Integrated assessment modelling of future air quality in the UK to 2050, and synergies with net zero strategies.

Helen ApSimon [1], Tim Oxley [1,*], Huw Woodward [1], Daniel Mehlig [1], Mike Holland [2], Sarah Reeves [3]

[1] Centre for Environmental Policy, Imperial College London, London SW7 2AZ, UK
[2] EMRC, 2 New Building, Whitchurch Hill, Reading RG8 7PW, UK
[3] Department for Environment, Food and Rural Affairs, 2 Marsham Street, London SW1P 4DF, UK

* Correspondence: t.oxley@imperial.ac.uk

Supplementary Information

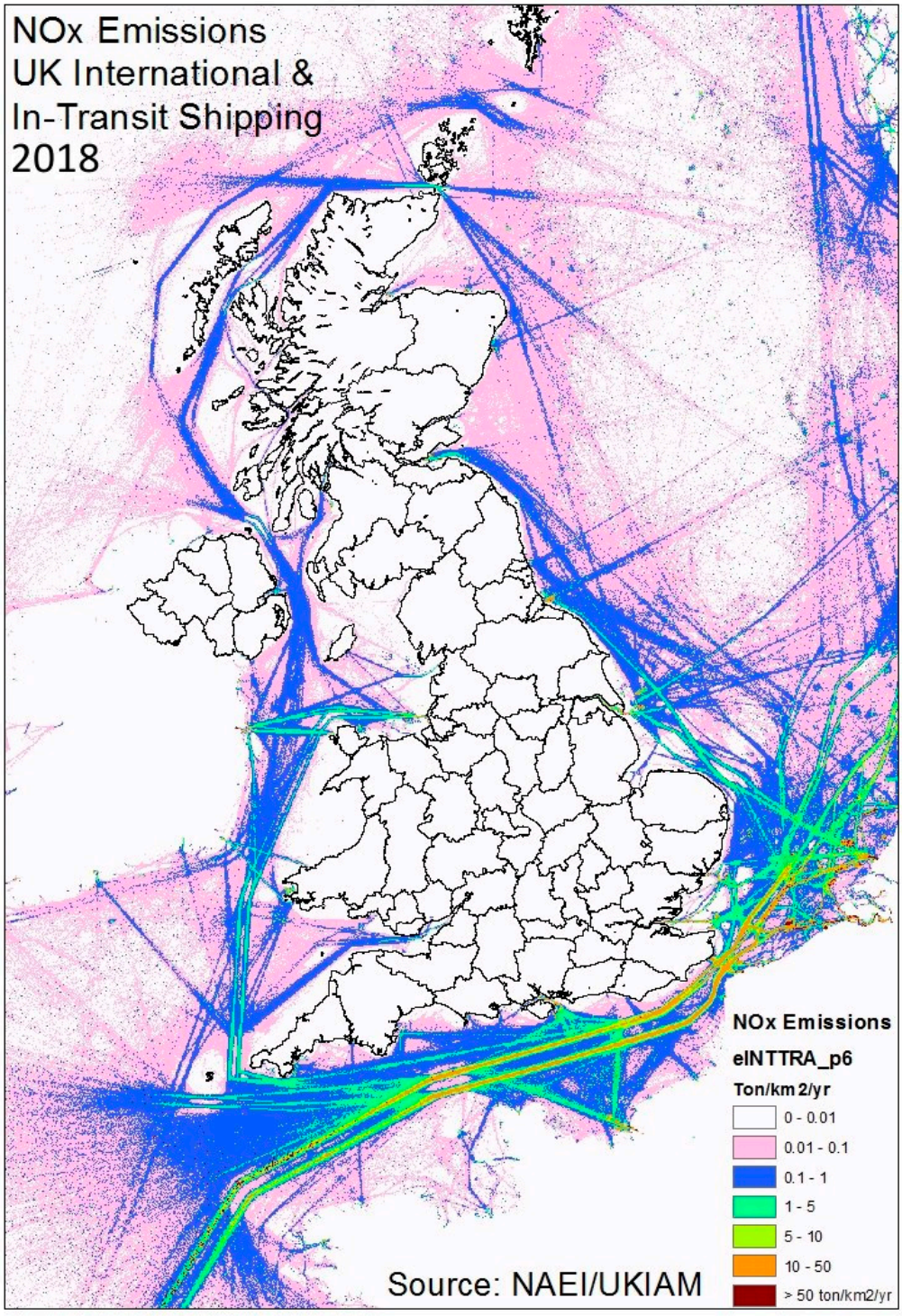


Figure S1 *- NOx emissions from international and in-transit shipping in sea areas surrounding the United Kingdom, when combined with domestic shipping, exceed the UK land-based emissions of NOx in 2018.*

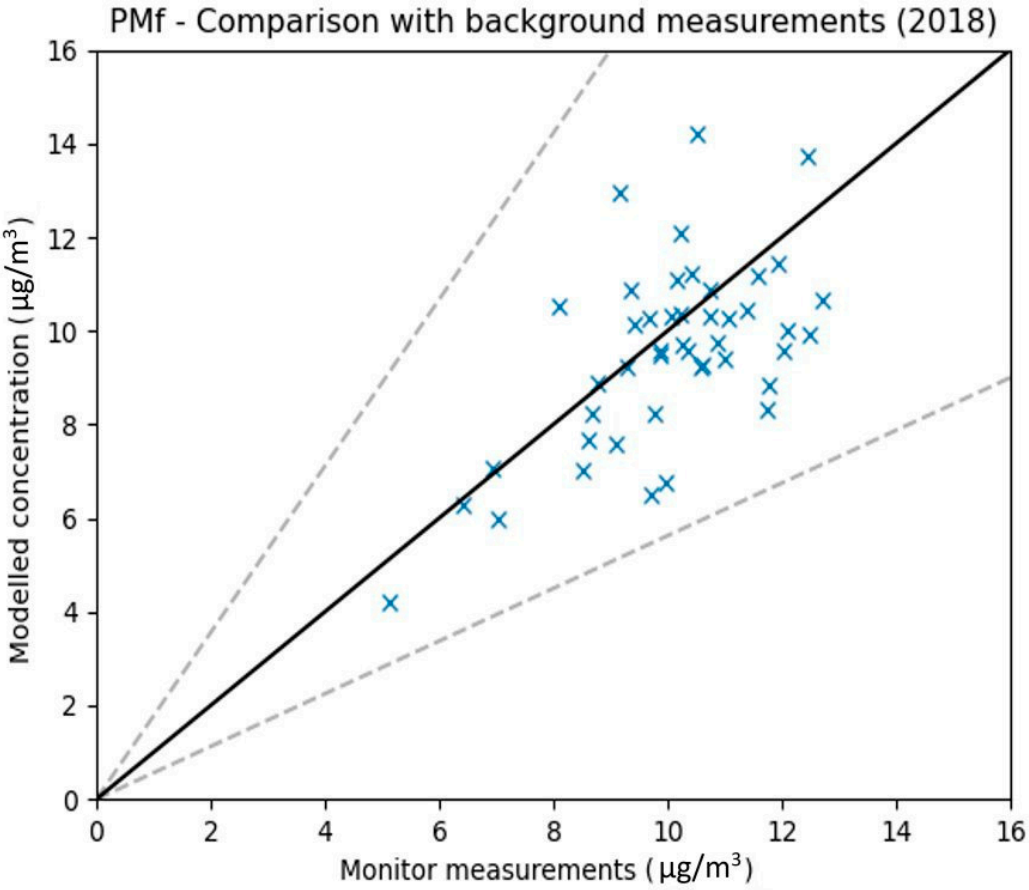


Figure S2 *- Comparison modelled concentrations against AURN measurements for B2018*

Table S1 - (B2018) Statistical comparison at monitoring locations. N=number of measurements, Obs.=mean of all measurements, Mod.=mean of all modelled concentrations, r=Pearson correlation, FAC2=fraction of modelled values within a factor 2 of measured value, NMSE=Normalised Mean-Square Error, RMSE=Root Mean-Square Error, NAD=Normalised absolute difference.

Model	N	UKIAM	EMEP4UK	r	FAC2	FB	RMSE	NAD
Total $PM_{2.5}$	51	9.41	9.43	0.83	1	0	1.09	0.04

Fractional bias (FB): $$\mathrm{FB} = \frac{2\overline{C_o - C_p}}{(\overline{C_o} + \overline{C_p})}$$

Normalised Mean-Square Error: $$\mathrm{NMSE} = \frac{\overline{(C_o - C_p)^2}}{(\overline{C_o}\,\overline{C_p})}$$

Normalised Absolute Difference: $$\mathrm{NAD} = \frac{\overline{|C_o - C_p|}}{(\overline{C_o} + \overline{C_p})}$$

Here C_o is the measured, or observed, concentration and C_p is the modelled concentration. The overbar indicates that the mean is taken.

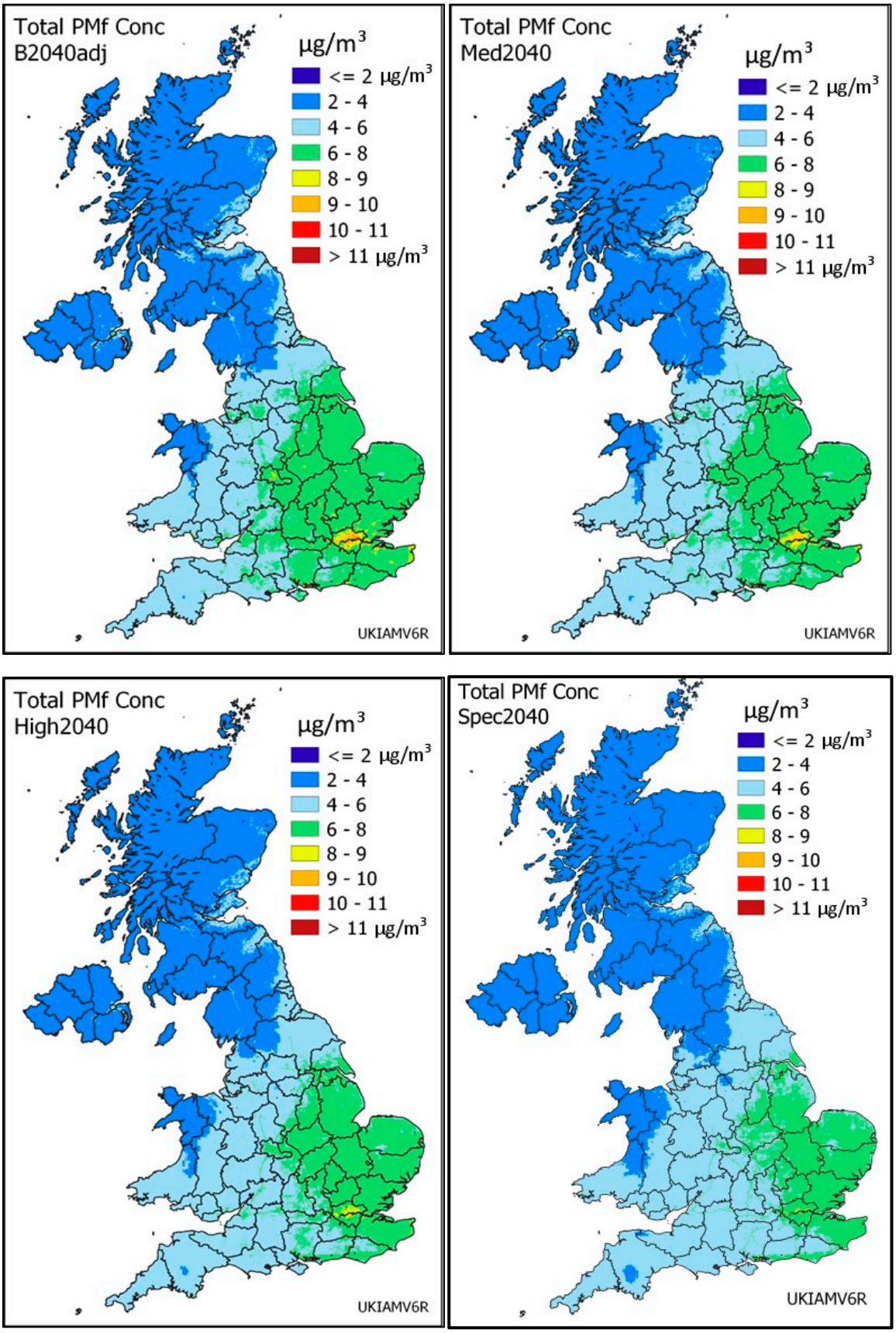


Figure S3 – *Maps of total $PM_{2.5}$ concentrations in 2040. There is already a clear reduction in concentrations relative to 2018 (see Figure 3) for the baseline (business-as-usual) scenario; Progressively more ambitious abatement strategies show a further significant redcution of concentrations across the UK.*

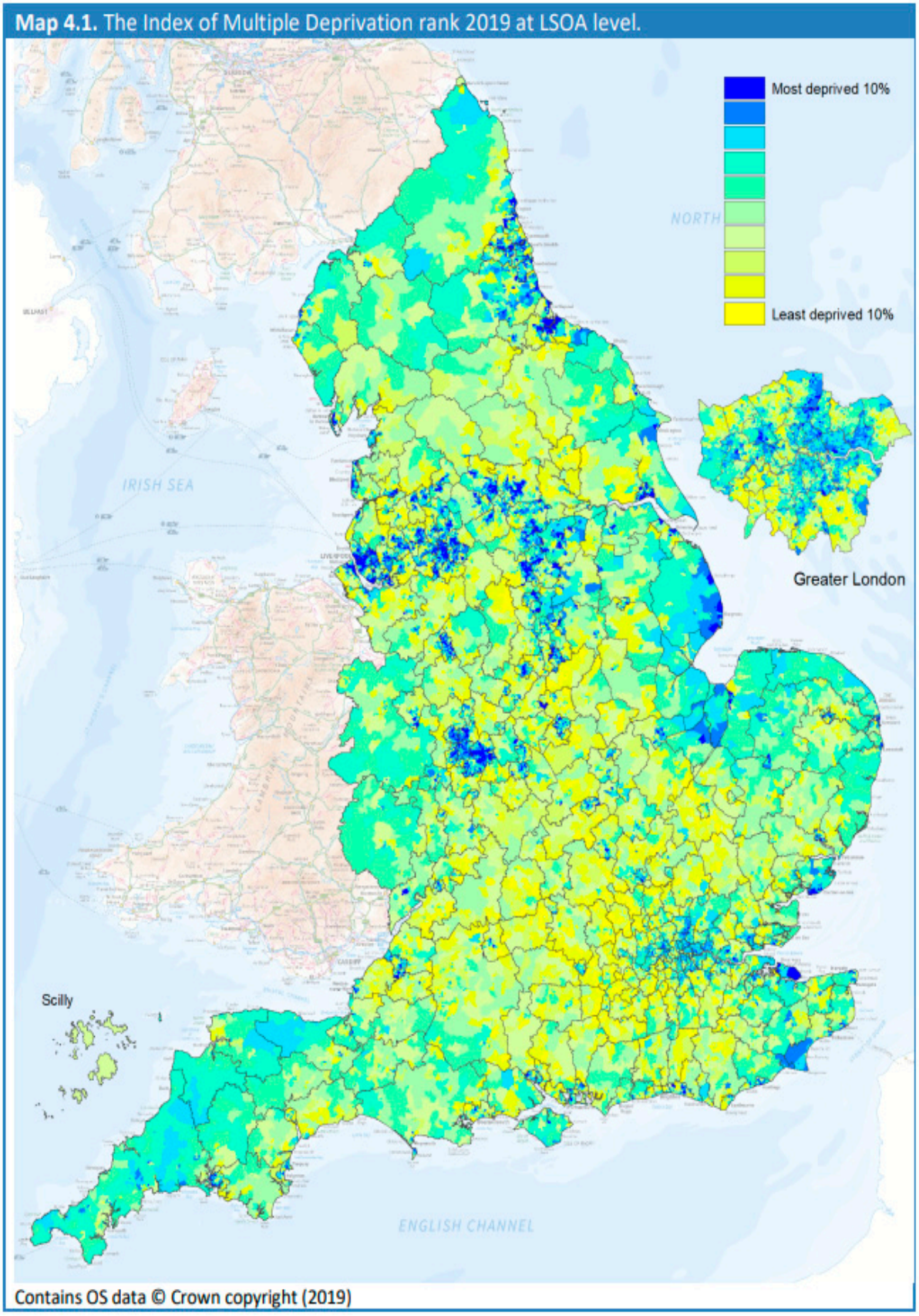
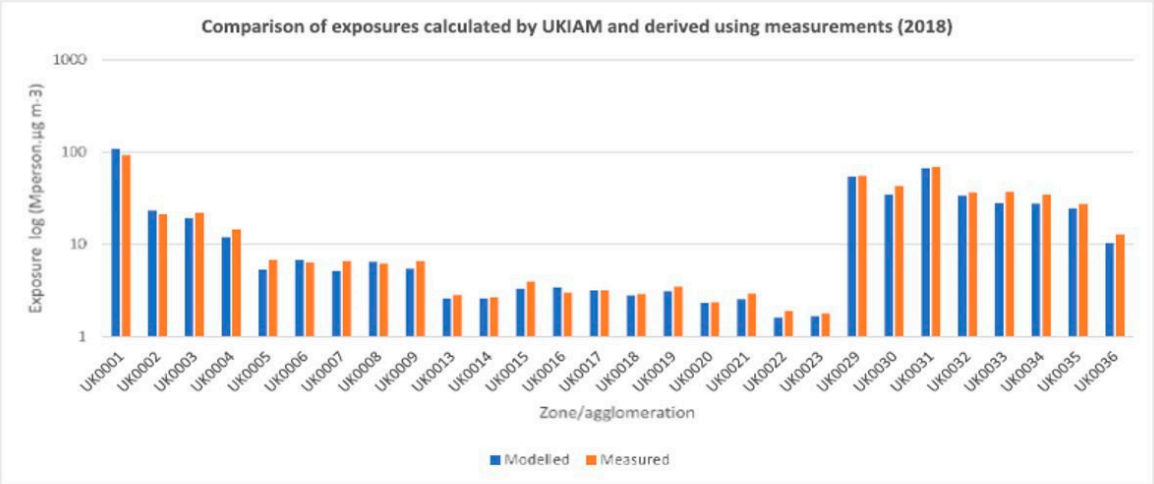


Figure S4 – *Map of the Index of Multiple Deprivation (IMD) at the LSOA level. Reproduced from https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019*



UK0001	Greater London Urban Area
UK0002	West Midlands Urban Area
UK0003	Greater Manchester Urban Area
UK0004	West Yorkshire Urban Area
UK0005	Tyneside
UK0006	Liverpool Urban Area
UK0007	Sheffield Urban Area
UK0008	Nottingham Urban Area
UK0009	Bristol Urban Area

UK0014	The Potteries
UK0015	Bournemouth Urban Area
UK0016	Reading/Wokingham Urban Area
UK0017	Coventry/Bedworth
UK0018	Kingston upon Hull
UK0019	Southampton Urban Area
UK0020	Birkenhead Urban Area
UK0021	Southend Urban Area
UK0022	Blackpool Urban Area

UK0023	Preston Urban Area
UK0029	Eastern
UK0030	South West
UK0031	South East
UK0032	East Midlands
UK0033	North West & Merseyside
UK0034	Yorkshire & Humberside
UK0035	West Midlands
UK0036	North East

Figure S5 *– A comparison of modelled PWMC and PWMC derived from monitoring data for 2018 highlights the generally slightly higher exposures based on measurements since monitor locations tend to be in areas of higher concentrations.*

Table S2 - Cumulative (2023-2040) air quality benefits in England from reduced damage to health, productivity, ecosystems and soiling of buildings, broken down by sensitivity (2020 prices, £m)

	Medium Scenario			**High Scenario**		
	Low	Central	High	Low	Central	High
Total Air Quality Benefits	£5,327	£23,150	£71,255	£9,142	£37,891	£114,332

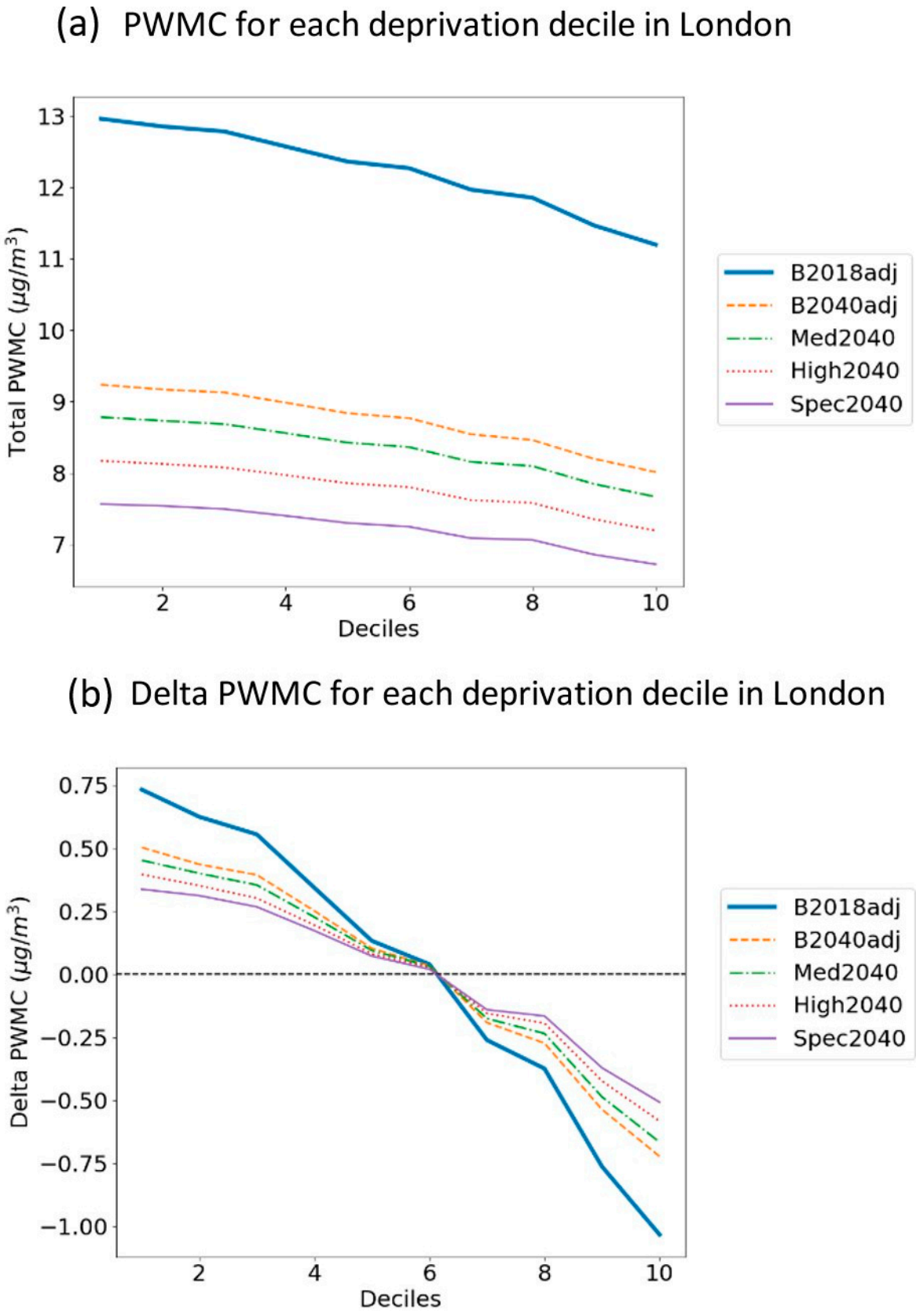


Figure S6 *- Population Weighted Mean Concentration (PWMC) and Delta PWMC for each deprivation decile across London, consistently showing higher concentrations in the most deprived deciles. The Delta PWMC shows that the disparity across all deciles reduces with the more ambitious abatement scenarios.*

BOX S1 – Summary of key assumptions in the Medium, High & Speculative scenarios

Baseline scenario

The target Baseline reflects existing interventions and policies with a natural technology turnover. The baseline assumes NAEI2018 projections with some adjustments reflecting more recent findings.

The Medium scenario

Includes the implementation of proven technologies and limited behavioural changes, with increasing levels of implementation and uptake in 2030, 2040 and 2050 relative to 2018, including:

- The use of eco-design stoves and reducing the use of open fires by 50%
- Up to 10% reduction in urban traffic, designed to capture behavioural changes resulting from increases in active travel, Clean Air Zones (CAZ), and road charging
- Uptake of electric/hydrogen non-road mobile machinery (NRMM) reaching 50% uptake by 2050
- Reduced industrial combustion and increased use of filtration technologies to reduce PM emissions

The High Scenario

Includes uptake of technologies considered likely to be implementable in the future, an increased rate of behavioural change and more rapid uptake of measures, including:

- The banning of domestic indoor wood burning in smoke control areas
- Restrictions on domestic outdoor burning
- A 30% reduction in urban traffic, reflecting a need for CAZs and increased road charging
- Uptake of electric/hydrogen non-road mobile machinery (NRMM) reaching 95% uptake by 2050

The Speculative Scenario

Includes all feasible measures including emerging technologies and assumptions of significant behaviour change, including:

- Up to a 100% ban on domestic indoor wood burning nationally
- Up to a 60% reduction in urban domestic car traffic
- New technologies designed to capture particulates from tyre wear
- Uptake of electric/hydrogen non-road mobile machinery (NRMM) reaching 95% uptake by 2040
- An assumption that the NO_x emission control area (NECA) is expanded to include shipping in the Irish sea, implementable by the International Maritime Organisation (IMO).

The Net Zero Scenario

This scenario is based on projections of future energy generation, derived by the DDM energy model for BEIS, with climate measures aimed at reaching net zero greenhouse gas emissions. This scenario reflects the commitment to achieve net zero emissions from electricity production by 2035, the year in which new ICE cars and vans are phased out with replacement by electric vehicles. This scenario does not include any of the additional abatement measures in the medium, high and speculative scenarios above.

Table S3 *- Population Weighted Mean Concentrations (PWMC) of $PM_{2.5}$ for all the target setting scenarios up to 2050. Includes PWMC for the Devolved Regions and London (µg/m^3)*

Scenario		National	Urban	Rural	London	England*	Scotland	Wales	Northern Ireland
2018	**Baseline**	9.16	9.54	7.84	12.34	9.70	5.45	7.93	6.44
2030	**Baseline**	7.11	7.36	6.24	9.61	7.48	4.50	6.40	5.17
	Medium	6.86	7.09	6.09	9.19	7.22	4.38	6.23	5.00
	High	6.62	6.81	5.95	8.82	6.95	4.27	6.06	4.80
	Speculative	6.16	6.30	5.67	8.16	6.46	4.07	5.68	4.40
	Net Zero	7.06	7.30	6.23	9.46	7.44	4.47	6.36	5.09
2040	**Baseline**	6.93	7.18	6.05	9.40	7.29	4.43	6.24	5.04
	Medium	6.41	6.60	5.73	8.60	6.72	4.19	5.88	4.69
	High	6.03	6.18	5.52	8.03	6.32	4.02	5.61	4.37
	Speculative	5.64	5.76	5.24	7.47	5.90	3.84	5.29	4.10
	Net Zero	6.35	6.54	5.69	8.48	6.66	4.14	5.86	4.66
2050	**Baseline**	6.94	7.20	6.04	9.43	7.30	4.45	6.24	5.05
	Medium	6.12	6.28	5.55	8.12	6.41	4.05	5.69	4.55
	High	5.80	5.92	5.37	7.63	6.06	3.90	5.47	4.31
	Speculative	5.45	5.54	5.14	7.08	5.69	3.74	5.19	4.09
	Net Zero	6.08	6.25	5.50	8.08	6.37	4.03	5.69	4.48

***** excludes London