SUPPLEMENTARY MATERIALS 1: APPENDICES

MANUSCRIPT TITLE

Development and evaluation of rapid, national-scale outdoor air pollution modelling and exposure assessment: Hybrid Air Dispersion Exposure System (HADES).

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APPENDIX 0: Geographic regions of England and Wales

The following publication often summarises its findings at the regional level, which is the highest tier of sub-national division in Great Britain (GB). There are 11 regions in GB, which include the nations of Wales and Scotland, with England then divided into 9 areas: East of England, East Midlands, London, North East, North West, South East, South West, West Midlands, Yorkshire & The Humber.

Air pollution modelling was conducted across Wales and all regions of England (coloured red):

Map Data © OpenStreetMap Contributors (OSM 2024)

APPENDIX 1: The creation of HADES model parameters, their upper and lower limits (reflective of the training data), and required transformations

Group	Name	Description	Unit	Data Limits		Transformation	Model
				Lower	Upper		
Topography	Built-up	The percentage of land covered by buildings within 100m of the receptor location. Calculated by applying a square scanning window to a 10x10m land-use raster surface (focal statistic).	Percent	0.01	99.99	Logit (x)	C1, C2
	Building Height (BH)	The mean height of all buildings within 100m of the receptor location. Calculated by applying a square scanning window to a 10x10m land-use raster surface (focal statistic). Set to 0 if there are no nearby buildings.	Meters	0	100	Neglog (x)	M1
	Building Height Variability (BHV)	The standard deviation of building heights within 100m of the receptor location. Calculated by applying a square scanning window to a 10x10m land-use raster surface (focal statistic). Set to 0 if there are no nearby buildings.	Meters	0	100	Neglog (x)	M1
	Elevation-A	The (local) elevation contrast, between the receptor location and all physical features within 1km. The local mean elevation is calculated by applying a square scanning window to a 10x10m DEM raster surface (focal statistic).	Meters	- 50	+ 50	Neglog (x)	C1, C2
	Elevation-B	The elevation contrast, between the receptor location and the national mean elevation of land features. The mean elevation of the British Isles (UK and IE) is 150m above sea level.	Meters	- 300	+ 300	Neglog (x)	C2
	Greenspace	The percentage of land covered by greenspace within 50m of the receptor location. Calculated by applying a square scanning window to a 10x10m land-use raster surface (focal statistic). Greenspace is defined as agricultural land and natural environments formed of grassland, trees, or wetlands.	Percent	0.01	99.99	Logit (x)	M2, M3
	Roadway	Roadway locations. A cell on the 10x10m land-use raster surface that is occupied by a road. Roadway locations contain all the traffic (kerbside) site-type pollution monitoring stations in the UK AURN.	Binary	0	1	None	C1

Group	Name	Description	Unit	Data Limits		Transformation	Model
				Lower	Upper		
Topography	Urban Index (UI)	A hybrid classification scheme based on established European Commission and OECD urban-rural population density thresholds, applied to a 100x100m raster surface: • Urban Centre cells (UI = 1) have ≥ 1,500 inhabitants per km² and a total population of ≥ 5,000 per km² from a first-order rook's case neighbourhood search. • Urban cells (UI = 0.8) have ≥ 300 inhabitants per km² and a total population of ≥ 5,000 per km² from a first-order queen's case neighbourhood search. • Suburban cells (UI = 0.6) have ≥ 300 inhabitants per km² and are not deemed as Urban. • Intermediate cells (UI = 0.4) have ≥ 150 and < 300 inhabitants per km². • Thinly populated cells (UI = 0.2) have < 150 inhabitants per km². • Unpopulated cells (UI = 0) have 0 inhabitants per km² from a first-order queen's case neighbourhood search. The scheme is resampled to a continuous value 10x10m raster surface, using Inverse distance weighted (IDW) interpolation.	Fraction	0	1	None	C1, C2, M3
Dispersion	Road-NOx	Nitrogen oxides (NOx) emitted by road-transport within 500m of the receptor location. COPERT-5 emission functions are applied to hourly-annual traffic counts and speed profiles on each road link. Dispersion kernels (focal statistics) then describe the spatiotemporal meteorological relationship between receptor and source locations.	$\mu g/m^3$	0	40	Log (x + 0.01)	C1
	AP-NOx	Nitrogen oxides (NOx) emitted by large industrial point sources within 4km, and area sources within 2km of the receptor location. Dispersion kernels are applied to spatiotemporally resampled records from national atmospheric emission inventories.	$\mu g/m^3$	0	80	Log (x + 0.01)	C2

Group	Name	Description	Unit	Data Limits		Transformation	Model
				Lower	Upper		
Dispersion	Calibrated Road-NOx (C1)	The calibrated concentration of NOx emitted by road-transport within 500m of the receptor location, accounting for urban canyon and terrain influences on pollutant dispersion.	$\mu g/m^3$	0	175	None	M1
	Calibrated AP-NOx (C2)	The calibrated concentration of NOx emitted by area and point sources within 4km, accounting for urban canyon and terrain influences on pollutant dispersion.	$\mu g/m^3$	0	75	None	M1
Weather	Temperature	The IDW hourly annual mean (dry-bulb) temperature of air measured by nearby weather stations with a thermometer freely exposed to the air, but shielded from radiation and moisture.	Degrees Celsius	0	20	None	M2, M3
	Relative-Humidity (RH)	The IDW hourly annual mean relative humidity value of nearby weather stations. Describes the amount of water in the air relative to the maximum capacity at the prevailing temperature.	Percent	0	100	None	M2, M3
Remote Sensing	Regional-NO_2	Satellite ground-level air pollution estimates from the Copernicus Atmosphere Monitoring Service (CAMS) at 10x10km. Aggregated to hourly-annual estimates, and resampled to 10x10m using IDW.	$\mu g/m^3$	0	80	None	M2
	Regional-O_3	Satellite ground-level air pollution estimates from the Copernicus Atmosphere Monitoring Service (CAMS) at 10x10km. Aggregated to hourly-annual estimates, and resampled to 10x10m using IDW.	$\mu g/m^3$	0	80	None	M3
Outputs	Nitrogen Oxides (Total-NOx)	The estimated pollutant concentrations from Model 1 (M1).	$\mu g/m^3$	0	175	None	M2, M3
	Nitrogen Dioxide (Total-NO_2)	The estimated pollutant concentrations from Model 2 (M2).	$\mu g/m^3$	0	80	None	M3
	Ozone (Total-O_3)	The estimated pollutant concentrations from Model 3 (M3).	$\mu g/m^3$	0	80	None	-

APPENDIX 2: Building height profiles for England and Wales

The following tables summarise the building heights of commercial, industrial, and residential buildings under various conditions. The profiles are based on Ordnance Survey MasterMap [1] spatial polygon feature records from 2019, which were rasterised into 10x10m surfaces, resulting in the creation of 25,186,000 building cells across England and Wales.

These profiles may be used to assist with the creation of synthetic building height data, in locations where such information is not readily available.

The average (and standard deviation) height profiles of residential, commercial, and industrial buildings across England and Wales in relation to a locations Urban Index score is:

Urban Index	Residential	Commercial	Industrial
0.0	7.9m (±2.8m)	9.3m (±5.4m)	8.7m (±3.5m)
0.1	8.1m (±2.6m)	9.6m (±5.4m)	8.9m (±3.6m)
0.2	8.4m (±3.4m)	11.1m (±7.5m)	9.7m (±4.6m)
0.3	8.4m (±3.0m)	10.6m (±6.6m)	9.8m (±5.0m)
0.4	8.6m (±3.3m)	10.4m (±5.5m)	10.2m (±6.0m)
0.5	8.6m (±3.3m)	10.4m (±5.4m)	10.2m (±5.9m)
0.6	8.8m (±3.4m)	10.3m (±5.2m)	10.4m (±6.0m)
0.7	8.6m (±2.9m)	9.9m (±4.3m)	10.3m (±5.6m)
0.8	8.8m (±3.1m)	10.0m (±4.3m)	10.8m (±6.0m)
0.9	8.7m (±2.8m)	9.9m (±4.7m)	10.5m (±5.6m)
1.0	9.0m (±2.9m)	9.9m (±4.3m)	10.7m (±5.3m)

See Appendix 1 and Appendix 24 for the procedure to calculate the Urban Index at a 10x10m resolution. A value of 1 on the Urban Index represents a densely populated area.

Three further height profiles are provided that consider the impact of building density and building composition in a 100x100m grid.

[1] Ordnance Survey (OS 2023). OS MasterMap topography layer™: Technical specification. UK Government, Southampton.

The first of these provides the average height of residential buildings, with respect to the percent of land within a 50m radius that is covered by: (a) buildings of any type, and (b) residential buildings:

Land Cover: 50m radius		Residential Buildings										
		1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
All Buildings	1%	8.1m										
	10%	10.4m	9.4m									
	20%	12.4m	11.5m	10.0m								
	30%	14.0m	13.7m	13.3m	11.7m							
	40%	15.5m	15.5m	15.2m	14.2m	12.6m						
	50%	17.2m	17.7m	17.3m	16.3m	15.5m	14.7m					
	60%	20.0m	20.0m	19.2m	18.0m	17.0m	17.0m	16.1m				
	70%	20.7m	22.8m	20.5m	21.7m	17.9m	18.0m	17.1m	17.4m			
	80%	21.3m	21.6m	24.1m	21.6m	19.9m	19.1m	20.7m	18.6m	19.4m		
	90%	22.2m	22.5m	25.5m	25.7m	22.4m	19.1m	15.8m	22.0m	14.7m	19.9m	
	99%	23.4m	23.2m	28.0m	28.4m	21.6m	23.2m	21.4m	13.6m	18.1m	13.9m	22.0m

The following profile provides the average height of industrial buildings, with respect to the percent of land within a 50m radius that is covered by: (a) buildings of any type, and (b) industrial buildings:

Land Cover: 50m radius		Industrial Buildings										
		1%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
All Buildings	1%	9.3m										
	10%	10.0m	11.6m									
	20%	11.1m	11.6m	12.7m								
	30%	12.8m	12.1m	12.5m	13.8m							
	40%	14.3m	12.9m	12.9m	14.0m	14.4m						
	50%	16.2m	14.1m	13.8m	14.2m	15.5m	15.3m					
	60%	18.8m	16.0m	15.2m	14.9m	14.3m	15.9m	17.1m				
	70%	20.4m	18.0m	16.5m	15.4m	17.2m	15.5m	16.1m	17.7m			
	80%	20.5m	19.4m	17.2m	17.1m	17.0m	19.9m	16.9m	18.2m	19.0m		
	90%	20.6m	16.7m	19.2m	17.0m	17.2m	20.3m	18.7m	24.4m	19.4m	20.1m	
	99%	20.7m	23.1m	22.2m	21.3m	28.8m	27.9m	24.4m	41.9m	31.4m	26.3m	23.2m

The following profile provides the average height of commercial buildings, with respect to the percent of land within a 50m radius that is covered by: (a) buildings of any type, and (b) commercial buildings:

Land Cover: 50m radius		**Commercial Buildings**										
		1%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
All Buildings	**1%**	9.0m										
	10%	9.9m	11.3m									
	20%	10.6m	12.2m	13.0m								
	30%	12.1m	13.4m	14.0m	14.8m							
	40%	12.8m	14.2m	15.2m	16.0m	16.4m						
	50%	14.4m	15.0m	15.8m	17.8m	18.5m	17.4m					
	60%	14.8m	15.9m	16.0m	18.9m	20.0m	20.7m	20.5m				
	70%	15.6m	16.1m	17.0m	18.5m	22.0m	23.4m	22.2m	21.1m			
	80%	19.6m	16.6m	18.2m	17.8m	20.3m	27.5m	22.4m	23.2m	20.9m		
	90%	15.5m	16.2m	13.6m	14.9m	17.9m	21.1m	31.8m	27.1m	20.8m	23.0m	
	99%	14.8m	18.2m	18.1m	13.6m	21.4m	21.5m	21.1m	25.3m	24.5m	23.3m	23.7m

It is recommended that synthetic building heights created from a combination of the four previous profiles are ranked, and redistributed across a representative range of building heights. The final profile shows the percentile distribution of building heights across England and Wales in 2019:

Height Percentile	**Residential**	**Industrial**	**Commercial**
0.01%	5.1m	5.1m	5.1m
5%	5.5m	5.6m	5.7m
10%	6.0m	6.2m	6.2m
15%	6.4m	6.6m	6.7m
20%	6.8m	7.0m	7.1m
25%	7.1m	7.3m	7.4m
30%	7.3m	7.6m	7.7m
35%	7.5m	7.9m	8.0m
40%	7.7m	8.2m	8.3m
45%	7.9m	8.6m	8.6m
50%	8.1m	8.9m	9.0m
55%	8.3m	9.2m	9.3m
60%	8.5m	9.6m	9.7m
65%	8.8m	10.1m	10.2m
70%	9.0m	10.7m	10.8m
75%	9.3m	11.3m	11.5m
80%	9.7m	12.2m	12.3m
85%	10.3m	13.3m	13.4m
90%	11.2m	15.2m	15.2m
95%	13.0m	18.4m	18.6m
99%	19.4m	29.6m	30.6m
99.99%	70.9m	102.2m	112.8m

APPENDIX 3: Resampling CORINAIR SNAP 94 Sector emissions to landcover classes

CORINAIR is a European Union emission inventory programme, established in 1985, to assist in the development of consistent, comparable, and transparent national inventories for air pollutants. Complete harmonisation between the United Nations Intergovernmental Panel on Climate Change (IPCC) and the European Environment Agency CORINEAIR classification schemes was achieved in 1994, with the release of the "Selected Nomenclature for sources of Air Pollution" (SNAP 94) scheme. The CORINAIR SNAP 94 scheme consists of 11 main sectors that separate into 57 sub-sectors and 277 detailed activities [(2)].

The UK government annually compiles a National Atmospheric Emission Inventory (NAEI), across the eleven CORINAIR SNAP 94 sectors. Emissions released from large industrial stacks (known as 'Point' sources) are recorded by operators and have precise coordinates, whereas 'Area' source releases that are too small and numerous to be inventoried individually are modelled at a 1x1km resolution.

The 'Area' source emissions were resampled to a 10x10m raster surface, by equally allocating the releases in a 1km tile to all relevant land use cells nested within. The landcover surface consists of eleven classes: "Agricultural Land", "Air Traffic", "Commercial Buildings", "Grassland", "Industrial Buildings", "Industrial Land", "Railways", "Residential Buildings", "Trees", "Waterways", and "Wetland". This simplification ensures reproducibility with other data, whilst maintaining sufficient detail to map against CORINAIR SNAP sector emissions by land use across England and Wales:

CORINAIR SNAP 94 Sector	HADES: Resample to Landcover	NOx released in 2019 (Tonnes)
01: Combustion in Energy Production and Transformation	"Industrial Buildings", "Industrial Land"	2,130
02: Combustion in Commercial, Institutional, Residential and Agriculture	"Commercial Buildings", "Residential Buildings"	52,402
03: Combustion in Industry	"Industrial Buildings", "Industrial Land"	57,684
04: Production Processes	"Industrial Buildings"	3,617
05: Off-Shore Extraction and Distribution of Fossil Fuels	"Waterways"	0 *
06: Solvent Use	"Industrial Buildings"	52
07: Road-transport	Not required	N/A
08: Other Transport and Mobile Machinery	"Agricultural Land", "Air Traffic", "Industrial Land", "Railways", "Waterways"	104,151
09: Waste Treatment and Disposal	"Industrial Buildings", "Industrial Land"	409
10: Agriculture, Forestry and Land Use Change	"Agricultural Land", "Grassland", "Trees"	25,168
11: Nature	"Grassland", "Trees", "Wetland"	1,361

** There are no off-shore fossil fuel operations within 2km of the English and Welsh mainland coastline.*

[2] European Environment Agency (EEA 1996). Selected nomenclature for air pollution for CORINEAIR 94 inventory (SNAP 94), version 1.1. European Topic Centre on Air Emissions (ETC/AE).

The percentile distribution of resampled NOx emissions in 2019 (grams per second) by landcover type across England and Wales, per 10x10m cell is as follows:

Landcover	Distribution of NOx emission rates per 10x10m (grams per second)						
	5%	10%	25%	50%	75%	90%	95%
Agricultural Land	0.002	0.003	0.003	0.004	0.005	0.008	0.019
Air Traffic	< 0.001	< 0.001	0.001	0.003	0.242	1.705	3.611
Commercial Buildings	0.070	0.122	0.196	0.249	0.310	0.417	0.531
Grassland	< 0.001	< 0.001	0.001	0.001	0.002	0.003	0.004
Industrial Buildings	0.030	0.124	0.750	2.323	5.302	12.563	24.428
Industrial Land	< 0.001	< 0.001	< 0.001	0.002	0.116	1.877	3.994
Railways	0.001	0.002	0.006	0.026	0.155	0.764	1.519
Residential Buildings	0.043	0.082	0.172	0.229	0.281	0.350	0.420
Trees	0.001	0.001	0.001	0.002	0.003	0.005	0.006
Waterways	< 0.001	< 0.001	< 0.001	0.001	0.005	0.033	0.108
Wetland	< 0.001	< 0.001	< 0.001	0.001	0.001	0.001	0.002

These landcover profiles may be used to assist with the creation of synthetic 'Area' source emission data, in locations where only national or regional total NOx values are published.

APPENDIX 4: Procedure for modelling and spatiotemporally scaling annual average daily traffic (AADT) counts across Great Britain, for 2013 to 2020.

Modelled annual average daily traffic (AADT) counts on all major and minor roads across Great Britain in 2013, were provided by Gulliver et al [(3)]. In terms of the road networks hierarchical ranking, observed vehicle counts were shown to correlate well to modelled AADT in 2013 (Spearman's rho. = 0.78, R^2 = 0.68). This simulated road network approach can be replicated in other locations following the approach of Gulliver et al, using an OpenStreetMap road network and traffic count sites on major roads [(3)].

AADT counts were collected from 44,597 traffic count sites across Great Britain, for 2010 to 2020:

- 33,998 'UK Department for Transport' (DFT) automatic and manual count sites with traffic data from 2010 to 2020 were considered [(4)]. These sites cover all road types and are geographically spread across Great Britain.
- 10,599 'Highways England' (HE) automatic count sites with traffic data from 2013 to 2020 were considered [(5)]. These sites are geographically restricted to major roads in England (i.e., motorways, trunk, and a-roads).

The AADT count data from DFT was cleaned to mitigate the appearance of erroneous entries. 55% of the DFT dataset derives from traffic surveys of varying duration across the year, which are published as modelled AADT estimates. The split of DFT sites by road type and AADT collection method is:

AADT Method *	Major road locations		Minor road locations		
	Motorway	A-Road	B-Road	C-Road	Unclassified
Automatic counters	724	3,792	1,872	2,641	6,441
Survey estimate	441	14,063	445	1,060	2,519

** Automatic traffic counters are permanent installations in the form of Automatic Number Plate Recognition (ANPR) cameras, Piezoelectric Sensors embedded in the road surface, or radar classification. DfT conducts approximately 8,000 manual traffic counts on a representative sample of minor road sites each year, on a weekday by a trained enumerator for a twelve-hour period (7am to 7pm). These short surveys are carried out between March and October, excluding all public holidays and school holidays, due to weather and light considerations at the count locations. Other surveys are conducted over several weeks and/or over multiple times of the year with pneumatic tube axle sensors that automatically count traffic.*

Phase 1 of the data cleaning process involved the replacement of AADT records with NULL values where, major road counts have less than 2 vehicles per minute (AADT < 2880), and minor road counts have less than 1 vehicle per hour (AADT < 24).

AADT counts were only missing (or invalid) at 6% of the DFT sites in 2019, therefore, scaling factors for other years were subsequently created with respect to the AADT counts in 2019. Phase 2 of the data cleaning process involved the removal of extreme outlying scaling factors for any individual year. Extreme outliers were defined as three times above or below the interquartile range [(6)].

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[3] Morley D, and Gulliver J. (2016). Methods to improve traffic flow and noise exposure estimation on minor roads. Environmental Pollution, Volume 216, pp.746-754.

[4] UK Department for Transport (DFT 2021). Road traffic statistics: Average annual daily traffic flows (in both directions) across Great Britain. URL: https://roadtraffic.dft.gov.uk/regions

[5] Highways England (HE 2022). WebTRIS traffic information system. URL: https://webtris.highwaysengland.co.uk

[6] Tukey, J (1977). Exploratory data analysis. Addison-Wesley, Reading, Massachusetts, USA.

Phase 3 of the data cleaning process involves the geographic imputation of missing entries, based on the Inverse-Distance Weighting (IDW) of the six nearest observations from a similar road class. Minor roads were treated as a single collective group in the IDW imputation process. Phase 4 involves the replacement of records with NULL values based on the same AADT count thresholds used in phase 1.

The raw AADT count data from HE experienced the same four phase data cleaning process, because the published counts derive from sites with varying levels of hourly data capture. Once again, the year with the best AADT coverage is 2019, where counts are missing from 36% of the HE sites. The hourly capture rate by site type in 2019 is as follows:

Road Class	Traffic Counter: Hourly data capture in 2019						
	Missing	70-74%	75-79%	80-84%	85-89%	90-94%	95% +
Motorway	2906	109	195	319	263	509	3060
A-Road	908	55	125	198	173	327	1452

It appears that HE does not publish traffic count data at locations with <70% hourly data capture in a specific year.

The two traffic count datasets were then combined, and the AADT scaling factors were converted to use a baseline year of 2013 instead of 2019. A final procedural check was conducted to identify sites with unusual entries:

1) If the average scaling factor for 2010-12 and 2014-19 are 100% above or below the 2013 traffic levels (flagged sites = 23)
2) If any scaling factors for 2010-12 and 2014-19 are 200% above the 2013 traffic levels (flagged sites = 15)
3) If any scaling factors for 2010-19 are less than 50% of the 2013 traffic levels (flagged sites = 120)
4) DFT: If the scaling factors for 2010-12 and 2014-19 are universally greater or less than 2013 traffic levels (flagged sites = 7,799)
5) HE: If the scaling factors for 2014-19 are universally 25% higher or 25% lower than 2013 traffic levels (flagged sites = 62)

In total, 7972 of the candidate sites were removed from the AADT count dataset. Appendix 4 presents a summary of the valid and cleaned AADT count sites, profiled by road class and region in Great Britain for 2013-2020.

The road network of Great Britain with modelled AADT counts for 2013 was subsequently scaled in accordance to spatiotemporal changes at the 36,626 valid traffic count sites across Great Britain:

- The analysis used AADT counts from 26,088 DFT sites (77% of those initially available).
- The analysis used 10,537 HE sites (99% of those initially available).

AADT scaling factors for individual road links were obtained using Inverse-Distance Weighting (IDW) of the six nearest observations from a similar road class (i.e., separate interpolations were conducted for motorways, a-roads, and minor roads).

APPENDIX 5: Annual average daily traffic (AADT) count profiles by road class and region in Great Britain for 2013-2020, constructed from 36,625 automatic and manual traffic count sites managed by the UK Department for Transport [7] and Highways England [8]

REGION	ROAD NETWORK				AADT SCALING FACTOR							
	GROUP	CLASS	COUNTS	AADT	2013	2014	2015	2016	2017	2018	2019	2020
Great Britain (Total)	Major	Motorway	8,340	78,966	1	1.025	1.048	1.084	1.098	1.094	1.104	0.833
		A-Road	16,644	22,427	1	1.020	1.035	1.051	1.051	1.045	1.052	0.813
	Minor	B-Road	1,802	6,590	1	1.028	1.036	1.035	1.035	1.034	1.039	0.848
		C-Road	2,856	2,947	1	1.020	1.032	1.040	1.042	1.042	1.044	0.855
		Unclassified	6,983	1,822	1	1.018	1.028	1.026	1.017	1.013	1.015	0.830
East Midlands	Major	Motorway	805	83,256	1	1.041	1.059	1.121	1.123	1.115	1.137	0.868
		A-Road	1,440	23,308	1	1.021	1.045	1.072	1.082	1.082	1.088	0.837
	Minor	B-Road	128	7,386	1	1.039	1.033	1.030	1.052	1.053	1.055	0.859
		C-Road	243	2,684	1	1.029	1.034	1.045	1.048	1.043	1.043	0.855
		Unclassified	509	1,453	1	1.020	1.033	1.039	1.034	1.032	1.033	0.840
East of England	Major	Motorway	806	101,286	1	1.032	1.062	1.092	1.109	1.115	1.113	0.864
		A-Road	1,992	25,468	1	1.025	1.045	1.076	1.082	1.080	1.089	0.846
	Minor	B-Road	207	5,427	1	1.029	1.025	1.054	1.077	1.074	1.076	0.870
		C-Road	437	2,511	1	1.004	1.014	1.050	1.075	1.076	1.080	0.872
		Unclassified	895	1,673	1	1.025	1.028	1.028	1.047	1.037	1.038	0.841
London	Major	Motorway	263	87,954	1	1.019	1.030	1.068	1.09	1.097	1.102	0.823
		A-Road	1,494	25,245	1	1.004	0.996	0.987	0.986	0.984	0.986	0.785
	Minor	B-Road	111	9,945	1	1.027	1.042	1.053	1.026	0.993	1.010	0.844
		C-Road	130	7,282	1	1.013	1.018	1.034	1.027	1.000	1.013	0.840
		Unclassified	428	2,771	1	0.993	1.042	1.054	1.024	1.001	1.012	0.838
North East	Major	Motorway	-	-	-	-	-	-	-	-	-	-
		A-Road	861	25,894	1	1.015	1.028	1.047	1.046	1.043	1.053	0.811
	Minor	B-Road	113	5,950	1	1.064	1.078	1.014	1.006	1.033	1.037	0.869
		C-Road	111	3,702	1	1.042	1.054	1.023	1.009	1.033	1.034	0.862
		Unclassified	349	1,912	1	1.026	1.042	1.013	0.994	1.004	1.008	0.846
North West	Major	Motorway	1,554	77,746	1	1.013	1.039	1.058	1.082	1.072	1.088	0.834
		A-Road	1,809	18,646	1	1.018	1.029	1.034	1.011	0.992	0.998	0.774
	Minor	B-Road	166	7,867	1	1.027	1.033	1.007	1.010	1.022	1.028	0.858
		C-Road	262	3,625	1	1.035	1.050	1.051	1.039	1.049	1.051	0.866
		Unclassified	775	2,009	1	1.028	1.036	1.029	1.015	1.025	1.028	0.846
Scotland	Major	Motorway	201	44,227	1	1.026	1.041	1.078	1.098	1.111	1.125	0.823
		A-Road	1,374	13,855	1	1.020	1.035	1.055	1.056	1.045	1.052	0.809
	Minor	B-Road	171	4,297	1	1.013	1.030	1.028	1.028	1.033	1.038	0.842
		C-Road	160	1,997	1	1.003	1.037	1.039	1.034	1.033	1.035	0.833
		Unclassified	348	1,491	1	0.996	1.007	1.006	0.996	0.997	0.999	0.807

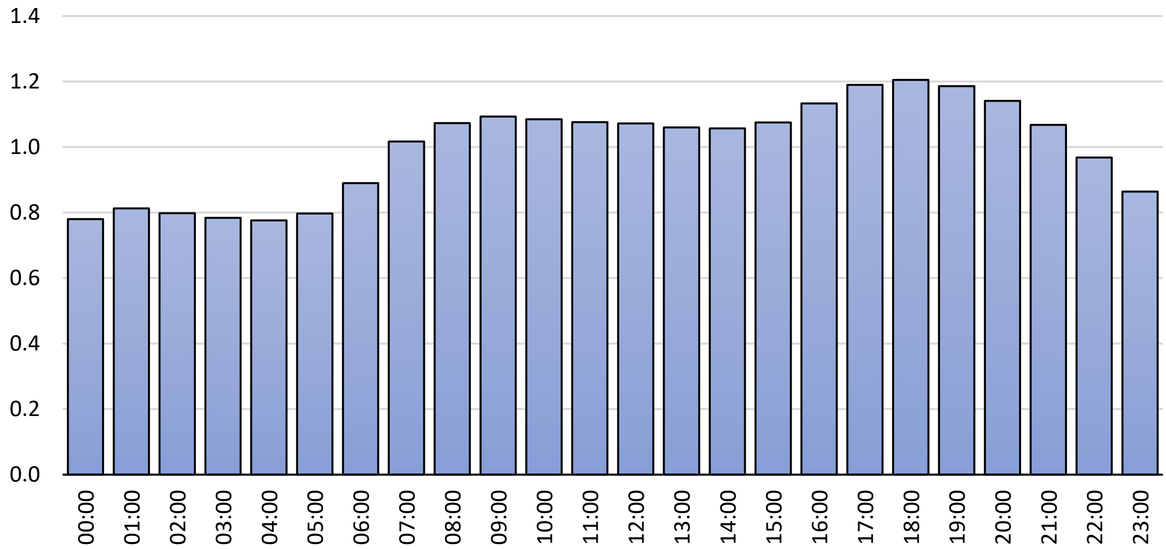
[7] UK Department for Transport (DFT 2021). Road traffic statistics: Average annual daily traffic flows (in both directions) across Great Britain. URL: https://roadtraffic.dft.gov.uk/regions

[8] Highways England (HE 2022). WebTRIS traffic information system. URL: https://webtris.highwaysengland.co.uk

REGION	ROAD NETWORK				AADT SCALING FACTOR							
	GROUP	CLASS	COUNTS	AADT	2013	2014	2015	2016	2017	2018	2019	2020
South East	Major	Motorway	1,656	84,713	1	1.017	1.042	1.067	1.075	1.064	1.067	0.790
		A-Road	2,257	27,284	1	1.022	1.044	1.057	1.053	1.046	1.051	0.811
	Minor	B-Road	217	7,164	1	1.025	1.031	1.036	1.030	1.018	1.021	0.813
		C-Road	370	3,375	1	1.022	1.022	1.042	1.053	1.047	1.050	0.848
		Unclassified	1153	1,816	1	1.017	1.015	1.021	1.010	0.995	0.997	0.800
South West	Major	Motorway	734	65,238	1	1.050	1.085	1.118	1.122	1.126	1.136	0.800
		A-Road	1,512	17,281	1	1.017	1.031	1.058	1.065	1.061	1.069	0.818
	Minor	B-Road	200	6,302	1	1.025	1.026	1.035	1.044	1.043	1.047	0.853
		C-Road	487	2,093	1	1.022	1.029	1.026	1.030	1.036	1.039	0.858
		Unclassified	807	1,278	1	1.027	1.020	1.010	0.997	0.993	0.994	0.818
Wales	Major	Motorway	46	61,666	1	1.039	1.061	1.071	1.092	1.098	1.122	0.807
		A-Road	862	13,813	1	1.017	1.034	1.049	1.047	1.045	1.050	0.794
	Minor	B-Road	155	4,673	1	1.020	1.020	1.014	1.017	0.992	0.992	0.793
		C-Road	179	2,107	1	1.031	1.039	1.030	1.022	1.003	1.000	0.814
		Unclassified	330	1,166	1	1.007	1.018	1.012	1.000	0.986	0.985	0.805
West Midlands	Major	Motorway	1,148	79,025	1	1.023	1.031	1.08	1.094	1.082	1.075	0.819
		A-Road	1,433	21,635	1	1.022	1.039	1.055	1.052	1.049	1.055	0.813
	Minor	B-Road	176	7,563	1	1.016	1.051	1.051	1.039	1.052	1.055	0.848
		C-Road	252	2,865	1	1.021	1.038	1.042	1.037	1.045	1.044	0.856
		Unclassified	651	2,336	1	1.011	1.032	1.031	1.020	1.021	1.023	0.834
Yorkshire & The Humber	Major	Motorway	1,127	66,862	1	1.024	1.051	1.096	1.117	1.128	1.150	0.888
		A-Road	1,610	28,310	1	1.027	1.045	1.066	1.070	1.066	1.078	0.834
	Minor	B-Road	158	7,077	1	1.039	1.049	1.050	1.032	1.045	1.048	0.891
		C-Road	225	2,990	1	1.010	1.046	1.052	1.033	1.038	1.039	0.875
		Unclassified	738	2,068	1	1.025	1.037	1.038	1.021	1.027	1.029	0.860

APPENDIX 6: Area and Point source activity profiles by time-of-day in Great Britain for 2018-2020

The National Grid Electricity System Operator (ESO) for Great Britain has published records of the total national electricity demand, at half-hourly intervals dating back to 2009 (9). National Demand (measured in MW) is measured as the sum of metered generation, but excludes generation required to meet station load, pump storage pumping and interconnector exports. We assume that peaks in high electricity demand are approximate to increased commercial, industrial, and residential activities. The following plot displays the distribution of these hourly-annual scaling factors for a typical day in 2018:



The scaling factors used to convert the annual-average area and point source emission rates (g/s) into hourly-annual emission rates (g/s) are:

Hour	Hourly Scaling Factor		
	2018	**2019**	**2020**
00:00	0.780	0.779	0.786
01:00	0.813	0.805	0.819
02:00	0.798	0.794	0.803
03:00	0.784	0.781	0.788
04:00	0.776	0.777	0.782
05:00	0.797	0.794	0.798
06:00	0.890	0.898	0.884
07:00	1.017	1.027	0.992
08:00	1.073	1.081	1.05
09:00	1.093	1.096	1.073
10:00	1.085	1.086	1.071
11:00	1.076	1.077	1.068

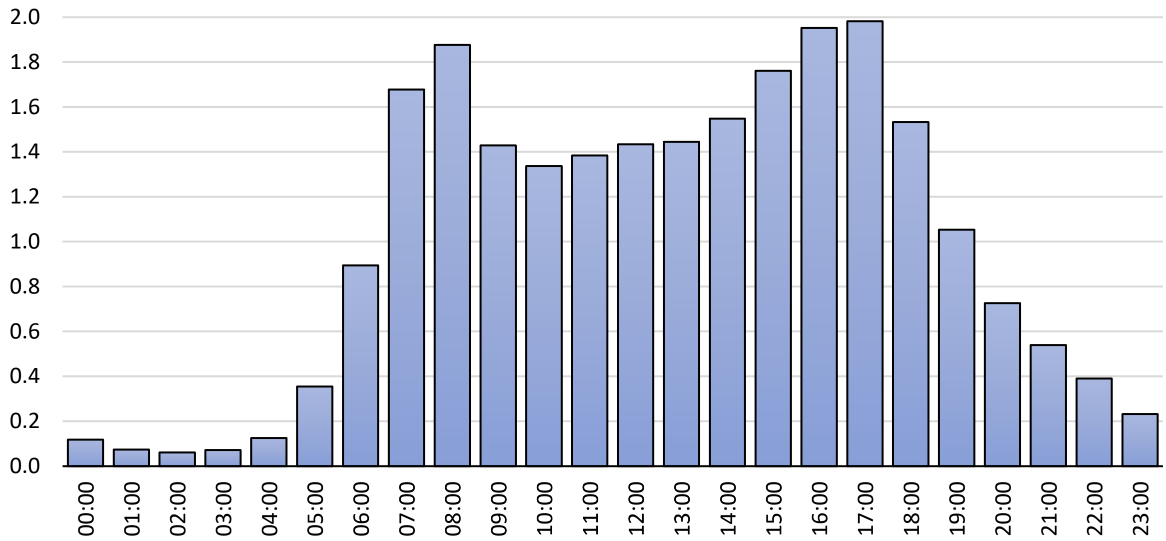
Hour	Hourly Scaling Factor		
	2018	**2019**	**2020**
12:00	1.072	1.072	1.073
13:00	1.060	1.059	1.061
14:00	1.057	1.055	1.054
15:00	1.075	1.073	1.073
16:00	1.133	1.132	1.136
17:00	1.190	1.187	1.21
18:00	1.205	1.202	1.225
19:00	1.186	1.185	1.196
20:00	1.141	1.141	1.141
21:00	1.068	1.068	1.068
22:00	0.968	0.969	0.975
23:00	0.864	0.863	0.875

[9] National Grid Electricity System Operator (2022). Historic Demand Data. URL: https://data.nationalgrideso.com/demand/historic-demand-data

APPENDIX 7: Road traffic distribution profiles by time-of-day across Great Britain in 2018-2020

The UK Department for Transport's annual-average distribution profiles of total traffic counts by time-of-day, were used to scale the modelled annual average daily traffic (AADT) into hourly-annual estimates [(10)].

The following plot displays the distribution of these hourly-annual scaling factors for a typical weekday, on all road types across Great Britain in 2018:



The weekday scaling factors used to convert AADT into hourly-annual daily traffic estimates, for all road types across Great Britain in 2018-2020:

Hour	AADT Hourly Scaling Factor			Hour	AADT Hourly Scaling Factor		
	2018	2019	2020		2018	2019	2020
00:00	0.118	0.116	0.106	12:00	1.434	1.444	1.552
01:00	0.074	0.074	0.070	13:00	1.445	1.456	1.579
02:00	0.061	0.061	0.059	14:00	1.548	1.561	1.686
03:00	0.072	0.073	0.069	15:00	1.761	1.770	1.864
04:00	0.125	0.127	0.124	16:00	1.952	1.949	1.986
05:00	0.355	0.359	0.363	17:00	1.982	1.971	1.904
06:00	0.894	0.897	0.871	18:00	1.533	1.522	1.417
07:00	1.678	1.668	1.579	19:00	1.053	1.049	0.988
08:00	1.877	1.860	1.751	20:00	0.726	0.723	0.690
09:00	1.429	1.429	1.416	21:00	0.539	0.534	0.492
10:00	1.337	1.346	1.403	22:00	0.390	0.386	0.344
11:00	1.384	1.394	1.487	23:00	0.232	0.229	0.199

[10] UK Department for Transport (DFT 2021). TRA0307: Motor vehicle traffic distribution by time of day and day of the week on all roads, Great Britain. URL: www.gov.uk/government/statistical-data-sets/road-traffic-statistics-tra

APPENDIX 8: Distribution of road-transport NOx emission rates across England and Wales in 2019

Bidirectional road centrelines were used in the calculation of NOx emissions from road-transport. The percentile distribution of road-transport NOx emissions (grams per hour per meters of road length) across England and Wales in 2019, is as follows:

OSM Road Class	Distribution of NOx emission rates (grams per hour per road meter)						
	5%	10%	25%	50%	75%	90%	95%
Motorway	0.244	0.378	0.680	1.024	1.409	1.740	1.955
Trunk Road	0.123	0.160	0.236	0.349	0.503	0.707	0.879
Primary Road	0.057	0.078	0.123	0.185	0.260	0.342	0.406
Secondary Road	0.047	0.058	0.082	0.120	0.154	0.187	0.210
Tertiary Road	0.023	0.029	0.044	0.066	0.084	0.102	0.114
Residential Road	0.010	0.013	0.018	0.023	0.028	0.035	0.039
Unclassified Road	0.006	0.008	0.011	0.018	0.028	0.037	0.042

These road profiles may be used to assist with the creation of synthetic road-transport emission data, in locations where AADT traffic models are unreliable and only national or regional total NOx values are published. In these instances, the total length of road centrelines by road class is to be calculated for each 10x10m cell, appropriate emission rates are assigned and multiplied by the total road length of each cell. Finally, the synthetic road-transport emission surface is scaled in accordance to national or regional records of total NOx emitted by road-transport.

APPENDIX 9: Pasquill-Turner stability categories as a function of net radiation, calculated from wind speed, cloud cover, and cloud base height. Classification system adapted from Turner 1964 [(11)] and USEPA 2000 [(12)].

Wind Speed		Net Radiation Index (NRI) *						
(knots)	**(m/s)**	**4**	**3**	**2**	**1**	**0**	**-1**	**-2**
0, 1	≤ 0.7	A	A	B	C	D	F	G
2, 3	0.8 - 1.8	A	B	B	C	D	F	G
4, 5	1.9 - 2.8	A	B	C	D	D	G	F
6	2.9 - 3.3	B	B	C	D	D	G	F
7	3.4 - 3.8	B	B	C	D	D	D	G
8, 9	3.9 - 4.8	B	C	C	D	D	D	G
10	4.9 - 5.4	C	C	D	D	D	D	G
11	5.5 - 5.9	C	C	D	D	D	D	D
≥ 12	≥ 6	C	D	D	D	D	D	D

* Procedure for determining the Net Radiation Index (NRI):

1) NRI equals 0, when it is completely overcast (8 Oktas) and the cloud ceiling is <7,000 ft.
2) For night-time (one hour before sunset to one hour after sunrise):
   a. NRI equals -2, when the cloud cover is 0-4 Oktas.
   b. NRI equals -1, when the cloud cover is 5-8 Oktas.
3) For daytime, NRI equals the solar insolation code when cloud cover is 0-4 Oktas.
4) For daytime, use a revised solar insolation code when cloud cover is 5-8 Oktas:
   a. Subtract 2 when the cloud ceiling is <7,000 ft.
   b. Subtract 1 when the cloud ceiling is 7,000 to 16,000 ft.
   c. Ensure that no modified insolation values are less than 1.

[11] Turner DB (1964). A diffusion model for an urban area. Journal of Applied Meteorology and Climatology. Volume 3, Issue 1, p.83-91

[12] U.S. Environmental Protection Agency (US EPA 2000). Meteorological Monitoring Guidance for Regulatory Modeling Applications. No. EPA-454/R-99-005. Office of Air Quality Planning and Standards, North Carolina.

APPENDIX 10: Modified-Sigma-Theta (MST) method to determine atmospheric stability classifications from page 776 of Mitchell 1982 (13)

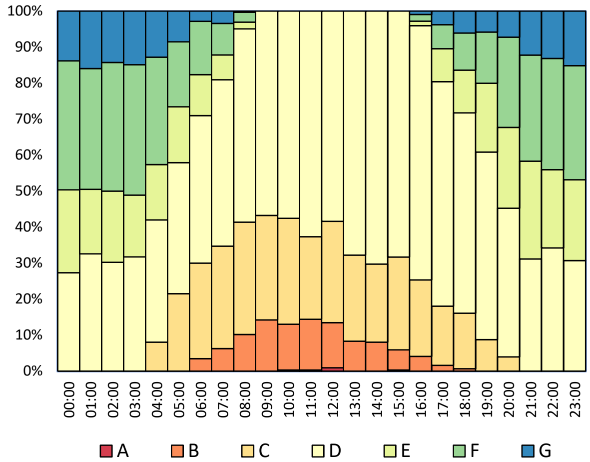
Sigma theta (degrees)	Daytime stability class†	Wind speed ($m\,s^{-1}$)	Night-time* stability class‡
Sigma $\geq$ 22.5	A	$u < 2.4$	G
		$2.4 \leq u < 2.9$	F
		$2.9 \leq u < 3.6$	E
		$3.6 \leq u$	D
22.5 > Sigma $\geq$ 17.5	B	$u < 2.4$	F
		$2.4 \leq u < 3.0$	E
		$3.0 \leq u$	D
17.5 > Sigma $\geq$ 12.5	C	$u < 2.4$	E
		$2.4 \leq u$	D
12.5 > Sigma $\geq$ 7.5	D	all wind speeds	D
7.5 > Sigma $\geq$ 3.8	E	all wind speeds	E
3.8 > Sigma $\geq$ 2.1	F	all wind speeds	F
2.1 > Sigma	G	all wind speeds	G

* Night-time is defined as the period from 1 h before sunset to 1 h after sunrise.
† More applicable to describing horizontal dispersion parameter, sigma y, at night.
‡ More applicable to describing vertical dispersion parameter, sigma z, at night.

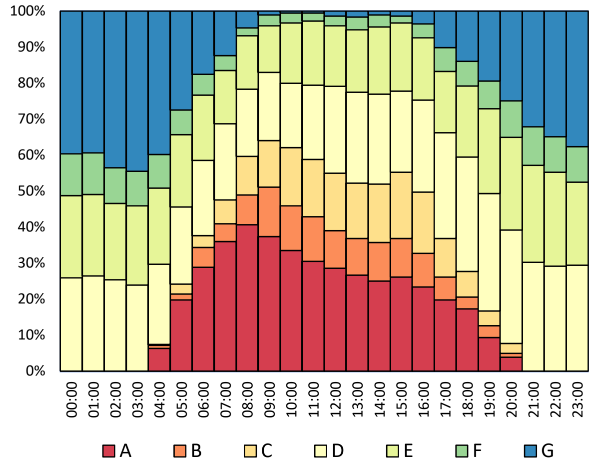
[13] Mitchell AE (1982). A comparison of short-term dispersion estimates resulting from various atmospheric stability classification methods. Atmospheric Environment. Volume 16, Issue 4, p.765-773

APPENDIX 11: Frequency of Pasquill atmospheric stability classes by hour of the day in 2019, for the Pasquill-Turner and an experimental Modified-Sigma-Theta (MST) classification scheme.

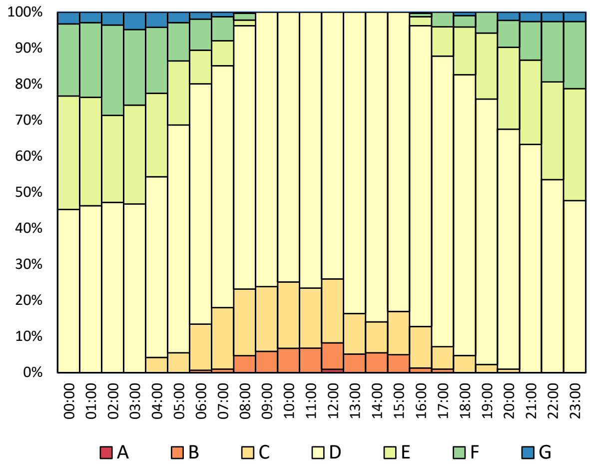
London Gatwick: Turner stability [(a)]



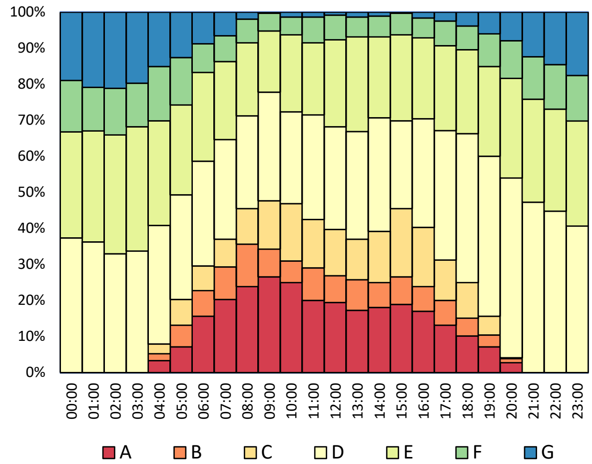
London Gatwick: MST 3-hour stability [(a)]



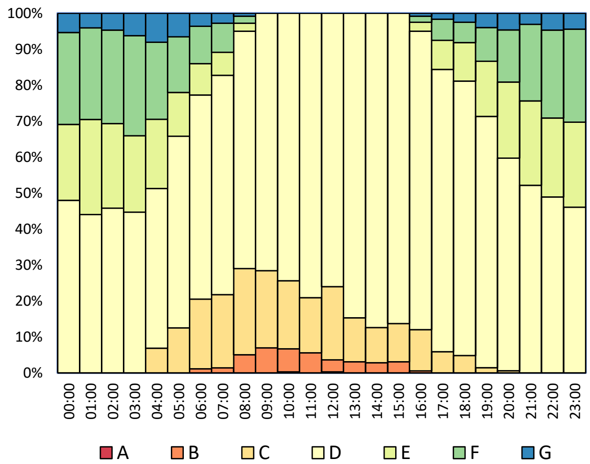
London Heathrow: Turner stability [(b)]



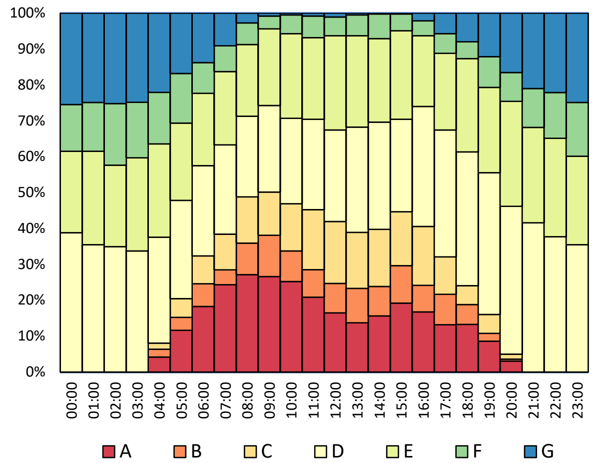
London Heathrow: MST 3-hour stability [(b)]



RAF Northolt: Turner stability [(b)]



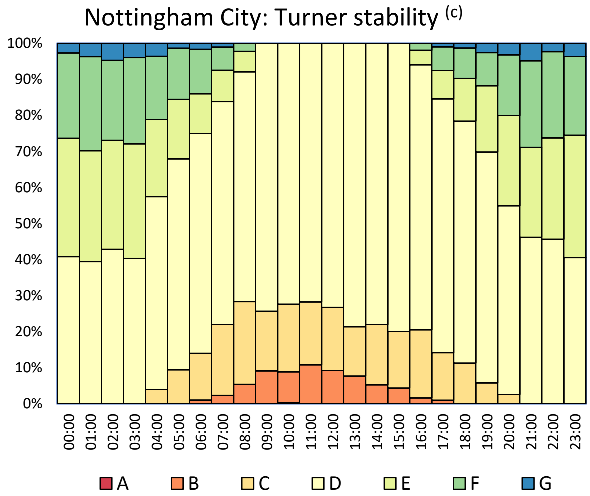
RAF Northolt: MST 3-hour stability [(b)]

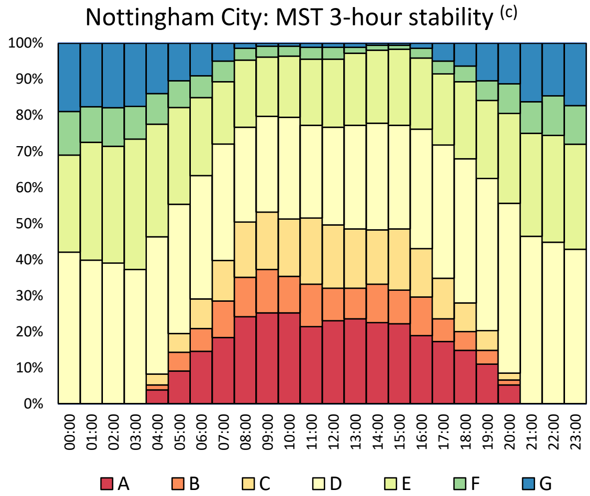


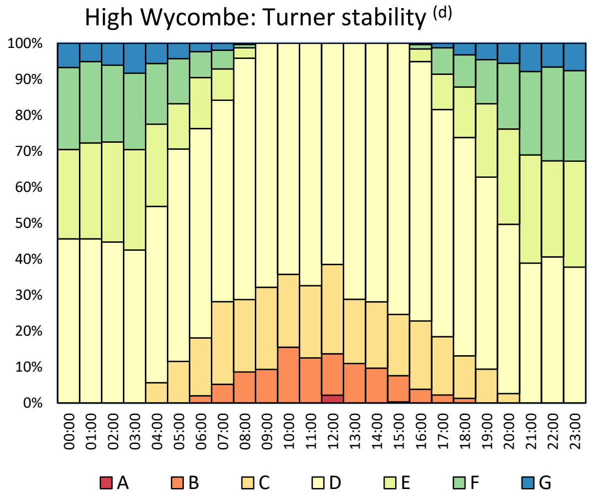
(a) Charlwood weather station (USAF: 037690), located 1km to the west of Gatwick Airport. Hourly Turner and MST estimates have a mean difference of ±1.1 (SD = 0.9) stability classes in 2019.

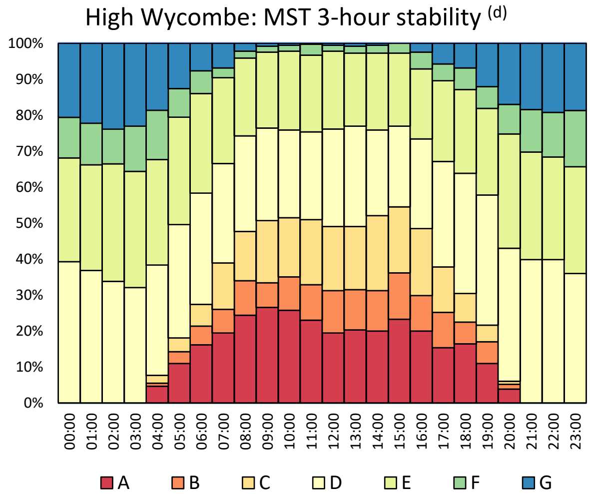
(b) London Heathrow Airport (USAF: 037720) and Royal Air Force Northolt (USAF: 036720) presented hourly Turner and MST estimates with a mean difference of ±1.0 (SD = 0.9) stability classes in 2019.

APPENDIX 11 [Continued]









(c) Nottingham City weather station (USAF: 037690) presented hourly Turner and MST estimates have a mean difference of ±1.1 (SD = 0.9) stability classes in 2019.

(d) High Wycombe town weather station (USAF: 037720) presented hourly Turner and MST estimates with a mean difference of ±1.0 (SD = 0.9) stability classes in 2019.

APPENDIX 12: Road-transport effective plume heights by stability class and wind-speed

The effective plume height (**H**) is a summation of the stack height (**H_s**) and the initial plume rise (**H_r**), which is calculated using [14]:

$$H = H_s + H_r$$

$$H_r = \lambda * \left[\left(-0.029 * \left(\frac{V*D}{U}\right)\right) + \left(5.35 * \frac{{Q_h}^2}{U}\right)\right]$$

Where **V** is the stack gas exit velocity (meters per second), **D** is the stack exit diameter (meters), **U** is the wind speed at stack exit (meters per second), **Q_h** is the heat emission rate (kilojoules per second), and **λ** is a stability correction factor. The following function was fitted to extend Carson and Moses's stability correction factors across the Pasquill stability categories (**P_s**), which are converted from alphabet letters to descending numbers (i.e., A=1, D=4 and G=7):

$$\lambda = 2.6845 * ({p_s}^{-0.689})$$

The parameters required to calculate plume rise are source specific. Parameters for cars were used to derive road-transport plume heights, where a tailpipe height (**H_s**) of 0.2m and exhaust diameter (**D**) of 0.06m is typical. We approximate **Q_h** as 12.96 KJ/s for cars operating across gears 3-6 in environments of 1013mb and 15°C, where **V** equals 15 m/s [15]. **H** was set to a minimum height of 1.5m to reflect traffic-induced turbulence. Based on these parameters, road-transport effective plume heights are defined as:

Plume Height (m)		Atmospheric Stability Class						
		A	**B**	**C**	**D**	**E**	**F**	**G**
Wind Speed (m/s)	**1**	51.2m	32.2m	24.4m	21.0m	17.2m	15.2m	13.3m
	2	25.7m	16.2m	12.3m	10.6m	8.7m	7.7m	6.7m
	3	17.2m	10.9m	8.3m	7.1m	5.9m	5.2m	4.6m
	4	12.9m	8.2m	6.3m	5.4m	4.5m	4.0m	3.5m
	6	8.7m	5.5m	4.2m	3.7m	3.0m	2.7m	2.4m
	8	6.6m	4.2m	3.2m	2.8m	2.3m	2.1m	1.8m
	10	5.3m	3.4m	2.6m	2.3m	1.9m	1.7m	1.5m
	12	4.5m	2.9m	2.2m	1.9m	1.6m	1.5m	1.5m

[14] Carson J, and Moses H (1969). The Validity of Several Plume Rise Formulas. Journal of the Air Pollution Control Association, Volume 19, Issue 11, Pages 862-866.

[15] Madaro F, Mehdipour I, Caricato A, Guido F, Rizzi F, Carlucci A, and De Vittorio M (2020). Available Energy in Cars' Exhaust System for IoT Remote Exhaust Gas Sensor and Piezoelectric Harvesting. Energies 2020, 13, 4169.

APPENDIX 13: Creating the stack release profiles of 'Area' and 'Point' sources

UK and European emission inventories tend to only record pollutant emission rates, with other stack parameters not routinely collected or made freely available.

The US state of Pennsylvania's Department of Environmental Protection, collects comprehensive information on all commercial and industrial emission sources for publication within the US Environmental Protection Agencies (EPA) national emissions inventory. These records are updated annually and are openly published by the State government of Pennsylvania [16].

Emission source stack release profiles were created using the following procedure:

1) Select records for all sites operating in 2019 (N= 10,265)
2) Select emission sources that are vertical stacks (N = 7,332)
3) Convert stack heights to meters, round to the nearest 5m to create height bands, and remove any stacks less than 5m.
4) Convert stack diameters to meters, round to the nearest 0.1m, remove any stacks less than 0.1m.
5) Convert gas velocities to m/s, and remove any records less than 1m/s
6) Convert the temperature of an exit gas stream measured in degrees Fahrenheit, to degrees Celsius.
7) Convert the stack gas flow rate (Actual Cubic Feet per Second) to a Mass Flow rate (Kg/s)
8) For the valid sites (N = 3,638), create summary profiles based on the median facility parameters of each stack height band.

The parameters profiles of commercial and industrial sites from Pennsylvania, likely approximate similar activities within the UK. Both locations are well regulated with overlapping guidance on best practices, and they represent temperate climates with four defined seasons with comparable temperature ranges (i.e., 2 to 7°C in the winter, and 18 to 25°C in the summer).

HADES uses the stack profiles of 5m and 10m emission sources from the following table to model 'Area' and 'Point' sources, respectively:

[16] Commonwealth of Pennsylvania. Emissions Inventory System (EIS): 2017-2019. URL: https://data.pa.gov/Energy-and-the-Environment/Emissions-Inventory-System-EIS-Facilities-2017-Cur/e7ip-7qrs/data

Stack Parameters				Exit Gas Parameters		
Height (m)	Count (n)	Diameter (m)	Flow (m/s)	Temperature (°C)	Mass Flow (kg/s) *	Emission Heat (KJ/s) **
5	710	0.60	13.64	135.00	1.87	225.19
10	1,452	0.60	13.21	135.00	3.44	413.64
15	509	0.80	13.22	163.33	4.87	724.90
20	291	0.70	14.43	73.89	4.49	265.34
25	177	0.90	14.29	107.22	5.50	508.99
30	133	1.20	12.14	137.78	9.00	1,108.89
35	63	1.20	7.65	232.22	5.68	1,238.13
40	37	1.70	9.35	287.78	13.92	3,810.39
45	49	1.80	11.08	204.44	10.86	2,064.52
50	37	1.90	11.12	215.56	23.97	4,824.25
55	31	3.00	17.80	219.44	75.01	15,388.72
60	36	2.70	15.27	176.67	50.29	8,158.84
65	17	1.20	16.76	190.56	13.76	2,424.16
70	22	2.65	12.39	189.72	32.29	5,661.45
75	12	4.70	17.20	148.06	68.95	9,206.25
80	5	3.70	7.72	153.89	53.26	7,423.17
85	12	2.50	17.79	150.56	50.15	6,821.20
90	12	2.40	20.03	98.89	14.38	1,210.49
95	15	1.70	25.33	135.00	56.08	6,753.15
100	6	3.00	5.47	147.50	37.10	4,932.96
120	5	3.70	20.36	132.22	111.42	13,106.36
185	7	5.90	31.81	73.89	653.64	38,627.58

* Air density (kg/m^3) was calculated using the exit gas temperature at a standard atmospheric pressure (101,325 Pa) with a gas constant for dry air (287.05 J/kg-K). Height above sea level was assumed to equal the stack height.

** Calculated for an air temperature of 15°C

APPENDIX 14: Dispersion parameters for gaussian plume models in urban and rural settings

The direction and magnitude of plume dispersion in HADES is informed by hourly estimates of atmospheric stability, and measurements of wind speed and direction. Atmospheric stability measures the tendency for an air parcel to rise or resit vertical motion, as it is horizontally displaced by the prevailing wind. These three processes are the main determinants of how pollutants released into the lower atmosphere are dispersed.

HADES uses the sevenfold Pasquill-Turner classification system to describe atmospheric stability, which ranges from highly turbulent (A), to neutral (D), and extremely stable day (F) or night-time (G) conditions. These stability categories are associated with unique vertical ($\boldsymbol{\sigma_z}$) and horizontal ($\boldsymbol{\sigma_y}$) dispersion parameters, which define how plume concentrations deviate from their point of release in a gaussian dispersion model.

In urban locations, $\boldsymbol{\sigma_z}$ and $\boldsymbol{\sigma_y}$ are calculated using Briggs-McElroy-Pooler functions, where **x** is a measured distance in meters, downwind of the pollutant source on the x-axis [17, 18]

Stability Class	Briggs-McElroy-Pooler Formulas	
	σZ (meters)	σY (meters)
A/B	$(0.24x) * (1+0.0010x)^{-0.5}$	$(0.32x) * (1+0.0004x)^{-0.5}$
C	$(0.20x)$	$(0.22x) * (1+0.0004x)^{-0.5}$
D	$(0.14x) * (1+0.0003x)^{-0.5}$	$(0.16x) * (1+0.0004x)^{-0.5}$
E/F *	$(0.08x) * (1+0.0015x)^{-0.5}$	$(0.11x) * (1+0.0004x)^{-0.5}$

* In accordance to US Nuclear Regulatory Commission regulatory guidance [19], σ_y and σ_z for stability class "G" are obtained by multiplying the calculated values under stability class "F" by 0.6 and 0.667, respectively. The values under stability class "G" ignore plume meander and other lateral enhancements.

For rural locations, $\boldsymbol{\sigma_z}$ and $\boldsymbol{\sigma_y}$ are calculated using Pasquill-Gifford functions [20, 21]

$$\sigma_z = a * \left(\frac{x}{1000}\right)^b$$

$$\sigma_y = 465.11628 * \left(\frac{x}{1000}\right) * \tan\left(0.017453293 * \left[c - d * \log\left(\frac{x}{1000}\right)\right]\right)$$

Where **x** is a measured distance in meters, downwind of the pollutant source on the x-axis. Coefficients **a**, **b**, **c**, and **d** are obtained from the following table [adapted from 21]:

[17] McElroy, J.L. and F. Pooler, 1968: The St. Louis Dispersion Study. U.S. Public Health Service, National Air Pollution Control Administration, Report AP-53

[18] Briggs, G.A. (1973) Diffusion Estimation for Small Emissions, ATDL Contributions File No. (Draft) 79, Air Resources Atmospheric Turbulence and Diffusion Laboratory. National Oceanic and Atmospheric Administration, Oak Ridge.

[19] US Nuclear Regulatory Commission (1983). Regulatory Guide 1.145. Washington, D.C.

[20] Turner D (1970). Workbook of Atmospheric Dispersion Estimates. PHS Publication No. 999-AP-26. U.S. Department of Health, Education and Welfare, National Air Pollution Control Administration, Cincinnati, Ohio.

[21] U.S. Environmental Protection Agency (US EPA 1995). User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volume 2: Description of Model Algorithms. No. 4541B-95-003B. Office of Air Quality Planning and Standards, North Carolina.

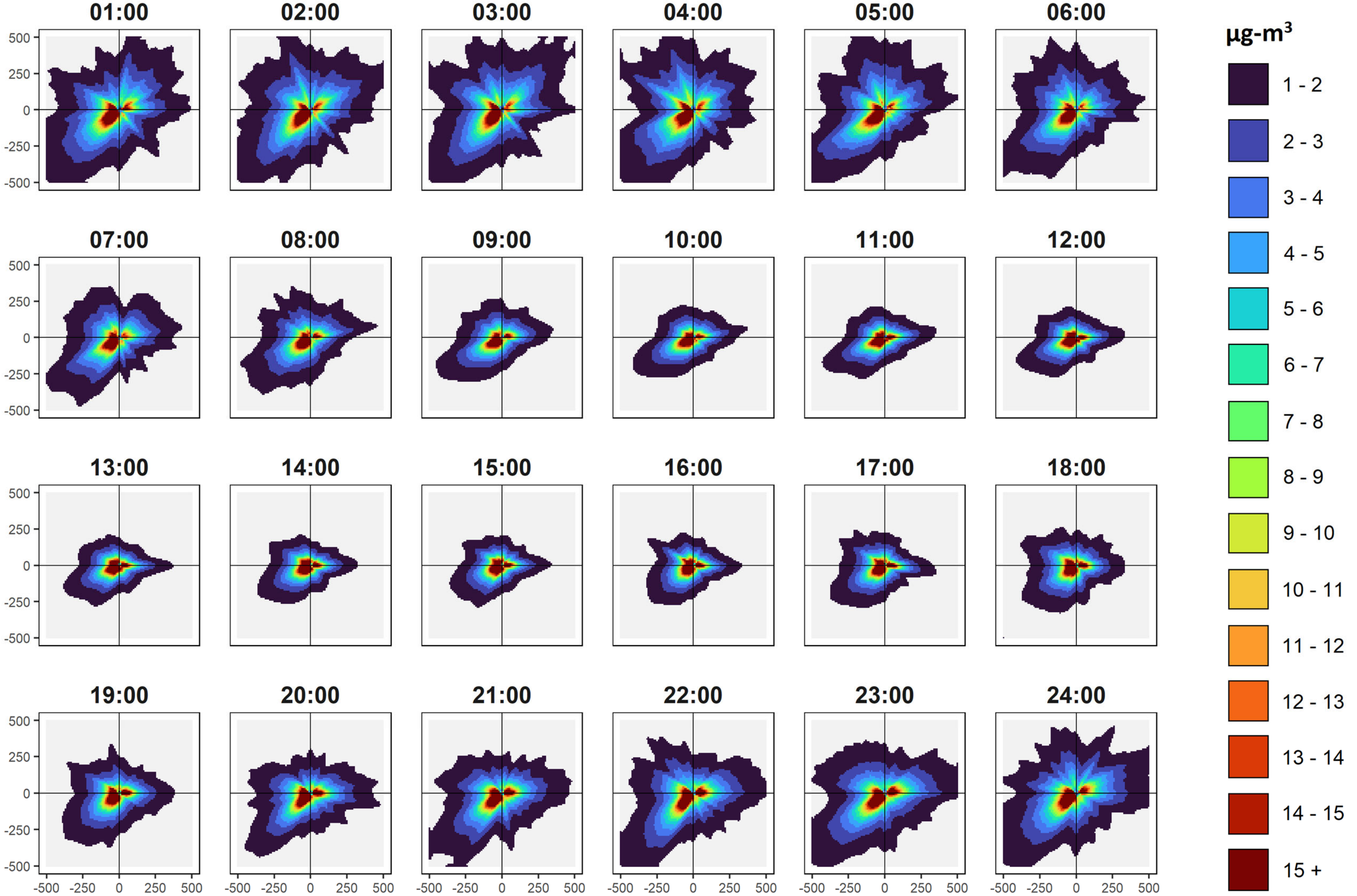
Stability Category	x (meters)	Pasquill-Gifford Coefficients			
		a	b	c	d
A *	< 100	122.800	0.94470	24.1670	2.5334
	100 - 159	158.080	1.05420		
	160 - 209	170.220	1.09320		
	210 - 259	179.520	1.12620		
	260 - 309	217.410	1.26440		
	310 - 409	258.890	1.40940		
	410 - 509	346.750	1.72830		
	510 - 3,109	453.850	2.11660		
	≥ 3,110	**	**		
B *	< 200	90.673	0.93198	18.3330	1.8096
	200 - 399	98.483	0.98332		
	≥ 400	109.300	1.09710		
C *	All - All	61.141	0.91465	12.5000	1.0857
D	< 300	34.459	0.86974	8.3330	0.7238
	300 - 1009	32.093	0.81066		
	1,010 - 3,009	32.093	0.64403		
	3,010 - 10,009	33.504	0.60486		
	10,010 - 29,999	36.650	0.56589		
	≥ 30,000	44.053	0.51179		
E	< 100	24.260	0.83660	6.2500	0.5429
	100 - 309	23.331	0.81956		
	310 - 1009	21.628	0.75660		
	1,010 - 2,009	21.628	0.63077		
	2,010 - 4,009	22.534	0.57154		
	4,010 - 10,009	24.703	0.50527		
	10,010 - 20,009	26.970	0.46713		
	20,010 - 39,999	35.420	0.37615		
	≥ 40,000	47.618	0.29592		
F/G ***	< 200	15.209	0.81558	4.1667	0.3619
	200 - 709	14.457	0.78407		
	710 - 1,009	13.953	0.68465		
	1,010 - 2,009	13.953	0.63227		
	2,010 - 3,009	14.823	0.54503		
	3,010 - 7,009	16.187	0.46490		
	7,010 - 15,009	17.836	0.41507		
	15,010 - 30,009	22.651	0.32681		
	30,010 - 59,999	27.074	0.27436		
	≥ 60,000	34.219	0.21716		

* If the calculated value of σ_z exceeds 5000 meters, σ_z is set to 5000 meters.

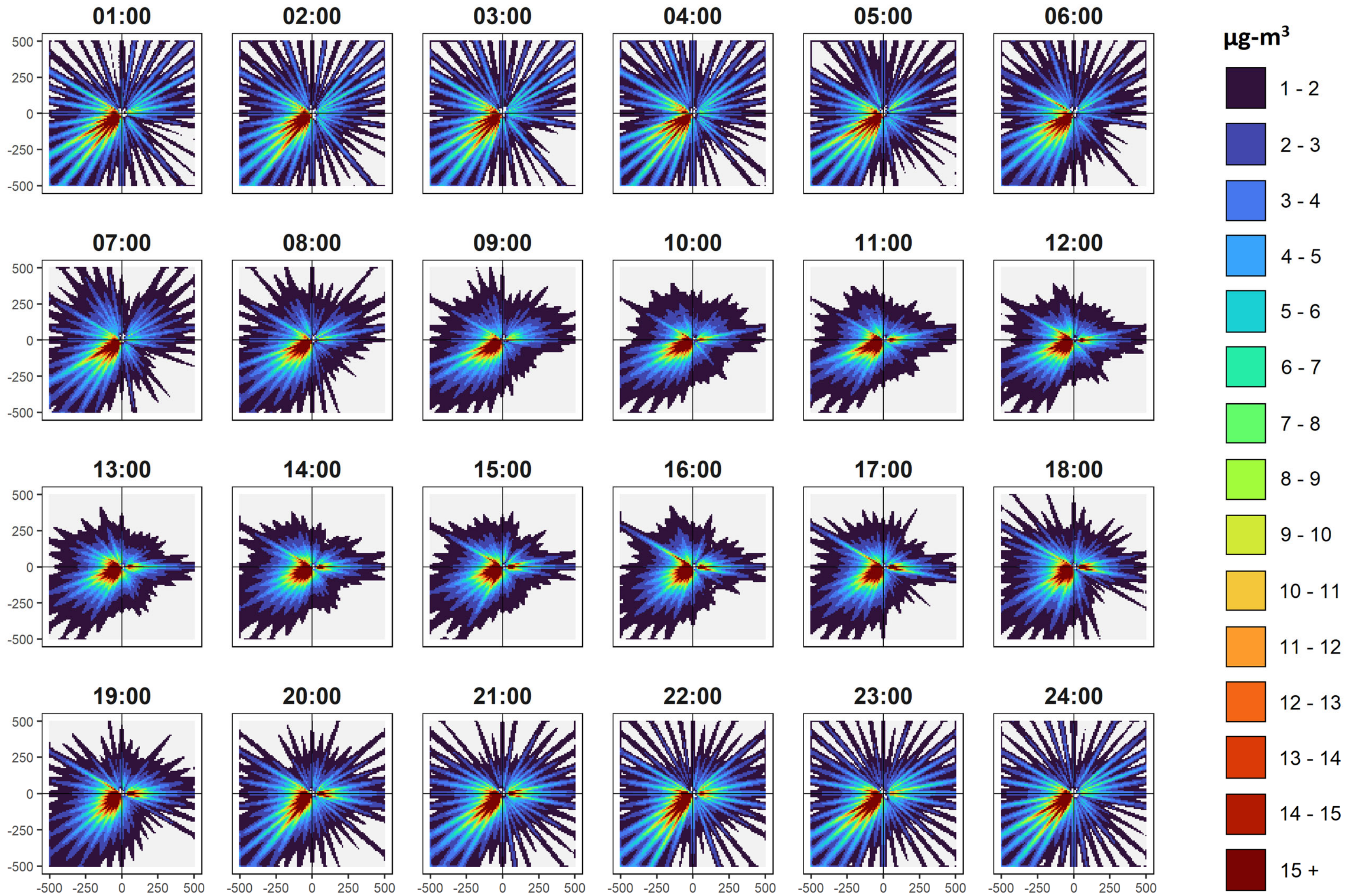
** σ_z is set to 5000 meters.

*** In accordance to US Nuclear Regulatory Commission regulatory guidance [19], σ_y and σ_z for stability class "G" are obtained by multiplying the calculated values under stability class "F" by 0.6 and 0.667, respectively. The values under stability class “G” ignore plume meander and other lateral enhancements.

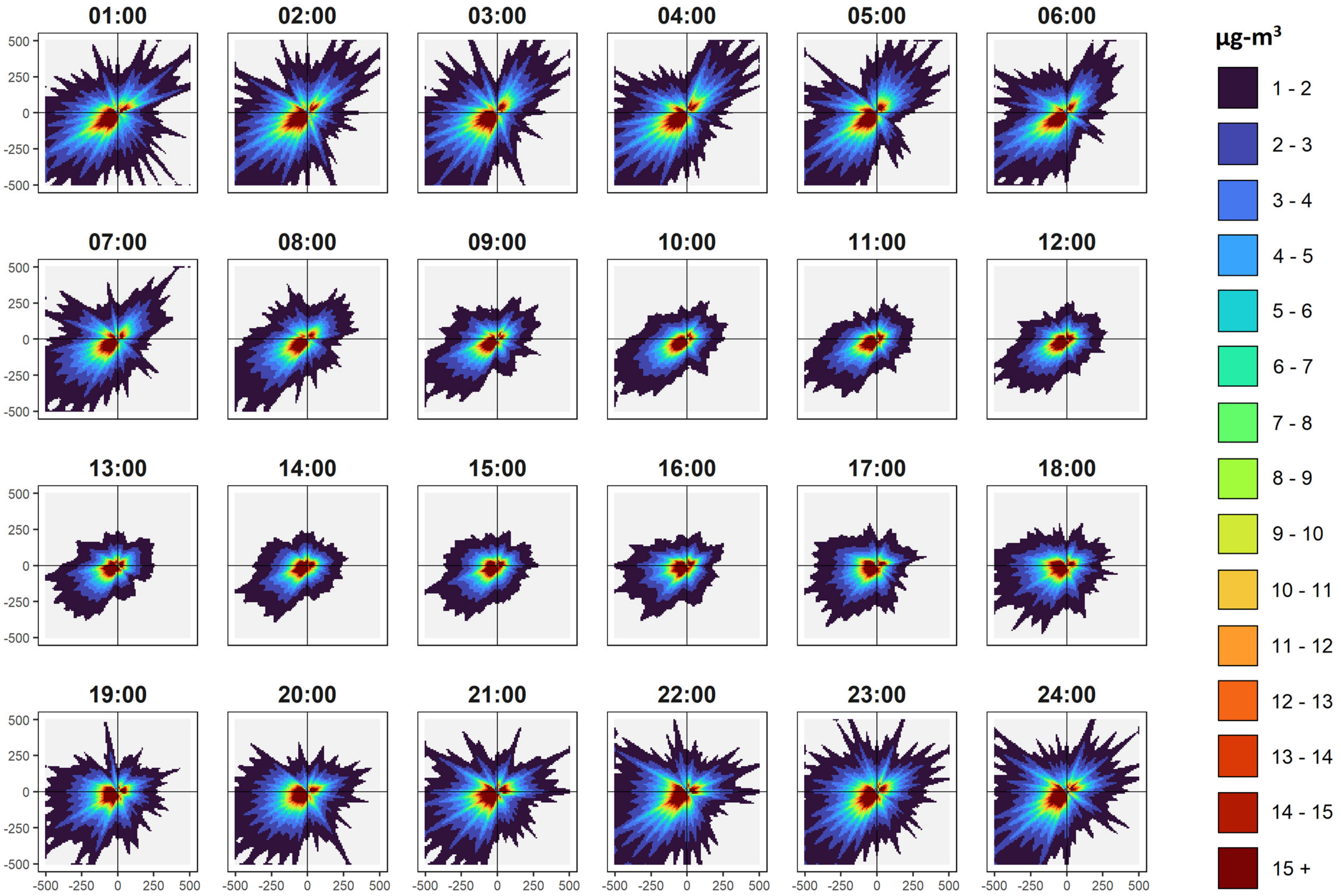
APPENDIX 15: Central London hourly-annual average dispersion kernel plot profiles in 2019 (Oxford Street: Urban Index = 100%)



APPENDIX 16: Central London hourly-annual average dispersion kernel plot profiles in 2019 (Inner Hyde Park: Urban Index = 0%)



APPENDIX 17: Nottingham City (East Midlands) hourly-annual average dispersion kernel plot profiles in 2019 (Urban Index = 75%)



APPENDIX 18: Calibration of the road-transport NOx emissions (C1)

A log-linear model is used to convert the road-transport NOx emissions dispersion model results into real-world concentrations:

$$Y_i = EXP(\beta_0 + (\beta_1 * X_1) + \dots + (\beta_N * X_N))$$

The model uses log-transformed road-transport NOx emissions dispersed to the receptor locations, and land-use variables that act as additional weights (0-1) in the calibration.

Predictor Variables			Estimate	P-Value	95% CI Estimates		75% HDI Estimates	
Effects	Group	Name			Lower	Upper	Lower	Upper
Fixed	Baseline	Intercept	+ 2.537	< 0.01	+ 2.535	+ 2.537	+ 2.519	+ 2.552
	Land Weights (Normalised 0-1)	W0 = Roadway	-	-	-	-	-	-
		W1 = Urban Index	-	-	-	-	-	-
		W2 = Built-up	+ 1.176	< 0.01	+ 1.176	+ 1.179	+ 1.138	+ 1.219
		W3 = Elevation-A	- 0.376	< 0.01	- 0.377	- 0.376	- 0.394	- 0.359
	Dispersion	Road-NOx	+ 0.058	< 0.01	+ 0.057	+ 0.058	+ 0.054	+ 0.061
		Road-NOx * W0	+ 0.147	< 0.01	+ 0.146	+ 0.147	+ 0.143	+ 0.149
		Road-NOx * W2	+ 0.410	< 0.01	+ 0.409	+ 0.410	+ 0.399	+ 0.418
	Topography	W1 * W2 * W3	+ 2.186	< 0.01	+ 2.186	+ 2.190	+ 2.143	+ 2.236
	Kerbside Interactions	W0 * W1	+ 5.632	< 0.01	+ 5.627	+ 5.632	+ 5.534	+ 5.723
		W0 * W1 * W2	- 11.206	< 0.01	- 11.206	- 11.191	- 11.415	- 10.973
		W0 * W1 * W3	- 10.667	< 0.01	- 10.667	- 10.650	- 10.816	- 10.489
		W0 * W2 * W3	+ 4.921	< 0.01	+ 4.921	+ 4.928	+ 4.868	+ 4.986
		W0 * W1 * W2 * W3	+ 17.768	< 0.01	+ 17.716	+ 17.768	+ 17.330	+ 18.113
Random	Time (Hour)	00:00	+ 0.084	< 0.01	+ 0.081	+ 0.084	+ 0.073	+ 0.090
		01:00	+ 0.088	< 0.01	+ 0.085	+ 0.088	+ 0.077	+ 0.094
		02:00	+ 0.071	< 0.01	+ 0.069	+ 0.071	+ 0.060	+ 0.077
		03:00	+ 0.029	0.23	+ 0.027	+ 0.029	+ 0.018	+ 0.035
		04:00	+ 0.056	0.02	+ 0.054	+ 0.056	+ 0.045	+ 0.063
		05:00	+ 0.101	< 0.01	+ 0.099	+ 0.101	+ 0.091	+ 0.108
		06:00	+ 0.141	< 0.01	+ 0.139	+ 0.141	+ 0.131	+ 0.147
		07:00	+ 0.121	< 0.01	+ 0.120	+ 0.121	+ 0.113	+ 0.128
		08:00	+ 0.099	< 0.01	+ 0.098	+ 0.099	+ 0.091	+ 0.106
		09:00	+ 0.085	< 0.01	+ 0.084	+ 0.085	+ 0.077	+ 0.091
		10:00	- 0.002	0.92	- 0.002	- 0.002	- 0.009	+ 0.006
		11:00	- 0.091	< 0.01	- 0.091	- 0.089	- 0.097	- 0.082
		12:00	- 0.156	< 0.01	- 0.156	- 0.153	- 0.161	- 0.145
		13:00	- 0.185	< 0.01	- 0.185	- 0.181	- 0.189	- 0.174
		14:00	- 0.178	< 0.01	- 0.178	- 0.175	- 0.183	- 0.167
		15:00	- 0.145	< 0.01	- 0.145	- 0.143	- 0.150	- 0.135
		16:00	- 0.108	< 0.01	- 0.108	- 0.106	- 0.113	- 0.099
		17:00	- 0.090	< 0.01	- 0.090	- 0.088	- 0.095	- 0.080
		18:00	- 0.042	0.08	- 0.042	- 0.041	- 0.048	- 0.033
		19:00	+ 0.005	0.85	+ 0.005	+ 0.005	- 0.002	+ 0.012
		20:00	+ 0.025	0.29	+ 0.025	+ 0.025	+ 0.018	+ 0.032
		21:00	+ 0.032	0.18	+ 0.031	+ 0.032	+ 0.024	+ 0.039
		22:00	+ 0.027	0.25	+ 0.027	+ 0.027	+ 0.019	+ 0.034
		23:00	+ 0.033	0.16	+ 0.032	+ 0.033	+ 0.024	+ 0.040

APPENDIX 19: Calibration of the national atmospheric emission inventory NOx emissions (C2)

A log-linear model is used to calibrate the combined contributions of the point (large industrial stacks) and area (commercial, domestic, other industrial and natural) source dispersion models:

$$Y_i = EXP\ (\beta_0 + (\beta_1 * X_1) + \ldots + (\beta_N * X_N))$$

The model uses log-transformed road-transport NOx emissions dispersed to the receptor locations, and land-use variables that act as additional weights (0-1) in the calibration.

Predictor Variables			Estimate	P-Value	95% CI Estimates		75% HDI Estimates	
Effects	**Group**	**Name**			**Lower**	**Upper**	**Lower**	**Upper**
Fixed	Baseline	Intercept	+ 2.582	< 0.01	+ 2.582	+ 2.583	+ 2.577	+ 2.588
	Land Weights (Normalised 0-1)	W0 = Elevation-A	-	-	-	-	-	-
		W1 = Elevation-B	-	-	-	-	-	-
		W2 = Urban Index	+ 0.394	< 0.01	+ 0.394	+ 0.394	+ 0.387	+ 0.401
		W3 = Built-up	-	-	-	-	-	-
	Dispersion	AP-NOx	+ 0.094	< 0.01	+ 0.094	+ 0.094	+ 0.089	+ 0.099
		AP-NOx * W0	+ 0.109	< 0.01	+ 0.109	+ 0.109	+ 0.101	+ 0.117
		AP-NOx * W1	+ 0.265	< 0.01	+ 0.265	+ 0.265	+ 0.257	+ 0.272
		AP-NOx * W2 *W3	+ 0.214	< 0.01	+ 0.214	+ 0.214	+ 0.204	+ 0.223
	Topography	W0 * W1	+ 0.548	< 0.01	+ 0.548	+ 0.548	+ 0.528	+ 0.567
Random	Time (Hour)	00:00	- 0.135	< 0.01	- 0.135	- 0.134	- 0.143	- 0.125
		01:00	- 0.211	< 0.01	- 0.211	- 0.209	- 0.219	- 0.200
		02:00	- 0.278	< 0.01	- 0.278	- 0.276	- 0.286	- 0.267
		03:00	- 0.290	< 0.01	- 0.290	- 0.288	- 0.297	- 0.279
		04:00	- 0.206	< 0.01	- 0.206	- 0.204	- 0.213	- 0.195
		05:00	+ 0.000	0.99	+ 0.000	+ 0.000	- 0.009	+ 0.009
		06:00	+ 0.204	< 0.01	+ 0.202	+ 0.204	+ 0.193	+ 0.211
		07:00	+ 0.302	< 0.01	+ 0.300	+ 0.302	+ 0.291	+ 0.309
		08:00	+ 0.295	< 0.01	+ 0.293	+ 0.295	+ 0.285	+ 0.302
		09:00	+ 0.200	< 0.01	+ 0.199	+ 0.200	+ 0.190	+ 0.208
		10:00	+ 0.088	< 0.01	+ 0.087	+ 0.088	+ 0.079	+ 0.096
		11:00	- 0.004	0.88	- 0.004	- 0.004	- 0.013	+ 0.004
		12:00	- 0.069	0.01	- 0.069	- 0.068	- 0.077	- 0.060
		13:00	- 0.102	< 0.01	- 0.102	- 0.101	- 0.110	- 0.093
		14:00	- 0.086	< 0.01	- 0.086	- 0.086	- 0.094	- 0.077
		15:00	- 0.023	0.39	- 0.023	- 0.023	- 0.031	- 0.015
		16:00	+ 0.043	0.11	+ 0.043	+ 0.043	+ 0.035	+ 0.051
		17:00	+ 0.085	< 0.01	+ 0.084	+ 0.085	+ 0.076	+ 0.092
		18:00	+ 0.096	< 0.01	+ 0.095	+ 0.096	+ 0.087	+ 0.104
		19:00	+ 0.088	< 0.01	+ 0.087	+ 0.088	+ 0.079	+ 0.096
		20:00	+ 0.058	0.03	+ 0.058	+ 0.058	+ 0.049	+ 0.066
		21:00	+ 0.030	0.26	+ 0.030	+ 0.030	+ 0.021	+ 0.038
		22:00	- 0.011	0.68	- 0.011	- 0.011	- 0.020	- 0.002
		23:00	- 0.074	0.01	- 0.074	- 0.074	- 0.083	- 0.065

APPENDIX 20: Model used to calculate total NOx concentrations (M1)

A linear model (intercept-free) is used to combine the contributions from road-transport and area-point sources, accounting for residence (removal) time and building canyon effects:

$$Y_i = (\beta_1 * X_1) + \ldots + (\beta_N * X_N)$$

All the predictive variables are normalised to defined lower and upper limits.

Variables (Normalised 0-1)			Estimate	P-Value	95% CI Estimates		75% HDI Estimates	
Effects	Group	Name			Lower	Upper	Lower	Upper
Fixed	Dispersion	Calibrated Road-NOx (C1)	+ 175.42	< 0.01	+ 175.41	+ 175.43	+ 174.18	+ 176.66
		Calibrated AP-NOx (C2)	+ 24.85	< 0.01	+ 24.85	+ 25.02	+ 24.19	+ 25.83
	Topography	Building Heights (BH)	-	-	-	-	-	-
		Building Height Variability (BHV)	- 115.14	< 0.01	- 115.76	- 115.14	- 118.79	- 112.64
		BH * BHV	+ 173.85	< 0.01	+ 173.85	+ 174.67	+ 170.02	+ 179.21

APPENDIX 21: Model used to calculate total NO_2 concentrations (M2)

A linear model is used to calculate nitrogen dioxide concentrations based on local (modelled NOx) and regional (satellite observations) concentrations, weather, and vegetation influences:

$$Y_i = \beta_0 + (\beta_1 * X_1) + \ldots + (\beta_N * X_N)$$

All the predictive variables are normalised to defined lower and upper limits.

Variables (Normalised 0-1)			Estimate	P-Value	95% CI Estimates		75% HDI Estimates	
Effects	Group	Name			Lower	Upper	Lower	Upper
Fixed	Baseline	Intercept	+ 98.786	< 0.01	+ 96.854	+ 98.786	+ 93.282	+ 100.55
	Dispersion	Total-NOx	+ 34.568	< 0.01	+ 34.470	+ 34.568	+ 33.013	+ 35.947
		Regional-NO_2	+ 32.887	< 0.01	+ 32.887	+ 33.030	+ 32.611	+ 33.439
		Total-NOx * Regional-NO_2	- 40.921	< 0.01	- 40.921	- 40.880	- 42.541	- 39.261
	Weather	Temperature	- 78.403	< 0.01	- 78.403	- 76.846	- 81.896	- 71.926
		Relative-Humidity (RH)	- 102.934	< 0.01	- 102.934	- 100.535	- 104.780	- 96.403
		Temperature * RH	+ 72.808	< 0.01	+ 70.789	+ 72.808	+ 65.018	+ 76.697
	Nature	Greenspace (GS)	- 4.165	< 0.01	- 4.177	- 4.165	- 4.364	- 3.988
	Interactions	Total-NOx * Temperature	+ 61.916	< 0.01	+ 61.916	+ 62.063	+ 59.883	+ 64.233
		Total-NOx * RH * GS	- 12.855	< 0.01	- 12.952	- 12.855	- 14.534	- 11.321
Random	Time (Hour)	00:00	+ 2.833	< 0.01	+ 2.738	+ 2.833	+ 2.608	+ 2.876
		01:00	+ 3.012	< 0.01	+ 2.904	+ 3.012	+ 2.770	+ 3.045
		02:00	+ 3.363	< 0.01	+ 3.243	+ 3.363	+ 3.100	+ 3.392
		03:00	+ 3.945	< 0.01	+ 3.815	+ 3.945	+ 3.661	+ 3.975
		04:00	+ 5.048	< 0.01	+ 4.908	+ 5.048	+ 4.741	+ 5.082
		05:00	+ 6.013	< 0.01	+ 5.874	+ 6.013	+ 5.692	+ 6.062
		06:00	+ 5.579	< 0.01	+ 5.461	+ 5.579	+ 5.284	+ 5.642
		07:00	+ 3.444	< 0.01	+ 3.364	+ 3.444	+ 3.211	+ 3.520
		08:00	+ 0.485	0.17	+ 0.454	+ 0.485	+ 0.320	+ 0.591
		09:00	- 2.123	< 0.01	- 2.123	- 2.099	- 2.230	- 1.968
		10:00	- 3.893	< 0.01	- 3.893	- 3.821	- 3.967	- 3.676
		11:00	- 4.853	< 0.01	- 4.853	- 4.743	- 4.913	- 4.574
		12:00	- 5.273	< 0.01	- 5.273	- 5.141	- 5.333	- 4.951
		13:00	- 5.329	< 0.01	- 5.329	- 5.181	- 5.388	- 4.976
		14:00	- 5.144	< 0.01	- 5.144	- 4.992	- 5.206	- 4.779
		15:00	- 4.702	< 0.01	- 4.702	- 4.554	- 4.766	- 4.345
		16:00	- 4.172	< 0.01	- 4.172	- 4.040	- 4.238	- 3.844
		17:00	- 3.343	< 0.01	- 3.343	- 3.234	- 3.409	- 3.061
		18:00	- 2.038	< 0.01	- 2.038	- 1.962	- 2.115	- 1.811
		19:00	- 0.483	0.17	- 0.483	- 0.445	- 0.576	- 0.315
		20:00	+ 0.902	0.01	+ 0.898	+ 0.902	+ 0.780	+ 1.021
		21:00	+ 1.924	< 0.01	+ 1.888	+ 1.924	+ 1.767	+ 2.012
		22:00	+ 2.364	< 0.01	+ 2.304	+ 2.364	+ 2.178	+ 2.434
		23:00	+ 2.443	< 0.01	+ 2.362	+ 2.443	+ 2.234	+ 2.498

APPENDIX 22: Model used to calculate total O_3 concentrations (M3)

A linear model is used to calculate ozone concentrations based on local (modelled NOx and NO_2) and regional (satellite observations) concentrations, weather, topography, and vegetation influences:

$$Y_i = \beta_0 + (\beta_1 * X_1) + \ldots + (\beta_N * X_N)$$

All the predictive variables are normalised to defined lower and upper limits.

Variables (Normalised 0-1)			Estimate	P-Value	95% CI Estimates		75% HDI Estimates	
Effects	Group	Name			Lower	Upper	Lower	Upper
Fixed	Baseline	Intercept	+ 27.805	0.01	+ 27.805	+ 30.867	+ 26.670	+ 34.964
	Dispersion	Total-NOx	-	-	-	-	-	-
		Total-NO_2	- 68.802	< 0.01	- 69.761	- 68.802	- 71.592	- 67.892
		Regional-O_3	+ 31.418	< 0.01	+ 31.227	+ 31.418	+ 30.676	+ 31.788
		Total-NOx * Total-NO_2	+ 131.941	< 0.01	+ 131.53	+ 131.94	+ 127.09	+ 136.03
	Weather	Temperature	+ 106.812	< 0.01	+ 104.44	+ 106.81	+ 99.521	+ 109.42
		Relative-Humidity (RH)	+ 31.140	0.01	+ 27.858	+ 31.140	+ 23.495	+ 32.333
		Temperature * RH	- 146.155	< 0.01	- 146.155	- 143.523	- 149.823	- 137.311
	Topography	Urban Index (UI)	- 30.362	< 0.01	- 30.367	- 30.349	- 31.332	- 29.402
	Nature	Greenspace * Temperature	- 3.259	0.01	- 3.415	- 3.259	- 3.810	- 3.013
	Interactions	Total-NOx * Temperature	- 86.260	< 0.01	- 86.260	- 84.777	- 87.365	- 82.254
		UI * Total-NOx	-	-	-	-	-	-
		UI * Total-NO_2	+ 48.442	< 0.01	+ 48.432	+ 48.460	+ 46.920	+ 49.969
		UI * Total-NOx * Total-NO_2	- 98.639	< 0.01	- 98.639	- 98.547	- 102.503	- 94.669
		UI * Temperature	- 13.387	0.02	- 13.689	- 13.387	- 15.589	- 11.719
		UI * Temperature * RH	+ 73.451	< 0.01	+ 73.451	+ 73.805	+ 69.469	+ 78.055
Random	Time (Hour)	00:00	- 3.618	< 0.01	- 3.618	- 3.520	- 3.669	- 3.375
		01:00	- 5.000	< 0.01	- 5.000	- 4.891	- 5.047	- 4.738
		02:00	- 6.186	< 0.01	- 6.186	- 6.065	- 6.230	- 5.903
		03:00	- 7.394	< 0.01	- 7.394	- 7.260	- 7.439	- 7.085
		04:00	- 8.164	< 0.01	- 8.164	- 8.008	- 8.202	- 7.816
		05:00	- 8.256	< 0.01	- 8.256	- 8.086	- 8.291	- 7.885
		06:00	- 7.322	< 0.01	- 7.322	- 7.164	- 7.360	- 6.971
		07:00	- 4.894	< 0.01	- 4.894	- 4.788	- 4.941	- 4.637
		08:00	- 1.116	< 0.01	- 1.116	- 1.090	- 1.209	- 0.974
		09:00	+ 2.326	< 0.01	+ 2.275	+ 2.326	+ 2.138	+ 2.410
		10:00	+ 4.109	< 0.01	+ 4.004	+ 4.109	+ 3.839	+ 4.170
		11:00	+ 4.552	< 0.01	+ 4.414	+ 4.552	+ 4.230	+ 4.599
		12:00	+ 4.715	< 0.01	+ 4.560	+ 4.715	+ 4.363	+ 4.758
		13:00	+ 4.742	< 0.01	+ 4.582	+ 4.742	+ 4.377	+ 4.789
		14:00	+ 4.893	< 0.01	+ 4.735	+ 4.893	+ 4.530	+ 4.942
		15:00	+ 5.021	< 0.01	+ 4.870	+ 5.021	+ 4.672	+ 5.070
		16:00	+ 5.538	< 0.01	+ 5.401	+ 5.538	+ 5.218	+ 5.587
		17:00	+ 6.009	< 0.01	+ 5.894	+ 6.009	+ 5.732	+ 6.057
		18:00	+ 5.808	< 0.01	+ 5.728	+ 5.808	+ 5.590	+ 5.868
		19:00	+ 4.403	< 0.01	+ 4.366	+ 4.403	+ 4.246	+ 4.488
		20:00	+ 2.589	< 0.01	+ 2.589	+ 2.599	+ 2.483	+ 2.713
		21:00	+ 0.584	0.09	+ 0.584	+ 0.630	+ 0.502	+ 0.753
		22:00	- 0.993	< 0.01	- 0.993	- 0.922	- 1.058	- 0.789
		23:00	- 2.347	< 0.01	- 2.347	- 2.263	- 2.403	- 2.126

APPENDIX 23: Townsend Deprivation Index (England and Wales, 2021)

The Townsend index is an indicator of material deprivation that has been widely used to identify socio-economic confounding in crime, education, and health research in England (22). This deprivation index is constructed from four unweighted UK Census variables, which describe the level of total unemployment, overcrowding, private vehicle ownership, and home ownership in each community.

Census 2021 tables RM024, TS052, TS045, and TS054 provided information on the four required measures, in 188,880 Output Area communities across England and Wales:

Variable 1: Proportion of "Total Unemployment" (RM024) *

Description *	"Unemployed Persons Age 16-74y" ÷ "Economically Active Age 16-74y"

** All students are considered as economically active by the original Index.*

Variable 2: "Proportion of "Overcrowded Households" (TS052)

Calculation **	("Households with a negative Bedroom Standard"/ "All Households")

*** The original index measured overcrowding in terms of 'persons per room', with any household with a number over 1 defined as overcrowded. In the 2021 UK Census, 'persons per room' was replaced with the 'Bedroom Standard' occupancy rating, where the following should have their own bedroom:*

1. *Married or cohabiting couple;*
2. *Single parent;*
3. *Person aged 16 years and over;*
4. *Pair of same-sex persons aged 10 to 15 years;*
5. *Person aged 10 to 15 years paired with a person under 10 years of the same sex;*
6. *Pair of children aged under 10 years, regardless of their sex;*
7. *Person aged under 16 years who cannot share a bedroom with someone in 4, 5 or 6 above.*

An occupancy rating of:

- *-1 or less: Implies that a household has fewer bedrooms than is required (overcrowded).*
- *+1 or more: Implies that a household's accommodation is under-occupied.*
- *0: suggests that a household's accommodation has an ideal number of bedrooms*

Although it is a more accurate measurement, it prevents the direct comparison with previous census years.

Variable 3: Proportion of "Households without Vehicle Ownership" (TS045)

Calculation	"Households without a Car or Van" ÷ "All households"

Variable 4: Proportion of "Households that are not owner occupied" (TS054)

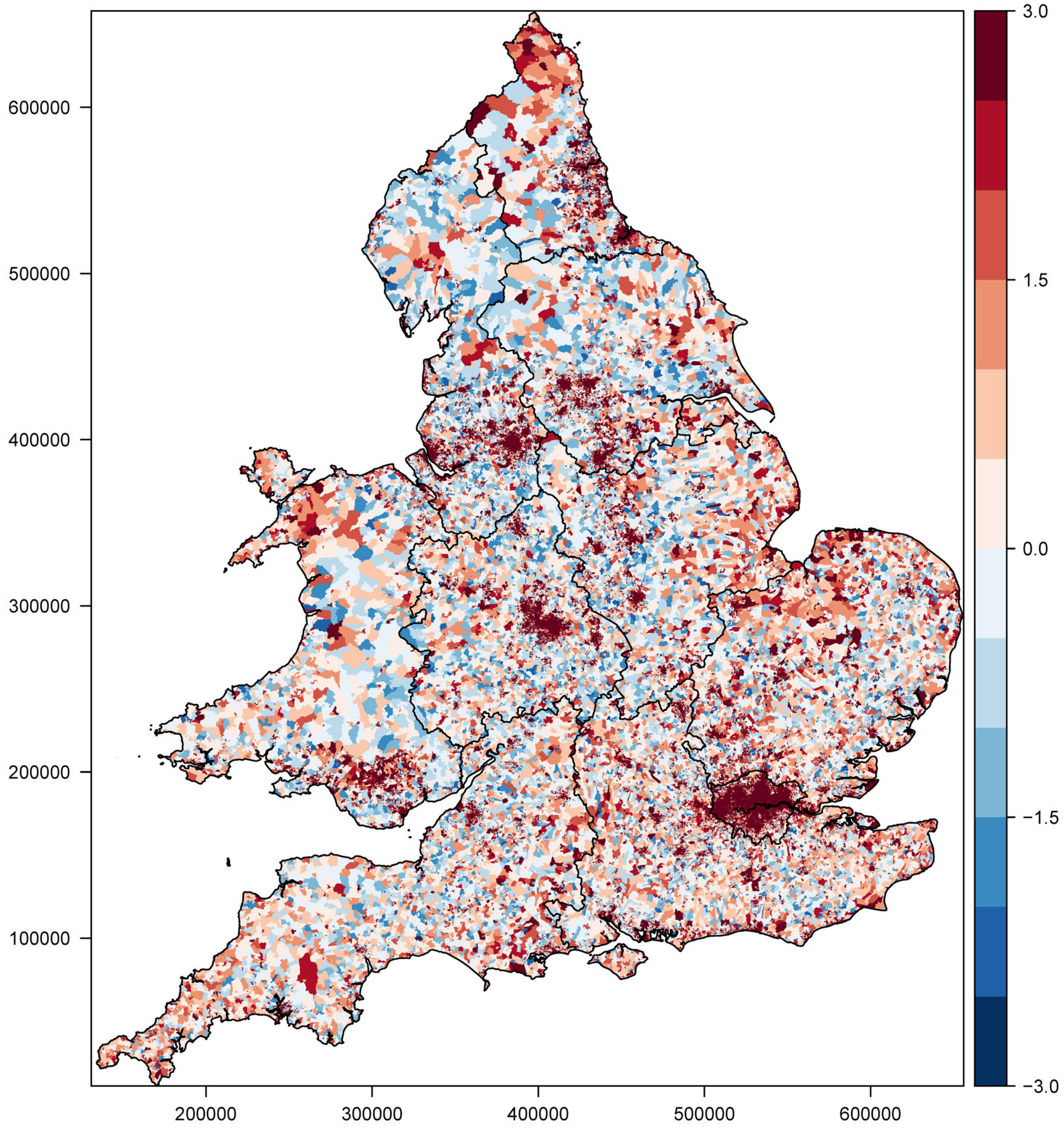
Calculation	("Social rented" + "Private rented" + "Living rent free") ÷ "All households"

[22] Townsend P, Phillimore P., and Beattie A. (1989). Health and Deprivation Inequality and the North. Routledge, London, UK. DOI: 10.4324/9781003368885

The four variables are converted in percentages, with the overcrowding and unemployment dimensions then experiencing a log transformation to reduce skewness within the distributions:

- Unemployment: LN ((Variable 1 * 100) + 1)
- Overcrowding: LN ((Variable 2 * 100) + 1)
- Vehicle Ownership: Variable 3 * 100
- Home ownership: Variable 4 * 100

Each of these variables were then converted into z-scores, and summed to return an index value measuring the relative level of material deprivation in each community. A value of 0 identifies communities that follow the national average of England and Wales, with negative values representing standard deviations of increased affluence, and positive values identifying standard deviations of increasing deprivation. Values were restricted to a range of -3 to +3 on the Townsend Index:



APPENDIX 24: Creating the "Urban Index" (UI) and devising a "Rural Urban Classification" (RUC)

We have devised a hybrid classification scheme called the Urban Index, which is based on established European Commission [(23)] and OECD [(24)] urban-rural population density thresholds. This scheme considers population counts in local and adjacent cells of a gridded surface to create a 0-1 index that records urban centres with a value of 1. Population count raster surfaces are available for all nations are available from www.worldpop.org at a 100x100m resolution on an annual basis from 2000 to 2020.

The following procedure is used to define the Urban Index (UI) value of each land cell:

- Urban Centre cells (UI = 1) have ≥ 1,500 inhabitants per km² and a total population of ≥ 5,000 per km² from a first-order rook's case neighbourhood search.
- Urban cells (UI = 0.8) have ≥ 300 inhabitants per km² and a total population of ≥ 5,000 per km² from a first-order queen's case neighbourhood search.
- Suburban cells (UI = 0.6) have ≥ 300 inhabitants per km² and are not deemed as Urban.
- Intermediate cells (UI = 0.4) have ≥ 150 and < 300 inhabitants per km².
- Thinly populated cells (UI = 0.2) have < 150 inhabitants per km².
- Unpopulated cells (UI = 0) have 0 inhabitants per km² from a first-order queen's case neighbourhood search.

The scheme is then resampled to a continuous value 10x10m raster surface, using Inverse distance weighted interpolation. This index appears to suitably identify and describe built-up areas within the United Kingdom (UK).

A national census of all people and households is conducted every ten years in the UK. Each census typically devises a Rural Urban Classification (RUC) of community areas that is used in national policy. In 2021, there were 188,880 UK Census Output Area (COA) communities within England and Wales. These COA's have an average area of 0.8 km^2 (SD = 3.5 km^2) and a median population of 306 (interquartile range of 263-355 residents).

At the time of this publication, a RUC has not been released for the UK since the 2011 census. The classification is limited by its infrequent release, which fails to adequately capture temporal change in land use over shorter timeframes. Furthermore, this is a scheme that is specific to the UK and cannot be transferred to other locations.

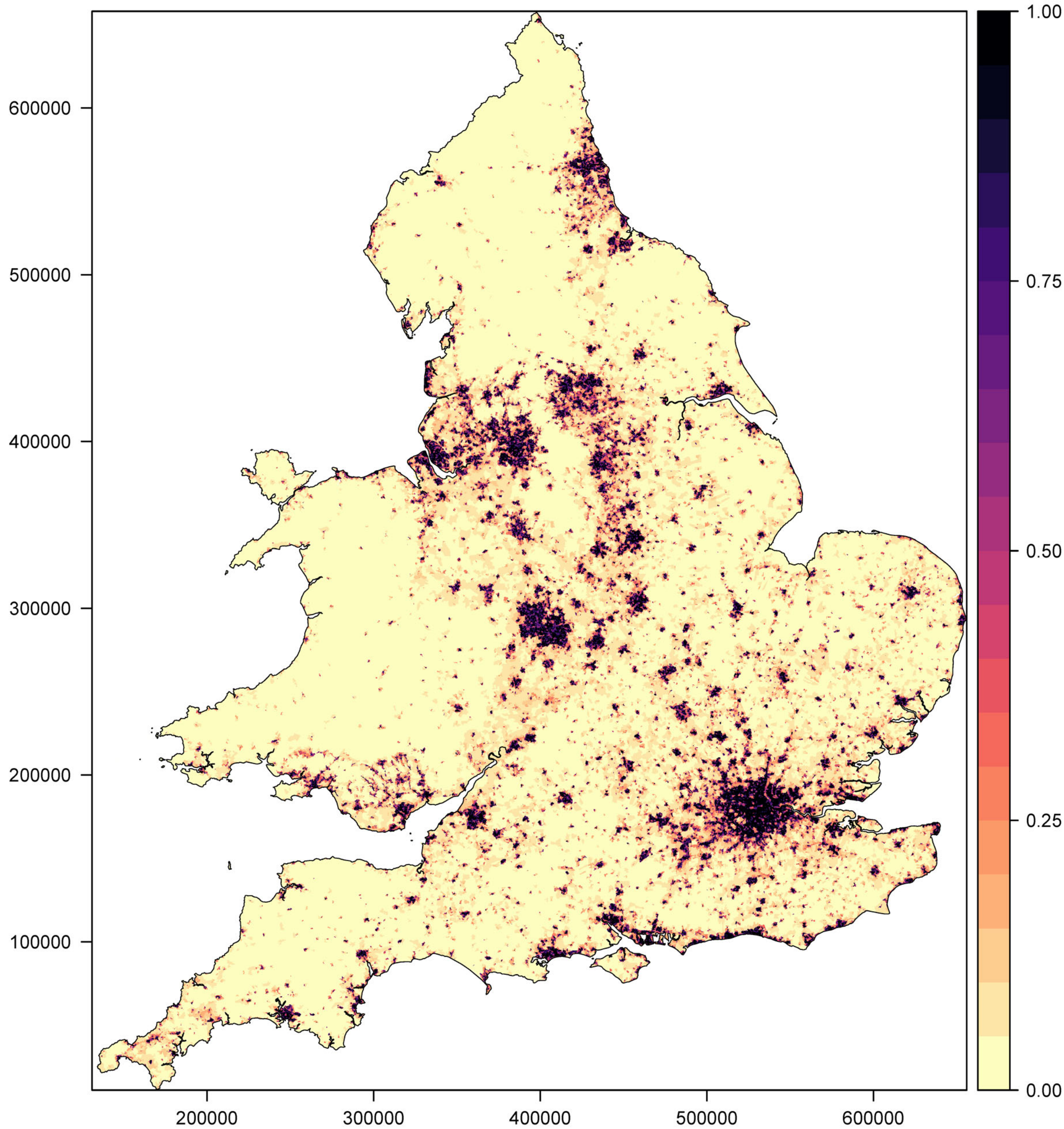
To solve these issues, it appears appropriate to calculate the mean UI value of all land 10x10m cells within each COA community. At a higher community level, the UI is equivalent to a RUC, where values:

1) Rural: < 0.25
2) Peri-Rural: 0.25 to 0.49
3) Peri-Urban: 0.50 to 0.74
4) Urban: >= 0.75

[23] European Commission (EC 2014). A harmonised definition of cities and rural areas: The new degree of urbanisation. Regional and Urban Policy, Regional Working Paper. URL: https://ec.europa.eu/regional_policy/sources/work/2014_01_new_urban.pdf

[24] Organisation for Economic Co-operation and Development (OECD 2016). OECD Regional Outlook 2016: Productive Regions for Inclusive Societies, OECD Publishing, Paris. URL: https://doi.org/10.1787/9789264260245-en

The Rural Urban Classification (RUC) of COA communities within England and Wales is as follows:



This RUC scheme shows that 93% of the landmass is covered by rural and peri-rural areas. This agrees with the latest UK government estimates that rural areas make up 90% of England [25], and more than 90% of Wales [26]. Approximately, 21% of the population are living in these rural and peri-rural locations in 2020. This is again in near agreement with the current government estimates that 17% of the population in England lived in rural areas in 2019 [27]. Therefore, with reasonable confidence we can recommend this approach for devising RUC schemes in other locations and for other timeframes.

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[25] House of Lords (2018). Time for a strategy for the rural economy. Select Committee on the Rural Economy, Report of Session 2017–19, Paper 330, House of Lords, London. URL: https://publications.parliament.uk/pa/ld201719/ldselect/ldrurecon/330/330.pdf

[26] European Commission (2023). Factsheet on 2014-2020 Rural Development Programme for Wales.
URL: https://agriculture.ec.europa.eu/system/files/2023-11/rdp-factsheet-wales_en.pdf

[27] UK Government (2021). Trend Deck 2021: Urbanisation. Government Office for Science, London.
URL: www.gov.uk/government/publications/trend-deck-2021-urbanisation/trend-deck-2021-urbanisation

APPENDIX 25: Annual NOx emissions across England and Wales in 2018-2020, by region and major source. Point (large industrial stacks) and area (commercial, domestic, other industrial, and natural) sources were resampled from the UK National Atmospheric Emission Inventory (1x1km) by land use (10x10m). Road-transport emissions were modelled within HADES.

Region	Year	NOx Emissions (Tonnes)			
		Point	Area	Road	Total
England & Wales (Total)	2018	148,299	241,412	288,102	677,813
	2019	133,436	246,974	275,207	655,617
	2020	132,152	199,207	212,988	544,347
East Midlands	2018	31,773	24,615	28,684	85,072
	2019	21,449	25,565	27,324	74,338
	2020	17,528	20,650	21,444	59,622
East of England	2018	9,114	29,638	38,411	77,163
	2019	8,023	30,398	36,604	75,025
	2020	8,439	24,388	28,904	61,731
London	2018	3,770	16,781	14,039	34,590
	2019	3,920	16,772	13,248	33,940
	2020	4,882	13,529	10,042	28,453
North East	2018	8,626	9,404	12,024	30,054
	2019	9,501	9,699	11,469	30,669
	2020	8,724	7,871	8,885	25,480
North West	2018	15,621	29,147	35,138	79,906
	2019	15,649	29,802	33,503	78,954
	2020	15,794	23,992	26,438	66,224
South East	2018	16,489	35,660	48,941	101,090
	2019	16,187	36,121	46,898	99,206
	2020	15,620	29,004	35,791	80,415
South West	2018	4,530	27,278	32,088	63,896
	2019	4,421	28,109	30,943	63,473
	2020	5,352	22,931	23,024	51,307
Wales	2018	15,525	17,542	19,058	52,125
	2019	15,716	17,977	18,356	52,049
	2020	14,369	14,304	13,864	42,537
West Midlands	2018	7,442	27,406	30,614	65,462
	2019	7,617	27,835	28,692	64,144
	2020	7,774	22,531	22,379	52,684
Yorkshire & The Humber	2018	35,409	23,941	29,105	88,455
	2019	30,952	24,696	28,171	83,819
	2020	33,671	20,007	22,216	75,894

APPENDIX 26: HADES model performance and summary statistics for the prediction of subsets of the hourly-annual average NO_2 and O_3 concentrations.

Pollutant	Hour	HADES: Development (2018/19)					HADES: Cross-Validation (2020)				
		Count	Mean (µg/m^3)	R^2	RMSE	NRMSE *	Count	Mean (µg/m^3)	R^2	RMSE	NRMSE *
Nitrogen Dioxide (NO_2)	00:00	251	18.3	0.76	4.2	6.4%	127	13.3	0.79	3.8	12.4%
	01:00	251	16.5	0.74	3.7	6.8%	127	12.0	0.78	3.4	13.5%
	02:00	251	15.4	0.73	3.5	6.7%	127	11.2	0.75	3.1	13.7%
	03:00	251	15.2	0.72	3.6	7.0%	127	11.3	0.70	3.1	13.9%
	04:00	251	16.9	0.68	4.4	8.4%	128	12.8	0.64	3.7	14.4%
	05:00	251	21.1	0.68	5.9	9.6%	128	16.2	0.63	4.7	12.8%
	06:00	251	25.8	0.73	6.5	8.9%	128	20.0	0.70	5.0	11.7%
	07:00	251	28.5	0.77	6.4	8.3%	128	22.0	0.74	5.0	10.7%
	08:00	251	28.0	0.79	6.2	8.1%	128	21.5	0.76	4.9	10.4%
	09:00	251	25.6	0.79	5.9	7.8%	128	19.6	0.77	4.9	10.6%
	10:00	251	23.5	0.78	5.9	7.7%	128	18.0	0.75	5.0	10.9%
	11:00	251	22.2	0.77	6.0	7.8%	128	17.1	0.75	4.9	10.4%
	12:00	251	21.6	0.77	6.1	8.0%	128	16.7	0.75	4.8	10.2%
	13:00	251	21.6	0.77	6.2	8.1%	128	16.8	0.75	4.8	10.2%
	14:00	251	22.5	0.77	6.3	8.3%	128	17.6	0.75	5.0	10.3%
	15:00	251	24.4	0.78	6.5	8.6%	128	19.0	0.76	5.2	10.1%
	16:00	251	26.8	0.78	6.7	8.8%	128	20.7	0.75	5.4	10.6%
	17:00	251	28.2	0.78	6.6	8.7%	128	21.6	0.76	5.4	11.0%
	18:00	251	28.5	0.79	6.3	8.2%	128	21.8	0.77	5.3	11.4%
	19:00	251	28.0	0.79	5.8	7.6%	128	21.4	0.78	5.2	11.6%
	20:00	251	26.8	0.79	5.5	7.2%	128	20.4	0.78	5.1	11.9%
	21:00	251	25.4	0.79	5.3	7.0%	128	19.1	0.78	4.9	12.1%
	22:00	251	23.3	0.78	5.2	6.8%	128	17.2	0.78	4.6	12.1%
	23:00	251	20.6	0.77	4.7	6.4%	128	15.0	0.78	4.0	11.6%
Ozone (O_3)	00:00	118	44.5	0.80	3.5	8.4%	59	48.3	0.64	3.9	12.7%
	01:00	118	44.2	0.74	3.6	9.3%	59	47.8	0.60	3.8	13.4%
	02:00	118	43.8	0.72	3.7	9.8%	59	47.4	0.57	3.8	13.8%
	03:00	118	43.0	0.70	3.9	10.1%	59	46.5	0.59	3.7	13.2%
	04:00	118	41.5	0.73	3.9	9.9%	59	45.2	0.62	3.8	12.4%
	05:00	118	39.6	0.78	3.9	9.1%	59	43.6	0.68	3.8	10.8%
	06:00	118	38.4	0.84	3.8	8.2%	59	42.7	0.75	3.7	9.3%
	07:00	118	39.1	0.87	3.6	7.6%	59	43.6	0.77	3.7	9.1%
	08:00	118	42.3	0.87	3.5	7.2%	59	46.5	0.76	3.9	9.9%
	09:00	118	47.0	0.85	3.7	7.7%	59	50.7	0.73	4.2	10.7%
	10:00	118	51.6	0.83	3.9	7.9%	59	54.8	0.70	4.4	11.4%
	11:00	118	55.4	0.81	4.0	8.0%	59	58.2	0.70	4.4	11.2%
	12:00	118	58.1	0.80	4.0	8.1%	59	60.6	0.69	4.5	11.5%
	13:00	118	59.8	0.81	4.0	7.9%	59	62.2	0.68	4.6	11.6%
	14:00	118	60.2	0.82	3.9	7.8%	59	62.6	0.68	4.7	11.6%
	15:00	118	59.2	0.83	4.0	7.9%	59	61.8	0.68	4.7	11.4%
	16:00	118	56.9	0.84	3.9	7.8%	59	59.9	0.67	4.8	11.6%
	17:00	118	54.3	0.85	3.8	7.6%	59	57.7	0.66	4.8	12.0%
	18:00	118	51.8	0.86	3.7	7.4%	59	55.4	0.66	4.6	12.2%
	19:00	118	49.1	0.86	3.6	7.2%	59	53.0	0.66	4.5	12.5%
	20:00	118	46.9	0.86	3.5	7.3%	59	50.9	0.67	4.3	12.4%
	21:00	118	45.3	0.85	3.7	7.5%	59	49.4	0.68	4.1	11.8%
	22:00	118	44.4	0.84	3.6	7.7%	59	48.7	0.70	3.8	11.3%
	23:00	118	44.3	0.82	3.5	7.8%	59	48.4	0.67	3.7	11.5%

* Normalisation of the RMSE by the range of measured concentrations (max-min);

APPENDIX 27: HADES model performance and summary statistics for the prediction of NOx in 2018-19, with cross-validation performance on future predictions in 2020.

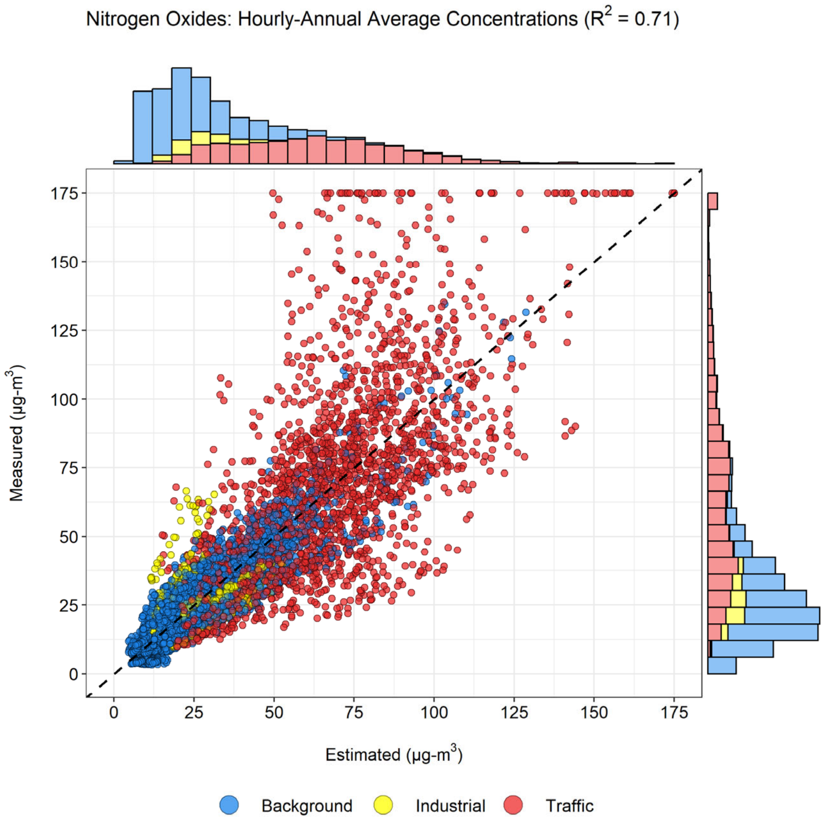
Summary Statistics			Calibration 1: Road-transport NOx	Calibration 2: Domestic-Commercial -Industrial NOx	Model 1: NOx Concentrations
Description	Model Family		Multilevel	Multilevel	OLS
	Model Relation		Log-linear	Log-linear	Linear
	Observations (N)		5,592	3,480	6,024
Goodness-of-Fit	R-squared (R^2)		0.70	0.65	0.71
	Nagelkerke's Pseudo-R-Squared (PR^2)		0.77	0.67	0.71
Residuals *	Root Mean Square Error (RMSE)		19.06	7.86	18.01
	Normalised RMSE ($NRMSE_{RANGE}$)		11.1%	10.8%	10.5%
	Mean Absolute Percentage Error (MAPE)		31.1%	27.7%	32.3%
	Site-Weighted MAPE		13.5%	6.4%	13.1%
	Median Absolute Percentage Error		23.3%	22.5%	24.2%
Chi-Square (p-value)	Full model		< 0.01	< 0.01	< 0.01
	Hierarchical effects		< 0.01	< 0.01	-
Cross-Validation (95% HDI) **	CV-R^2	Upper	0.69	0.64	0.71
		Lower	0.66	0.60	0.68
	CV-RMSE	Upper	19.16	7.94	18.02
		Lower	17.83	7.46	16.81
	CV-$NRMSE_{RANGE}$	Upper	11.2%	10.9%	10.5%
		Lower	10.4%	10.2%	9.8%
Cross-Validation (2020 Dataset)	Observations (N)		2,856	1,752	3,072
	CV-R^2		0.69	0.63	0.70
	CV-RMSE		15.32	7.41	16.53
	CV-$NRMSE_{RANGE}$		11.0%	11.6%	11.8%
	CV-R^2 ***		-	-	0.70
	CV-RMSE ***		-	-	12.12
	CV-$NRMSE_{RANGE}$ ***		-	-	8.7%

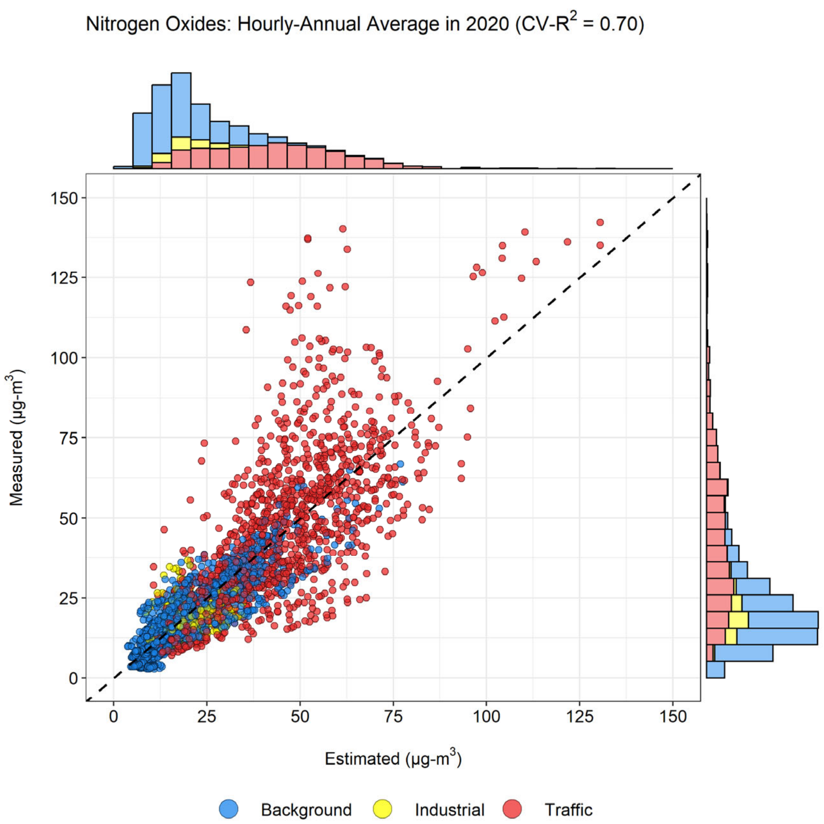
* $NRMSE_{RANGE}$ is the normalisation of the RMSE by the range of measured concentrations (max-min).

** Cross-Validation (CV) was achieved by 10,000 Monte Carlo simulations, with 20% of the data from 2018-19 randomly withheld and used for model validation. Summary statistics from the 95% Highest Density Interval (HDI) of model simulations are presented.

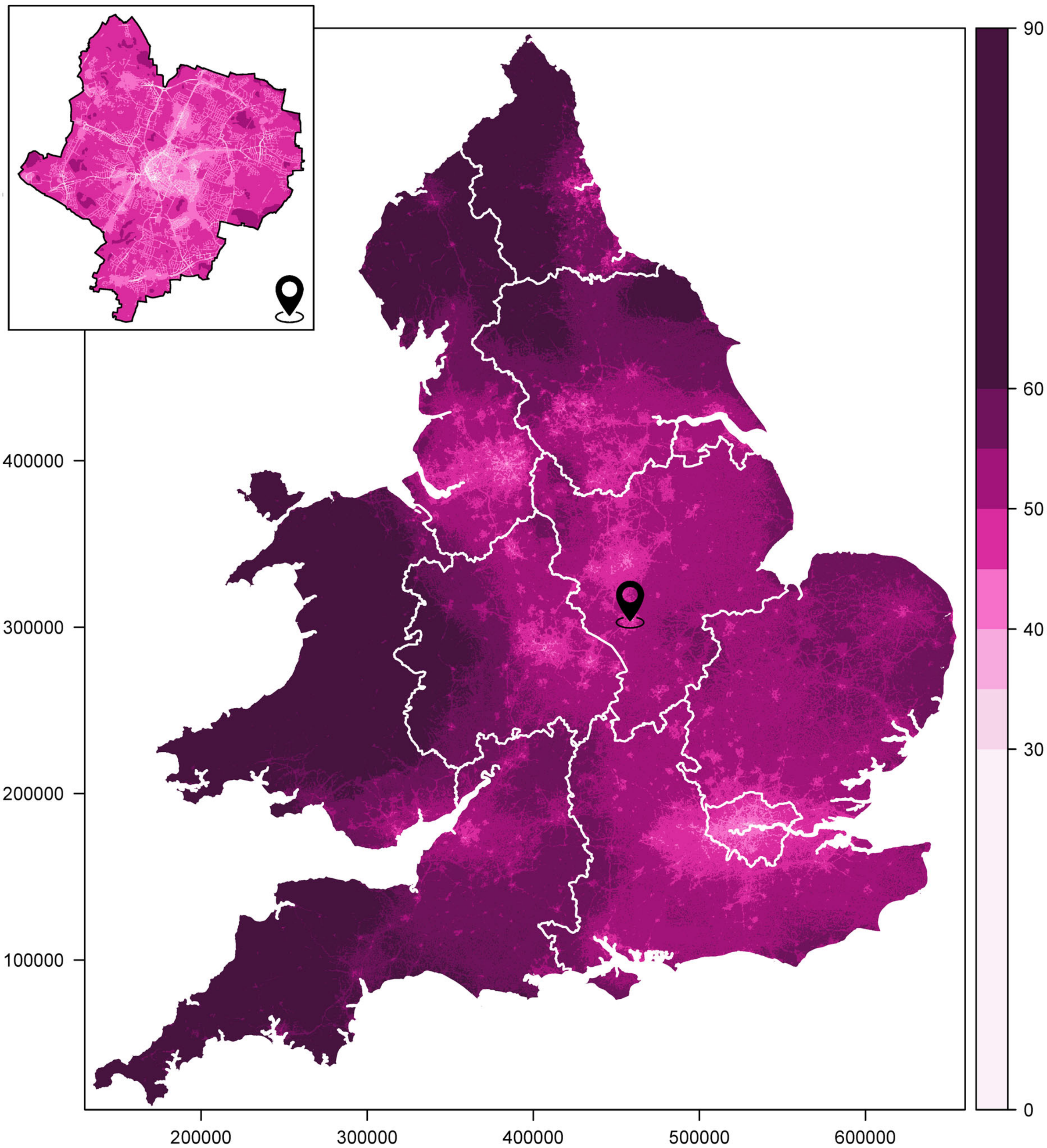
*** Linear calibration applied to adjust the NOx emission trend in 2020: NOx = 0.841 + ("Model 1" x 0.741)

APPENDIX 28: HADES versus monitored hourly-annual average concentrations of nitrogen oxide (NOx) in 2018-19, and cross-validated against data from 2020 (linear calibration applied)





APPENDIX 29: Annual average (24-hour) ozone concentrations in µg/m³ across England and Wales for 2018-19. Insert displays the City of Leicester located within the East Midlands.



APPENDIX 30: Area-Weighted annual-average exposures from a 10x10m grid across England and Wales comprising of 1,512,446,193 locations. Land based classification schemes were constructed from 188,880 UK Census Output Area community boundaries in 2021 (COA21).

Scheme	Group	Land Cover	Annual-Average Concentrations (µg/m^3)								
			24-Hour NO_2			24-Hour O_3			8-Hour O_3 *		
			2018	2019	2020	2018	2019	2020	2018	2019	2020
National	All	100 %	8.6	9.9	8.7	56.7	55.2	57.8	64.2	62.4	65.3
	England	86 %	9.1	10.5	9.2	55.9	54.2	57.0	63.5	61.5	64.5
	Wales	14 %	6.0	6.2	5.3	61.8	61.5	63.1	68.5	68.2	70.2
Rural-Urban	Urban	5 %	19.3	21.1	17.7	48.1	46.0	50.7	55.5	53.4	58.3
	Peri-Urban	2 %	15.3	17.1	14.5	50.5	48.4	52.4	57.9	55.7	59.9
	Peri-Rural	4 %	12.6	14.4	12.4	52.4	50.1	53.7	60.0	57.4	61.3
	Rural	89 %	7.7	8.9	7.9	57.5	56.1	58.5	65.0	63.3	66.0
Regional	East Midlands	10 %	10.2	12.2	10.9	53.6	50.7	54.1	61.4	57.7	61.6
	East England	13 %	9.1	10.7	10.1	54.3	52.6	55.0	62.8	60.7	63.9
	London	1 %	22.3	25.9	21.4	46.0	41.9	48.1	54.6	50.6	56.9
	North East	6 %	7.1	6.5	5.9	59.1	61.0	63.1	64.7	66.3	68.6
	North West	9 %	9.4	10.4	8.5	57.4	54.9	59.0	64.2	61.0	65.4
	South East	12 %	10.7	13.2	11.0	53.8	50.4	54.3	62.3	59.2	63.1
	South West	16 %	6.0	7.2	6.5	59.1	58.1	59.5	66.7	66.2	67.1
	Wales	14 %	6.0	6.2	5.3	61.8	61.5	63.1	68.5	68.2	70.2
	West Midlands	9 %	9.9	11.0	9.8	56.2	54.3	57.7	63.9	60.9	65.1
	Yorkshire & The Humber	10 %	9.4	10.1	9.4	55.5	55.3	56.6	62.4	61.5	63.1
Deprivation (Quantiles)	Q1: Affluent	42 %	8.2	9.3	8.2	57.2	55.7	58.2	64.6	62.8	65.6
	Q2	38 %	8.2	9.4	8.3	57.1	55.6	58.0	64.7	62.9	65.6
	Q3: Expected	15 %	9.0	10.2	9.0	56.3	55.0	57.6	63.8	62.3	65.1
	Q4	3 %	14.0	15.6	13.4	51.8	49.9	53.5	59.3	57.2	61.1
	Q5: Deprived	2 %	19.6	21.6	18.2	47.6	45.2	50.0	54.9	52.3	57.4

** Statistical approximation of the annual-average daily maximum 8-hour rolling mean ozone concentration, calculated by combining the mean with the standard deviation of the hourly annual-average surfaces (n=24)*

APPENDIX 31: Summary of the annual-average NOx exposure surfaces from HADES based on (a) area-weighted 1,512,446,193 locations from a 10x10m grid, and (b) population-weighted exposure of 1,377,387 residential postcode centroid points locations across England and Wales.

Scheme	Group	NOx Concentrations (µg/m³)					
		Area-Weighted			Population-Weighted		
		2018	2019	2020	2018	2019	2020
National	All	13.0	12.9	10.1	26.6	26.5	18.9
	England	13.2	13.2	10.3	26.8	26.6	19.0
	Wales	11.3	11.3	9.0	23.6	23.4	16.6
Rural-Urban	Urban	29.9	29.6	20.9	29.8	29.6	21.0
	Peri-Urban	22.9	22.7	16.4	24.7	24.5	17.5
	Peri-Rural	17.5	17.3	12.9	21.8	21.6	15.6
	Rural	11.6	11.6	9.2	15.8	15.7	11.6
Regional	East Midlands	13.2	13.2	10.3	25.2	25.1	18.0
	East England	13.1	13.1	10.2	24.1	24.0	17.1
	London	27.9	27.7	19.7	32.5	32.3	22.8
	North East	12.3	12.3	9.7	27.3	27.0	19.3
	North West	13.6	13.6	10.5	28.0	27.8	19.9
	South East	13.6	13.6	10.5	24.6	24.4	17.4
	South West	12.1	12.1	9.5	23.6	23.5	16.7
	Wales	11.3	11.3	9.0	23.6	23.4	16.6
	West Midlands	13.7	13.7	10.6	27.5	27.3	19.6
	Yorkshire & The Humber	12.9	12.9	10.1	26.6	26.4	18.8
Deprivation (Quantiles)	Q1: Affluent	12.1	12.1	9.5	21.7	21.6	15.6
	Q2	12.3	12.3	9.6	23.1	23.0	16.5
	Q3: Expected	13.7	13.7	10.6	26.1	26.0	18.5
	Q4	21.1	20.9	15.3	28.8	28.7	20.3
	Q5: Deprived	30.2	30.0	21.2	19.6	21.6	18.2

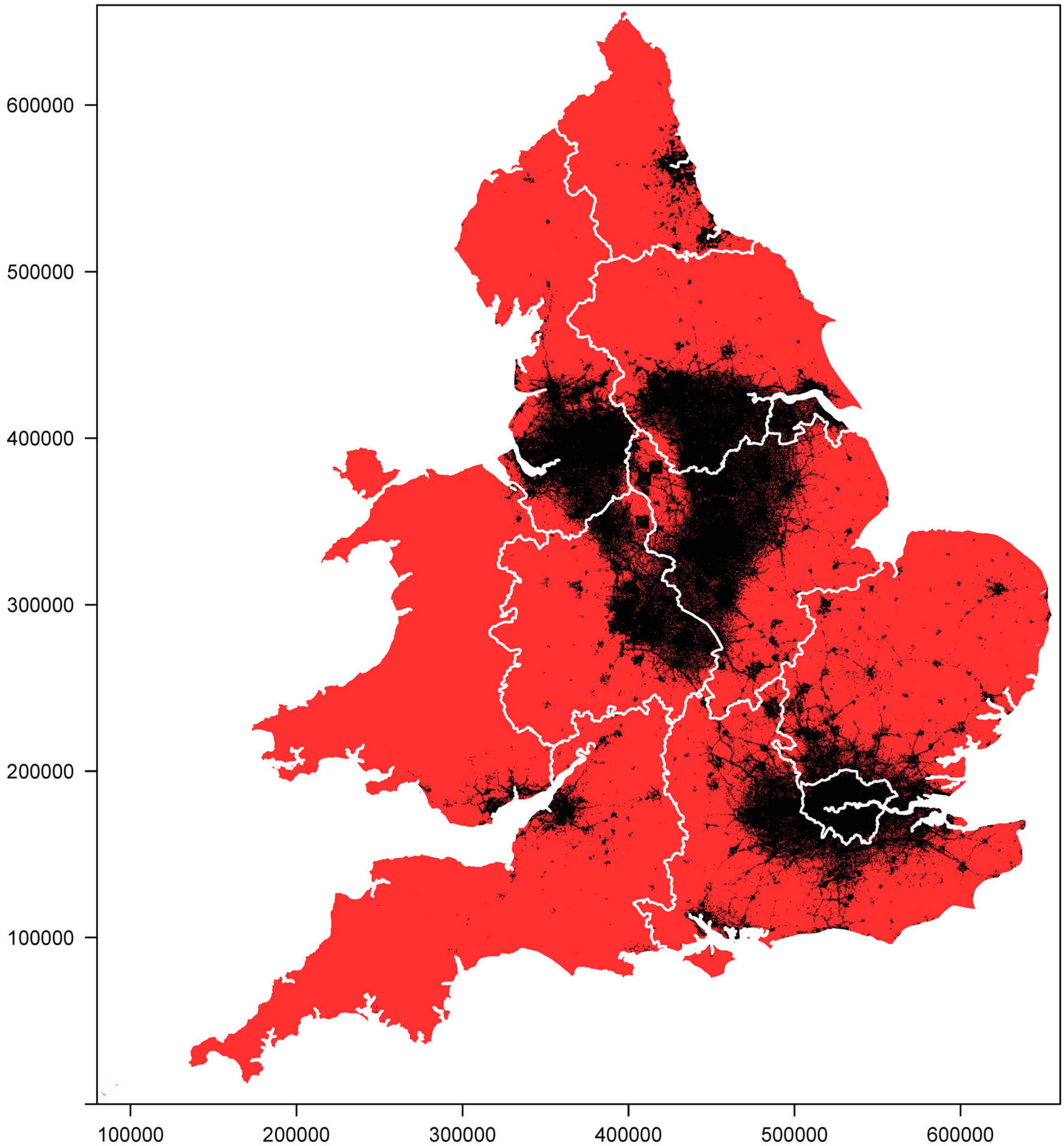
APPENDIX 32: Hourly-annual average nitrogen dioxide concentrations across the urban local authority of Leicester in 2018-19.

Leicester, is the largest city in the East Midlands, recording 368,600 residents in the 2021 UK Census. Leicester covers 73km^2, it is 83% urban, and is located approximately 140km northwest of London. In 2019, the total NOx emission rate for Leicester was 23.8 tonnes per km^2, of which 61.2%, 8.5% and 30.3% originated from area, industrial point, and road-transportation, respectively. For context, the total NOx emission rate across England and Wales (7% urban landmass) was 4.3 tonnes per km^2, of which 37.6%, 20.4% and 42% originated from area, industrial point, and road-transportation, respectively. As previously discussed, it is a combination of quantity and release height that determines a sources potential contribution to surface concentrations.

In 2018/19, approximately 0.4% of Leicester city was likely in exceedance of the 40µg/m^3 annual average limit for NO_2. These exceedances are limited to a few kerbside locations and are heavily influenced by commuter patterns. Between the hours of 07:00-08:00 and 16:00-19:00, approximately 1.7-2.8% of Leicester city appears above this limit. All of Leicester currently exceeds the 10 µg/m^3 air quality guideline for NO_2 recommend by the WHO in 2021 - even during periods of low activity (between 01:00 and 05:00) more than 90% of landcover exceeds 10 µg/m^3.

Hour	Mean (µg/m^3)	Percentile Range (µg/m^3)					% Area in exceedance of			
		1%	25%	50%	75%	100%	40 µg/m^3	30 µg/m^3	20 µg/m^3	10 µg/m^3
00:00	17.0	9.9	15.1	17.0	18.7	50.8	< 0.1	0.2	12.5	100.0
01:00	15.3	8.7	13.6	15.3	16.8	43.4	< 0.1	< 0.1	3.7	99.7
02:00	14.1	7.8	12.5	14.2	15.6	39.8	< 0.1	< 0.1	1.3	97.1
03:00	13.6	7.2	11.9	13.6	15.1	40.5	< 0.1	< 0.1	1.0	92.3
04:00	14.8	7.9	12.9	14.8	16.5	48.1	< 0.1	0.1	4.0	97.5
05:00	17.7	9.2	15.2	17.6	19.7	63.3	0.1	0.8	22.5	99.9
06:00	20.8	10.2	17.4	20.4	23.2	64.4	0.7	6.2	54.3	100.0
07:00	22.5	10.4	18.3	21.8	24.9	65.2	2.1	11.8	64.9	100.0
08:00	22.0	9.9	17.9	21.2	24.4	66.1	2.0	11.0	61.1	100.0
09:00	20.3	8.9	16.5	19.6	22.6	68.0	1.1	6.7	46.2	99.9
10:00	18.5	7.5	14.9	17.9	20.6	70.6	0.7	4.4	29.6	98.5
11:00	17.5	6.8	14.0	16.9	19.6	73.3	0.5	3.5	22.7	94.5
12:00	17.1	6.5	13.6	16.5	19.1	75.6	0.5	3.1	20.7	93.7
13:00	17.3	6.7	13.8	16.6	19.3	77.2	0.5	3.2	21.4	94.9
14:00	18.1	7.3	14.6	17.4	20.2	77.9	0.6	4.1	26.2	98.5
15:00	19.7	8.3	15.9	18.9	21.8	78.0	1.0	6.1	38.9	99.8
16:00	21.9	10.0	17.9	21.1	24.2	76.9	1.9	10.3	60.6	100.0
17:00	23.7	11.6	19.6	22.9	26.0	75.2	2.8	14.0	73.0	100.0
18:00	24.5	12.8	20.6	23.8	26.8	73.5	2.5	14.7	78.0	100.0
19:00	24.5	13.6	20.9	24.0	26.8	71.9	1.7	13.5	79.9	100.0
20:00	23.8	13.6	20.6	23.4	26.1	70.0	0.9	10.3	78.4	100.0
21:00	22.8	13.2	19.9	22.6	24.9	68.4	0.5	6.6	74.4	100.0
22:00	21.1	12.3	18.5	20.9	23.1	66.6	0.2	2.8	61.3	100.0
23:00	18.9	11.1	16.7	18.8	20.8	61.1	0.1	0.6	34.3	100.0
24-hours	19.5	9.7	16.4	19.1	21.6	65.2	0.4	3.4	39.5	100.0

APPENDIX 33: Locations expected to be in exceedance (red) and compliance (black) of the WHO recommended guideline for average daily maximum 8-hour mean O_3 concentrations of 60 µg/m^3 during the 6-month peak-season [(28)]. The reclassified surface is from a statistical approximation of the annual-average maximum daily 8-hour rolling mean ozone concentration, calculated by combining the mean with the standard deviation of the hourly annual-average surfaces in HADES.



[28] World Health Organization (WHO 2021). WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. ISBN: 9789240034228

APPENDIX 34: Annual NOx emissions from road-transport across England and Wales in 2018-2020, by region and road type.

Region	Road Network		AADT (km Weighted Mean)			NOx Emissions (Tonnes)		
	Group	Length (km)	2018	2019	2020	2018	2019	2020
England & Wales (Total)	Major	53,754	17,883	18,018	13,590	205,254	195,482	151,753
	Minor	297,818	1,669	1,675	1,333	82,847	79,725	61,235
	Total	351,573	4,148	4,174	3,207	288,102	275,207	212,988
East Midlands	Major	5,338	17,003	17,239	13,219	20,904	19,843	15,691
	Minor	27,483	1,679	1,684	1,333	7,779	7,481	5,754
	Total	32,822	4,171	4,214	3,266	28,684	27,324	21,444
East of England	Major	6,028	19,481	19,549	15,037	26,726	25,306	20,150
	Minor	36,013	1,926	1,934	1,540	11,685	11,298	8,755
	Total	42,040	4,443	4,460	3,475	38,411	36,604	28,904
London	Major	2,481	23,816	23,817	18,168	9,813	9,256	6,995
	Minor	13,474	1,911	1,923	1,561	4,226	3,992	3,047
	Total	15,955	5,318	5,328	4,144	14,039	13,248	10,042
North East	Major	2,606	14,924	15,178	11,453	7,607	7,238	5,557
	Minor	14,311	1,804	1,815	1,463	4,418	4,231	3,328
	Total	16,917	3,825	3,874	3,002	12,024	11,469	8,885
North West	Major	6,441	19,156	19,389	14,800	26,425	25,086	19,913
	Minor	32,251	1,662	1,670	1,337	8,714	8,417	6,525
	Total	38,692	4,574	4,620	3,578	35,138	33,503	26,438
South East	Major	8,451	21,757	21,817	16,132	36,994	35,366	27,004
	Minor	43,221	1,720	1,726	1,359	11,947	11,533	8,787
	Total	51,672	4,997	5,012	3,775	48,941	46,898	35,791
South West	Major	6,617	15,208	15,347	11,260	21,516	20,709	15,212
	Minor	45,205	1,406	1,413	1,121	10,572	10,233	7,813
	Total	51,823	3,168	3,192	2,416	32,088	30,943	23,024
Wales	Major	5,267	10,844	10,976	8,134	11,846	11,406	8,631
	Minor	28,956	1,441	1,443	1,125	7,212	6,950	5,234
	Total	34,223	2,888	2,910	2,204	19,058	18,356	13,864
West Midlands	Major	5,498	18,264	18,149	13,649	22,233	20,740	16,309
	Minor	29,237	1,715	1,721	1,366	8,381	7,952	6,069
	Total	34,735	4,334	4,321	3,310	30,614	28,692	22,379
Yorkshire & The Humber	Major	5,027	17,845	18,222	13,993	21,190	20,533	16,292
	Minor	27,666	1,680	1,687	1,368	7,915	7,639	5,924
	Total	32,693	4,166	4,229	3,309	29,105	28,171	22,216

APPENDIX 35: Annual NOx emissions from area sources across England and Wales in 2018-2020, by region and emission sector.

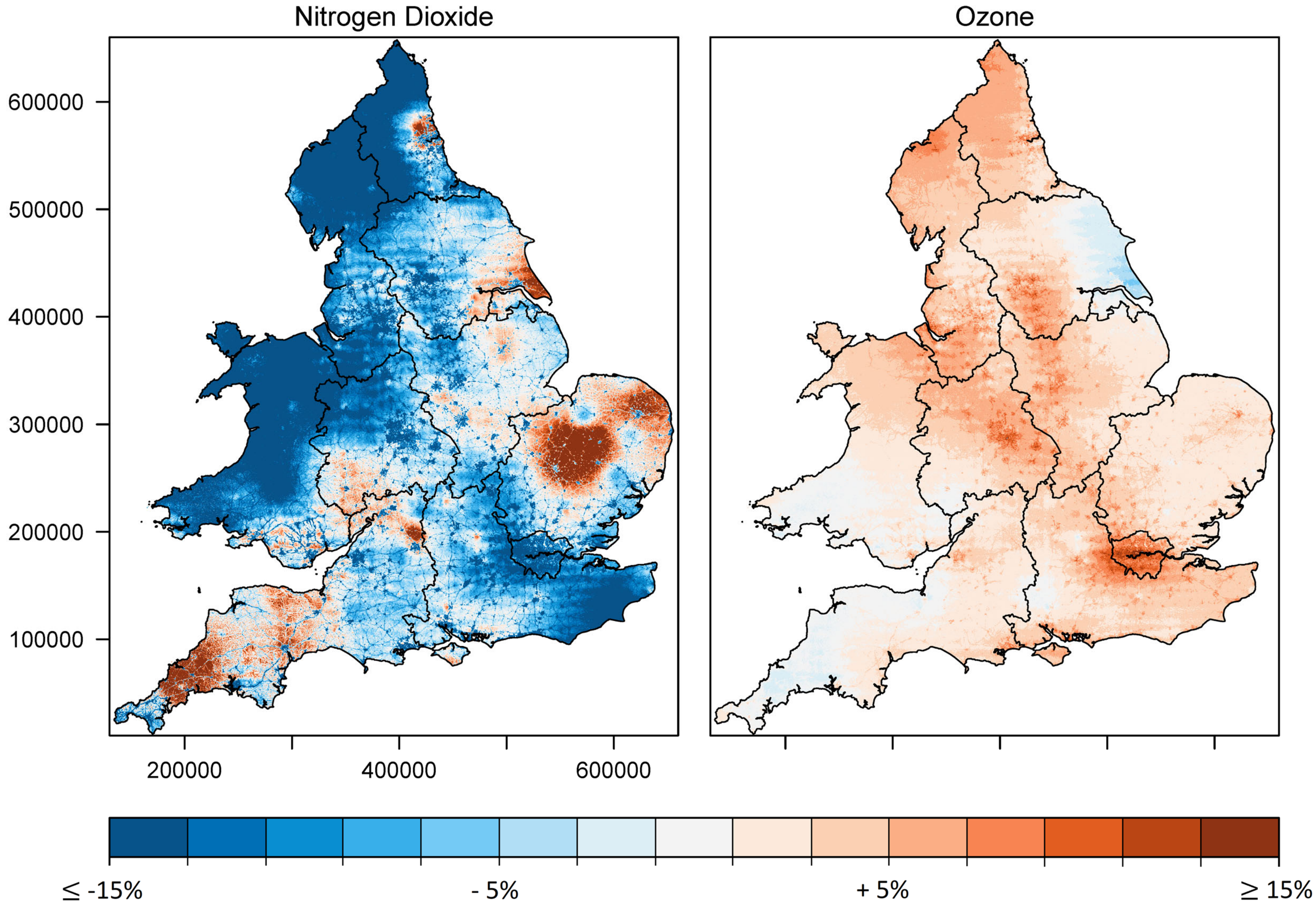
Region	Sector	NOx Emissions (Tonnes)		
		2018	2019	2020
England & Wales (Total)	Industry	60,889	63,483	51,224
	Domestic and Commercial	51,843	52,402	45,995
	Off-Road Transport	106,124	104,151	79,525
	Waste	410	409	515
	Agriculture	21,097	25,168	20,910
	Nature	1,049	1,361	1,039
East Midlands	Industry	7,388	7,900	6,403
	Domestic and Commercial	4,076	4,120	3,654
	Off-Road Transport	10,142	9,954	7,600
	Waste	39	39	49
	Agriculture	2,883	3,440	2,858
	Nature	86	112	86
East of England	Industry	8,391	8,612	6,781
	Domestic and Commercial	5,313	5,370	4,769
	Off-Road Transport	12,272	12,044	9,196
	Waste	50	49	62
	Agriculture	3,493	4,167	3,462
	Nature	120	155	119
London	Industry	2,592	2,633	2,219
	Domestic and Commercial	6,938	7,013	5,843
	Off-Road Transport	7,166	7,033	5,370
	Waste	44	44	56
	Agriculture	35	42	35
	Nature	6	7	6
North East	Industry	2,377	2,533	2,064
	Domestic and Commercial	2,207	2,231	1,960
	Off-Road Transport	3,869	3,797	2,899
	Waste	16	16	20
	Agriculture	870	1,038	863
	Nature	65	84	64
North West	Industry	7,328	7,860	6,379
	Domestic and Commercial	6,506	6,577	5,740
	Off-Road Transport	13,716	13,461	10,278
	Waste	48	48	60
	Agriculture	1,464	1,746	1,451
	Nature	85	110	84

Region	Sector	NOx Emissions (Tonnes)		
		2018	2019	2020
South East	Industry	7,842	8,025	6,240
	Domestic and Commercial	8,464	8,555	7,625
	Off-Road Transport	16,796	16,484	12,587
	Waste	65	65	82
	Agriculture	2,320	2,767	2,299
	Nature	173	224	171
South West	Industry	6,610	6,834	5,697
	Domestic and Commercial	5,029	5,083	4,550
	Off-Road Transport	11,702	11,485	8,769
	Waste	45	45	57
	Agriculture	3,716	4,433	3,683
	Nature	176	229	175
Wales	Industry	4,862	4,985	3,760
	Domestic and Commercial	3,430	3,467	3,112
	Off-Road Transport	7,203	7,069	5,398
	Waste	21	21	27
	Agriculture	1,860	2,219	1,844
	Nature	166	215	164
West Midlands	Industry	6,867	7,071	5,909
	Domestic and Commercial	4,948	5,001	4,399
	Off-Road Transport	13,408	13,158	10,047
	Waste	42	42	53
	Agriculture	2,058	2,455	2,040
	Nature	83	108	82
Yorkshire & The Humber	Industry	6,633	7,029	5,771
	Domestic and Commercial	4,933	4,986	4,342
	Off-Road Transport	9,849	9,666	7,380
	Waste	39	39	50
	Agriculture	2,398	2,860	2,376
	Nature	89	116	88

APPENDIX 36: Meteorological summary of rural-background weather stations in 2018-20

Region	Sites	Year	Air Temperature			Wind				
			Mean (°c)	Hours Above		Mean (m/s)	Hourly Direction Profile			
				15°c	20°c		NE	SE	SW	NW
England & Wales (Total)	90	2018	10.4	25%	8%	4.5	21%	20%	37%	22%
		2019	10.2	22%	5%	4.4	16%	20%	40%	24%
		2020	10.5	22%	5%	4.9	18%	16%	44%	21%
East Midlands	9	2018	10.4	25%	8%	5.3	21%	20%	39%	19%
		2019	10.3	23%	6%	5.2	15%	19%	44%	22%
		2020	10.6	22%	5%	5.7	18%	16%	48%	18%
East of England	12	2018	10.9	28%	10%	4.5	22%	20%	38%	19%
		2019	10.7	25%	7%	4.5	15%	19%	43%	22%
		2020	11.1	26%	8%	4.9	18%	16%	47%	19%
London	2	2018	12.0	33%	14%	3.9	26%	16%	37%	21%
		2019	11.7	30%	10%	3.9	19%	15%	42%	24%
		2020	12.1	30%	11%	4.3	20%	13%	46%	21%
North East	4	2018	8.9	18%	4%	4.0	16%	22%	37%	25%
		2019	8.9	15%	2%	3.9	14%	21%	39%	26%
		2020	9.1	14%	2%	4.3	16%	17%	43%	24%
North West	10	2018	8.9	18%	4%	5.2	17%	24%	37%	22%
		2019	8.8	15%	3%	5.1	15%	25%	37%	23%
		2020	9.0	14%	3%	5.5	16%	20%	42%	23%
South East	11	2018	11.2	29%	9%	4.3	26%	16%	37%	21%
		2019	11.0	26%	6%	4.3	19%	15%	42%	24%
		2020	11.4	27%	7%	4.8	21%	13%	45%	21%
South West	12	2018	10.8	26%	7%	4.6	24%	18%	34%	23%
		2019	10.7	23%	5%	4.5	17%	19%	38%	26%
		2020	11.2	24%	5%	4.9	20%	16%	42%	23%
Wales	13	2018	10.1	21%	4%	5.0	21%	20%	40%	20%
		2019	10.1	19%	2%	5.0	17%	20%	41%	23%
		2020	10.4	18%	3%	5.5	19%	15%	45%	21%
West Midlands	6	2018	10.4	25%	9%	3.6	22%	20%	36%	22%
		2019	10.0	21%	5%	3.4	15%	21%	39%	25%
		2020	10.4	22%	6%	3.7	18%	17%	43%	22%
Yorkshire & The Humber	11	2018	10.0	23%	7%	4.6	16%	24%	35%	25%
		2019	9.9	21%	4%	4.5	13%	24%	37%	26%
		2020	10.1	20%	4%	5.0	15%	20%	42%	23%

APPENDIX 37: The percentage change in annual-average (24-hour) concentrations across England and Wales in 2020, compared to 2018-19.



The figure above shows the percentage change in annual average NO_2 and O_3 concentrations for 2020, with respect to modelled concentrations in 2018-19 across England and Wales. When interpreted in conjunction with Figure 5 of the main manuscript, it is clearly revealed that major urban centres across England experienced large decreases in NO_2 and unusually high O_3 concentrations. Some rural and coastal communities experiencing an increase in human activity. The exact location, extent, and magnitude of this anthropogenic change was previously unknown, restricted to the analysis of select monitoring sites or regional satellite-based models.

A 29.1% reduction in NOx across London in 2020 coincided with only a 11.2% reduction in NO_2, and an unusual 9.4% increase in O_3 as a consequence of favourable weather conditions and limited street level emissions entering the nitrogen cycle. Similar trends were observed in other urban environments: NO_2 concentrations fell across >97% of Birmingham, Leeds, Liverpool, and Manchester local authority district; with 31.9%, 34.3%, 79.7%, and 67.2% of the land within these cities reducing by ≥10%, respectively. Conversely, 20.1% of Leicester city experienced increased NO_2 concentrations, with only 17.5% of the city reporting reductions of ≥10%; these findings appear indicative of local compliance to the travel restrictions.

It is estimated that 33.8% of the UK workforce stayed home throughout 2020, with wealthier resident relocating to second homes outside of urban areas [(29)]. Hot-spots of activity appear to coincide with the above, with 61.9% of the 2,630km^2 of land in the local authority districts of East Cambridgeshire, South Cambridgeshire and West Suffolk (East of England) experiencing >15% increase in NO_2 concentrations. Cornwall (3,549km^2 in the South West) and the Cotswolds (1,165km^2 in central South West) recorded increases in NO_2 across 77.8% and 54.7% of the local authority districts, respectively. Coastal locations outside of urban areas in the East of England and North East also coincided with pockets of increased NO_2 concentrations.

[29] International Labour Organization (ILO 2021). From potential to practice: Preliminary findings on the numbers of workers working from home during the COVID-19 pandemic. ILO policy brief, Geneva, Switzerland