Cambridge Clean Air Zone Feasibility Study - Appendices

Final Report for the Greater Cambridge Partnership

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A Developing air quality mitigation options

This task established a list of intervention options to improve air quality. There are a large number of options that could be implemented in Cambridge covering different CAZ classes (A/B/C/D)[1], geographic scope, and wider emission reduction measures. To develop a shortlist of options for the modelling a structured sifting approach was followed.

The overall objective of a CAZ would be to improve air quality in Cambridge City by reducing emissions from vehicles, with two primary goals:

1. Achieve compliance with the National Air Quality Objectives (AQOs);
2. Further reduce vehicle emissions in Cambridge, as further health benefits are associated with decreases below the AQOs.

The target of the zone is the city centre. The CAZ would be at the core of this vision but supported by a range of other measures to promote the uptake of low and zero emission vehicles.

The sections below set out the work done to develop the air quality mitigation options, and the final short list of mitigation options.

A.1 Stakeholder engagement

Without stakeholder commitment, the improvements in air quality will be hard to deliver. The City Council has worked hard to engage with a wide range of stakeholders, and to build trust and commitment to the AQAP and air quality intervention strategy.

Two main stakeholder engagement activities were carried out during the project: an early internal stakeholder workshop and a further engagement workshop which came later in the project. Below is a summary of the two workshops.

A.1.1 CAZ Feasibility Study workshop, May 2018

This initial workshop was held on Tuesday, 29th May 2018 in Cambridge and its key objectives were to:

- Present the objectives of the study and the work to a wide range of relevant internal stakeholders
- Reach a view on the short list of potential options to improve air quality in Cambridge from internal stakeholders.

Attendees included environment officers, transport planners, and development planners from the City Council, Cambridgeshire County Council (as the transport authority), and the GCP.

There was a wide-ranging discussion in relation to the overall CAZ concept and specific scheme options. A short list of air quality mitigation options was used to define scenarios for the air quality modelling.

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/612592/clean-air-zone-framework.pdf

A.1.2 Second stakeholder workshop, August 2018

A second workshop was held later in the study. This was timed to be held when the initial air quality modelling results for the scenarios were available, and the initial economic assessments had been completed.

The outputs from this work were presented to and discussed with the group from the feasibility study workshop, together with stakeholders from a public health perspective, for their views. The outcome of the workshop supported the overall multi-criteria assessment and selection of the final short listed options as described below.

A.2 Long list of options

The list of options was compiled from air quality reports, and communication with the teams in Cambridge responsible for air quality, including the Environmental Health team. Primary written public sources of information that were used were:

- The Air Quality Action Plan 2018
- Air Quality Annual Status Report 2016
- Air Quality Annual Status Report 2017
- Climate change strategy 2016-21
- Cambridgeshire Local Transport Plan 2011-2031.

A wide range of potential air quality mitigation measures or options were collated, uniquely identified and thematically grouped into those that applied to:

- Freight (8)
- Taxis (11)
- Buses (8)
- Cycling (4)
- Demand management (36)
- Behavioural change (2)

The number of measures identified are in brackets.

A number of criteria were used to produce and refine the long list. These criteria were:

- Will the measure help bring the 2020 compliance forward?
- Is it likely to be effective?
- What is the timescale?
- Can it be delivered?
- What are the co-benefits (for example, are there reductions in greenhouse gas emissions?)
- What is the likely uptake?
- What are the positive benefits?
- What might be the negative impacts?
- Is it a “complementary measure”?
- Is the effect quantifiable?
- Has it already been implemented / planned?
- Is the measure Part of the City Access Programme[2]?

Considering these criteria constituted a simplified multi criteria assessment (MCA).

[2] https://www.greatercambridge.org.uk/transport/transport-projects/city-access/

B Air dispersion modelling

This section describes the non-source inputs for the air dispersion modelling work. The compilation of the emissions inventories used in the modelling is described in detail in Section C.

B.1 Dispersion model

The modelling was carried out using the latest version of the RapidAir dispersion model, described in below.

The dispersion modelling was carried out in the RapidAir dispersion modelling system using the emissions inventory developed as described above and national background concentration maps.

RapidAir is an urban air quality dispersion model developed by Ricardo Energy & Environment focusing on road traffic emissions. Whilst the dispersion model has been developed as a proprietary solution by Ricardo, RapidAir is based on the USEPA AERMOD model. The advantage of RapidAir is the coupling of a tried and tested pollution model with a novel calculation methodology which significantly speeds up the analysis.

The approach we have developed is based on loose-coupling of three elements:

- Road traffic emissions model conducted using fleet specific COPERT V algorithms to prepare grams/kilometre/second emission rates of NOx in the pyCOPERT model as described above;
- AERMOD dispersion model for development of “kernels” at resolutions ranging from 1m to 125m;
- The kernel based RapidAir model running in ArcGIS to prepare dispersion fields of concentration.

B.2 Meteorology

Modelling was conducted using the 2017 annual surface meteorological dataset measured at Cambridge Airport, supplemented by data measured at the Bedford and Andrewsfield sites. The 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 processed with the surface data in the US Environmental Protection Agency (USEPA) AERMET model[3]. Data filling was carried out 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. A uniform surface roughness value of 0.5 m was modelled to represent a typical urban to suburban environment.

The wind rose of the meteorological data is presented in Figure 1. The wind rose shows the frequency of winds blowing from particular directions over the year. The length of each "spoke" around the circle is the frequency that the wind blows from that direction. The wind rose is typical for southern England, where south-westerly winds predominate.

[3] https://www.epa.gov/scram/meteorological-processors-and-accessory-programs

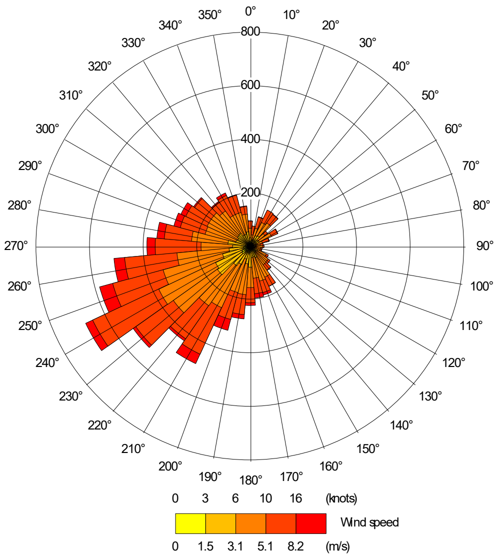


Figure 1: Wind rose derived from Cambridge airport meteorological data, 2017

B.3 Canyon modelling

The presence of buildings either side of a road can introduce ‘street canyon’ effects which result in pollutants becoming trapped, leading to increased pollutant concentrations. The densely packed buildings and narrow roads of central Cambridge produce a large number of street canyons, which contribute significantly to air quality issues in the city centre.

Street canyon impacts were modelled using the RapidAir R-Canyon module. Building height data was sourced from Ordnance Survey (OS) Mastermap data provided by Cambridge City Council.[4]

B.4 Gradient and flyovers

Gradient effects were not included in the modelling, based on expert judgement; the Cambridge region has very limited relief, and so any gradient effects will be insignificant. All road links were modelled at ground level in order to provide a conservative estimate of ground level concentrations; roads above ground will have a reduced impact on ground level concentrations due to elevation of the plume centreline.

B.5 Chemistry

NOx to NO_2 chemistry was modelled using the NOx:NO_2 calculator published by Defra[5]. Modelled annual mean road NOx concentrations were combined with background NOx and modelled primary NO_2 fraction results 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.

[4] https://www.ordnancesurvey.co.uk/business-and-government/products/mastermap-products.html
[5] https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html

C Emissions inventory compilation

C.1 Outline methodology and model domain

The development of the emission inventories was carried out through the following process:

1. Collation of traffic data;
2. Collation of fleet fuel and technology statistics from various sources;
3. The traffic and fleet data were combined with emission factors from the most recent version of the Emission Factor Toolkit (EFT), version 8.0.1[6] to provide total annual emissions of NOx and PM for the modelled road links;
4. An initial RapidAir dispersion modelling run was carried out, and the results verified against actual measured data in 2017 to provide a model calibration factor, described in Section D.

The emissions and air quality modelling has been carried out to cover the whole city. The focus has been on the road traffic emissions from the main roads including those in the city centre. The area covered by the modelling work is shown in Figure 2.

Figure 2: Model domain

Three main sources of road traffic emissions were considered in the assessment:

1. Emissions from free-flowing traffic
2. Emissions from traffic idling due to congestion
3. Emissions from idling at bus stops.

Further detail on the emissions inventory compilation for each scenario is provided in the sections below.

[6] https://laqm.defra.gov.uk/review-and-assessment/tools/emissions-factors-toolkit.html

C.2 Emission factors

Emissions from all modelled road traffic sources were calculated using speed-dependent vehicle emission factors for NOx, primary NO_2, and particulates from COPERT v5[7], and the Emission Factor Toolkit (EFT) version 8.0.1[6]. COPERT is a European database of emission factors which is recommended for the quantification of road-transport emissions and is the basis of the EFT. These factors provide emission factors categorised by vehicle size, age, and Euro classification, taking into account average vehicle mileage and engine degradation.

C.3 Vehicle fleet composition

C.3.1 Size and type distribution

A uniform vehicle size and type distribution was modelled for all years. Vehicle fleet composition data was primarily derived from an automatic number plate recognition (ANPR) survey carried out by the GCP in June 2017. Euro emission standard categories, fuel types, and some size split data for each vehicle type were provided for three days across 96 sites, providing good spatial coverage of the model domain. Any sites on roads which were not included in the Cambridge Sub-Regional Traffic Model 2 (CSRM2) transport model were removed from the analysis.

The model domain was separated into two regions; the city centre, comprising the inner ring road and the area inside it, and the surrounding area. Where no detailed information on vehicle type or size splits was available from the CSRM2 traffic model, information from the ANPR survey described above was used to derive a split.

Separate vehicle type splits were calculated for these two regions, reflecting the differences in vehicle composition between central Cambridge and its surroundings. The two vehicle fleet regions are shown in Figure 3.

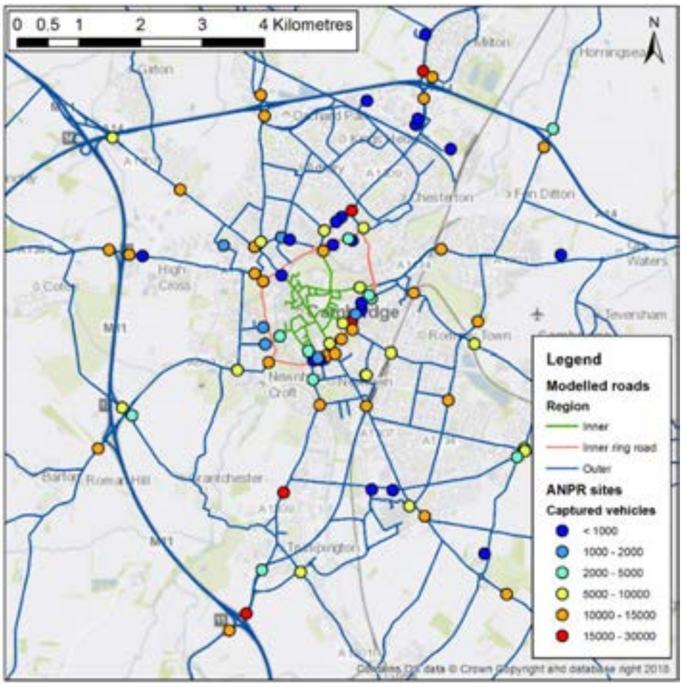


Figure 3: Modelled vehicle fleet composition regions and ANPR sites, categorised by average daily captured vehicles

[7] http://www.emisia.com/utilities/copert/

The modelled size splits for HGVs, and for buses and coaches, are presented in Table 1.

Table 1: Vehicle type splits derived from ANPR data

Vehicle category	Type	Outside inner ring road	Inside and around inner ring road
HGV	Rigid	93.7%	98.9%
	Articulated	6.3%	1.1%
Bus/coach	Local	77.5%	84.5%
	Non-local & coaches	22.5%	15.5%

The CSRM2 model does not separate taxis from cars; the split between cars and taxis was calculated on a regional basis using traffic counts from a Vehicle Emission Measurement study analysis from 2013[8], provided by Cambridge City Council. Measurements were taken at 5 sites, providing counts both inside and outside the city centre. This information was augmented by local knowledge, and expert judgement. The splits used are presented in Table 2.

Table 2: Taxi percentage for different model areas

Region	% taxis (of all light vehicles)
Inside inner ring road and around Cambridge rail station	10%
Outside inner ring road	2.5%
Inner ring road	4%

C.3.2 Fuel and engine technology

The 2017 baseline vehicle fleet composition was collated using data from a number of sources, as no one source of data offers a complete and robust dataset covering all vehicles in Cambridge. In all cases, the most robust available dataset was used for each vehicle category. Information was available from:

- The 2017 baseline vehicle fleet composition for cars, LGVs, HGVs, non-local buses and coaches, including fuel classification, emission standards, and age, was derived from the ANPR survey.
- Fleet data for local buses, taxis and private hire vehicles was provided by Cambridge City Council.
- Motorcycle and moped fleet compositions were taken from national projections for vehicle fleet composition published by the department for Business, Energy and Industrial Strategy (BEIS).[9]

Fuel use splits for private cars were derived from the ANPR survey. These splits are presented in Table 3. Note that the projected electric component for 2031 is higher than the projected national average in urban locations (2.8%), reflecting the fact that electric vehicles comprise a higher percentage of private cars in Cambridge in 2017 than the national average.

[8] Vehicle Emissions Measurement and Analysis, Dr. James Tate, 2013
[9] http://naei.beis.gov.uk/resources/rtp_fleet_projection_NAEI_2015_Base_2016_v4.0_Final.xlsx

Table 3: Private car fuel use by region

Region	Fuel type	2017	2021	2031
Inside inner ring road	Petrol	47.3%	47.0%	57.1%
	Diesel	52.4%	52.3%	38.8%
	Electric	0.3%	0.6%	4.1%
Outside inner ring road	Petrol	51.5%	50.4%	58.9%
	Diesel	48.3%	49.0%	37.3%
	Electric	0.2%	0.6%	3.8%

Fleet composition data for the future year baseline scenarios was produced by projecting the 2017 fleet to each future year using national projections for fleet composition published by the Department for Business, Energy and Industrial Strategy (BEIS)[10].

The local bus fleet was assumed to stay constant between 2017 and 2031; this is a conservative assumption which ignores turnover and replacement by newer vehicles. Upgrades to the local bus fleet were modelled as intervention options.

The Cambridge City Council Hackney Carriage and Private Hire Licensing Policy, adopted in October 2018, identifies a number of incentives and regulatory policies which are designed to encourage and reward the uptake of ultra low emission vehicles and electric vehicles within the taxi fleet. This policy is separate to any interventions in this study, and its effects are included in the baseline for this assessment. However, as the requirement is for all taxis to be ULEV by 2028, there is a long time-lag to reach the desired emission improvement in the fleet. Following advice from Cambridge City Council, the effects of this policy were assumed to be:

- In 2021, 50% of Cambridge City Council taxis (Hackney carriages and Private Hire Vehicles) were assumed to be ULEVs, with the remaining taxis following the 2017 fleet.
- In 2031, 100% of Cambridge City Council licensed taxis were assumed to be ULEVs.

Fleet data for each modelled intervention was derived from the baseline for each year. Standard behavioural responses published by the Defra and DfT Joint Air Quality Unit (JAQU) were used to derive projected compliance within the zone, as presented in Table 4. Assumptions for vehicles cancelling journeys or avoiding the zone were not incorporated into the compliance percentages.

Table 4: JAQU behavioural response assumptions, as proportions of total vehicles

	Car	LGV	HGVs	Buses
Compliant	0.90	0.76	0.90	1.00
Non-compliant	0.10	0.24	0.10	0.00

Table 5 to

Table 12 present the modelled fleet composition for each year and intervention scenario.

10 http://naei.beis.gov.uk/data/ef-transport

Table 5: 2017 baseline fleet composition

	Car		LGV		HGV		Taxi		Buses and coaches	
Standard	Petrol	Diesel	Petrol	Diesel	Rigid	Articulated	Petrol	Diesel	Local	Non-local
Pre-Euro 1/I	1.1%	0.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 1/I	0.1%	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 2/II	1.0%	0.2%	1.8%	0.4%	0.3%	0.0%	0.0%	0.0%	0.0%	2.0%
Euro 3/III	9.8%	3.5%	19.7%	5.1%	3.3%	0.0%	0.0%	0.0%	0.4%	8.1%
Euro 4/VI	35.1%	24.9%	51.4%	34.2%	20.9%	10.3%	7.5%	7.6%	3.1%	26.9%
Euro 5/V	32.8%	49.2%	21.5%	50.6%	55.4%	22.5%	75.7%	76.9%	62.9%	45.8%
Euro 6/VI	20.2%	22.2%	4.6%	9.5%	19.9%	67.2%	16.8%	15.4%	33.6%	17.2%

Table 6: 2021 baseline fleet composition

	Car		LGV		HGV		Taxi		Buses and coaches	
Standard	Petrol	Diesel	Petrol	Diesel	Rigid	Articulated	Petrol	Diesel	Local	Non-local
Pre-Euro 1/I	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 1/I	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 2/II	0.0%	0.0%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
Euro 3/III	2.0%	0.7%	9.6%	1.7%	1.2%	1.0%	0.0%	0.0%	0.4%	4.4%
Euro 4/VI	15.7%	10.9%	44.5%	20.3%	8.8%	7.0%	7.5%	7.5%	3.1%	14.1%
Euro 5/V	28.2%	39.0%	27.0%	43.8%	38.1%	26.9%	75.7%	75.7%	62.9%	35.9%
Euro 6/VI	54.2%	49.4%	18.5%	34.1%	51.9%	65.1%	16.8%	16.8%	33.6%	45.3%

Table 7: 2021 "non-CAZ intervention", modelled fleet composition inside proposed boundary

	Car		LGV		HGV		Taxi		Buses and coaches	
Standard	Petrol	Diesel	Petrol	Diesel	Rigid	Articulated	Petrol	Diesel	Local	Non-local
Pre-Euro 1/I	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 1/I	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 2/II	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 3/III	2.0%	0.7%	2.3%	0.4%	0.1%	0.1%	0.0%	0.0%	0.4%	0.0%
Euro 4/VI	15.7%	10.9%	52.1%	4.8%	0.9%	0.7%	7.5%	7.5%	2.7%	0.0%
Euro 5/V	28.2%	39.0%	27.0%	10.4%	3.7%	2.6%	75.7%	75.7%	54.7%	0.0%
Euro 6/VI	54.2%	49.4%	18.5%	84.3%	95.3%	96.6%	16.8%	16.8%	42.2%	100.0%

Table 8: 2021 charging CAZ, modelled fleet composition inside proposed boundary by CAZ Class

	Car (Class D)		LGV (Class C & D)		HGV (Class B, C, D)		Taxi (All)		Buses and coaches (All)	
Standard	Petrol	Diesel	Petrol	Diesel	Rigid	Articulated	Petrol	Diesel	Local	Non-local
Pre-Euro 1/I	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 1/I	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 2/II	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 3/III	0.2%	0.1%	2.3%	0.4%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
Euro 4/VI	17.5%	1.1%	52.1%	4.8%	0.9%	0.7%	7.5%	0.0%	0.0%	0.0%
Euro 5/V	28.2%	3.8%	27.0%	10.4%	3.7%	2.6%	75.7%	0.0%	0.0%	0.0%
Euro 6/VI	54.2%	95.0%	18.5%	84.3%	95.3%	96.6%	16.8%	100.0%	100.0%	100.0%

Table 9: 2031 baseline fleet composition, modelled fleet composition inside proposed boundary

	Car		LGV		HGV		Taxi		Buses and coaches	
Standard	Petrol	Diesel	Petrol	Diesel	Rigid	Articulated	Petrol	Diesel	Local	Non-local
Pre-Euro 1/I	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	ULEV/ZEV, 100% compliance		0.0%	0.0%
Euro 1/I	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%			0.0%	0.0%
Euro 2/II	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%			0.0%	0.0%
Euro 3/III	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%			0.4%	0.0%
Euro 4/VI	0.0%	0.0%	4.0%	0.3%	0.0%	0.0%			3.1%	0.0%
Euro 5/V	5.7%	7.8%	15.4%	5.0%	1.5%	0.2%			62.9%	3.5%
Euro 6/VI	94.3%	92.2%	80.5%	94.8%	98.5%	99.8%			33.6%	96.5%

Table 10: 2031 charging CAZ A (minimum emission standards), modelled fleet composition inside proposed boundary

	Car		LGV		HGV		Taxi		Buses and coaches	
Standard	Petrol	Diesel	Petrol	Diesel	Rigid	Articulated	Petrol	Diesel	Local	Non-local
Pre-Euro 1/I	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	ULEV/ZEV, 100% compliance		0.0%	0.0%
Euro 1/I	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%			0.0%	0.0%
Euro 2/II	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%			0.0%	0.0%
Euro 3/III	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%			0.0%	0.0%
Euro 4/VI	0.0%	0.0%	4.0%	0.3%	0.0%	0.0%			0.0%	0.0%
Euro 5/V	5.7%	7.8%	15.4%	5.0%	1.5%	0.2%			0.0%	0.0%
Euro 6/VI	94.3%	92.2%	80.5%	94.8%	98.5%	99.8%			100.0%	100.0%

Table 11: 2031 charging CAZ C (ambitious emission standards), modelled fleet composition inside proposed boundary

	Car		LGV		HGV		Taxi		Buses and coaches	
Standard	Petrol	Diesel	Petrol	Diesel	Rigid	Articulated	Petrol	Diesel	Local	Non-local
Pre-Euro 1/I	0.0%	0.0%	ULEV/ZEV, 100% compliance		0.0%	0.0%	ULEV/ZEV, 100% compliance		ULEV/ZEV, 100% compliance	ULEV/ZEV, 100% compliance
Euro 1/I	0.0%	0.0%			0.0%	0.0%				
Euro 2/II	0.0%	0.0%			0.0%	0.0%				
Euro 3/III	0.0%	0.0%			0.0%	0.0%				
Euro 4/VI	0.0%	0.0%			0.0%	0.0%				
Euro 5/V	5.7%	7.8%			0.2%	0.0%				
Euro 6/VI	94.3%	92.2%			99.8%	100.0%				

Table 12: 2031 charging CAZ D (ambitious emission standards), modelled fleet composition inside proposed boundary

	Car		LGV		HGV		Taxi		Buses and coaches	
Standard	Petrol	Diesel	Petrol	Diesel	Rigid	Articulated	Petrol	Diesel	Local	Non-local
Pre-Euro 1/I	ULEV/ZEV, 100% compliance		ULEV/ZEV, 100% compliance		0.0%	0.0%	ULEV/ZEV, 100% compliance		ULEV/ZEV, 100% compliance	ULEV/ZEV, 100% compliance
Euro 1/I					0.0%	0.0%				
Euro 2/II					0.0%	0.0%				
Euro 3/III					0.0%	0.0%				
Euro 4/VI					0.0%	0.0%				
Euro 5/V					0.2%	0.0%				
Euro 6/VI					99.8%	100.0%				

C.4 Free-flowing traffic

The emission factors described in Section C.2 were combined with traffic flow and speed data to calculate emissions for each modelled scenario.

C.4.1 Free-flowing traffic speeds

Trafficmaster speed data for 2017 was used in the modelling for all years, with the underlying assumption that future traffic growth or changes will not significantly impact road speeds. For committed infrastructure improvements, road speeds were taken from the nearest similar road, based on expert judgement.

C.4.2 Traffic flows

Annual average daily traffic flows (AADTs) for Cars, LGVs, HGVs, and buses and coaches derived from the CSRM2 traffic model were provided by Atkins for 2015 and 2031 on behalf of Cambridge City Council. CRSM2 is a multi-modal transport model which was developed in line with WebTAG guidance[11]. The model covers the Cambridgeshire local authority areas of Cambridge City Council, South Cambridgeshire District Council, East Cambridgeshire District Council and Huntingdonshire District Council.

The node-to-node traffic flows from the traffic model were matched to Ordnance Survey Mastermap road geometries. This data was extensively validated to remove errors. The CSRM2 traffic model produces traffic flows for Cars, LGVs, HGVs, and PSUs for peak hours. These peak hour flows were converted to traffic flows using factors provided by the County Council.

Manual traffic count data provided by the Department for Transport was used to calculate the ratio of motorcycles to cars; motorcycle flows were then derived as a fraction of the car flow for each road for each modelled scenario.

Local bus flows were derived from two sources:

- In a region encompassing the proposed boundary and nearby roads, bus flow data was derived from bus timetables provided by Cambridge City Council. Bus routes were derived from information available on operator's websites and Google Maps.
- Outside this region, local bus flow data was derived from the CRSM2 model.

Traffic flow data was projected to 2017 using a growth factor of 1.27%, derived from National Trip End Model (NTEM) estimates, accessed using the Tempro software[12]. Traffic flow data for 2017 was projected to 2021 using demand growth factors provided by Arup on behalf of Cambridgeshire County Council. These factors are presented in Table 13. Local bus flows were increased by 15%, reflecting GCP expectations for the increased provision of services in 2021.

Traffic growth from 2017 to 2021 were provided for each vehicle type by the City Council, derived from demand modelling work carried out in 2018. The growth factors are presented in Table 13.

Table 13: 2017 to 2021 traffic growth factors

Vehicle type	Growth factor
Cars	1.072
Taxis	1.061
Non-local buses and coaches	1.007

[11] https://www.gov.uk/guidance/transport-analysis-guidance-webtag
[12] https://data.gov.uk/dataset/11bc7aaf-ddf6-4133-a91d-84e6f20a663e/national-trip-end-model-ntem

Vehicle type	Growth factor
LGV	1.061
HGV	1.061
Other	1.061
Motorcycle	1.072

No changes to traffic flows were assumed to occur with the implementation of any intervention measures.

Traffic data for 2031 was derived following the same approach as for 2017. A single 2031 forecast year scenario, referred to as the CSRM2 Foundation Case, was provided by the County Council. The CSRM2 Foundation Case is a forecast of potential conditions in 2031, and represents the likely land use and transport supply scenario in 2031. The Foundation Case represents a scenario agreed with Cambridge City Council which is consistent with proposed Local Plans for the four Local Authority Districts represented in the model (Cambridge City, South Cambridgeshire, Huntingdonshire and East Cambridgeshire) as of 2017, including local assumptions on housing, employment and other developments, along with transport schemes which are either committed or expected to be required to support development. The 2031 Foundation Case does not include expected demand management impacts on traffic flows; these were calculated separately as described below.

Local bus flows were increased by 100% relative to 2017 flows, reflecting the GCP commitment for the increased provision. The additional bus flows were assumed to run along the same routes in place in 2017, in the absence of data on proposed new routes.

The GCP has made a commitment to reduce traffic flows in Cambridge by 10-15% relative to 2011 levels by 2031. No traffic modelling data is currently available for the planned implementation of a Demand Management area within Cambridge. Instead, the GCP advised that traffic flows for private cars and HGVs should be reduced by 2031 by 10-15% relative to 2011 levels, as per GCP stated targets. The upper range of that target, 15%, would represents a 30.0% decrease in traffic flows relative to the 2031 case without the implementation of a Demand Management area.

C.5 Stationary traffic (congestion)

Cambridge city centre is highly congested, with significant emissions deriving from idling traffic. Emissions from idling traffic were calculated following LAQM.TG(16) guidance published by the Department for Environment Food and Rural Affairs[13]: exhaust emission factors for vehicles travelling at $5km.h^{-1}$ were used. No non-exhaust particulate emissions were modelled for idling vehicles, as tyre wear, road wear, brake wear, and resuspension do not occur when a vehicle is stationary.

Roads with significant idling traffic were identified using typical traffic data from Google Maps, and aerial photography. Congested periods for each link were estimated from Google Earth traffic data and TrafficMaster speed data; the idling times used are shown in Figure 4.

[13] https://laqm.defra.gov.uk/documents/LAQM-TG16-February-18-v1.pdf

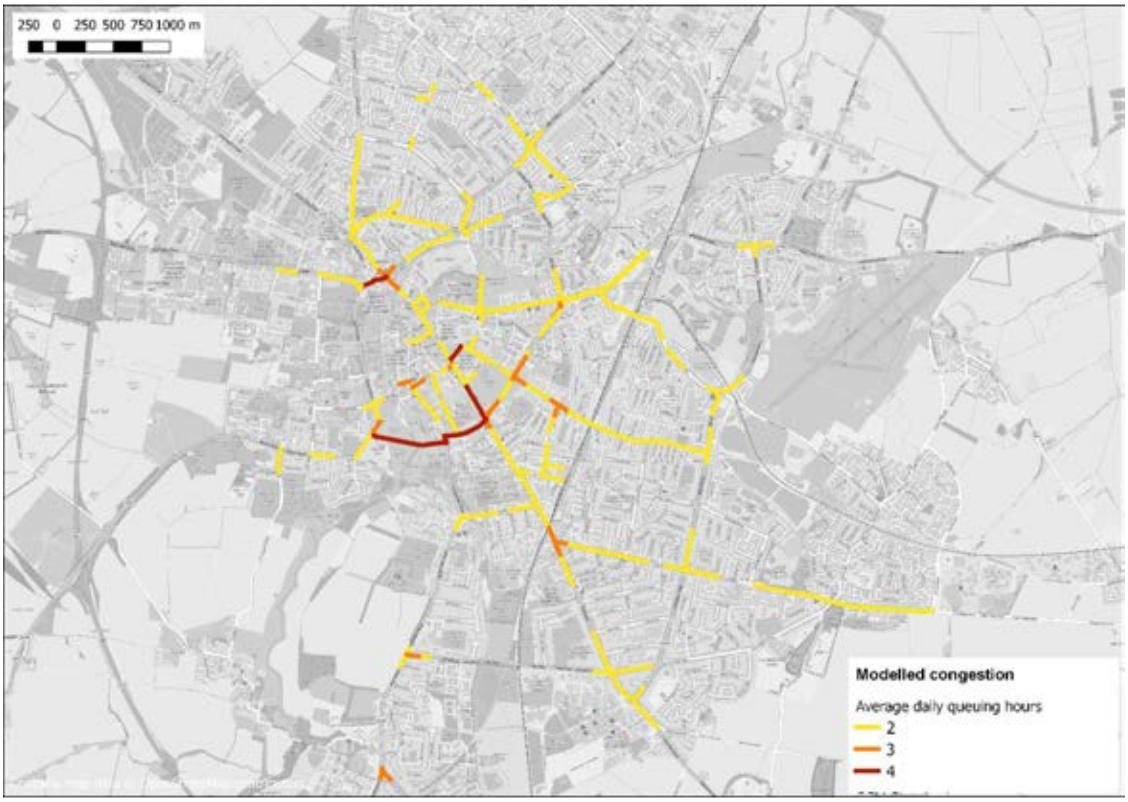


Figure 4: Modelled queue locations and average daily queuing lane-hours

Congestion may occur along one or more lanes of a road. Roads representing bidirectional traffic flows may be congested in one or both directions. The number of queuing lanes was determined from aerial imagery and the road layout, with the assumption that any congested link would only be congested the direction entering the nearest major junction. Queuing in both directions was modelled along sections of Regent Street, Parker Street, Lensfield Road, and Fen Causeway. Congested links were assumed to have idling traffic for 20 minutes of each hour. Congested link idling times and locations were assumed to be equal for all modelled years and scenarios.

An average queuing vehicle length of 6.75m was derived from aerial imagery of traffic queues in Cambridge. This may lead to a slight overestimation of queuing impacts along roads with a high proportion of HGVs or buses, or a slight underestimation of queuing impacts along roads with very low proportions of these longer vehicles.

C.6 Bus stops

Emissions from buses idling at bus stops in an area encompassing the city centre, and extending to the region around the rail station, were calculated using route data and stop locations provided by Cambridge City Council on behalf of the GCP. Bus stops were modelled as 30m long road sources, oriented parallel to the road. The modelled bus stops are shown in Figure 5.

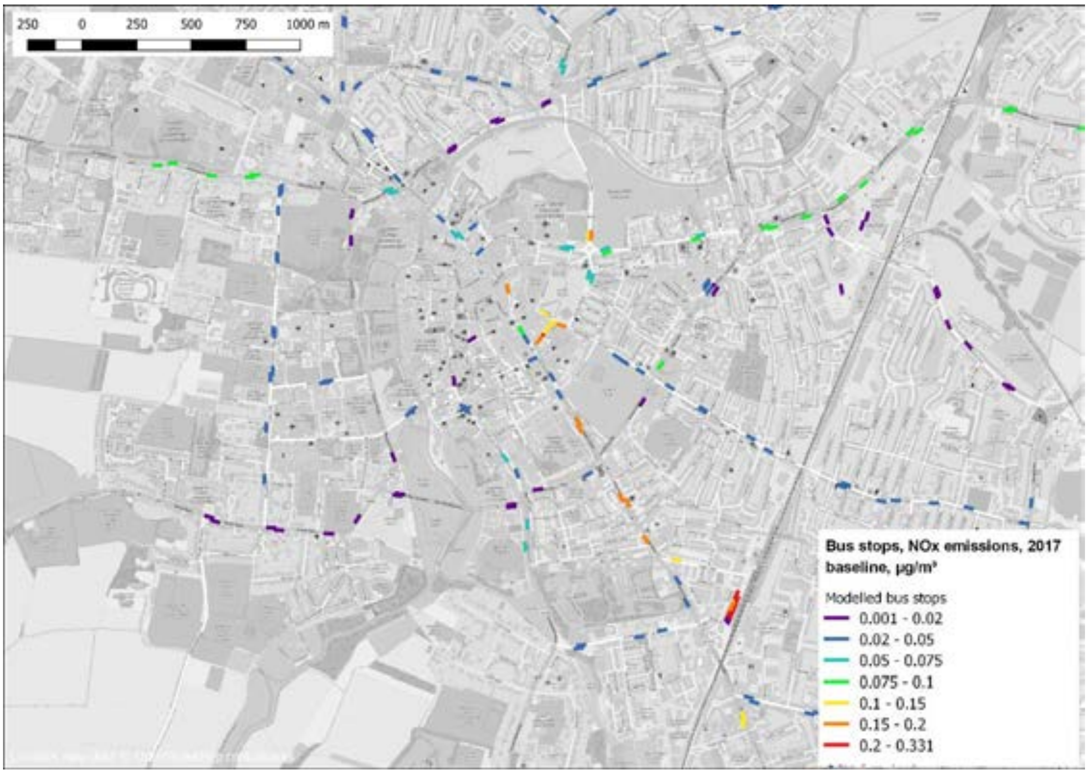


Figure 5: Bus stop locations, coloured by NOx emissions in 2017 baseline emissions inventory (µg.m^{-3})

All buses travelling along a given route were assumed to stop at all relevant bus stops. Buses were assumed to spend an average of 30 seconds idling at each bus stop, except at the Drummer Street and bus stops; at these stops, an average idling time of 120s was provided by the City Council.

Consistent with the approach taken to stationary traffic emissions, emissions were calculated using exhaust emission factors for vehicles travelling at 5km.h^{-1}, in line with guidance in LAQM.TG(16).

C.7 Other sources

Emissions from point sources on the Addenbrookes site were modelled explicitly using the US Environmental Protection Agency (USEPA) AERMOD dispersion model[14], using source parameters provided by Cambridge City Council.

Background pollutant concentrations are provided by Defra on their website[15]. The background mapping data provides estimates of annual mean background concentrations of key pollutants at a resolution of 1 x 1 km for the UK projected from a base year of 2015. These background maps were used to provide spatially-varying background concentrations which included all other sources. Impacts from all road sources except for minor roads were removed from the background data.

D Model verification

Once the base year model has been developed it is then verified against monitoring data and adjusted to ensure best fit. Any adjustment factors are then applied to all future modelled years. Following this adjustment, model verification is carried out by comparing the total predicted NO_2 concentrations against the measured NO_2 concentrations.

[14] https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod
[15] https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html

D.1 Monitoring sites

In 2017 Cambridge City Council operated a total of 5 automatic monitoring sites across the city, and 65 diffusion tube locations monitoring NO_2 concentrations. Monitoring is also carried out for PM_{10} at three of the automatic monitoring sites, and for $PM_{2.5}$ at two automatic monitoring sites. Full details of the monitoring carried out by the City Council is provided in Appendix G.

Locations for all monitoring sites are available from the Cambridge City Council website[16]. In some cases modelled site locations were adjusted to correctly locate the monitoring site relative to the kerb.

A number of diffusion tube sites (monitoring annual mean NO_2) were removed from the adjustment and verification analysis on the basis that the measured concentrations included significant contributions from unmodeled local sources. Derivation of an adjustment factor using these sites would therefore lead to the derived adjustment factor for NO_2 being unrealistic for other sites across Cambridge. A summary of the removed sites is provided in Table 14.

Table 14: Removed monitoring sites

Site ID	Site name	Reason for exclusion
DT22	Madingley Road	Substantial congestion not modelled (site is outside area of modelled congestion), leading to underprediction of concetrations
DT29	Cherry Hinton Road	Site is located on the corner between one modelled and one unmodelled road, leading to underprediction
DT35	Abbey Road	Site is shielded by a row of buildings from Victoria Avenue (the nearest major road), leading to overprediction of concentrations
DT6	Long Road	Site is adjacent to a local car park and the entrance to block of flats, leading to underprediction
DT2	Histon Road 2	Site is located next to an unmodelled bus stop, leading to underprediction
DTS4	Addenbrookes Access Road	Site is located close to a construction site and bus stop, leading to underprediction

D.2 Adjustment

Adjustment factors for emissions from roads were derived following the methodology described in LAQM.TG(16)[17], whereby the predicted roads contribution to NOx and PM concentrations was compared with measured values.

Diffusion tubes measure NO_2 rather than NOx; the road contribution to NOx concentrations at these sites was estimated using the NOx to NO_2 calculator published by Defra.[18] Background NO_2 concentrations for use in this tool were taken from the Defra background maps. This approach uses background concentrations of NO_2 as an input.

The road contribution to particulate concentrations was calculated by subtracting the Defra background map values (excluding road sources) from the measured concentrations.

The derived adjustment factors are presented in Table 15. The derived adjustment factor for PM_{10} and $PM_{2.5}$ were applied for all years, on the basis that any current underprediction is likely to be related to

[16] https://www.cambridge.gov.uk/air-pollution-levels-and-monitoring-them
[17] https://laqm.defra.gov.uk/documents/LAQM-TG16-February-18-v1.pdf, accessed 4th September 2018
[18] https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html

a combination of congestion which is not taken into account in the model, and the underestimation of emission factors, which is unlikely to change in future years.

Table 15: Adjustment factors for Cambridge, derived from 2017 monitoring and predicted data

Pollutant	Adjustment factor
NOx / primary NO_2	1
Particulates (PM_{10} and $PM_{2.5}$)	6.14

The adjustment factor for PM_{10} and $PM_{2.5}$ is significantly higher than that for NOx. Larger adjustment factors are common for PM_{10} and $PM_{2.5}$, as there is a high level of uncertainty in the estimation of non-exhaust emissions from vehicles. As there are currently no exceedences of the relevant AQOs measured at any location in Cambridge, no further investigation was carried out into possible causes of this underestimation.

D.3 Verification

The model was verified against annual average NO_2 concentrations using the 2017 baseline emissions inventory described in Section C. NO_2 concentrations were derived from modelled road NOx contributions, primary NO_2 contributions, and background concentrations using the Defra NOx:NO_2 calculator. The model verification for annual average NO_2 is presented in Figure 6.

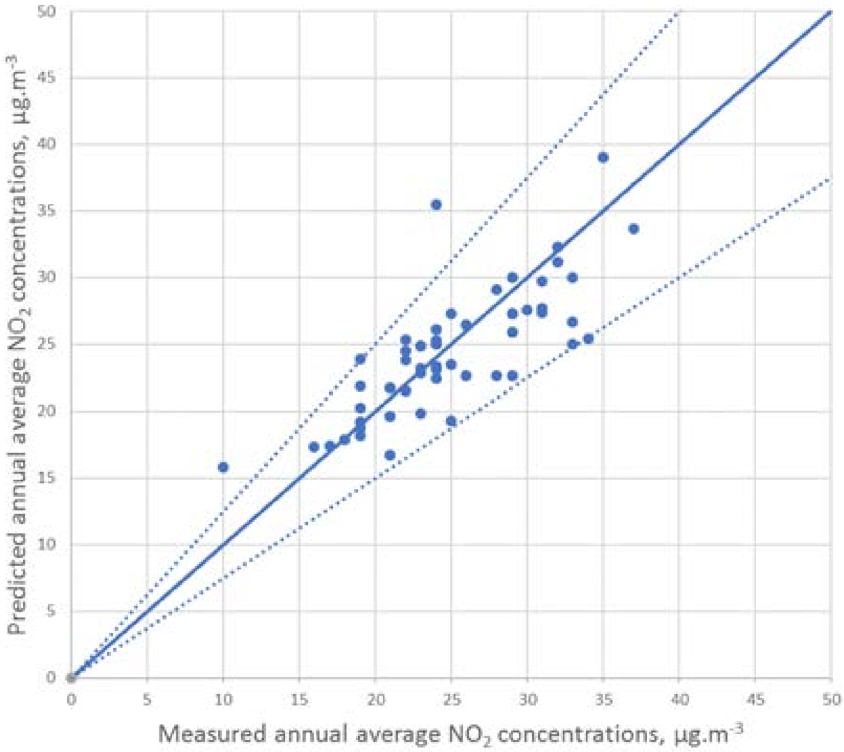


Figure 6: Predicted annual average NO_2 concentrations against measured concentrations at monitoring locations. The 25% confidence intervals are also plotted

Following guidance in LAQM.TG(16)[18], the Root Mean Square Error (RMSE) was calculated to define the average error or uncertainty of the model, as described in Box 7.17 of this guidance. The Root Mean Square Error for the model verification is 3.5 µg.m^{-3}, corresponding to 8% of the AQO. This is within the 10% ideal threshold specified in LAQM.TG(16)[18]. The main contributors to the high RMSE are the Victoria Road diffusion tube, which is located in a small local street canyon where recirculation effects may be overpredicted by the model, and at an urban background site where the model overpredicts.

The model was also verified for PM_{10}. The results of the model verification are presented in Table 16.

Table 16: Measured vs. modelled PM_{10} concentrations at monitoring locations in 2017, µg.m^{-3}

Site ID	Site name	Measured	Modelled
CM1	Gonville Place	18	19.7
CM2	Montague Road	20	20.8
CM4	Parker Street	21	18.7

These results show that the model is performing well at the majority of locations in Cambridge for both NOx and PM_{10},and gives confidence to the prediction of future concentrations and $PM_{2.5}$ emissions.

E Emissions analysis

E.1 Total emissions

This section presents the calculated road traffic emissions for each modelled scenario, together with an analysis of the effects of the proposed CAZ interventions.

Table 17 presents the total calculated road traffic emissions across the model domain in the 2017 baseline scenario, including the effects of model adjustment. Table 18 presents the calculated percentage in reduction in emissions relative to the 2017 baseline for each future year, without any proposed CAZ interventions.

Table 17: Total emissions across the model domain, 2017 baseline, tonnes per year

Year	Scenario	Total emissions across Cambridge (tonnes/year)			
		NOx	Primary NO_2	PM_{10}	$PM_{2.5}$
2017	Baseline	799.0	185.3	375.5	224.3
2021	Without CAZ	652.5	152.2	373.3	213.3
2031	Without CAZ	405.9	67.2	294.2	161.8

Table 18: Emission reduction relative to 2017 baseline

Year	Scenario	% Reduction in emissions relative to 2017			
		NOx	Primary NO_2	PM_{10}	$PM_{2.5}$
2021	Without CAZ	18.3%	17.9%	0.6%	4.9%
2031	Without CAZ	49.2%	63.7%	21.7%	27.9%

Without any further interventions, the projected natural evolution of the vehicle fleet over time leads to increased compliance with more stringent emission standards, particularly Euro 6/VI, in the 2021 'without CAZ' and 2031 'without CAZ' scenarios. An increase in the proportion of petrol and electric vehicles in the fleet relative to diesel vehicles is also predicted to occur in future years. These fleet changes lead to significant decreases in total NOx and primary NO_2 emissions across the model domain, and smaller decreases in total PM_{10} and $PM_{2.5}$ emissions.

However, there is significant uncertainty in fleet assumptions and vehicle emission factors for future years; historically vehicle emissions have underperformed substantially compared with early emission factor estimates in real-world driving conditions, and as a result real-world reductions in total emissions in future years may be smaller than those predicted.

NOx emissions in the 2021 baseline scenario are 81.7% of total NOx emissions in the 2017 baseline. Primary NO_2 emissions are also reduced, reflecting improvements in vehicle technology, particularly the projected shift from diesel private cars to petrol private cars.

In the 2031 baseline, the effects of improvement in vehicle technologies are compounded by the proposed traffic reduction in central Cambridge described in Section C.4. As a result, NOx emissions in 2031 are only 51% of the total emissions in 2017. However, in some locations emissions may increase due to the expected 100% increase in bus flows along congested routes; as such these reductions may not necessarily lead to a reduction in exposure in the areas of worst air quality.

The results for particulate matter emissions (PM_{10}) show a different pattern to those for NOx. In understanding these results there are two key points to note:

- The impact of improvements from earlier Euro standards on urban PM_{10} and $PM_{2.5}$ emissions have been much more significant to date than is the case for NOx emissions. The key benefit of improving standards for PM_{10} and $PM_{2.5}$ occurred before the Euro 5 and Euro V[19] emission standards, with only relatively minor further improvements anticipated afterwards. As such, the reduction in PM_{10} and $PM_{2.5}$ which naturally occurs in the baseline has been starting to flatten out. As a result, by 2031 there is only a 22% reduction in PM_{10} emissions for the baseline from 2021 to 2031, and 28% reduction in $PM_{2.5}$ emissions.

- PM_{10} and $PM_{2.5}$ emissions have two components: one related to exhaust emissions and one related to non-exhaust emissions such as tyre wear and road dust. As the exhaust component reduces, the non-exhaust component becomes much more significant as a proportion of total emissions. Even though they will continue to reduce exhaust emissions, CAZs will still have PM_{10} and $PM_{2.5}$ emissions from tyre wear and road dust, limiting the overall reductions that are achievable.

As a result, the evolution of the fleet, and the introduction of any CAZ, has a smaller impact on PM_{10} and $PM_{2.5}$ emissions than it does on NOx. Substantial reductions in PM_{10} and $PM_{2.5}$ emissions are seen in 2031 as the result of the GCP target for reduction of traffic flows rather than expected improvements in vehicle technology. $PM_{2.5}$ emissions are predicted to decrease by 27.9% in the 2031 'without CAZ' scenario relative to 2017; this decrease can be expected to deliver the proposed target of 15% reduction in $PM_{2.5}$ concentrations at urban background without the requirement for any further interventions.

E.2 Source apportionment

Detailed source apportionment analysis was carried out for NOx and PM_{10} for the 2017, 2021, and 2031 baseline.

E.2.1 2017 baseline

Table 19 and Table 20 present the total road traffic NOx emissions across the model domain for 2017, apportioned by vehicle type, traffic type and area. Table 20 presents the total PM_{10} emissions for 2017.

[19] Euro 4, 5, 6 refer to the regulations for light duty vehicles, Euro IV, V VI relate to regulations for heavy duty vehicles

Table 19: Source apportionment of road NO_x emissions, tonnes per year, 2017 baseline inventory

Vehicle type	Total emissions inside inner ring road					Total emissions outside inner ring road				
	Flowing traffic	Queuing	Bus stops	Total	%	Flowing traffic	Queuing	Bus stops	Total	%
Petrol Cars	2.0	0.3	0.0	2.2	3.7%	50.5	0.6	0.0	51.2	6.9%
Diesel Cars	14.7	2.3	0.0	17.0	28.3%	277.0	4.5	0.0	281.5	38.1%
Electric Cars	0.0	0.0	0.0	0.0	0.0%	0.0	0.0	0.0	0	0.0%
LGVs	4.5	0.8	0.0	5.3	8.9%	110.0	1.7	0.0	111.7	15.1%
Rigid HGVs	2.6	0.7	0.0	3.4	5.6%	194.6	1.2	0.0	195.8	26.5%
Artic HGVs	0.0	0.0	0.0	0.0	0.0%	7.9	0.1	0.0	8	1.1%
Non-local buses & coaches	6.0	2.8	0.0	8.8	14.6%	17.5	1.7	0.0	19.2	2.6%
Local Buses	7.6	9.0	4.1	20.7	34.5%	36.0	4.2	7.6	47.7	6.5%
Motorcycles	0.1	0.0	0.0	0.1	0.1%	2.0	0.0	0.0	2.04	0.3%
Taxis	2.1	0.5	0.0	2.6	4.3%	21.6	0.3	0.0	21.9	3.0%
Total	39.6	16.5	4.1	60.1		717.1	14.3	7.6	738.9	

Table 20: Source apportionment of road PM_{10} emissions, tonnes per year, 2017 baseline inventory

Vehicle type	Total emissions inside inner ring road					Total emissions outside inner ring road				
	Flowing traffic	Queuing	Bus stops	Total	%	Flowing traffic	Queuing	Bus stops	Total	%
Petrol Cars	3.3	0.0	0	3.3	5.5%	95.9	0.0	0.0	95.9	13.0%
Diesel Cars	5.0	0.0	0	5.0	8.3%	114.9	0.1	0.0	115.0	15.6%
Electric Cars	0.0	0.0	0	0.0	0.0%	0.4	0.0	0.0	0.4	0.1%
LGVs	1.4	0.0	0	1.4	2.3%	34.5	0.0	0.0	34.5	4.7%
Rigid HGVs	0.5	0.0	0	0.5	0.8%	84.9	0.0	0.0	84.9	11.5%
Artic HGVs	0.0	0.0	0	0.0	0.0%	6.3	0.0	0.0	6.3	0.9%
Non-local buses & coaches	0.9	0.0	0	1.0	1.6%	4.0	0.0	0.0	4.0	0.5%
Local Buses	1.4	0.0	0	1.5	2.5%	11.9	0.0	0.1	12.0	1.6%
Motorcycles	0.0	0.0	0	0.0	0.1%	1.1	0.0	0.0	1.1	0.2%
Taxis	0.6	0.0	0	0.6	0.9%	6.2	0.0	0.0	6.2	0.8%
Total	13.1	0.1	0	13.3		360.2	0.1	0.1	360.4	

E.2.2 2021

Source apportionment of NOx and PM_{10} emissions for 2021 is presented in Table 21 and Table 22.

Table 21: Source apportionment of road NOx emissions, tonnes per year, 2021 baseline inventory

Vehicle type	Total emissions inside inner ring road					Total emissions outside inner ring road				
	Flowing traffic	Queuing	Bus stops	Total	%	Flowing traffic	Queuing	Bus stops	Total	%
Petrol Cars	1.39	0.21	0	1.59	2.9%	32.4	0.4	0.0	32.8	5.5%
Diesel Cars	13.0	1.98	0	15.0	27.4%	243.4	3.6	0.0	247.0	41.3%
Electric Cars	0.00	0.00	0	0.00	0.0%	0.0	0.0	0.0	0.0	0.0%
LGVs	4.07	0.74	0	4.80	8.8%	102.1	1.4	0.0	103.5	17.3%
Rigid HGVs	1.85	0.62	0	2.47	4.5%	119.5	1.0	0.0	120.6	20.1%
Artic HGVs	0.02	0.01	0	0.03	0.1%	8.5	0.1	0.0	8.6	1.4%
Non-local buses & coaches	4.16	2.37	0	6.54	12.0%	11.8	1.5	0.0	13.3	2.2%
Local Buses	8.78	8.64	4.73	22.2	40.6%	41.5	4.5	8.7	54.6	9.1%
Motorcycles	0.04	0.01	0	0.04	0.1%	1.6	0.0	0.0	1.6	0.3%
Taxis	1.60	0.32	0	1.92	3.5%	16.4	0.2	0.0	16.6	2.8%
Total	34.9	14.9	4.73	54.5		577.1	12.7	8.7	598.6	

Table 22: Source apportionment of road PM_{10} emissions, tonnes per year, 2021 baseline inventory

Vehicle type	Total emissions inside inner ring road					Total emissions outside inner ring road				
	Flowing traffic	Queuing	Bus stops	Total	%	Flowing traffic	Queuing	Bus stops	Total	%
Petrol Cars	3.5	0.01	0	3.6	26.3%	102.3	0.03	0	102.3	28.5%
Diesel Cars	4.6	0.13	0	4.8	35.3%	109	0.23	0	109.2	30.4%
Electric Cars	0.02	0	0	0.02	0.1%	0.4	0	0	0.4	0.1%
LGVs	1.3	0.05	0	1.3	9.8%	32.2	0.08	0	32.3	9.0%
Rigid HGVs	0.46	0.02	0	0.48	3.5%	83.6	0.03	0	83.7	23.3%
Artic HGVs	0.01	0	0	0.01	0.0%	6.8	0	0	6.8	1.9%
Non-local buses & coaches	0.83	0.06	0	0.89	6.6%	3.6	0.04	0	3.7	1.0%
Local Buses	1.6	0.2	0.02	1.8	13.6%	13.6	0.1	0.03	13.8	3.8%
Motorcycles	0.04	0	0	0.04	0.3%	1	0	0	1	0.3%
Taxis	0.58	0.01	0	0.59	4.4%	6.4	0.01	0	6.4	1.8%
Total	13.0	0.47	0.02	13.5		359.1	0.52	0.03	359.6	

Source apportionment for 2021 shows a similar pattern to that in 2017. The total NOx emissions for all vehicle types except for local buses decrease due to improvements in vehicle technology and natural fleet turnover as described in Section C.3. Emissions from diesel cars, the largest contributor to NOx emissions in 2017, decrease by 12% across the domain due the projected improvement in the diesel vehicle fleet. However, NOx emissions from local buses across the model domain increase by 12%, as the local bus fleet is not assumed to change significantly between 2017 and 2021 without further action, and the total bus traffic in the City will increase by 15% in line with GCP expectations.

As for 2017, cars are the main contributor to PM_{10} emissions both inside and outside the city centre. The fuel type is not significant for PM_{10} emissions, as the main source of emissions is non-exhaust.

E.2.3 2031

Source apportionment of NOx and PM_{10} for 2031 scenario is presented in Table 23 and Table 24.

Table 23: Source apportionment of road NOx emissions, tonnes per year, 2031 baseline inventory

Vehicle type	Total emissions inside inner ring road					Total emissions outside inner ring road				
	Flowing traffic	Queuing	Bus stops	Total	%	Flowing traffic	Queuing	Bus stops	Total	%
Petrol Cars	1.15	0.20	0	1.36	2.3%	24.6	0.41	0	25.0	7.2%
Diesel Cars	3.58	0.66	0	4.24	7.2%	65.3	1.26	0	66.5	19.1%
Electric Cars	0.00	0.00	0	0.00	0.0%	0.00	0.00	0	0.00	0.0%
LGVs	3.26	0.58	0	3.85	6.6%	76.4	1.22	0	77.6	22.3%
Rigid HGVs	0.31	0.30	0	0.62	1.1%	13.5	0.48	0	14.0	4.0%
Artic HGVs	0.00	0.00	0	0.01	0.0%	0.94	0.03	0	0.97	0.3%
Non-local buses & coaches	0.50	0.81	0	1.31	2.2%	2.51	0.94	0	3.45	1.0%
Local Buses	18.5	16.8	10.7	46.1	78.8%	117.7	13.9	19.6	151.3	43.5%
Motorcycles	0.03	0.00	0	0.03	0.1%	0.99	0.01	0	1.00	0.3%
Taxis	0.81	0.17	0	0.97	1.7%	7.54	0.12	0	7.7	2.2%
Total	28.2	19.6	10.7	58.4		309.5	18.4	19.6	347.5	

Table 24: Source apportionment of road PM_{10} emissions, tonnes per year, 2031 baseline inventory

Vehicle type	Total emissions inside inner ring road					Total emissions outside inner ring road				
	Flowing traffic	Queuing	Bus stops	Total	%	Flowing traffic	Queuing	Bus stops	Total	%
Petrol Cars	3.13	0.00	0	3.1	5.4%	80.6	0.00	0	80.6	23.2%
Diesel Cars	2.26	0.01	0	2.27	3.9%	52.8	0.01	0	52.8	15.2%
Electric Cars	0.22	0.00	0	0.22	0.4%	5.09	0.00	0	5.09	1.5%
LGVs	1.39	0.00	0	1.39	2.4%	31.4	0.01	0	31.4	9.0%
Rigid HGVs	0.31	0.00	0	0.31	0.5%	56.7	0.00	0	56.7	16.3%
Artic HGVs	0.00	0.00	0	0.00	0.0%	4.63	0.00	0	4.63	1.3%
Non-local buses & coaches	0.39	0.00	0	0.39	0.7%	4.59	0.00	0	4.59	1.3%
Local Buses	2.94	0.06	0.04	3.04	5.2%	38.5	0.05	0.07	38.6	11.1%
Motorcycles	0.04	0.00	0	0.04	0.1%	0.97	0.00	0	0.97	0.3%
Taxis	0.62	0.00	0	0.62	1.1%	6.09	0.00	0	6.09	1.8%
Total	11.3	0.08	0.04	11.4		281.3	0.08	0.07	281.5	

Source apportionment for 2031 shows the overall trend observed in the 2021 figures continuing; as the bus fleet is predicted to remain static without further intervention, bus emissions increase in line with GCP expectations that bus flows will increase by 100% relative to 2017. As a result, NOx emissions from local buses inside the CAZ are predicted to be 2.4 times higher in 2031 than 2017, and local bus emissions are predicted to account for 79% of total NOx emissions inside the proposed CAZ area. Local buses are also the largest contributor to PM_{10} emissions inside the CAZ region, although NOx emissions from cars remain the primary contributor outside the CAZ.

NOx emissions from other vehicles decrease substantially as the result of improving vehicle technologies; in particular, emissions from diesel cars are predicted to decrease to 24% of 2017 levels as the result of expected improvements in vehicle technology and the GCP commitment to traffic reduction.

F Pollution concentration results

This Appendix presents contour plots for the modelled scenarios.

F.1 2017 baseline

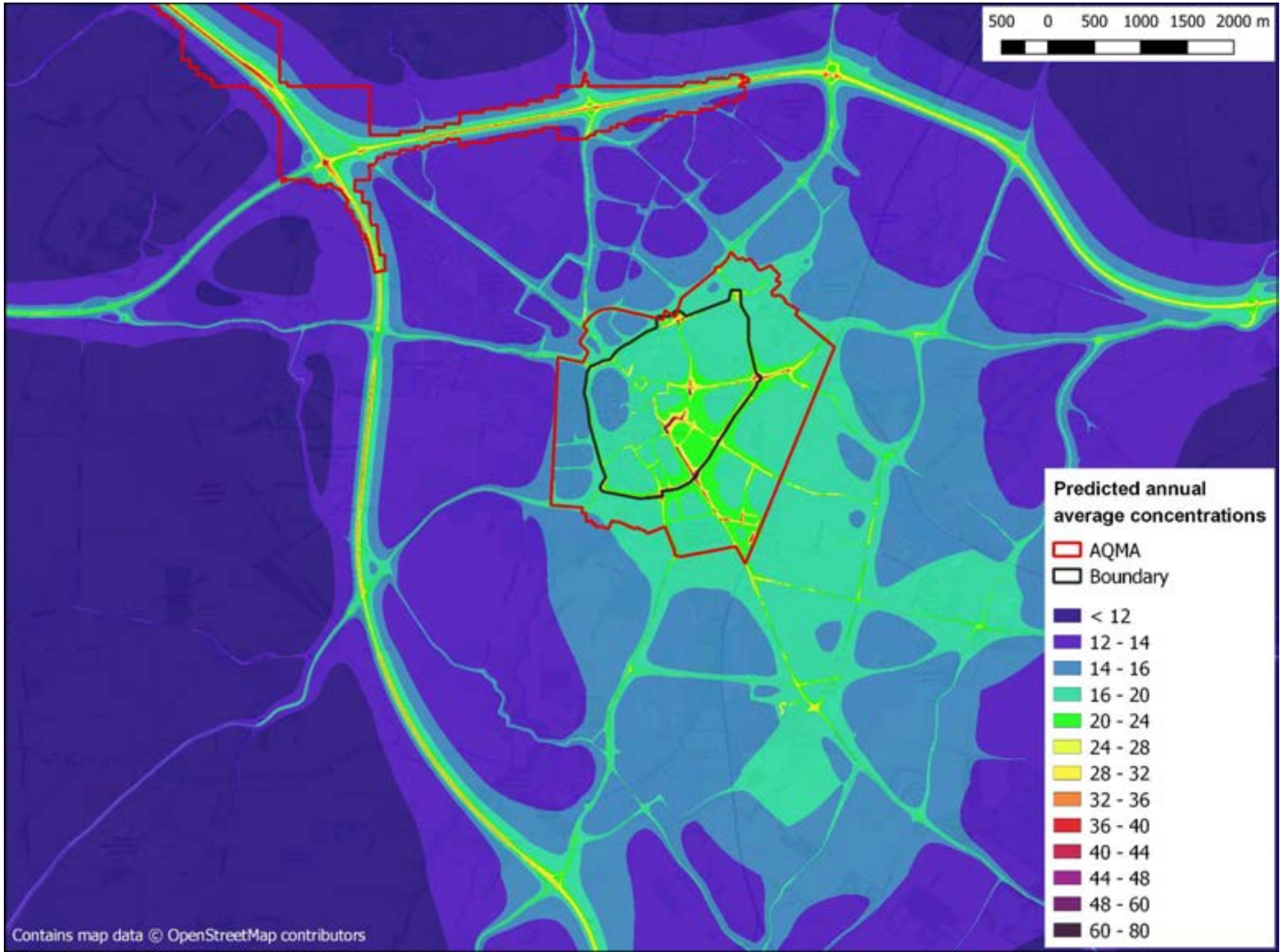


Figure 7: Annual average NO_2 concentrations, 2017 baseline, Cambridge, µg.m^{-3}

Figure 8: Annual average NO_2 concentrations, 2017 baseline, city centre, $\mu g.m^{-3}$

Figure 9: Annual average NO_2 concentrations, 2017 baseline, South Cambridge, µg.m^{-3}

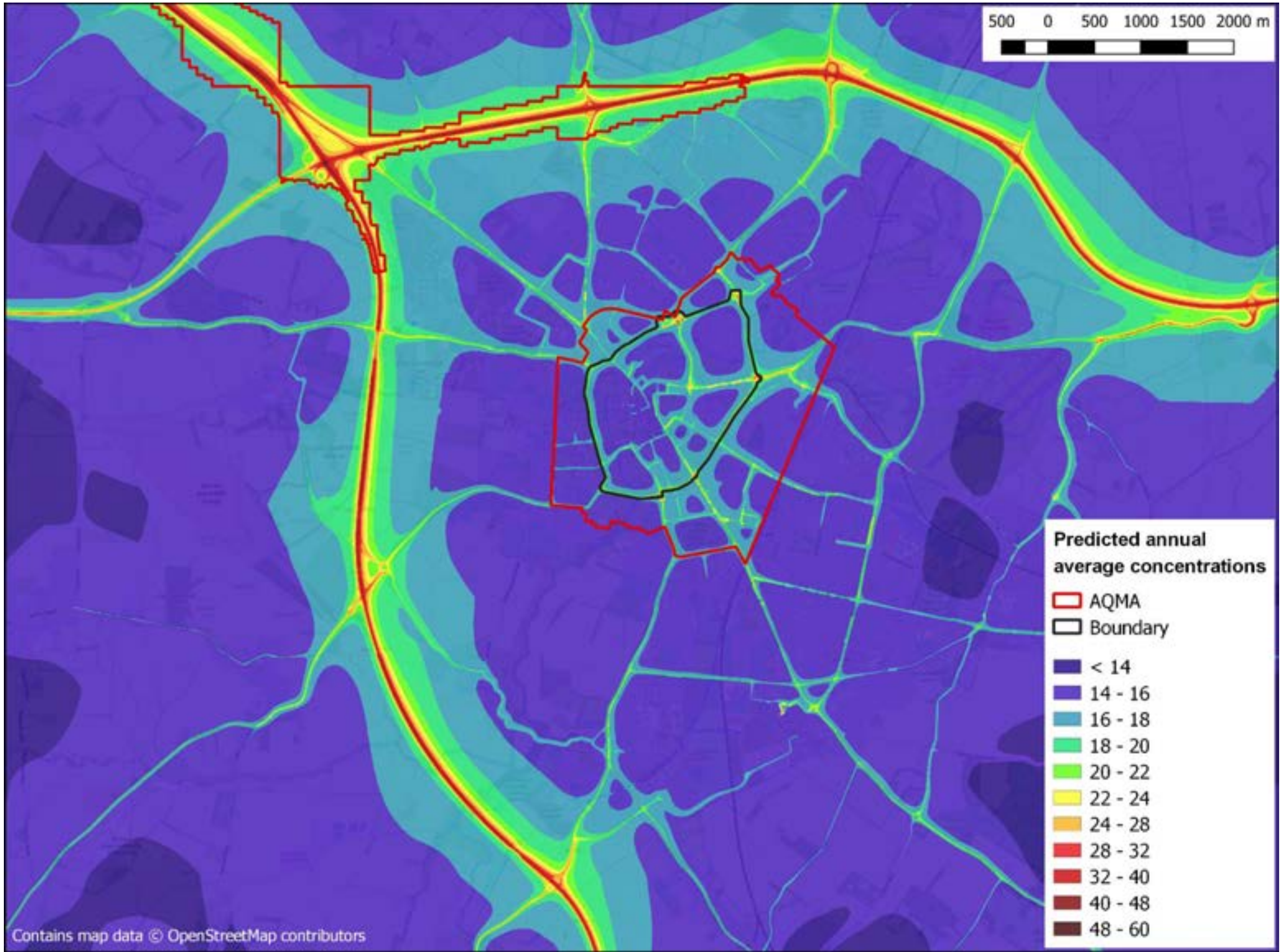


Figure 10: Annual average PM_{10} concentrations, 2017 baseline, Cambridge, $\mu g.m^{-3}$

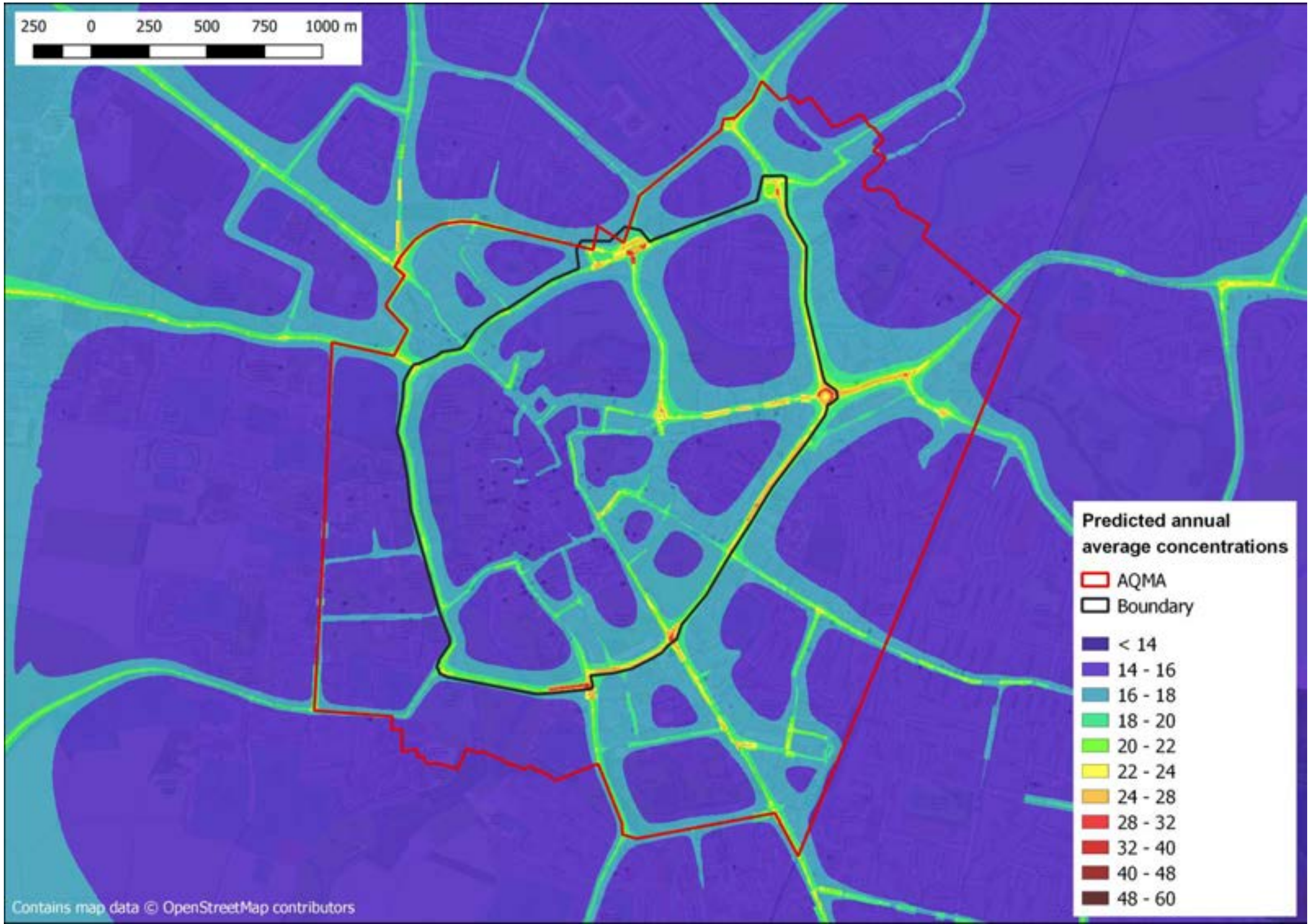


Figure 11: Annual average PM_{10} concentrations, 2017 baseline, city centre, $\mu g.m^{-3}$

Figure 12: Annual average PM_{10} concentrations, 2017 baseline, South Cambridge, $\mu g.m^{-3}$

1.1 2021 baseline

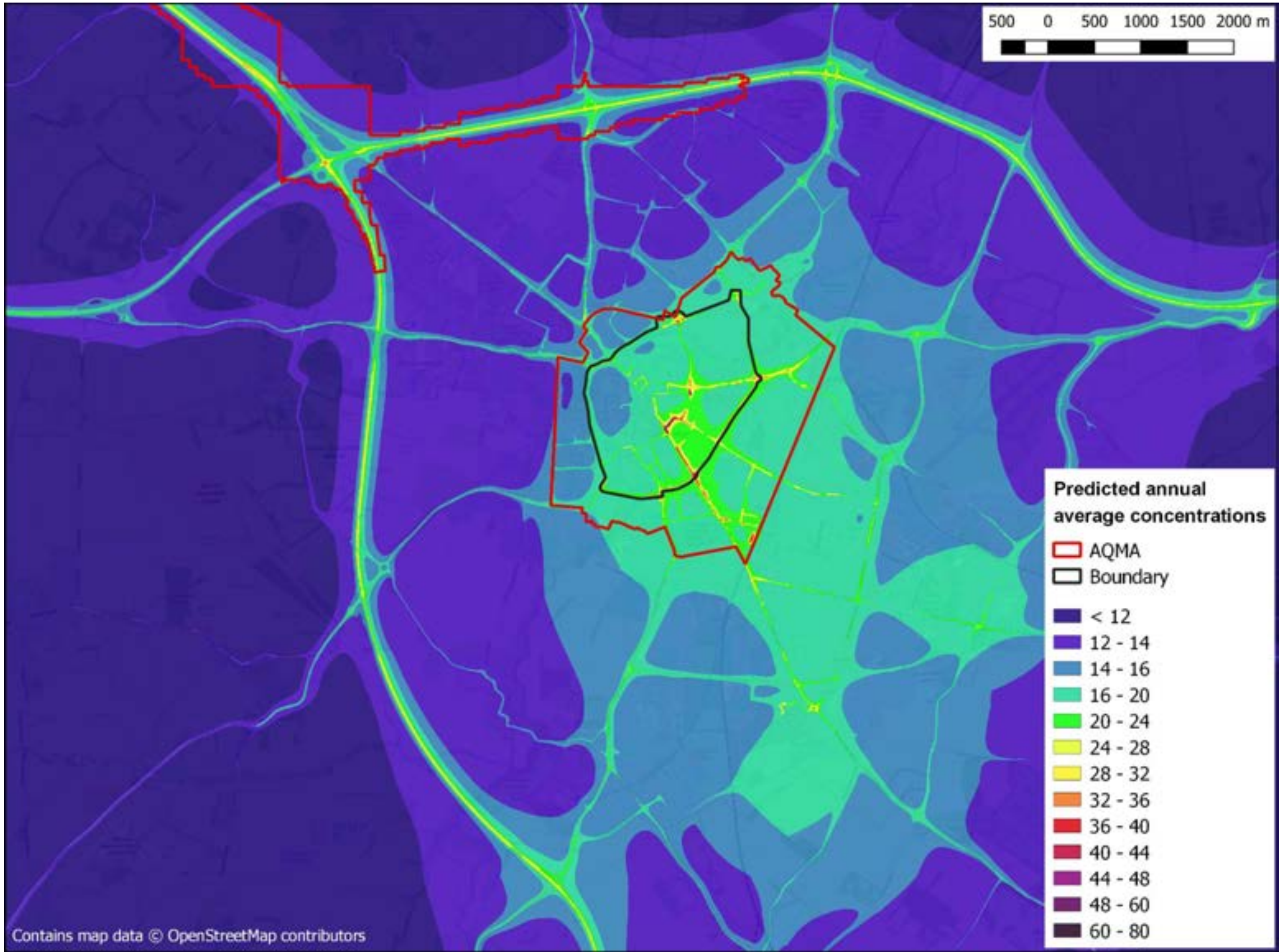


Figure 13: Annual average NO_2 concentrations, 2021 baseline, Cambridge, µg.m^{-3}

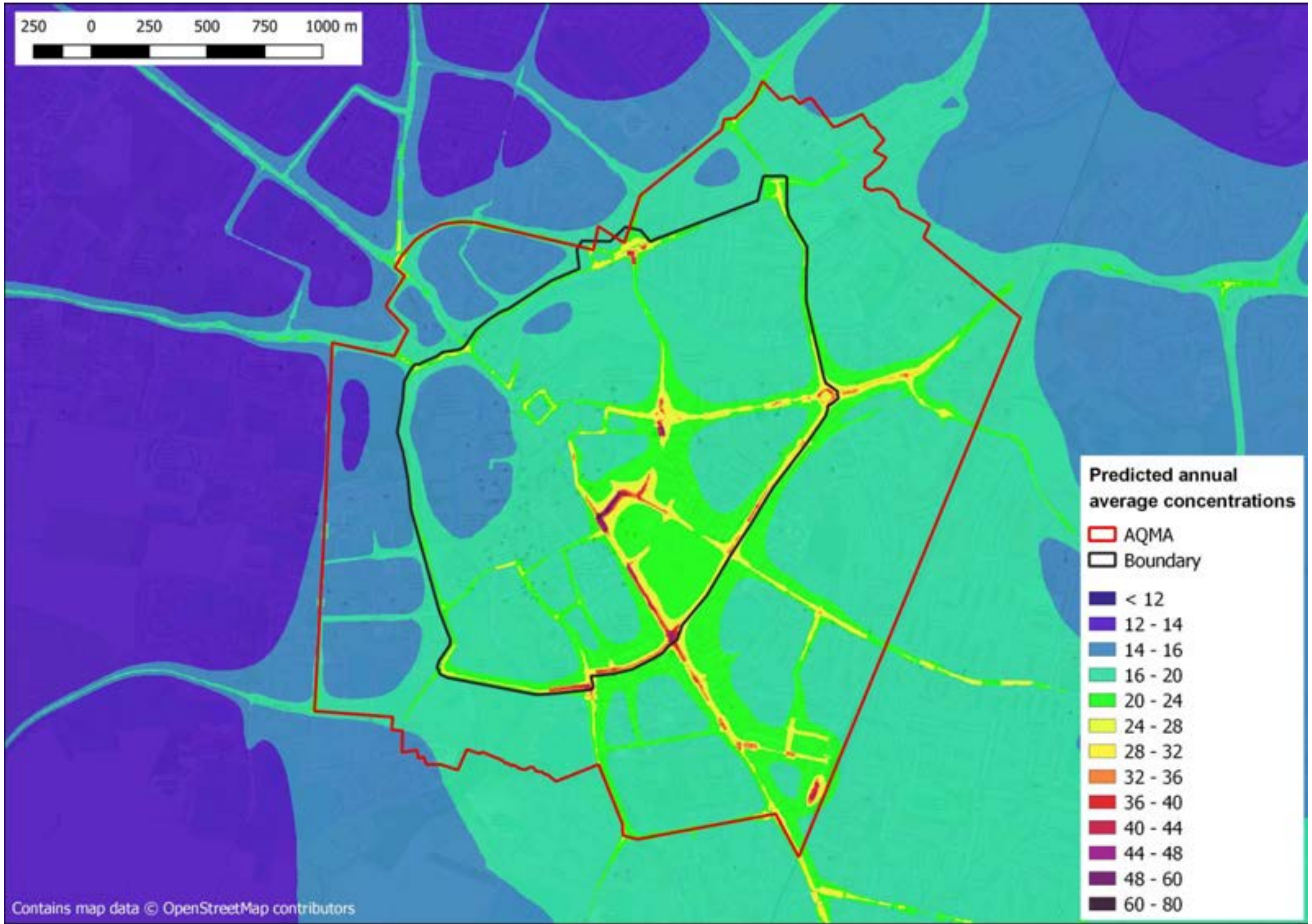


Figure 14: Annual average NO_2 concentrations, 2021 baseline, city centre, $\mu g.m^{-3}$

Figure 15: Annual average NO_2 concentrations, 2021 baseline, South Cambridge, µg.m^{-3}

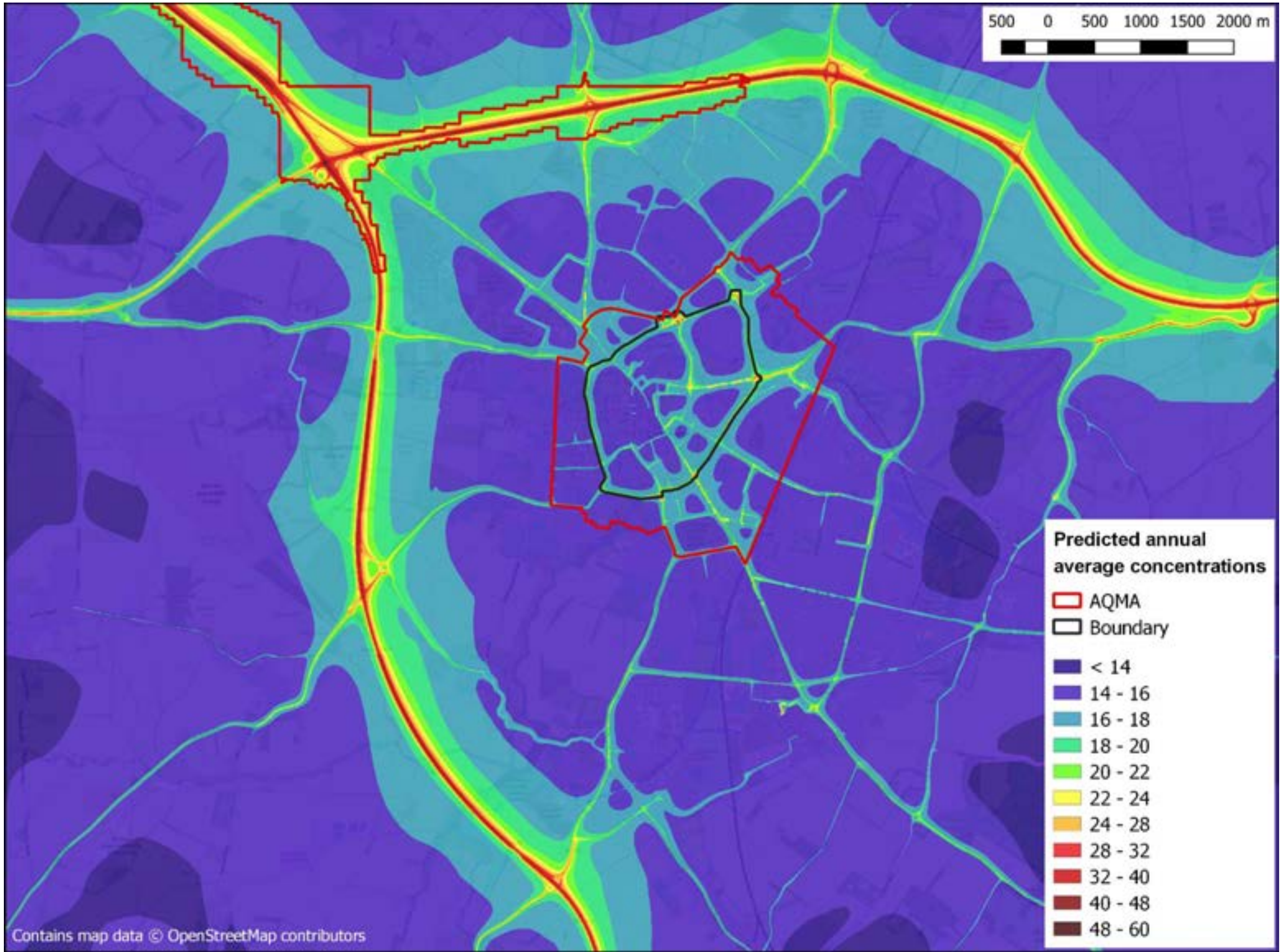


Figure 16: Annual average PM_{10} concentrations, 2021 baseline, Cambridge, $\mu g.m^{-3}$

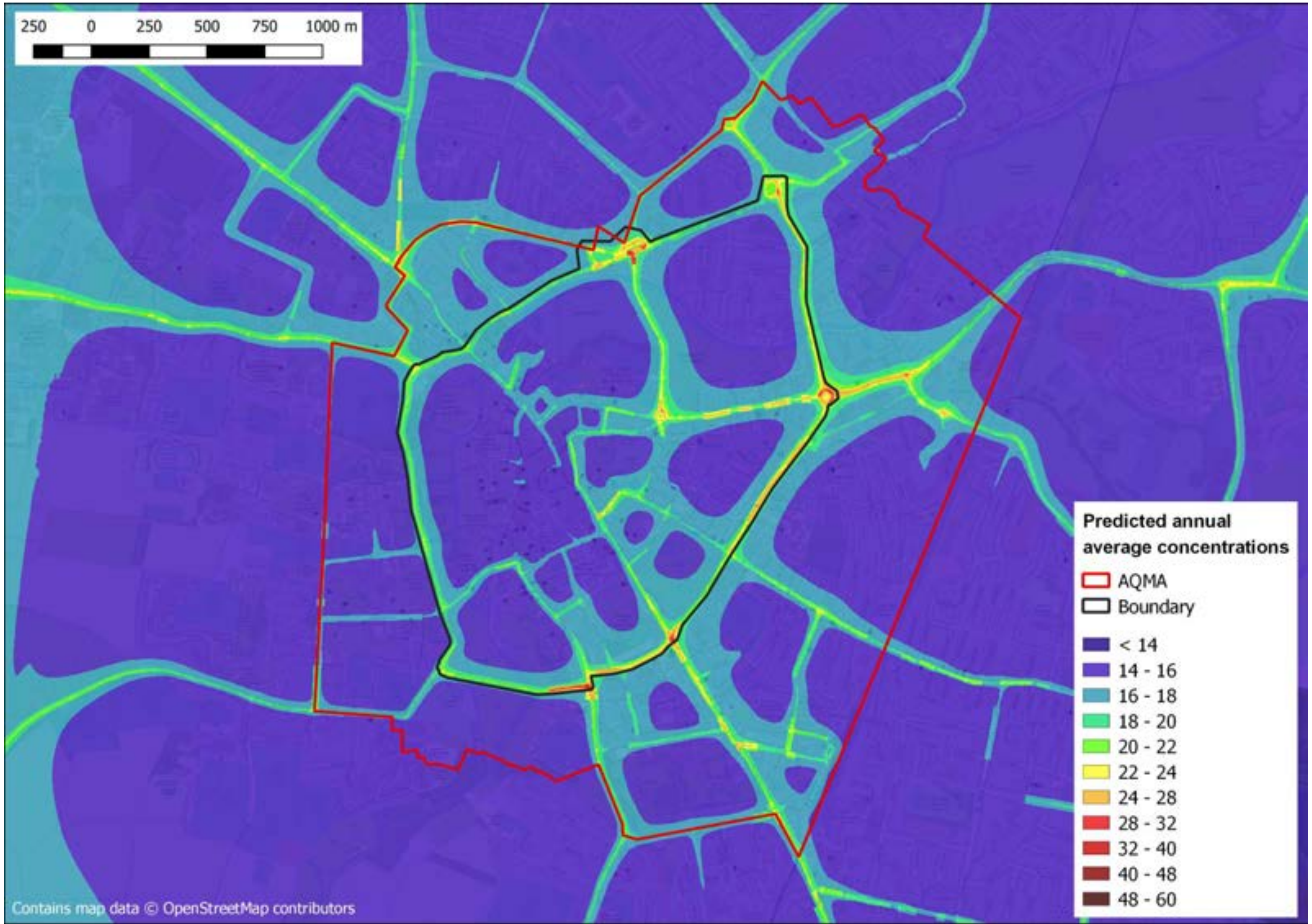


Figure 17: Annual average PM_{10} concentrations, 2021 baseline, city centre, $\mu g.m^{-3}$

Figure 18: Annual average PM_{10} concentrations, 2021 baseline, South Cambridge, $\mu g.m^{-3}$

1.2 2021 non-CAZ intervention

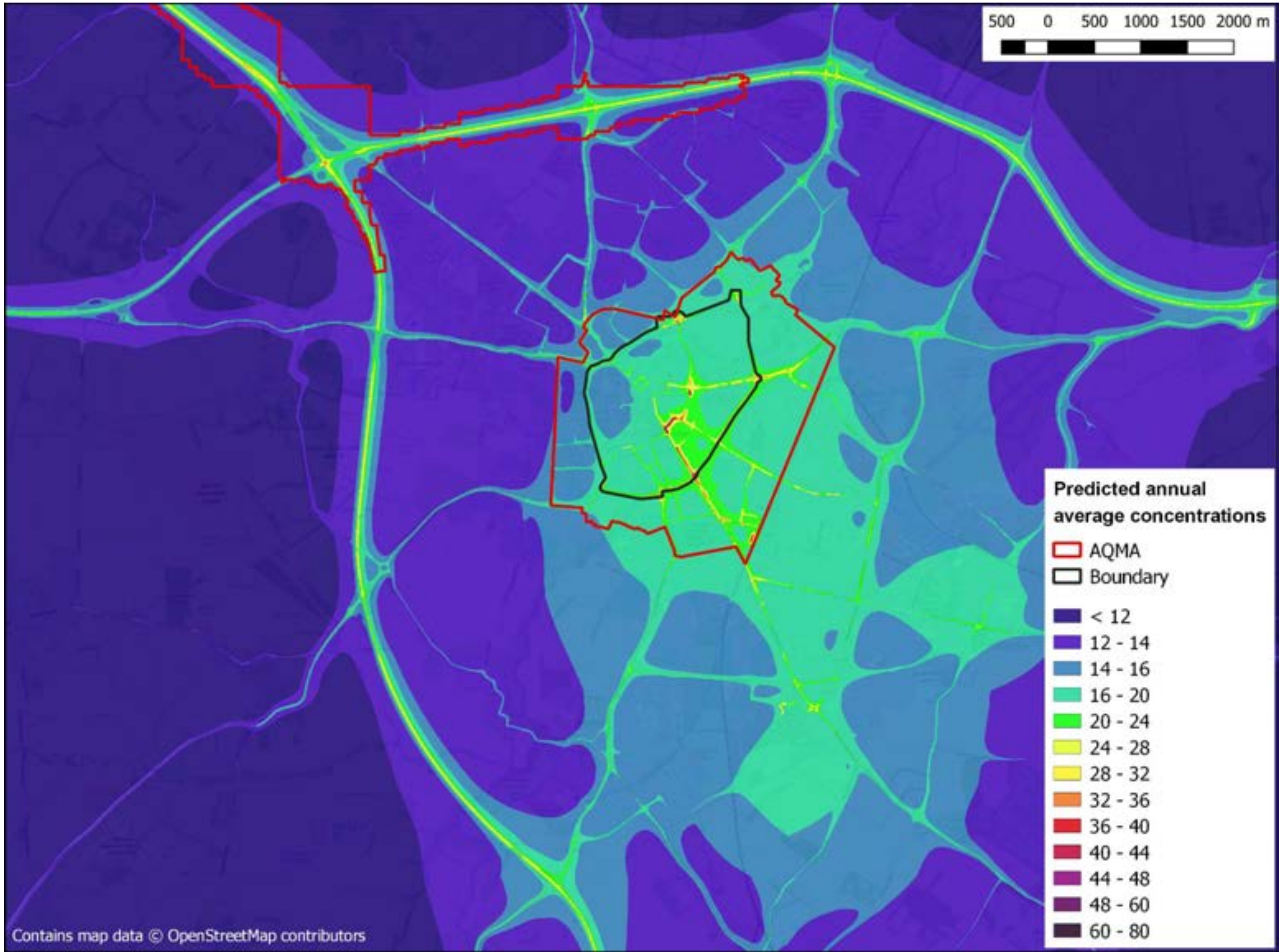


Figure 19: Annual average NO_2 concentrations, 2021 non-CAZ intervention, Cambridge, μg.m^{-3}

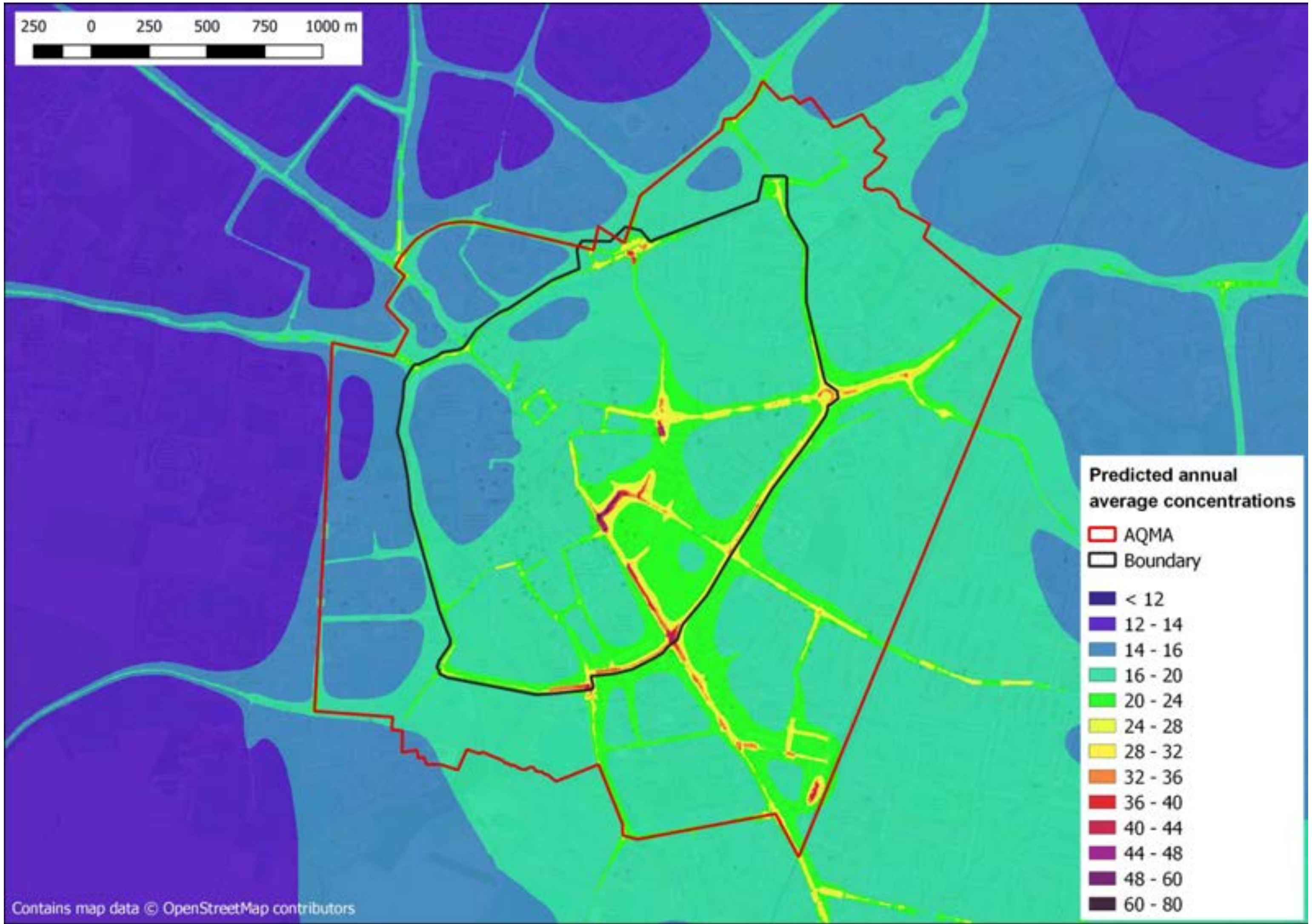


Figure 20: Annual average NO_2 concentrations, 2021 non-CAZ intervention, city centre, $\mu g.m^{-3}$

Figure 21: Annual average NO_2 concentrations, 2021 non-CAZ intervention, South Cambridge, µg.m^{-3}

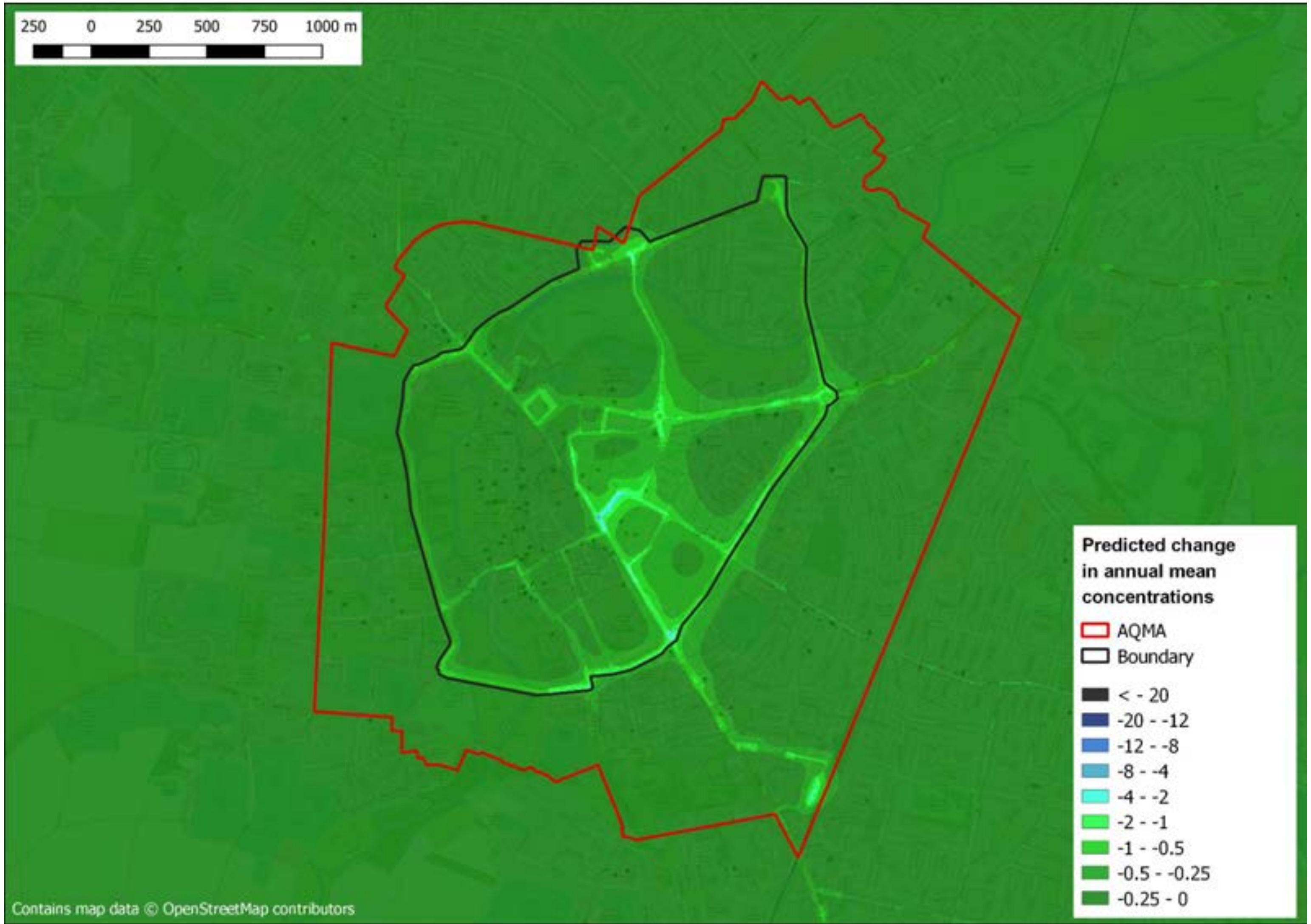


Figure 22: Change in annual average NO_2 concentrations, 2021 non-CAZ intervention, µg.m^{-3}

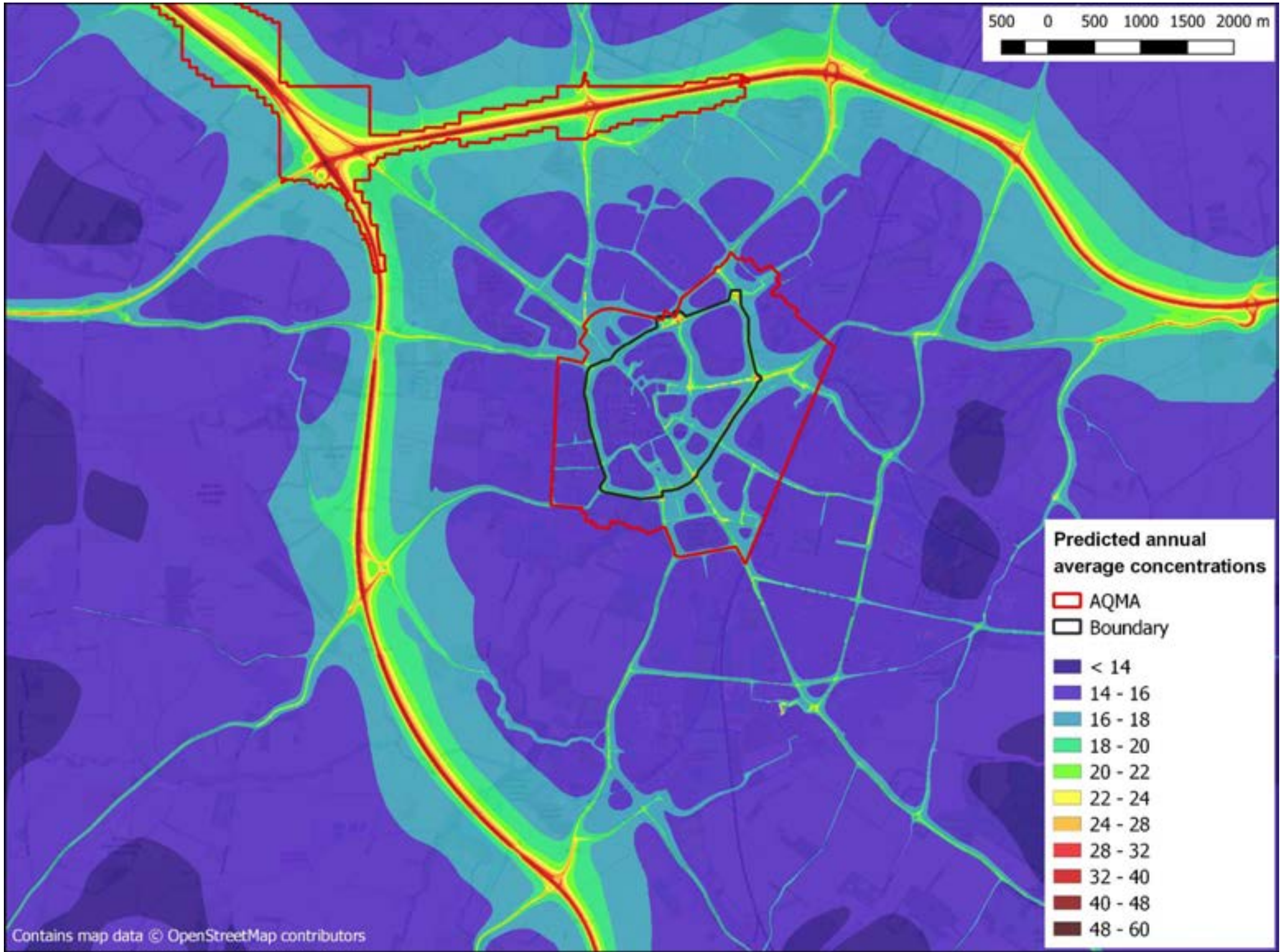


Figure 23: Annual average PM_{10} concentrations, 2021 non-CAZ intervention, Cambridge, $\mu g.m^{-3}$

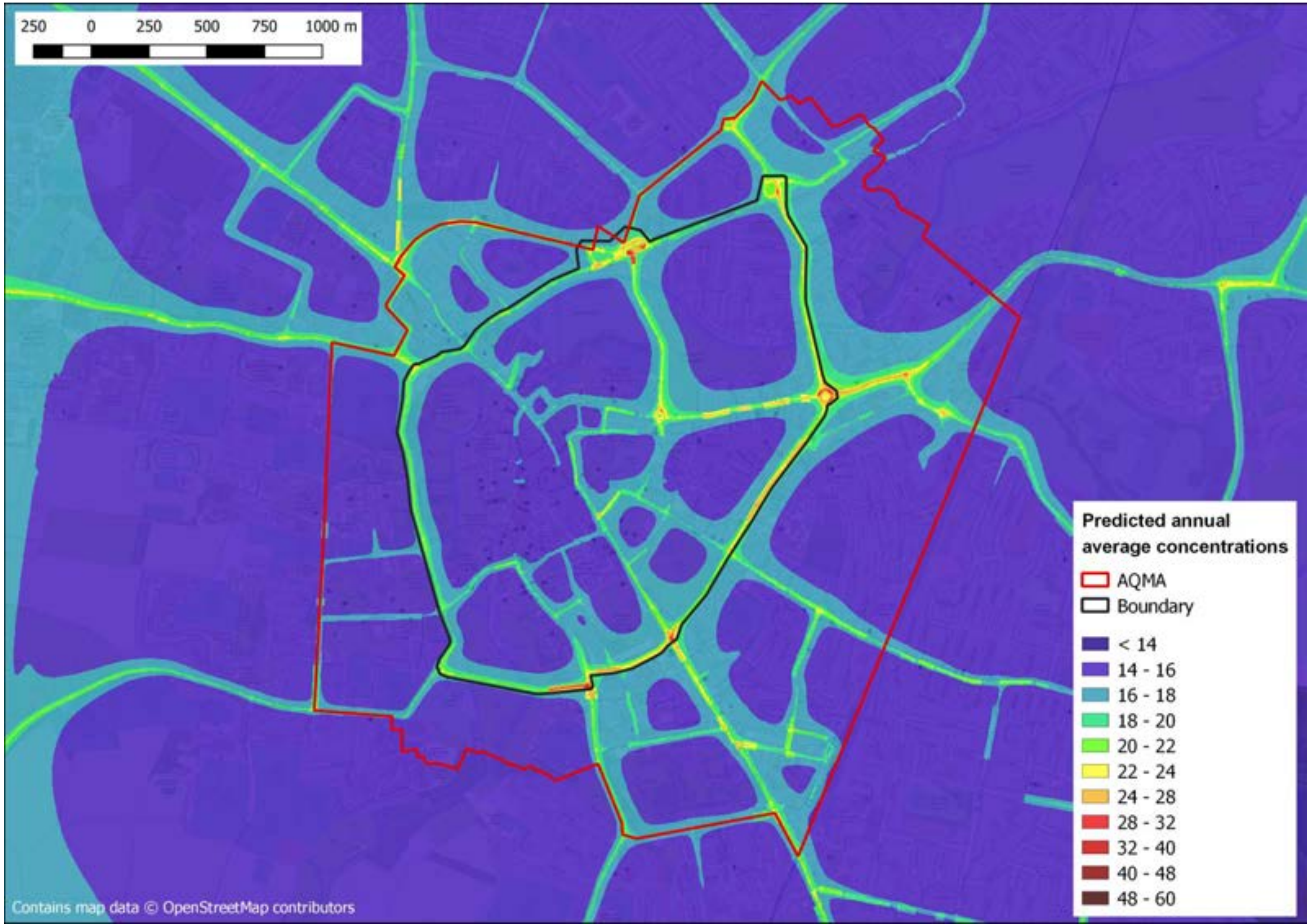


Figure 24: Annual average PM_{10} concentrations, 2021 non-CAZ intervention, city centre, $\mu g.m^{-3}$

Figure 25: Annual average PM_{10} concentrations, 2021 non-CAZ intervention, South Cambridge, $\mu g.m^{-3}$

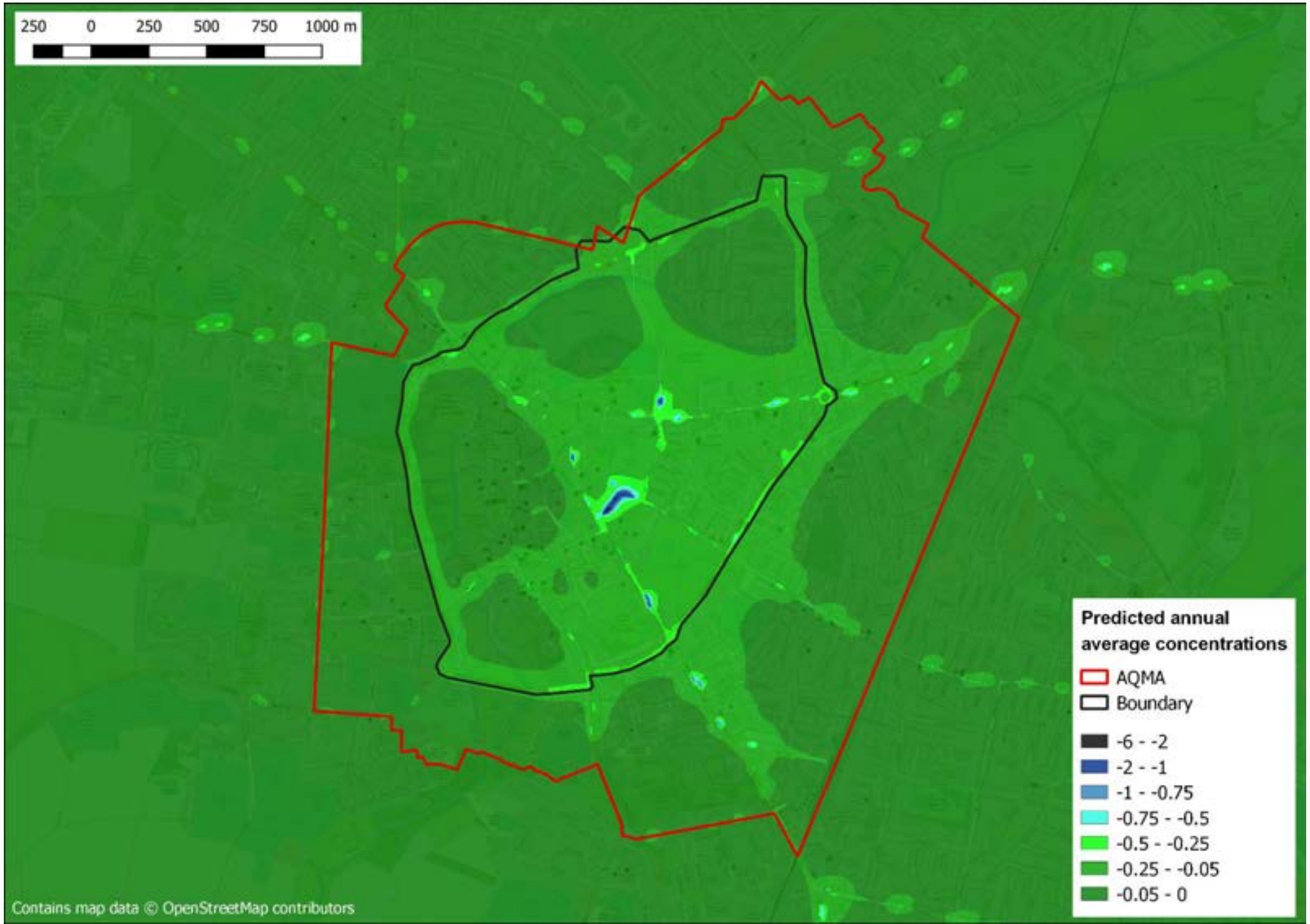


Figure 26: Change in annual average PM_{10} concentrations, 2021 non-CAZ intervention, $\mu g.m^{-3}$

1.3 2021 class A charging CAZ

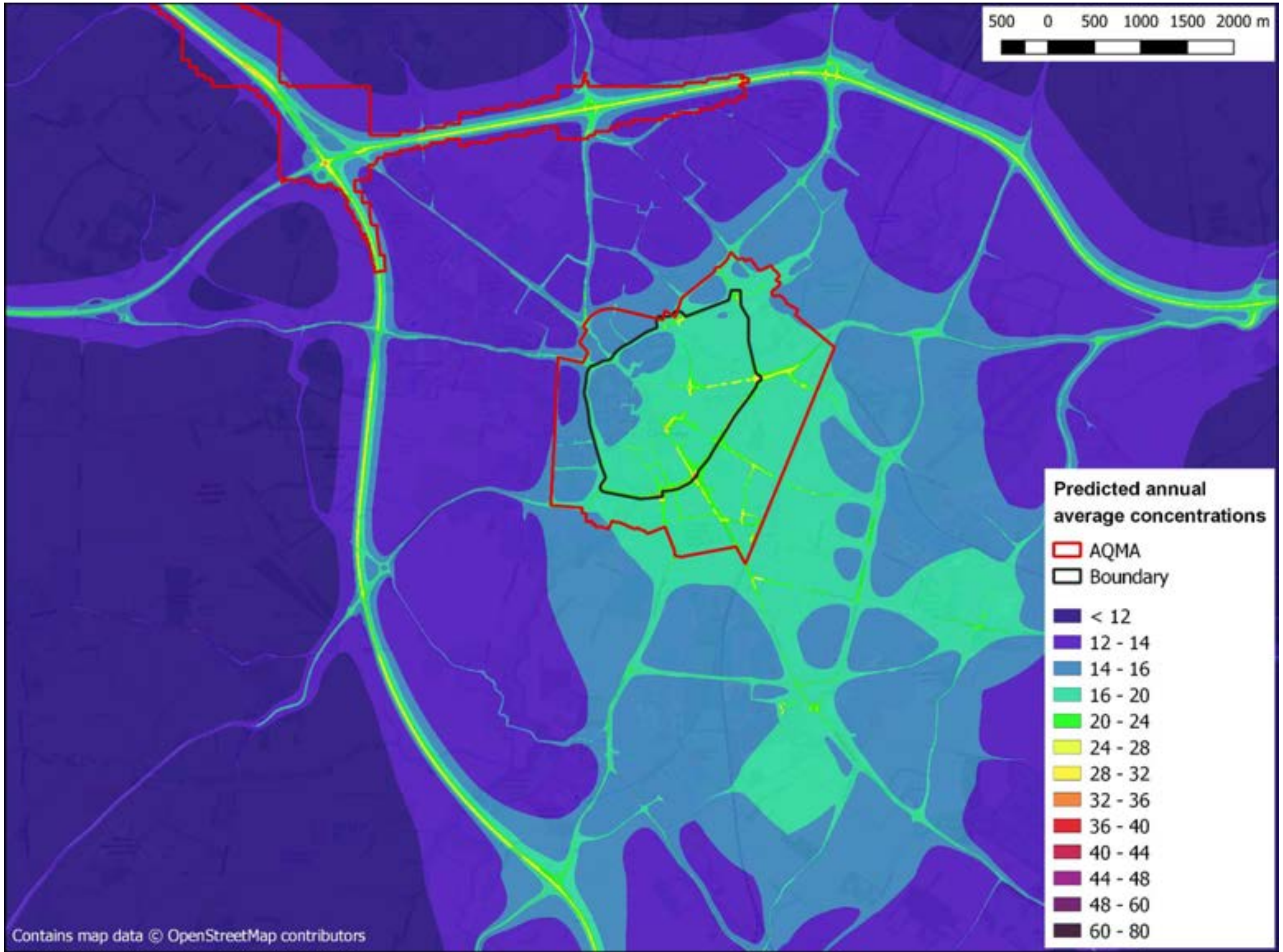


Figure 27: Annual average NO_2 concentrations, 2021 class A charging CAZ, Cambridge, μg.m^{-3}

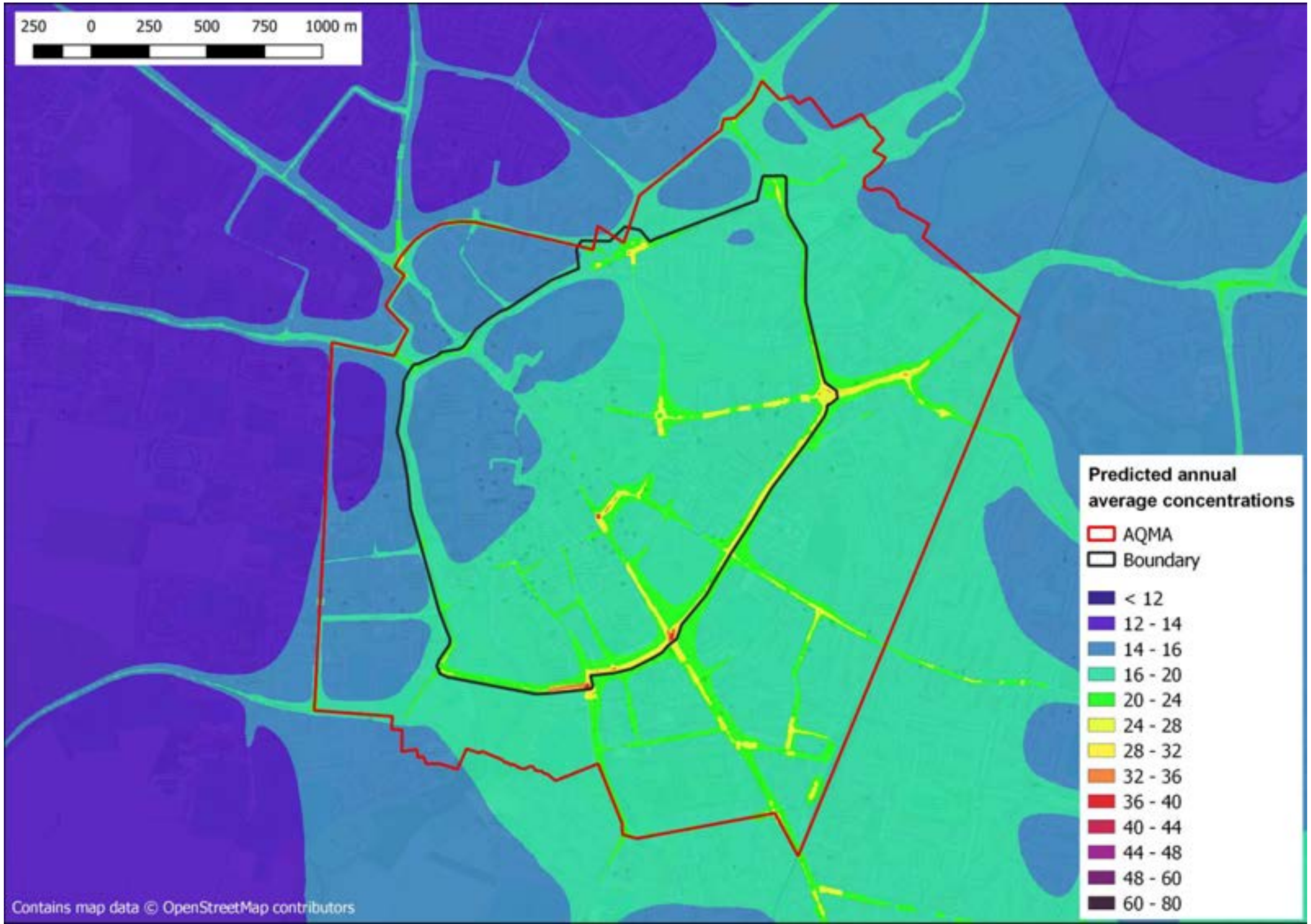


Figure28: Annual average NO_2 concentrations, 2021 class A charging CAZ, city centre, µg.m^{-3}

Figure 29: Annual average NO_2 concentrations, 2021 class A charging CAZ, South Cambridge, µg.m^{-3}

Figure 30: Change in annual average NO_2 concentrations, 2021 class A charging CAZ, $\mu g.m^{-3}$

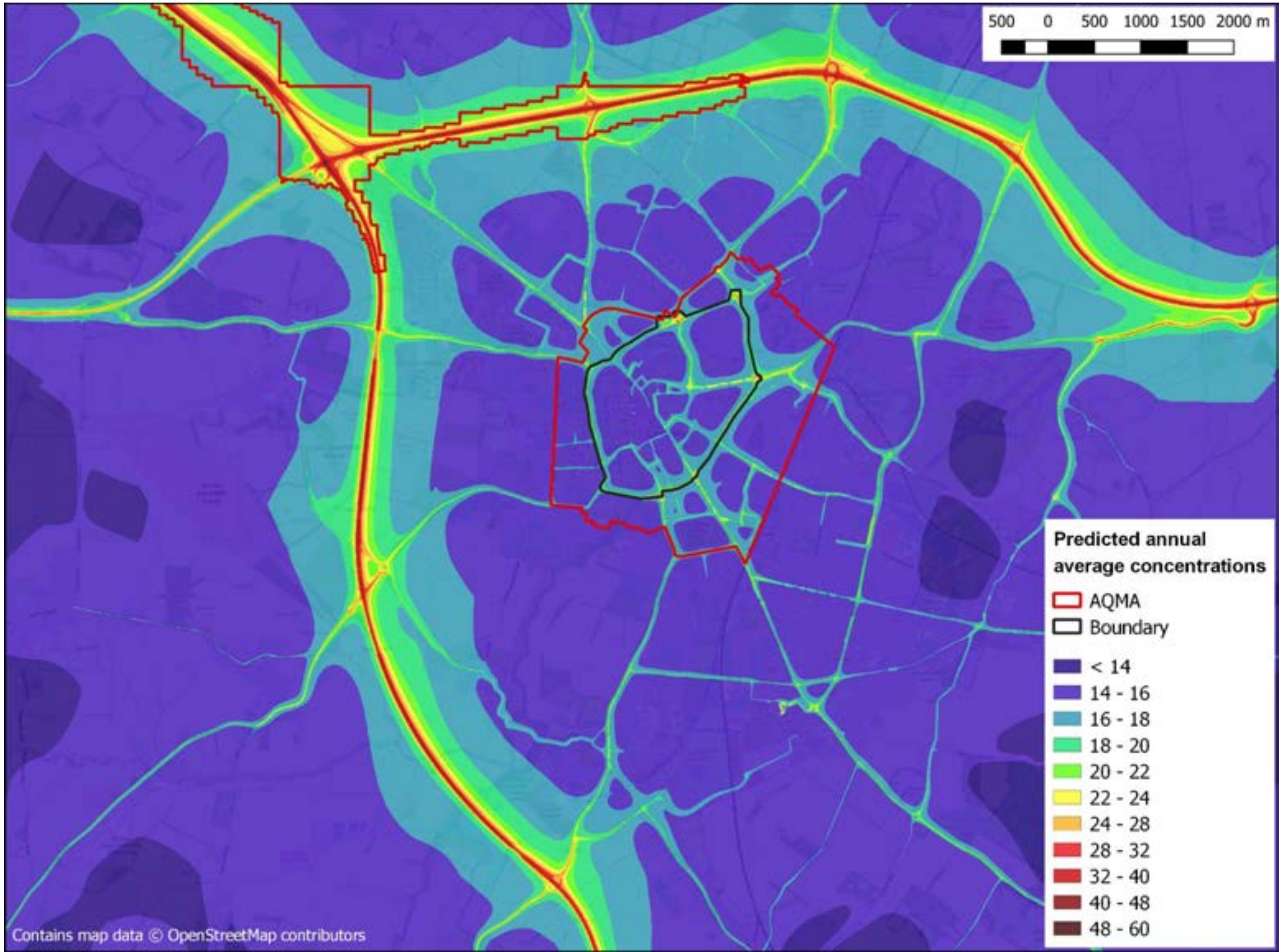


Figure 31: Annual average PM_{10} concentrations, 2021 class A charging CAZ, Cambridge, $\mu g.m^{-3}$

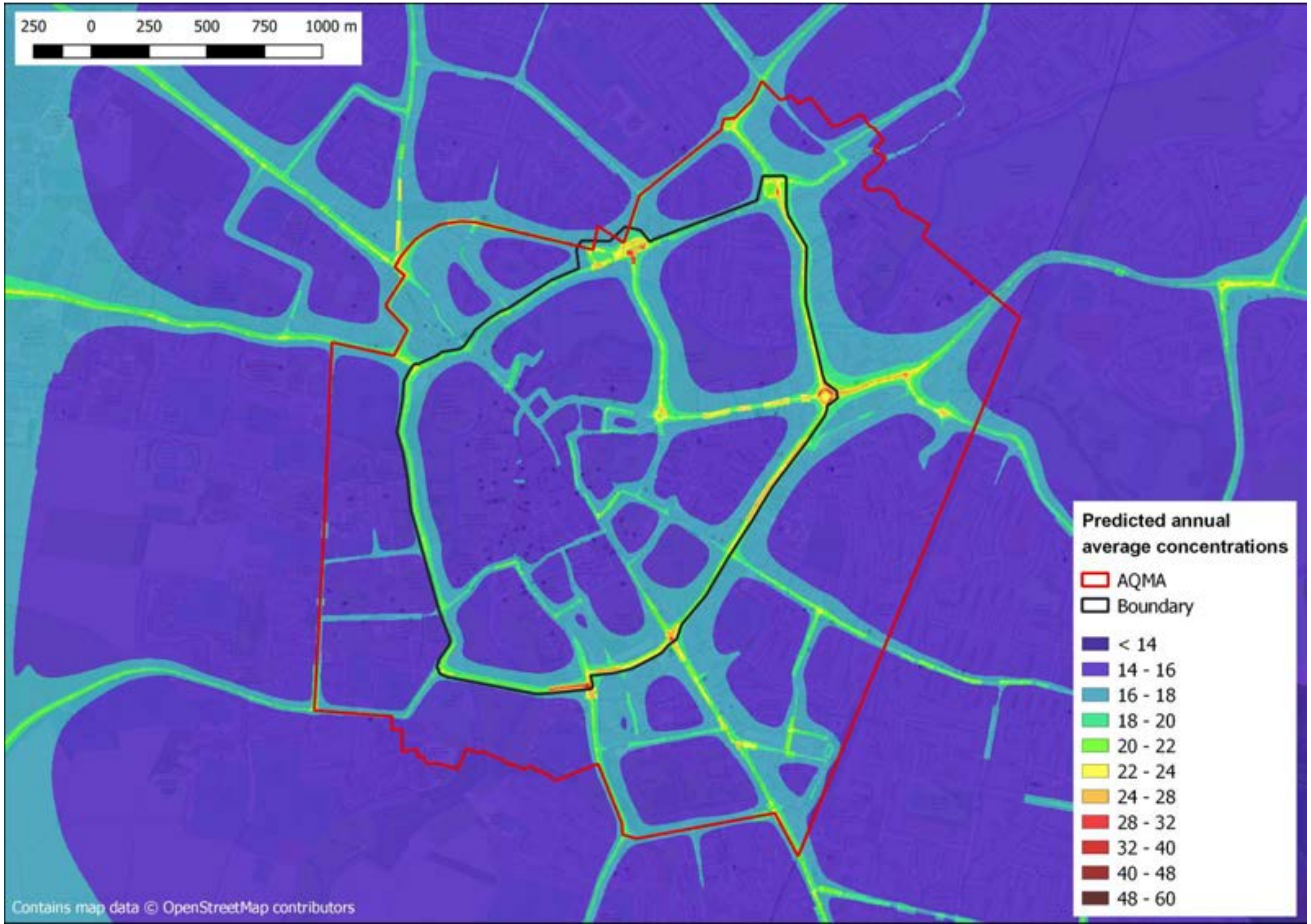


Figure 32: Annual average PM_{10} concentrations, 2021 class A charging CAZ, city centre, $\mu g.m^{-3}$

Figure 33: Annual average PM_{10} concentrations, 2021 class A charging CAZ, South Cambridge, µg.m^{-3}

Figure 34: Change in annual average PM_{10} concentrations, 2021 class A charging CAZ, $\mu g.m^{-3}$

1.4 2021 class D charging CAZ

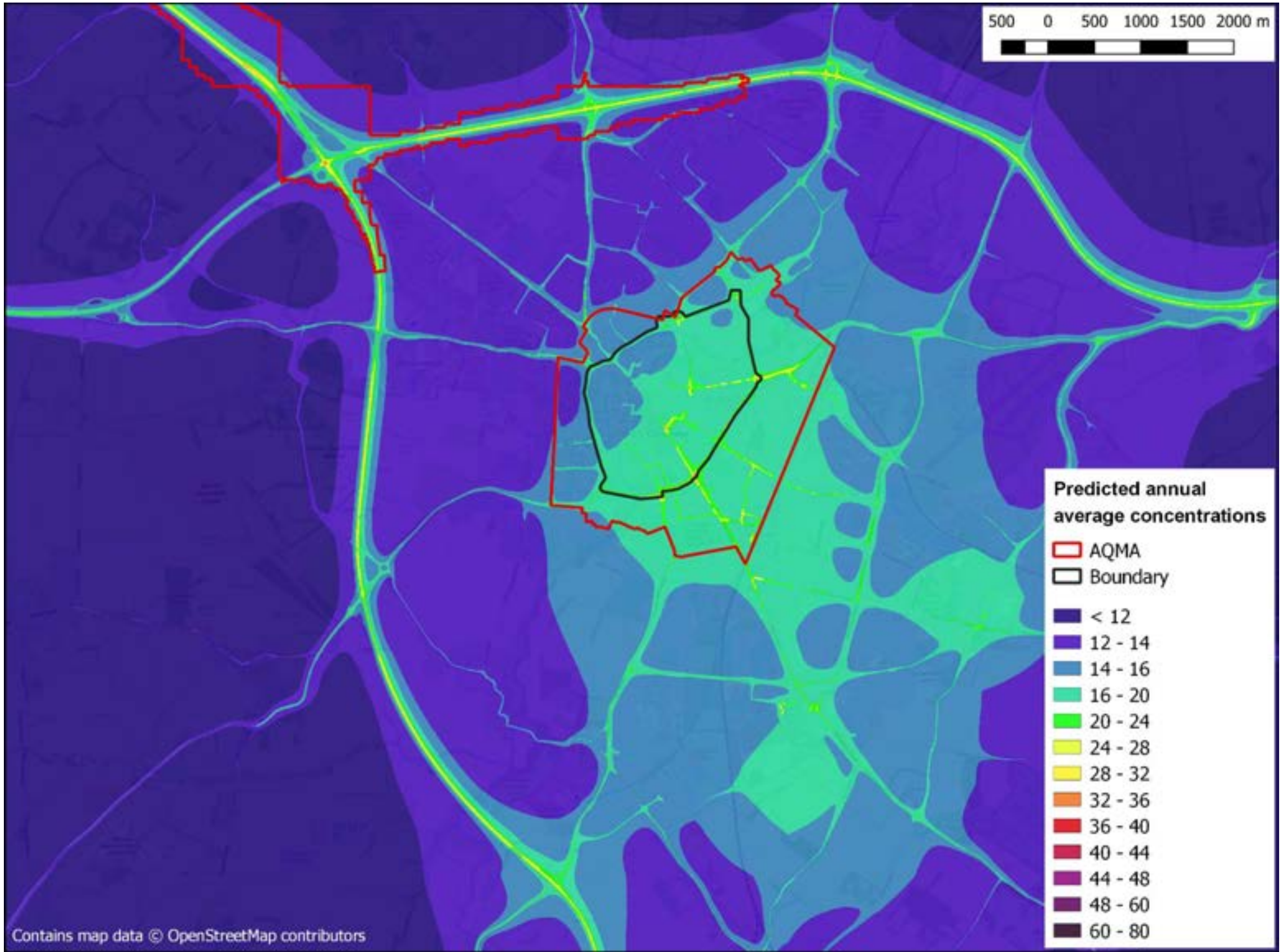


Figure 35: Annual average NO_2 concentrations, 2021 class D charging CAZ, Cambridge, $\mu g.m^{-3}$

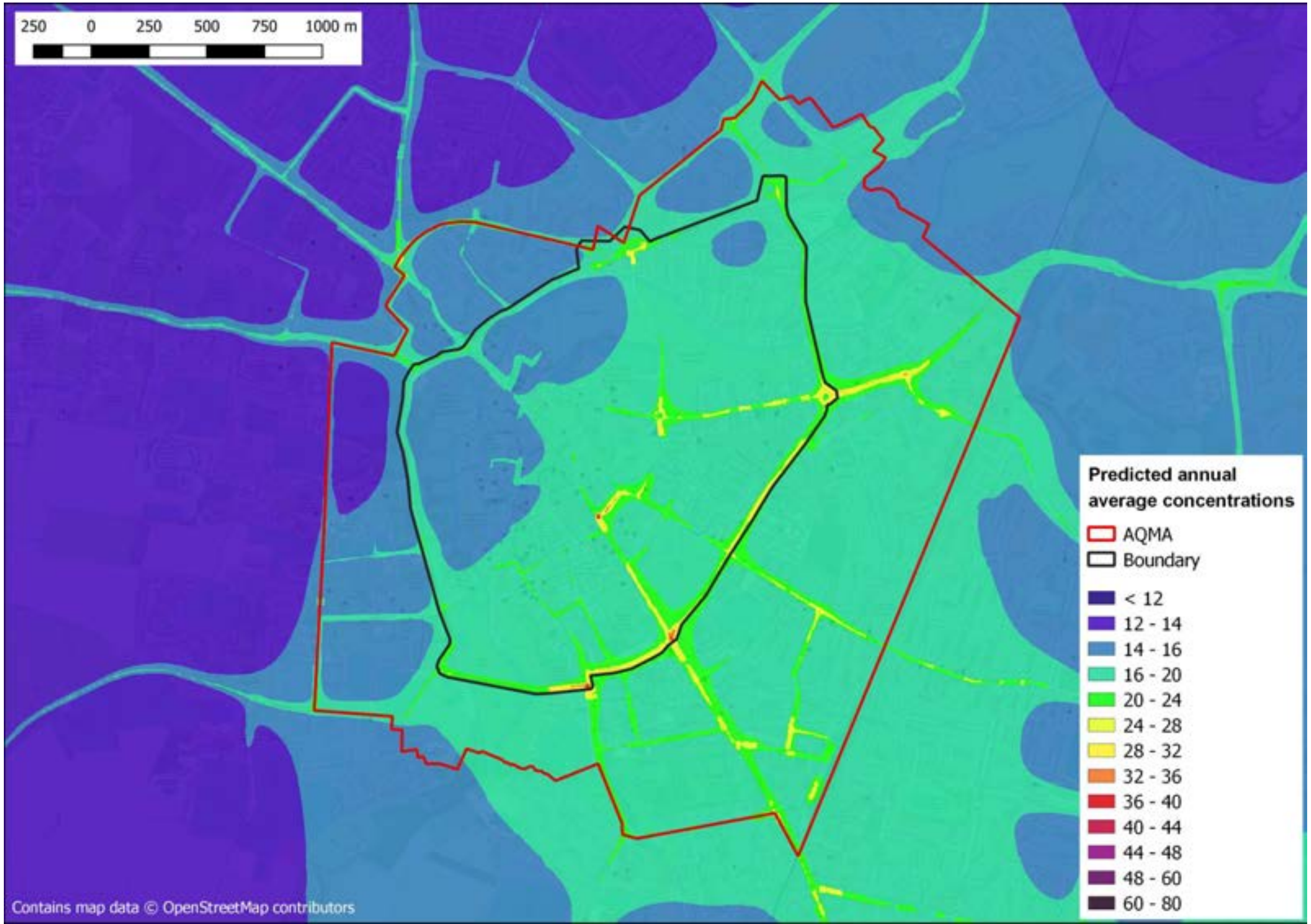


Figure 36: Annual average NO_2 concentrations, 2021 class D charging CAZ, city centre, µg.m^{-3}

Figure 37: Annual average NO_2 concentrations, 2021 class D charging CAZ, South Cambridge, µg.m^{-3}

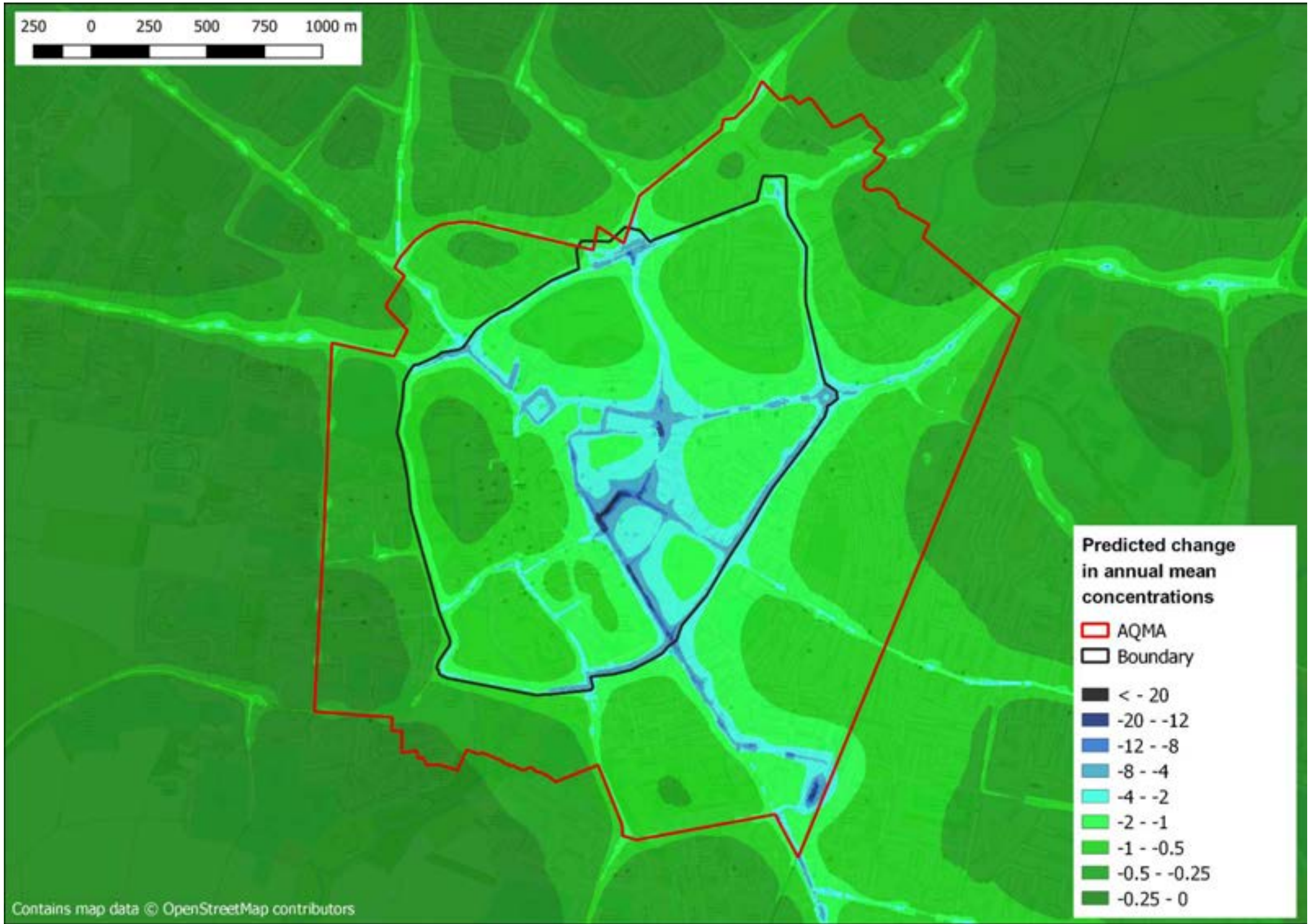


Figure 38: Change in annual average NO_2 concentrations, 2021 class D charging CAZ, µg.m^{-3}

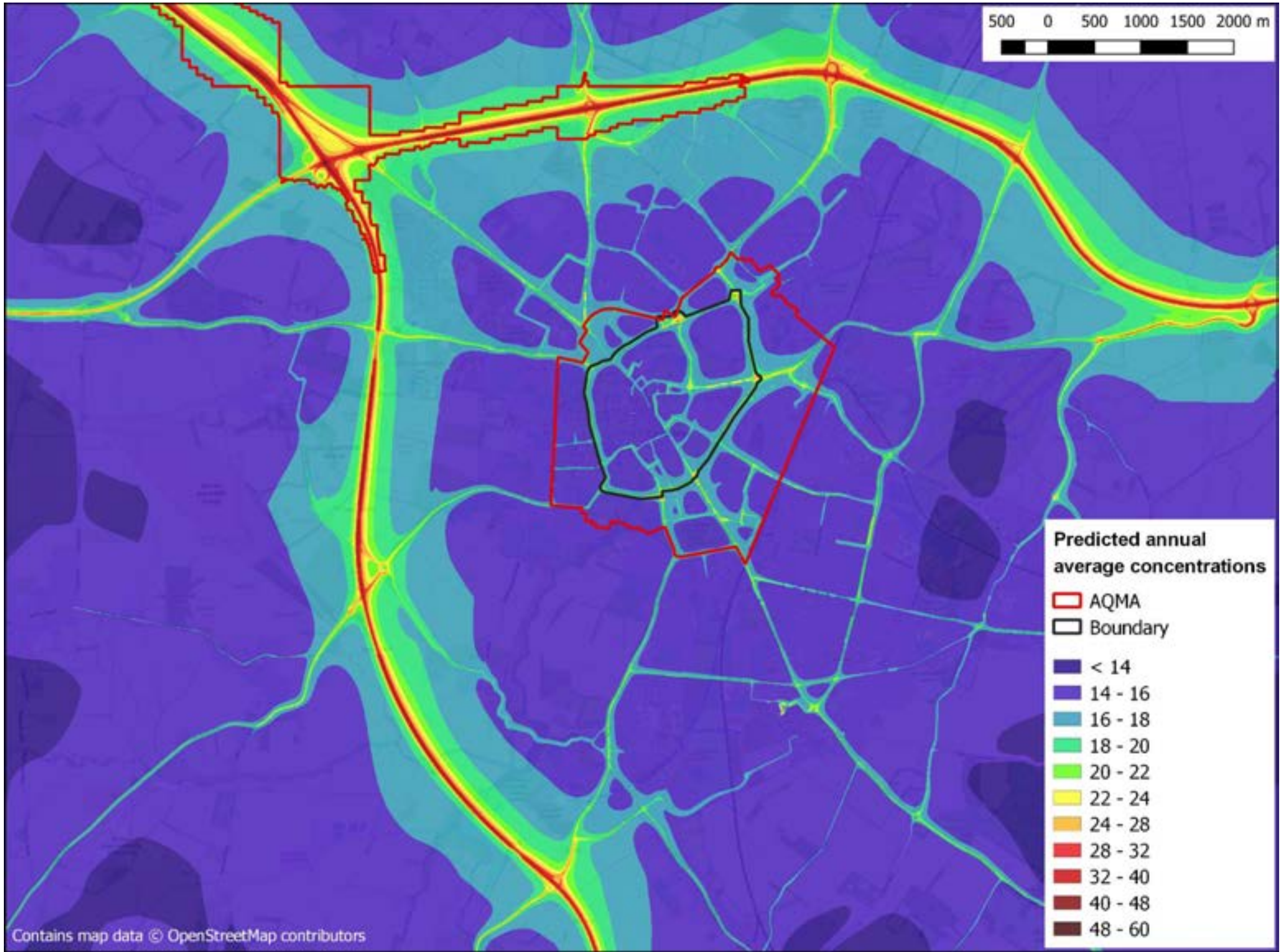


Figure 39: Annual average PM_{10} concentrations, 2021 class D charging CAZ, Cambridge, $\mu g.m^{-3}$

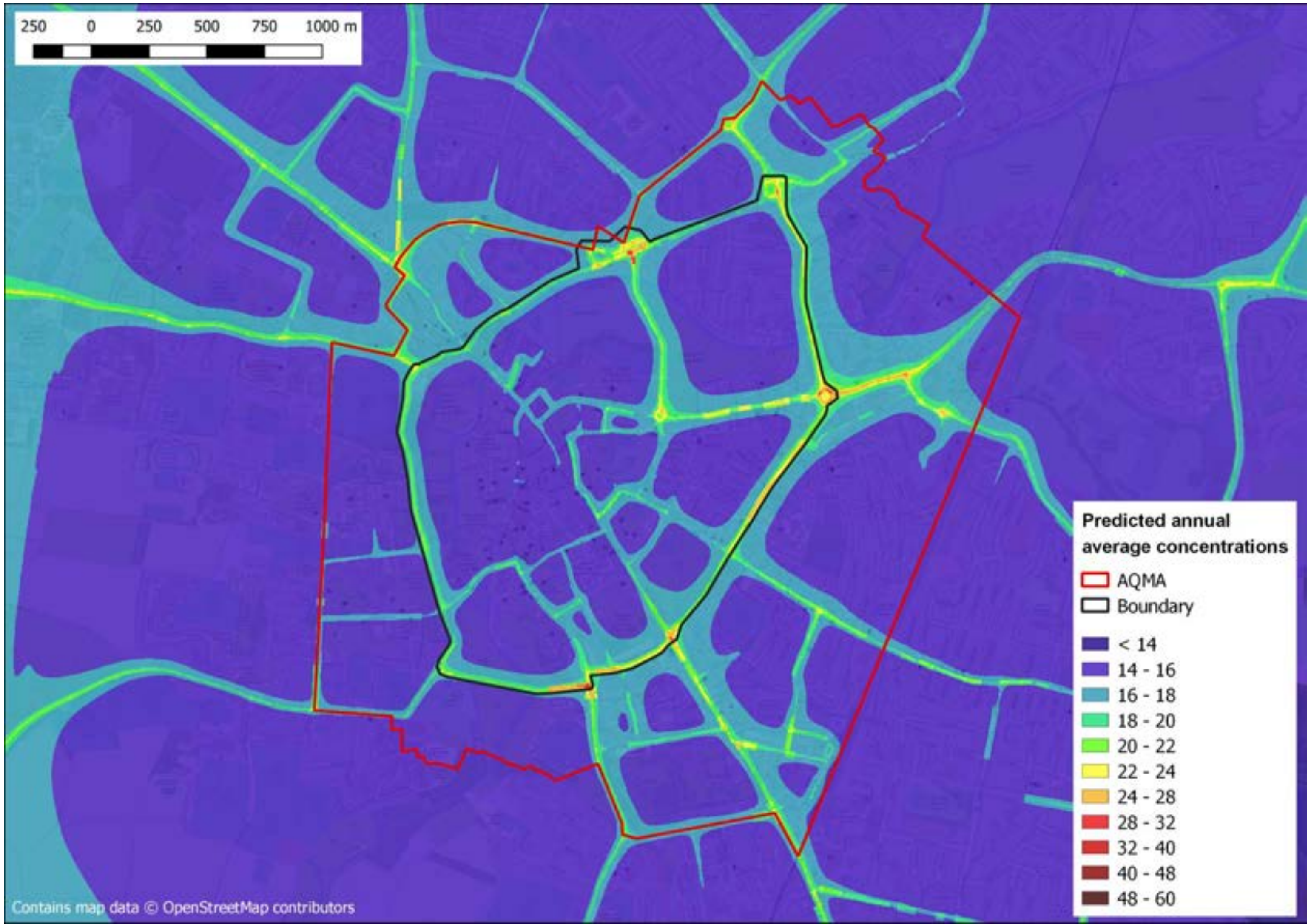


Figure 40: Annual average PM_{10} concentrations, 2021 class D charging CAZ, city centre, $\mu g.m^{-3}$

Figure 41: Annual average PM_{10} concentrations, 2021 class D charging CAZ, South Cambridge, µg.m^{-3}

Figure 42: Change in annual average PM_{10} concentrations, 2021 class D charging CAZ, $\mu g.m^{-3}$

F.2 2031 baseline

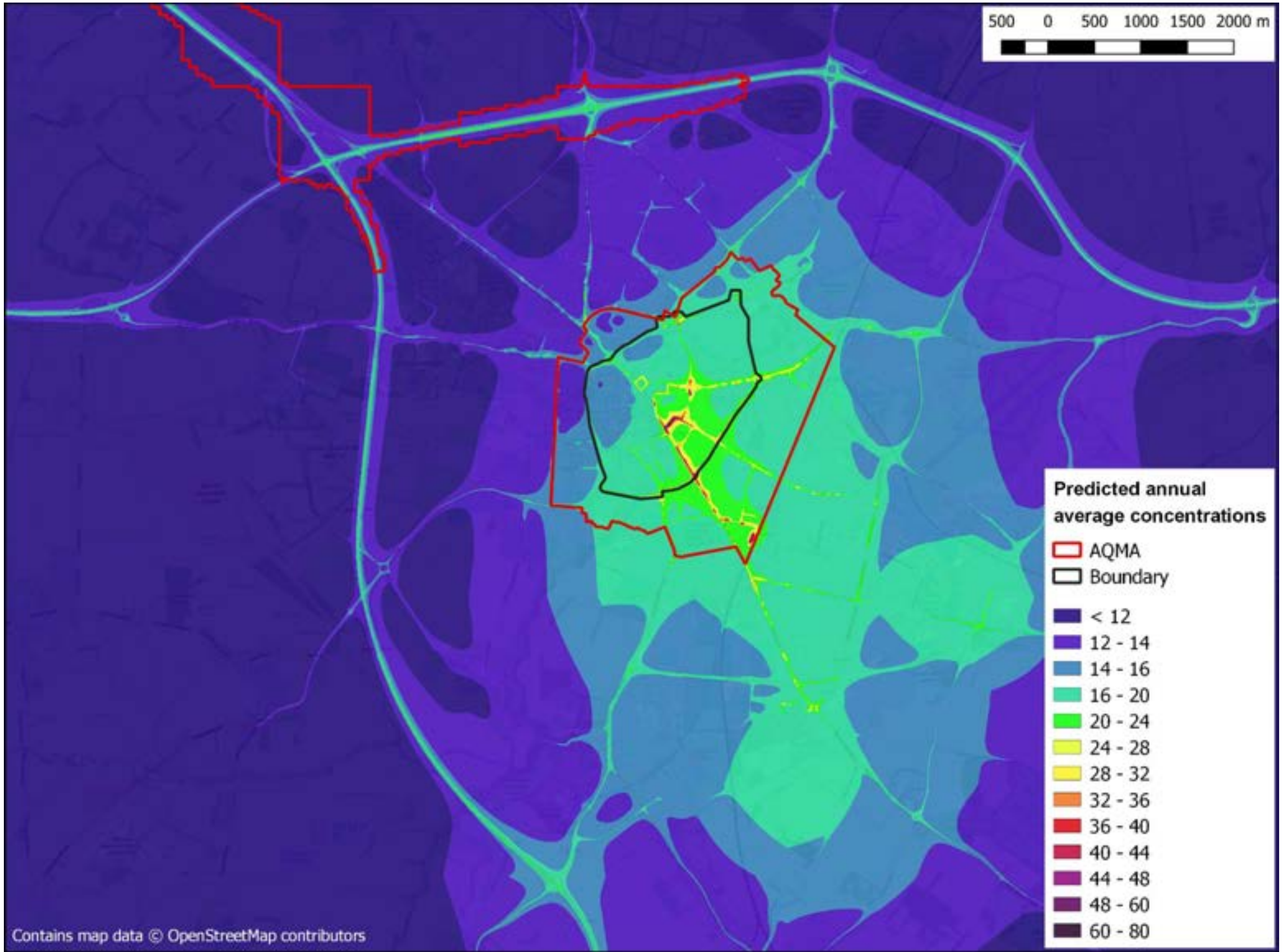


Figure 43: Annual average NO_2 concentrations, 2031 baseline, Cambridge, $\mu g.m^{-3}$

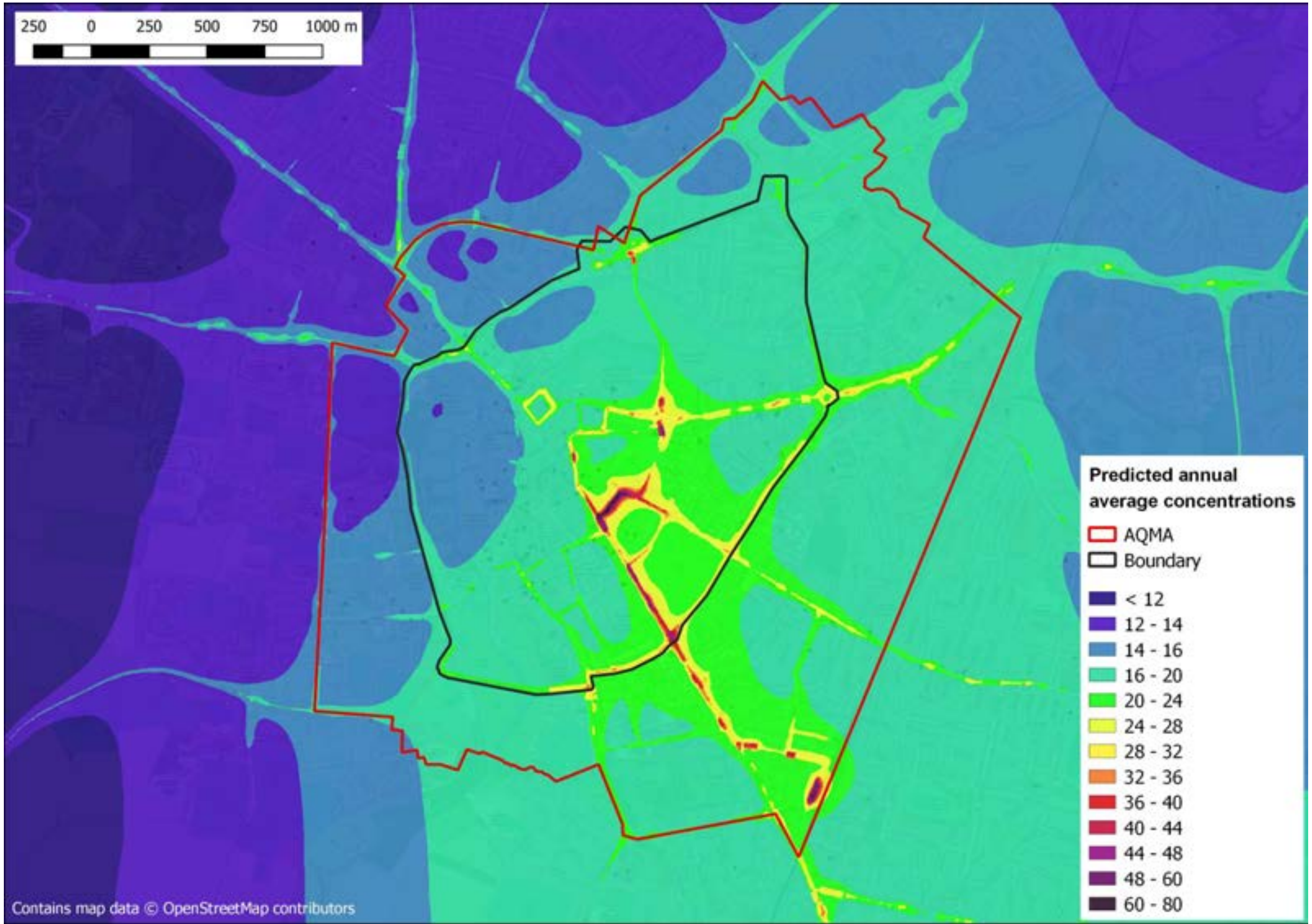


Figure 44: Annual average NO_2 concentrations, 2031 baseline, city centre, $\mu g.m^{-3}$

Figure 45: Annual average NO_2 concentrations, 2031 baseline, South Cambridge, $\mu g.m^{-3}$

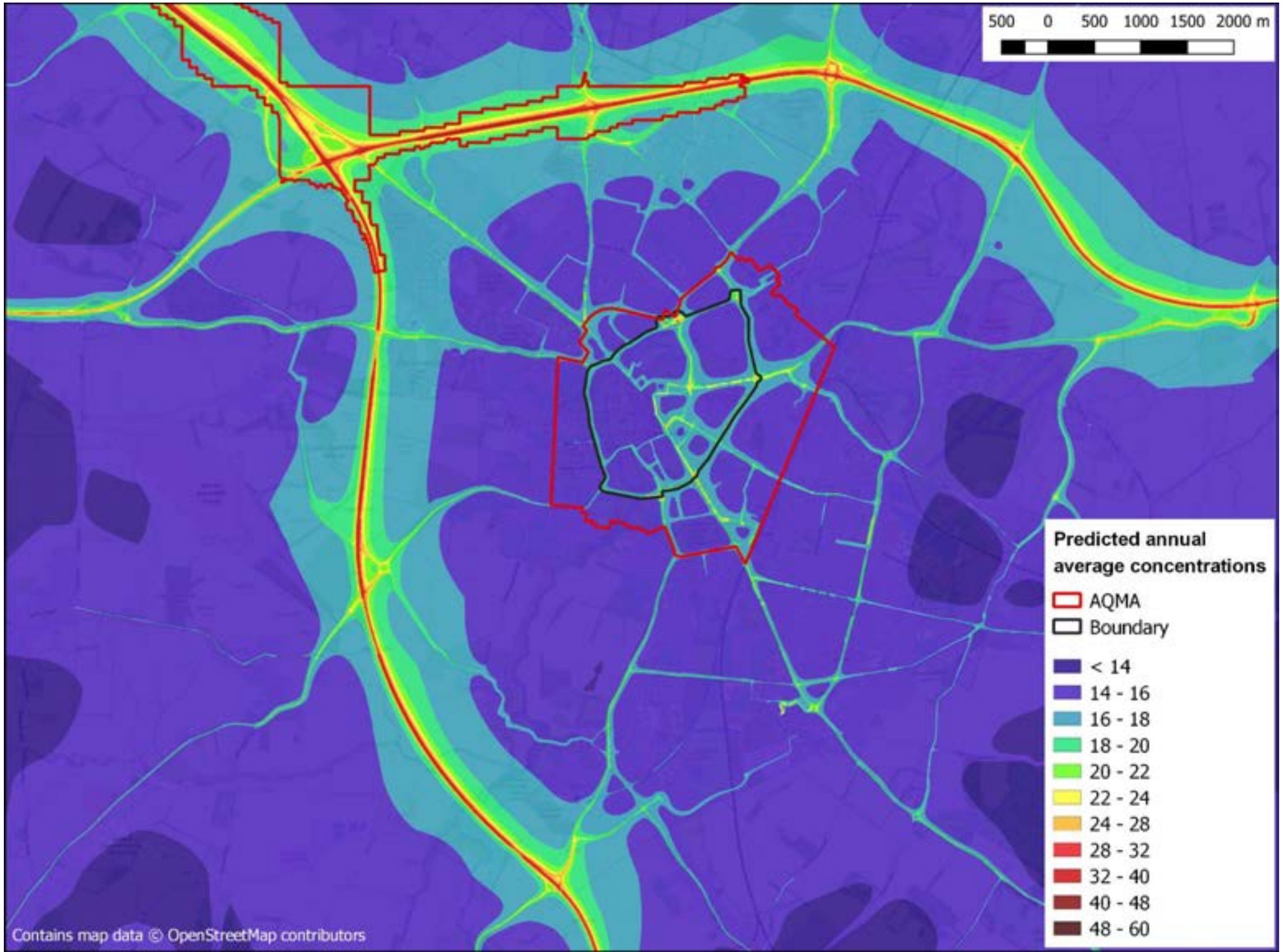


Figure 46: Annual average PM_{10} concentrations, 2031 baseline, Cambridge, $\mu g.m^{-3}$

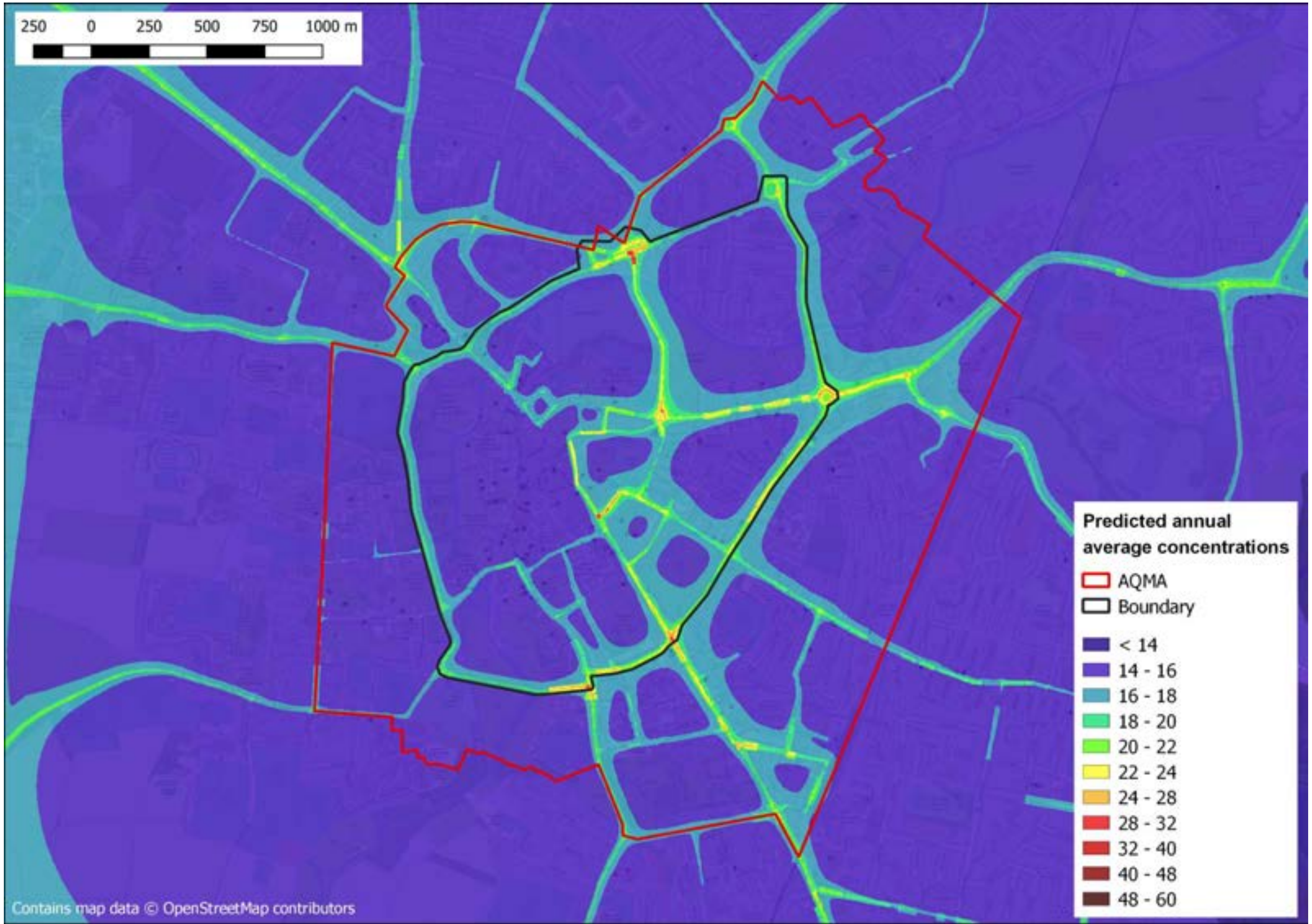


Figure 47: Annual average PM_{10} concentrations, 2031 baseline, city centre, $\mu g.m^{-3}$

Figure 48: Annual average PM_{10} concentrations, 2031 baseline, South Cambridge, $\mu g.m^{-3}$

F.3 2031 class A charging CAZ

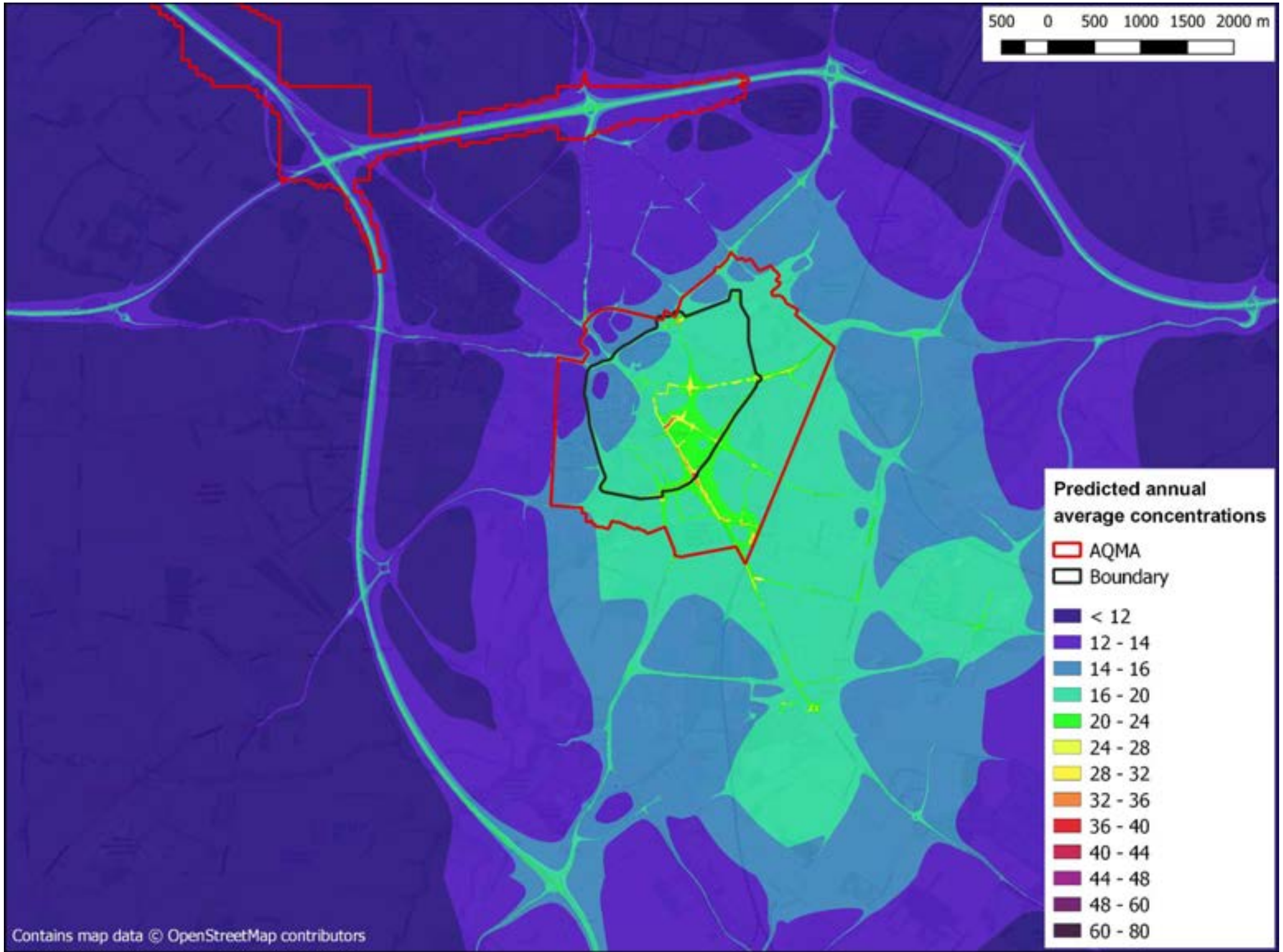


Figure 49: Annual average NO_2 concentrations, 2031 class A charging CAZ, Cambridge, $\mu g.m^{-3}$

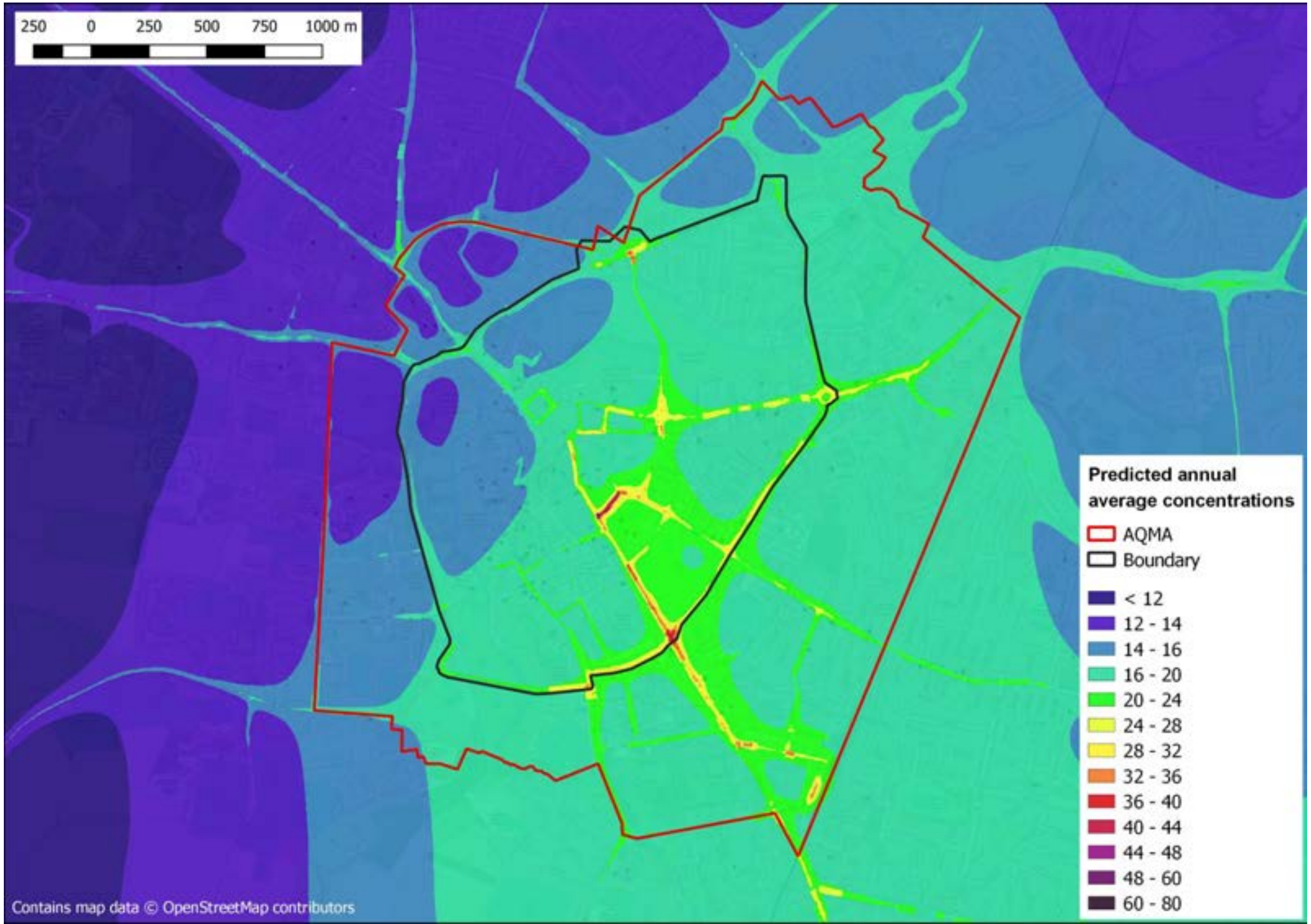


Figure 50: Annual average NO_2 concentrations, 2031 class A charging CAZ, city centre, µg.m^{-3}

Figure 51: Annual average NO_2 concentrations, 2031 class A charging CAZ, South Cambridge, µg.m^{-3}

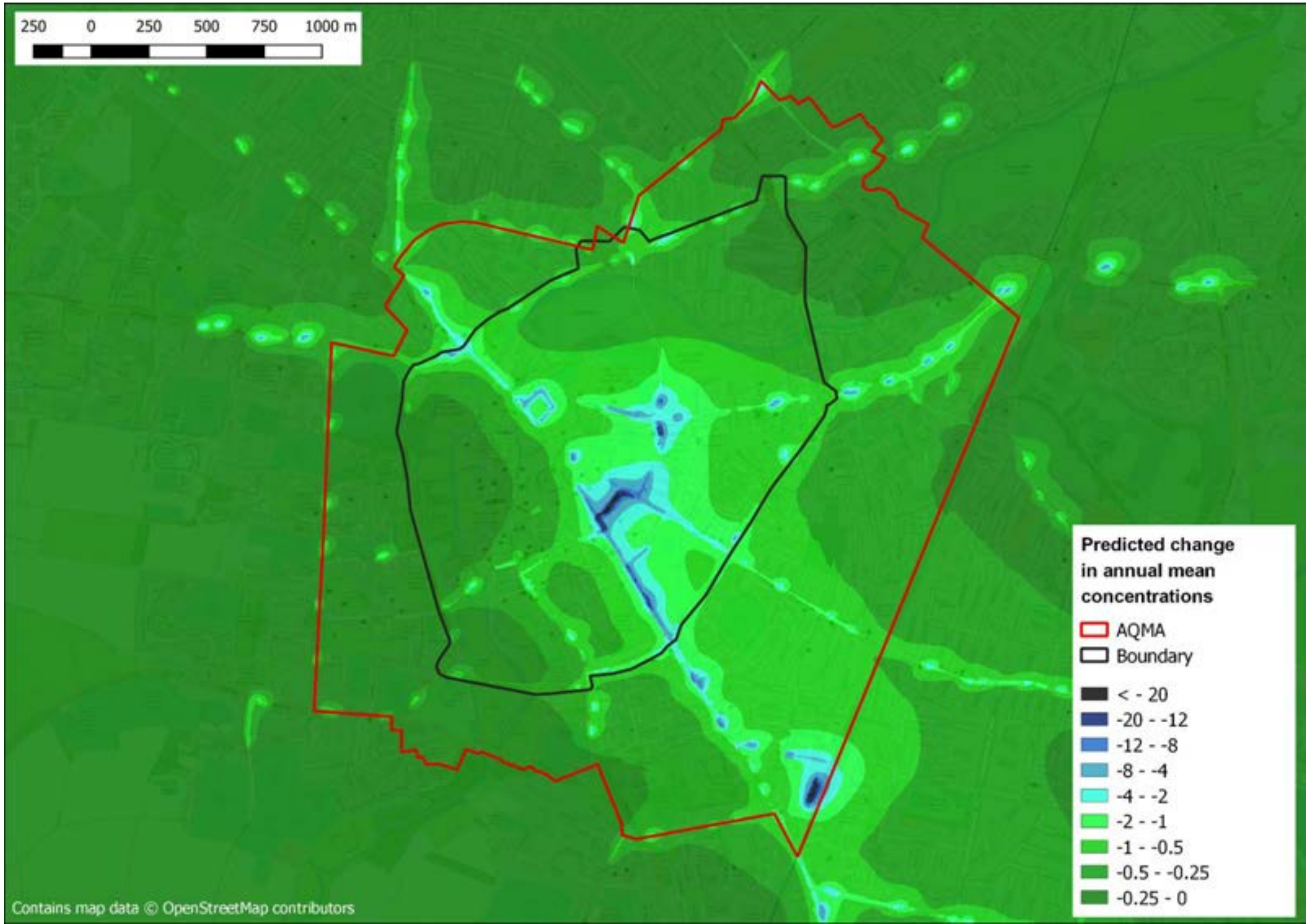


Figure 52: Change in annual average NO_2 concentrations, 2031 class A charging CAZ, μg.m^{-3}

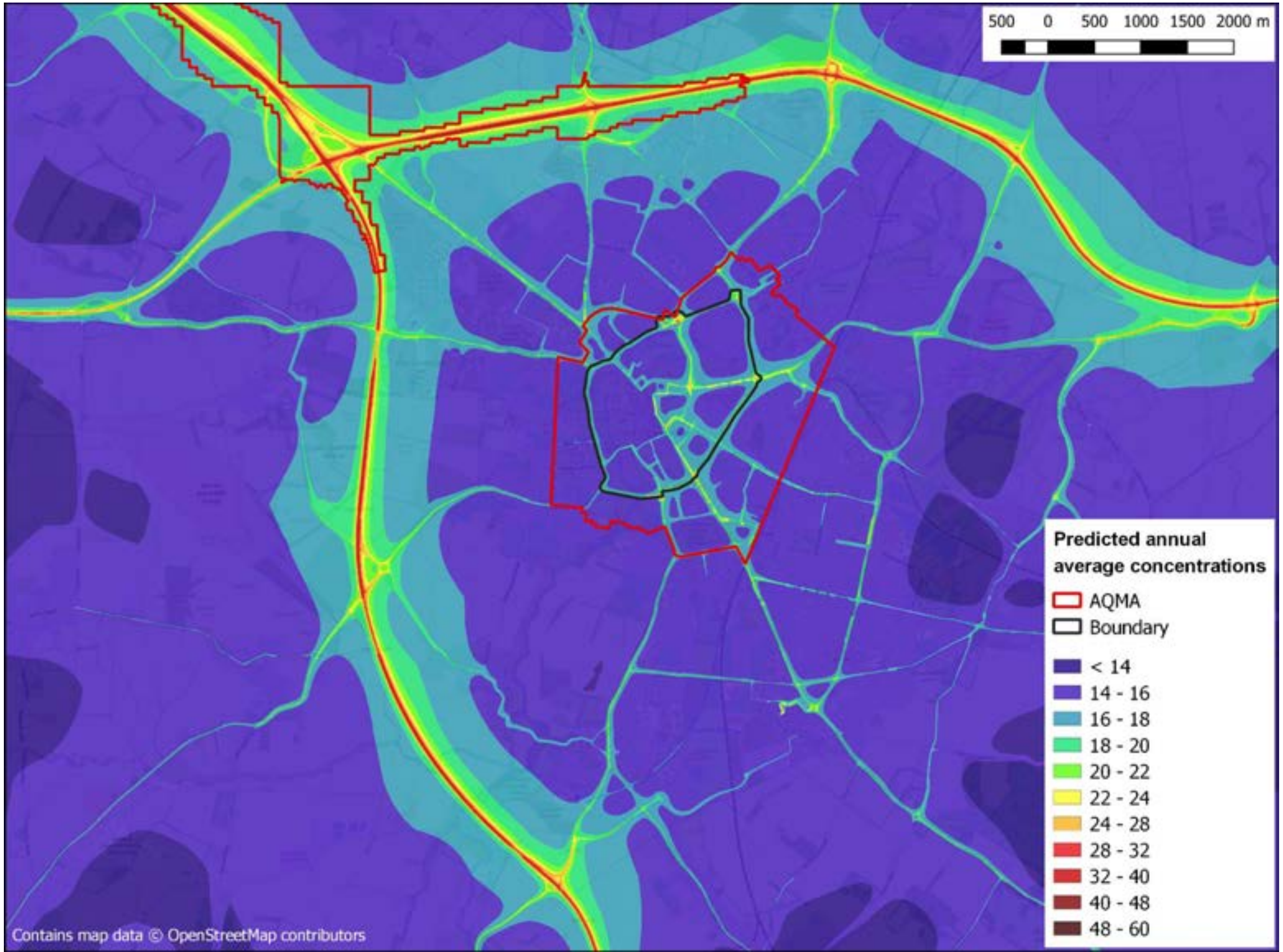


Figure 53: Annual average PM_{10} concentrations, 2031 class A charging CAZ, Cambridge, $\mu g.m^{-3}$

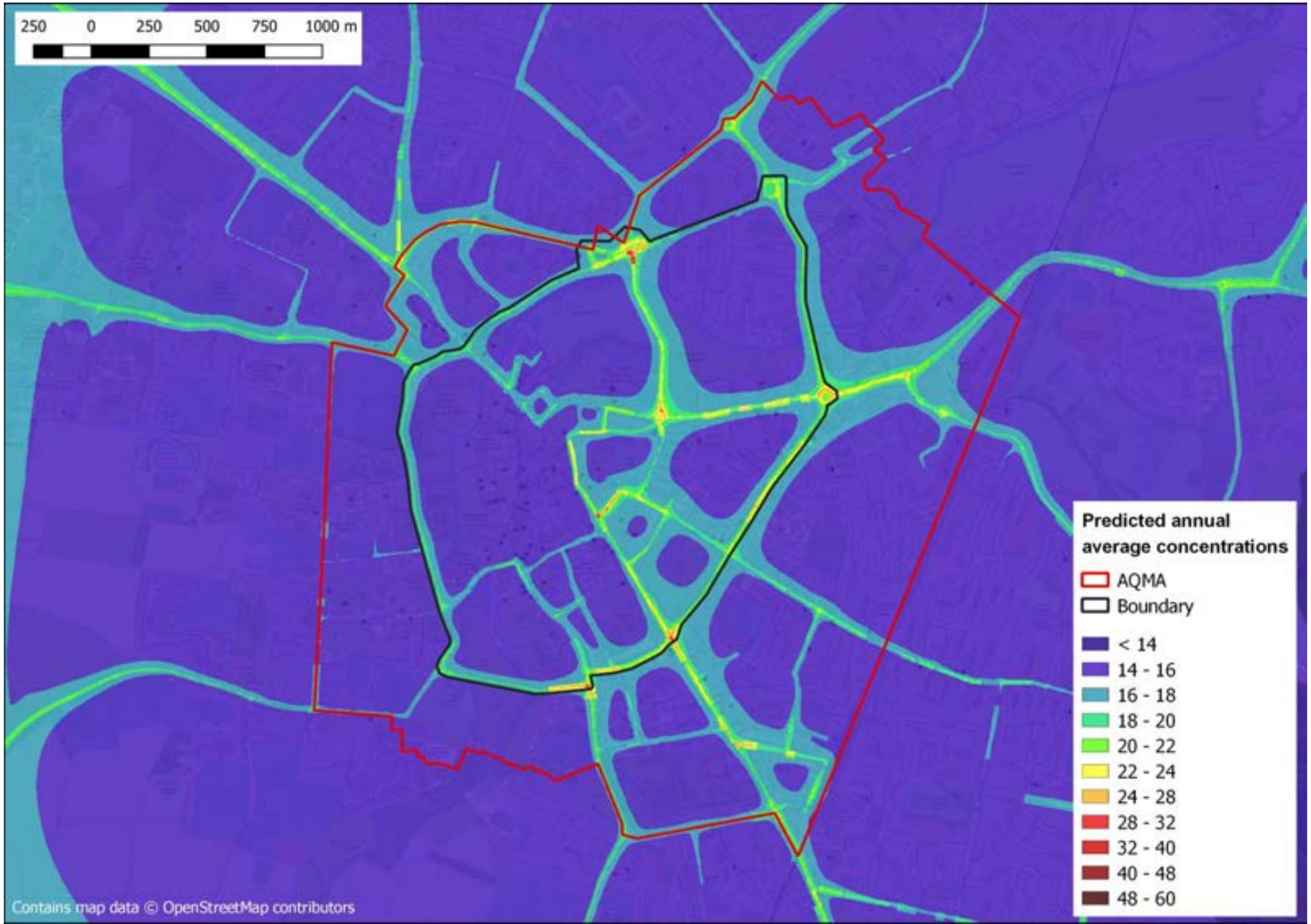


Figure 54: Annual average PM_{10} concentrations, 2031 class A charging CAZ, city centre, $\mu g.m^{-3}$

Figure 55: Annual average PM_{10} concentrations, 2031 class A charging CAZ, South Cambridge, $\mu g.m^{-3}$

Figure 56: Change in annual average PM_{10} concentrations, 2031 class A charging CAZ, $\mu g.m^{-3}$

F.4 2031 class C charging CAZ

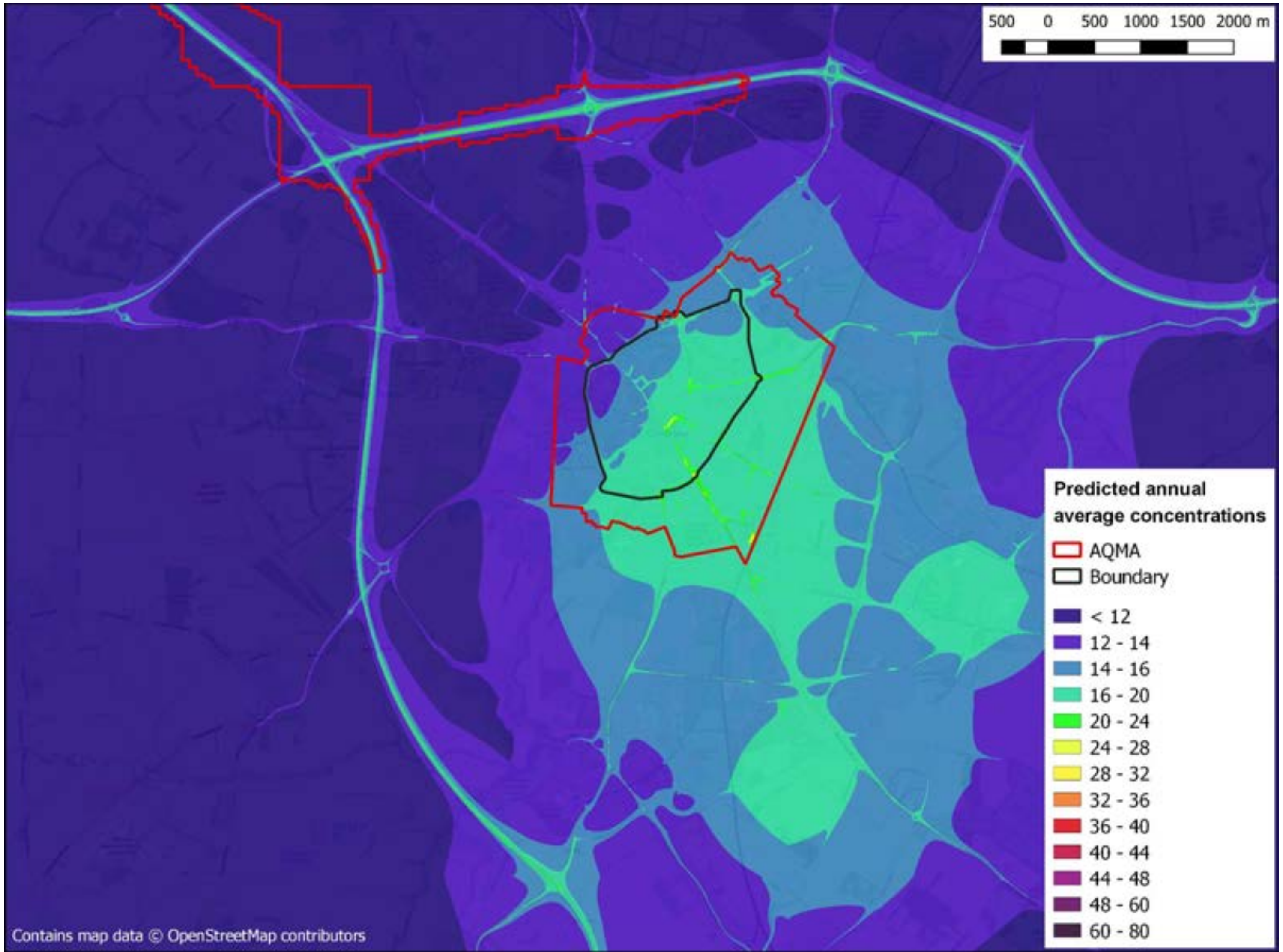


Figure 57: Annual average NO_2 concentrations, 2031 class C charging CAZ, Cambridge, $\mu g.m^{-3}$

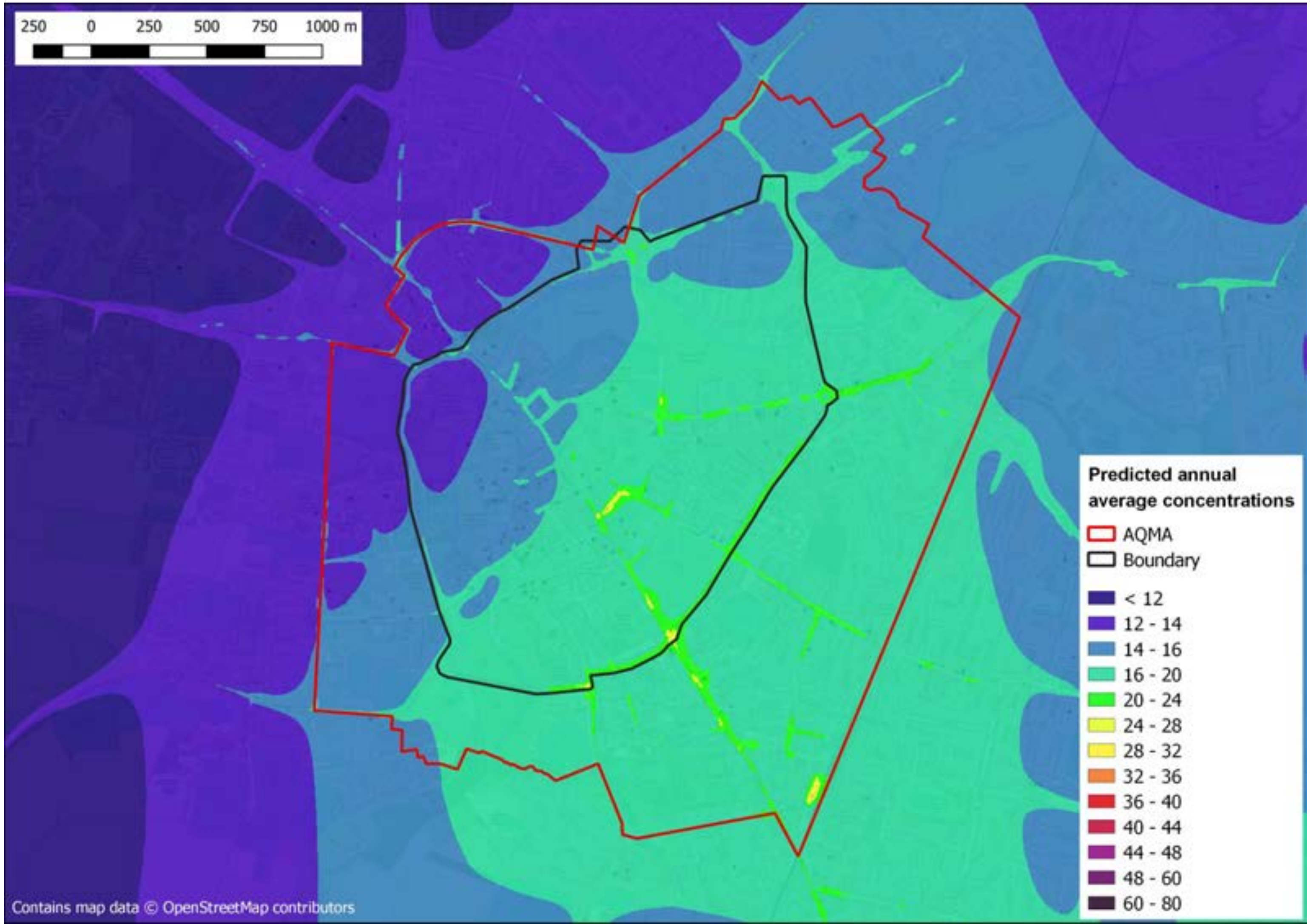


Figure 510: Annual average NO_2 concentrations, 2031 class C charging CAZ, city centre, µg.m^{-3}

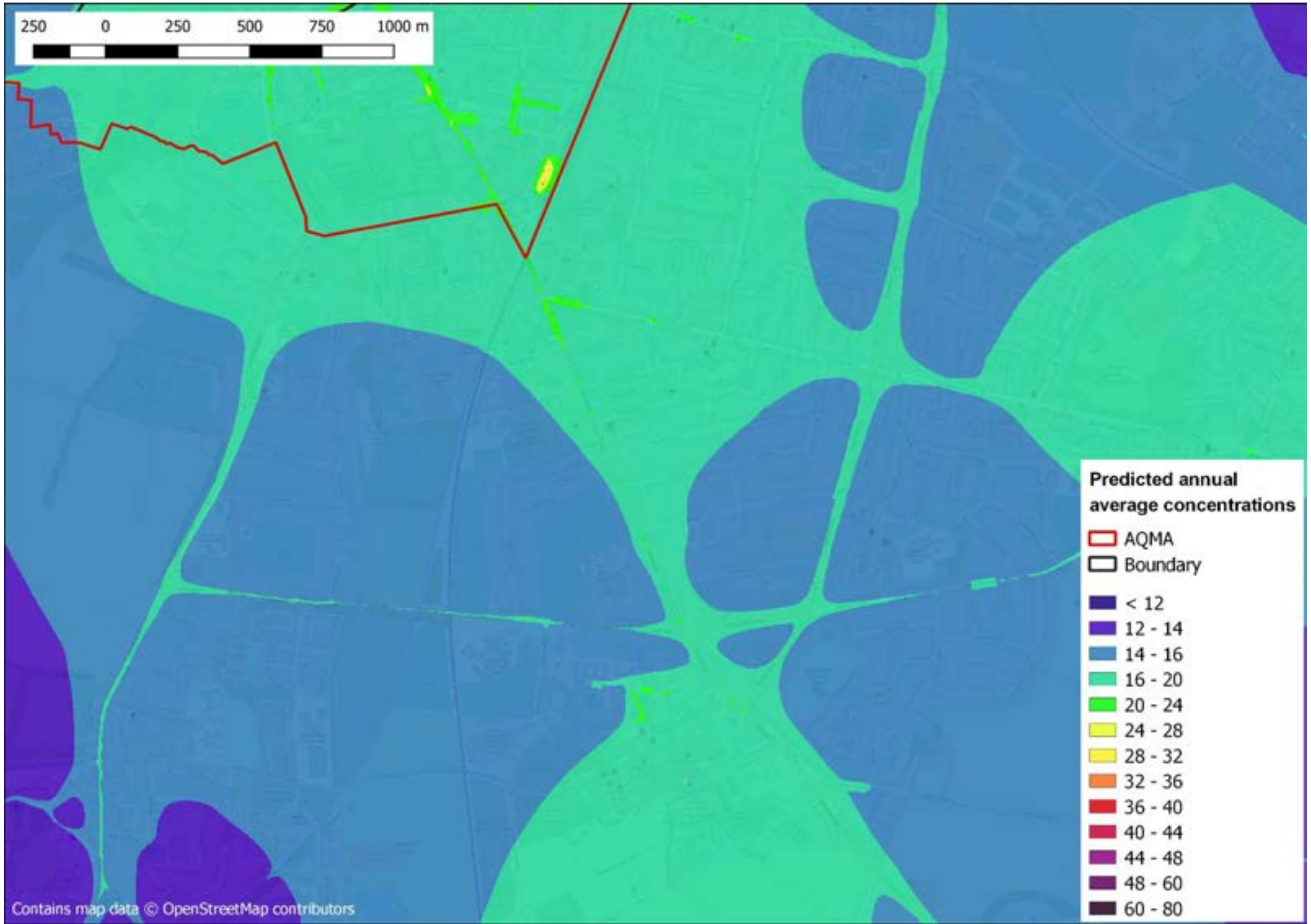


Figure 511: Annual average NO_2 concentrations, 2031 class C charging CAZ, South Cambridge, µg.m^{-3}

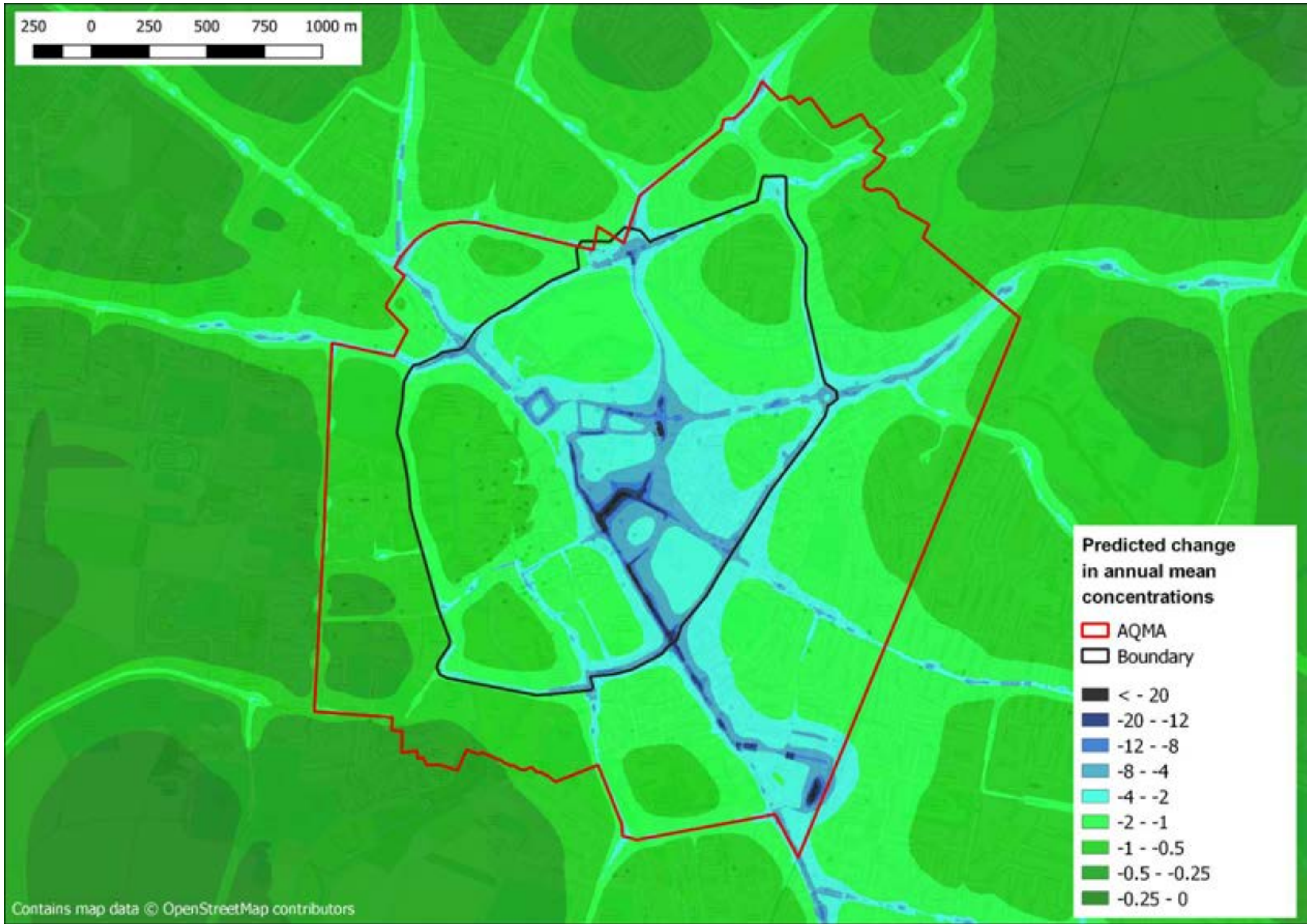


Figure 60: Change in annual average NO_2 concentrations, 2031 class C charging CAZ, µg.m^{-3}

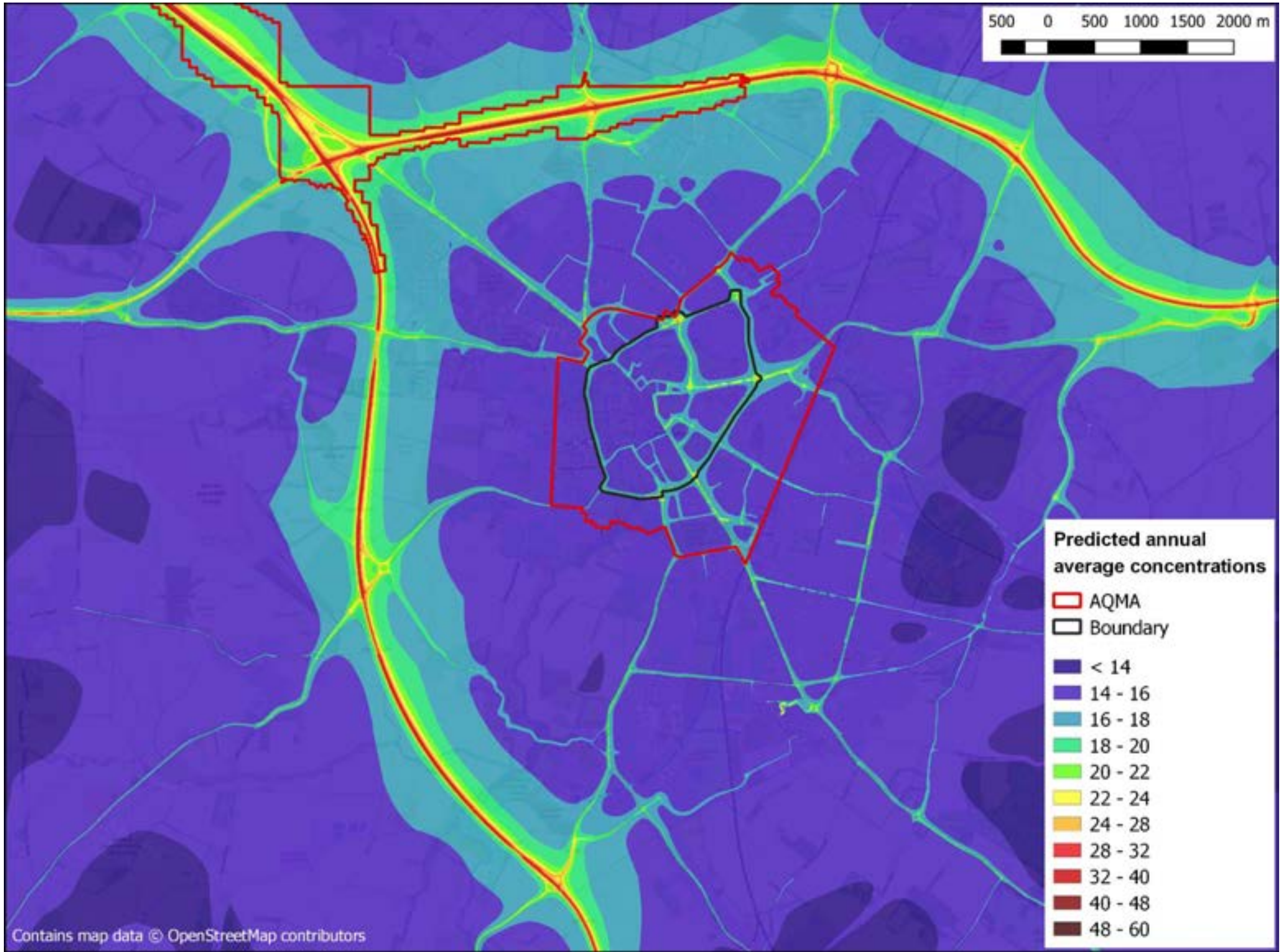


Figure 61: Annual average PM_{10} concentrations, 2031 class C charging CAZ, Cambridge, $\mu g.m^{-3}$

Figure 62: Annual average PM_{10} concentrations, 2031 class C charging CAZ, city centre, µg.m^{-3}

Figure 63: Annual average PM_{10} concentrations, 2031 class C charging CAZ, South Cambridge, µg.m^{-3}

Figure 64: Change in annual average PM_{10} concentrations, 2031 class C charging CAZ, µg.m^{-3}

G Cambridge monitoring sites

Table 25 identified monitoring sites in Cambridge as of 2017; these sites were used in the model verification process described in Section D.

Table 25: Monitoring sites in Cambridge, 2017

Site ID	Site name	Site type	Location (m)			Annual average NO_2 concentration, μg/m³				
			X	Y	Z	2013	2014	2015	2016	2017
CM1	Gonville Place automatic monitor	Roadside	545508	257828	2	35	37	35	36	31
CM2	Montague Road automatic monitor	Roadside	546057	259487	2	29	24	23	27	24
CM3	Newmarket Road automatic monitor	Roadside	546317	258900	2	28	26	25	24	26
CM4	Parker Street automatic monitor	Roadside	545366	258391	2.5	46	45	45	41	37
CM5	Regent Street automatic monitor	Roadside	545289	258118	5	38	39	34	32	29
DT1	Emmanuel Street	Roadside	545293	258418	2.5	38	39	35	38	34
DT2	Histon Road 2	Roadside	544284	261273	2.5	28	32	31	28	23
DT3	Magdalene Street	Roadside	544674	258992	2.5	29	30	28	27	29
DT4	Northampton Street	Roadside	544492	259021	2.5	38	39	38	37	33
DT5	Silver Street	Roadside	544783	258116	2.5	32	36	33	34	29
DT6	Long Road	Kerbside	544867	255709	2	41	42	45	45	40
DT7	Newmarket Road 1	Roadside	546195	258867	2	35	39	39	35	32
DT8	Milton Road	Roadside	545977	260352	2	23	23	23	20	19
DT9	Drummer Street	Roadside	545247	258472	2.5	33	35	32	31	25
DT10	Gilbert Road	Roadside	545314	259777	2	22	21	21	22	21
DT11	Latham Road	Background	544784	256746	2	12	13	12	13	10
DT12	Newmarket Road 2	Roadside	547998	259349	2	28	29	28	29	28
DT13	East Road	Roadside	545908	258439	2.5	29	30	28	26	24
DT14	Mill Road	Roadside	546080	257944	2	27	28	27	25	24
DT15	Hills Road 1	Roadside	545557	257695	2	34	37	35	36	31
DT16	Regent Street	Roadside	545289	258118	5.5	32	33	34	30	29
DT17	Coldhams Lane	Roadside	547216	258286	2	27	25	26	24	22
DT18	Pembroke Street	Roadside	544884	258098	2	39	43	39	36	34
DT19	Huntingdon Road 2	Roadside	543101	260344	2	27	23	27	23	21
DT20	Elizabeth Way	Roadside	546062	259260	2.5	32	35	32	31	26
DT21	Victoria Road	Roadside	544425	259560	2	33	33	30	28	25
DT22	Madingley Road	Kerbside	543784	259093	2	36	40	38	37	33
DT23	Huntingdon Road 1	Roadside	543761	259813	2	25	25	24	23	19
DT24a	Histon Road 1	Kerbside	544308	259664	2	29	-	-	-	-
DT24b	Histon Road 1 - new	Kerbside	544305	259580	2	30	32	35	27	29
DT25	Barton Road	Roadside	544100	257473	2	21	20	22	22	19
DT26	Fen Causeway	Roadside	544943	257567	2	25	24	23	22	19
DT27	Trumpington Road	Roadside	544575	255307	2	27	30	25	24	19
DT28	Babraham Road	Roadside	546948	255169	2	21	21	22	24	19
DT29	Cherry Hinton Road	Roadside	548331	256242	2.5	23	23	23	22	21
DT30	Arbury Road	Roadside	545693	260473	2	20	21	20	19	18
DT31	Newnham Road	Roadside	544529	257730	2	42	44	42	33	31
DT32	Hills Road 2	Roadside	546186	256530	2.5	28	30	28	29	24
DT33	Victoria Avenue	Roadside	545331	259438	2	41	40	38	37	35
DT34	Parker Street	Roadside	545370	258399	2.5	39	40	39	39	32
DT35	Abbey Road	Roadside	546163	258983	2	24	23	22	21	19
DT36	Cockburn Street	Urban	546596	257594	2	18	19	20	20	17
DT37	Oaktree Avenue	Background	545885	260088	2	18	18	17	18	16
DT38	Chesterton Road	Roadside	545566	259578	2	25	26	26	26	23
DT39	Maids Causeway	Kerbside	545710	258782	2	34	33	34	32	28
DT40	Emmanuel Road	Roadside	545405	258521	2	40	40	42	39	33
DT41	Downing Street	Roadside	545162	258240	2	36	38	34	36	28
DT42	Trumpington Street	Roadside	544999	257871	2	26	26	26	27	24
DT43	Lensfield Road	Roadside	545271	257675	2	38	34	34	36	32
DT44	Park Terrace	Roadside	545429	258271	2.5	29	30	30	31	23

Site ID	Site name	Site type	Location (m)			Annual average NO_2 concentration, µg/m³				
			X	Y	Z	2013	2014	2015	2016	2017
DT45	St Andrew's St	Urban centre	545147	258367	2.5	43	41	40	37	33
DT46	Parkside	Kerbside	545539	258295	2	25	25	23	25	23
DT47	Gonville Place	Roadside	545508	257828	2	35	37	36	35	31
DT48	Gonville Place	Roadside	545508	257828	2	35	37	36	35	31
DT49	Gonville Place	Roadside	545508	257828	2	35	37	36	35	31
DT50	Hills Road 3	Roadside	545893	257152	2	33	32	32	32	23
DT51	Shelford Road	Roadside	544960	254220	2	26	26	27	27	24
DT52	Station Road 1	Kerbside	546019	257300	2.5	32	34	31	34	30
DT53	Station Road 2	Kerbside	545897	257325	2.5	30	31	31	34	22
DT54	Tenison Road 1	Kerbside	546027	257663	2.5	25	28	23	23	21
DT55	Tenison Road 2	Kerbside	546005	257405	2.5	24	27	26	25	25
DT56	Coldhams Lane 2	Kerbside	546602	258796	2	28	30	27	27	23
DT57	Great Northern Road	Roadside	546080	257130	2.5	-	-	-	25	33
DT58	Station Place	Kerbside	546100	257390	2.5	-	-	-	36	32
DTS1	Brooklands Avenue	Roadside	545894	257025	2.5	-	-	-	27	22
DTS2	Shelford/Trumpington Rd Junction	Roadside	544614	254646	2.5	-	-	-	36	32
DTS3	Shelford Road 2	Kerbside	544664	254600	2.5	-	-	-	25	21
DTS4	Addenbrookes Access Road	Roadside	545237	254212	2.5	-	-	-	22	18
DTS5	Fendon Road	Roadside	546702	255380	2.5	-	-	-	27	24
DTS6	Hills Road 4	Roadside	546700	255374	2.5	-	-	-	27	22
DTS7	Trumpington road 2	Kerbside	545245	256860	2.5	-	-	-	32	25

Table 26 presents the locations, and measured concentrations, at sites measuring annual average PM_{10} concentrations in Cambridge.

Table 26: Measured annual average PM_{10} concentrations at monitoring sites in Cambridge, 2013 to 2017

Site ID	Site name	Site type	Location (m)			Annual average PM_{10} concentration, $\mu g.m^{-3}$				
			X	Y	Z	2013	2014	2015	2016	2017
CM1	Gonville Place automatic monitor	Roadside	545508	257828	2	23	19	21	20	18
CM2	Montague Road automatic monitor	Roadside	546057	259487	2	23	20	22	22	20
CM4	Parker Street automatic monitor	Roadside	545366	258391	2.5	26	22	23	22	21

G.1 Modelled annual average NO_2 concentrations for all modelled scenarios at monitoring locations

Table 27 presents modelled annual average NO_2 concentrations at monitoring locations.

Table 27: Modelled annual average NO_2 concentrations for all modelled scenarios at monitoring locations

Site ID	Site name	Modelled annual average NO_2 concentrations, µg.m^{-3}						
		2017 baseline	2021 'without CAZ'	2021 'with CAZ'	Reduction with CAZ, 2021	2031 'without CAZ'	2031 'with CAZ'	Reduction with CAZ, 2031
CM1	Gonville Place	27.4	25.9	25.2	0.7	25.8	21.6	4.2
CM2	Montague Road	23.3	21.9	21.5	0.4	19.0	17.2	1.8
CM3	Newmarket Road	26.4	24.6	24.3	0.3	22.7	19.9	2.9
CM4	Parker Street	31.5	31.8	30.5	1.2	35.2	24.3	11.0
CM5	Regent Street	27.2	28.4	27.5	0.8	29.7	22.3	7.4
DT1	Emmanuel Street	38.9	36.9	35.2	1.7	46.2	27.6	18.6
DT2	Histon Road 2	16.3	15.6	15.5	0.0	13.0	12.3	0.6
DT3	Magdalene Street	22.7	21.5	20.9	0.6	21.1	16.7	4.4
DT4	Northampton Street	25.0	23.4	22.7	0.7	21.5	16.6	4.9
DT5	Silver Street	30.0	27.1	26.4	0.7	23.4	20.0	3.4
DT6	Long Road	22.2	20.8	20.7	0.1	18.8	17.3	1.5
DT7	Newmarket Road 1	31.2	28.2	27.6	0.6	23.7	20.5	3.2
DT8	Milton Road	18.2	17.6	17.5	0.1	16.8	15.5	1.3
DT9	Drummer Street	26.5	25.7	25.0	0.8	30.2	21.5	8.7
DT10	Gilbert Road	19.6	18.8	18.7	0.1	18.1	16.1	2.0
DT11	Latham Road	15.8	16.0	16.0	0.0	16.4	16.1	0.3
DT12	Newmarket Road 2	22.6	21.3	21.2	0.2	19.3	17.1	2.2
DT13	East Road	35.5	31.8	30.7	1.1	26.6	21.9	4.6
DT14	Mill Road	26.1	24.6	24.4	0.2	23.2	20.7	2.5
DT15	Hills Road 1	29.7	28.5	27.9	0.6	29.5	23.6	5.9
DT16	Regent Street	27.2	28.4	27.5	0.8	29.7	22.3	7.4
DT17	Coldhams Lane	21.5	20.6	20.5	0.1	19.6	17.9	1.7
DT18	Pembroke Street	25.4	23.7	23.2	0.5	22.4	19.1	3.3
DT19	Huntingdon Road 2	17.3	16.3	16.2	0.0	14.8	13.6	1.2
DT20	Elizabeth Way	22.6	21.5	21.1	0.4	19.3	17.5	1.8
DT21	Victoria Road	19.3	18.0	17.9	0.1	16.1	14.4	1.7
DT22	Madingley Road	19.9	18.7	18.6	0.2	17.1	14.5	2.6
DT23	Huntingdon Road 1	18.7	17.5	17.4	0.1	15.1	13.8	1.3
DT24b	Histon Road 1	25.9	23.7	23.4	0.2	21.8	17.4	4.4
DT25	Barton Road	20.3	19.0	18.9	0.0	17.1	16.3	0.8
DT26	Fen Causeway	25.8	24.2	23.6	0.6	21.3	19.3	2.0
DT27	Trumpington Road	19.2	18.4	18.3	0.1	17.0	15.9	1.2
DT28	Babraham Road	21.9	20.8	20.8	0.1	19.5	18.0	1.5
DT29	Cherry Hinton Road	21.4	20.9	20.8	0.1	20.5	19.2	1.3
DT30	Arbury Road	17.9	16.8	16.7	0.0	14.9	14.0	0.8
DT31	Newnham Road	27.7	25.1	24.3	0.7	21.5	18.9	2.6
DT32	Hills Road 2	25.0	23.9	23.7	0.2	23.9	20.5	3.4
DT33	Victoria Avenue	43.1	39.3	37.4	1.9	36.8	25.8	11.1
DT34	Parker Street	31.5	31.8	30.5	1.2	35.2	24.3	11.0
DT35	Abbey Road	22.8	21.6	21.2	0.4	19.7	17.9	1.8

Table 28: Modelled annual average NO_2 concentrations for all modelled scenarios at monitoring locations (continued)

Site ID	Site name	Modelled annual average NO_2 concentrations, $\mu g.m^{-3}$						
		2017 baseline	2021 'without CAZ'	2021 'with CAZ'	Reduction with CAZ, 2021	2031 'without CAZ'	2031 'with CAZ'	Reduction with CAZ, 2031
DT36	Cockburn Street	17.4	17.6	17.5	0.1	18.1	17.2	0.9
DT37	Oaktree Avenue	17.3	17.0	16.9	0.1	16.4	15.3	1.1
DT38	Chesterton Road	19.6	19.5	19.2	0.3	18.5	16.6	1.9
DT39	Maids Causeway	29.1	27.1	26.4	0.8	25.7	21.2	4.5
DT40	Emmanuel Road	26.6	26.6	25.9	0.7	27.6	21.2	6.4
DT41	Downing Street	27.1	25.7	25.1	0.6	25.9	20.8	5.1
DT42	Trumpington Street	21.6	20.8	20.5	0.3	20.2	18.4	1.8
DT43	Lensfield Road	32.3	29.9	29.0	0.9	27.3	22.6	4.7
DT44	Park Terrace	23.5	21.8	21.4	0.4	23.4	19.9	3.5
DT45	St Andrew's St	30.0	28.6	27.5	1.0	32.2	22.4	9.7
DT46	Parkside	25.7	24.8	24.1	0.6	26.4	21.3	5.1
DT47	Gonville Place	27.4	25.9	25.2	0.7	25.8	21.6	4.2
DT48	Gonville Place	27.4	25.9	25.2	0.7	25.8	21.6	4.2
DT49	Gonville Place	27.4	25.9	25.2	0.7	25.8	21.6	4.2
DT50	Hills Road 3	26.2	24.6	24.4	0.2	24.3	20.9	3.3
DT51	Shelford Road	23.1	21.5	21.4	0.1	18.6	17.0	1.7
DT52	Station Road 1	27.5	26.7	26.1	0.6	30.0	22.8	7.2
DT53	Station Road 2	26.2	24.0	23.6	0.4	24.9	21.0	3.9
DT54	Tenison Road 1	23.4	22.5	22.4	0.1	21.3	19.7	1.5
DT55	Tenison Road 2	36.8	29.5	29.3	0.2	26.0	23.0	3.0
DT56	Coldhams Lane 2	23.2	22.0	21.9	0.1	20.0	18.5	1.5
DT57	Great Northern Road	21.4	28.2	27.3	0.9	35.2	23.6	11.6
DT58	Station Place	24.9	23.9	23.7	0.2	23.0	20.2	2.8
DTS1	Brooklands Avenue	28.6	26.6	26.4	0.2	25.0	22.0	3.0
DTS2	Shelford/Trumpington Rd Junction	19.0	19.8	19.7	0.1	18.2	16.3	1.9
DTS3	Shelford Road 2	16.7	16.7	16.7	0.0	15.7	14.8	0.9
DTS4	Addenbrookes Access Road	16.1	15.9	15.8	0.0	15.1	14.6	0.5
DTS5	Fendon Road	25.3	24.1	23.8	0.3	23.4	19.6	3.8
DTS6	Hills Road 4	23.8	22.8	22.6	0.3	22.3	19.0	3.2
DTS7	Trumpington road 2	23.5	22.5	22.4	0.1	21.6	19.5	2.2

H Detailed economic assessment results

H.1 Air quality and health impacts

The potential introduction of the CAZ is one way of achieving compliance with EU legislation[20] governing the maximum level of air pollution in cities in the UK. As such the main aim of the policy is to facilitate the move towards less polluting vehicles and improve the air quality, delivering health benefits for residents, workers and other visitors to the centre of Cambridge.

The associated air quality model tells us that the implementation of a Clean Air Zone, under our working assumptions, would deliver substantial reductions in key pollutants associated with having negative impacts on health. It would:

- reduce the total emissions of Nitrogen Oxide (NO_x) by almost 51 tonnes in 2021 and over 155 tonnes in 2031;
- reduce emissions of particulate matter ($PM_{2.5}$) by 31.4 tonnes in 2021 and 8.9 tonnes by 2031.

The results of implementing the CAZ measures defined above are shown in Table 29.

Table 29 - Pollution reductions under a CAZ, Tonnes/year

	Baseline	Class C Clean Air Zone
NOx		
2021	652.5	601.7
2031	405.9	250.5
$PM_{2.5}$		
2021	213.3	181.9
2031	161.8	152.9

The value of these emissions reductions (and consequent improvements in health) can be expressed in monetary terms through application of 'damage costs' following central Government guidance for the appraisal of such impacts [21]. These damage costs estimate the health impacts associated with changes in air pollutant emissions and place a monetary value on these effects. It does so through capturing the cost savings to public health services from reductions in negative health effects, and the tacit value that individuals place on avoiding such effects.

Two key health effects are captured in the damage costs (and are hence included in the monetary valuation):

1. Premature mortality due to chronic exposure – this is the key effect captured in the damage costs, manifesting itself in Life Years Lost;
2. Hospital and GP emissions for respiratory or cardio-vascular due to acute exposure. A recent study funding by the British Lung Foundation showed a stark contrast between spikes in air pollution and the levels of hospital emissions on the same day[22].

Applying the damage costs, the emissions benefits delivered by the proposed bundles of CAZ measures represent £31 million in 2021, and £13.6 million in 2031, reflecting the increased ambition

[20] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe
[21] Unpublished – provided by JAQU directly to cities.
[22] https://www.dundee.ac.uk/news/2018/air-pollution-levels-linked-to-spikes-in-hospital-and-gp-visits.php

of the modelled CAZ in 2031. These results clearly show that there is a strong health benefit achieved through the implementation of the proposed CAZ measures.

However, the damage costs do not capture a range of other health effects which have a strong association with exposure to air pollution. These effects are increasingly being recognised in the appraisal of air quality proposals but have not yet filtered through to formal guidance. As a result, on top of the effects captured by the damage costs, reductions in air pollution will also deliver benefits through reduction in:

- Chronic bronchitis associated with exposure to particulates;
- Asthma in adults and small children associated with exposure to NO_2;
- Coronary heart disease (CHD) associated with exposure to $PM_{2.5}$;
- Stroke associated with exposure to $PM_{2.5}$;
- Diabetes Type 2 associated with exposure to $PM_{2.5}$;
- Lung cancer associated with exposure to $PM_{2.5}$;
- Working days lost and minor restricted activity days associated with exposure to PM_{10}.

The reduction in the levels of NOx and $PM_{2.5}$ that would occur as the result of a Clean Air Zone would not only help improve the health of local residents but will also have a positive monetary value on the Cambridge economy.

H.2 Implementation costs

Another key area that warrants consideration is the costs of implementing the CAZ. The key costs captured in the economic analysis can be divided into two key types:

- Costs associated with the implementation and operation of the supporting CAZ monitoring and enforcement infrastructure;
- Costs associated with the charging network to support uptake of electric vehicles (EVs).

Note: this analysis captures the economic cost of these actions. It does not account for who will face these costs, only that these costs will be associated with the implementation of the zone. In addition, it does not account for whether funding has already been achieved for some aspects – all costs are counted here for fair comparison against the benefits of the scheme. The total estimated costs are set out in Table 30.

Table 30 - Total costs

	2021	2031
Upfront costs	1,690,000	-
Ongoing Costs	162,000	162,000
EV Charging Infrastructure	-	32,400,000
Total	**1,850,000**	**32,500,000**

H.2.1 CAZ monitoring and enforcement infrastructure

The costs borne in 2021 primarily stem from the initial set up of the Clean Air Zone and the technology and infrastructure that is required to implement it, including cameras, signs and road markings. These initial costs are calculated as a function of the number of roads that would allow vehicles to enter or leave the Clean Air Zone.

There are 27 roads that join the ring road that acts as the boundary to the CAZ. It is assumed that each one will require: cameras (2 per crossing) and gantries (for 1/3 of crossings), signs (two per road, both at the boundary and further out) and road markings (four per road). To estimate overall costs, unit costs for each of these items were drawn from other CAZ feasibility studies. However, costs may vary for Cambridge depending on the supply contracts the City Council has in place.

In addition to these upfront costs, ongoing costs are also considered. These primarily revolve around the operational costs of the cameras, including:

- repairs and maintenance;
- data collection & Vehicle registration assessment & processing;
- Compliance check & assessment of fee to be charge;
- processing of payments;
- issuing of notices for non-compliant vehicles who do not pay the charge; and
- processing of Disputes/Appeals/Correspondence.

The total cost estimated for 2021 is £1.7 million of upfront costs and £162,000 operational costs recurring on an annual basis. The ongoing costs are associated with both the 2021 and 2031 ambition.

H.2.2 Electric vehicle charging network

The main cost that occurs for the 2031 'with CAZ' modelled scenario is a result of the need to deploy EV charging points to support the ambition for increased uptake of electric vehicles under the scenario (buses, coaches and LGVs).

The economic and air quality assessment assumes that all vehicles entering the Clean Air Zone will be 'compliant' (i.e. EV) by 2031, this will produce a large uptake in the number of electric vehicles entering the city and hence a large increase in the number of charging points needed to facilitate this increase.

These costs are calculated by applying an assumed required charging density for each vehicle type, and a unit cost per charger. The density of standard, fast and rapid chargers per vehicle, and costs per charger are consistent with those applied in the Oxford ZEZ report. The assumptions are set out below in Table 31.

Table 31 – EV charging assumptions

	Chargers per vehicle			
	Standard - home	Standard	Fast	Rapid
Suitability	*Cars, Vans*	*Cars, Vans*	*LGVs, HGVs, coaches, buses*	*LGVs, HGVs, coaches, buses*
Cost	*666*	*1800*	*10000*	*40000*
Car petrol	0.8	0.2		
Car diesel	0.8	0.2		
Taxi HC				
Taxi PH				
LGV petrol		0.65	0.2	
LGV diesel		0.65	0.2	
HGV rigid			0.85	0.004

Source: Oxford ZEZ study

In the modelling, around 17,000 EVs enter the fleet in response to the CAZ in 2031, requiring anywhere between 3,000 to 11,500 chargers to support their operation (depending on the assumed mix of standard, fast and rapid chargers deployed). While the implementation of EV infrastructure is counted in 2031 it could occur at any point in the decade preceding this date.

Table 32 – Monetised costs and benefits on implementing a Clean Air Zone (£m, 2018 prices)

	Impacts of CAZ option						
Ambition year	Air Quality	Upgrade costs	Implementation costs	Opex costs (Upgrade only)	Fuel consumption (Upgrade only)	CO_2 emissions (Upgrade only)	NPV
2021	30.60	-20.97	-3.35	1.35	3.29	2.40	13.33
2031	13.61	-99.76	-40.94	-9.17	75.75	108.03	47.53
Total	44.21	-120.73	-44.29	-7.82	79.05	110.43	60.86

Notes: +ve values denote benefit / -ve values denote costs; all impacts are in 2018 prices; all impacts are discounted to 20

H.3 Detailed methodology

H.3.1 Introduction and over-arching approach

This section sets out a more detailed discussion of the economics assessment for a Clean Air Zone (CAZ) set up within Cambridge as a method of improving the air quality within the city. The assessment utilises a Cost-Benefit Analysis (CBA) approach, the aim of which is to try and determine the net balance of impacts: i.e. whether the positives (or benefits) of an option or policy outweigh the negatives (or costs), or vice versa. To facilitate this comparison, all impacts are expressed in monetary terms.

There will be a wide range of impacts associated with the implementation of a CAZ. The following key impacts have been quantified in the analysis:

- Costs of replacing vehicles: this is the upfront and ongoing (i.e. maintenance and fuel) costs associated with purchasing and running the CAZ compliant vehicle
- Infrastructure cost: including the cost of installing sufficient vehicle recharging infrastructure to support the uptake of battery electric vehicles (BEVs)
- Implementation costs: this represents the cost of the technology and systems to monitor and enforce the zones to achieve compliance
- Air quality benefits: this captures the benefit of reductions in air pollutant emissions associated with the cleaner vehicles introduced in response to the CAZ
- Greenhouse gas (GHG) benefits: cleaner vehicles could also reduce the emissions of GHGs, which will provide an additional benefit to help the UK meet its climate change objectives.

JAQU (the Joint Air Quality Unit) have provided detailed guidance regarding the economic appraisal of CAZ options. This provides a steer for many of the key data inputs and assumptions that have framed the analysis undertaken. The key guidance documents include:

- Options Appraisal – Guidance (2017)[23] (and preceding versions of this guidance)
- National data inputs for Local Economic Models (2017)[24].

We base our analysis on this guidance, but it has been necessary to construct additional assumptions and approaches specific for Cambridge's purposes.

The analysis is underpinned by the following general assumptions:

- Each impact is assessed relative to a 'do nothing' counterfactual
- All impacts are presented in real terms with a Price Year of 2018
- A lifetime approach has been adopted and all impacts that are assessed at the two points in time (2021 and 2031) are appraised over a subsequent 10 year period.
- All impacts are discounted to 2021 applying Green Book discount factor of 3.5%.

[23] Unpublished – provided directly by JAQU to cities
[24] Unpublished – provided directly by JAQU to cities

H.4 Definition of modelling scenario

The analysis looks at the impacts of implementing a Class C charging Clean Air Zone. Specifically:

- The scheme places minimum emissions standards on certain vehicles entering the zone, specifically: buses, taxis, HGVs, coaches and LGVs. This is intended to deter non-compliant vehicles from entering the zone. Where non-compliant vehicles enter they will face a fine.
- Analysis takes place at two points in time, the year 2021 (assumed to be the year when the CAZ is implemented) and 2031 (when the requirements of the zone are tightened).

The ambition of this scenario has been developed through discussion with the Greater Cambridge Partnership (GCP).

The boundary of the CAZ is assumed to be the Inner Ring Road (IRR), including the ring road itself. This area includes a majority of the colleges of the University of Cambridge as well as the major shopping areas and the bus station. The zone does not cover several other key traffic destinations, namely Anglia Ruskin University, Cambridge Train Station and the Cambridge Biomedical Campus which includes Addenbrooke's Hospital.

In terms of behavioural response to the Clean Air Zone, the same assumptions are applied as those in the air quality modelling. To facilitate the modelling, a number of additional assumptions have been made:

- Where a proportion of vehicles upgrading has not been defined, we have defaulted to the JAQU behavioural response assumptions (i.e. LGVs and HGVs in 2021)
    - Upgrade response is applied only to those vehicles that are 'non-compliant' with the standards of the Clean Air Zone
    - It has been assumed that avoidance or changing modes of transport would not occur under the CAZ. Hence the economic and air quality impacts of individuals avoiding or changing mode has not been modelled. The proportions assumed to cancel or avoid the zone are redistributed to upgrade response
- Where the 'compliant' vehicle standard has not been defined, again we have defaulted to the JAQU 'compliant' standards
- Motorbikes and cars are not charged to enter the CAZ and hence have not been modelled in this economic analysis, however their emissions have been included within the air quality model.

The behavioural response assumptions applied are set out in Table 33.

Table 33 – Behavioural response assumptions

Response	LGV	HGV	Bus	Coach
2021				
Upgrade	37%	60%	N/A	N/A
Cancel / Change Mode / avoid	0%	0%	N/A	N/A
Pay	63%	40%	N/A	N/A
2031				
Upgrade	100%	N/A	100%	100%
Cancel / Change Mode / avoid	0%	N/A	0%	0%
Pay	0%	N/A	0%	0%

N/A – denotes where no ambition is assumed in this year.

A separate Cambridge City Council policy already requires registered taxis and Private Hire Vehicles licensed by the City Council to be compliant and hence any behavioural changes that occur will not be due to the CAZ (hence any associated impacts are not captured in this assessment).

JAQU's behavioural response assumptions are intended to be applied to a policy akin to the CAZ framework set out in the National Plans: i.e. where non-compliant vehicles pay a charge to enter a zone. In this case, the aim is to completely deter non-compliant vehicles from entering the zone (and if they do they will be fined), rather than them having the option to pay a charge. Hence there is a question as to whether JAQU's behaviour response assumptions are still applicable in this case. In the absence of better information regarding the response of vehicles to a charging zone (and to maintain consistency with the air quality modelling) , we retain JAQU's assumption for the quantitative analysis and discuss this point further as part of the caveats around the analysis.

H.5 Scope of impacts assessed

Any scheme to tackle air quality will impact different parts of the environment, economy and society. The economic analysis seeks to quantify and value as many of these impacts as possible given the time, resource and modelling methodologies available.

JAQU's guidance sets the basis for the scope of impacts to be assessed for a CAZ appraisal. In some cases, we have grouped impacts by the methodology taken to appraise them and hence may in places refer to different impacts using different terminology to that set out in the JAQU guidance.

The scope of impacts captured by the CBA, and their correspondence to the impact categories described in the JAQU guidance, are presented in Table 34.

A quantitative assessment of the impacts associated with the options has been undertaken where possible. However, in some cases it has not been possible to complete a full quantitative assessment given limitations in the data available. Where impacts have not been assessed quantitatively, a qualitative assessment has been performed and the results presented as caveats to the main results.

All responses to the options are modelled twice, once in 2021 and again in 2031 In practice, these upgrades (and their associated impacts) could occur before or after the implementation of the options.

Table 34 - Impact description and mapping

Impact name	Description
Upgrade costs	The impact on those vehicles owners that respond to the CAZ measures by replacing their vehicle. These are the upfront costs for vehicle owners associated with switching from a non-compliant to a compliant vehicle. This encompasses the vehicle scrappage cost and the consumer welfare impact as described in the JAQU guidance
Operating cost impacts	Those savings or additional costs that can result from a CAZ's implementation. This includes both changes in fuel consumption and the associated cost, and change in operating and maintenance costs
Implementation costs	Cost of upfront and ongoing activity and assets required to implement, monitor and enforce the CAZ by the administering authority.
Air quality emissions	The impact on affected populations by a change in NOx and PM emissions as a result of the CAZ's implementation
Greenhouse Gas impacts	The impact on affected populations by a change in greenhouse gas emissions that result from a CAZ's implementation

H.6 Developing the fleet baseline

A key input into the impact assessment (and in particular for the calculation of upgrade costs) is the number of unique vehicles that will be affected by the CAZ.

Although some sources of data are available that hint at what this figure may be, no one source of data offers a complete and robust dataset which can be used. Hence an assumption on the number of vehicles affected is built up, drawing on the data available and sense checked against other sources. The development of this assumption, and the calculation steps are set out in this section.

The baseline fleet was developed by using data provided by GCP/CCC where available. This was the case for vehicles whose operations in the city centre are regulated by CCC which included buses, taxis and private hire vehicles. Although South Cambridge taxis (and taxis licenced in other areas) will also enter Cambridge City centre, we have not included these vehicles in the fleet which would upgrade in response to the CAZ given their much broader patterns of travel.

This was complemented by data from ANPR (Automatic number plate recognition) cameras for non-regulated vehicles. Analysis of data for one day in June 2017[25] was used and tracked the number of unique vehicles entering and leaving the city. The subsequent data was used to assess the number of coaches, LGVs and HGVs operating within the proposed charging zone.

Annual, not daily data was of interest to the modelling team. Therefore, two sets of uplift factors were applied to the ANPR data to consider the additional vehicles entering the areas of interest throughout the year.

1. Day-to-week: one uplift factor was based on analysis of weekly ANPR data from another CAZ feasibility study[26], and the typical number of unique vehicles picked up per day relative to over the course of a week.
2. Week-to-year: These uplift factors were again based on expert judgement, considering a range of factors, including:
    a. analysis of the ANPR data which described the number of times a vehicle entered the areas of interest. This allowed the modelling team to estimate the vehicle types that are likely to enter the CAZ on a regular basis and those that enter less frequently.
    b. the type and typical nature of travel of different vehicle types (e.g. most of buses run frequent routes over the course of a week, and hence are more likely captured in the weeks' worth of ANPR data, whereas HGVs operate more national travel patterns, travelling less frequently to the same city areas).
    c. The amenities located in each proposed CAZ area.

These day-to-year uplift factors were not applied to the number of taxis, private hire vehicles and buses. The numbers for the vehicle types are more certain given data was sourced directly from CCC regarding total number of vehicles in local fleets.

Two further calculation steps were made to all vehicle data (both ANPR and licence data) to define the fleet in the modelling years:

- The CAZ is anticipated to be introduced in 2021 and steps up in ambition in 2031. Therefore factors are required to reflect the growth in vehicles between 2017 to 2021, and onwards to 2031. In this case we utilised the vehicle kilometres (vkm) assumed in the underlying air quality modelling.
- The fleet split by Euro standard in 2021 and 2031 was also adopted from the air quality modelling.

[25] The ANPR camera ran for one week however only 1 day was used due to limitations in linking the data between days
[26] Data was used from Southampton, which had ANPR data available for a full week such that a number of unique vehicles over a week could be identified.

Presented below are the raw numbers of unique vehicles derived from the ANPR and fleet data for the IRR in 2017, and the numbers of vehicles that result from application of the uplift factors, fleet growth, and fleet composition adjustments to 2021 and 2031 as described above.

Table 35 – Assumed numbers of vehicles entering the CAZ

	Input data		Model assumptions	
	No. of vehicles registered (2017)	No. of total vehicles (ANPR data, 2017/day)	No. of vehicles (Modelled data, 2021/yr)	No. of vehicles (Modelled data, 2031/yr)
Bus	263		302	526*
HGV		1,284	9,483	7,120
LGV		6,273	26,385	30,130
Coaches		286	1,046	1,432
Taxi	224		237	238
PH vehicles	226		236	222

* The number of Local Buses in 2031 accounts for anticipated 100% increase in traffic flow modelled in baseline

Given data for buses and taxis is available from registration data, and hence represents a direct estimate of total number of vehicles operating in and around Cambridge, only limited uplifts need to be applied (i.e. uplifts from daily ANPR to yearly equivalent do not need to be applied).

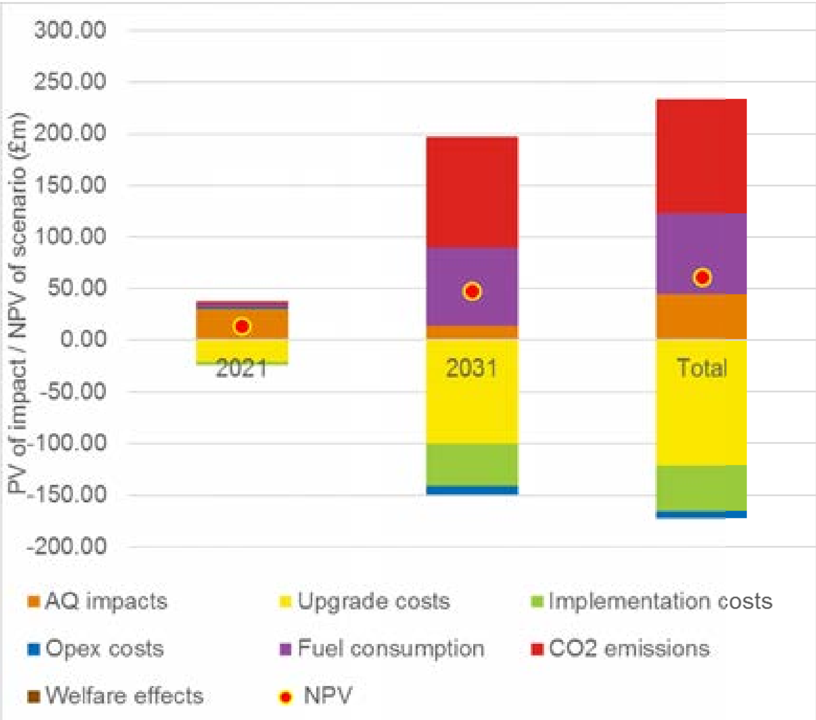
Private cars are not included in the table given there is no ambition regarding these vehicles as part of the assessed policy option.

H.7 Results

H.7.1 Summary of results

The Present Value (PV) of impacts and Net Present Value (NPV) results of our economic analysis are presented in Figure 12 and Table 36.

Figure 12 – PV of impacts and NPV of CAZ options



Note: Bars represent present value (PV) of impacts; dots represent aggregate net present value (NPV) of all impacts associated with CAZ option; all impacts are assessed relative to ‘do nothing’ baseline; all impacts presented in 2018 prices.

Table 36 - Monetised impacts associated with options (cumulative discounted impact (PV) over appraisal period 2021-41 (£m 2018 prices))

	Impacts of CAZ option						
Ambition year	AQ	Upgrade costs	Implementation costs	Opex costs (Upgrade only)	Fuel consumption (Upgrade only)	CO_2 emissions (Upgrade only)	NPV
2021	30.60	-20.97	-3.35	1.35	3.29	2.40	13.33
2031	13.61	-99.76	-40.94	-9.17	75.75	108.03	47.53
Total	44.21	-120.73	-44.29	-7.82	79.05	110.43	60.86

Notes: +ve values denote benefit / -ve values denote costs; all impacts are in 2018 prices; all impacts are discounted to 2021

H.7.2 Commentary on results

Air quality impacts:

- The air quality impact of the Clean Air Zone is significant particularly for reducing the amount of Nitrogen Oxide emitted in the city centre.
- The CAZ is anticipated to save 9.9 tonnes of NOx in 2021, and 155.4 tonnes in 2031, alongside this the CAZ also saves 0.6 tonnes of PM in 2021 and 4.9 tonnes on Particulate Matter in 2031.
- These impacts, in particular for those in 2021, tail off over time as the baseline catches up due to natural turnover of the fleet.
    - Post 2031, the baseline catches up more slowly with the ambition to push vehicles to EV given it is uncertain whether vehicle owners would have upgraded to EV anyway, and if so at what point.

Vehicle Upgrade Costs

- This impact captures the cost to vehicle owners that choose to swap their non-compliant vehicle for a compliant vehicle in response to the CAZ. In turn this captures several effects:
    - Scrappage costs of non-compliant vehicles, the cost of buying a new compliant vehicle, as well as the cost of swapping a non-compliant used to a compliant used vehicle.
- Upgrade costs are calculated based on a number of assumptions, including the number of unique vehicles assumed to enter the CAZ and the proportion who chose to upgrade their vehicles in response rather than avoid the area or otherwise.
- Upgrade costs are a key impact in the analysis - they are the largest individual cost in 2021 and second largest effect in 2031.
- Upgrade costs in 2021 are driven mainly by costs of upgrading HGVs to meet the compliance standard (Euro VI): although fewer HGVs are upgraded than LGVs, the unit cost of upgrading HGVs is much higher.
- Upgrade costs are also associated with the increase in ambition in 2031 – this step change in ambition renders a new sample of vehicles as 'non-compliant', to which many vehicle owners are assumed to upgrade their vehicles.
- The costs are higher in 2031, relative to 2021
    - Although there is no further ambition regarding HGVs in 2031
    - In 2031, buses are also required to upgrade to ULEV
    - The largest contributor to costs in 2031 is the ambition that 50% of LGVs operating in the centre should be ULEV.
        - As with other vehicle categories, ULEV alternatives for LGVs are more expensive than conventional fuelled vehicles, and there are a large number of LGVs which access the city centre.

Implementation costs

- Implementation costs represent the costs to CCC or other implementing bodies of putting the CAZ in place
    - Two types of implementation cost have been included: a cost for monitoring and enforcing the charging zone (i.e. the cameras, back-office function, etc), and for the supporting EV charging infrastructure
    - The split of costs between these two cases of implementation can be seen in Table 30
- Implementation costs have been estimated by Ricardo as a placeholder based on CAZ feasibility studies elsewhere – these costs should be refined further as the mitigation option develops and CCC develop their own costs to implement.

- Note: this analysis captures the economic cost of these actions. It does not account for who will face these costs, only that these costs will be associated with the implementation of the zone. Also it does not account for if funding has already been achieved for some aspects – all costs are counted here for fair comparison against the benefits of the scheme.

- There are initial implementation costs for the CAZ in 2021 due to the need to install physical infrastructure to track the movement of vehicles in and out of the city centre.
- In 2031, the CAZ enforcement structure is already in place, so the costs of continued enforcement of the zone are small.
    - However, significant investment will be required to develop the charging infrastructure to support the greater uptake of ULEVs incentivised by the CAZ, in particular to support the 15,000 or so BEV LGVs which will operate in and around the city (as estimated in the economic analysis).
- The costs of ULEZ's in 2031 reflects the scale effect of the growth in EV's and associated fall in cost in the future, A similar fall in cost of charging infrastructure will likely accompany this however significantly less data is known about this and hence is not reflected in the economic analysis.

Operating, fuel consumption and CO_2 emission savings benefits:

- Newer vehicles are likely to breakdown less and also be more fuel efficient, delivering savings on both repair and fuel costs.
    - Upgrading vehicles through the CAZ will deliver benefits in the way of operating and fuel cost, and GHG emission savings.
- Both fuel cost and GHG emission savings provide a greater benefit in 2031 compared to 2021. This is because: 1. More vehicles are upgraded in 2031 relative to 2021, and 2. More vehicles upgrade to ULEVs with the tightening of standards under the zone
    - Although ULEVs have a higher upfront cost (and also have greater operating costs), they typically deliver much greater fuel and GHG emissions savings which are a key driver of the positive value associated with the CBA in 2031.
- These three costs, in addition to the changes in air quality are the main benefits that the introduction of a CAZ can bring.

Caveats

Although this analysis gives an illustration of the comparative size of some of the key effects associated with the CAZ, there are a number of caveats to keep in mind when considering the results.

First, many of the calculations in the model are built on the number of vehicles impacted by the CAZ. Given only one day of ANPR data could be used for the Cambridge analysis (out of a 7-day survey), this is uplifted to yearly data again based on data drawn from other CAZ feasibility studies.

In addition, it is noted that several effects are not captured by the quantitative analysis:

- The CAZ is assumed to lead to vehicles upgrading to achieve compliance with the emissions standard. The economic analysis focuses on the effects of these vehicles upgrading in response. Where vehicles enter the zone which do not comply, they will face a large fine in order to deter them from entering. Hence unlike under the CAZ framework set out in JAQU's National Plan, vehicles are unable to (or less willing to) 'pay the charge' in the same way
    - This first raises the question as to whether JAQU's behavioural assumptions for assessing responses to CAZ still apply to the policy option modelled here. In practice, if vehicles are unable to pay in the same way, those predicted to pay in the JAQU assumptions will likely take another course of action, leading to a higher behavioural response for these alternatives. What response the vehicle will take will depend on the individual situation and options available to the driver, but it may be the case that more vehicles choose to upgrade in response all other things being equal, than assumed here
    - JAQU's assumptions also suggest a certain proportion of vehicles could 'cancel trips', 'shift mode' or 'avoid the zone' in response to a charging zone. This analysis has only assumed that vehicles upgrade in response to the CAZ – no change in travel patterns (or 'demand for travel) is assumed in response to the zone. In practice, this is a stretching assumption as vehicle owners will adopt a behavioural response which minimises their costs of movements – for some this may be avoiding the zone or cancelling journeys. Where this is the case, there will be welfare costs (i.e. the cost to the individual of adopting a travel pattern which is not its first preference) associated

    with adopting these alternatives. This cost is not captured in the CBA. However, if more adopt these alternative responses, less vehicles will upgrade, meaning the upgrade costs (and operating benefits) are over-stated in the current modelling
  - Alongside welfare impacts for impacted vehicles, changes in travel patterns in response to the CAZ will also have a wider impact on congestion. Where vehicles avoid the zone or cancel journeys, this will further reduce congestion in the zone, reducing travel times. This is a secondary benefit not captured in the quantitative assessment.
- The air quality modelling only captures impacts within the air quality domain. Where upgraded vehicles travel outside this domain, this may deliver additional air quality benefits not captured in the modelling.
- The scenario depicts strong uptake of ULEVs. However, the CBA only presents the costs and benefits of uptake. It overlooks a range barriers and hurdles observed in practice which often limit uptake of ULEVs, in particular BEVs. These should be considered going forward to allow these levels of ambition to be achieved.

I Glossary

AADT	Annual Average Daily Traffic
ANPR	Automatic Number Plate Recognition
AQAP	Air Quality Action Plan
AQMA	Air Quality Management Area
BAU	Business as usual
BEIS	Department for Business, Energy & Industrial Strategy
BEV	Battery electric vehicles
CAZ	Clean Air Zone
CBA	Cost-benefit analysis
CO_2	Carbon dioxide
E-REV	Extended-range electric vehicle
EST	Energy savings trust
EV	Electric vehicle
FCEV	Hydrogen fuel cell electric vehicles
DfT	Department for transport
GHG	Greenhouse Gas
HGV	Heavy Goods Vehicle
IGCB	Interdepartmental Group on Costs and Benefits’
JAQU	Joint Air Quality Unit
LEZ	Low emission zone
LGVs	Light Goods Vehicles
MCA	Multi criteria assessment
NAEI	National Atmospheric Emission Inventory
NO_2	Nitrogen dioxide
NOx	Nitrogen oxide
NPV	Net present value
OTS	Oxford Transport Strategy (OTS)
PHEV	Plug-in hybrid electric vehicles
PM	Particulate matter
TfL	Transport for London
TRO	Traffic regulation order
Vkm	Vehicle kilometres
ZEV	Zero emission vehicle
ZEZ	Zero Emission Zone

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