Imperial College London

Learning to Love Your Taxi Driver

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In the UK, the Health and Safety Executive estimates that more than **100,000 workers** could be exposed to **high levels** of **diesel engine exhaust fumes**, but Imperial College, the IOM and others put the figure closer to **500,000**

Significance

- 233,861 lorry drivers
- 259,161 van drivers
- 127,518 bus/coach drivers
- 174,780 taxi drivers

(ONS, 2011)

- 3.6% of the English and Welsh adult working population (26,681,568 in 2011)

(ONS, 2011)

Behndig AF et al. Thorax. 2011;66(1):12-9.
(Experimentally generated diesel exhaust induced airway inflammation in human volunteers)
Barath S et al., Part Fibre Toxicol. 2010;7:19.
(Experimentally generated diesel exhaust impairs vasomotor function and endogenous fibrinolysis)
McCreanor J, et al. N Engl J Med. 2007 Dec 6;357(23):2348-58.
(Real world diesel exposures in asthmatics induced inflammation and impaired lung function)
Samoli E et al. Occup Environ Med. 2016 May;73(5):300-7.
(Elemental and black carbon are the best predictors of adult cardiovascular and paediatric respiratory hospitalisations in London)

Main Risk Employment Areas

- Mining
- Construction
- Shipping
- Energy extraction
- Tunnelling
- Vehicle repair

Non-road mobile machinery

Background and research gaps

- Traffic related air pollution has been found to have more adverse health effects compared to other sources.
- Diesel engine exhaust classified as a type 1 carcinogen by IARC in 2012.
- However, in practice it is difficult to measure diesel exhaust exposure, so black carbon (BC) is often used as a proxy measure.
- Literature review found 20 papers on in-vehicle BC exposure with significant variation in results.
- There have been very few studies investigating exposures of professional drivers, who spend most of their working day in the “commuting” environment.

The Diesel Mitigation Study

We hypothesise that professional drivers working in congested cities are exposed to diesel emission far above the general population and therefore at increased risk of harm.

The aims of DeMIST were to:

- characterise the diesel exhaust exposure of professional drivers in London during a typical workday.
- identify low-cost intervention methods to reduce exposure and health risk.

Methods

- Recruit 150 drivers across different sectors.
- Each driver is monitored for 96 continuous hours (4 days) at 1-minute resolution.
- The latest generation of personal GPS-linked black carbon sensors (Microaethalometer MA300/350) are used.
- The drivers are asked to complete a questionnaire, detailing their vehicle ventilation preferences and the number of hours they drive during the day.
- Using GPS information, participants activities are determined between driving at work, not driving at work, commuting and at home.
- After baseline monitoring a subset of 50 drivers was used to test the effectiveness of in-cabin filters.

Headline numbers

- First study conducted on professional drivers in Europe and largest study of its kind to date.
- Engaged with 191 professional drivers from 18 different companies
- 149 drivers for the baseline study, 42 intervention study
- 638 shifts and over 14,500 hours of black carbon data collected
- Delivered 16 preliminary reports to companies on reducing exposure to their drivers.
- Raised awareness of air pollution in the professional driving sector.

Baseline Results

Activity	Number of participants	Mean (standard deviation) for hours monitored	Mean (standard deviation) black carbon exposure (μg/m^3) Average participant*	Minimum participant	Median participant	Maximum participant
At work driving	135	13.9 (9.5)	4.2 (4.2)	0.8 (14.2)	3.1 (3.9)	42.6 (32.2)
At work not driving	135	18.4 (11.1)	2.2 (3.2)	0.4 (5.3)	1.7 (2.4)	27.7 (17.6)
At work unknown	6	35.3 (12.9)	2.1 (3.0)	1.0 (0.4)	2.0 (3.1)	3.0 (5.9)
At work	**141**	**33.2 (10.8)**	**3.1 (4.0)**	**0.5 (1.4)**	**2.3 (2.1)**	**32.6 (31.6)**
Commuting	119	3.2 (2.4)	3.6 (3.9)	0.5 (1.7)	3.0 (6.9)	19.5 (25.2)
At home	122	49.4 (34.9)	1.1 (2.1)	0.1 (1.6)	1.0 (2.2)	5.2 (17.5)
Not at work unknown	6	44.2 (19.2)	1.0 (2.0)	0.3 (0.7)	0.9 (1.7)	2.1 (3.4)
Not at work	**128**	**53.0 (34.3)**	**1.2 (2.5)**	**0.2 (0.9)**	**1.0 (2.6)**	**4.4 (16.0)**
All times	**141**	**81.5 (39.1)**	**2.0 (3.6)**	**0.4 (4.2)**	**1.6 (2.6)**	**10.6 (23.1)**

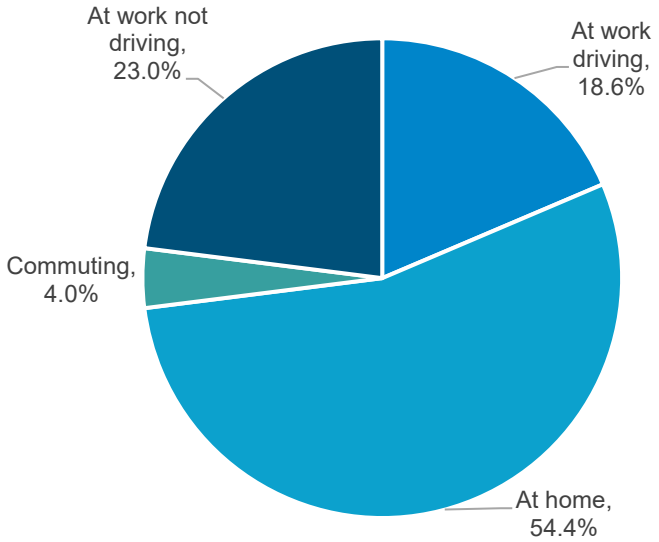
*standard deviation is presented as the average standard deviation across all participants

Results

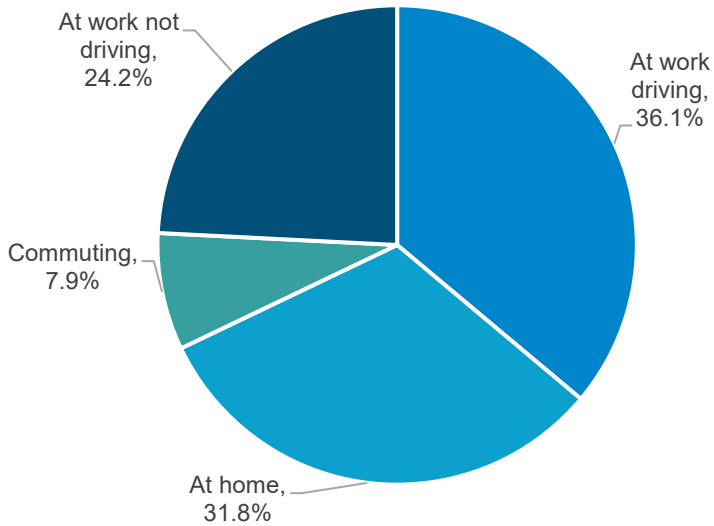
Sector	Participants	Shifts	Mean (standard deviation) black carbon exposure (μg/m^3) At work driving	At work not driving	At home	Commute
Taxi	20	70	6.6 (4.9)	3.5 (3.6)	1.1 (2.0)	5.3 (5.1)
Courier	18	56	5.5 (7.1)	2.9 (3.4)	1.4 (2.2)	3.8 (4.4)
Waste Removal	20	67	4.3 (7.1)	2.9 (3.2)	1.1 (3.1)	2.8 (3.6)
Heavy Freight	26	99	3.9 (2.2)	2.0 (1.3)	1.0 (1.9)	3.6 (3.4)
Utility Services	10	33	3.1 (2.1)	1.3 (1.0)	0.6 (1.4)	3.8 (3.2)
Emergency Services	39	28	2.3 (0.8)	1.2 (0.5)	1.0 (2.0)	3.5 (3.9)
Other	8	134	2.8 (1.4)	1.4 (0.9)	0.8 (1.3)	2.2 (2.6)
All	**141**	**487**	**4.1 (4.6)**	**2.2 (2.5)**	**1.1 (0.7)**	**3.6 (2.5)**

Contribution of microenvironment on exposure

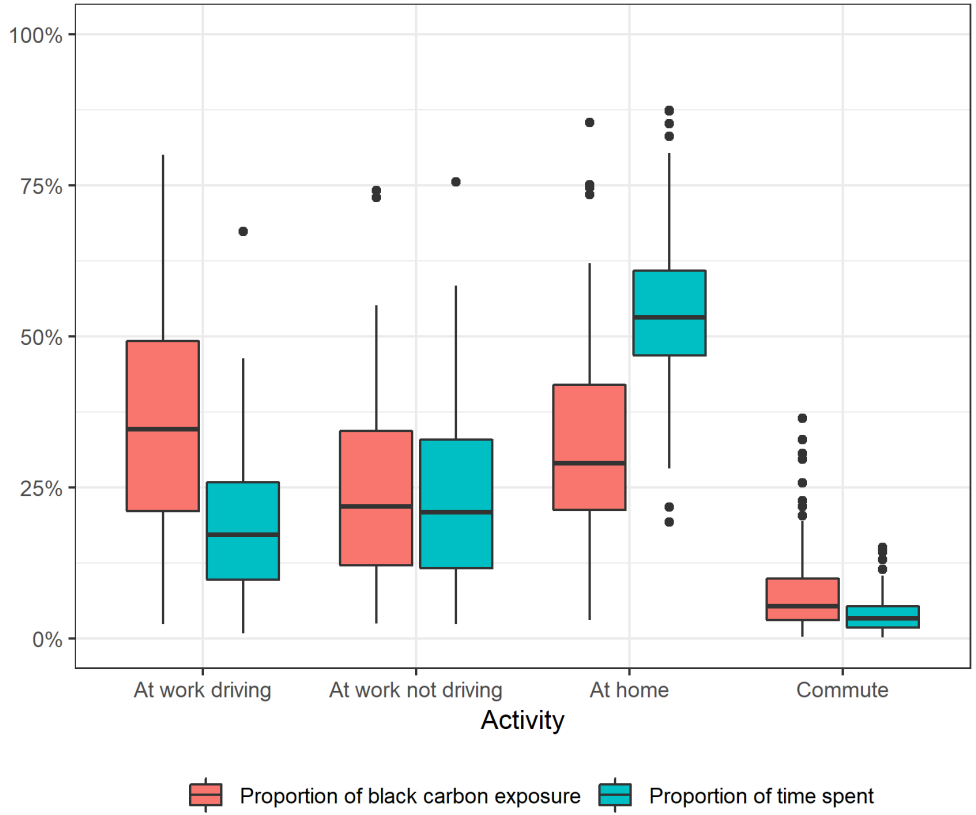
Proportion of time spent



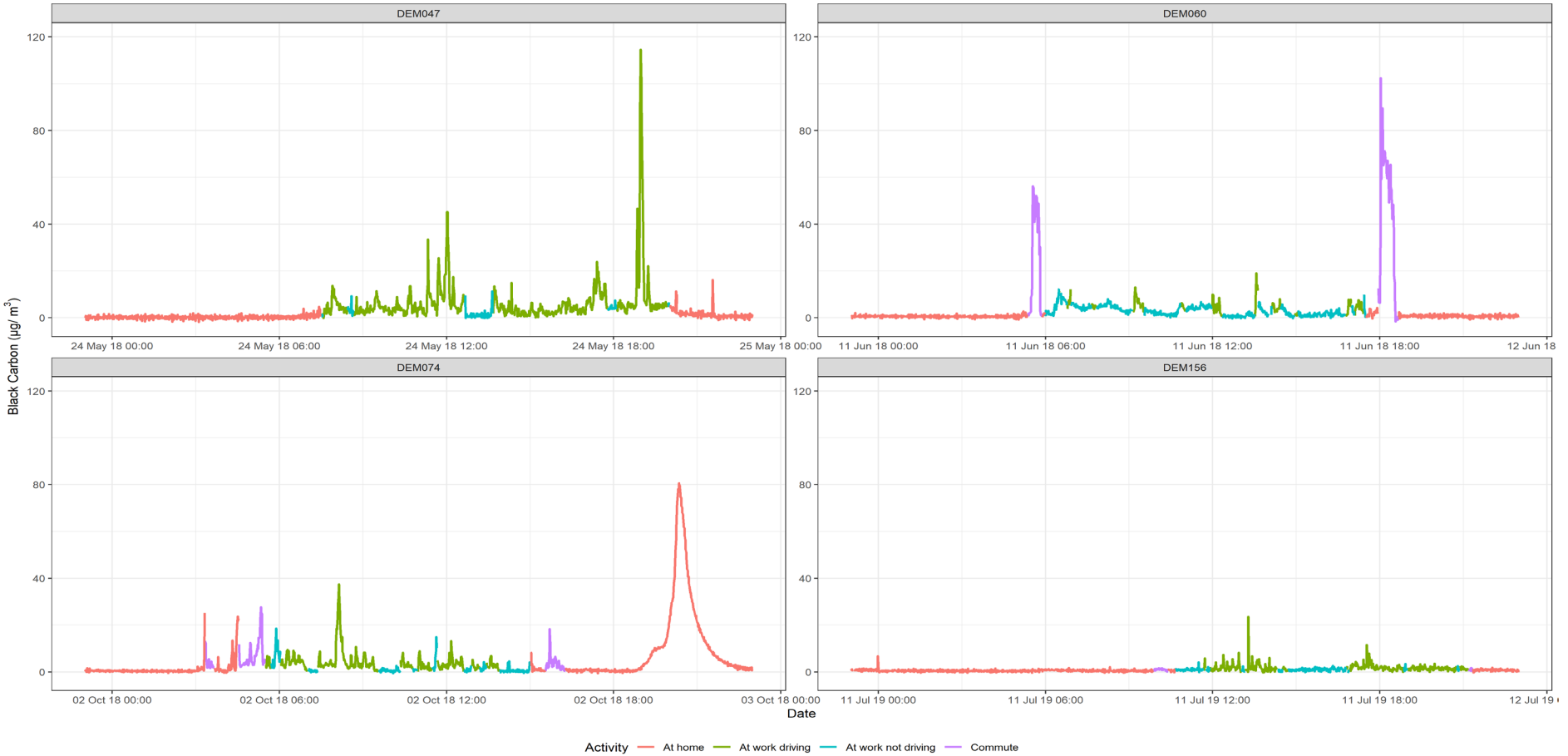
Proportion of total BC exposure



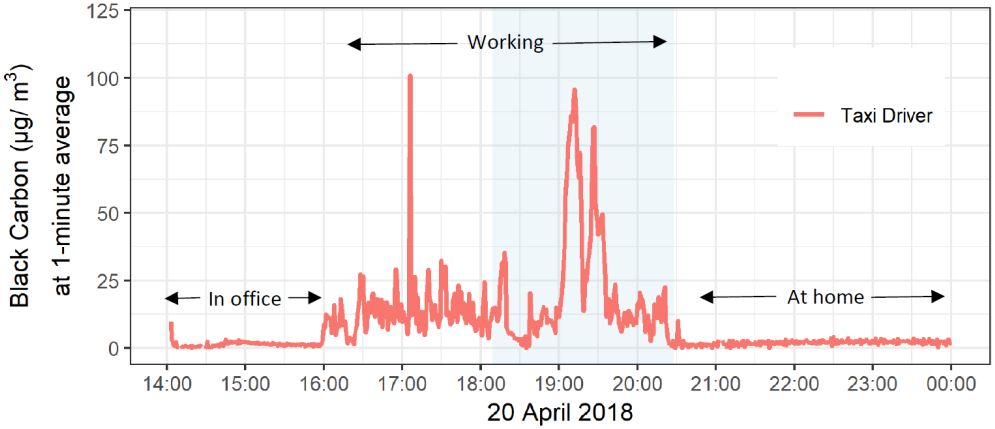
Time weighted exposure

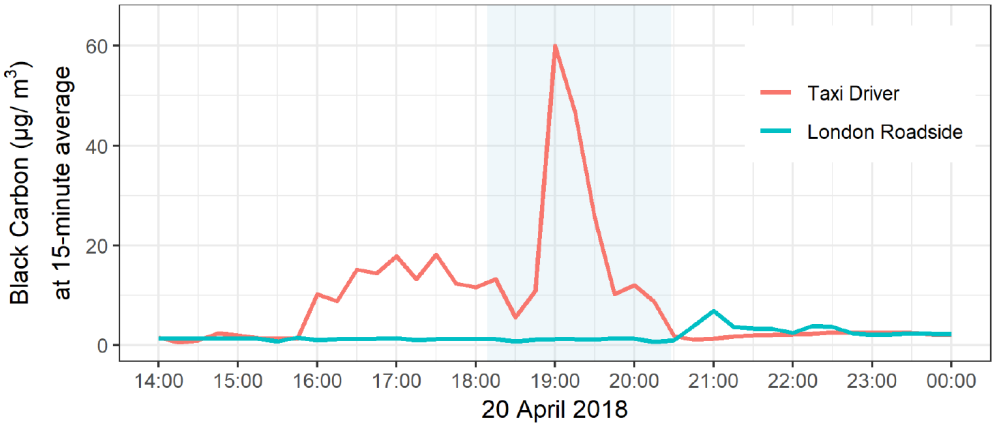


Exposure characterisation



Pollution spikes while driving





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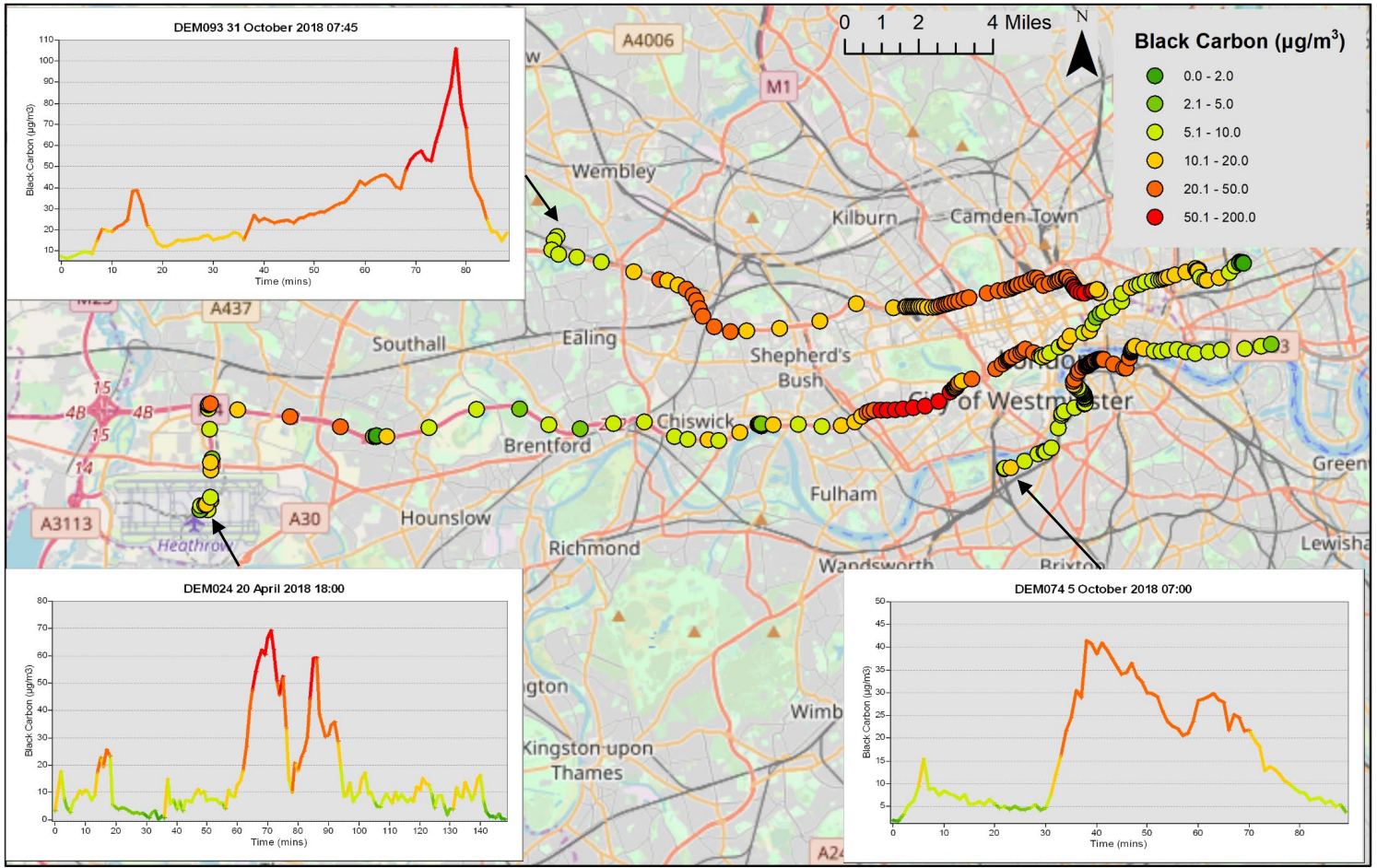
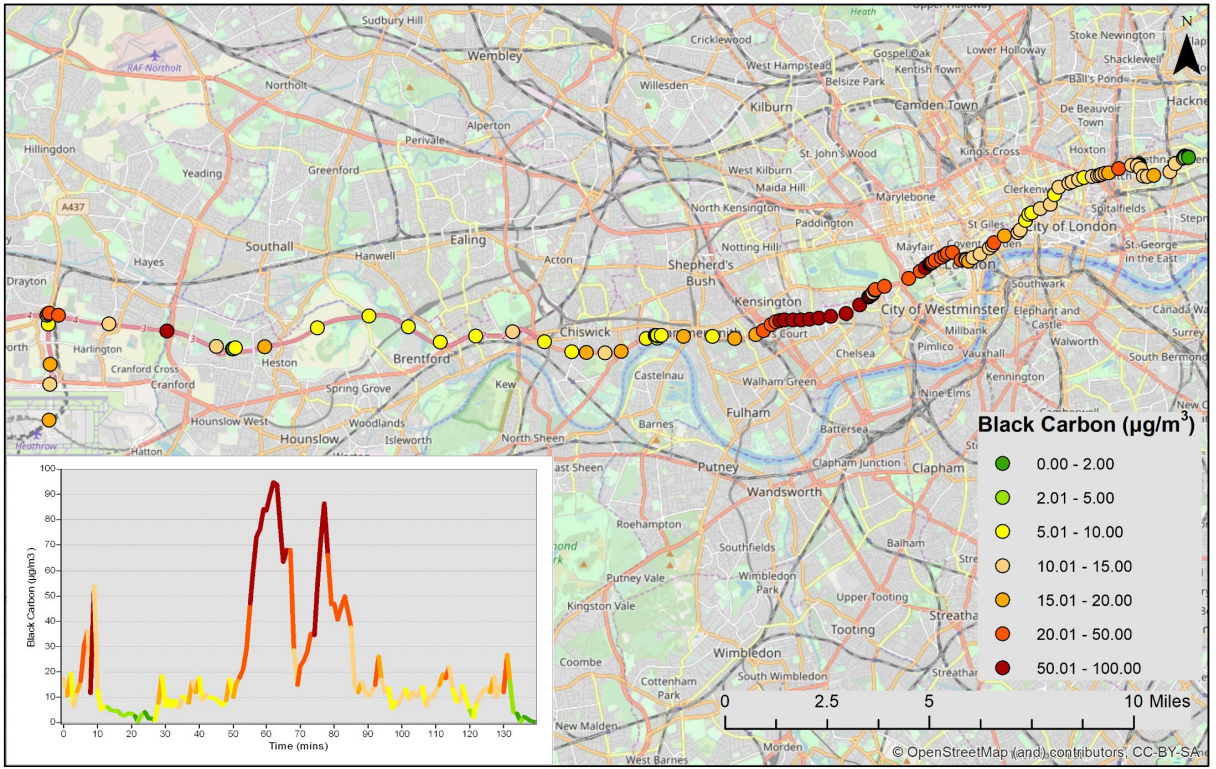
Exposure spikes while driving

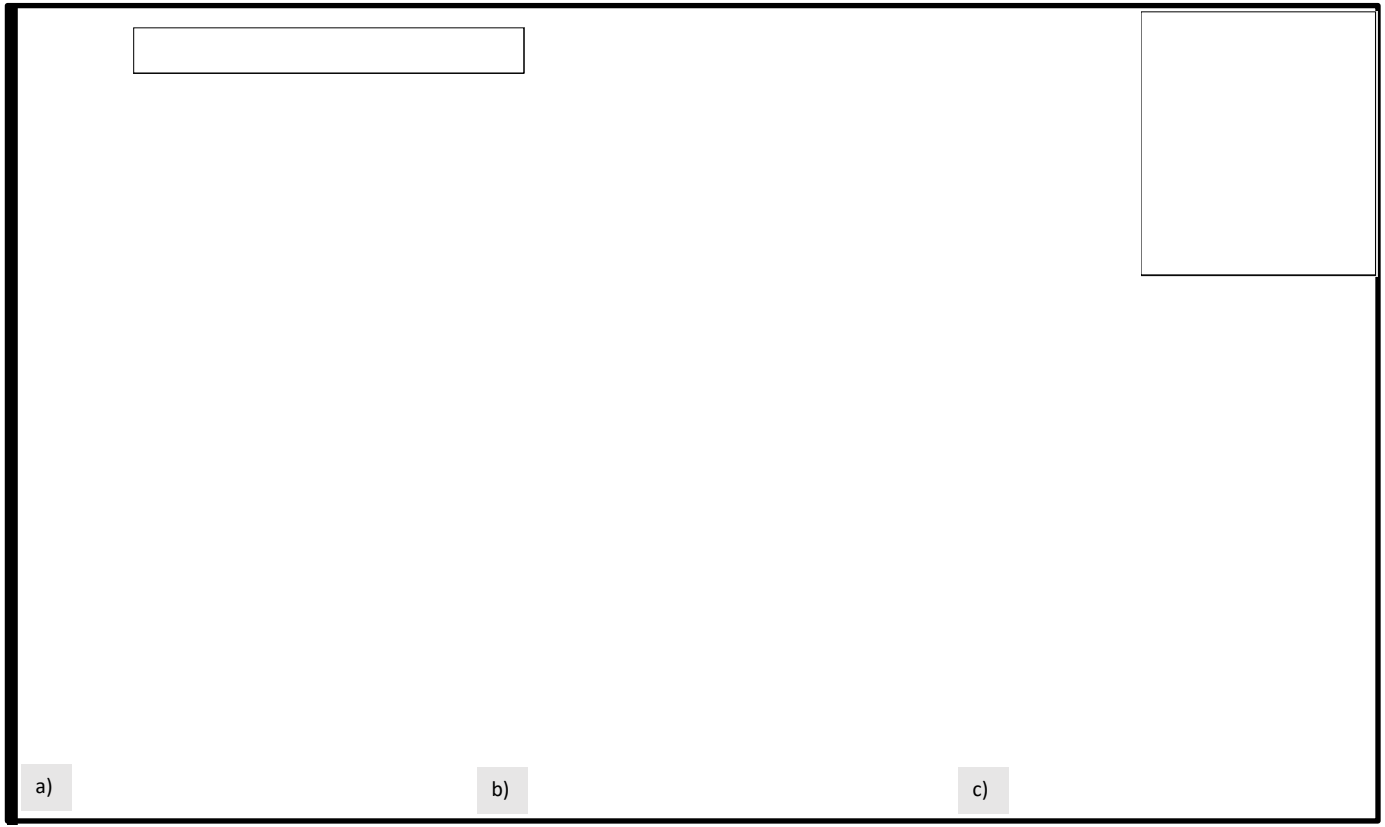


Pollution spikes across space



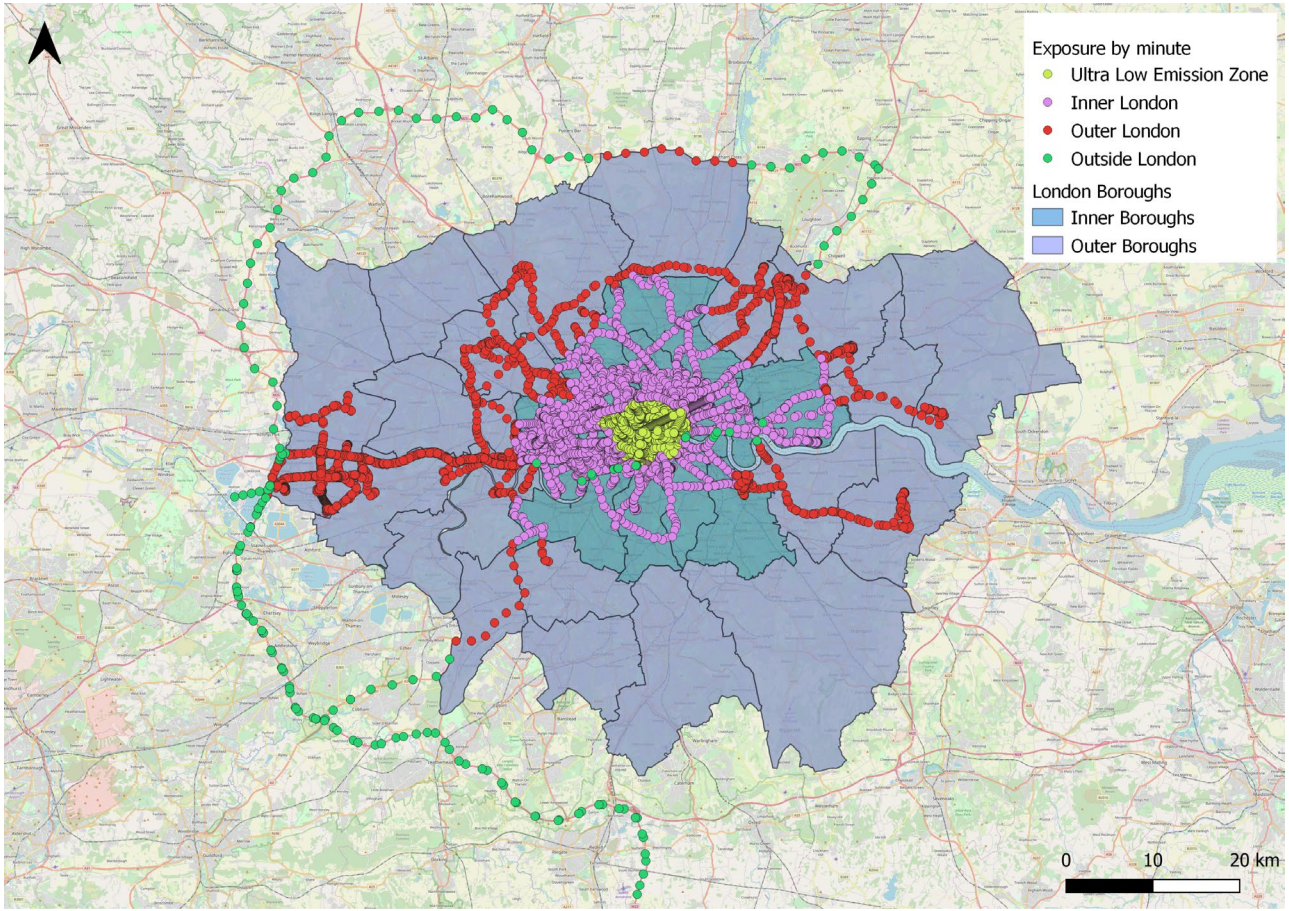
Pollution spikes in tunnels

Tunnels

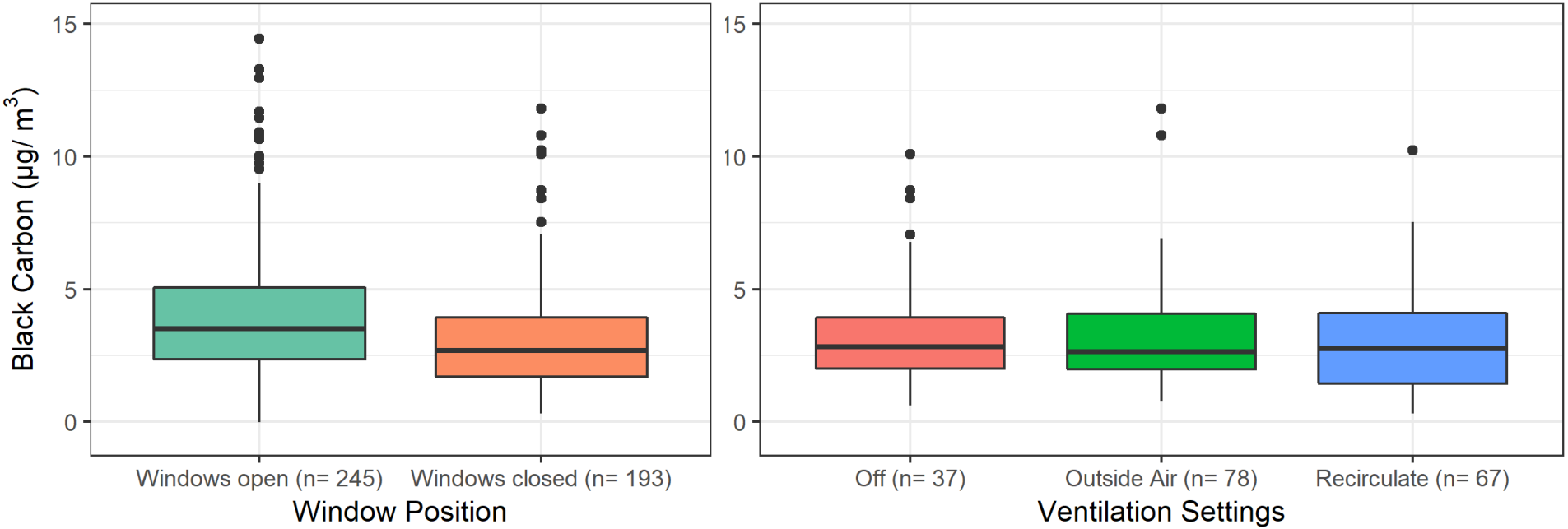


Spatial exposures of taxi drivers

	At work driving	
	Hours	Mean (sd) black carbon exposure (μg/m^3)
ULEZ	72.3	8.2 (11.1)
Inner London	84.8	6.4 (7.6)
Outer London	28.3	5.7 (5.5)
Outside London	1.3	5.3 (5.8)
All	**186.7**	**7.0 (8.9)**



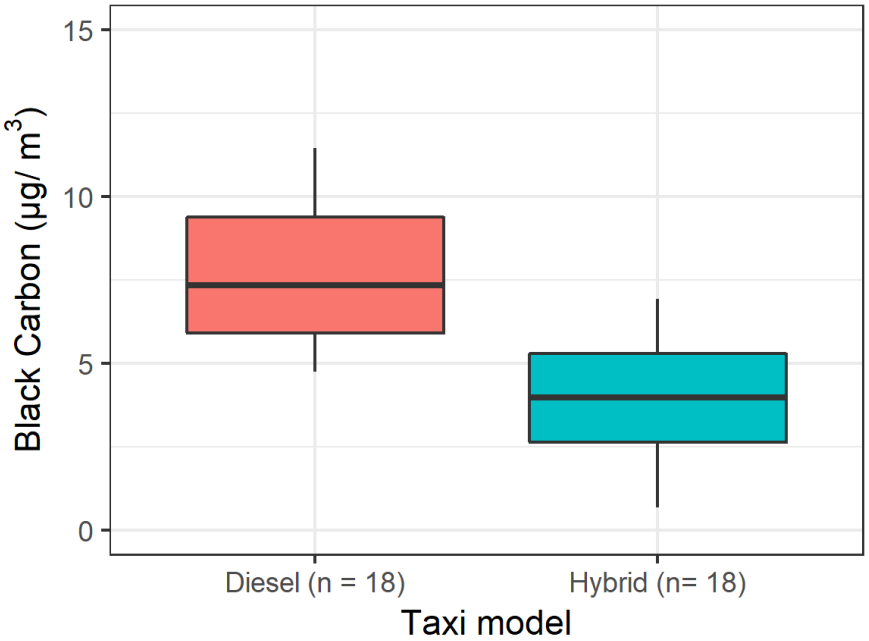
Ventilation setting results



While driving, windows open had average shift exposures at 4.7 µg/m^3 compared to windows closed at 3.6 µg/m^3 ($p<0.05$).

While driving, ventilation settings set to ‘off’ had average shift exposures at 3.4 µg/m^3 , ‘outside air’ at 3.2 µg/m^3 and ‘recirculate’ at 3.0 µg/m^3 . ($p =0.45$)

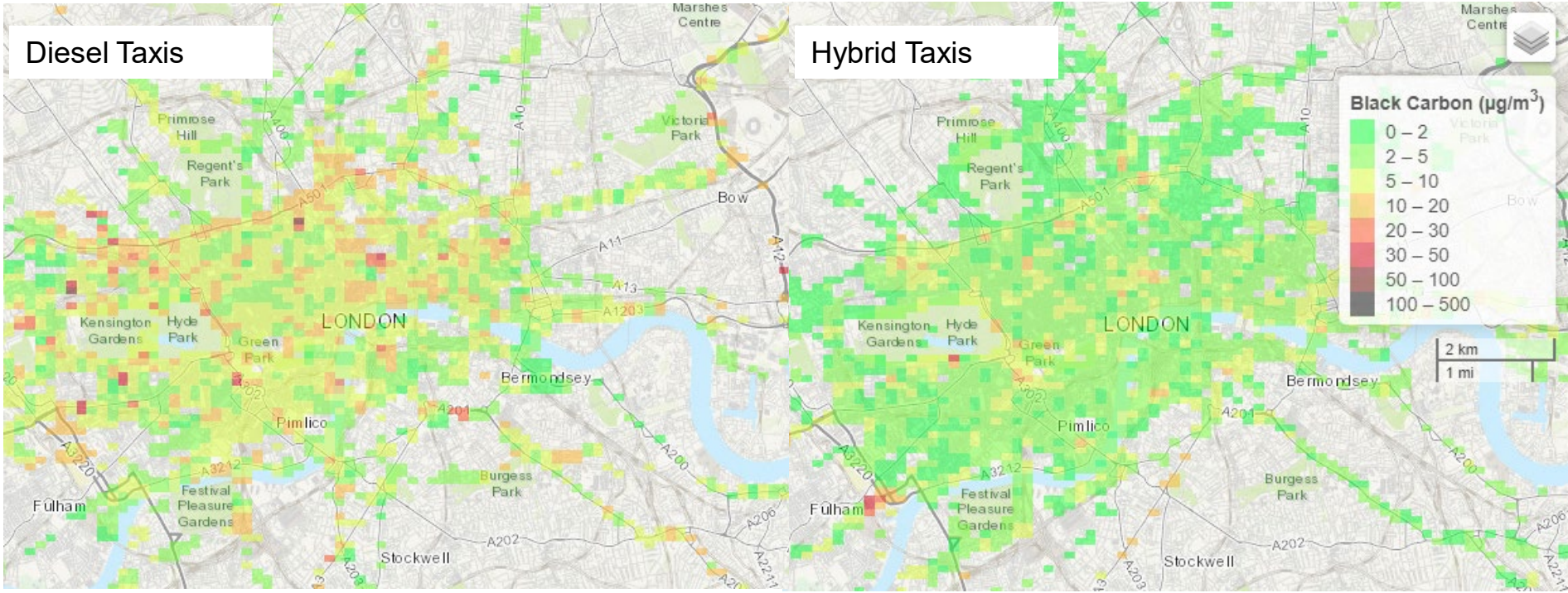
Diesel and Hybrid Taxis



https://www.autocar.co.uk/car-news/new-cars/first-levc-tx-london-black-cab-now-operational-capital

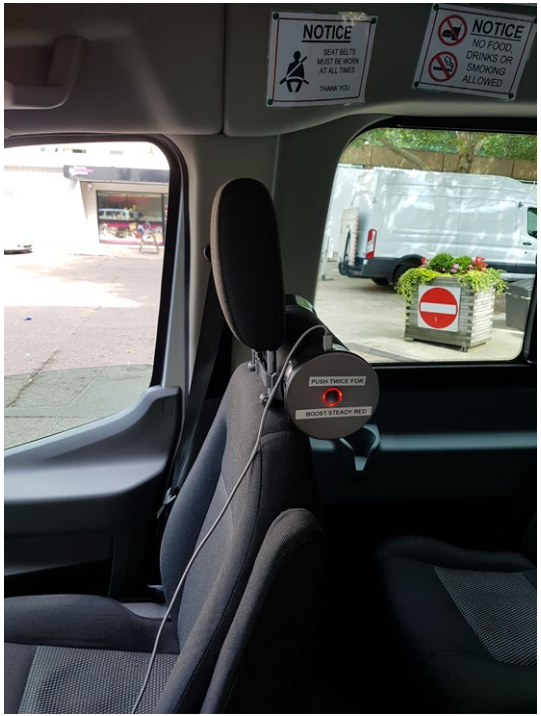
While driving, hybrid taxi drivers had average shift exposures at 3.9 µg/m^3 compared to diesel taxi drivers at 7.8 µg/m^3 ($p<0.01$).

Spatial analysis of Taxis

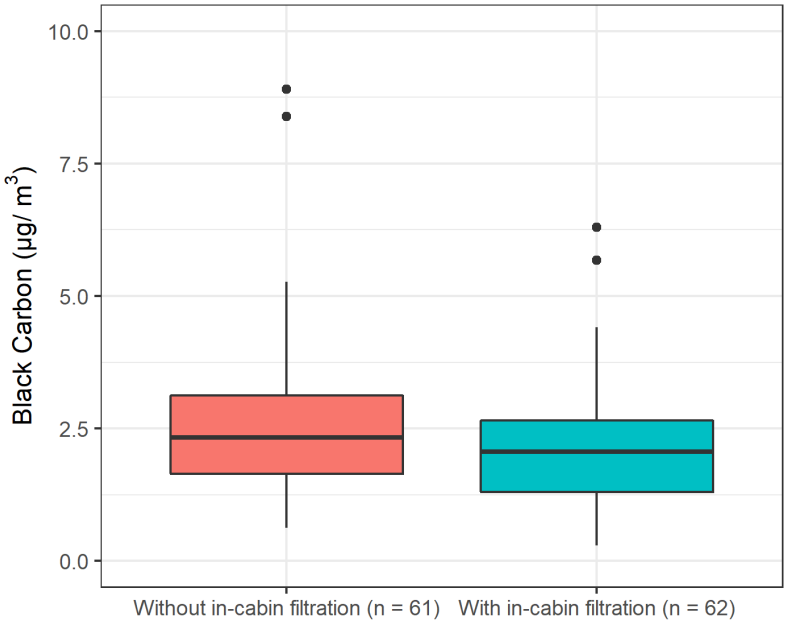


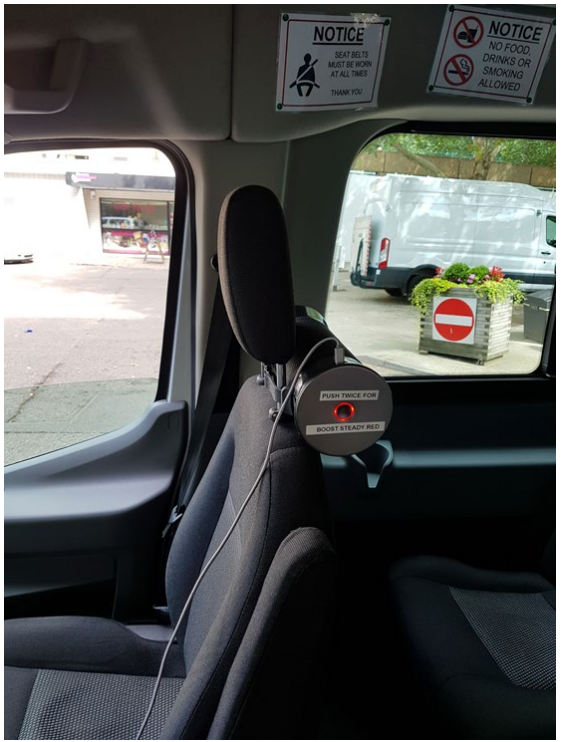
Intervention testing methods

- A subset of 42 participants were asked to repeat monitoring to quantify the effectiveness of in-vehicle filters.
- Participants were asked to complete two shifts using an air bubbl and two days without, where possible these days were mixed between participants during the monitoring week.
- Participants were asked to set the device to “boost” mode.
- A similar questionnaire to the baseline was provided to participants
- Participants were asked to keep their windows closed if possible during the shift, however most did not adhere to this request.



Using in-cabin filtration





Drivers using filtration devices had average shift exposures at 2.7 µg/m^3 compared to without at 2.2 µg/m^3 ($p<0.05$).

Identifying determinants which influence high black carbon exposure to drivers.

- Identify the influence of meteorology on driver exposure including temperature, wind speed, precipitation and time of day.
- Identify mechanical determinants of driver exposures including vehicle speed, ventilation settings, window position and vehicle type.
- Investigate spatial variability in exposure using GIS techniques to investigate the effect of urban features on driver exposure including traffic signals, aspect ratios, tunnels, congestion and vehicle number on exposure.
- Create a mixed-effects statistical model to establish dominant variables of driver exposure.

Mixed effects model methods

- Due to the repeated measurements of the exposure dataset (i.e. exposure at time n is dependent on exposure at time n-1) and unequal sample sizes, mixed effects models were run to best identify the determinants of driver exposure.
- These models adjusted for the random effect of each participant and assessed fixed effects of all other determinants.
- Data was not transformed (i.e. log) as the outputs provide a better understanding of the absolute exposure effect for each determinant.

The mixed effects model are presented as:

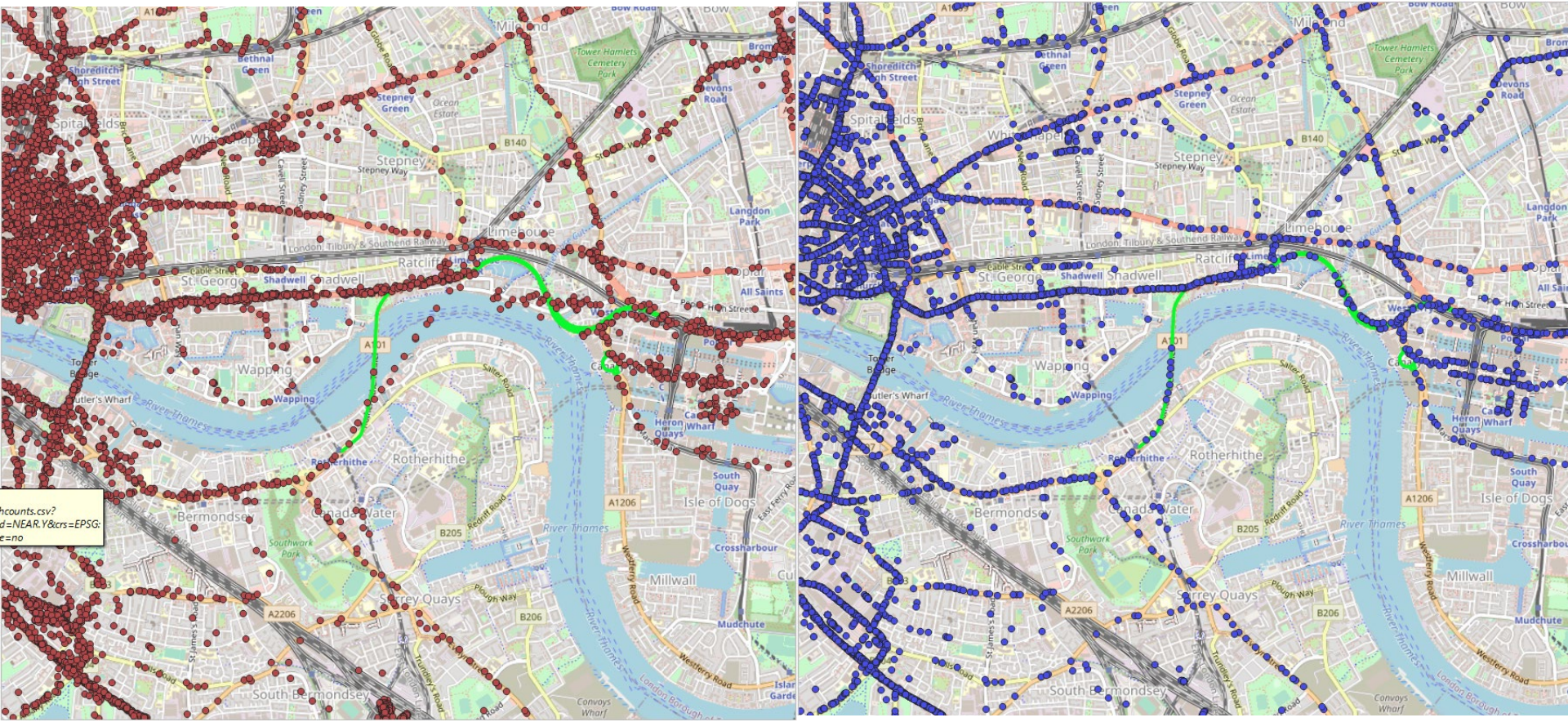
$$(bc\ driving)_{ij} = \alpha + (participant)_i + \beta_n(fixed\ effect)_{ij} +_{.} \ldots + \varepsilon_{ij}$$

Mixed effects model

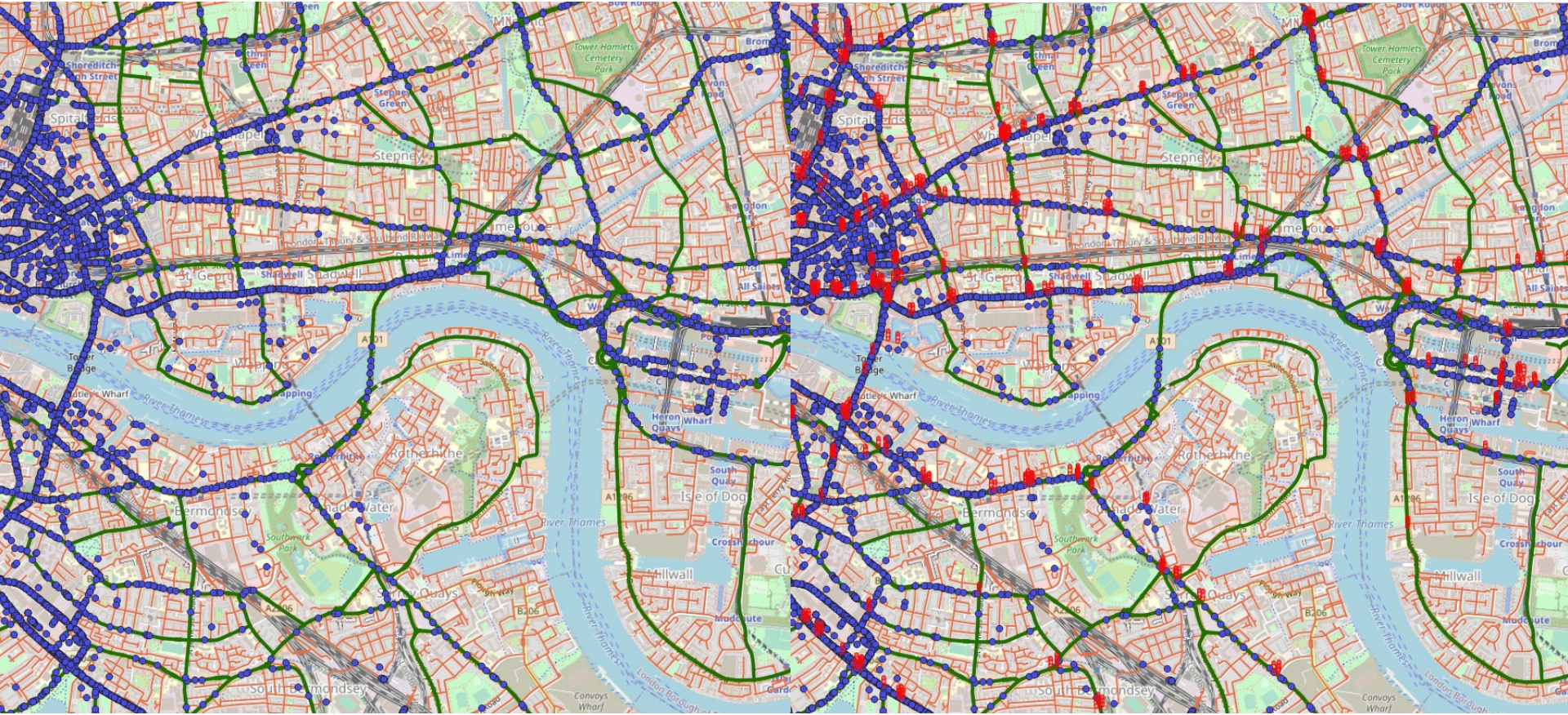
Fixed Effect determinants	Categorical Comparison	Estimate	95% CI (lower, upper)	p-Value
(Intercept)		8.85	6.51, 11.19	<0.0001 ***
Background Black Carbon (μg/m^3)		0.50	0.44, 0.56	<0.0001 ***
Fuel	Electric ~ Diesel	-1.23	-5.07, 2.60	ns
	Hybrid ~ Diesel	-4.31	-8.56, -0.07	0.05 *
Location	Outside ~ Central London	-1.93	-2.13, -1.73	<0.0001 ***
	Outer London ~ Central London	-0.78	-0.92, -0.63	<0.0001 ***
	Inner London ~ Central London	-0.37	-0.47, -0.27	<0.0001 ***
Time of day	Night time ~ Day time	-0.19	-0.32, -0.05	0.006 **
	Morning peak ~ Day time	-0.10	-0.20, 0.01	ns
	Evening peak ~ Day time	0.69	0.55, 0.82	<0.0001 ***
Sector	Bus ~ Taxi	-5.08	-8.95, -1.22	0.01 *
	Courier ~ Taxi	-2.66	-6.10, 0.79	ns
	Emergency Services ~ Taxi	-5.54	-8.28, -2.81	0.0001 ***
	Heavy Freight ~ Taxi	-4.87	-8.00, -1.74	0.003 **
	Utility Services ~ Taxi	-5.55	-9.22, -1.89	0.004 **
	Waste Removal ~ Taxi	-4.63	-7.74, -1.52	0.004 **
Smoker Status	Not reported ~ Non-smoker	4.23	1.05, 7.41	0.01 **
	Smoker ~ Non-smoker	2.15	-0.28, 4.57	ns
Vehicle Speed (km/hr)		0.03	0.02, 0.04	<0.0001 ***
Day of week	Weekend ~ Weekday	-1.32	-1.48, -1.15	<0.0001 ***
Window position	Not reported ~ Window closed	1.20	-0.02, 2.42	ns
	Windows open ~ Windows closed	0.31	0.15, 0.48	0.0002 ***
Wind speed (m/s)		-0.27	-0.30, -0.24	<0.0001 ***

Observations 101,817 minutes out of 112,676 drive minutes, caused by NA background black carbon, wind speed and vehicle speed

Drivers points matched to geographic features



Drivers points matched to geographic features



Mixed effects model

Fixed Effect determinants	Categorical Comparison	Estimate	95% CI (lower, upper)	p-Value
(Intercept)		8.67	6.34, 11.00	<0.0001 ***
Background Black Carbon (μg/m^3)		0.50	0.44, 0.56	<0.0001 ***
Fuel	Electric ~ Diesel	-1.30	-5.13, 2.52	ns
	Hybrid ~ Diesel	-4.35	-8.58, -0.12	0.05 *
Location	Outside ~ Central London	-1.77	-1.97, -1.57	<0.0001 ***
	Outer London ~ Central London	-0.63	-0.78, -0.49	<0.0001 ***
	Inner London ~ Central London	-0.31	-0.41, -0.21	<0.0001 ***
Time of day	Night time ~ Day time	-0.23	-0.37, -0.10	0.001 ***
	Morning peak ~ Day time	-0.09	-0.20, 0.01	ns
	Evening peak ~ Day time	0.66	0.53, 0.79	<0.0001 ***
Sector	Bus ~ Taxi	-5.04	-8.89, -1.18	0.01 *
	Courier ~ Taxi	-2.59	-6.02, 0.84	ns
	Emergency Services ~ Taxi	-5.47	-8.20, -2.75	0.0001 ***
	Heavy Freight ~ Taxi	-4.85	-7.98, -1.73	0.003 **
	Utility Services ~ Taxi	-5.56	-9.22, -1.91	0.003 **
	Waste Removal ~ Taxi	-4.60	-7.70, -1.50	0.004 **
Smoker Status	Not reported ~ Non-smoker	4.26	1.09, 7.44	0.009 **
	Smoker ~ Non-smoker	2.10	-0.32, 4.52	ns
Vehicle Speed (km/hr)		0.03	0.02, 0.04	<0.0001 ***
Day of week	Weekend ~ Weekday	-1.32	-1.48, -1.16	<0.0001 ***
Window position	Not reported ~ Window closed	0.73	-0.60, 2.07	ns
	Windows open ~ Windows closed	0.30	0.14, 0.47	0.0003 ***
Wind speed (m/s)		-0.27	-0.30, -0.24	<0.0001 ***
Tunnel	In tunnel ~ Not in tunnel	6.10	5.17, 7.02	<0.0001 ***
Number of traffic signals within 50m		0.20	0.17, 0.23	<0.0001 ***

Observations 100,546 minutes out of 111,232 minutes GPS not interpolated, caused by NA background black carbon, wind speed and vehicle speed

Conclusions

- Exposures both between sectors, drivers and time and space are highly variable.
- Average exposure is 3 times higher at work compared to home environments, while driving at work had 4 times higher exposure compared to home environments
- Taxi drivers have the highest exposures while emergency services have the lowest while working.
- The results of the study show that there are simple practical steps which can reduce exposure to drivers. Window position, route choice and vehicle type all appear to influence driver exposure.