building on the 2014 study Southampton commissioned a wider based Low Emission Strategy study to assess options for reducing emissions from transport across the city. This study provided the basis for Southampton's approach to developing a Clean Air Zone, based on cost benefit assessment of potential emission reduction measures. The study set out a potential charging Clean Air Zone and a range of non-charging or supporting measures.

Subsequent work by DEFRA updated its air quality plan using more recent information on the expected real-world emission performance of vehicles. This latest analysis is suggesting that emission from vehicles will be higher than previously estimated and so breaches of the air quality limits are likely to persist for longer and over a wider area.

The current study has carried out a fully updated assessment of air quality in and around Southampton in relation to the European limit value for NO_2 using the latest data on emission factors and traffic activity. This assessment has been used to establish the extent of any air quality compliance issues in Southampton and to assess the options needed to solve these compliance problems. A first full assessment of the baseline air quality and potentially mitigation measures was reported in March 2018. This was further refined for full OBC submission in July 2018 and used as the basis of a public consultation of the proposed measures.

As part of the consultation work detailed engagement was carried out with key stakeholders, in particular the Port of Southampton, to review the underlying data and assumptions supporting the analysis. Following this review and wider feedback from the consultation the analysis has been updated to provide the most robust evidence available. Changes to the modelling methodology and assumptions are reported in this update to AQ2 with the final results being provided in the results report AQ3.

1.2 Outline scheme options

The Low Emission Strategy (LES) study developed a package of measures to reduce emissions covering all key transport modes in the city: cars, freight, buses and taxis. This provided the initial evidence for a potential city wide Clean Air Zone charging scheme and a package of non-charging measures that could be considered as an alternative.

Although a formal Low Emission Zone (or charging CAZ) was not assessed as part of the LES, potential elements of such a scheme were considered including: Euro VI standards for city centre deliveries; a ULEV standard (Euro VI plus 30% lower CO2) for buses on key bus corridors; emission standards in taxi licensing. These elements effectively constituted a class B CAZ based mainly around the city centre.

---

[2] Low Emission Zone Feasibility Study, Western Approaches, Ricardo AEA/LES Ltd 2014

In terms of a non-charging CAZ specific measures were considered for targeting vehicle movements to and from the port, along with measures to manage buses emissions, taxi emissions and freight emissions. Over the course of the study the measures have evolved through consideration of the air quality results and consultation with key stakeholders both within the city council and externally such as the bus and freight companies, the port and neighbouring authorities.

In defining options for the charging CAZ a long list of options has been considered and was sifted down to a short list of 3 options for detailed assessment. The long list of options considered is presented in Table 1. This was considered to provide a range of scheme options for a charging CAZ to allow for sifting and selecting the most appropriate. The potential boundaries are illustrated in Figure 2.

Table 1 – Long-list of CAZ options

	Scenario	Red	Blue	Brown WA+CC	Brown WA+CC	Brown CC	Brown CC
		Citywide	Outer RR	inc Inner RR	exc Inner RR	inc Inner RR	exc Inner RR
1	Citywide B	B					
2	Citywide C	C					
3	Citywide D	D					
4	OuterRR B		B				
5	OuterRR C		C				
6	OuterRR D		D				
7	Inner WA+CC (Inc InnerRR) B			B			
8	Inner WA+CC (Inc InnerRR) C			C			
9	Inner WA+CC (Inc InnerRR) D			D			
10	Inner WA+CC (Exc InnerRR) B				B		
11	Inner WA+CC (Exc InnerRR) C				C		
12	Inner WA+CC (Exc InnerRR) D				D		
13	Citywide Doughnut BD	B				D	
14	Citywide Doughnut BC	B				C	

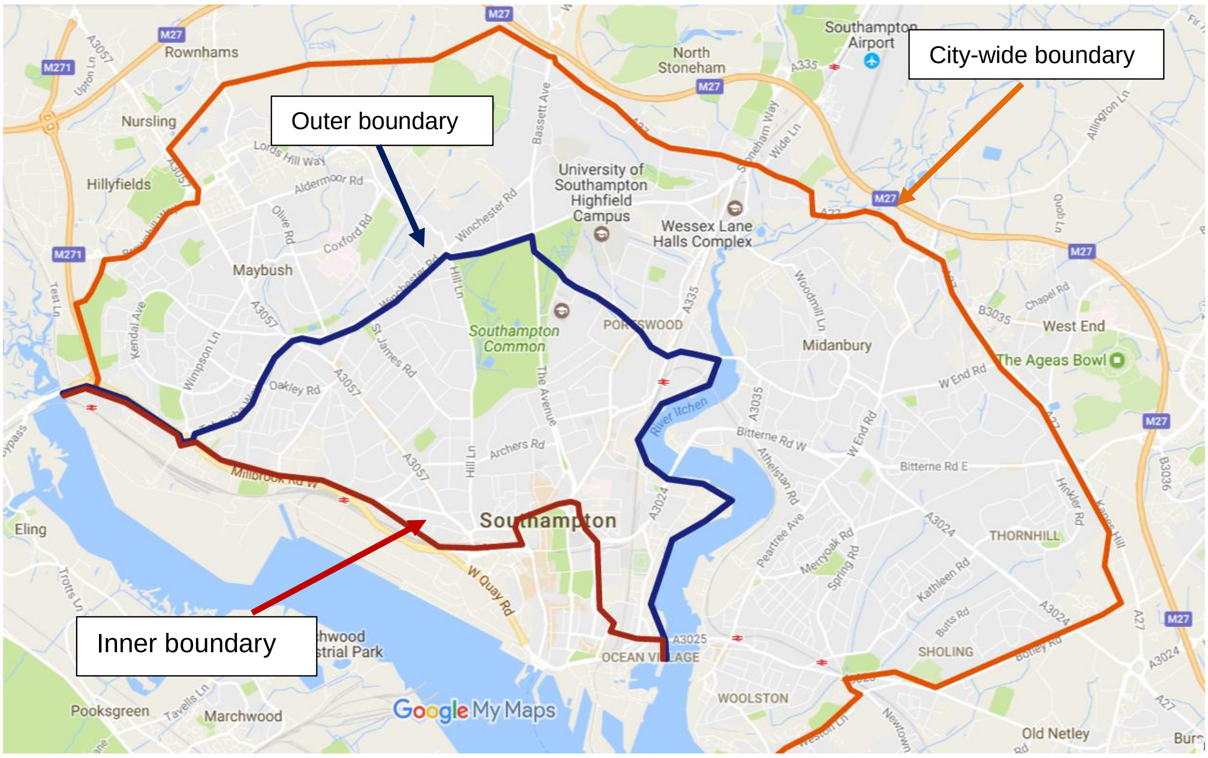
The sifting of the long list was based on simplified transport model runs covering:

- Changes in flows of compliant and non-compliant vehicles, weighted by average emissions, to provide an estimate of change in emissions;
- Transport impacts covering: change in total vkm on the network, change in travel time on the network, change in delays at key junctions;
- Simplified ranking of costs and revenues.

Based on this a set of 3 charging CAZ options along with a potential package of non-charging measures was assessed for the OBC as set out below:

- Option 1 – a citywide Class B CAZ;
- Option 1a – a city wide HGV charging scheme complemented by a buss traffic condition based on Euro VI for the city centre and incentives to upgrade taxis;
- Option 2 – a city centre Class A CAZ, complemented by bus retrofit grants, taxi upgrade incentives, an expansion of the freight consolidation centre and related DSP initiative and work with the port on promoting Euro VI HGVs
- Option 3 – a non-charging CAZ comprising a bus traffic condition for Euro VI buses in the city centre supported by retrofit grants, taxi upgrade incentives and the freight measures from option 2.

Figure 2 Illustrative CAZ boundaries



Following the consultation and wider engagement with key stakeholders three scenarios were taken through for assessment within the final full business case:

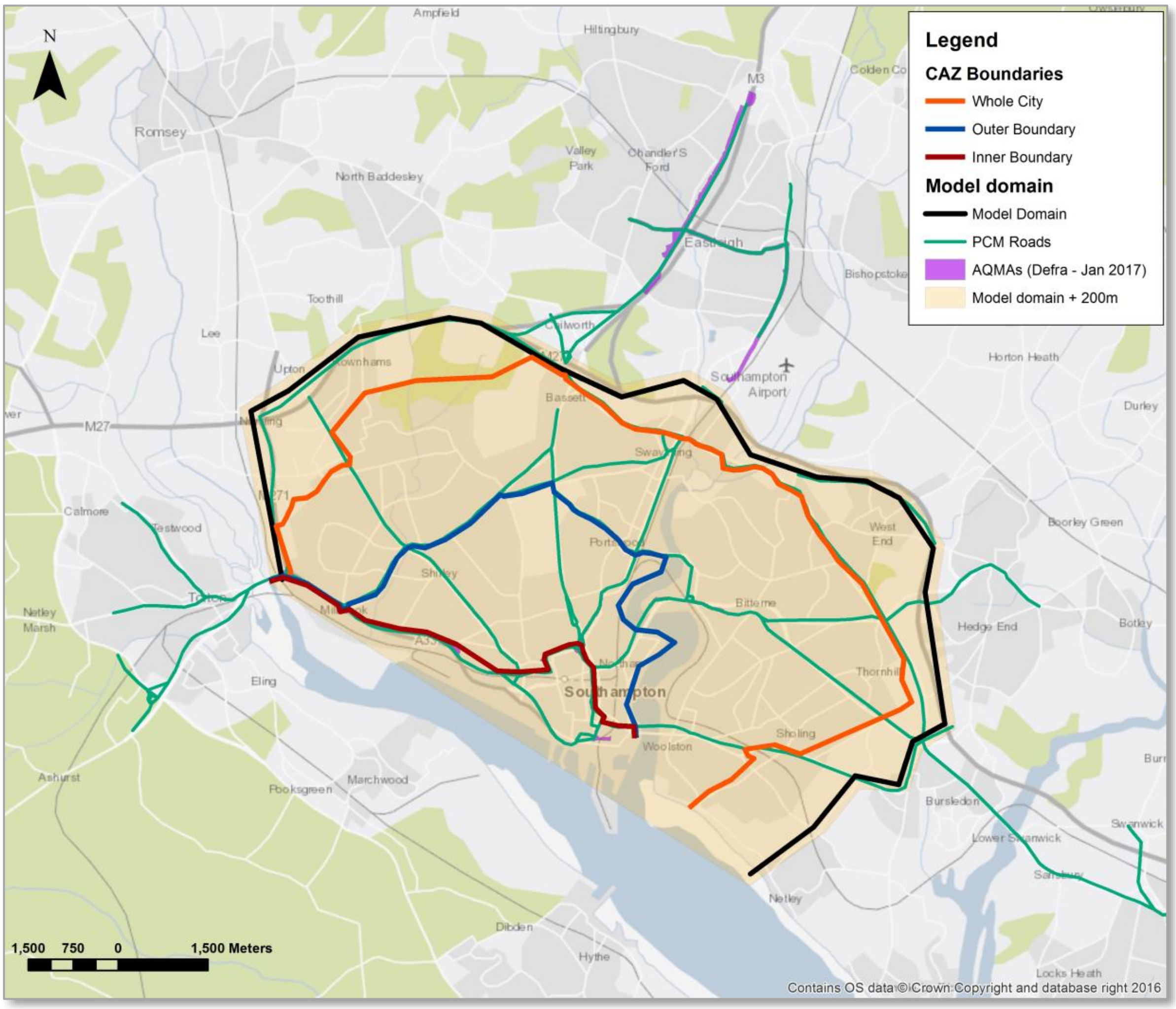
- *The 'do minimum' baseline* – this is the updated baseline with revised assumptions plus the inclusion of measures that have already received funding from the Government's 'Early Measures Fund'
- *The non-charging CAZ package* – covering the freight, bus and taxi measures, refined from the original option 3 non-charging package, plus some additional measures agreed with the port.
- *A City-Wide Class B charging CAZ* – as defined for the OBC.

1.3 Modelling domain and years

In carrying out the modelling of the transport and air quality impacts of the options a model domain is required that covers the scheme options, relevant AQMAs and potential diversion routes. Therefore, the model domain shown in Figure 3 has been used to cover the following:

- All the AQMAs in Southampton including the main area of concern from the national modelling assessment along the Western Approach;
- The wider transport network out to and including the M27 and M271 which will cover all the likely key diversion routes should vehicles seek to avoid the AQMA

Figure 3 Model domain



Two key model years are used in the modelling work: a 2015 base year and a target implementation year for the CAZ of 2020. The base year is taken as 2015 as this is the base year for the most recently validated transport model covering the area. To compliment this 2015 air quality data has been used to validate the air quality model. In addition, we have interpolated interim years between 2015 and 2020.

Table 2 Model years

Year	Description
2015	**Base year** – using latest available data on air quality and transport.
2016-2019	**Interim years** – interpolated between the base and implementation year.
2020	**Implementation year** – latest date when CAZ scheme is due to be in place.

1.4 Background modelling

The primary cause of the air pollution problems in Southampton is related to traffic activity and the impact of the CAZ will target this traffic activity. As such the focus of the modelling is the transport emissions. However, there are several other background sources that are important, particularly in Southampton, and have been covered specifically in the modelling work:

- Emissions from port related activity – including both vessels and onshore port activity;
- Industrial emissions related to the Viridor incinerator and the gas power station both located just opposite the port in the Marchwood industrial site.

The details of how these sources have been treated, particularly the port, and their relation to the wider background is described in section 4.3.

2 Details of the Modelling Domain

The core air quality model domain covers the area of Southampton bounded by the M271 and M27 motorways to the north and west (but includes these links) and extends south to Southampton Water and east as far as Netley. Displacement of traffic due to the implementation of a charging CAZ is not expected to occur beyond the proposed model domain and the sub-regional traffic model used in the study (discussed in 'Transport Modelling Methodology Report' and built and run by SYSTRA) has been chosen as it fully encompasses the affected areas.

A map showing the extent of the air quality domain relative to the initial CAZ zones and the associated traffic model network is presented in Figure 4. A map showing the model domain relative to roads included in the national Pollution Climate Mapping (PCM) model is presented in Figure 5. All road links in the PCM model pertinent to Southampton are included in the model domain specification.

Southampton City Council has declared 10 Air Quality Management Areas (AQMA's) across the city to date, all of which are within the proposed model domain. A map showing the locations of the AQMA's relative to the model domain is presented in Figure 6

All of Southampton City Council's 2015 NO_2 roadside measurements will be used in the air quality modelling assessment to verify the model outputs, assuming data capture and QA/QC are satisfactory for the 2015 baseline year. A map showing the sites at which NO_2 concentrations were measured during 2015 is presented in Figure 7.

Figure 4: CAZ study domain and relationship to SYSTRA's sub-regional transport model links

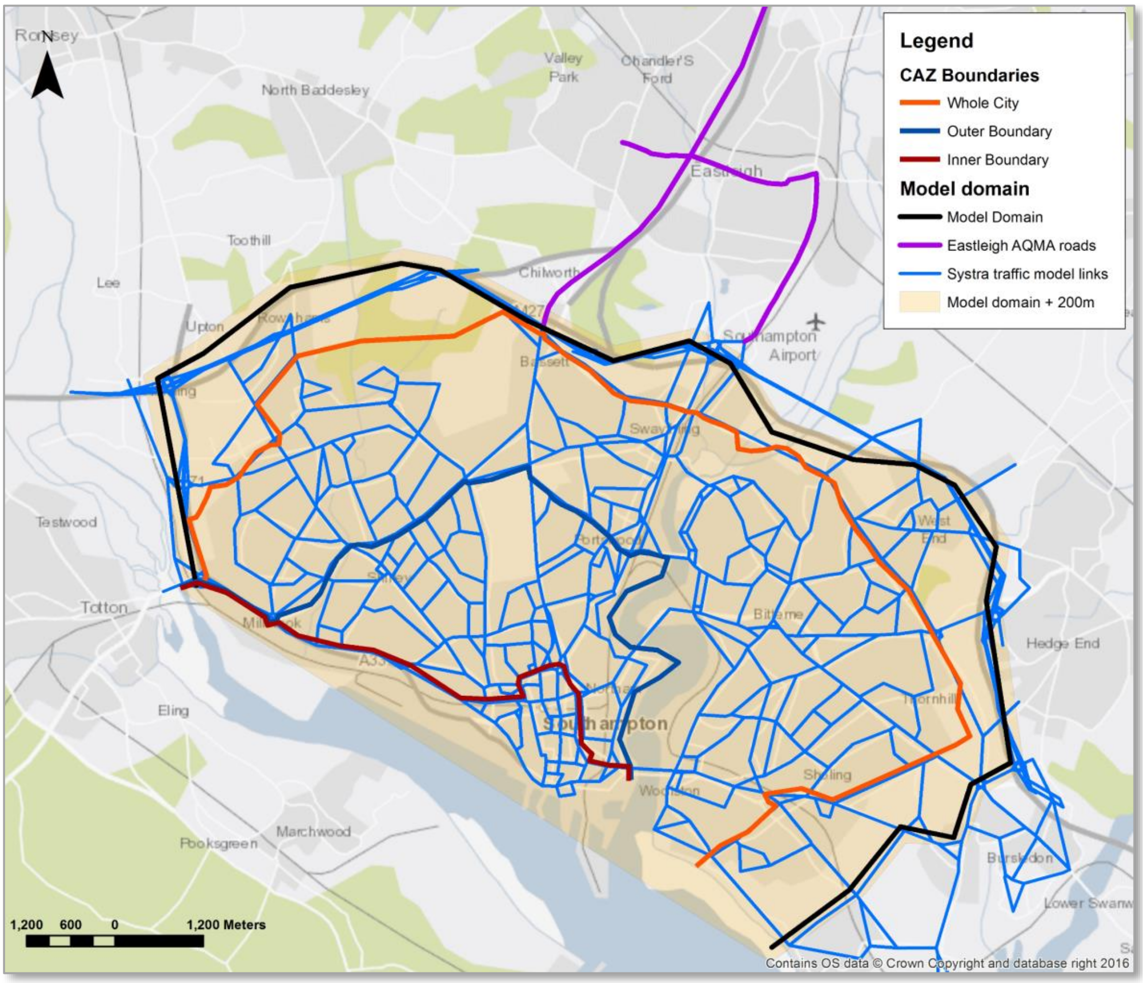


Figure 5: PCM model road links within the CAZ study domain 2015

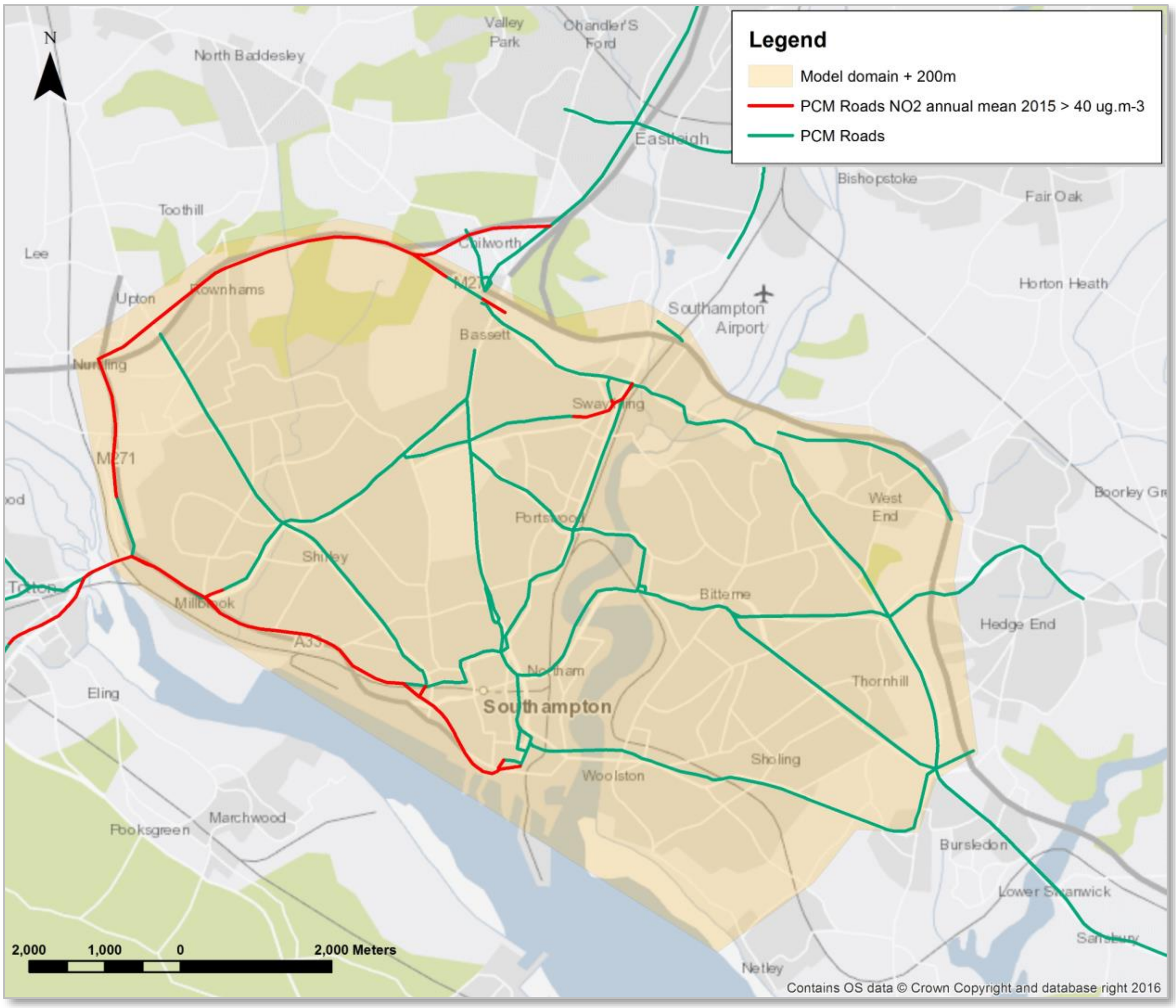


Figure 6: Southampton City Councils AQMA locations

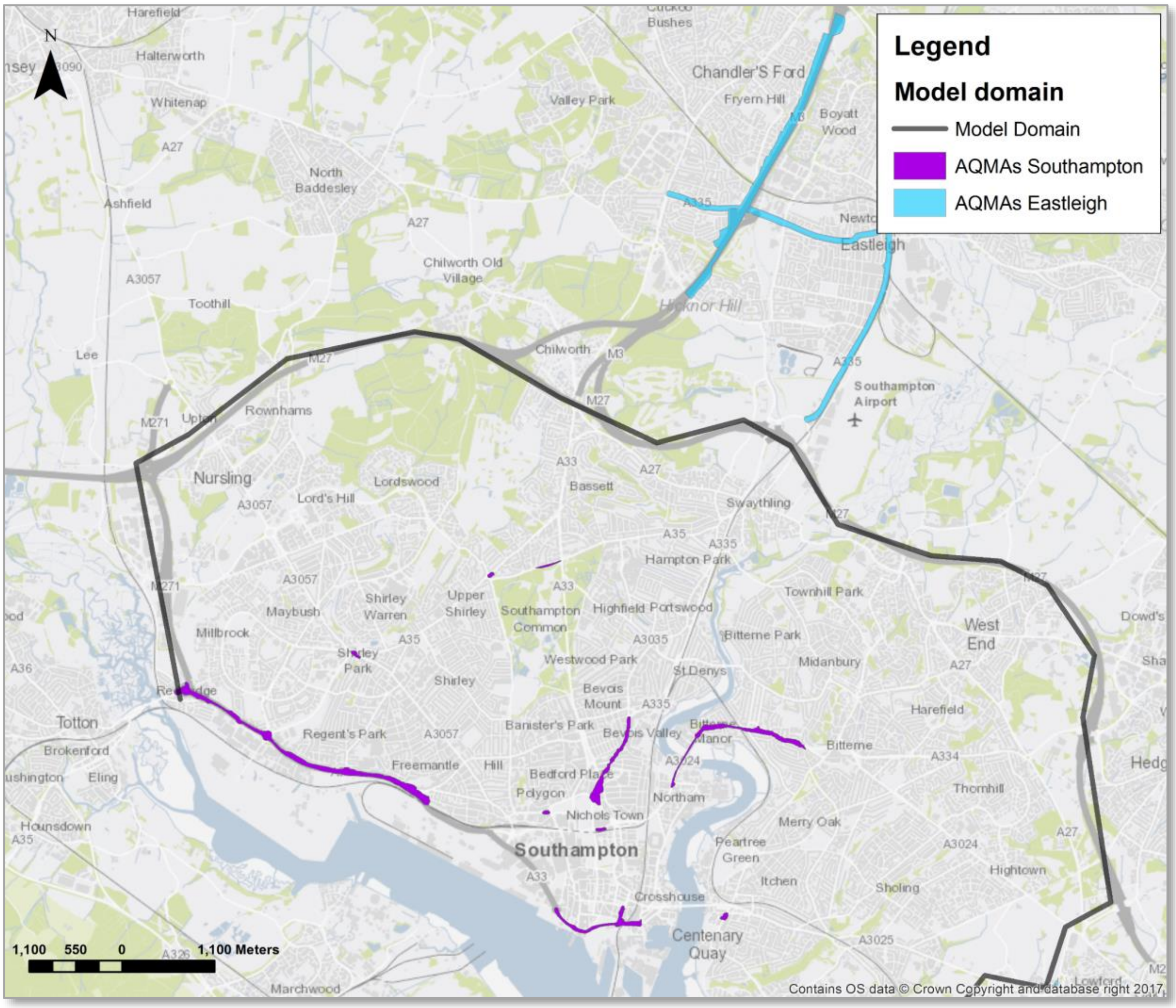
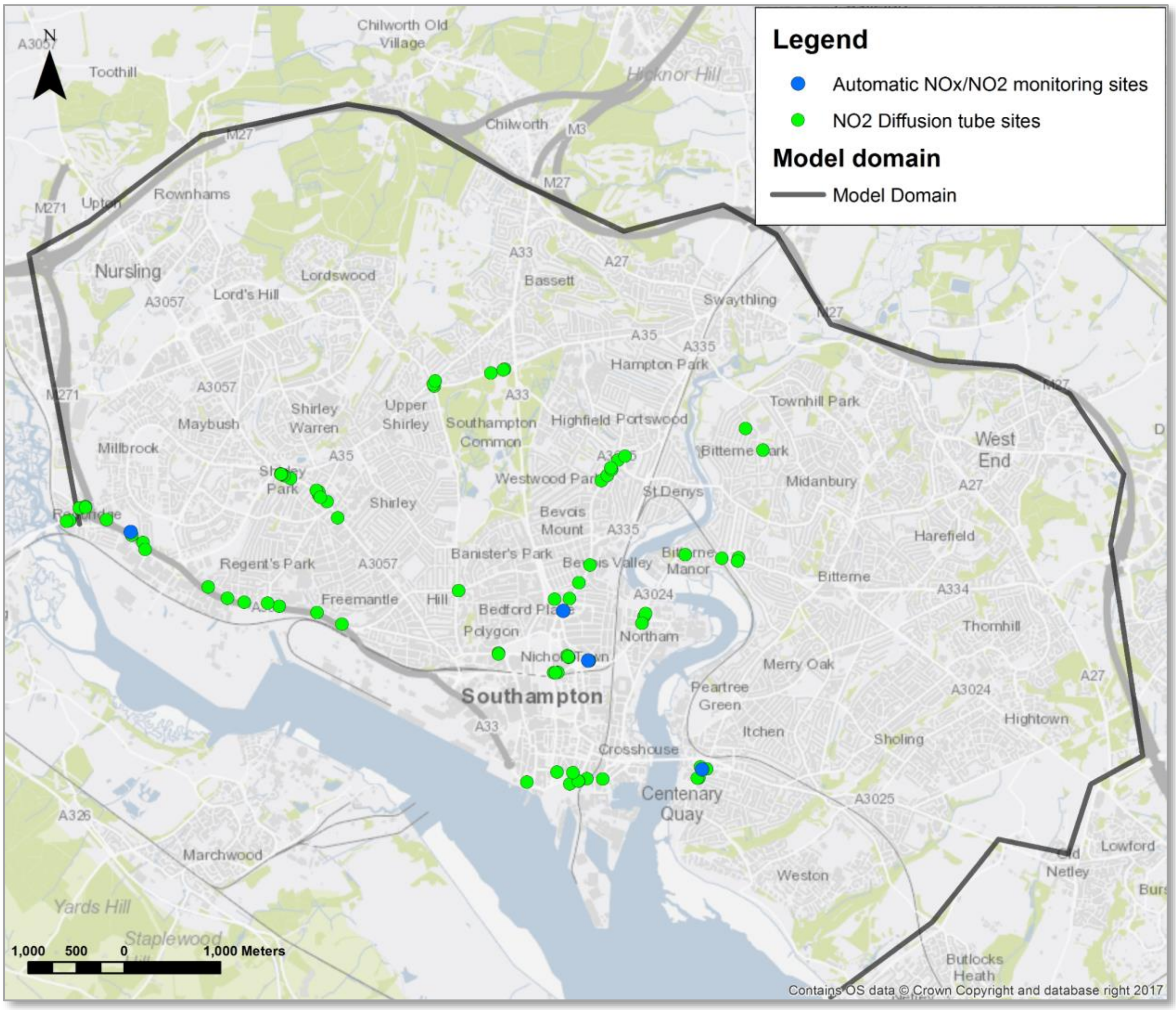


Figure 7 Southampton City Council NO_2 monitoring sites 2015



3 Model and receptor location selection

3.1 Dispersion model

We have used the RapidAir modelling system for the study. This is Ricardo Energy & Environment's proprietary modelling system developed for urban air pollution assessment and the model that was used previously in Southampton for the LES study. The compliance assessment for this model against the JAQU requirements is set out in Air Quality Tracker table (AQ1) with further description of the model provided here.

The model is based on convolution of an emissions grid with dispersion kernels derived from the USEPA AERMOD[3] model. The physical parameterisation (release height, initial plume depth and area source

[3] https://www3.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod

configuration) closely follows guidance provided by the USEPA in their statutory road transport dispersion modelling guidance[4]. AERMOD provides the algorithms which govern the dispersion of the emissions and is an accepted international model for road traffic studies (it is one of only two mandated models in the US and is widely used overseas for this application). The combination of an internationally recognised model code and careful parameterisation matching international best practice makes RapidAir demonstrably fit for purpose for this study.

The USEPA have very strict guidelines on use of dispersion models and in fact the use of AERMOD is written into federal law in 'Appendix W' of the Guideline on Air Quality Models[5]. The RapidAir model uses AERMOD at its core and is evidently therefore based on sound principles given the pedigree of the core model.

The model produces high resolution concentration fields at the city scale (1 to 3m scale) so is ideal for spatially detailed compliance modelling. A validation study has been conducted in London using the same datasets as the 2011 Defra inter-comparison study[6]. Using the LAEI 2008 data and the measurements for the same time period the model performance is consistent (and across some metrics performs better) than other modelling solutions currently in use in the UK. The results of this study have been published in Environmental Modelling and Software[7].

3.2 Core aspects of the modelling

3.2.1 Chemistry, meteorology and topology

NOx to NO_2 chemistry was modelled using the Defra NOx/NO_2 calculator. Modelled annual mean road NOx concentrations were combined with background NOx and a receptor specific (i.e. at each receptor) fNO_2 fraction to calculate NO_2 annual mean concentrations. The receptor specific fNO_2 fraction was calculated by dividing the modelled road NOx by modelled road NO_2 at each receptor.

3.2.2 Meteorology

Modelling was conducted using the 2015 annual surface meteorological dataset measured at Southampton Airport. The dataset was processed in house using our own meteorological data gathering and processing system. We use freely available overseas meteorological databases which hold the same observations as supplied by UK meteorological data vendors. Our RapidAir model also takes account of upper air data which is used to determine the strength of turbulent mixing in the lower atmosphere; this was obtained from the closest radiosonde site and process with the surface data in the USEPA AERMET model. We have utilised data filling where necessary following USEPA guidance which sets out the preferred hierarchy of routines to account for gaps (persistence, interpolation, substitution). AERMET processing was conducted following the USEPA guidance. To account for difference between the meteorological site and the dispersion site, surface parameters at the met site were included as recommended in the guidance and the urban option specified for the dispersion site.; land use parameters were accessed from the CORINE land cover datasets[8].

A uniform surface roughness value of 1.0 m was modelled to represent a typical city/urban environment.

---

[4] https://www.epa.gov/state-and-local-transportation/project-level-conformity-and-hot-spot-analyses
[5] 40 CFR Part 51 Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule, Environmental Protection Agency, 2005
[6] https://uk-air.defra.gov.uk/research/air-quality-modelling?view=intercomparison
[7] Masey, Nicola, Scott Hamilton, and Iain J. Beverland. "Development and evaluation of the RapidAir® dispersion model, including the use of geospatial surrogates to represent street canyon effects." *Environmental Modelling & Software* (2018). DOI: https://doi.org/10.1016/j.envsoft.2018.05.014
[8] EEA (2018) https://www.eea.europa.eu/publications/COR0-landcover

3.2.3 Canyon modelling

The platform includes two very well-known street canyon algorithms with significant pedigree in the UK and overseas. The first replicates the functionality of the USEPA 'STREET' model. The code was developed by the Office of Mobile Source Air Pollution Control at the USEPA and published in a series of technical articles aimed at operational dispersion modellers in the regulatory community[9,10]. The STREET model has been used for many years and has been adopted in dispersion modelling software such as AirViro. The USEPA canyon model algorithms are essentially the same as those recommended by the European Environment Agency for modelling canyons in compliance assessment[11].

The RapidAir model also includes the AEOLIUS model which was developed by the UK Met Office in the 1990s. The AEOLIUS model was originally developed as a nomogram procedure[12]. The scientific basis for the model is presented in a series of papers by the Met Office[13,14,15,16,17.] The model formulation shares a high level of commonality with the Operational Street Pollution Model[1819] (OSPM) which in turn forms the basis of the basic street canyon model included in the ADMS-Roads software. Therefore, the AEOLIUS based canyon suite in RapidAir aligns well with industry standards for modelling dispersion of air pollutants in street canyons.

Using available information on building heights and road widths, candidate locations for street canyons were identified. These locations were then checked using Google Street View to confirm the presence of a street canyon. For roads assigned as street canyons, the required information for the AEOLIUS street canyon model was populated – this includes building height, emissions and number of vehicles per hour. Further details on the model parameters required are provided in the equations in Appendix 3. The canyon model is only turned on if the wind is blowing parallel across the canyon (± 5 degrees) i.e. the wind must be between 40 and 50 degrees from the orientation of the canyon. For each hour in the meteorological data (same as that described in 3.2.2) with wind direction matching the criteria to turn the street canyon on, the leeward, windward and parallel street canyon concentrations were calculated. To provide annual street canyon concentrations, the sum of the data contained within each of leeward, windward and parallel was calculated.

The results from the street canyon module were combined with the concentrations modelled in the dispersion step of RapidAir. The annual leeward and annual windward concentrations were added together, then this was added to the dispersion modelled road NO_x. The concentrations from the parallel contribution of the street canyon model were not included as including this would result in double counting of the road NOx when combined with the dispersion NO_x.

3.2.4 Gradient, tunnels and flyovers

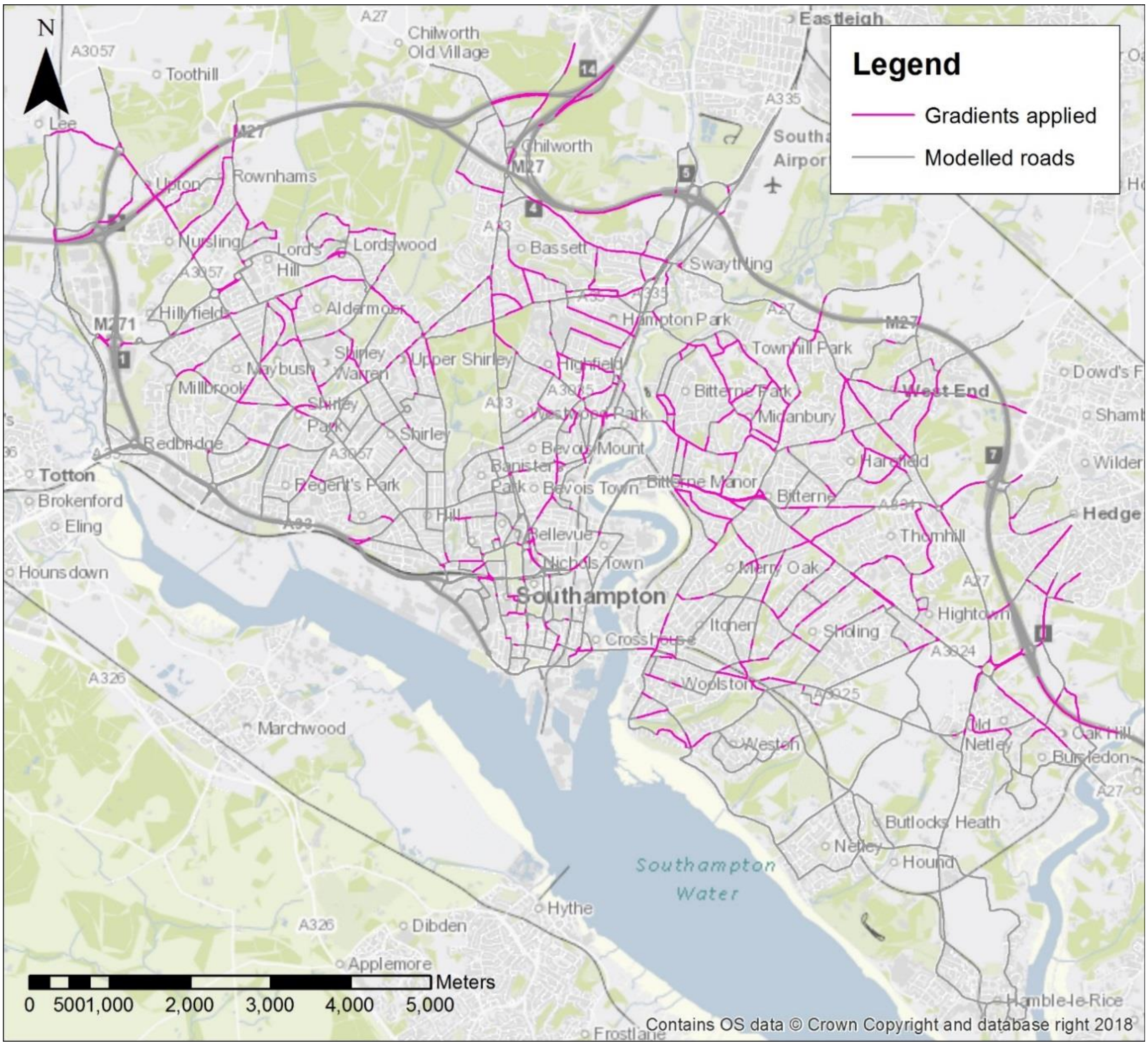
Gradient effects have been included for relevant road links during emissions calculations. LIDAR Composite Digital Terrain Model (DTM) datasets at 1m and 2m resolution are available over the

[9] Ingalls., M. M., 1981. Estimating mobile source pollutants in microscale exposure situations. US Environmental Protection Agency. EPA-460/3-81-021
[10] USEPA Office of Air Quality Planning and Standards., 1978. Guidelines for air quality maintenance planning and analysis, Volume 9: Evaluating indirect sources. EPA-450/4-78-001
[11] http://www.eea.europa.eu/publications/TEC11a/page014.html
[12] Buckland AT and Middleton DR, 1999, Nomograms for calculating pollution within street canyons, Atmospheric Environment, 33, 1017-1036.
[13] Middleton DR, 1998, Dispersion Modelling: A Guide for Local Authorities (Met Office Turbulence and Diffusion Note no 241: ISBN 0 86180 348 5), (The Meteorological Office, Bracknell, Berks).
[14] Buckland AT, 1998, Validation of a street canyon model in two cities, Environmental Monitoring and Assessment, 52, 255-267.
[15] Middleton DR, 1998, A new box model to forecast urban air quality, Environmental Monitoring and Assessment, 52, 315-335.
[16] Manning AJ, Nicholson KJ, Middleton DR and Rafferty SC, 1999, Field study of wind and traffic to test a street canyon pollution model, Environmental Monitoring and Assessment, 60(2), 283-313.
[17] Middleton DR, 1999, Development of AEOLIUS for street canyon screening, Clean Air, 29(6), 155-161, (Nat. Soc for Clean Air, Brighton, UK).
[18] Hertel O and Berkowicz R, 1989, Modelling pollution from traffic in a street canyon: evaluation of data and model development (Report DMU LUFT A129), (National Environmental Research Institute, Roskilde, Denmark).
[19] Berkowicz R, Hertel O, Larsen SE, Sørensen NN and Nielsen M, 1997, Modelling traffic pollution in streets, (Ministry of Environment and Energy, National Environmental Research Institute, Roskilde, Denmark).

proposed model domain[20]. Link gradients across the model domain can be calculated using GIS spatial analysis of LIDAR DTM datasets.

The method described in TG(16) provides a method of adjusting road link emission rates for gradients greater than 2.5%; it is applicable to broad vehicle categories for heavy vehicles only. As per the guidance and clarification provided by JAQU this adjustment has been applied to all pre Euro VI HGVs and buses. Figure 8 shows the roads where gradient effects were included during emissions calculations.

Figure 8: Locations where gradient effects have been included during emission calculations



No modelling of tunnels or flyovers was included as the RapidAir kernel approach applies the same source height across the model domain. If modelling of flyovers was considered to be beneficial for this assessment, we could have modelled road link at a higher elevation using a dispersion kernel created with a different source height in AERMOD. It was not however considered beneficial to do this for this assessment.

[20] http://environment.data.gov.uk/ds/survey/#/survey

3.3 Receptor locations

Southampton has a wide network of monitoring locations comprising a mix of passive and active sampling. All available monitoring locations for 2015 will be treated as receptors in the model as the 2015 NO_2 annual mean measurements will be used for model verification and producing model performance statistics. A map of these monitoring locations is shown above in Figure 7 in relation to the modelling domain

The RapidAir model can comfortably deal with about 500 million gridded locations which provides for over 20,000 cells in the 'x' and 'y' axes. We can therefore model 20km x 20km, which is roughly the size of the Southampton modelling domain, down to a 1m resolution. Therefore we have used this 1m resolution for our work in Southampton. The canyon model is set to the same resolution as the grid model so that they align perfectly spatially.

As RapidAir produces concentration grids (in raster format), modelled NO_2 concentrations can be extracted at receptor locations anywhere on the 1m resolution model output grid. For comparison with PCM model results, annual mean concentrations at a distance of 4m from the kerb have been extracted from the RapidAir data and presented as a separate model output file. This will allow the selected locations to be assessed according to the Air Quality Directive (AQD) requirements Annex III A, B, and C3.

Southampton has several AQMAs all of which contain numerous residential receptors. RapidAir, by virtue of its very high resolution outputs, can produce discrete estimates at every single residential property in Southampton (every 1m 'square' in actual fact); any location where there is a risk of the objective being exceeded can therefore be included in the modelling and outlined during post processing.

To aid interpretation of the outcomes of the study when considering compliance with the air quality directive (AQD), annual mean concentrations at the roadside exceedance locations identified in the PCM model will be extracted from the RapidAir dispersion model results and presented as a separate model output file. Roadside receptor locations in the PCM model are at a distance of 4m from the kerb and at 2m height. A subset of the OS Mastermap GIS dataset provided spatially accurate polygons representing the road carriageway, receptor locations were then placed at 50m intervals along relevant road links using a 4m buffer around the carriageway polygons.

Annex III of the AQD specifies that macroscale siting of sampling points should be representative of air quality for a street segment of no less than 100 m length at traffic-orientated sites. To provide results relevant to this requirement, for roadside locations where there is public access and the Directive applies; road links with exceedances of the NO_2 annual mean objective stretching over link lengths of 100m or greater can be presented as a separate GIS layer of model results.

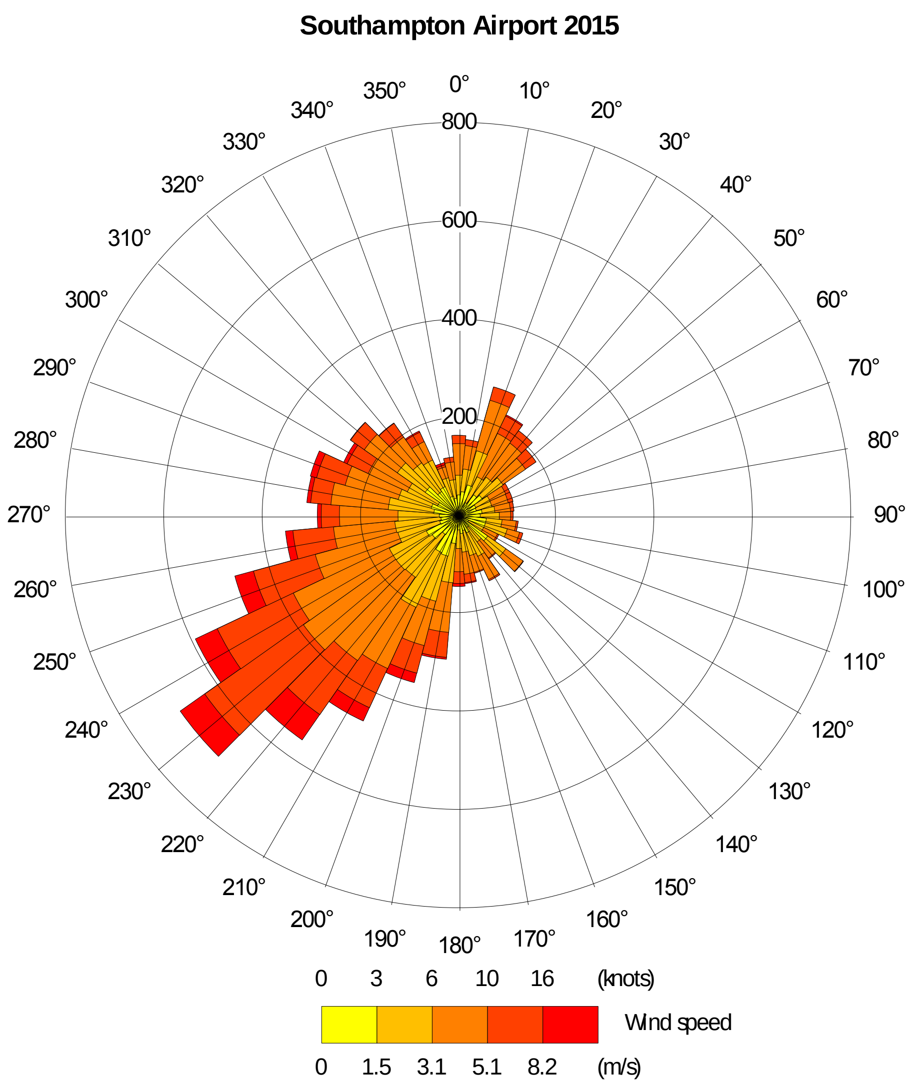
Annex III of the AQD also specifies that microscale sampling should be at least 25 m from the edge of major junctions. When reporting model results relevant to compliance with the AQD, locations up to 25m from the edge of major junctions in the model domain have also been excluded.

4 Base year modelling

4.1 Base year and meteorological dataset

As described in section 1.3 we have modelled a baseline year of 2015. We have used the 2015 annual surface meteorological dataset measured at Southampton Airport which has been processed in house using our own meteorological data gathering and processing system. We use open overseas meteorological databases which hold the same observations as supplied by UK meteorological data vendors. Our RapidAir model also takes account of upper air data which is used to determine the strength of turbulent mixing in the lower atmosphere; we have derived this from the closest radiosonde site and process with the surface data in the USEPA AERMET model. Where necessary we have utilised data filling following USEPA guidance which sets out the preferred hierarchy of routines to account for gaps (persistence, interpolation, substitution). A wind rose for the 2015 Southampton airport met dataset is presented in Figure 9.

Figure 9: Windrose

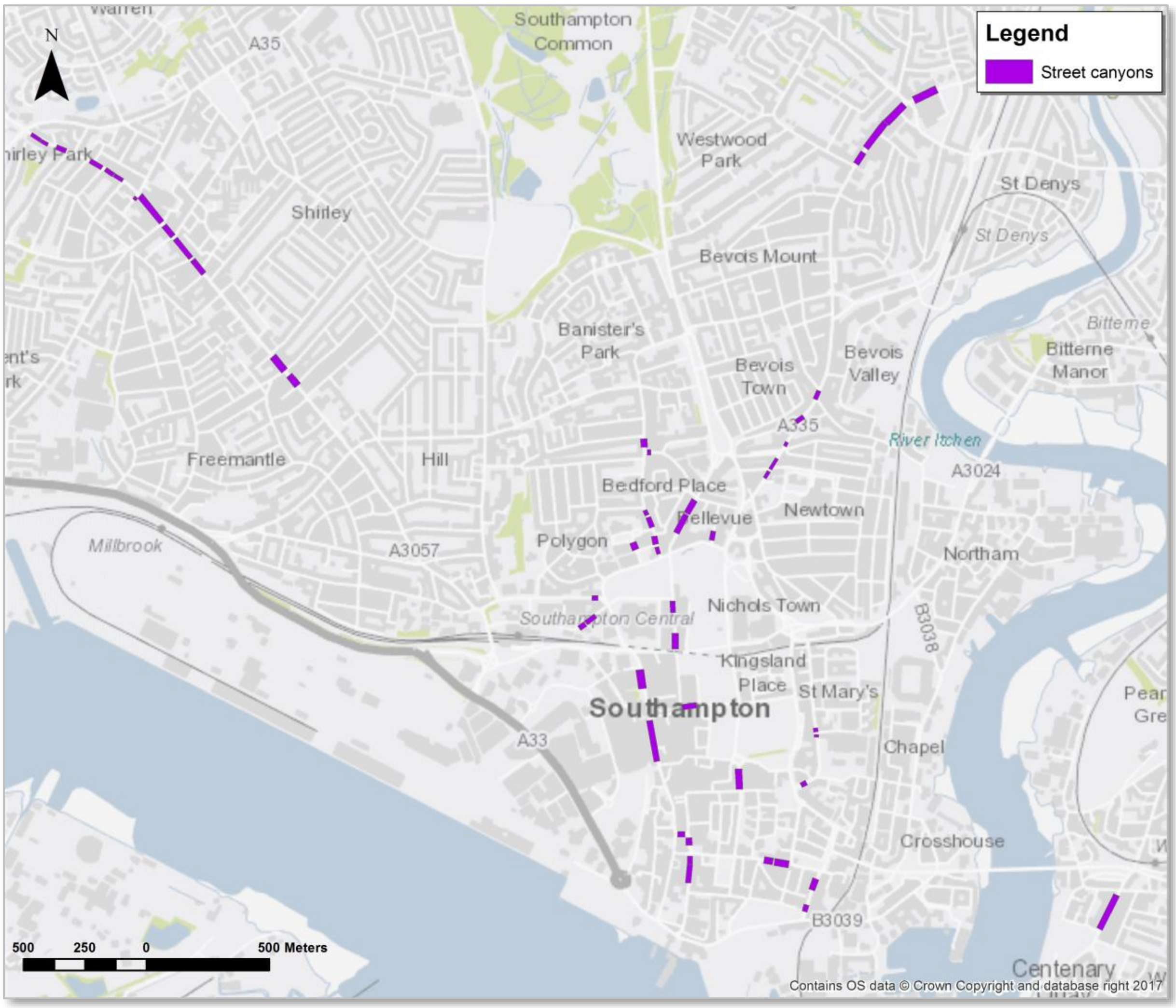


4.2 Representation of road locations and canyons

A realistic representation of road locations has been modelled by assigning emissions to the road links represented in the Ordnance Survey ITN Roads GIS dataset; it contains spatially accurate road centreline locations for various road categories e.g. Motorway, A road, B road, minor road, local street etc. Link gradients across the model domain were calculated using LIDAR DTM datasets.

A map showing the locations where canyon effects were modelled is presented in Figure 10.

Figure 10: Location of street canyons modelled



4.3 Road traffic modelling

4.3.1 Average daily vehicle flow and speeds

Baseline and future year annual average daily traffic (AADT) link flows for each model link were provided by SYSTRA using outputs from the Sub-Regional Transport Model (SRTM) that covers the areas of Southampton, Portsmouth and South Hampshire. This network was manually extended to cover the in-port roads using data from port gate ANPR this is described further in Appendix 1.

Baseline daily average link speeds were calculated using the DfT Traffic Master GPS measured datasets cross referenced with the Ordnance Survey ITN roads GIS dataset. This will provide observed average speed data over defined road links at a fairly well resolved spatial resolution. It should also provide a reasonable representation of the change in emissions at locations where typical vehicle speeds are reduced e.g. approaching junctions. A typical UK week day diurnal profile[21] was assumed and applied as time varying emissions in AERMOD when creating the RapidAir dispersion kernel.

[21] DfT (2018) Table TRA0307_2015 Traffic distribution on all roads by time of day and day of the week in Great Britain

4.3.2 Vehicle fleet composition

Vehicle emission rates for the vehicle categories buses (including coaches), taxis, rigid HGVs, articulated HGVs, LGVs, cars and motorcycles can be calculated using the latest COPERT v5 NOx emission functions.

The traffic model will provide vehicle flows for four highway user classes which are: Car, HGV, LGV and Buses. A further breakdown of the HGV into rigid and articulated categories and an estimate of the proportion of car traffic that are taxis has been conducted using local traffic count data and ANPR data. An assessment of the ANPR data indicated that the rigid/artic split and proportion of taxis across the city was not constant. To account for this two distinct zoning approaches has been used to reflect the key differences:

- *Rigid/artic split* – this has been zoned as the Western approach to the port and the rest of the city. The splits used are as follows:
  - Western approach: 28.5% rigid, 71.5% artic
  - Rest of city: 69.9% rigid, 30.1% artic
- *Taxi split* – this has been zoned as city centre, with 6.3% of car movements as taxis and rest of the city with 2.4% of car movements as taxis.

Emission calculations for each vehicle category will be based on vehicle fuel type and Euro classification. Information on the local fuel type mix and Euro standard distribution has been collected from the ANPR surveys conducted over one week from the 5th to 11th December 2016. An assessment of the ANPR suggested that for light duty vehicles the Euro class distribution was consistent across the monitoring locations, and for the heavy duty vehicles there was greater variation but not clear pattern as was seen for the rigid/artic split data. Based on this a common distribution of fuel types and euro classifications was used across the whole model domain for each vehicle type. The distribution of fuel type and Euro classification from the local data is shown in figures 8 to 13 below compared to the national average data taken from the NAEI.

Modelling coach emissions

When using the EFT or our in-house equivalent road traffic emissions calculator RapidEms; the assumed fraction of coaches in the bus fleet is 28%. This is the coach fraction specified for Urban/rural UK roads (outside London) in the 2013 and 2015 base year NAEI fleet projections[22]. We are however aware that coach movements were not included in the traffic model outputs so all bus movements would be passenger service vehicles. To account for this when calculating bus emissions, we used an identical local euro fleet breakdown for both the bus and coach vehicle categories. This will however mean that emissions from the additional bus/coach AADT not represented in the traffic model have not been included.

[22] NAEI (2014) rtp_fleet_projection_Base2013_v3.0_final -

Figure 11 Car fuel type split

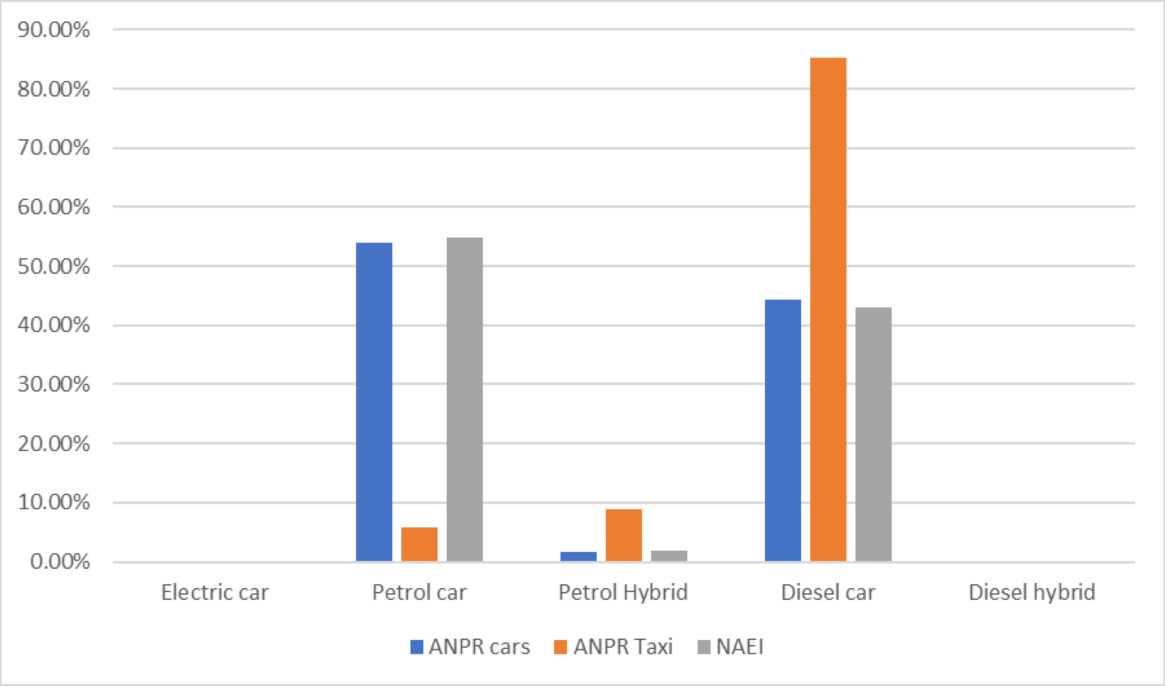


Figure 12 Diesel car Euro classification distribution

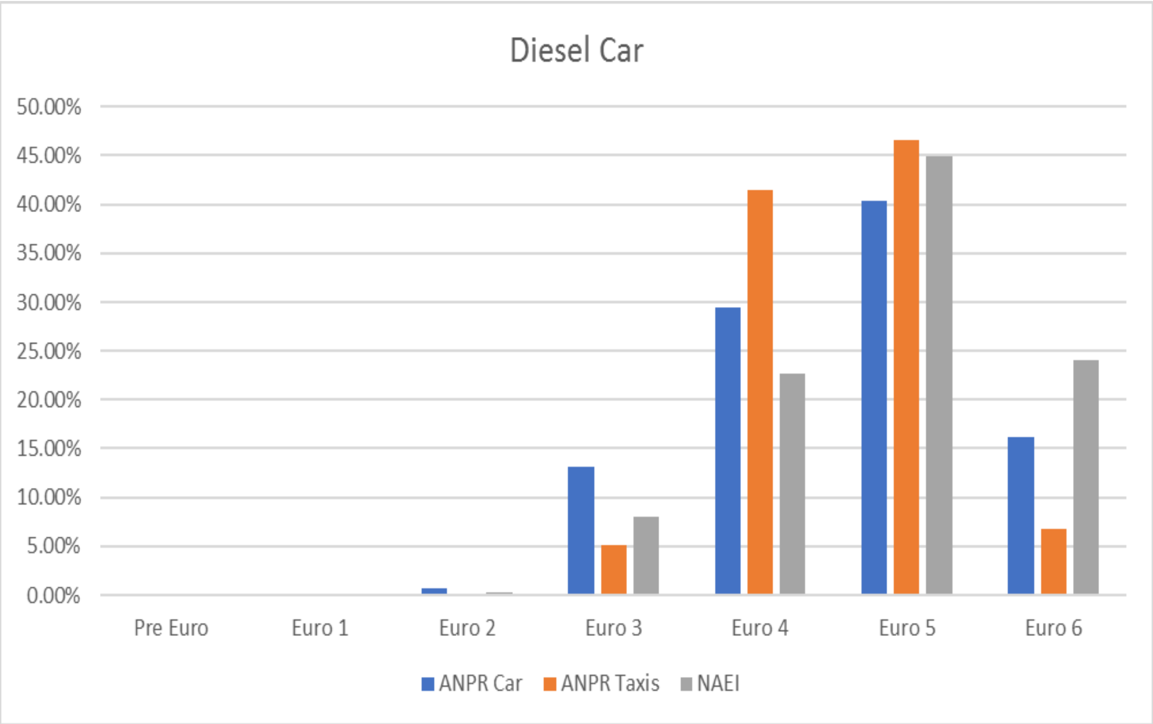
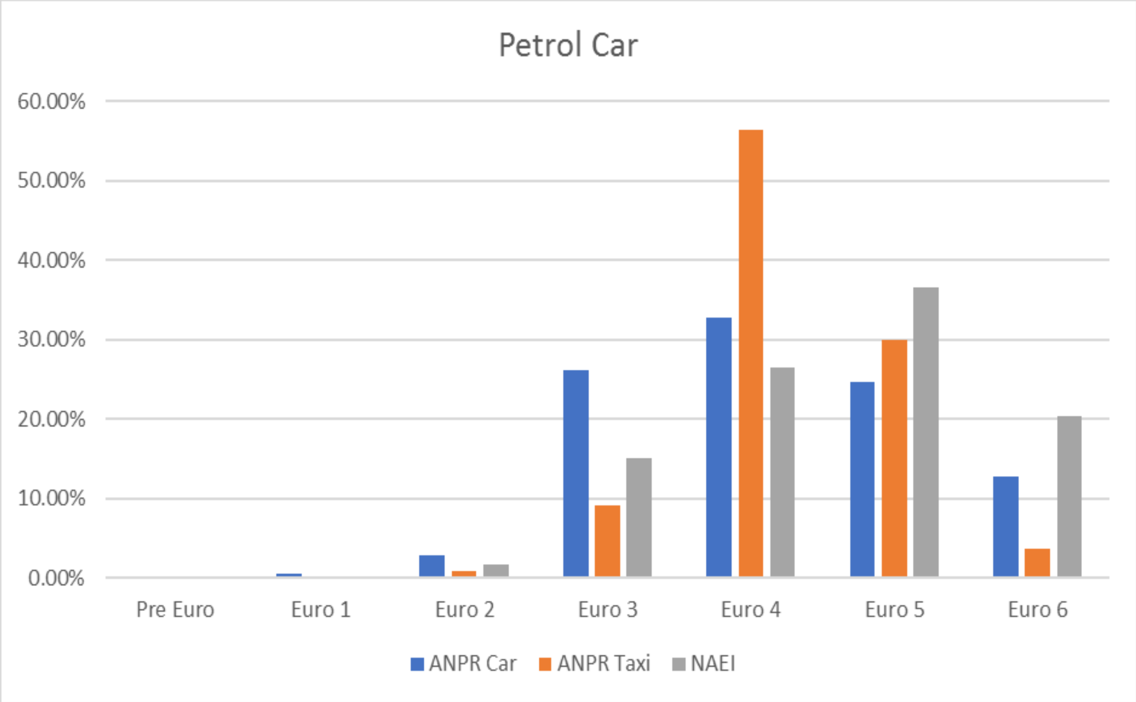


Figure 13 Petrol car Euro classification distribution



The data for cars shows that the fuel type is pretty consistent with the national average, but with taxis having a much higher proportion of diesel as would be expected. The taxis also have a higher proportion of hybrids which is a trend seen in many cities. In relation to Euro classification the local fleet is slightly older than the national average.

Figure 14 Diesel van Euro classification distribution

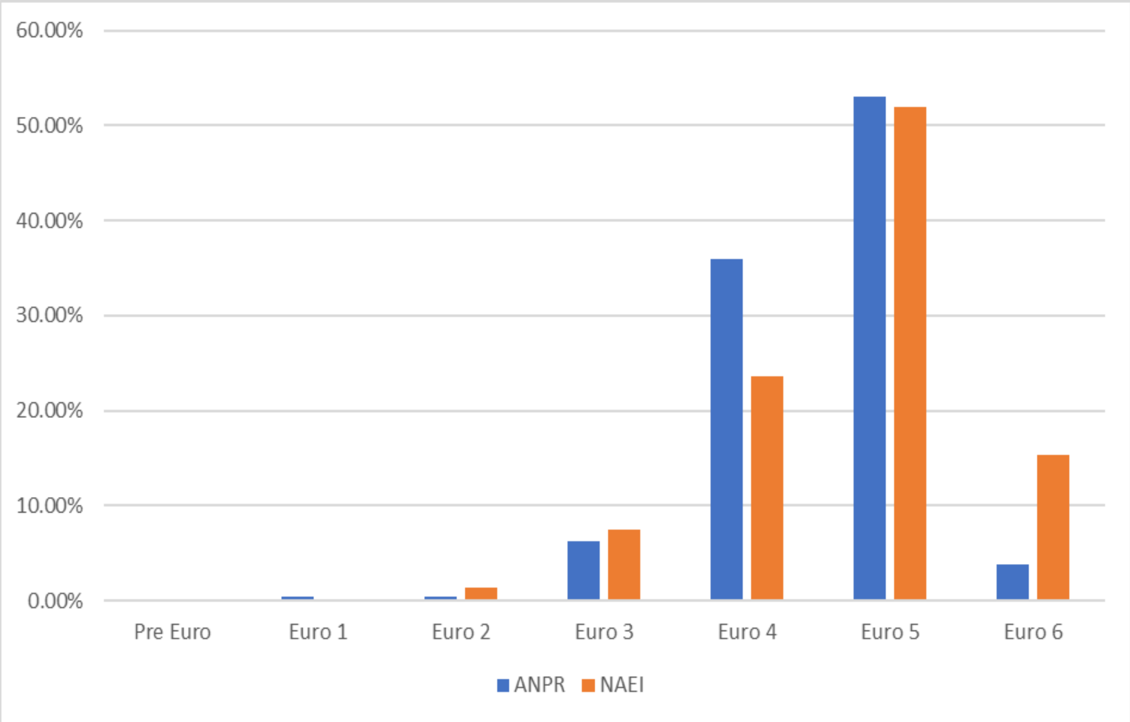


Figure 15 Rigid HGV Euro Classification distribution

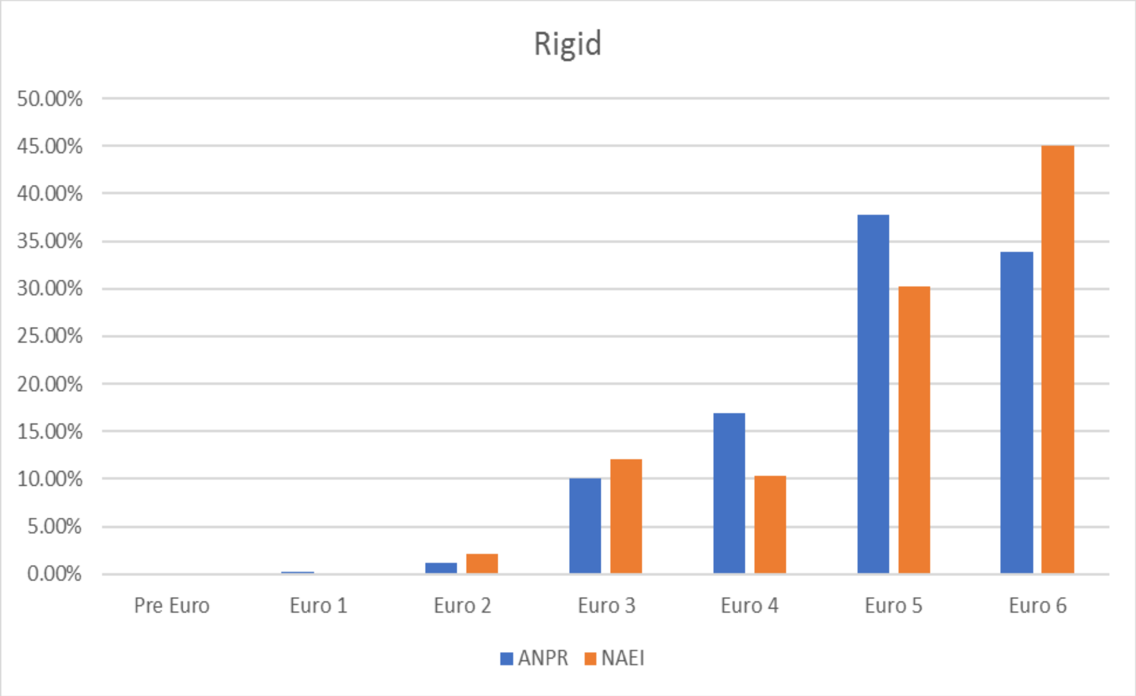
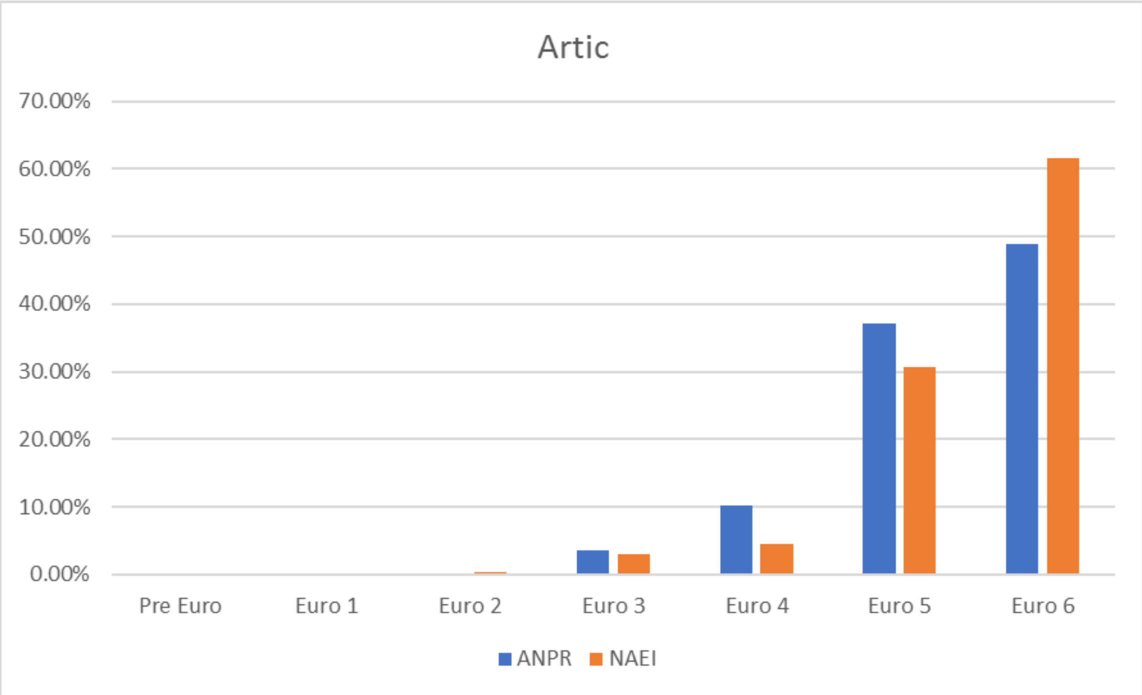


Figure 16 Artic HGV Euro Classification



Like the cars the Euro classification taken from the ANPR data shows a somewhat older van and HGV fleet in Southampton compared to the national data.

4.3.3 NOx/NO_2 emissions assumptions

Link specific NOx emission factors have been calculated using the COPERT v5 emission functions for all vehicles up to and including Euro 6/VI. Emission rates have been calculated with our in-house emission calculation tool RapidEms as agreed by JAQU, which is fully consistent with COPERT v5 and links directly to our RapidAir dispersion modelling system.

JAQU recommend the use of data on primary NO_2 emissions (fNO_2) by vehicle type which is available via the NAEI website (based on 2014 NAEI) to provide a more detailed breakdown than the LAQM NOx to NO2 convertor. This suggests a link specific f-NO_2 emissions estimate for use in the NO_2 modelling.

Based on this requirement, the RapidEms road emissions calculation tool now includes additional functionality to calculate NO_2 emission rates for each road link. Link specific fNO_2 fractions can then be calculated for each link by dividing NO_2 by total road NOx emission rate. Calculating link specific NO_2 emission rates also facilitates dispersion modelling of both road NOx and NO_2 across the entire model domain to produce separate concentration rasters, which can then be combined with background concentrations to calculate NO_2 concentrations in each grid cell.

The recently updated version (v5.3) of the LAQM NO_x to NO_2 conversion spreadsheet has been used to convert road NOx, fNO_2 and background NOx into NO_2 concentrations where results at discrete receptor locations are required. This currently includes all NO_2 monitoring site locations and receptors placed at 4m from the PCM road links.

The city-wide domain has been modelled at 1m resolution, the modelled concentration grid rasters have approximately 188 million cells. The JAQU guidance note for assigning fNO_2 when calculating NO_2 acknowledges that for large model domains and high resolution models, use of the spreadsheet tool will not be practical because the calculator is limited to a maximum of 64.6K lines in the excel spreadsheet. The guidance note recommends that it may be possible to use the calculator to define statistical relationships between NO_2 concentrations and the input parameters and use these relationships to calculate NO_2. In this case the statistical relationship was derived using an ordinary least squares (OLS) regression model. The OLS model was derived by defining background NOx, road NOx and road fNO_2 as the independent variables, and total NO_2 as the dependent variable.

4.4 Non-road transport modelling and background concentrations

We have modelled four types of non-road transport sources of NO_x emissions (or background concentration) data.

1. **Southampton port related emissions**: these are perhaps the most important non-road transport source and cover emissions from vessels whilst travelling to and berthed at the port and emissions from on-shore port operations, including from road vehicles on private port roads not otherwise captured by the public road transport modelling. Further details of our approach to the port related sources are provided in appendix 1.

2. **Large local point sources**: Emissions from two nearby industrial sources categorised as large point sources in the NAEI have been modelled explicitly using the AERMOD dispersion model at 10m grid resolution. Modelling these sources explicitly aims to provide a more resolved footprint of each sources' contributions to background NOx/NO_2 concentrations than are available from the 1km LAQM background maps. The point sources modelled were:
    - Marchwood Power Station
    - Marchwood Incinerator

The stack parameters for these large point sources as modelled for the PCM were provided by Defra. Emission rates were calculated using 2015 data from the large combustion plant (LCP) inventory[23]. In the absence of site specific, or published European data on temporal emission profiles, typical operating profiles and weighting factor files as found on the USEPA Clearinghouse for Inventories and Emissions Factors (CHIEF)[24] website were applied to calculate daily and seasonal time varying profiles in AERMOD.

3. **Rail emissions:** As port rail sources were being modelled, it was also necessary to model the national rail network. The latest available (2013) NAEI annual NOx emissions data for the rail network within the model domain was provided by Defra. Dispersion of rail emissions were modelled using rapid air with a bespoke dispersion kernel at 1m resolution. The kernel was created using a release height and initial vertical dimension of the area plume representative of a typical diesel locomotive.

4. **General background sources:** The 1km resolution LAQM background maps were used to provide estimates of all sources not modelled individually as described above.

Road sector contributions from the 2013 base year maps were adjusted to take into account new COPERT 5 emissions using adjustment factors provided by JAQU. The contribution from all road source sectors that were modelled explicitly were subtracted from the background maps.

To avoid double counting of any explicitly modelled non-road transport sources**;** gridded concentrations modelled at fine resolution were resampled to represent average concentrations from these sources over the equivalent 1km background map resolution. The contribution from each source type could then be discounted from the relevant sector in the background maps.

4.5 Measurement data for model calibration

Southampton City Council's 2015 automatic and diffusion tube annual mean NO_2 measurements from roadside sites were used for model verification. Information on monitoring data QA/QC, diffusion tube bias adjustment factors etc. will be as presented in the Southampton City Council 2016 LAQM Annual Progress Report.

5 Projected future year scenario modelling

5.1 Road transport future year baseline

Future year baseline scenarios have currently been modelled in the year 2020. The basic projections used for the future year baseline scenario are:

- **AADT flows for future baseline year** were provided from the SYSTRA sub-regional traffic model. Further information on how these traffic flows were derived and how local growth in traffic is calculated is presented in 'Transport Modelling Methodology Report'.
- **Projected fleet split (vehicle type):** All future year scenarios will have the 4 core vehicle category fleet splits provided from the traffic model in the same breakdown as provided for the 2015 base

[23] European Environment Agency (2017) LCP inventory – available at http://cdr.eionet.europa.eu/Converters/run_conversion?file=gb/eu/lcpes/envwrwsia/LCP__Summary_of_emission_inventory__1.xml&conv=538&source=remote

[24] USEPA(2017) https://www.epa.gov/chief

year. The further split of HGV's into artic and rigid, and for taxis will use the same ratios as derived for the 2015 baseline.

- **Projected fuel type and Euro class distribution:** a local fuel type and Euro class distribution has been projected forward from the local ANPR results to provide Euro class distributions for each of the future modelling years. This project has been carried out in line with the draft methodology provided by JAQU. This has been done by deriving future scaling factors from the national NAEI data, applying these to the local ANPR results and then normalising to 100%. This gives an evolution of the local fleet that is slightly behind the national fleet.
- **Future year scenarios average vehicle speed data:** Average link speeds for all future year scenarios will be calculated by adjusting the observed baseline speed data (Traffic Master) by the ratio of the 2015 baseline vs future baseline journey times calculated by the traffic model
- **Projected vehicle NOx emission rates** will be calculated using the latest COPERT v5 NOx emission functions applied to the projected average flows, fleet and vehicle age composition for each future baseline year being modelled.

Further to the baseline developed for the OBC the following updates have been made in relation traffic flows from the traffic model and are detailed further in the updated 'Transport Modelling Methodology Report':

- *An updated version of the version of the SRTM has been used* – since the initial work on the modelling started in 2017 the SRTM model has been refined and updated. This latest version has been used in the new baseline modelling.
- *Updated coding of the Redbridge roundabout* – to account for the current confirmed scheme design.
- *Use of the latest 2018 National Road Traffic Forecast (NRTF)* – this has been used for HGV and LGV traffic growth rates and replaces the 2015 NRTF that had been used previously.
- *Changes to the port related road traffic covering:*
    - A revision to the port growth assumptions using the latest data from 2018, rather than previous master plan data from 2016;
    - A revision to the rail freight share accounting for the latest 2018 data, changes to the rail freight subsidy regime and the confirmed lengthening of the rail freight terminal at the port.

In addition to these modelling and forecasting updates the baseline has been updated to account for funding that has now been confirmed from the Government's 'Early Measures Fund' to become the do minimum scenario against which mitigation scenarios are compared. The measures included were:

- *A package of cycling infrastructure improvement measures* – added to the transport model;
- *The Clean Bus Technology Fund (CBTF)* – which is being used to upgrade the core bus fleet in Southampton to Euro VI by 2020;
- *The taxi incentive programme* – to support upgrades to the taxi fleet to hybrid vehicles.

5.2 Non-road transport projections

5.2.1 Vessels travelling to and berthed at the port

The vessel emissions from the updated NAEI shipping emissions inventory described in Appendix 1 were projected to 2020. The assumptions used for this projection deviated from the assumptions made in the NAEI for national ship emission projections in some cases to account for the local situation in Southampton. These projections account for the following four changes over time from the base year:

- Changes in activity levels, with assumptions specific for Southampton (up to approximately 5km from the port). The annual average growth rates specific to Southampton have been based on the latest growth forecasts provided by ABP[25] for container vessels, RoRo vessels, cruise ships and bulk carriers. For other vessel types, annual average growth rates for specific vessel categories were taken from the Port of Southampton Master Plan 2016 consultation document section on trade and demand forecasts[26].

- Changes in fuel types of vessels. The impacts of the tighter fuel sulphur limit of 0.1% within the SECA from 2015 is accounted for by assuming that vessel operators that used 1.0% S heavy fuel oil in 2014 comply by switching to marine distillate fuel. This is relevant for NO_X due to the slightly lower NO_X emission factor for marine distillates. Based on ABP forecasts[27], LNG is assumed to be used in 20% of cruise ships in 2020 (and those LNG powered vessels are assumed to have 85% lower NOx emission factors compared to vessels combusting distillate fuel. This assumption deviates from the assumptions made in the NAEI for national ship emission projections, in which LNG is used from 2021 as a route to comply with the forthcoming NOx emission control area in the North Sea and English Channel.

- Changes in vessel fuel efficiency (with consequent impacts on emissions), of annual improvement in vessel energy efficiency of 1% per year. This accounts for improvements from the Energy Efficiency Design Index, as well as changes over time in vessel capacities. This assumption aligns with the assumptions made in the NAEI for national ship emission projections.

- Changes in emission factors. An annual reduction of 1% in the NOx emission factor for ships to 2020 was assumed for vessels serving Southampton. This reduction factor relates to ongoing fleet turnover and thus increasing proportions of newer vessels meeting IMO NO_X Technical Code Tier II levels. This reduction factor specific to Southampton was assumed to be higher than the national average (0.7%) used in the NAEI ship emission projections, because of the port is understood to attract the latest and newest vessels[28].

5.2.2 Port operations

For projecting the business-as-usual changes in emissions from port operations, the emissions from each of the sources separately listed in Appendix 2 has been subject to two changes over time, implemented as scaling factors relative to the base year:

- Activity level changes. Similarly, to the vessels projections, the activity level changes have been based on the projected demand changes at the port for the most relevant vessel type as set out in the first bullet point in section 5.2.1. For example, the emission sources related to containers – e.g. straddle carriers etc. – have been scaled according to the forecast changes in demand for container vessels. The other emission sources have been similarly scaled with the appropriate commodity type demand forecasts.
- Emission factor changes. We have consulted with DP World and have obtained assumptions their latest plans (as at 2018) for fleet turnover of straddle carriers per emission standard and model type which have been used to project the straddle carrier NO_X emissions to 2020. Aside from straddle carriers (estimated as the largest NOx emission source in the port other than vessels), no other equipment fleet turnover has been accounted for. For the modelling of vehicle emissions on in-port roads that arrive/depart through the dock gates, the same assumptions relating to turnover in the vehicle fleet for in-port roads have been made as for public roads.

[25] Personal Communication, 15 August 2018.
[26] http://www.southamptonvts.co.uk/admin/content/files/New%20capital%20projects/Master%20Plan%202016/Master%20Plan%202016%20-%202035%20Consultation%20Document%20Oct%202016.pdf
[27] Personal Communication, 15 August 2018.
[28] Personal Communication, ABP, 14 August 2018.

The Redbridge rail lengthening project to increase rail freight capacity by allowing for longer trains (project due to be completed before 2020) has been considered. We have assumed for the modelling that this increase in capacity is provided by additional wagons without provision of any additional rail services. No increment in the locomotive emission factor has been assumed for this projection as no robust information has been identified on whether or not an appreciable fuel consumption and hence NO_X emission would occur.

In early October 2018, it was reported that the HOVIS flour mill on the port site is planning to close. The potential traffic movements associated with this planned closure were considered in the projections. However, no change to account for this closure has been modelled, as it is unclear whether another business would choose to occupy this site instead.

5.3 Modelling of the 2020 scenarios

Three scenarios have been modelled in detail as described in section 1.2 above including the 'do minimum' baseline. The basic components of these scenarios and the primary modelling assumptions are shown below in Table 3

Table 3 Final list of options for assessment

Option	Components	Modelling approach
Do Minimum baseline	Baseline traffic and non-transport activity	This includes: • Updated traffic model with NRTF18 and revised port related traffic assumptions as described above (section 5.1). • Updated port activity with reduced growth, cruise ship LNG usage and adjusted NOx factor forecast.
	Early measure cycling scheme – routes 1, 5, 8 and 10	Additional cycling infrastructure included in the traffic model and this affects private car demand.
	Clean Bus Technology Fund	All non-Euro VI buses retrofitted to Euro VI (total of 145 buses), so have set bus fleet to all Euro VI in the model
	Taxi incentives	Funding to upgrade taxis. Current upgrades are to petrol hybrids. Projected uptake of 113 vehicles. This increase in hybrids is similar to the existing up take rate assumed in the fleet project tool so no further changes made.
Non-charging CAZ	CBTF plus bus traffic condition	Same modelling assumption as Do Minimum above. Inclusion of road traffic condition has no further impact as all buses already Euro VI
	Taxi incentives	Same modelling assumption as Do Minimum above
	Early measure cycling scheme – routes 1, 5, 8 and 10	Additional cycling infrastructure included in the traffic model and this affects private car demand.
	Freight DSP and consolidation	Likely impact focused on hospital deliveries. A reduction in LGV and HGV trips to this zone has been included in the traffic model.
	Shore power for cruise liners	20% of cruise liners assumed to be connected to shore power, rather than running auxiliary engines, while at berth.
	Port emissions-based booking scheme	A £5 charge is applied to all non-compliant (non-Euro VI) HGVs accessing the container terminal during peak hours. This generates a shift from peak to off peak.

City Wide CAZ B	City Wide CAZ B	A City -wide CAZ B, using upgrade assumptions provided by JAQU, is run through the transport model to asses behaviour of non-complaint vehicles. The compliant and non-compliant fleet are then modelled in the AQ model
	CBTF	Same modelling assumption as Do Minimum above.
	Taxi incentives	Same modelling assumption as Do Minimum above
	Early measure cycling scheme – routes 1, 5, 8 and 10	Additional cycling infrastructure included in the traffic model and this affects private car demand.

Further detail on the future scenarios and how they have been modelled is included in the Air Quality Modelling Results Report (AQ2).

6 Sensitivity testing

In any type of modelling there is always a certain level of uncertainty related to how well the model reflects reality. When setting up the air quality and transport models this general uncertainty is managed to some degree by validating the models to existing air quality measurement data and traffic data. The validation of the air quality model is described in the Air Quality Modelling Report (AQ3) with the level of model performance defined in terms of the Root Mean Squared Error (RMSE). The performance of the transport model is described the Transport Model Validation report (T2).

When forecasting forward further uncertainty is introduced in relation to the forecast activity levels and assumptions made about the measures being assessed. To explore the impact of these uncertainties on the robustness of the results and the conclusions drawn a set of sensitivity tests have been performed. These have been carried out on the forecast ‘do minimum’ baseline, the options modelling and some wider tests related to emissions and fleet forecasting.

Some general guidance on the sensitivity tests to be carried out has been provided by JAQU. The details of the tests carried out for Southampton, taking account of this guidance, are set out below.

6.1 Baseline and options sensitivity tests

The current updated baseline results reported in AQ3 indicate that compliance will be achieved within the ‘do minimum’ baseline. Any mitigation options applied will improve compliance further and so reduce risk from uncertainty in the baseline. This refocuses the importance of the sensitivity tests to the ‘do minimum’ baseline scenario and in particular tests that could give rise to not achieving compliance. The key changes to the baseline discussed in section 5 above that could be considered for sensitivity tests comprise:

1. *Updates to the underlying transport model and the national road traffic forecasts* – these changes are essentially ensuring that the latest model is WebTag compliant so are not appropriate for sensitivity testing.

2. *Inclusion of measures that already have funding* – these could be considered for sensitivity testing. However, the cycling scheme and the taxi incentive had very little impact so there is little room for tests here. The CBTF scheme has a greater impact and lack of uptake of the scheme by operators would reduce its impact. However, bus traffic along the main area of concern (the Western Approaches) is limited so the impact here will be small and unlikely to affect the outcome.

3. *Port growth assumptions* – there was a significant reduction of growth in the latest projection, particularly for the container port, compared to the 2016 Master Plan which was the original source for the forecast. Although the latest data available supports these lower growth projections if higher growth did occur this could have an impact along the Western Approaches.

Based on these considerations the key sensitivity test that has been taken forward for the baseline is to return the port growth to that originally sourced from the 2016 Port Masterplan, with all other assumptions keep the same, as a worst-case scenario.

The sensitivity testing for the options, given modelled compliance in the baseline, is now much less important in terms of affecting the outcome. Any mitigation measures that are taken forward should be seeking to improve the confidence in compliance by 2020. Given this the consideration on sensitivity testing for the options is as follows:

- *CAZ B sensitivity test* – given the current position with the baseline this option is a much less likely outcome. Also, the proposed test of a 0% upgrade assumption as a worst case scenario is likely to yield results little different from the baseline. This is because the original modelling of the city-wide CAZ B showed little diversionary affect, with the greatest impact on concentrations being a result of the upgrade assumption. Based on this it is not proposed to carry out any further sensitivity testing of the CAZ B option.

- *Non-charging CAZ* – the final set of measures tested for the non-charging CAZ are significantly reduced in scope and scale of uptake, since the original test was considered very optimistic. As such the impact of the option is expected to be a small but useful benefit. Given this any tests that reduce the impact of the non-charging scheme further are limited. Based on this only a very simple test is proposed that halves the benefit of the non-charging scheme on concentrations.

6.2 Wider air quality modelling sensitivity tests

A set of wider sensitivity tests on areas of uncertainty in the air quality modelling were suggested by JAQU as part of their guidance. This list has been reviewed in light of the results from the modelling work to derive a set of tests that explore whether any of the areas of uncertainly may affect the outcome of the analysis or not. Table 4 below provides a summary of the tests suggested by JAQU and the approach adopted within this study.

Table 4 Wider Air Quality modelling sensitivity tests

Area of uncertainty	Sensitivity testing suggested by JAQU	Sensitivity test adopted	Which modelling options is test applied to?
Future emissions standards	Low scenario: Euro 6d-temp emissions equivalent to Euro 6d High scenario: Euro 6d-temp emissions halfway between Euro 6 & Euro 6d-temp and Euro 6d emissions halfway between Euro 6d-temp and Euro 6d	Adjust LDV Euro 6 fleet mix to all Euro 6a as worst-case scenario and re-run emissions and dispersion models	Only necessary for the 2020 Do minimum case to see if compliance is still achieved.
Projecting f-NO2	Lower f-NO2 values in projected year by 40%.	Apply test as proposed	Apply to all future scenario results

Gradient based emission factors	Remove the effect of gradients (if modelled), add the effect of gradients (if not modelled).	Gradients are not present along areas of concern (Western approach) so this test is not necessary.	Not applied at all
Canyon effects	Use canyon module (if not used in 'central' modelling), use separate calibration for canyon road links (if not done in 'central' modelling). Alternatively, cite information provided by JAQU.	Canyons are not present along areas of concern (Western approach) so this test is not necessary.	Not applied at all
Emissions at low speeds	Low scenario: Emissions factors for HDVs used to speeds recommended in COPERT 4. High scenario: Emissions factors for HDVs used to 5kph.	Provide comments justifying approach used in modelling and discussing the extent of the difference this could make.	For this and all below provide a discussion. Discussion done in relation to baseline as all these will affect all options equally.
Zonal vs full model domain calibration	Full model domain calibration (if zonal applied), zonal calibration (if full model domain applied).		
Background NO2 calibration	Calibrate background NO2 (if uncalibrated background maps used), remove background NO2 calibration (if calibrated background maps used).		
f-NO2 and calibration	Calibrate NOx using chemiluminescence monitors only (or cite information provided by JAQU).		
Surface roughness length	High and low surface roughness values (to be discussed with JAQU on a case by case basis).		
Meteorology	Model in projected year using alternative years of meteorological data (or cite information provided by JAQU).		

Appendices

Appendix 1: Details of port modelling

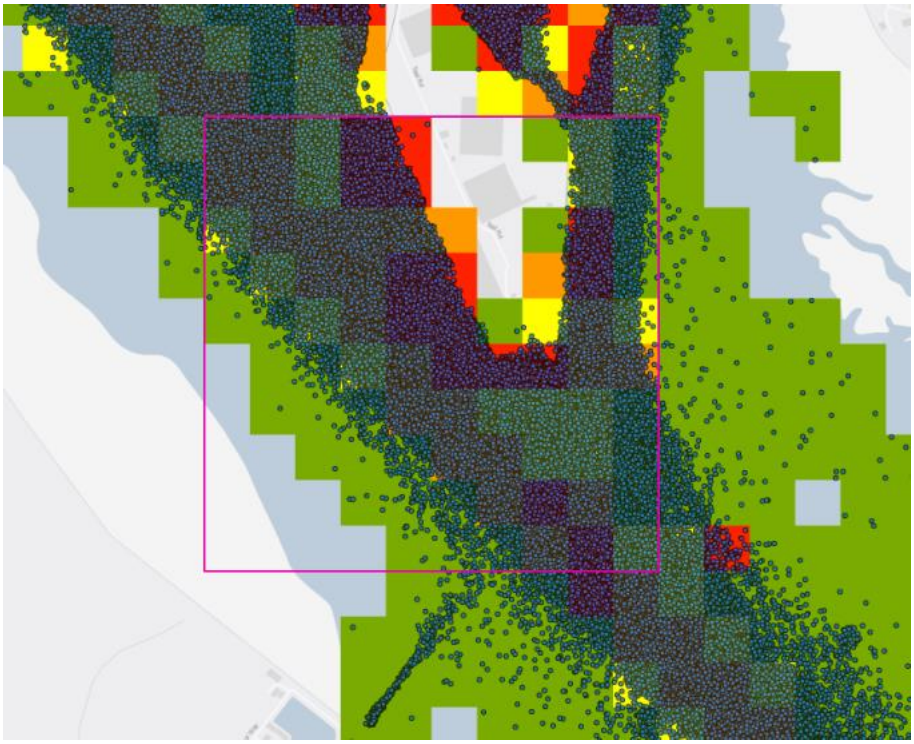
Appendix 1 – Details of port modelling

A1 Vessels travelling to, from and berthed at the port

NO_X emissions from vessels travelling to, from and berthed at the port have been taken from the latest estimates in the National Atmospheric Emissions Inventory (NAEI). This is based on the latest update made to the estimation of emissions from shipping in the NAEI, as published in December 2017[29]. Permission has been obtained from the sponsor (the Department for Business, Energy and Industrial Strategy, BEIS) and data provider (the Maritime and Coastguard Agency, MCA) in order to use the latest estimates.

The updated spatially disaggregated shipping emissions inventory is derived nationally from Automatic Identification System (AIS) data that was provided by the Maritime and Coastguard Agency to Ricardo Energy & Environment. This inventory reflects the actual ship movements for the year 2014, and has been assumed to represent the base year 2015 in terms of quantity and spatial distribution of emissions. The inventory includes annual NO_X emissions per 1km by 1km grid resolution; however, for the purposes of this analysis for Southampton this has been refined to NO_X emissions per 100m by 100m resolution (Figure 17). All vessels that are in scope of the inventory are included, regardless of whether they are undertaking international or domestic voyages.

Figure 17 AIS positions of vessels around the Eastern docks, with purple outline showing 1km resolution, which has been refined to 100m resolution for the purposes of the modelling.



The inventory aims to provide near-complete coverage of vessel activity in Southampton Water. It covers all vessels that transmit positions via AIS, with the exception of some vessel types. The vessel types covered and not covered by the updated inventory are shown in Table 5. The emissions from

[29] https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1712140936_ED61406_NAEI_shipping_report_12Dec2017.pdf

vessel types not included in the updated NAEI shipping inventory (recreational, military) will not be estimated or modelled. However, these are assumed to be negligible compared to the large vessels docking at Southampton port.

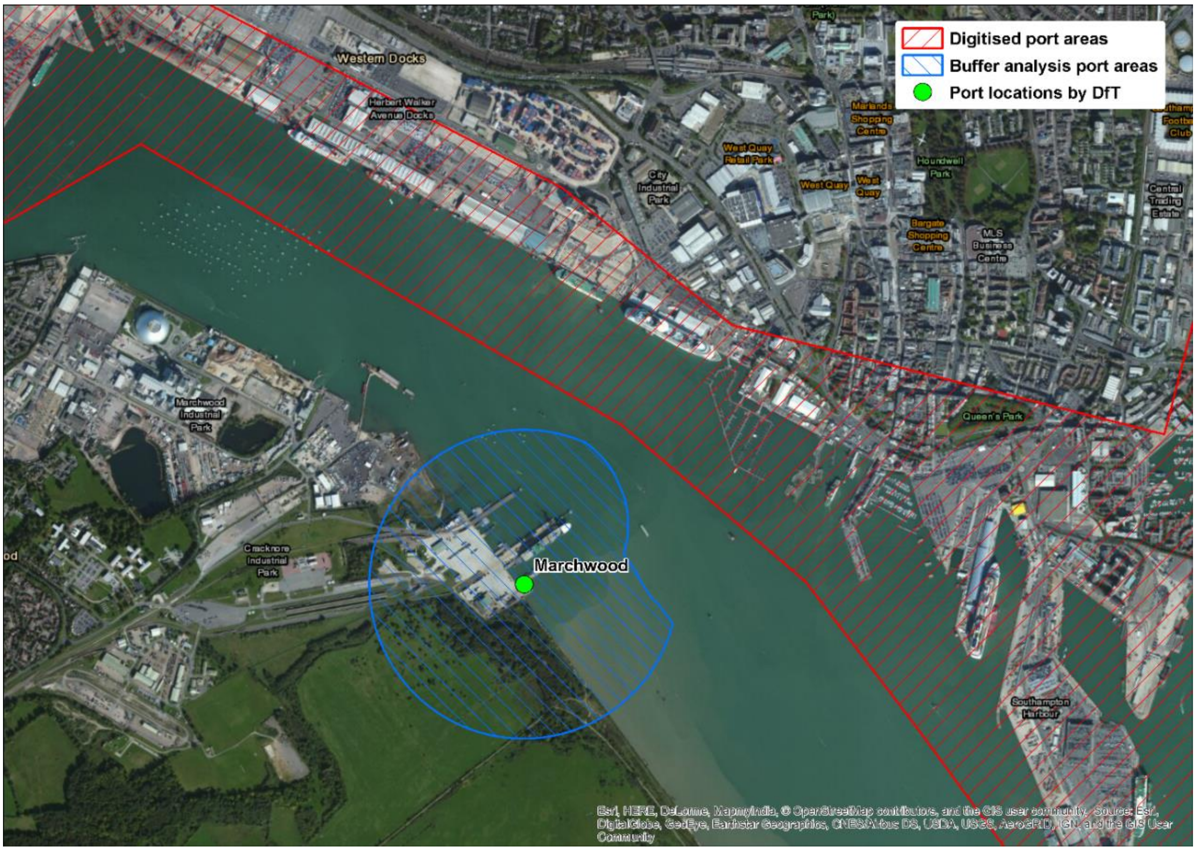
The inventory includes estimates of emissions from vessel main engines as well as their auxiliary engines (generators) and auxiliary boilers if relevant for the vessel type. Cruise ship incinerators are assumed not to be operated whilst in port.

The inventory includes vessels whilst underway, manoeuvring and whilst at berth. The inventory defines vessels as being at berth when they are reported under AIS as moving at less than 1 knot, and when their coordinates are within a port boundary (example shown in Figure 18). The port area for Southampton is considered to be the boundary of the red zone of Figure 18 (zoom only shows western and eastern docks, container terminal not shown but is included). The inventory includes emissions from vessels' auxiliary engines and boilers running whilst the vessel is at berth, capped at a maximum of 24 hours, i.e. if vessels are deemed to be at berth for longer than 24 hours then all their engines are assumed to be off.

Table 5 Vessel types covered and excluded from the updated NAEI shipping emissions inventory

Vessel types included in the spatially disaggregated NAEI inventory		Vessel types excluded from the spatially disaggregated NAEI inventory
• Bulk carrier • Chemical tanker • Container • General cargo • Liquefied gas tanker • Oil tanker • Other liquids tankers • Ferry-pax only • Cruise	• Refrigerated bulk • Ro-Ro • Vehicle • Service - tug • Miscellaneous - fishing • Offshore • Service – other (including e.g. dredgers) • Miscellaneous - other	Recreational vessels – pleasure craft and other inland waterway vessels Military vessels. Noting Marchwood Military Port is on south side of Southampton Water. Any other vessels that did not operate AIS

Figure 18 Sample port boundaries used to define when vessels are at berth



The emission release heights that have been assumed per vessel type are shown in Table 6. These are based on:

- For cruise ships, inspection of planned cruise ship calls at Southampton in 2017, and literature research on vessel heights excluding draught.
- For container ships, inspection of recent container ship calls at Southampton, and weighted average according to vessels over 300m length (assumed funnel height of 57m), vessels 200-300m length (assumed funnel height 39m) and vessels less than 200m (assumed funnel height above water 26m)
- All other merchant vessels assumed 30m based on EC study[30]
- Ferry-pax based on average estimated heights of Red funnel ferries and Hythe ferry
- Other vessel types estimated.

The dispersion modelling of vessel emission releases made further assumptions on the 'effective' release height given plume buoyancy (e.g. due to exhaust gas temperature and velocity).

[30] http://ec.europa.eu/environment/enveco/taxation/ship_emissions/pdf/app2final.pdf

Table 6 Assumed vessel emission release heights

Vessel type	Height above waterline (m)
Bulk carrier	30
Chemical tanker	30
Container	44
General cargo	30
Liquefied gas tanker	30
Oil tanker	30
Ferry-pax only	10
Cruise	61
Refrigerated bulk	30
Ro-Ro	30
Service - tug	5
Miscellaneous - fishing	5
Offshore	10
Service - other	5
Miscellaneous – other	5

A2.2 Rail

Emissions from freight and passenger trains operating on the mainline through Southampton City Centre have been taken from the background NAEI maps as the emissions in the NAEI for rail freight have been spatially disaggregated across the core rail network which includes the main line at Southampton.

The NAEI base maps of emissions from rail have been used. However, rather than including these at the 1km resolution, they have been refined to instead represent the emissions as line sources along the Network Rail Strategic Route networks, for each rail subsector of rail freight, intercity and regional.

A2.3 Port operations

The assessment of port operation emission sources has identified the main sources of NO_X emissions from the port, and assigned them as point, line (mobile) or area sources for dispersion modelling. The following emission sources have been estimated:

- Cargo handling equipment:
  - Straddle carriers
  - Freight Trains
  - HGVs-containers
  - Car transporters
  - HGVs – other goods e.g. foodstuffs
- Other service vehicles:
  - Forklifts
  - Any top/side loaders
  - Other port vehicles
- Emissions from vehicles driven off (import) and driven on to (export) RoRo vessels
- Employee and visitor (e.g. cruise customer) private vehicles
- On site power generation (combustion plant) e.g. engines

Shore-side and rail freight container terminal gantry cranes are 100% electric powered and so have not been included in the port inventory. No permanent on-site power plants are operated (but temporary generators have been accounted for).

Straddle carriers

NO_X emissions from straddle carriers have been taken from real-world data in a Ricardo study for DP World which measured NO_X and NO_2 emissions for six types of non-road mobile machinery (NRMM) straddle carrier diesel engines in use at the port of Southampton. From these measurements it generated total annual emission estimates for the fleet, accounting for each emission standard of straddle carrier. That work developed a complete inventory of straddle carriers operated at the port; that inventory has been updated with the latest straddle carrier fleet information from DP World for this study.

The straddle carriers have been modelled as two area sources, one area for the 4-high straddle carriers (assumed emission release height 15 metres) which operate landside only (not shipside, nor to the freightliner terminal), and one area for the 3-high carriers (assumed emission release height 12 metres) which also operate shipside and to the freightliner terminal. The diurnal variation in operation of the straddle carriers has been taken into account in the dispersion modelling, based on data from DP World[31] on the average number of straddle carriers operated at different times of day.

Freight Trains

The emissions associated with freight train operation when departing from the mainline and whilst idling during loading/unloading have been modelled as line sources, and have been modelled as additional to the rail emissions in the NAEI which do not account for specific rail terminal operation.

The emissions from the freight trains (container, vehicle and gypsum) servicing each terminal have been estimated. Activity rates per terminal (number of train services per week) have been obtained through consultation with a rail freight operator (Deutsche Bahn) at the port, and are shown in Table 7. All activity is assumed to be carried out by line haul locomotives without additional shunting locomotives.

The fuel consumption rates in litres/hour for both idling and for arrival/departure from the port have been identified from engineers in a rail freight operator (9.1kg/hr whilst idling, and 38.6kg/hr during arrival/departure from the port). NO_X emissions have been estimated from the fuel consumption using the NO_X emission factor taken from the NAEI for rail (105.5kg NOx/ tonne of fuel). Estimates of the time taken for travel into and out of the port from the mainline have been agreed through consultation with a rail freight operator. The extent of the class 66 locomotives that currently deploy start-stop technology (to turn engines off whilst idling) has also been taken into account.

The activity has been assumed to be spread equally through the year. The emission source has been modelled as a line source, assumed to be emitted at 4m height above land. The specific sources considered are summarised in Table 7:

Table 7 Summary of Southampton port rail services. The maritime terminal is assumed to be used in preference to the Millbrook terminal.

Cargo	Location	Operator	Number of services	Idling time / service	Duration of travel from and return to mainline
Cars	Eastern docks (Figure 19)	Deutsche Bahn	25-30/week, 46 weeks/year	1.25 hours*	0.5 hours

[31] Personal Communication. DP World, 4 October 2018.

Vans	Western docks Ro-Ro terminal (Figure 20)	Deutsche Bahn	3/week, 46 weeks/year	1.25 hours*	0.5 hours
Gypsum	Bulk terminal, Herbert Walker Avenue (Figure 20)	GB Rail Freight	2/week, 46 weeks/year	1.25 hours	0.5 hours
Containers	Maritime terminal (Figure 21)	Freightliner	60/week, 50 weeks/year	1.25 hours	0.25 hours
Containers	Rail terminal, Herbert Walker Avenue (Figure 20)	Deutsche Bahn	26/week, 50 weeks/year	1.25 hours*	0.5 hours

** 90% of idling time is with engines off, due to stop-start technology retrofitted to Deutsche Bahn Class 66 locomotives*

Figure 19 Location of terminal in Eastern docks. Emissions estimated from departure from mainline, shown by red line

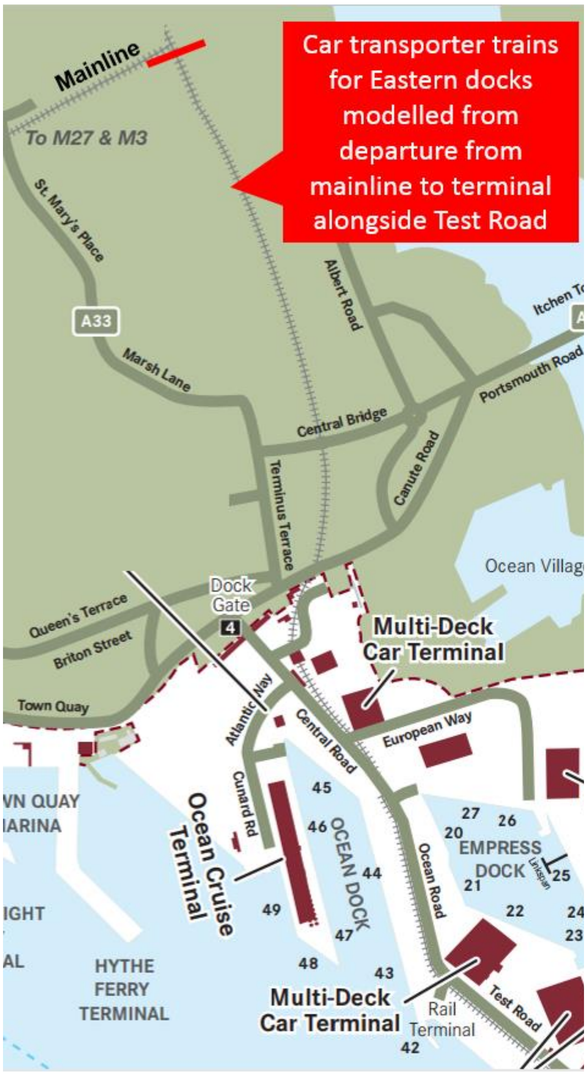


Figure 20 Location of terminal at Herbert Walker Avenue. Emissions estimated from departure from mainline, shown by red line

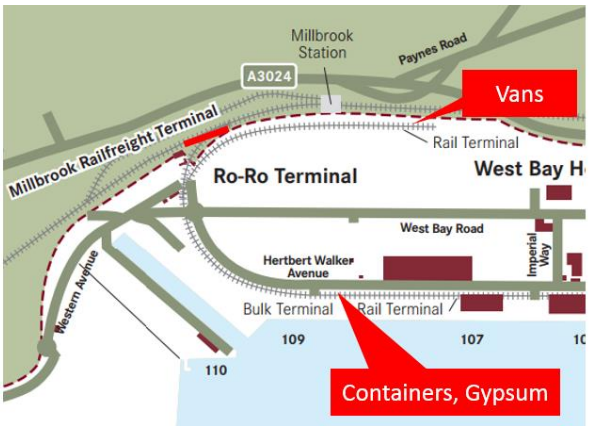


Figure 21 Location of freightliner terminal. Emissions estimated from departure from mainline, shown by red lines

No assessment has been made of the railway network running to the Marchwood military port on the south side of the River Test estuary.

Vehicles operating within the port having entered from public roads

NO_X emissions from vehicles that operate within the port having entered to the dock via dock gates has been modelled as an extension of the road traffic modelling. The modelling includes motorbikes, cars (and taxis), light goods vehicles, heavy goods vehicles (including containers and car/van transporters) and coaches. The same fleet (Euro standard) mix of vehicles as are assumed in the road traffic modelling to operate on nearby public roads has been adopted.

Annual average daily flows per road link have been estimated from:

- Count data per vehicle type from a fortnight in 2015 from Southampton City Council, multiplied up to represent one year (Table 8)
- Assumptions related to which road links within the port each vehicle type will travel on depending on the dock gate entered (Table 10).

This assumes no idling during unloading/loading. The resulting estimated annual vehicle flow rates are shown in Table 9.

Table 8 Number of journeys via each dock gate per vehicle type in 2015 (estimated from 2 weeks of SCC count data from summer 2015)

Entry/exit	Motorbike	Car/taxi	LGV	Rigid HGV	Artic HGV	Bus/coach
Dock gates 4+5	12,168	343,311	139,191	77,467	42,718	4,752
Dock gate 8	1,300	58,773	26,741	5,083	1,313	878
Dock gate 10	11,622	263,673	109,031	52,546	72,852	4,849
Dock gate 20	17,433	285,032	79,313	182,806	234,338	2,015

Table 9 Vehicle counts assumed in 2015 per road link, excluding exclusively in-port vehicles

Road link	Motor-bike	Car	LGV	Rigid HGV	Artic HGV	Coach / Bus
Central road N of roundabout	12,168	343,311	139,191	77,467	42,718	4,752
Central road S of roundabout to junction with European Way	6,692	188,821	92,794	51,645	35,598	2,376
Central road from junction with European Way to Ocean Road	5,476	154,490	46,397	25,822	21,359	2,376
Old road	0	0	0	0	7,120	0
Atlantic way	12,168	343,311	139,191	77,467	42,718	4,752
Cunard road	10,951	308,979	46,397	25,822	0	2,376
Ocean road	5,476	154,490	46,397	25,822	21,359	2,376
Test road	5,476	154,490	46,397	25,822	21,359	2,376
European Way	1,217	34,331	46,397	25,822	14,239	0

Road link	Motor-bike	Car	LGV	Rigid HGV	Artic HGV	Coach / Bus
Eastern end of Herbert Walker Avenue to T junction with Solent Road	1,300	58,773	26,741	5,083	1,313	878
Solent road (between roundabout and T junction)	0	0	13,371	2,542	657	0
Southern road	11,622	263,673	109,031	52,546	72,852	4,849
Eastern end of Herbert Walker Avenue to T junction with Solent Road	3,874	87,891	0	0	0	0
Solent road (between roundabout and T junction)	3,874	87,891	54,516	26,273	36,426	4,849
Herbert Walker Avenue between Solent road and Imperial Way	3,874	87,891	54,516	26,273	36,426	4,849
Herbert Walker Avenue between Imperial Way and roundabout meeting West Bay road	0	0	54,516	26,273	36,426	0
West Bay road east of junction with Imperial Way	7,748	175,782	109,031	52,546	72,852	4,849
West Bay road west of junction with Imperial Way	0	0	54,516	26,273	36,426	0
Imperial way	7,748	175,782	109,031	52,546	72,852	4,849
First avenue from A33 to roundabout	17,433	285,032	79,313	182,806	234,338	2,015
Western avenue west of roundabout junction with First Avenue	8,717	142,516	0	0	140,603	0
Western avenue east of roundabout junction with First Avenue to roundabout with T3	8,717	142,516	79,313	182,806	234,338	2,015
Western avenue east of roundabout with T3 until roundabout with West Bay Road	8,717	142,516	79,313	182,806	23,434	2,015
West Bay road east of junction with Imperial Way	8,717	142,516	0	0	0	0
Herbert Walker Avenue between Imperial Way and roundabout meeting West Bay road	0	0	79,313	182,806	23,434	2,015

Table 10 Assumptions for traffic routes within the port.

<table>
<tr><th>Dock Gate</th><th>Road link</th><th>Comments-car and motorbike</th><th>Comments-Artic HGV</th><th>Comments rigid HGV and LGV</th><th>Comments buses and coaches</th></tr>
<tr><td rowspan="9">Dock Gates 4+5</td><td>Central road N of roundabout</td><td rowspan="9">Assume that 10% of car traffic that enters at dock gate 4 is to the campus, and 90% for the cruise, which is then 50:50 split of car traffic between two cruise termini. Doesn't cover parking areas.</td><td rowspan="9">Assume all artic HGV traffic is car transporters, split 50% along ocean road (3 of 6 multi decks are here), 33% European way (2 multidecks) and 17% to old road (1 multideck).</td><td rowspan="9">Assumed rigid HGV traffic is equally split along Cunard, Ocean and European Way</td><td rowspan="9">Assume half service QEII terminal and half service the Ocean cruise terminal</td></tr>
<tr><td>Central road S of roundabout to junction with European Way</td></tr>
<tr><td>Central road from junction with European Way to Ocean Road</td></tr>
<tr><td>Old road</td></tr>
<tr><td>Atlantic way</td></tr>
<tr><td>Cunard road</td></tr>
<tr><td>Ocean road</td></tr>
<tr><td>Test road</td></tr>
<tr><td>European Way</td></tr>
<tr><td rowspan="2">Dock Gate 8</td><td>Eastern end of Herbert Walker Avenue to T junction with Solent Road</td><td rowspan="2">Assume passengers will only enter dock gate 8 for city cruise terminal</td><td rowspan="2" colspan="2">Assume half go to City Cruise terminal and half to near the Hovis mill</td><td rowspan="2">Assume all go to City Cruise terminal</td></tr>
<tr><td>Solent road (between roundabout and T junction)</td></tr>
<tr><td rowspan="8">Dock Gate 10</td><td>Southern road</td><td rowspan="8">Assume passengers will be 1/3 City Cruise and 2/3 Mayflower cruise terminal. Assume half of Mayflower customers use drop off along quayside.</td><td rowspan="8" colspan="2">Assume half LGV+HGV traffic loops <Southern road-Solent road-Herbert Walker avenue-Imperial way-West Bay Road-Southern Road>, and the other half loop <Southern Road-WestBay Road-Imperial Way-Herbert Walker Avenue-West Bay road-Southern Road></td><td rowspan="8">Assume all loop <Southern road-Solent road-Herbert Walker avenue-Imperial way-West Bay Road-Southern Road></td></tr>
<tr><td>Eastern end of Herbert Walker Avenue to T junction with Solent Road</td></tr>
<tr><td>Solent road (between roundabout and T junction)</td></tr>
<tr><td>Herbert Walker Avenue between Solent road and Imperial Way</td></tr>
<tr><td>Herbert Walker Avenue between Imperial Way and roundabout meeting West Bay road</td></tr>
<tr><td>West Bay road east of junction with Imperial Way</td></tr>
<tr><td>West Bay road west of junction with Imperial Way</td></tr>
<tr><td>Imperial way</td></tr>
<tr><td rowspan="6">Dock Gate 20</td><td>First avenue from A33 to roundabout</td><td rowspan="6">Assume 50% cars and motorbikes entering at dock gate 20 are destined to park in western most car parks, west of Container port, rest travel through to West Bay Road</td><td rowspan="6">Assume 90% of artic-HGV traffic is containers, split equally to T1, T2 and T3. Remaining 10% travels through to Herbert Walker Ave.</td><td rowspan="6">Assume rigid HGVs travel to scrap operator in western docks</td><td rowspan="6">Assume bus/coaches travel to Mayflower cruise terminal</td></tr>
<tr><td>Western avenue west of roundabout junction with First Avenue</td></tr>
<tr><td>Western avenue east of roundabout junction with First Avenue to roundabout with T3</td></tr>
<tr><td>Western avenue east of roundabout with T3 until roundabout with West Bay Road</td></tr>
<tr><td>West Bay road east of junction with Imperial Way</td></tr>
<tr><td>Herbert Walker Avenue between Imperial Way and roundabout meeting West Bay road</td></tr>
</table>

HGV tug/tractor units operating exclusively inside the port

NO_X emissions from HGVs tractor units that deliver containers between the DP World container terminal and the Herbert Walker Avenue rail freight container terminal have been modelled as a line source along in-port roads – assumed to travel along Western Avenue, West Bay Road east of the junction with Imperial Way, and on Herbert Walker Avenue between Imperial Way and the junction with West Bay Road. Data provided by DP World suggested 834 such movements for one week in June 2015. This was assumed to be representative of a typical week, and assuming 51 working weeks per year yielded an estimate of 42,500 movements per year. The emissions for these articulated HGV tractor units have been modelled as part of the city-wide road traffic modelling, with the same fleet mix of Euro standards. This assumes no idling during unloading/loading.

Miscellaneous sources: cranes, NRMM, and vehicles driven on/off RoRo vessels

This category includes stevedoring equipment and vehicles operated and driven within the port and which are not driven outside of the port gates. Due to the large number of small but mobile sources operating across port, these emission sources have collectively been modelled as two area sources: one area source covering the Eastern Docks and a second covering the Western Docks. For all of the above except vehicles driven on/off RoRO vessels, fuel consumption records or estimates from port operators have been sought. Where fuel consumption records were not identified, fuel consumption was estimated either from other similar equipment inventoried or from fuel consumption factors in the EMEP/EEA air pollutant emission inventory guidebook[32]. NOx emissions were estimated from the annual fuel consumption using NOx emission factors expressed per unit of fuel consumption, selected appropriately to match the equipment in question (also from the EMEP/EEA air pollutant emission inventory guidebook). It includes the sources listed in Table 11.

Table 11 Stevedoring emission sources accounted for

Operator	Source	Location	Data source
Wallenius Wilhelmsen Logistics (WWL)	Crew buses, forklifts, tractor units	Eastern docks	Fuel records
WWL	Mobile harbour cranes	Eastern docks	Estimated from operating profile
Southampton cargo handling	Various	Eastern docks	Assumed equal to WWL
Williams shipping	Temporary generators, crawler crane and forklift	Eastern docks	Estimated from annual average operational profiles
ABP	Equipment, including CIL harbour cranes. Vehicles including NRMM	Assume split equally Eastern and Western docks	Fuel records
Fruit terminal	Cranes [began operation 2016]	Western docks	Fuel records
S Norton (scrap operations)	Excavators, material handlers	Western docks	Fuel records

[32] https://www.eea.europa.eu/publications/emep-eea-guidebook-2016

Operator	Source	Location	Data source
Solent stevedoring	Mobile harbour cranes, excavators, bobcats	Assume split equally Eastern and Western docks	Fuel records
Solent stevedoring	Tugs/tractor units, reach stackers	Western docks	Operational profile

The emissions from import/export vehicles which are driven on to and off from Ro-Ro vessels have also been estimated. The total number of vehicles imported and exported in 2015 was 908,000 as reported in DfT statistics[33] of which the number of "high and heavy" NRMM vehicles imported and exported is around 37,000/yr[34] and it is assumed that the remaining vehicles are split 90% cars and 10% vans. The distances travelled to vehicle storage compounds (including multi-decks) in both Eastern and Western Docks were estimated based on the identified locations of Ro-Ro berths and the appropriate vehicle storage facilities. The emission factors applied were from the EMEP/EEA air pollutant emission inventory guidebook for road transport or NRMM as appropriate. All vehicles were assumed to be of the latest applicable euro standard in 2015.

Table 12 Assumptions for estimating NOx emissions from vehicles imported and exported

Vehicle type and storage location	Number imported / exported in 2015	Distance each vehicle driven in port from road/rail transporter to RoRo vessel or from RoRo vessel to road transporter	NOx emission factor
Cars – stored in Eastern docks	621,000	1km	Euro 6. Assumed 50% petrol (average medium, large: 0.06g/km), 50% diesel (any size: 0.5g/km).
Cars – stored in Western docks	162,900	3km	
Vans – Western docks	87,100	3km	Euro 6 diesel (0.5g/km).
NRMM ("high and heavy") – Eastern docks	37,000	0.5km	Fuel consumption assumed to be 5 mpg. NOx emissions factor taken as NRMM Stage V (Tier 2, Agriculture): 1861g/t fuel.
Sources	*DfT, ABP*	*Assumption*	*EEA Guidance 2016*[35]

33 Port Freight Statistics , Table PORT0211
34 Personal communication with ABP
35 https://www.eea.europa.eu/publications/emep-eea-guidebook-2016

Ricardo
Energy & Environment

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR
United Kingdom

t: +44 (0)1235 753000
e: enquiry@ricardo.com

ee.ricardo.com