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The past, the present, and future prospects for air quality management and health in the UK

Martin Williams Memorial Lecture

Roy M. Harrison
University of Birmingham
and National Centre for Atmospheric Science

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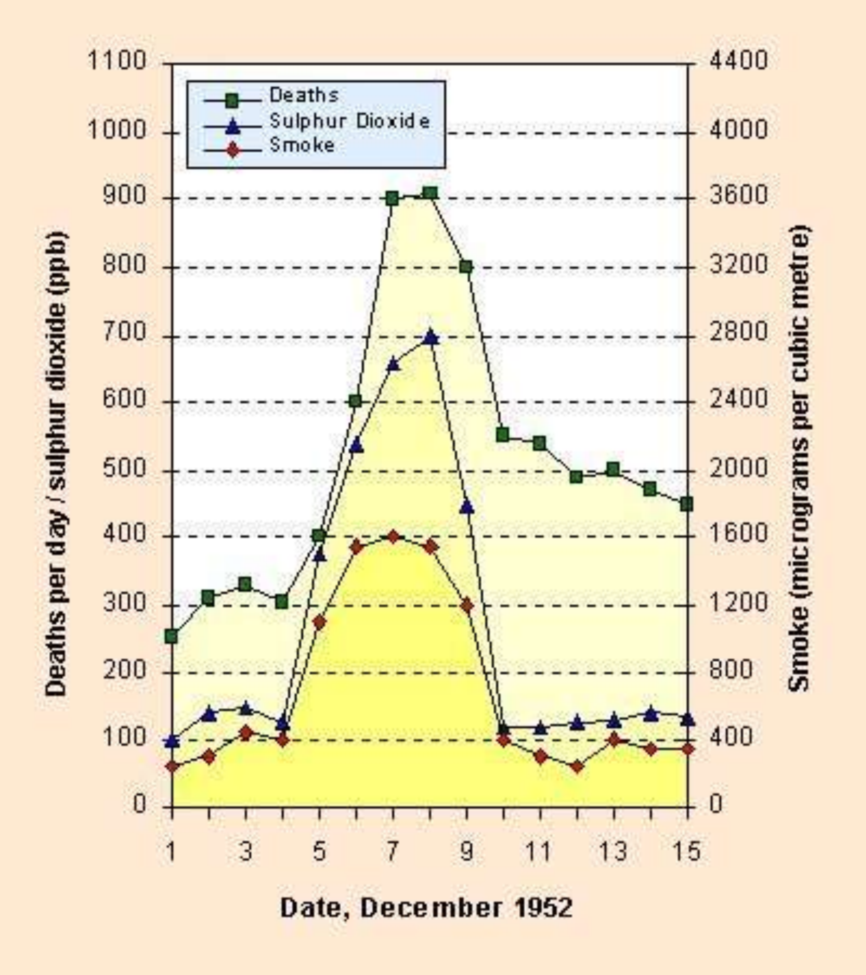
The past

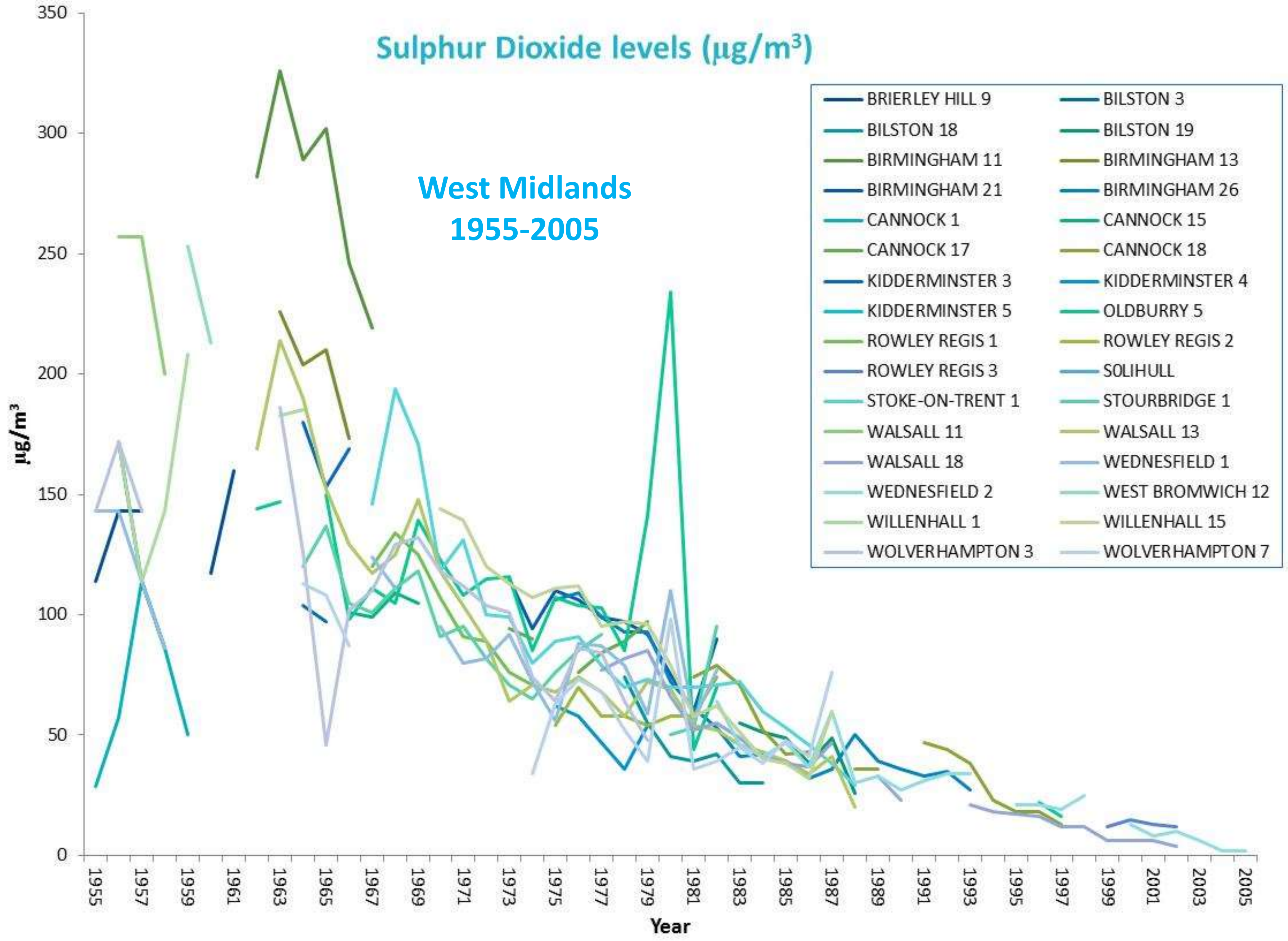
The Great London Smog, 1952

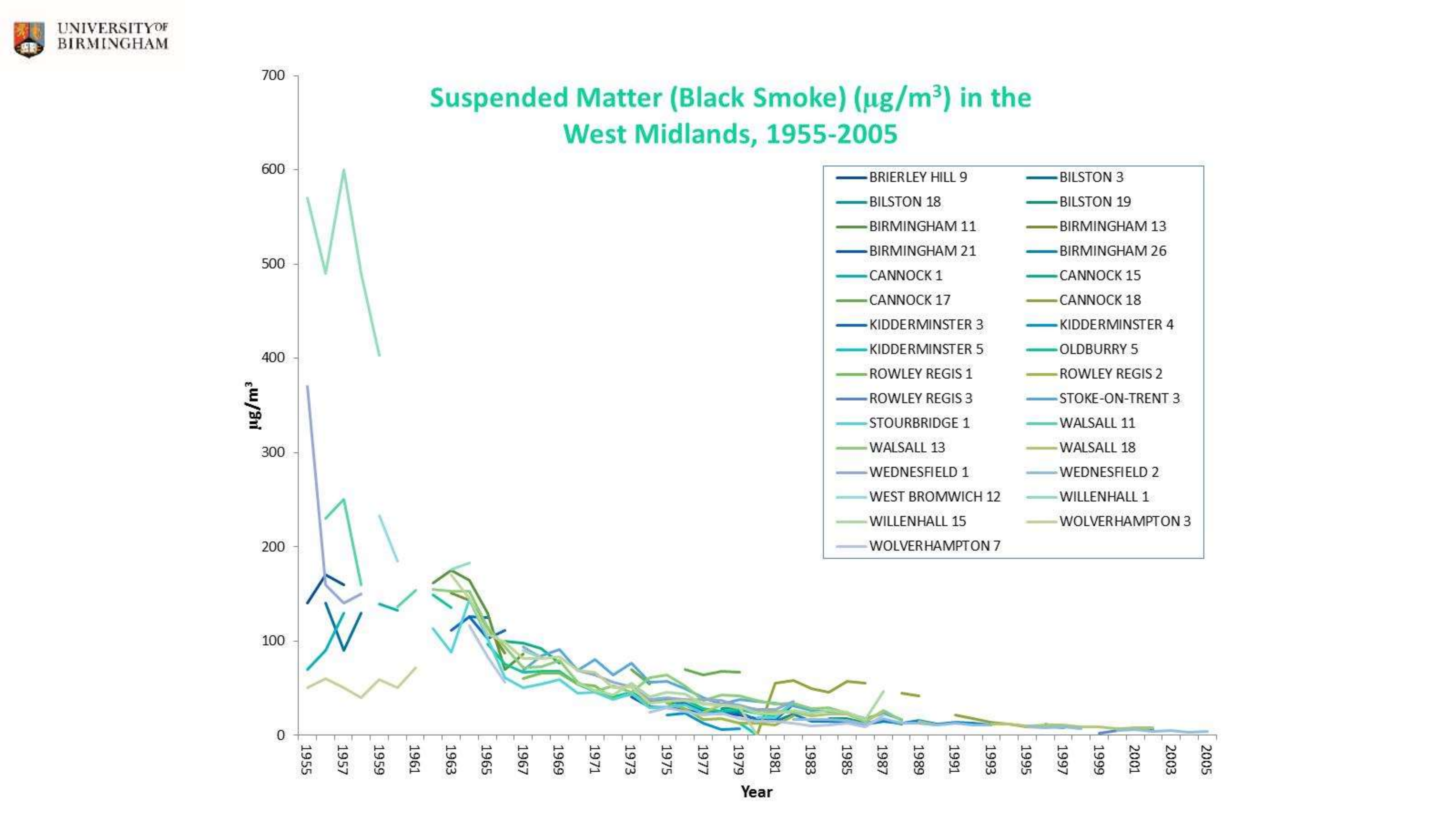


5th-9th Dec 1952: Fog period

1956 – Clean Air Act: Introduced smoke control areas, controlled chimney heights. Prohibited emission of dark smoke from chimneys, with some exceptions.

1968 – Clean Air Act Amendment: Extended the smoke control provisions of the 1956 Act and added further prohibitions on dark smoke emissions.


Sulphur Dioxide levels (µg/m³)
West Midlands
1955-2005
µg/m³
Year
350
300
250
200
150
100
50
0
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
BRIERLEY HILL 9
BILSTON 3
BILSTON 18
BILSTON 19
BIRMINGHAM 11
BIRMINGHAM 13
BIRMINGHAM 21
BIRMINGHAM 26
CANNOCK 1
CANNOCK 15
CANNOCK 17
CANNOCK 18
KIDDERMINSTER 3
KIDDERMINSTER 4
KIDDERMINSTER 5
OLDBURRY 5
ROWLEY REGIS 1
ROWLEY REGIS 2
ROWLEY REGIS 3
SOLIHULL
STOKE-ON-TRENT 1
STOURBRIDGE 1
WALSALL 11
WALSALL 13
WALSALL 18
WEDNESFIELD 1
WEDNESFIELD 2
WEST BROMWICH 12
WILLENHALL 1
WILLENHALL 15
WOLVERHAMPTON 3
WOLVERHAMPTON 7



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Suspended Matter (Black Smoke) (µg/m³) in the West Midlands, 1955-2005
BRIERLEY HILL 9
BILSTON 3
BILSTON 18
BILSTON 19
BIRMINGHAM 11
BIRMINGHAM 13
BIRMINGHAM 21
BIRMINGHAM 26
CANNOCK 1
CANNOCK 15
CANNOCK 17
CANNOCK 18
KIDDERMINSTER 3
KIDDERMINSTER 4
KIDDERMINSTER 5
OLDBURRY 5
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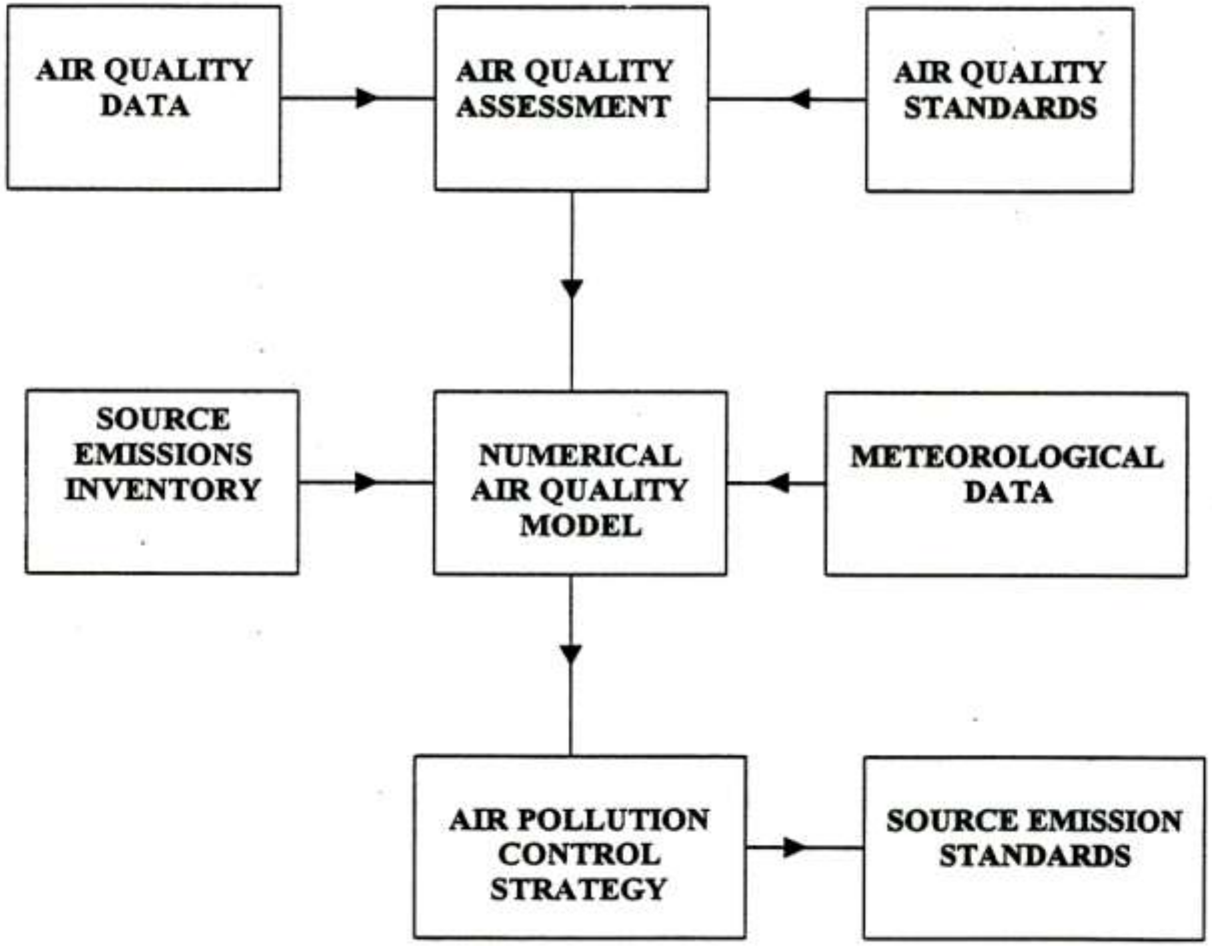
ROWLEY REGIS 2
ROWLEY REGIS 3
STOKE-ON-TRENT 3
STOURBRIDGE 1
WALSALL 11
WALSALL 13
WALSALL 18
WEDNESFIELD 1
WEDNESFIELD 2
WEST BROMWICH 12
WILLENHALL 1
WILLENHALL 15
WOLVERHAMPTON 3
WOLVERHAMPTON 7
µg/m³
700
600
500
400
300
200
100
0
Year
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005

Environment Act 1995

- Established the Environment Agency and Scottish Environmental Protection Agency
- Established Local Air Quality Management (LAQM) with air quality objectives
- The LAQM process places an obligation on all local authorities to regularly review and assess air quality in their areas, and to determine whether or not the air quality objectives are likely to be achieved.
- Where air quality objectives were exceeded, or there was an expectation of exceedance, an Air Quality Management Area was to be declared.

Key components of an air quality management strategy



Expert Panel on Air Quality Standards

- **<u>Benzene</u> - 5 ppb/running annual mean; reduction in due course to a target of 1 ppb**
- **<u>1,3-Butadiene</u> - 1 ppb/running annual mean**
- **<u>Carbon Monoxide</u> - 10 ppm/8-hour running mean**
- **<u>Ozone</u> - 50 ppb/8-hour running mean**
- **<u>PM_{10}</u> - 50 µg m^3/24-hour running mean**
- **<u>Sulphur Dioxide</u> - 100 ppb/15 minute mean**
- **<u>Nitrogen Dioxide</u> - 150 ppb/1-hour mean**
- **<u>Lead</u> - 0.25 µg m^3/annual mean**
- **<u>Polycyclic Aromatic Hydrocarbons</u> - 0.25 ng/m^3 benzo(a)pyrene/annual mean**

The present

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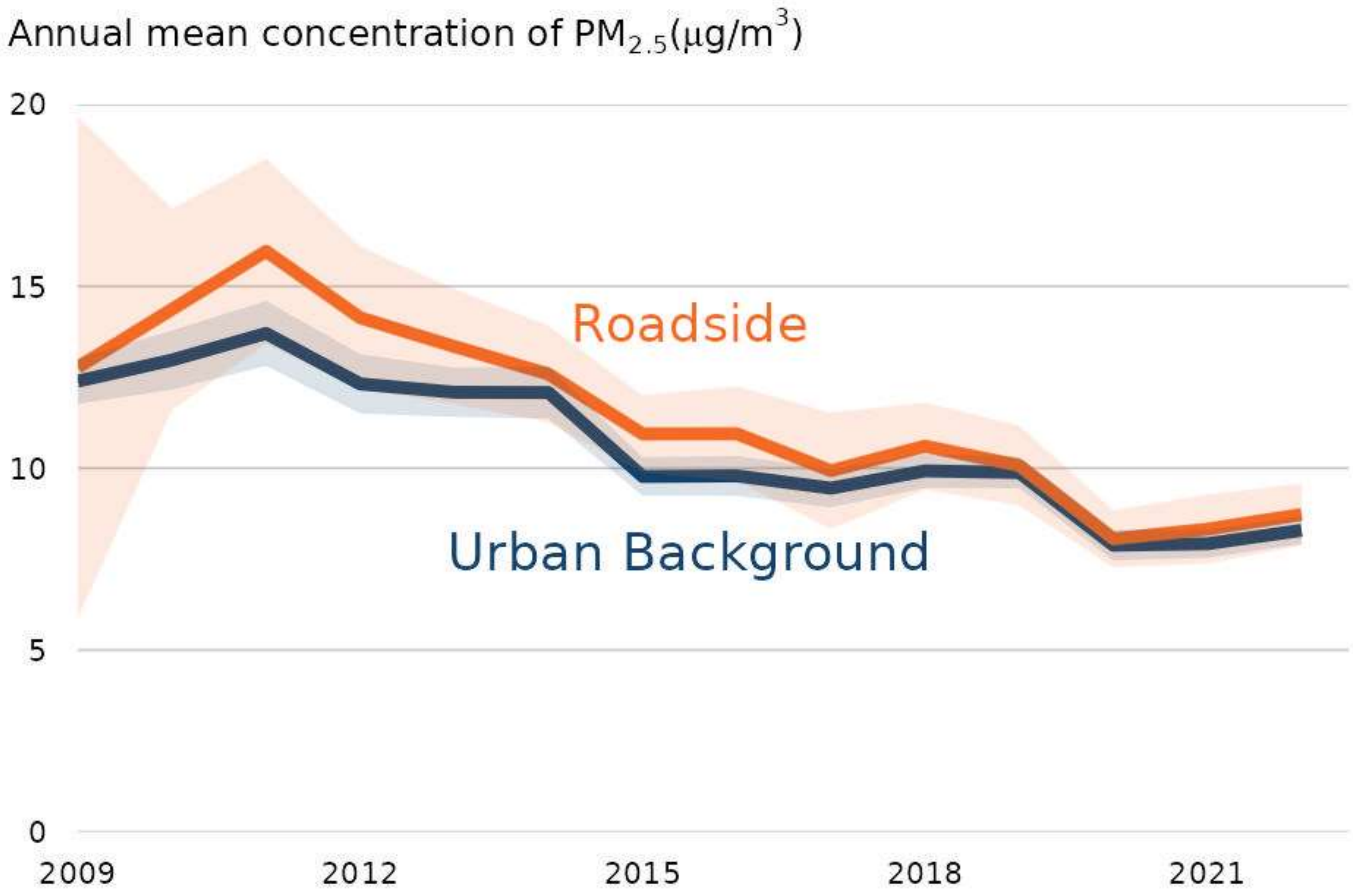
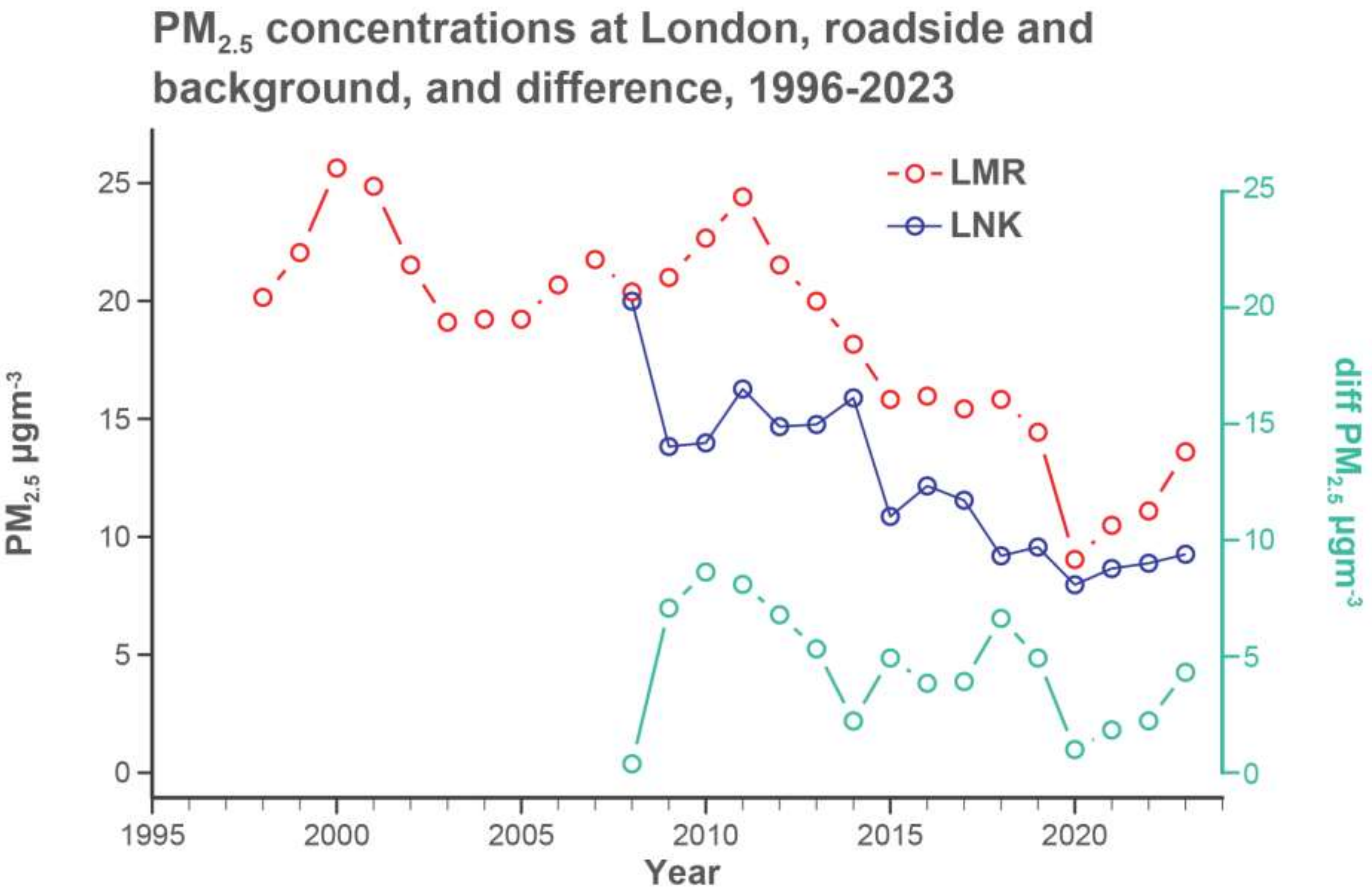
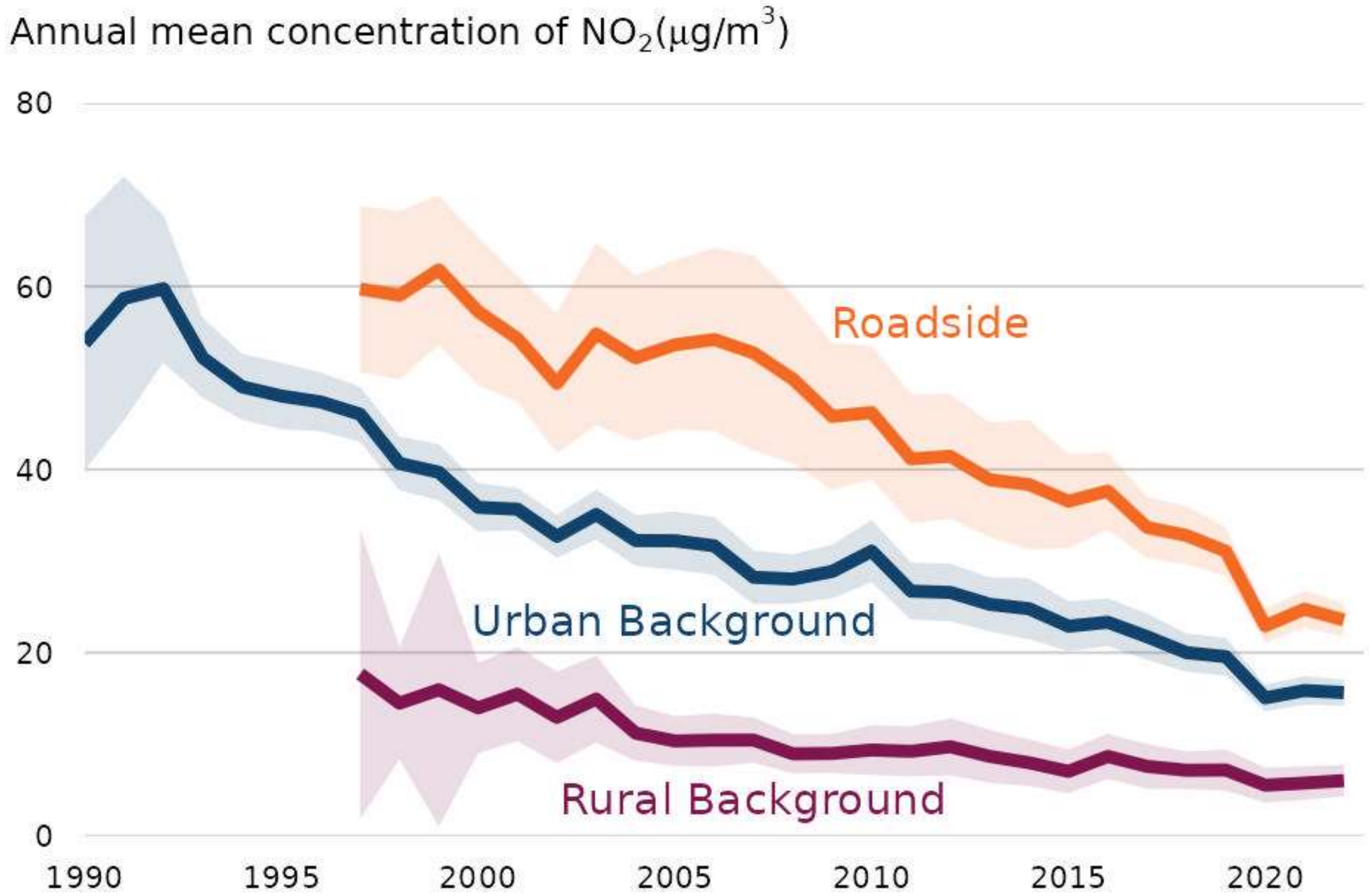
Annual concentrations of $PM_{2.5}$ in the UK, 2009 to 2022 (Defra statistics)



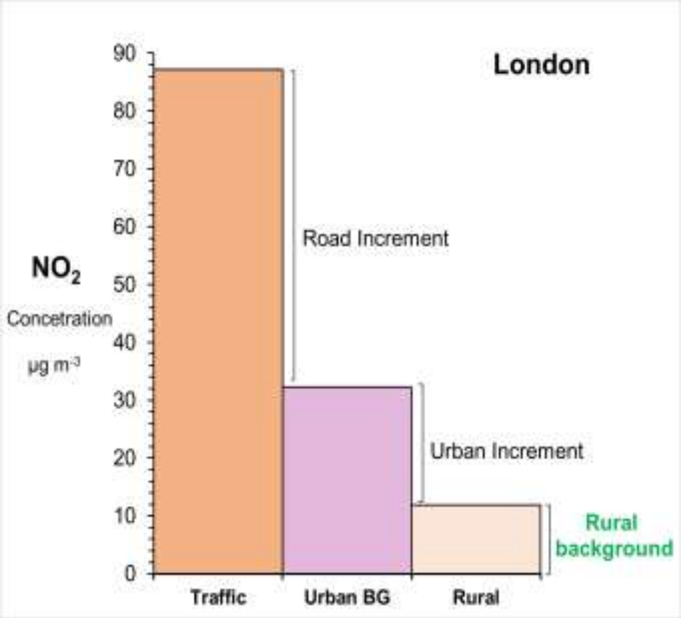


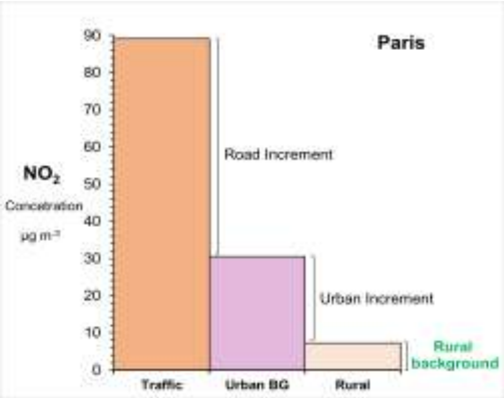
PM2.5 concentrations at London, roadside and background, and difference, 1996-2023
LMR
LNK
PM2.5 μgm-3
diff PM2.5 μgm-3
Year
0
5
10
15
20
25
1995
2000
2005
2010
2015
2020

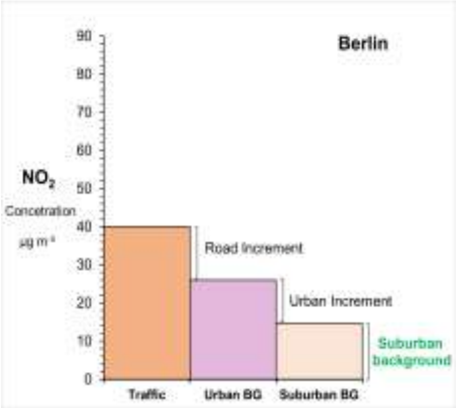
Annual mean concentrations of NO_2 in the UK, 1990 to 2022 (Defra statistics)

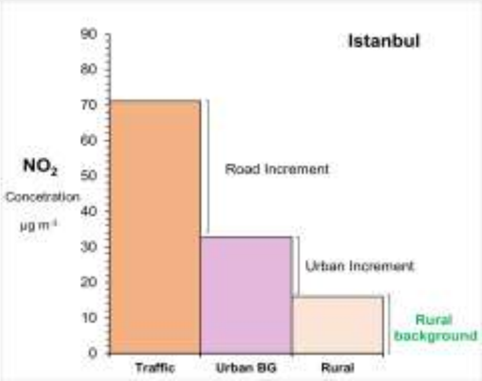


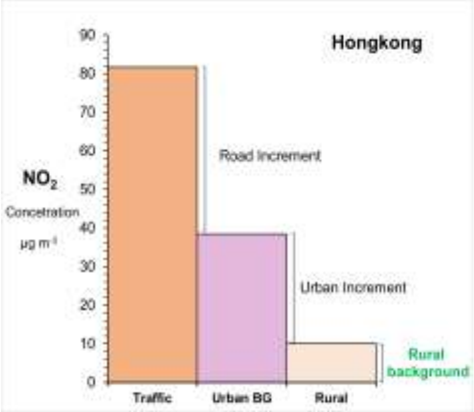
Roadside traffic and urban increments of nitrogen dioxide for the six cities, average of 2016-2018

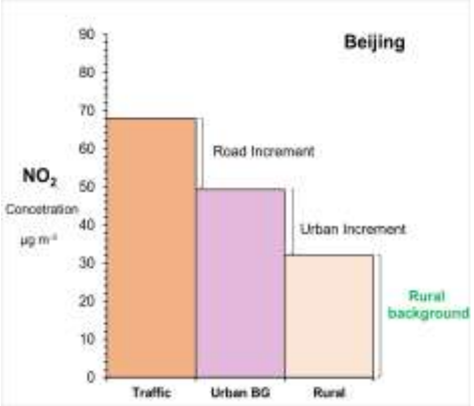




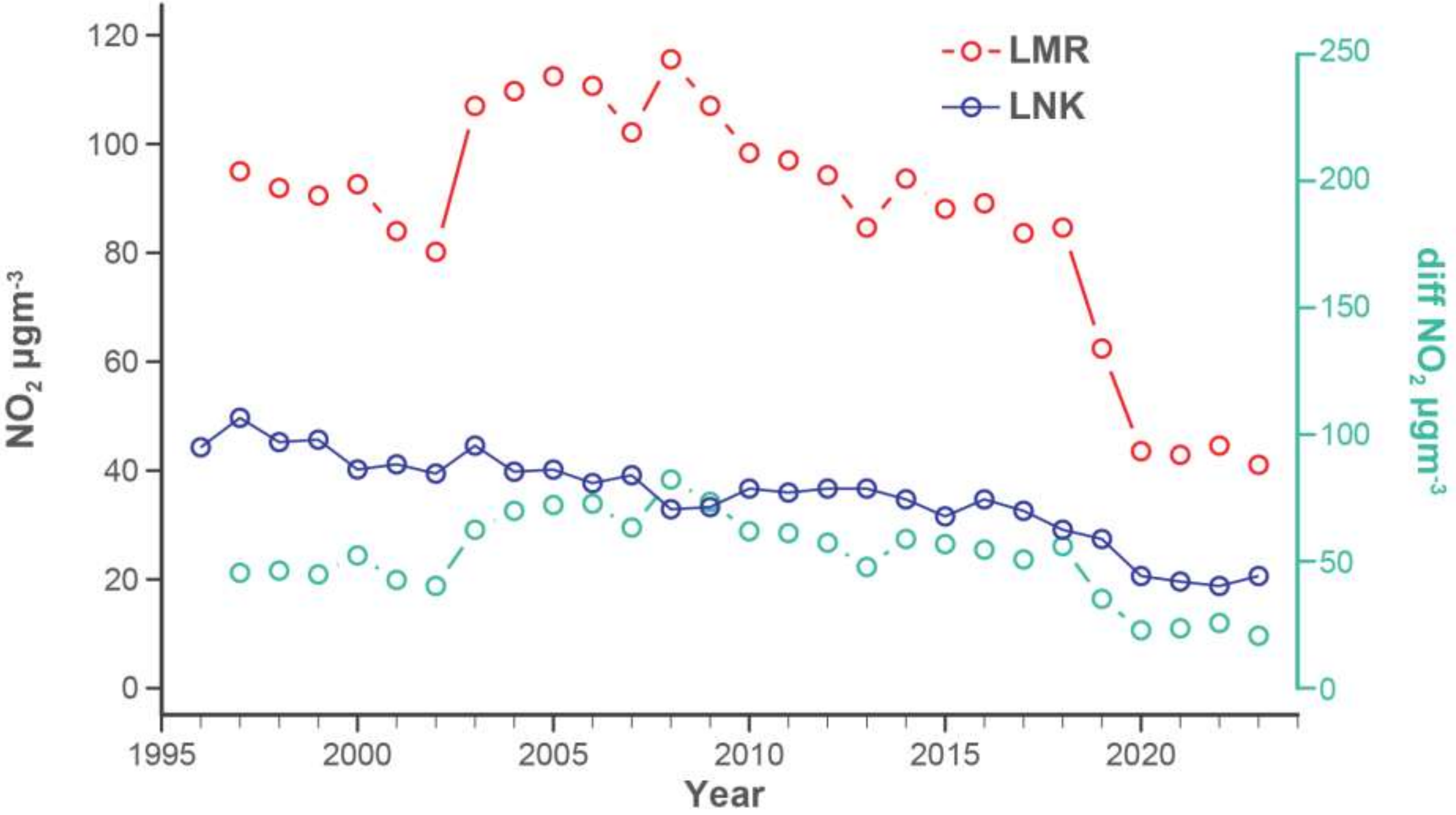




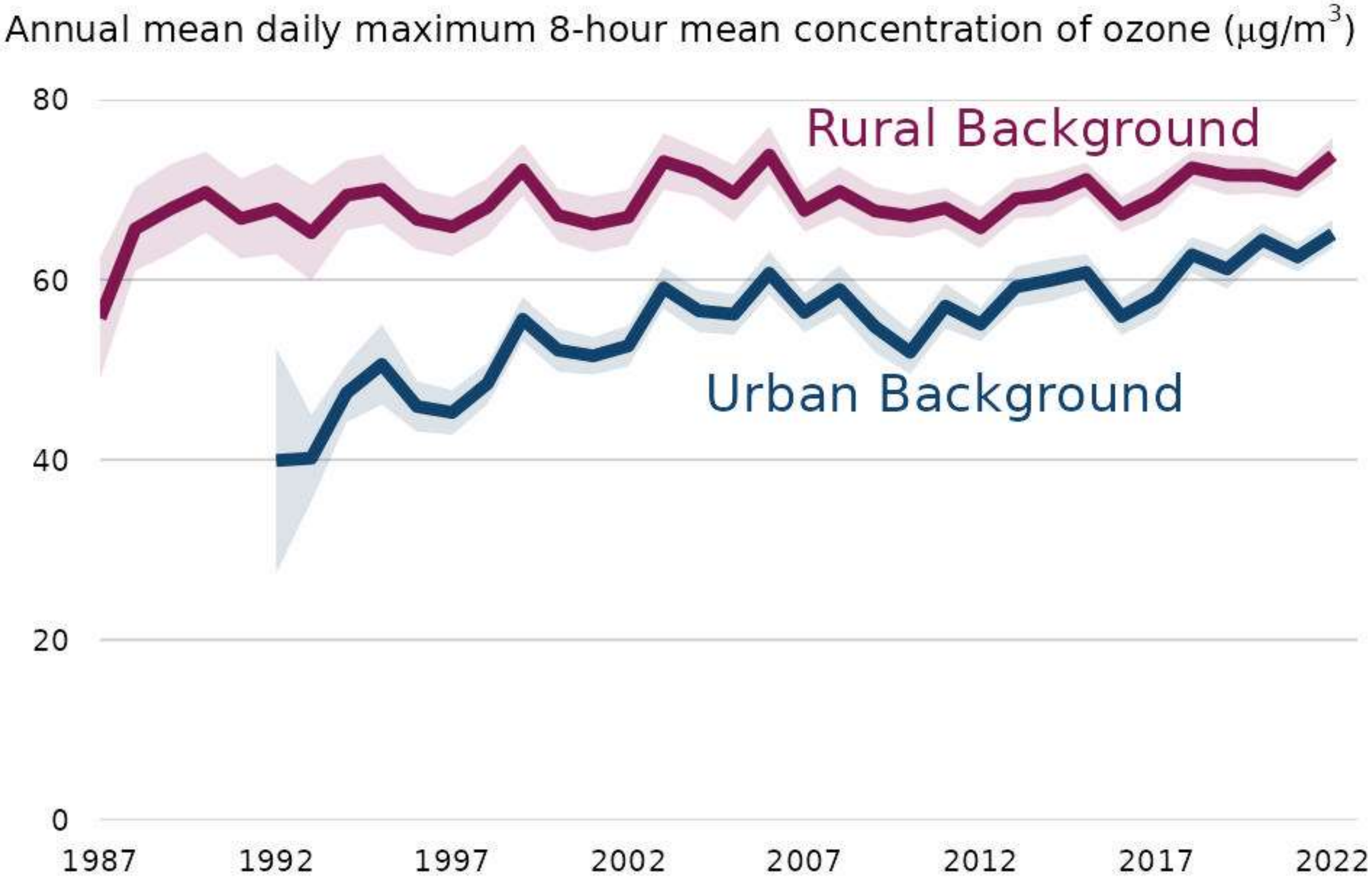




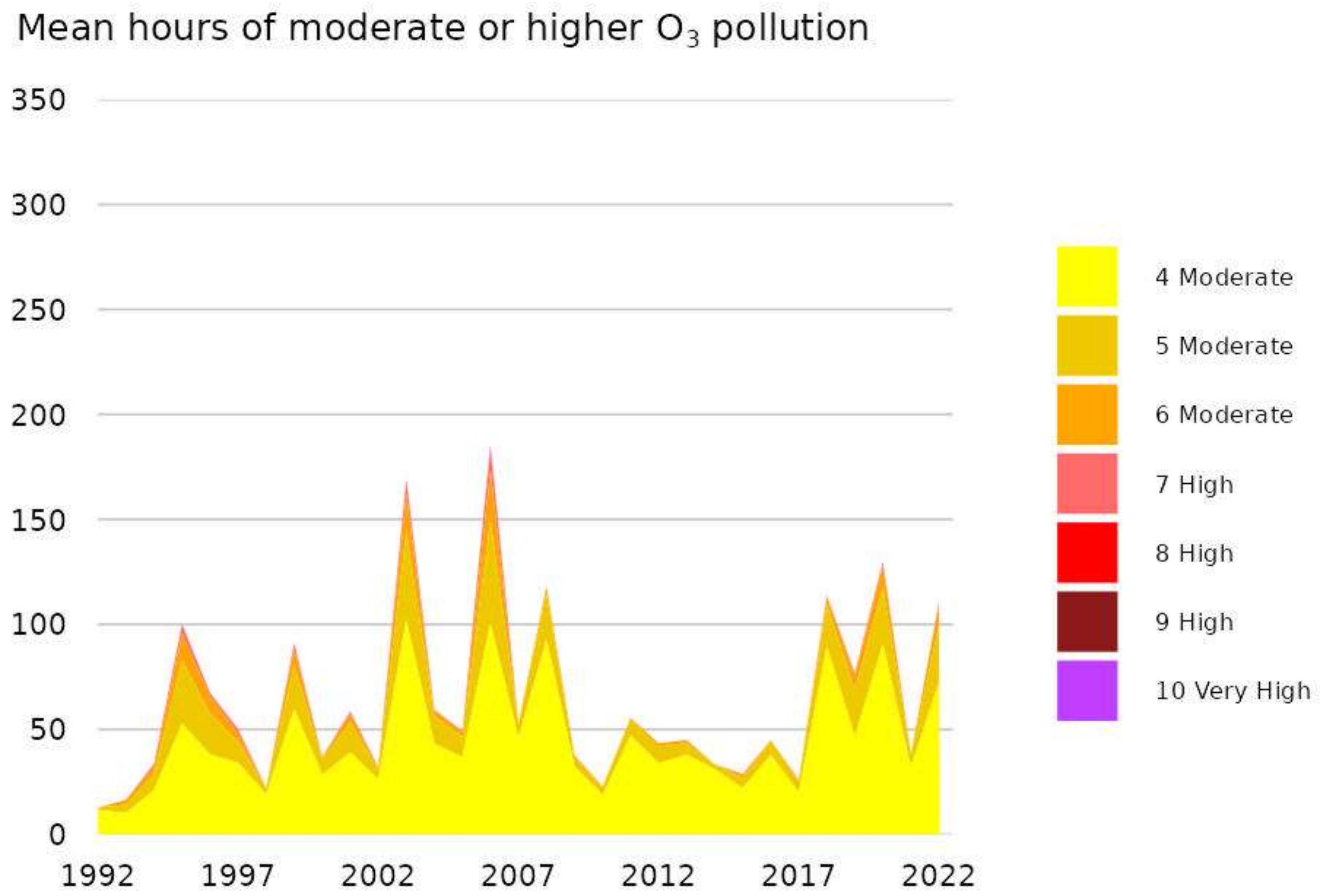
Nitrogen dioxide concentrations at London, roadside and background, and difference, 1996-2023



Annual mean concentrations of O_3 in the UK, 1987 to 2022 (Defra statistics)



Mean hours when O_3 pollution was ‘Moderate’ or higher for urban background sites, 1992 to 2022 (Defra)



What are the recent (10-20 years) trends in concentration in Western Europe?

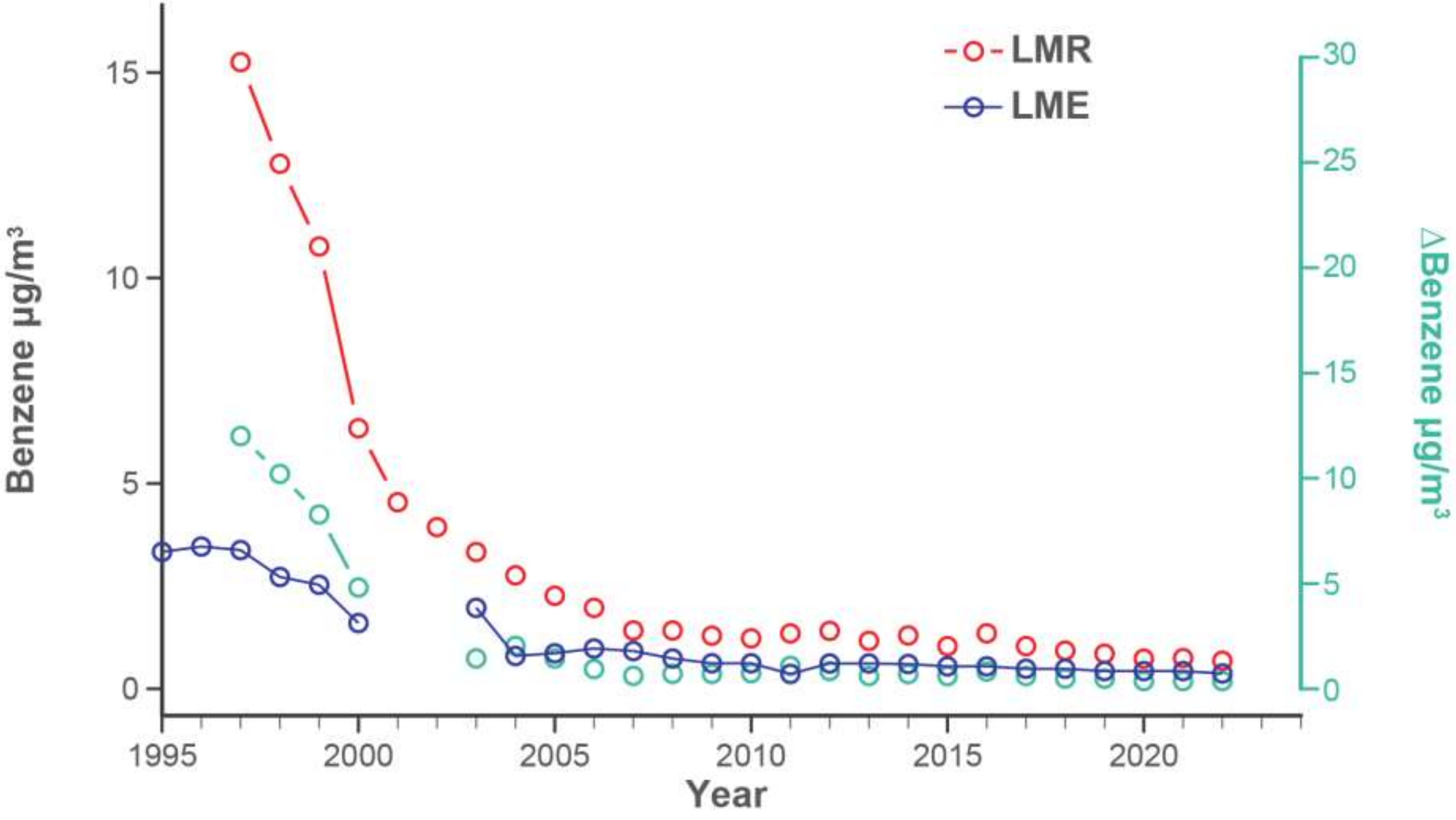
POLLUTANT	TREND
Particulate Matter	Slow improvement
Sulphur Dioxide	Fast downward
Nitrogen Dioxide	Flat, then slow improvement
Ozone	Peaks down; baseline upward
Carbon Monoxide	Fast downward
Benzene	Fast downward
Polycyclic Aromatic Hydrocarbons	Flat

Air quality pollutants

There have been some **success stories**, notably:

- Smoke and sulphur dioxide in many developed countries
- Carbon monoxide and benzene in most developed countries
- Lead from motor vehicles

Benzene concentrations at London, roadside and background, and difference, 1996-2023



Air quality pollutants

There have been some **notable failures**, e.g.

- *Nitrogen dioxide*, for two reasons
  (a) failure to reduce NO_x from diesels
  (b) Increased contribution of primary NO_2 from diesel
- *Ozone*, for which abatement policies in Europe have achieved a reduction in episodic peak concentrations, but the hemispheric background has increased
- *Particulate matter* ($PM_{2.5}$ and PM_{10}), mainly because of a large secondary contribution and poorly characterised primary sources

Why has progress been slow?

- **$PM_{2.5}$**
  - the diesel particle problem was recognised long before it was addressed
  - growth in domestic wood burning
  - non-linearities in secondary pollutant controls
  - failure to tackle ammonia emissions from agriculture
- **Nitrogen dioxide**
  - poor design of test procedure and cheating by motor industry

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Diesel Vehicle Emissions And Urban Air Quality

December 1993

Second Report of the
Quality of Urban Air Review Group

Prepared at the request of the
Department of the Environment

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Diesel vehicles and urban air quality

"In the view of the Review Group, the impact of diesel vehicles on urban air quality is a serious one. Any increase in the proportion of diesel vehicles on our urban streets is to be viewed with considerable concern unless problems of particulate matter and nitrogen oxides emissions are effectively addressed."

Quality of Urban Air Review Group

Diesel Vehicles and Urban Air Quality, December 1993

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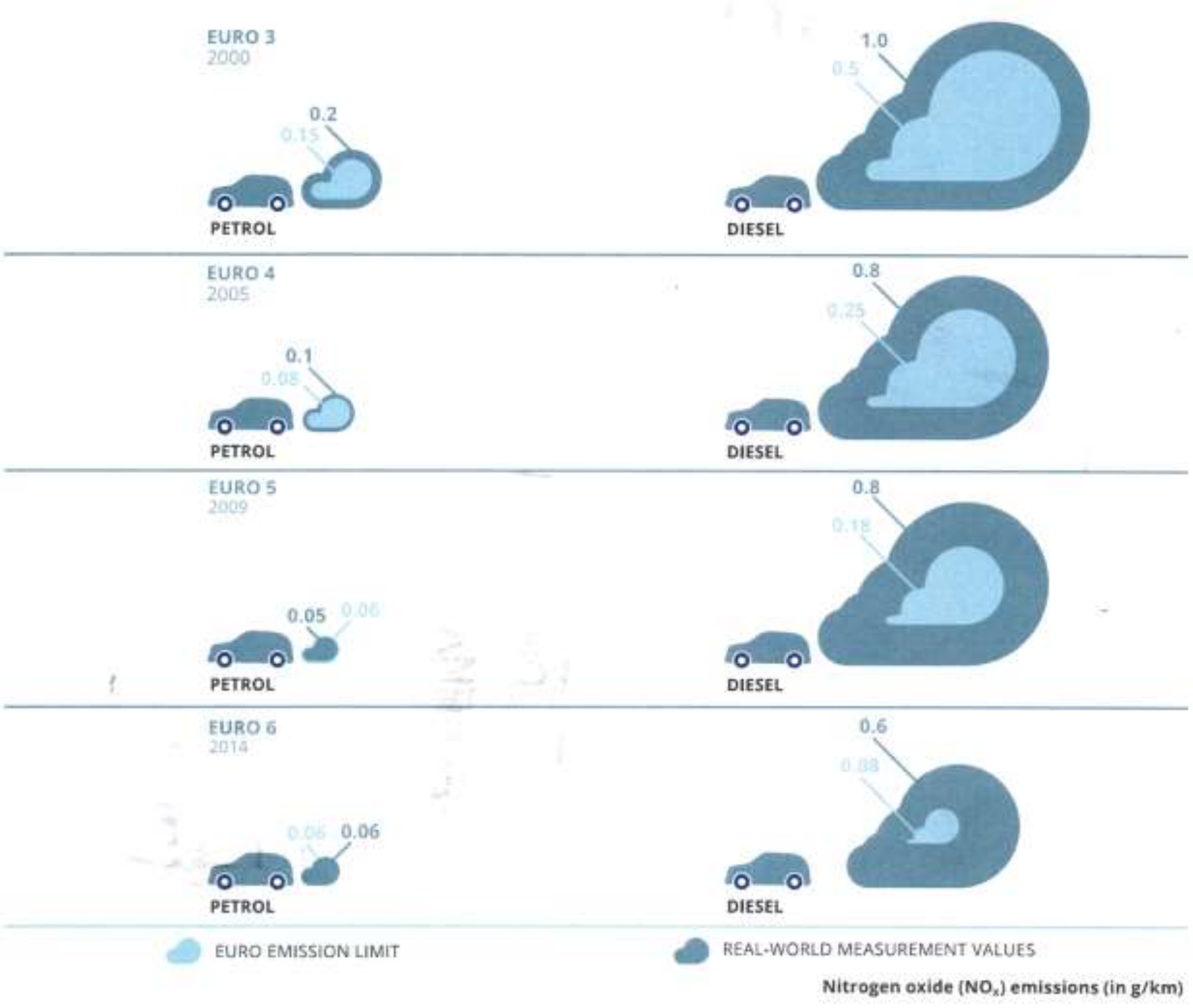
Comparison of NO_x standards and emissions for different Euro classes



Source: EEA, 2016d.

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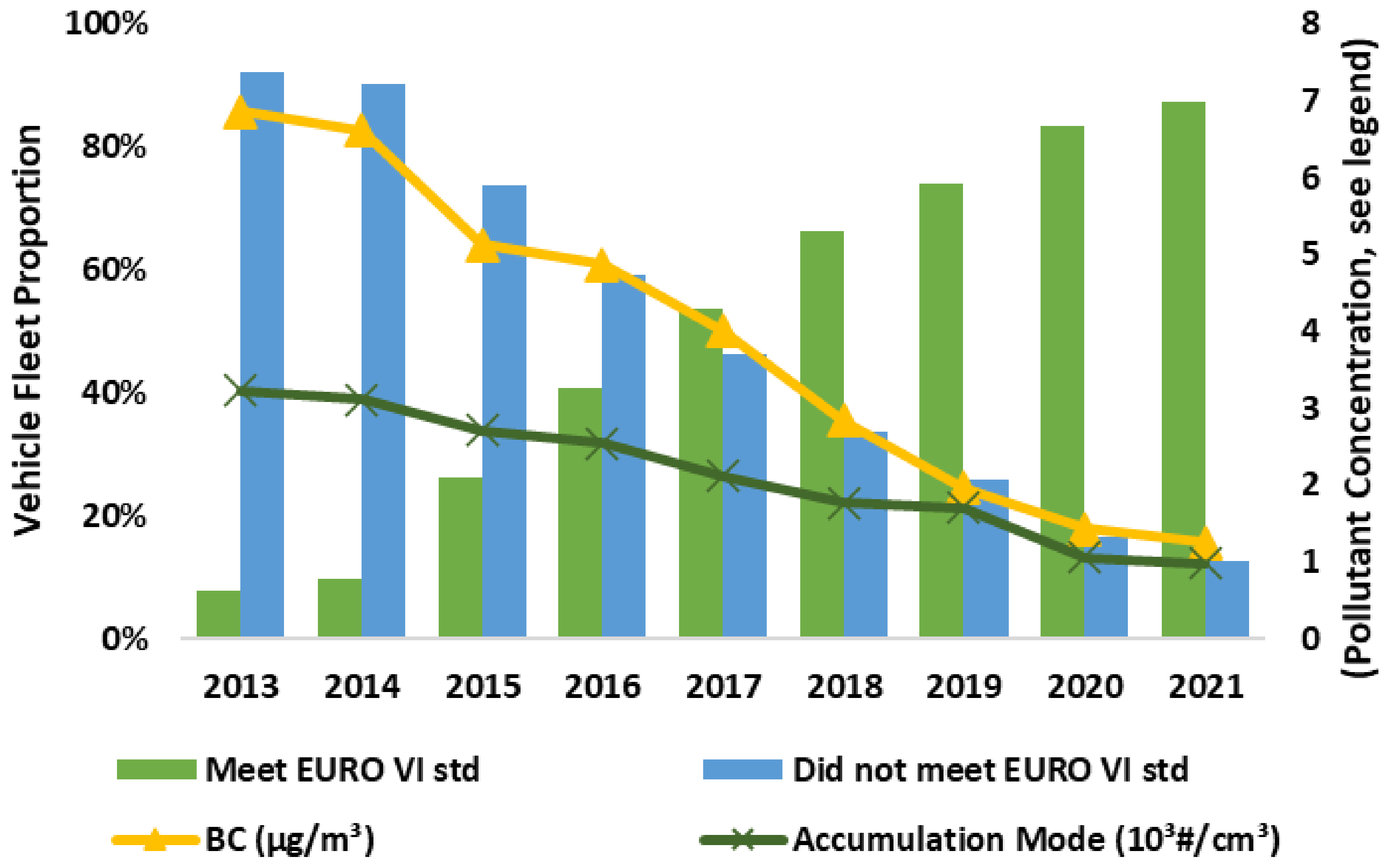
Temporal trends in Black Carbon and Accumulation Mode particle concentrations in relation to heavy duty truck traffic which did not meet the Euro VI emissions standard, 2013-2021



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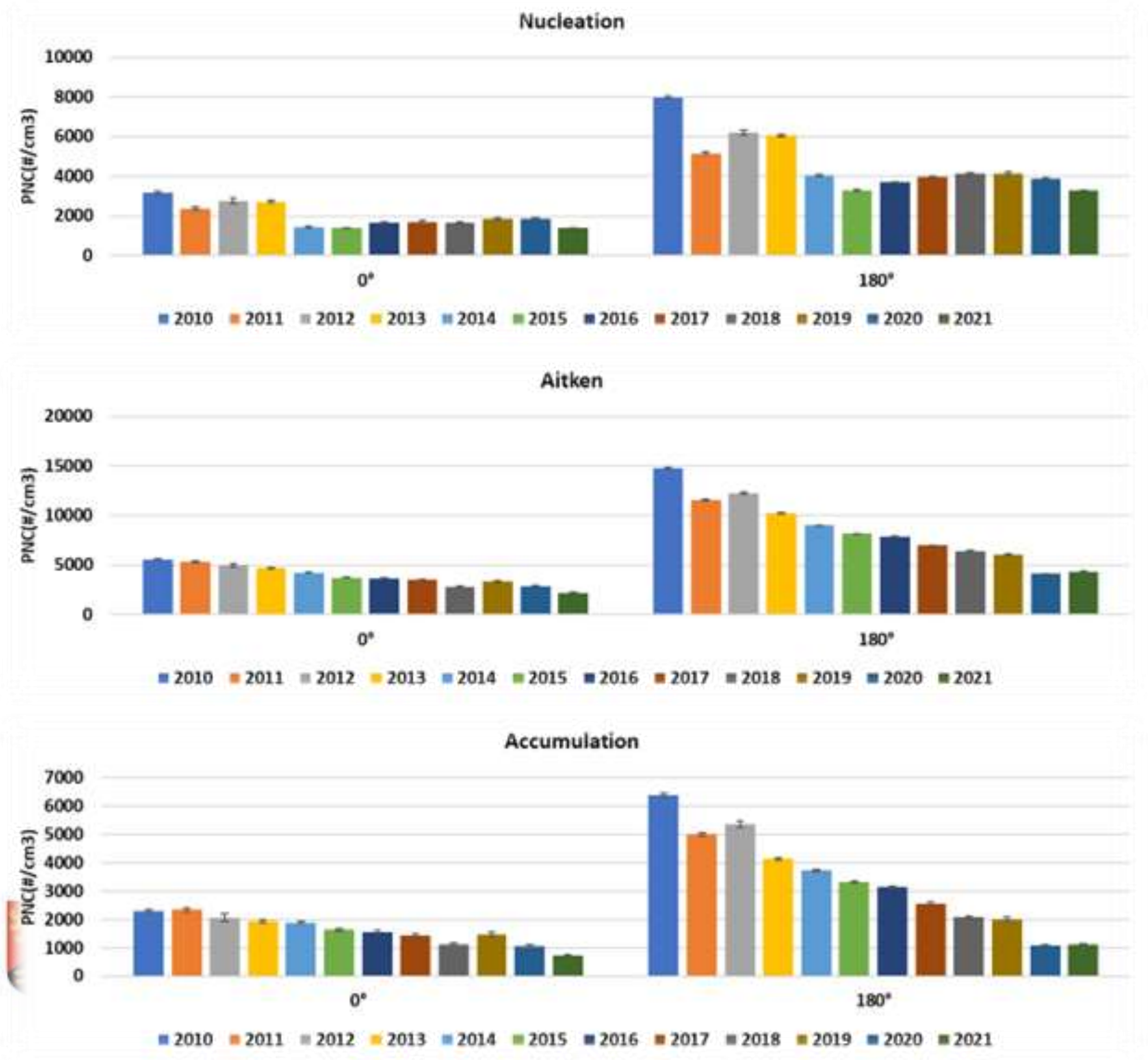
Trends in Particle Number at London, Marylebone Road



Trends in particle number: 2010 -2021

Nucleation : <30nm

Aitken: 30-100nm

Accumulation: >100nm

Annual mean concentration of each particle size mode split by year (2010-2021) and wind direction

The 180° and 225° data show the greatest contribution of Marylebone Road traffic

The 0° and 315° data are more reflective of background north London air

Damayanti et al., Limited impact of diesel particle filters on road traffic emissions of ultrafine particles. *Environ. Int*, 107888(2023)

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Trends in Particle Number

- We interpret the **rapid reduction in BC and PNC** as being largely **attributable to the progressive uptake of diesel particle filters as Euro 5 and 6** standard vehicles have entered the fleet since 2011.
- **The greatest impact has been upon the BC and Aitken and Accumulation mode particles**, **with little change seen in the Nucleation mode particles**, which are comprised largely of condensed lubricating oil, and form in the cooling exhaust after passage through the particle filter (Harrison et al., 2018)

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The Future

Will the UK meet WHO Guidelines?

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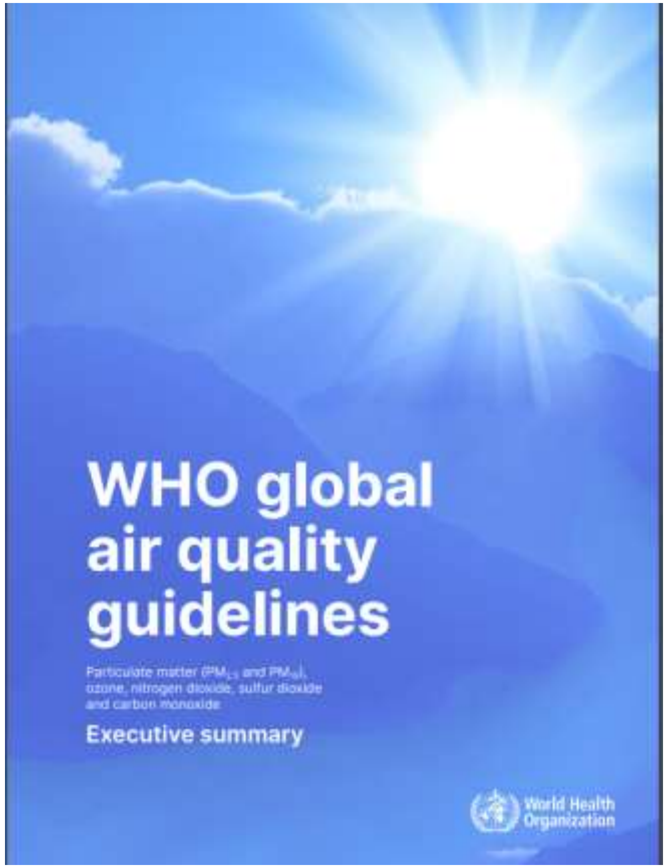
Revised WHO Guidelines (2021)

- $PM_{2.5}$ from 10µg m^{-3} to 5µg m^{-3} is very challenging
- NO_2 from 40µg m^{-3} to 10µg m^{-3} should be achievable



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The basis of WHO Air Quality Guidelines (2021)

- For chronic effects: conduct a systematic review
- Identify high quality studies showing a clear relationship between pollutant exposure and one of several key health outcomes (e.g. mortality or hospital admissions)
- Identify the 5th percentile exposure concentration in those studies
- Average the 5th percentiles from studies with a common health outcome
- Take the lowest mean value from all health outcomes as the Air Quality Guideline

Recommended 2021 AQG Levels Compared to 2005 Air Quality Guidelines

Pollutant	Averaging Time	2005 AQGs	2021 AQGs
$PM_{2.5}$, µg/m^3	Annual	10	5
	24-hour[a]	25	15
PM_{10}, µg/m^3	Annual	20	15
	24-hour[a]	50	45
O_3, µg/m^3	Peak season[b]	-	60
	8-hour[a]	100	100
NO_2, µg/m^3	Annual	40	10
	24-hour[a]	-	25
SO_2, µg/m^3	24-hour[a]	20	40
CO, mg/m^3	24-hour[a]	-	4

[a] 99th percentile (i.e. 3–4 exceedance days per year).
[b] Average of daily maximum 8-hour mean O_3 concentration in the six consecutive months with the highest six-month running- average O_3 concentration.
Note: Annual and peak season is long-term exposure, while 24 hour and 8 hour is short-term exposure.

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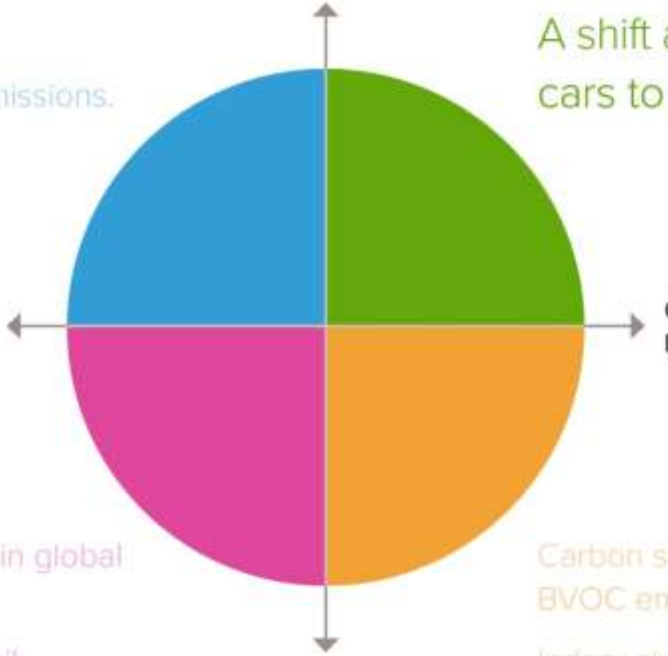
Electrification of transport and home heating with wind and solar power.

Carbon sequestration with low BVOC emitting tree species.

Improved nitrogen efficiency in agriculture.

A shift away from the use of passenger cars to walking and public transport.

Reduced sulphur emissions.



Continued increases in global CH_4 concentrations.

Continued coal and oil combustion for electrical power.

Carbon sequestration with high BVOC emitting tree species.

Indoor air quality declines with reduced ventilation of homes and offices.

Combustion of biomass or hydrogen increases NO_x and $PM_{2.5}$.

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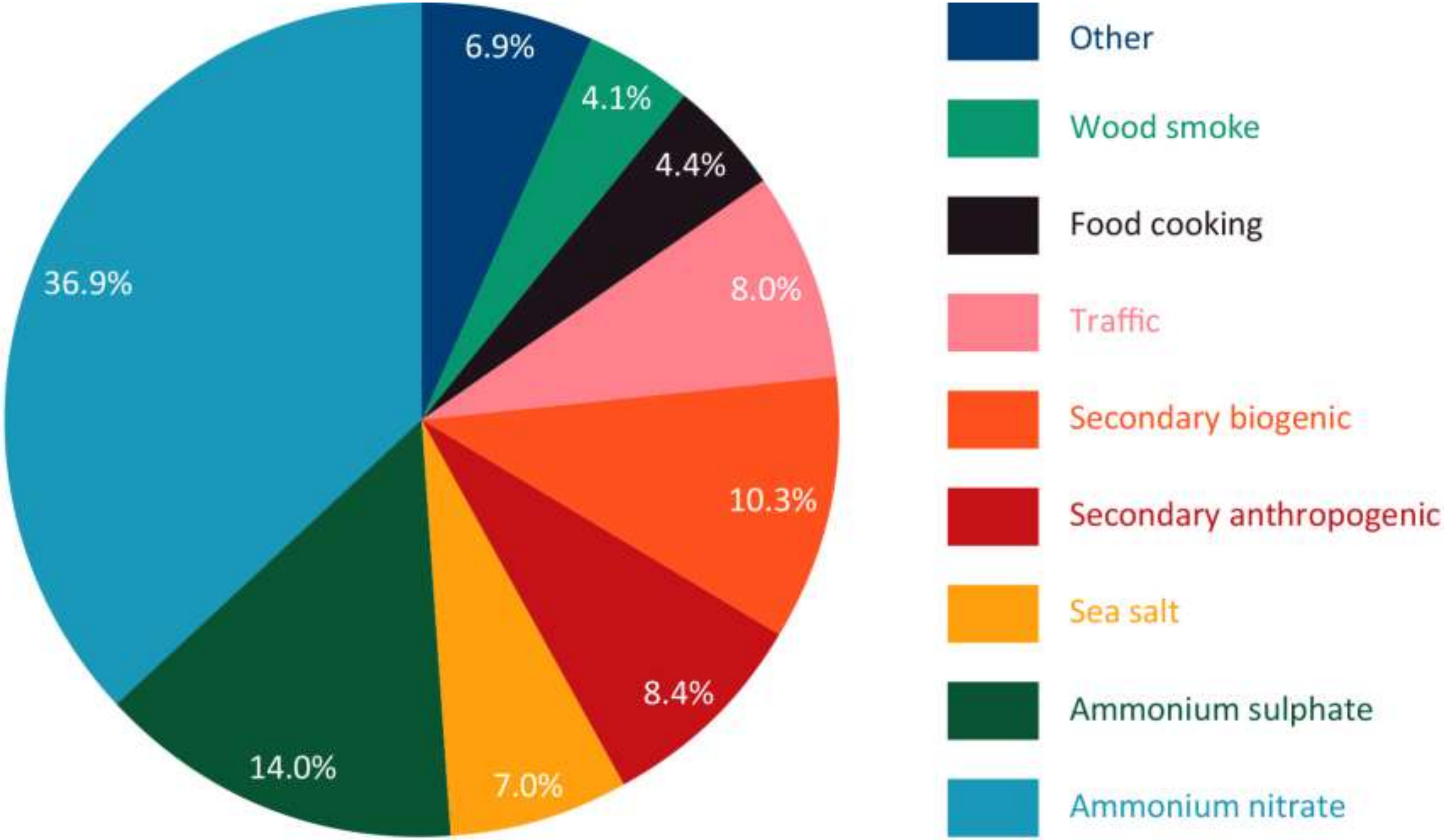
Source contributions to $PM_{2.5}$ at North Kensington (%)



Other = dust/soil (2.2%); coal (1.1%); vegetation (1.3%); natural gas (0.3%); unidentified (2.0%)

Domestic Woodsmoke Emissions

(from the National Atmospheric Emissions Inventory)

	1970	1980	1990	2000	2010	2020
$PM_{2.5}$ Emissions (kt)	5.8	5.8	8.6	9.8	10.0	14.0
Heat Generation (TJ)	7207	7207	10724	12577	14691	30303
Ratio (kT/TJ x 10,000)	8.0	8.0	8.0	7.8	6.8	4.6

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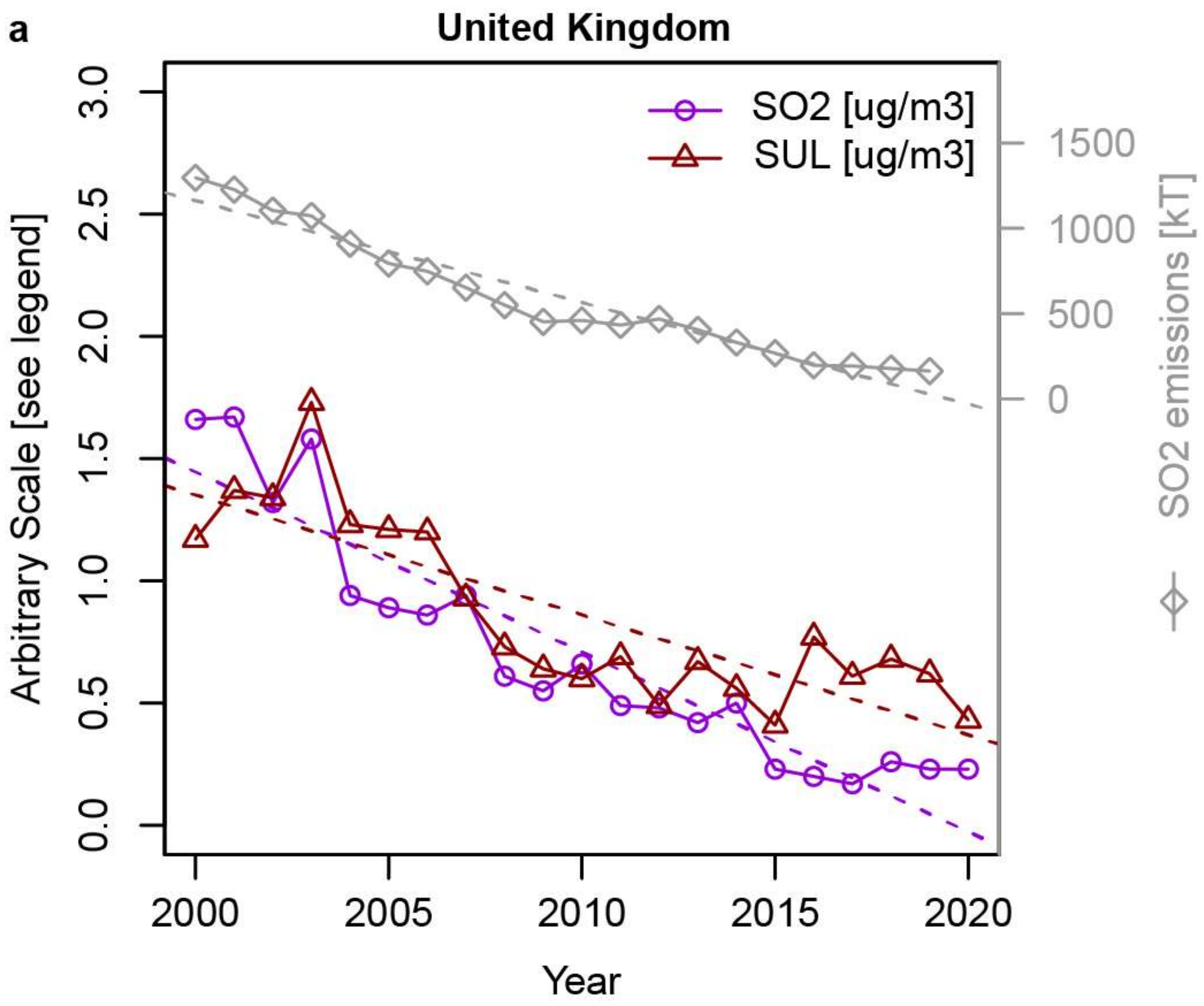
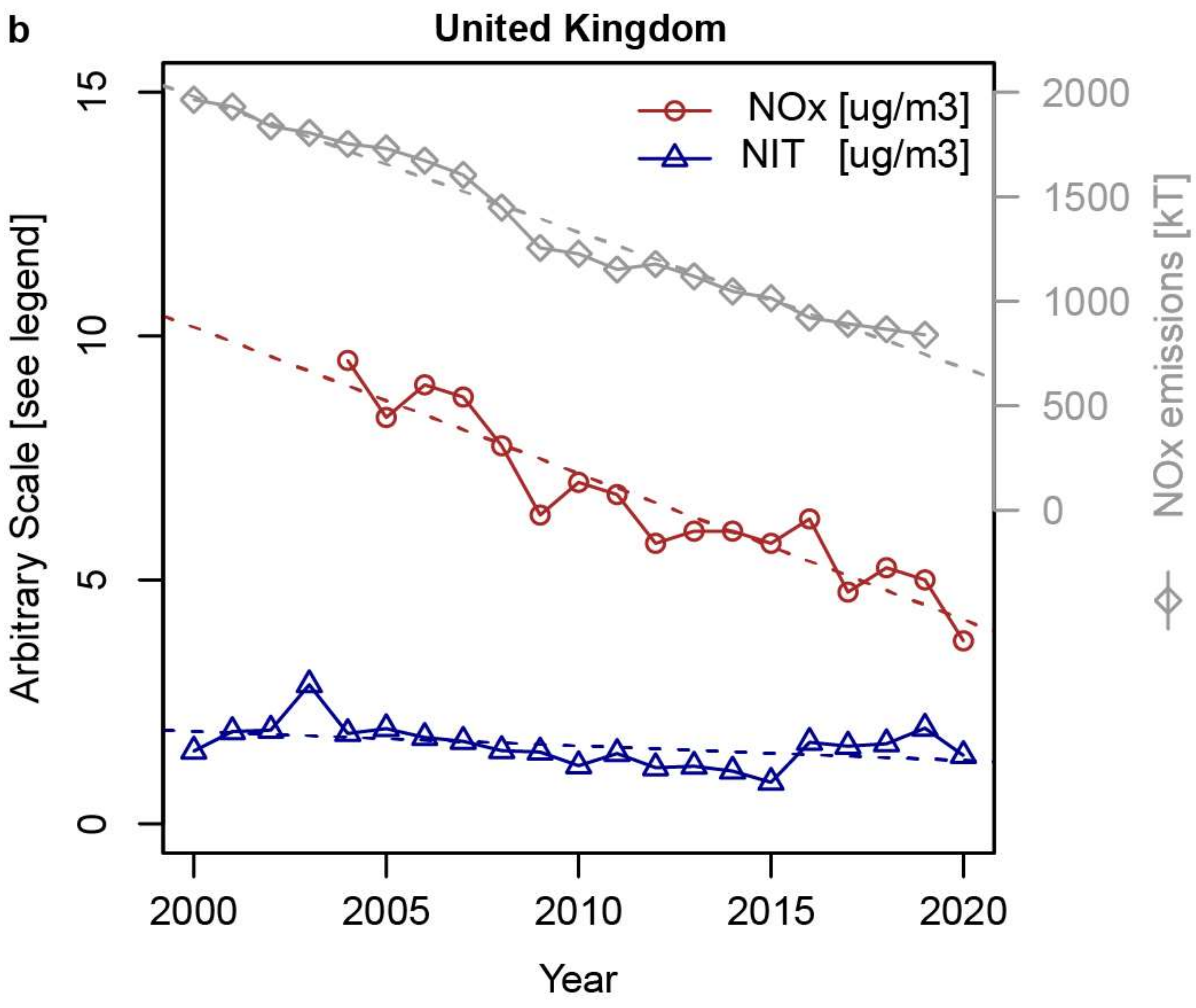
Trends in sulphate from the AGANET sites

(a) UK and relevant European emissions, and concentrations of SO_2 and sulphate



Trends in nitrate from the AGANET sites

(b) emissions and concentrations of NO_x, and nitrate concentrations, from 2000 to 2020 from the AGANET data



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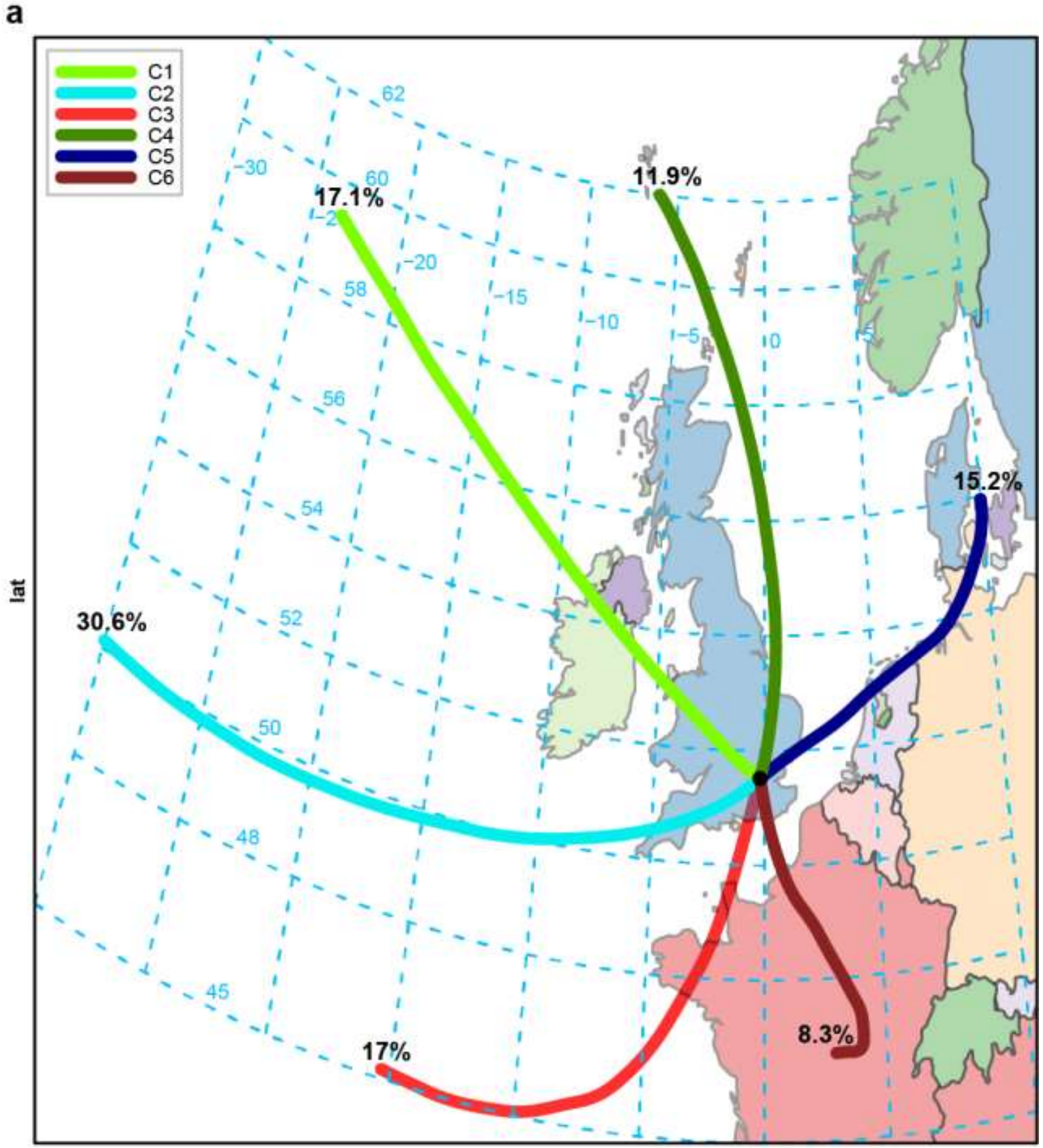
Clustered air mass back trajectories terminating in London, 2014-2018



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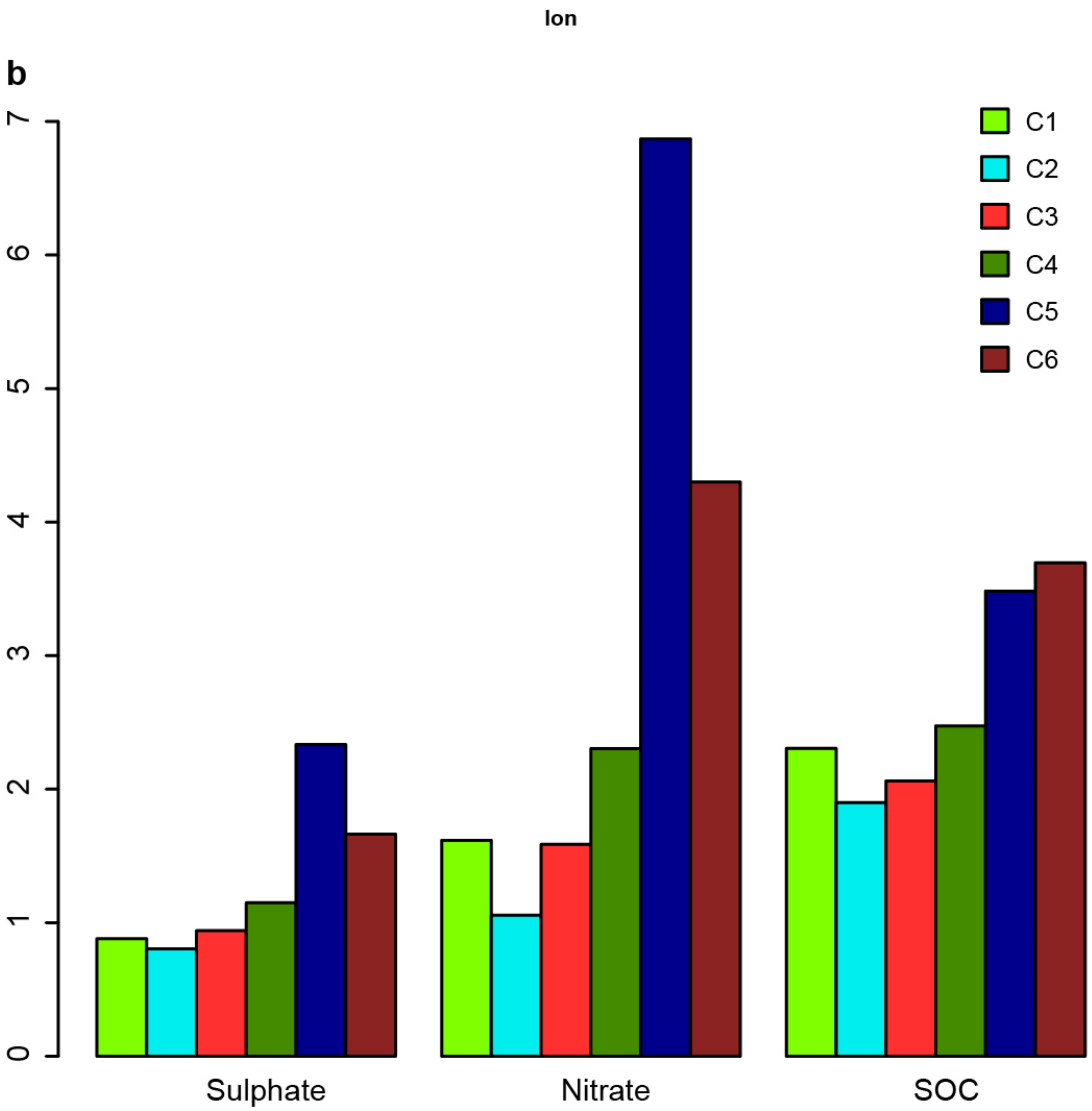
Results of air mass clustering

(b) mean concentration of nitrate, sulphate and SOC associated with each back trajectory (µg/m3). Clusters C1 to C4 are maritime; Clusters C5 and C6 are continental.



Air Pollution Abatement

- In southern England, 55% of nitrate, 42% of sulphate and 35% of secondary organic aerosol arrive in trajectories from mainland Europe. Much of this is generated in mainland Europe. These components comprise >60% of $PM_{2.5}$ at North Kensington.
- Consequently, the UK should have a strong interest in strengthening measures which limit emissions in other countries, i.e. the Gothenburg Protocol.
- Nonetheless, UK national emissions remain important, increasingly so when moving from south-east to north-west in Great Britain, so control of UK emissions is also important, especially ammonia from agriculture.

What are the European Union and UNECE considering?

- Euro 7 emissions standards, with:
  - Stricter exhaust emissions controls
  - A limit for brake wear emissions
  - A limit for tyre wear emissions
- Achieve 10µg/m3 PM2.5 by 2030 (94% of monitors predicted to achieve); c.f. UK target, also 10µg/m3 to be met everywhere by 2040.
- Achieve “zero air pollution” by 2050
- Enhanced air quality monitoring
  - A requirement for air quality supersites to provide detailed near-real time information on particle composition and gases such as ammonia
- Strengthening the Gothenburg Protocol and NECD

What can state-of the art monitoring techniques in supersites tell us?

- $PM_{2.5}$ composition in near-real time:
  - Nitrate
  - Sulphate
  - Elemental (black) carbon
  - Secondary (oxidised) organic carbon
  - Primary organic carbon (biomass smoke; coal smoke, traffic exhaust, cooking)
  - Tracers of tyre wear and brake wear
  - Other trace metals
  - Ultrafine particles and particle size distributions
  - Ammonia

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Cost-Benefit Analysis

- Can a value be put on good health?
- EU cost/benefit analysis shows benefits far outweigh costs
- The case for cleaner air is highly persuasive, but how does it compare with, for example:

  - research into Alzheimer's Disease
  - action on juvenile mental health
  - expensive cancer treatments
  - reducing perinatal mortality
  - preparedness for the next pandemic
  - action against obesity

Costs of air pollutant abatement

- Society meets the costs of social benefits in two main ways:
  - through direct taxation, or
  - by charging for goods and services
- In both cases, individuals pay, but there is a difference:
  - direct taxation is paid mainly by the more wealthy
  - levies on goods and services are paid by the consumer
- The costs of cleaning up road traffic and power generation emissions have fallen mainly on the consumer (the polluter pays). Therefore whereas most measures beneficial to public health are paid for through taxation, most of the costs incurred in cleaner air are paid by the consumer.
- This implies a very strong case for further air pollution control as long as health benefits are demonstrable, which clearly they are.

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