Department for Environment Food & Rural Affairs

Air Pollution in the UK 2022

September 2023

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Executive Summary

The UK's Air Quality Standards Regulations (2010) and the Environment Act (2021) require reporting of compliance and progress made on an annual basis. The underlying data is reported via the UK-AIR website at https://uk-air.defra.gov.uk. This report continues the series of annual reporting against the UK's Air Quality Standards Regulations (2010) and, for the first time this year, assesses progress made towards meeting two new targets set in the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023). This report provides background information on the pollutants covered by these regulations, their sources and effects, the UK's statutory monitoring networks, and the UK's modelling methodology. The report then summarises the UK's ambient air quality assessment for 2022, presenting air quality modelling data and measurements from national air pollution monitoring networks. The pollutants covered in this report are:

- Nitrogen oxides (NO_X) comprising NO and NO_2
- PM_{10} and $PM_{2.5}$ particles
- Ozone (O_3)
- Sulphur dioxide (SO_2)
- Carbon Monoxide (CO)
- Benzene
- 1,3-Butadiene
- Metals: lead, cadmium, nickel and mercury, and the metalloid arsenic
- Polycyclic aromatic hydrocarbons (PAH).

These data are reported on behalf of Defra (the Department for Environment, Food and Rural Affairs) and the Devolved Administrations of Scotland, Wales and Northern Ireland.

For the purposes of air quality monitoring and assessment of compliance with the Air Quality Standards Regulations (2010), the UK is divided into 43 zones. The 2022 results are detailed in Section 4 of this report and summarised below:

- The UK met the limit value for hourly mean nitrogen dioxide (NO_2) in all 43 zones.
- 34 zones met the limit value for annual mean NO_2, with nine zones exceeding.
- All zones required to meet the critical level for annual NO_X set for protection of vegetation (non-agglomeration zones) did so. This has been the case since 2008.

- All zones met the limit value for daily mean concentration of PM_{10} particulate matter, without the need for the subtraction of the contribution from natural sources.

- All zones met the limit value for annual mean concentration of PM_{10} particulate matter, without the need for the subtraction of the contribution from natural sources.

- All zones met both limit values for annual mean concentration of $PM_{2.5}$ particulate matter: the Stage 1 limit value, which came into force on 1st January 2015, and the Stage 2 limit value, which came into force in 2020.

- The UK has previously achieved its 2020 national exposure reduction target for $PM_{2.5}$, based on the Average Exposure Indicator (AEI) statistic. In 2022, the three-year running mean AEI was 8 $\mu g\ m^{-3}$; this statistic has therefore remained within the target value.

- The Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) set a legally mandatory target of 10 $\mu g\ m^{-3}$ for annual mean $PM_{2.5}$ concentrations at all monitoring stations in England, to be achieved by 2040. Six monitoring stations in England exceeded this target in 2022. No monitoring stations exceeded the interim target, to be met by January 2028.

- The Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) also set a legally mandatory $PM_{2.5}$ population reduction target of 35% compared to 2018 to be achieved by 2040. The population exposure for 2022 was 8.13 $\mu g\ m^{-3}$, which is a reduction of 19% compared to 2018. The interim target to be met by January 2028 is 22%.

- All zones met both the target values for ozone; the target value based on the daily maximum eight-hour mean, and the target value based on the AOT40 statistic.

- No zones were compliant with the long-term objective for ozone, set for the protection of human health. This is based on the daily maximum eight-hour mean.

- 32 zones met the long-term objective for ozone, set for the protection of vegetation. This is based on the AOT40 statistic, explained in Sections 4 and 5 of this report.

- All zones met the limit values for sulphur dioxide, carbon monoxide, benzene and lead, and the target values for arsenic and cadmium.

- Three zones exceeded the target value for nickel.

- Two zones exceeded the target value for benzo[a]pyrene.

A summary of the air quality assessment for 2022, and a comparison with previous years' air quality assessments since 2008 can be found in Section 4 of this report.

Section 5 presents a summary of spatial distribution of pollutant concentrations, and changes over time. Section 6 looks at specific periods of poor air quality – pollution ‘episodes’ – in 2022. It features a springtime particulate pollution episode in late March, two summer ozone episodes, and some measured air quality impacts of Bonfire Night celebrations around 5th November.

For more information on air quality in the UK visit the Defra website at www.gov.uk/defra and the UK Air Quality websites at uk-air.defra.gov.uk, scottishairquality.scot/, airquality.gov.wales and airqualityni.co.uk/.

Glossary

Agglomeration Zone. Any urban area with a population greater than 250,000.

Air Quality Directive. The European Union's Directive 2008/50/EC of 21st May 2008, on Ambient Air Quality and Cleaner Air for Europe, which is often referred to as 'the Air Quality Directive'.

Air Quality Standards Regulations (2010). Prior to 31st January 2020, the UK was a Member State of the European Union. As such, the UK was required to incorporate - or 'transpose' - the provisions of EU Directives into their own national law by a specified date. The Air Quality Standards Regulations (2010) are the legislation by which the UK fulfilled this requirement.

Air Quality Strategy. England's Air Quality Strategy is a framework for local authority delivery. It was published in April 2023 in line with requirements in the Environment Act (1995), as amended by the Environment Act (2021).

Ambient Air. Outdoor air.

Annual Mean Concentration Target (AMCT). A legally mandatory target set in the Environmental Targets (fine particulate matter) (England) Regulations (2023), for ambient concentrations of **$PM_{2.5}$**. This is for the annual mean $PM_{2.5}$ concentrations measured at all $PM_{2.5}$ monitoring stations in England, to be less than or equal to 10 µg m^{-3} by the end of 2040.

Annual Mean daily maximum 8-hour mean O_3 concentrations. This is an annual mean of the 'daily maximum 8-hour mean' for ozone – see below.

Arsenic (As). A toxic metalloid which occurs naturally in the environment but can also be emitted into the air from human activities, for example the open burning of waste wood that has been treated with products containing arsenic.

Average Exposure Indicator (AEI). The statistic on which the national exposure reduction target of the ***Air Quality Standards Regulations (2010)*** is based, for $PM_{2.5}$ between 2010 and 2020. The AEI for the UK is calculated as follows: the arithmetic mean $PM_{2.5}$ concentration at appropriate UK urban background sites is calculated for three consecutive calendar years, and the mean of these values taken as the AEI.

Benzene. A chemical compound that is harmful to human health. As an air pollutant, benzene can be emitted from domestic and industrial combustion processes, and road vehicles. Its chemical formula is $C_6 H_6$.

Benzo[a]pyrene. One of a group of compounds called ***polycyclic aromatic hydrocarbons (PAHs)*** that can be air pollutants. The main sources of B[a]P in the UK are domestic coal and wood burning, fires, and industrial processes such as coke production.

Beta Attenuation Monitor (BAM). A type of instrument used for monitoring concentrations of particulate matter, which measures the attenuation of beta rays passing through a paper filter tape on which particulate matter from sampled air has been collected.

1,3-Butadiene. This is an organic compound emitted into the atmosphere mainly from fuel combustion e.g. petrol and diesel vehicles. 1,3-butadiene is also an important chemical in certain industrial processes, particularly the manufacture of synthetic rubber. 1,3-butadiene is known to cause cancer in humans.

Cadmium (Cd). A toxic metallic element that can be released into the air, for example from combustion in the manufacturing industry and production processes.

Carbon Monoxide (CO) a pollutant gas released in road vehicle exhausts. When breathed in, carbon monoxide affects the blood's ability to carry oxygen around the body.

Clean Air Strategy (CAS): published in 2019, this is the UK Government's framework document setting out policy action to drive down national emissions of five damaging pollutants to achieve statutory emissions reduction commitments, reduce background pollution, and minimise human exposure to harmful concentrations of pollution.

Cleaner Air for Scotland 2 (CAFS2): published in 2021, sets out the framework for air quality policy in Scotland to 2026.

Daily maximum 8-hour mean O_3 concentrations. For a given day the 'daily maximum 8-hour mean' for ozone is derived from the highest of the 8-hour averages beginning with the 8-hour period from 17:00 p.m. on the previous day to 01:00 a.m. and ending with the 8-hour period from 16:00 p.m. to 00:00 a.m. The highest of the continuous 8-h averages running through each day is taken for each day.

Digitel™ Sampler. A type of sampler used in the PAH Network: air is drawn through a filter which is subsequently analysed for ***polycyclic aromatic hydrocarbons (PAHs).***

Environmental Targets (Fine Particulate Matter) (England) Regulations (2023). Regulations which came into force in January 2023 for England. They set a new target for ambient concentrations of ***$PM_{2.5}$*** particulate matter to be achieved by 2040, and for reduction of the population's exposure to $PM_{2.5}$ over the period between 2023 and 2040.

Episode (Air Pollution Episode). An 'air pollution episode' means a period of time (usually a day or several days) when air pollution is high (air quality is poor).

Eutrophication. Increased levels of plant nutrients such as phosphorus and nitrogen, in soil or bodies of water such as lakes or rivers. This can cause an increase in growth of water plants and algae which, in turn, can affect the water's ability to support other life such as fish.

Fidas™. A type of instrument which uses an optical technique for monitoring concentrations of particulate matter.

Fourth Daughter Directive. The European Union's Directive 2004/107/EC, which covers the four metallic elements cadmium, arsenic, nickel and mercury together with ***polycyclic aromatic hydrocarbons (PAH)***. (Its name comes from its origin as one of four so-called Daughter Directives set up under an overarching 'framework Directive'.) The provisions of the Fourth Daughter Directive were transposed into UK law by means of the Air Quality Standards Regulations (2010).

Gravimetric Sampler. A type of instrument used to measure ambient concentrations of ***particulate matter***. It works by drawing air through a filter, on which the particulate matter is collected. The filter is subsequently weighed and the ambient concentration of particulate matter calculated.

Lead (Pb). A toxic metallic element that can be an air pollutant. The main sources include industrial production processes, and vehicle tyre and brake wear.

Leckel SEQ^{TM}. A type of ***gravimetric sampler*** used for measuring ambient concentrations of PM_{10} or $PM_{2.5}$.

Limit value. The ***Air Quality Standards Regulations (2010)*** set 'limit values' for ambient concentrations of pollutants. Limit values are legally mandatory and must not be exceeded.

Long-Term Objectives. As well as limit values and target values, the ***Air Quality Standards Regulations (2010)*** set 'long-term objectives' for ozone concentration. These are similar to limit values but achievement is not legally mandatory. However, the UK is legally required to take all necessary measures not entailing disproportionate costs to meet the target values and long-term objectives.

Mercury (Hg). A toxic metallic element that can be an air pollutant. The main UK sources include coal use in energy production and industry, iron and steel production processes, and disposal of products containing mercury.

Member States. Countries that are part of the European Union.

Microgram per cubic metre ($\mu g\ m^{-3}$ or $\mu g/m^3$) Unit often used to express the concentration of a pollutant in air. 1 µg = 1 millionth of a gram or 1×10^{-6} g.

Micrometre (µm). Unit of length often used for the size of particulate pollutants. 1 µm = 1 millionth of a metre (1×10^{-6} m) or one thousandth of a millimetre.

Milligram per cubic metre ($mg\ m^{-3}$ or mg/m^3). Unit often used to express the concentration of carbon monoxide in air. 1 mg = 1 thousandth of a gram or 1×10^{-3} g.

Nanogram per cubic metre ($ng\ m^{-3}$ or ng/m^3). Unit often used to express concentrations of pollutants such as metallic elements and ***PAH**,* which are usually found at low concentrations in air. 1 ng = 1 billionth of a gram or 1×10^{-9} g.

Net Zero. Net zero emissions are reached when anthropogenic (i.e. human-caused) emissions of greenhouse gases to the atmosphere are balanced by anthropogenic removals over a specified period.

Nickel (Ni) A toxic metallic element found in ambient air as a result of releases from oil and coal combustion, metal processes, manufacturing and other sources.

Nitric oxide (NO). One of the oxides of nitrogen formed in combustion processes. NO is not harmful to human health but combines with oxygen to form nitrogen dioxide.

Nitrogen Dioxide (NO_2) One of the oxides of nitrogen formed in combustion processes. At high concentrations NO_2 is an irritant to the airways. NO_2 can also make people more likely to catch respiratory infections (such as flu), and to react to allergens.

Nitrogen Oxides (NO_X). Compounds formed when nitrogen and oxygen combine. NOx, which comprises nitric oxide (NO) and nitrogen dioxide (NO_2), is emitted from combustion processes. Main sources include power generation, industrial combustion and road transport.

Non-agglomeration zones. Zones with no single large urban population contained within them.

Ozone (O_3). A pollutant gas which is not emitted directly from any source in significant quantities but is produced by reactions between other pollutants in the presence of sunlight. (This is what is known as a ***'secondary pollutant'***.) Ozone concentrations are greatest in the summer. O_3 can travel long distances and reach high concentrations far away from the original pollutant sources. Ozone is an irritant to the airways of the lungs, throat and eyes: it can also harm vegetation.

Particulate Matter (PM). Small airborne particles. PM may contain many different materials such as soot, wind-blown dust or secondary components, which are formed within the atmosphere as a result of chemical reactions. Some PM is natural, and some is human made. Particulate matter can be harmful to human health when inhaled, and research shows a range of health effects associated with PM. In general, the smaller the particle the deeper it can be inhaled into the lung.

Partisol^{TM}. A type of ***gravimetric sampler*** used for measuring ambient concentrations of PM_{10} or $PM_{2.5}$.

PM_{10}. Particles which pass through a size-selective inlet with a 50% efficiency cut-off at 10 µm aerodynamic diameter, as defined in ISO 7708:1995, Clause 6. This size fraction is important in the context of human health, as these particles are small enough to be inhaled into the airways of the lung – described as the 'thoracic convention' in the above ISO standard. PM_{10} is often described as '*particles of less than 10 micrometres in diameter*' though this is not strictly correct.

$PM_{2.5}$. Particles which pass through a size-selective inlet with a 50% efficiency cut-off at 2.5 µm aerodynamic diameter, as defined in ISO 7708:1995, Clause 7.1. This size fraction is important in the context of human health, as these particles are small enough to be inhaled very deep into the lung – described as the 'high risk respirable convention' in the above ISO standard. $PM_{2.5}$ is often described as '*particles of less than 2.5 micrometres in diameter*' though this is not strictly correct.

Polycyclic Aromatic Hydrocarbons (PAH). PAHs are a large group of chemical compounds that are toxic and carcinogenic. Once formed, they can remain in the environment for a long time and can be passed up the food chain. The main sources are domestic coal and wood burning, outdoor fires, and some industrial processes. The pollutant ***benzo[a]pyrene*** is a PAH, and because it is one of the more toxic PAH compounds it is measured as a 'marker' for this group of pollutants.

Population Exposure Reduction Target (PERT). A legally mandatory target set in the Environmental Targets (fine particulate matter) (England) Regulations (2023), for ambient concentrations of ***$PM_{2.5}$***. This requires a reduction of at least 35% in population exposure to $PM_{2.5}$ (measured at urban background and suburban background monitoring stations in England) by the end of 31st December 2040, compared with a three-year baseline period of 2016 to 2018.

Primary pollutant. A pollutant which is emitted directly into the atmosphere from a source.

QA/QC (or QAQC): Quality Assurance and Quality Control.

Secondary pollutant. A pollutant which is formed by chemical reactions from other pollutants in the atmosphere. Ozone, for example, is a secondary pollutant. Particulate matter ($PM_{2.5}$ and PM_{10}) consists of a mix of primary material (directly emitted from sources) and secondary material (formed by reactions in the atmosphere).

Sulphur dioxide (SO_2). An acid gas formed when fuels containing sulphur impurities are burned. SO_2 irritates the airways of the lung. An alternative spelling of 'sulphur' is 'sulfur'.

Target Value. As well as limit values, the **Air Quality Standards Regulations (2010)** set target values for some pollutants. These are similar to limit values but achievement is not legally mandatory. The UK must take all necessary measures not entailing disproportionate costs to meet the target values. However, the targets set by the **Environmental Targets (fine particulate matter) (England) Regulations (2023)**, i.e. the **AMCT** and **PERT**, differ in that achievement by the specified date is legally mandatory.

TOMPs. This stands for 'Toxic Organic Micropollutants'. These are compounds that are present in the environment at very low concentrations but are highly toxic and persistent. They include dioxins and dibenzofurans.

1 Introduction

Clean air is vital for people's health and the environment, essential for making sure our cities are welcoming places for people to live and work now and in the future, and for our prosperity. Improving air quality remains a key priority for the UK. It is therefore important to monitor levels of air pollution. The broad objectives of monitoring air pollution in the UK are:

- To fulfil statutory air quality reporting requirements.
- To provide a sound scientific basis for the development of cost-effective control policies.
- To provide the public with open, reliable and up-to-date information on air pollution, enabling them to take appropriate action to minimise health impacts.
- To evaluate potential impacts on population, ecosystems and our natural environment.
- To provide a mechanism to test and validate models.

The UK's Air Quality Standards Regulations (2010) (UK Government, 2010), (Scottish Government, 2010), (Welsh Government, 2010), (Department of Environment Northern Ireland, 2010) [1] require the UK to undertake an air quality assessment and report the findings on an annual basis. The UK has statutory monitoring networks in place to meet the requirements of the above Regulations, with air quality modelling used to supplement the monitored data.

The Environmental Targets (Fine Particulate Matter) (England) 2023 Regulations also require annual assessment of progress towards the targets. Assessment uses data from the same monitoring network, but without any supplementation by air quality modelling.

The UK is also required to make the information available to the public. One way in which this is done is by the series of annual 'Air Pollution in the UK' reports. '*Air Pollution in the UK 2022*' continues this series, and has two aims:

- To provide a summary of the UK's 2022 air quality assessment and findings. A separate Compliance Assessment Summary document is also published, based upon Section 4 of this report. This provides a concise summary aimed at the public.

[1] Northern Ireland's former Department of Environment is now the Department of Agriculture, Environment and Rural Affairs.

- To act as a State of the Environment report, making information on the ambient air quality evidence base for the year publicly available. This includes an assessment of trends and spatial distribution, together with information on pollution events during the year.

This report:

- Outlines the air quality legislative and policy framework in the UK (**Section 2**).

- Describes the evidence base underpinning the UK's air quality assessment: the pollutants of concern, and where and how air pollution is measured and modelled (**Section 3**).

- Presents an assessment of the UK's compliance in 2022 with the limit values, target values and long-term objectives set out in the Air Quality Standards Regulations (2010) and with the $PM_{2.5}$ targets set in the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) (**Section 4**).

- Compares this with previous and recent years (**Section 4**).

- Explains the spatial distribution of the main pollutants of concern within the UK during 2022 and looks at how ambient concentrations have changed in recent years (**Section 5**).

- Explains noteworthy pollution events that occurred during 2022 (**Section 6**). This year, Section 6 looks at a springtime particulate pollution episode in late March, two summer ozone episodes associated with hot weather in July and August, and some measured air quality impacts of Bonfire Night celebrations around 5th November.

- Explains where to find out more (**Section 7**).

Further information on air quality in the UK can be found on Defra's online UK Air Information Resource (UK-AIR), at uk-air.defra.gov.uk.

2 Legislative and Policy Framework

The UK air quality framework is currently derived from a mixture of domestic and international legislation and consists of three main strands:

1) Legislation regulating concentrations of pollutants in ambient air – the Air Quality Standards Regulations (2010) and the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023).

2) Legislation regulating total national emissions of air pollutants – the National Emission Ceilings Regulations (2002) and the Gothenburg Protocol to the UNECE Convention on Long-range Transboundary Air Pollution.

3) Legislation regulating emissions from specific sources such as UK legislation implementing the Environmental Permitting Regulations and the Clean Air Act. Note: Northern Ireland does not have Environmental Permitting Regulations but instead regulates industrial emissions via the Pollution Prevention and Control (Industrial Emissions) Regulations (Northern Ireland) (2013) (as amended) (Department of Environment Northern Ireland, 2013).

In February 2022, the UK Government published the Air Quality Common Framework (UK Government, 2022a). This policy paper, which is available online at https://www.gov.uk/government/publications/air-quality-provisional-common-framework, explains how the UK Government and the Devolved Administrations propose to work together to develop air quality policy, following the UK's exit from the European Union.

Reducing air pollution requires action to reduce domestic emissions as well as working closely with international partners to reduce transboundary emissions (pollutants blown over from other countries) which, at times, can account for a significant proportion of pollutant concentrations experienced in the UK. For example, a 2013 report prepared by the Air Quality Expert Group on behalf of Defra and the Devolved Administrations estimated that emission sources within the UK only accounted for 50-55% of measured annual average fine particulate matter ($PM_{2.5}$) concentrations, the remainder being formed or emitted elsewhere (Air Quality Expert Group, 2013). Modelling that informed the $PM_{2.5}$ targets set through the Environment Act (2021) reached similar conclusions (Imperial College London, 2022).

2.1 The Air Quality Standards Regulations (2010)

2.1.1 Background to the Air Quality Standards Regulations (2010)

In the UK, concentrations of a range of pollutants in ambient air are regulated by the Air Quality Standards Regulations (2010) as follows:

- The Air Quality Standards Regulations (2010) (UK Government, 2010)

- The Air Quality Standards Regulations (2010) in England (UK Government, 2010), and their December 2016 amendment (UK Government, 2016)
- The Air Quality Standards (Scotland) Regulations (2010) in Scotland (Scottish Government, 2010), and their December 2016 amendment (Scottish Government, 2016)
- The Air Quality Standards (Wales) Regulations (2010) in Wales (Welsh Government, 2010)
- The Air Quality Standards Regulations (Northern Ireland) (2010) (Department of Environment Northern Ireland, 2010) and their January 2017 amendment (DAERA, 2017)
- The Air Quality Standards Regulations (Gibraltar) and their December 2016 amendment (HM Government of Gibraltar, 2016)

These Regulations have their origins in the following European Union legislation:

- Directive 2008/50/EC of 21st May 2008, on Ambient Air Quality and Cleaner Air for Europe (European Parliament and Council of the European Union, 2008). This is referred to in this report as 'the Air Quality Directive' and covers the following pollutants: sulphur dioxide, nitrogen oxides, particulate matter (as PM_{10} and $PM_{2.5}$), lead, benzene, carbon monoxide and ozone. It revised and consolidated previously existing EU air quality legislation relating to the above pollutants.

- Directive 2004/107/EC of 15th December 2004 (European Parliament and Council of the European, 2004), relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. This is referred to as 'the Fourth Daughter Directive' and covers the four elements cadmium, arsenic, nickel and mercury, together with polycyclic aromatic hydrocarbons (PAH).

Following the UK's exit from the European Union, the following amendments were made to the Air Quality Standards Regulations (2010):

- The Air Quality (Amendment of Domestic Regulations) (EU Exit) Regulations SI 2019/74 (UK Government, 2019). These amend the AQSR (2010) by introducing provisions to allow for PM_{10} limit values being exceeded due to the re-suspension of particulates following winter sanding or salting of roads and transfer responsibilities from the Member State to the Government.
- The Air Quality (Miscellaneous Amendment and Revocation of Retained Direct EU Legislation) (EU Exit) Regulations (2018) (UK Government, 2018a) makes amendments to transfer responsibilities from the Member State to the Government.

In addition, concentrations of fine particulate matter are regulated by more recent legislation, the Environmental Targets (fine particulate matter) (England) Regulations (2023) (UK Government, 2023) which are explained in **Section 2.2.2**.

2.1.2 Provisions of the Air Quality Standards Regulations (2010)

The Air Quality Standards Regulations (2010) set ‘limit values’, ‘target values’ and ‘long-term objectives’ for ambient concentrations of pollutants. These are explained below, as well as provisions regarding monitoring, and reporting of data.

Limit values must not be exceeded. They are set for individual pollutants and comprise a concentration value, an averaging period for the concentration value, a number of exceedances allowed (per year) and a date by which this must be achieved. Some pollutants have more than one limit value, for example relating to short-term average concentrations (such as the hourly mean) and long-term average concentrations (such as the annual mean). The UK is legally required to meet the limit values.

Target values and **long-term objectives** are set for some pollutants and are configured in the same way as limit values. The UK is legally required to take all necessary measures not entailing disproportionate costs to meet the target values and long-term objectives.

The Air Quality Standards Regulations (2010) include detailed provisions on the **monitoring and reporting** of air quality, including:

- The division of the UK into zones for the purposes of compliance reporting.
- The location and number of sampling points.
- The measurement methods to be used.
- Data quality objectives.
- Siting criteria each monitoring station must meet.
- Provision for reporting compliance.
- Provision of information to the public.

The UK has statutory monitoring networks in place to meet the requirements of the above legislation, with air quality modelling used to supplement the monitored data.

2.2 Environment Act (2021): $PM_{2.5}$ Targets

2.2.1 Background to the Targets

The UK Environment Act (2021) (UK Government, 2021) established a duty for the UK Government to set a legally mandatory target in England to reduce $PM_{2.5}$, alongside at least one further long-term target on air quality. The long-term target is part of the wider framework for setting legally binding environmental targets, which also covers biodiversity, water, waste reduction and resource efficiency.

Within this framework, the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) (UK Government, 2023) came into force in January 2023. These regulations set two new targets: for ambient concentrations of particulate matter measured as $PM_{2.5}$, and for $PM_{2.5}$ population exposure reduction over the period between 2018 and 2040.

These two targets are designed to work together to drive actions that both reduce concentrations where it is highest and reduce the pollution that everyone in the country experiences.

These targets are in addition to the Air Quality Standards Regulations (2010) and apply only in England. The $PM_{2.5}$ annual mean limit value and the National Exposure Reduction Target for the UK still stand in addition to these new targets.

The meaning of "targets" in this legislation is different to that of "target values" in the Air Quality Standards Regulations (2010) (explained in **Section 2.1.2**). There is a legal requirement to achieve the targets of the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) by the specified dates.

2.2.2 Provisions of The Environmental Targets (Fine Particulate Matter) (England) Regulations (2023)

The new targets are as follows:

- **The annual mean concentration target (AMCT),** which applies to all monitoring stations, is that by the end of 31st December 2040 the annual mean concentration of $PM_{2.5}$ in ambient air must be equal to or less than 10 µg m^{-3} ("the target level"). It will be met if, at every relevant monitoring station, the annual mean concentration of $PM_{2.5}$ in ambient air, rounded to the nearest whole number of µg m^{-3}, is equal to or less than the target level in the year 2040. This must be reported by 15th July 2041.

- **The population exposure reduction target (PERT)** is for at least a 35% reduction in population exposure by the end of 31st December 2040 ("the target date"), as compared with the average population exposure in the three-year period from 1st January 2016 to 31st December 2018 ("the baseline period").

Population exposure is assessed using the 'Population Exposure Indicator' (PEI) - a measure of average population exposure in the three-year period ending on 31st December in that year.

The PEI is based on measurements from urban background and suburban background monitoring stations which are representative of the exposure of people living in England. Monitoring stations are only included in any given year's PEI if they have met the minimum annual data capture requirement of 85% of the year. A statistical calculation method is used to accommodate changes in the monitoring network when comparing a given year's PEI against the PEI for the 2018 base year. The Regulations set out in detail how the

PERT is calculated, and further information can be found here: https://uk-air.defra.gov.uk/pm25targets/calculation.

The Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) also specify the siting criteria for monitoring stations (which are the same as those contained within the Air Quality Standards Regulations (2010)) and set the conditions for which the calculations and rounding should be carried out.

2.2.3 Monitoring Progress Towards the Targets

The Environmental Improvement Plan 2023 (Defra, 2023a) sets interim targets and outlines policies to meet these. The interim targets are that by January 2028 annual mean concentrations must be 12 µg m^{-3} or lower and the population exposure (based on the PEI for that year) must be reduced by at least 22% compared to 2018 using the same statistical method.

The Environment Act (2021) establishes a framework for reporting and reviewing all Environment Act targets. Progress is reported annually, and the Environmental Improvement Plan is updated at least every five years.

Data on progress towards these $PM_{2.5}$ targets (and how this is calculated) is published on the UK-AIR website here: https://uk-air.defra.gov.uk/pm25targets/calculation. More information on the development of these $PM_{2.5}$ targets can be found here: https://uk-air.defra.gov.uk/pm25targets/progress.

2.3 The National Emission Ceilings Regulations (2018)

The UK's National Emission Ceilings Regulations (NECR) (2018) (UK Government, 2018b) sets emission reduction commitments (ERCs) for anthropogenic emissions of oxides of nitrogen (NO_X), oxides of sulphur (SO_X), non-methane volatile organic compounds (NMVOC), ammonia (NH_3) and particulate matter as $PM_{2.5}$ in 2020 and 2030. The 2010 emission ceilings for NO_X, NMVOC, NH_3 and SO_X, in the NECR and Gothenburg Protocol (United Nations Economic Commission for Europe (UNECE), 1999), applied up to the end of 2019 and were then superseded by the 2020 ERCs. The NECR pollutants contribute to acidification and eutrophication of ecosystems whilst also playing a major role in the formation of ground-level ozone. Under the NECR and Gothenburg Protocol, the UK is required to prepare and annually update national emissions inventories for these and a number of other air pollutants.

The Gothenburg Protocol was revised in May 2012 to set emission reduction commitments (ERCs) for 2020 (from the 2005 baseline) for the same four pollutants and $PM_{2.5}$. The revised National Emission Ceilings Directive (European Parliament and Council of the European Union, 2016) came into force on 31st December 2016. This revised Directive was transposed into UK legislation in February 2018 via the National Emissions Ceilings Regulations (2018), and the new UK legislation came into force on 1st July 2018 (UK

Government, 2018b). The Environmental Improvement Plan, published in 2023, sets out how we will work towards these goals (see **Section 2.5.1**) (Defra, 2023a)

The UK did not meet its 2020-2029 emission reduction commitment for emissions of fine particulate matter ($PM_{2.5}$) in 2021. In 2021, the UK has met domestic and international 2020-2029 emission reduction commitments for emissions of NOx, SO_2, NMVOCs, and for ammonia (NH_3) with the inclusion of an approved adjustment. Under this adjustment, ammonia emissions from the application of non-manure digestates to land (referring to the solid substances produced by anaerobic digestion processes, which can be used as fertiliser) are excluded for compliance purposes. Under existing regulations an adjustment is permitted in certain cases, for example where a source was not in the inventory when the commitments were set but was later added to the inventory as an improvement, as was the case with the application of non-manure digestates to land. As required, the UK submitted an adjustment application to the UNECE, which was reviewed and accepted by UNECE experts. To fulfil the reporting requirements under the Convention for Long Range Transboundary Air Pollution (CLRTAP) and in the NECR, the UK compiles and reports its air pollutant emissions inventory on an annual basis. The latest emissions data available is for the year 2021 and can be found here: https://naei.beis.gov.uk/data/.

The UK's Revised National Air Pollution Control Programme (NAPCP) was published by Defra in February 2023 (Defra, 2023b). The NAPCP sets out how the UK can meet the legally binding 2020 and 2030 emission reduction commitments (ERCs). These commitments apply for the five pollutants: nitrogen oxides, ammonia, non-methane volatile organic compounds, fine particulate matter and sulphur dioxide.

2.4 The Environmental Permitting Regulations (EPR 2016 & 2018)

The Environmental Permitting (England and Wales) Regulations (2016) (as amended) (EPR) set standards and provisions to reduce the emissions of pollutants from a diverse range of industrial sources – from intensive pig and poultry farms to chemical manufacturing sites and power stations. The main mechanism for controlling emissions to air, land and water from industrial installations is through complying with an industrial installations permit under the EPR. The EPR aims to prevent or minimise pollution from industrial sources, and therefore protect the environment and human health. Equivalent legislation exists in Scotland (Scottish Government, 2018) and Northern Ireland (Department of Environment Northern Ireland, 2013).

Under the EPR, most industries must use best available techniques (BAT) to reduce their emissions. The UK is committed to maintaining high environmental standards and has put in place a process for determining future BAT for industrial emissions. Since 2018, Defra has jointly consulted with the devolved administrations on our approach for setting BAT for tackling industrial emissions from our largest industry in an integrated way. The new regime will be based on the principles followed since the UK originally devised the concept; a detailed, transparent, collaborative, data-led process that builds on existing high levels of environmental protection. Data suggests that, by applying BAT, pollution can be reduced by between 25% and 60%, depending on the sector and pollutant.

In addition, in the Environmental Improvement Plan (Defra, 2023a), we recognize the importance of fostering innovation within a well-defined regulatory framework for UK businesses. To this end, we have made a commitment to engage in consultations aimed at enhancing the mechanisms used to establish standards for industrial processes. These improvements will align more closely with our environmental priorities and facilitate business innovation, particularly in the context of achieving net-zero emissions. Additionally, we are dedicated to initiating consultations regarding a novel system for updating standards applicable to smaller industries, such as petrol stations, metals processing, and quarrying. Building upon the success of the BAT approach in mitigating emissions from larger industries, extending a similar framework to smaller industries will not only reduce pollution but also stimulate progress in these sectors.

2.5 Policies to Improve UK Air Quality

Domestic, EU and internationally driven environmental legislation introduced over the past seventy years has provided a strong impetus to reduce the levels of harmful air pollutants in the UK. As a result, current concentrations of many recognised pollutants are now at the lowest they have been since measurements began. The UK's 1956 Clean Air Act tackled city smog caused by domestic and industrial coal burning, and significant progress has continued to improve air quality throughout subsequent decades. Between 1970 and 2021 (the most recent year for which data are available), UK estimated emissions of nitrogen oxides have fallen by 77%, UK estimated emissions of PM_{10} particulate matter have fallen by 79% and UK estimated emissions of $PM_{2.5}$ particulate matter have fallen by 85% (Defra, 2023c).

The UK Government is addressing the issue of particulate pollution via the Environmental Targets (Fine Particulate Matter) (England) Regulations 2023, summarised in **Section 2.2** above.

In 2021 the Welsh Government consulted on a white paper for a Clean Air (Wales) Bill to improve air quality and reduce the impacts of air pollution on public health, biodiversity, the natural environment and the economy. The white paper set out how Welsh Government intends to enable more ambitious air quality targets and put in place a more robust regulatory framework to support them. The white paper can be accessed at https://gov.wales/white-paper-clean-air-wales-bill and the summary of consultation responses is at https://www.gov.wales/written-statement-publication-white-paper-clean-air-wales-bill-summary-responses. The current status of the Bill, including Explanatory Memorandum and scrutiny documentation, can be found on the Senedd Wales website at https://business.senedd.wales/mgIssueHistoryHome.aspx?IId=40984.

2.5.1 Environmental Improvement Plan 2023

The Environmental Improvement Plan 2023 (EIP) (Defra, 2023a) is the first five-yearly statutory review[2] of the 25 Year Environment Plan. The EIP applies to England only and is a delivery plan setting out how Government will improve all aspects of the environment. The clean air chapter of the EIP updates the 2019 Clean Air Strategy, setting out Government's delivery plan to achieve its statutory air quality targets. It builds on the vision set out in the 25 Year Environment Plan, and on the 2019 Clean Air Strategy and with new powers and duties from the Environment Act (2021).

The EIP clean air delivery plan focuses on four sectors, as well as supporting action by local authorities.

1. Reducing emissions in the home by managing domestic burning, which is the biggest source of emissions of fine particulate matter. Much of these emissions were in urban areas, increasing people's exposure to this harmful pollutant.
2. Maintaining and improving our regulatory framework for industrial emissions, which have already reduced significantly.
3. Supporting farmers to reduce the impact of ammonia emissions from agriculture on air quality. Farming is responsible for 87% of the ammonia emissions in the UK.
4. Reducing emissions from cars and other forms of transport which are still a major source of NO_2 and $PM_{2.5}$ emissions.
5. Driving effective local action through local authorities. They have the legal responsibility and powers to deliver clean air in their areas and so have the greatest power to support the achievement of the population exposure targets.

2.5.2 Air Quality Strategy 2023

The Air Quality Strategy 2023 fulfils the statutory requirement of the Environment Act (1995) as amended by the Environment Act (2021) to publish an Air Quality Strategy setting out air quality standards, objectives, and measures for improving ambient air quality every five years. The Strategy published in April 2023 replaces the 2007 version; it applies in England only, including London Boroughs. The 2007 Strategy (Defra, 2007) remains in force in Northern Ireland until the Clean Air Strategy for Northern Ireland is published. The Scottish Government intends to publish a replacement to the 2007 version, and until then that version remains in force. The Clean Air Plan for Wales: Healthy Air, Healthy Wales, published in 2020 (Welsh Government, 2020), sets the 10-year strategic direction across multiple policy areas. This now forms the National Air Quality Strategy for Wales, in place of the 2007 UK Strategy but retaining the air quality objectives. In April

[2] Environment Act 2021 (legislation.gov.uk) chapter 1, reg 10

2023 Welsh Government published an Update Report on Progress Against Actions in the Clean Air Plan for Wales (Welsh Government, 2023).

The Air Quality Strategy 2023 sets out the actions Government expects local authorities to take in support of achieving our long-term air quality goals, including the new $PM_{2.5}$ targets. It provides a framework to enable local authorities to make the best use of their powers and deliver for their communities.

There is an existing suite of air quality publications to which local authorities can refer; a comprehensive list can be found at Annex B of the Air Quality Strategy 2023. This includes local guidance as well as national strategies and plans. These documents set out actions that the UK Government will take to improve air quality. The Air Quality Strategy complements rather than replicates or replaces these publications and is a locally focused document to enable local authorities to clearly understand their role, responsibilities and powers relating to air quality. The Strategy sets out a strong support and capability-building framework to ensure local authorities have the necessary tools to take local action, supporting progress towards local and national targets.

The Department of Agriculture, Environment and Rural Affairs (DAERA) is developing Northern Ireland's first Clean Air Strategy. In autumn 2020, a Discussion Document was issued to public consultation. It invited views on a range of matters relating to air quality and was an opportunity for stakeholders to put ideas to the Department. The consultation closed in spring 2021 and responses were analysed in detail. A synopsis of the responses is available to view at https://www.daera-ni.gov.uk/clean_air_strategy_discussion_document. Preliminary findings were discussed with the then Minister and an inter-departmental working group was established to further develop proposals and identify policies for cross-departmental consideration. A further public consultation is planned for 2024, to seek views on the proposed draft strategy.

2.5.3 The UK Air Pollution Forecasting System

Daily UK air pollution forecasts are produced for five pollutants; nitrogen dioxide, sulphur dioxide, ozone, PM_{10} particles and $PM_{2.5}$ particles. The forecasts are communicated using the Daily Air Quality Index (http://uk-air.defra.gov.uk/air-pollution/daqi) which is a scale of one to ten divided into four bands. This allows the public to see at a glance whether the air pollution is low, moderate, high or very high, and to look up any recommended actions to take.

The group of pollutants covered, and the thresholds between the various index bands, were updated by Defra as of 1st January 2012, in the light of recommendations by the Committee on the Medical Effects of Air Pollutants (COMEAP) in their 2011 review of the UK air quality index (COMEAP, 2011). In December 2021, Defra (with support from DHSC and UKHSA) launched a comprehensive review into the way air quality information is communicated to the public. This review is being guided by an independent steering group of multidisciplinary experts. As part of the review process the steering group will make recommendations for any improvements that should be made to the Daily Air Quality

Index. Progress on the air quality information system review is being published on the UK-AIR website, at: https://uk-air.defra.gov.uk/research/aq-system-review.

Currently, the daily forecast is provided by the Met Office and is available from UK-AIR and from the Scottish, Welsh and Northern Ireland air quality websites (see **Section 7**), and is further disseminated via e-mail, X (formerly Twitter) and RSS feeds. Anyone may subscribe to the free air pollution bulletins at: https://uk-air.defra.gov.uk/subscribe. Latest forecasts are issued daily, at: https://uk-air.defra.gov.uk/forecasting/. Defra also provides automated updates on current and forecasted air quality via X @DefraUKAIR, and a free telephone information service, with current air pollution levels and forecasts updated every hour. To use this service, call 0800 556677 and follow the instructions.

2.5.4 NO_2 Air Quality Plans

In July 2017, the UK Government and Devolved Administrations published the *UK Plan for Tackling Roadside Nitrogen Dioxide Concentrations*, followed by a supplement in October 2018. The Plan and supplement set out how Government will achieve compliance with legal limits for NO_2 in the shortest possible time, supported by a £3.8 billion investment into air quality and cleaner transport. Government has allocated £883 million to help local authorities tackle NO_2 exceedances. This funding supports local authorities to deliver their air quality measures to improve the health of their residents and meet legal limits for NO_2. These air quality measures are varied and highly targeted, e.g. traffic management schemes, engineering solutions, grants and loans for vehicle upgrades and encouraging behavioural change. Measures may include Clean Air Zones; Bath, Birmingham, Bradford, Bristol, Portsmouth, Sheffield and the Tyneside conurbation covering Newcastle and Gateshead all have Clean Air Zones implemented between 2021 and 2023. A further Clean Air Zone is under review for Greater Manchester. The funding also includes a Clean Air Fund, accessible by those local authorities implementing measures to tackle NO_2 exceedances, to help them mitigate the impact of their plans on individuals and businesses. Local authorities have used this funding to provide grants to individuals and businesses to upgrade their fleets, Electric Vehicle (EV) charging infrastructure and discounted access to public transport. The UK Air Quality Plan for nitrogen dioxide, together with the supplement published in October 2018, is available at https://www.gov.uk/government/publications/air-quality-plan-for-nitrogen-dioxide-no2-in-uk-2017.

Government will assess whether a local authority has successfully delivered a reduction in NO_2 concentration that is sustained over multiple years and that is likely to be maintained if the local authority wishes to remove measures. At this point the legal obligation to continue with measures will have expired, and the local authority can exit the NO_2 Programme. The assessment that informs this process is separate to the national assessment of compliance with limit values, although it shares some of the same evidence (data from the AURN and UUNN).

Welsh Government funding of over £25m has been supporting two Welsh local authorities to introduce measures to tackle exceedances. In both cases, feasibility studies ruled out charging Clean Air Zones as alternative measures were identified which would be at least as effective at reducing NO_2 and could be delivered more quickly. The Welsh supplemental plan, which was published in November 2018, can be found at https://gov.wales/air-quality-plan.

Scotland has introduced Low Emission Zones for the improvement of air quality in four cities: Glasgow, Aberdeen, Dundee and Edinburgh. These were introduced on 31st May 2022, and local grace periods now apply until enforcement begins. In Glasgow, LEZ enforcement for buses began in 2022: enforcement for other vehicle types started on 1st June 2023 (a year later for residents within the zone). LEZ enforcement will begin on 30th May 2024 in Dundee, and on 1st June 2024 in Edinburgh and Aberdeen. Eligible households within defined areas may apply for a cash grant to incentivise disposal of a non-LEZ compliant vehicle.

Since 2018/19 significant funding has been made available to local authorities, transport operators and the general public to support LEZ introduction. Other Scottish local authorities with Air Quality Management Areas have completed assessments to determine whether an LEZ would be an appropriate intervention in their areas.

The Scottish Government also provides a total of £3.5 million per year to support local authority air quality work, spends over £1 billion per year on public transport and has committed to investing at least £320 million – or 10% of the total transport budget – on active travel by 2024/25.

In Northern Ireland, DAERA operate a funding mechanism for LAQM which councils can apply for to enable them to help meet their obligations under the provisions of Part III of the Environment (NI) (2002) (The Environment (Northern Ireland) Order 2002 (legislation.gov.uk)). Furthermore, as air quality is a cross-cutting issue, a number of other Northern Ireland Departments play a role. For example, the Climate Change Act (Northern Ireland) (2022) requires the Department for Infrastructure to develop sectoral plans for transport which set a minimum spend on active travel from the overall transport budgets of 10%.

2.5.5 Measures to Address Target Value Exceedances of B[a]P and Nickel

The Air Quality Standards Regulations (2010) set target values for a number of metallic elements including nickel and for benzo[a]pyrene (B[a]P). The UK exceeded target values for B[a]P and nickel during all years from 2013 to 2022 inclusive, except for nickel in 2017.

These exceedances are reported as part of the UK's annual compliance assessment. For details of previous exceedances please see earlier 'Air Pollution in the UK' reports in this series which are available at: https://uk-air.defra.gov.uk/library/annualreport/.

The UK published reports providing details of the assessment of the exceedances in years 2013 to 2020. These also reported the actions and measures already taken or planned, to help the UK meet the target values. An overview report was provided for each pollutant alongside more detailed information on any exceedances by zone.

The reports explain that we are taking steps to address all the exceedances through existing long-term measures, such as regular coke oven door maintenance and through improvements in our understanding to help target measures appropriately. The nickel overview report details existing and new measures put in place and the continued work with environmental regulators to improve understanding and management of these exceedances.

The reports are available at: https://uk-air.defra.gov.uk/library/bap-nickel-measures. At the time of writing, the 2020 reports are the most recent in the series: a report for 2021 is expected to be published in December 2023.

2.5.6 Environmental Improvement Plan and Interim Targets

In January 2023 the UK Government published its Environmental Improvement Plan 2023 (Defra, 2023a). This is the first five-yearly revision of the 25 Year Environment Plan, and includes 10 wide-ranging goals covering the following:

- Goal 1: Thriving plants and wildlife
- Goal 2: Clean air
- Goal 3: Clean and plentiful water
- Goal 4: Managing exposure to chemicals and pesticides
- Goal 5: Maximise our resources, minimise our waste
- Goal 6: Using resources from nature sustainably
- Goal 7: Mitigating and adapting to climate change
- Goal 8: Reduced risk of harm from environmental hazards
- Goal 9: Enhancing biosecurity
- Goal 10: Enhanced beauty, heritage, and engagement with the natural environment.

To deliver the goal of clean air, the Government’s delivery plan focuses on the following sectors:

1. *“Reducing emissions in the home by managing domestic burning, which is the biggest source of emissions of fine particulate matter. Much of these emissions were in urban areas, increasing people’s exposure to this harmful pollutant.”*

This will include: introducing tighter emission limits for solid fuel-burning stoves in Smoke Control Areas, from 5 g of smoke per hour to 3 g; extending the legislation covering solid fuels, including solid fuels burned outdoors; and implement measures to drive a shift away from older, more polluting appliances to newer, cleaner ones. Air quality will become a key consideration in the planning process, which will address both indoor and outdoor air quality. The Government will continue to review and improve how they communicate with the public regarding air quality and promote best practice in use of wood-burning stoves and open fires. There will also be new guidance on outdoor burning best practice.

2. *"Driving effective local action through local authorities. They have the legal responsibility and powers to deliver clean air in their areas and so have the greatest power to support the achievement of the population exposure targets."*

This will include reinforcement of the role of local authorities in improving air quality and providing them with the support they need to carry out their duties, and enabling them to use their powers as effectively as possible.

3. *Maintaining and improving our regulatory framework for industrial emissions, which have already reduced significantly.*

Defra will continue to drive progress in reducing emissions from large industry, by rolling out and continuing to develop the UK Best Available Techniques (BAT) system. This will address new technologies and the methods that industry should put in place to reduce emissions. They will improve the overall regulatory framework and aim to support businesses in innovating and delivering net zero, including by integrating the regulations of GHG emissions alongside other emissions from industry. They will also address emissions from small industrial processes, consulting on a new regulatory system for updating standards for processes such as petrol stations, metals processing, and quarrying.

4. *Supporting farmers to reduce the impact of ammonia emissions from agriculture on air quality. They are responsible for 87% of the ammonia emissions in the UK.*

Ammonia is a major precursor to the formation of secondary particulate matter. Defra will incentivise and fund measures by which farmers can reduce ammonia emissions. They will also consider extending environmental permitting conditions to dairy and intensive beef farms and put in place measures to reduce emissions from use of inorganic fertilisers, organic manures and anaerobic digestion processes.

5. *Reducing emissions from cars and other forms of transport which are still a major source of NO_2 and $PM_{2.5}$ emissions*."

Where road vehicle emissions are still leading to exceedances of air quality limit values for nitrogen dioxide (NO_2), Defra and the Department for Transport will enable the rollout of measures to address this, such as a further Clean Air Zone in Sheffield, as well as other types of measures in areas where they are appropriate. The Department of Transport will support the move away from petrol and diesel cars, deliver the Rail Environment Policy Statement (which includes addressing air quality in enclosed railway stations) and deliver the Clean Maritime Plan aimed at reducing the environmental impacts of shipping.

2.5.7 National Air Quality Statistics and Indicators

For many years, the UK has reported the following two indicators as National Air Quality Statistics for ambient air:

- **Annual average concentrations of particles and ozone**. These two types of air pollution are believed to have a significant impact on public health.

- **Number of days in the year when air pollution is 'Moderate' or higher**. This may relate to any one of five key air pollutants and is based on the UK's Daily Air Quality Index (see **Section 2.5.3** which deals with forecasting). From the 1st January 2012, $PM_{2.5}$ particles replaced carbon monoxide in this suite of pollutants. The thresholds used to define 'Moderate' and higher pollution levels in the air quality index were also revised at the beginning of 2012.

In 2018, new content was added, including the following:

- **Annual mean concentrations of fine particulate matter ($PM_{2.5}$)** at urban roadside and background monitoring sites. The inclusion of $PM_{2.5}$ reflects the increased interest in this size fraction.

- **Annual mean nitrogen dioxide (NO_2) concentrations** at urban roadside, urban background and rural background monitoring sites. The inclusion of NO_2 informs the public and scientific discussion regarding concentrations of this pollutant, particularly at the roadside.

- **Average hours per year in the 'Moderate' or higher categories** of the Daily Air Quality Index, for PM_{10}, $PM_{2.5}$, NO_2 and ozone. This is intended to highlight variation in short-term exposure per year to harmful levels of air pollution.

- **Variation in pollutant concentration by month of the year (for $PM_{2.5}$ and ozone), by day of the week (for NO_2), and by hour of the day - 'diurnal' variation – (for $PM_{2.5}$ and NO_2).** These are provided for the most recent year and intended to aid understanding of the nature of variation in pollutant concentrations at different types of site.

The National Air Quality Statistics summary for 2022 was released on 27th April 2023 and is available from the Defra website at https://www.gov.uk/government/statistics/air-quality-statistics .

The UK Government's Public Health Outcomes Framework for England 2016 – 2019 (Department of Health and Social Care, 2016) recognises the burden of ill-health resulting from poor air quality as well as other public health concerns. This Framework sets out 60 health outcome indicators for England, and includes as an indicator:

- The fraction of annual all-cause adult mortality attributable to long-term exposure to current levels of anthropogenic particulate air pollution (measured as fine particulate matter, $PM_{2.5}$).

This indicator is intended to enable Directors of Public Health to appropriately prioritise action on air quality in their local area. The indicator is calculated for each local authority in England based on modelled concentrations of fine particulate air pollution ($PM_{2.5}$). Annual estimates of the percentage of mortality attributable to long term exposure to particulate air pollution in England are available from the Public Health Outcomes Framework data tool at https://fingertips.phe.org.uk/profile/public-health-outcomes-framework. The most recent estimate for England at the time of writing, which is based on year 2021, is 5.5%.

The Defra document *'Air Quality: Public Health Impacts and Local Actions'* can be found at https://laqm.defra.gov.uk/documents/air_quality_note_v7a-(3).pdf.

Northern Ireland has a similar Public Health Strategy: *'Making Life Better – A Whole System Framework for Public Health 2013-2023'*. This document can be found at https://www.health-ni.gov.uk/topics/public-health-policy-and-advice/making-life-better-whole-system-strategic-framework-public, and also includes an air quality indicator.

Wales has a national indicator under the Well-being of Future Generations (Wales) Act 2015 and the Welsh Public Health Outcomes Framework, which has been published on StatsWales at https://statswales.gov.wales/Catalogue/Environment-and-Countryside/Air-Quality. Guidance has also been published for public health professionals in supporting the collective management of air quality across Wales. *Working together to reduce outdoor air pollution, risks and inequalities* can be found at https://gov.wales/sites/default/files/publications/2019-06/working-together-to-reduce-outdoor-air-pollution-risks-and-inequalities.pdf .

The Scottish Government's National Performance Framework (https://nationalperformance.gov.scot/) includes 81 National Indicators, many of which relate to environmental and human health.

2.5.8 National Emissions Statistics

The UK reports annual emissions of the following pollutants via an annual National Statistics Release, available at https://www.gov.uk/government/statistics/emissions-of-air-pollutants. This is a large publication comprising multiple sections: links to the individual sections for each pollutant are included alongside the main conclusions below.

- Sulphur dioxide (SO_2).
- Oxides of nitrogen (NO_X).
- Non-methane volatile organic compounds (NMVOCs).
- Ammonia (NH_3).
- Particulate matter (as PM_{10} and $PM_{2.5}$).

The most recent National Statistics Release covers 1970 to 2021 (the most recent year for which emission statistics are available). The main conclusions are as follows:

- *'Emissions of sulphur dioxide have fallen by 98 per cent since 1970, to 126 thousand tonnes in 2021. This was driven by a decline in coal use in the energy sector. Emissions from coal in the energy sector decreased by 8% from 1970 to*

1991, where emissions then began decreasing at a more rapid pace, falling by 83 per cent of 1991 levels by 2005, followed by a further 97 per cent reduction from 2005 levels through to 2021. Stricter limits being placed on the sulphur content of liquid fuels has also reduced emissions in the long-term. Emissions of sulphur dioxide decreased by 5 per cent from 2020 to 2021, dropping to the lowest level in the time series.' (From Section 2 of 'Sulphur Dioxide' at https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-sulphur-dioxide-so2.)

- *'Emissions of nitrogen oxides have fallen by 77 per cent since 1970, to 677 thousand tonnes in 2021. This trend was driven by a decline in coal use in power stations and modernisation of the road transport fleet. There was an increase of less than 1 per cent between 2020 and 2021. Total emissions have not changed by much since 2020, in part attributed to the COVID-19 restrictions which continued to reduce traffic on many roads in early 2021. This is in contrast to the long-term trend, since UK total emissions have fallen by an average of 4 per cent per year between 1990 and 2021.' (From Section 2 of 'Nitrogen Oxides' at https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-nitrogen-oxides-nox .)*

- *'Emissions of non-methane volatile organic compounds (NMVOCs) have fallen by 68 per cent since 1970, to 781 thousand tonnes in 2021. There was a decrease in emissions of 2 per cent between 2020 and 2021. NMVOC emissions reached the highest point in the time series in 1989 and then fell by an average of 5 per cent per year between 1990 and 2009. This was largely due to improvements to emissions standards for road transport and stricter limits applied to industrial processes. Since 2010, annual changes have been much smaller, averaging a decrease of just 2 per cent each year. Since 1990, NMVOC emissions have fallen by 72 per cent.' (From Section 2 of 'Non-methane volatile organic compounds (NMVOCs)' at https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-non-methane-volatile-organic-compounds-nmvocs .)*

- *'Emissions of ammonia have fallen by 14 per cent since 1980, to 265 thousand tonnes in 2021. The majority of this reduction occurred between 1980 and 2008. From 2008 to 2013 annual emissions of ammonia remained relatively stable. Annual ammonia emissions reached the lowest in the time series in 2013 at 255 thousand tonnes. This was followed by a 7 per cent increase in emissions between 2013 to 2017, then a 5 per cent decline to 2020, followed by an increase of 2 per cent to 2021. Over the longer-term, there was a gradual decrease in annual emissions of ammonia during the 1990s and 2000s. Changes in the trend of emissions of ammonia are largely driven by changes to farming practices and herd sizes.' (From Section 2 of 'Ammonia' at https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-ammonia-nh3 .)*

- *‘Annual emissions of PM_{10} have fallen by 79 per cent since 1970, to 143.9 thousand tonnes in 2021. There was an increase of 8 per cent between 2020 and 2021. Annual emissions of $PM_{2.5}$ have fallen by 85 per cent since 1970, to 83.2 thousand tonnes in 2021. There was an increase of 6 per cent between 2020 and 2021. The UK has seen a 28 per cent reduction in $PM_{2.5}$ emissions between 2005 and 2021. Therefore, in 2021, the UK did not meet the 30 per cent emission reduction commitment required between 2020 to 2029 as set out in the NECR and the CLRTAP. Levels of both pollutants generally decreased year-on-year between 1970 and the late-2000s. There are many reasons for this long-term decrease covering most emissions sectors, but the reduction in the burning of coal and improved emission standards for transport and industrial processes are major drivers. Since the late 2000s, annual emissions of particulate matter have fluctuated year-on-year. Considerable decreases in emissions from some sectors have been largely offset by increases in emissions from wood burning in domestic settings and from solid fuel burning by industry (particularly the burning of biomass).’ (From Section 2 of ‘Particulate Matter (PM_{10} and $PM_{2.5}$) at https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-particulate-matter-pm10-and-pm25 .)*

New emission statistics for 2022 will be published in February 2024.

2.6 Local Authority Air Quality Management

Requirements for local air quality management (LAQM) are set out in Part IV of the Environment Act (1995) (UK Government, 1995) as amended by the Environment Act (2021) (UK Government, 2021), and the Environment (Northern Ireland) Order (2002) (Northern Ireland Government, 2002). Authorities are required to carry out regular ‘Review and Assessments’ of air quality in their area and take action to improve air quality in those areas where objectives set out in regulation have been shown not to have been achieved, or areas where it is thought there is a risk that they will not be achieved.

Local authorities in England, Scotland, Wales and Northern Ireland undertake Review and Assessment against the Strategy’s objectives prescribed in the Air Quality (England) Regulations (2000) (UK Government, 2000), Air Quality (Scotland) Regulations (2000) (Scottish Government, 2000), Air Quality (Wales) Regulations (2000) (Welsh Government, 2000) and Air Quality (Northern Ireland) Regulations (2003) (Northern Ireland Government, 2003), together with subsequent amendments (UK Government, 2002), (Welsh Government, 2002), (Scottish Government, 2002), (Scottish Government, 2016).

With regards to LAQM statutory reporting requirements, in 2018 authorities in Wales adopted reporting in the form of an Annual Progress Report in line with the streamlined LAQM regime (Welsh Government, 2017). In England and Scotland, reporting in the form of the adopted Annual Status / Progress Reports has continued (Defra, 2022a) (Scottish Government, 2023), whilst London authorities continued working against the revised London specific London Local Air Quality Management policy guidance (Mayor of London, 2019) through the preparation of Annual Status Reports. Authorities in Northern Ireland commenced Round 8 of the Review and Assessment process in 2021, with appraisal of local air quality via Updating and Screening Assessments in line with the Round based approach to LAQM. Authorities in Northern Ireland were required to submit Progress Reports in 2022 as part of the round eight cycle.

When the Review and Assessment process identifies an exceedance of an Air Quality Strategy objective, the local authority must declare an 'Air Quality Management Area' (AQMA) and develop an Action Plan to tackle problems in the affected areas. Action Plans formally set out the measures the Local Authority proposes to take. As of 2022, local authorities in England (including London) must now state a date by which each measure will be carried out to secure achievement of air quality objectives. Actions may include a variety of measures such as traffic management, behaviour change campaigns or sustainable freight. Advice for local authorities preparing an Action Plan is available from the Defra LAQM web pages at https://laqm.defra.gov.uk/action-planning/aqap-supporting-guidance.html.

Information on the UK's AQMAs is summarised in **Table 2-1** below. At the time of writing (August 2023), 251 Local Authorities – 71.7% of those in the UK – have one or more AQMAs. Some AQMAs are for more than one pollutant, and many local authorities have more than one AQMA.

Table 2-1 Current UK-wide status of Air Quality Management Areas (AQMAs) (as of July 2023.)

Region	Total LAs	LAs with AQMAs	AQMAs for NO_2	AQMAs for PM_{10}	AQMAs for SO_2
England (outside London)	263	184	509	26	5
London	33	33	34	28	0
Scotland	32	14	25	26	1
Wales	22	11	43	1	0
Northern Ireland	11	9	17	2	0
TOTAL	**350**	**251**	**628**	**83**	**6**

Most AQMAs in the UK are in urban areas and have been established to address the contribution to air pollution from traffic emissions of nitrogen dioxide or PM_{10}, or in some cases both. A small number are for SO_2. There are no longer any AQMAs for benzene. The number of AQMAs for PM_{10} in Scotland is relatively high because of the more stringent objective for PM_{10} adopted in Scotland.

Where an AQMA is declared, the local authority specifies the main sources of pollutants involved – for example road transport, industrial emissions or domestic sources, or a mixture of several. The methodology for counting AQMAs by source has changed since the previous report in this series: the number of AQMAs by source is now split by geographic area rather than pollutant type. This is summarised in **Table 2-2**.

Table 2-2 Current UK Air Quality Management Areas by Source (as of July 2023)

Source	England	Wales	Scotland	Northern Ireland	London
County or Unitary Authority Road	186	21	4	0	1
Domestic Heating	1	0	0	1	0
Strategic Road Network	43	2	0	0	0
Industrial Source	8	1	1	0	0
Mixture of Road Types	79	5	2	1	2
Not Defined	1	0	1	2	0
Railways	1	0	0	0	0
Road Transport (unspecified)	187	15	27	15	27
Transport and Industrial Source	11	0	2	0	4
Transport, Industrial and Domestic Sources	5	0	2	0	1

From https://uk-air.defra.gov.uk/aqma/summary.

For up-to-date information on AQMAs throughout the UK, please refer to the interactive map on UK-AIR at https://uk-air.defra.gov.uk/aqma/maps/. This interactive map provides information on the location of the AQMA, the date it was declared, the pollutants for which it was declared, and information on the type of pollutant sources.

3 The Evidence Base

A programme of air quality assessment and research is in place in the UK which delivers the evidential needs of Defra and the Devolved Administrations. These needs include assessment of compliance with legislation, as well as the means to assess the effectiveness of air pollution mitigation policies.

This section explains Defra and the Devolved Administrations' evidence base for the annual assessment of compliance with the Air Quality Standards Regulations (2010) on ambient air quality. It describes the air pollutants which are of concern and how these are monitored and modelled in the UK.

3.1 Pollutants of Concern

This section summarises the sources, effects (both on human health and the environment) and typical UK concentrations of the pollutants being assessed in relation to the Air Quality Standards Regulations (2010).

The information on sources has largely been summarised from the National Atmospheric Emission Inventory (NAEI) pollutant information pages at https://naei.beis.gov.uk/ (National Atmospheric Emissions Inventory, 2022) together with Table 1 of the Air Quality Strategy (Defra, 2007). Information on health effects has been summarised from reports produced by the World Health Organization (WHO), the Expert Panel on Air Quality Standards (EPAQS) and the Committee on the Medical Effects of Air Pollutants (COMEAP). The latest estimate is that long-term exposure to the air pollution mixture in the UK has an annual effect equivalent to 29,000 to 43,000 deaths for adults aged 30 and over (UK Health Security Agency, 2022a).

3.1.1 Oxides of Nitrogen

There are several oxides of nitrogen. The ones of most interest, for air quality, are nitric oxide (NO) and nitrogen dioxide (NO_2). Together, they are often referred to as NO_X. Nitrogen oxides are emitted from combustion processes. Combustion in industry, passenger cars and other transport are the most important UK sources (National Atmospheric Emissions Inventory, 2022).

NO_2 is a respiratory irritant: short-term exposure to concentrations of NO_2 higher than 200 µg m^{-3} can cause inflammation of the airways and may increase susceptibility to respiratory infections (WHO, 2013). There is a high level of confidence that short-term exposure to NO_2 in outdoor air is associated with all-cause mortality (Orellano, et al., 2020). It has been difficult to identify the direct health effects of NO_2 at ambient concentrations, because it is emitted from the same sources as other pollutants such as particulate matter (PM). However, the WHO's REVIHAAP study (WHO, 2013), COMEAP's 2015 statement, (COMEAP, 2015) and COMEAP's 2018 report on associations of mortality with NO_2 have reported increasing evidence that NO_2 itself is responsible for health effects. NO is not considered harmful to human health at the concentrations usually found in ambient air but is quickly oxidised to form NO_2.

NO_X can contribute to the formation of other pollutants. In the presence of sunlight, NO_X can react with volatile organic compounds (VOCs) to produce photochemical pollutants including ozone. NO_X also contributes to particulate pollution, via the formation of secondary nitrate particles in the atmosphere.

NO_X can be damaging to the environment. High levels of NO_X deposition can harm plants. It contributes to acidification and eutrophication of terrestrial and aquatic ecosystems, damaging habitats and leading to biodiversity loss.

Peak hourly mean NO_2 concentrations in the UK rarely exceed applicable limit values, except at some congested urban roadside sites. Prior to 2020, annual mean limit values were frequently exceeded at roadside sites in the UK, and in many other countries. The extent of these exceedances was substantially reduced in 2020, and in subsequent years have remained low in comparison with pre-2020 years (see **Sections 4 and 6** for details).

3.1.2 Ozone

Ozone (O_3) is a secondary pollutant produced by the effect of sunlight on NO_X and VOCs from vehicles and industry. O_3 concentrations are therefore typically highest in the summer on hot, sunny, windless days, or days when moderate breezes blow ozone across from continental Europe.

In the upper atmosphere the O_3 layer has a beneficial effect, absorbing harmful ultraviolet radiation from the sun. However, ground level ozone is a pollutant. It irritates the respiratory system and eyes. High levels may exacerbate asthma or trigger asthma attacks in susceptible people and some non-asthmatic individuals may also experience chest discomfort. Evidence is also emerging of links with cardiovascular and metabolic effects and effects due to long-term exposure.

Ozone can cause damage to many plant species leading to loss of yield and quality of crops, damage to forests and impacts on biodiversity. O_3 is also a greenhouse gas implicated in climate change. It can travel long distances, accumulate, and reach high concentrations far away from the sources of the pollutants that contributed to its formation. NO_X emitted in cities reduces local O_3 concentrations as NO reacts with O_3 to form NO_2: therefore, levels of O_3 are often higher in rural areas than urban areas.

The UK has been compliant with applicable target values since 2009, but most years see long-term objectives exceeded in some areas. Weather conditions during the year determine how widespread such exceedances are.

3.1.3 Particulate Matter: PM_{10} and $PM_{2.5}$

PM_{10} can be ‘primary’ (emitted directly to the atmosphere) or ‘secondary’ (formed by the chemical reaction of other pollutants in the air such as SO_2 or NO_2). The main sources of primary PM_{10} particulate emissions in the UK are: combustion in production processes; industrial; residential and commercial fuel use; as well as agriculture; waste and road transport. In recent years, emissions from residential combustion have increased, both in real terms and as a percentage of the UK total, because of increased use of wood as a domestic fuel. This has offset reductions that have occurred due to decreasing use of coal and other solid fuels. Emissions of particulate matter from road transport include both tailpipe emissions, and tyre and brake wear. Natural sources include wind-blown dust, sea salt, pollens, and soil particles.

Like PM_{10}, the finer size fraction $PM_{2.5}$ can be primary or secondary: primary $PM_{2.5}$ has the same main emission sources. Research shows a range of health effects, including respiratory and cardiovascular illness and mortality, associated with PM_{10} and $PM_{2.5}$. (COMEAP, 2006), (COMEAP, 2009), (COMEAP, 2010), (COMEAP, 2018), (COMEAP, 2022). No threshold has been identified below which no adverse health effects occur. In 2016, COMEAP estimated that 722,660 cases of chronic bronchitis could be attributed to anthropogenic particulate pollution, although they considered the evidence insufficient to establish causality (COMEAP, 2016)).

$PM_{2.5}$ can penetrate deep into the lungs and research in recent years has strengthened the evidence that both short-term and long-term exposure to $PM_{2.5}$ are linked with a range of health outcomes including (but not restricted to) respiratory and cardiovascular effects.

The UK has been compliant with applicable limit values for PM_{10} and $PM_{2.5}$ for over a decade. Nonetheless, public health benefits would be expected from further reductions, given that the available evidence has not suggested a threshold for effects. The new $PM_{2.5}$ targets should support further reduction.

The environmental effects of particulate pollution are associated with two components of PM: black carbon, which is implicated in climate change, and secondary PM which includes sulphate, nitrate and ammonium. The latter is formed from SO_2, NO_X and NH_3 which are the main drivers for acidification and eutrophication.

3.1.4 Sulphur Dioxide (SO_2)

This acid gas is formed when fuels containing sulphur impurities are burned. The largest UK source of SO_2 is from fuel burning in residential, industrial and commercial settings. Other important sources are manufacturing industry and energy generation. It is a respiratory irritant that can cause constriction of the airways, and people with asthma are considered to be particularly sensitive. Health effects can occur very rapidly, making short-term exposure to peak concentrations important (COMEAP, 2011) (WHO, 2005).

SO_2 deposition is harmful to plants at high concentrations. It contributes to acidification of terrestrial and aquatic ecosystems, damaging habitats and leading to biodiversity loss. SO_2 is also a precursor to the formation of secondary sulphate particles in the atmosphere.

Ambient concentrations of SO_2 in the UK have not exceeded applicable limit values or objectives since 2004.

3.1.5 Carbon Monoxide (CO)

CO is produced when fuels containing carbon are burned with insufficient oxygen to convert all carbon inputs to carbon dioxide (CO_2). Residential fuel use and other stationary combustion are now the largest UK emission sources of CO; road and other transport now account for smaller, but still significant, proportions of emissions (National Atmospheric Emissions Inventory, 2022).

The effects of high levels of CO on human health are well-known. CO is toxic: it affects the ability of the blood to take up oxygen from the lungs and can lead to a range of symptoms, causing death at high concentrations. However, people are more likely to be exposed to dangerous concentrations of CO indoors, due to faulty or poorly ventilated cooking and heating appliances. Cigarette smoke is also a major source of exposure. In the environment, CO can contribute to the formation of ground-level ozone.

The UK has been compliant with all applicable limit values for this pollutant since 1999.

3.1.6 Benzene (C_6H_6)

Benzene (C_6H_6) is an organic chemical compound. Ambient benzene arises from domestic and industrial combustion processes, in addition to road transport (Defra, 2007).

Benzene is known to cause leukaemia and potentially other cancers in humans (Public Health England, 2019a). Therefore, no safe level can be specified for benzene in ambient air; however, the risk increases with increasing exposure. In the environment, benzene can pollute soil and water, leading to exposure via these routes.

Annual mean concentrations of benzene are now low (within limit values and objectives applicable in the UK) due to the introduction of catalytic converters on car exhausts in the 1990s. The UK has been compliant with all applicable limit values for benzene since measurements began in 2003.

3.1.7 Lead (Pb)

Lead (Pb) is a toxic metallic element. Historically, lead was used as an additive in petrol, and road vehicles were the main source. Leaded petrol was phased out in 1999, resulting in a 98% reduction of pre-1999 UK emissions. Today, the main sources are production processes and transport. However, the contribution from transport comes not from tailpipe emissions but tyre and brake wear (National Atmospheric Emissions Inventory, 2022). Recent research has found that airborne particulate matter in cities is still ‘enriched’ with lead, likely due to emissions from historic combustion of leaded petrol (Resongles, et al., 2021).

Lead inhalation can affect red blood cell formation and harm the kidneys, circulatory system, gastrointestinal tract, the joints, reproductive systems, and can cause acute or chronic damage to the central nervous system (CNS). The unborn child and young children are the most sensitive to lead toxicity (Public Health England, 2016). Long-term low-level exposure has been shown to affect intellectual development in young children and the unborn child (EPAQS, 2009).

In the environment, Pb can pollute soil and surface waters. Exposure to contaminated soil and water may then become a health risk. Lead may accumulate in other organisms such as fish and be passed up the food chain. The UK has been compliant with applicable limit values for ambient lead in air for over 20 years.

3.1.8 Nickel (Ni)

Nickel (Ni) is a toxic metallic element found in ambient air as a result of releases from oil and coal combustion, metal processes, manufacturing and other sources. Currently the main UK emission source is the combustion of petroleum coke, solid fuels containing petroleum coke, and heavy fuel oil, in residential and industrial settings (National Atmospheric Emissions Inventory, 2022). A small number of UK zones continue to regularly exceed applicable target values for annual mean Ni, due to local industrial emissions.

Nickel and its compounds are toxic by inhalation, ingestion and skin contact. Nickel compounds can cause cancer in humans. Nickel can cause irritation to the nose and sinuses (Public Health England, 2014)

As well as ambient air, Ni can pollute soil and water, leading to exposure via these routes.

3.1.9 Arsenic (As)

Arsenic (As) is a toxic metalloid which occurs naturally in the environment. Arsenic is emitted into the atmosphere in the form of particulate matter. Historically the largest source was coal combustion, but this has declined: the largest UK source of arsenic emissions is now the open burning of treated wood as waste (National Atmospheric Emissions Inventory, 2022). The UK has been compliant with applicable target values for As for many years.

Arsenic occurs in organic and inorganic forms. Inorganic arsenic compounds are highly toxic, while organic forms are less harmful. Inhalation of air containing high levels of inorganic As can cause lung damage, shortness of breath, chest pain and cough (Public Health England, 2019b). Long term inhalation exposure is associated with genotoxic and carcinogenic effects. However, for the general population, inhalation typically represents a minor route of exposure to inorganic arsenic.

3.1.10 Cadmium (Cd)

Cadmium (Cd) is a toxic metallic element. The main emission sources are combustion in the manufacturing industry and production processes. The incineration of municipal solid waste was once a significant source, but improved controls on waste to energy plant in the 1990s have reduced their contribution to 3% of the UK 2021 total (National Atmospheric

Emissions Inventory, 2022). The UK has been compliant with applicable target values for Cd for many years.

Acute inhalation exposure to Cd causes effects on the lung such as pulmonary irritation. Chronic exposure via inhalation can lead to lung cancer or cause a build-up of Cd in the kidneys that can lead to kidney disease. (WHO, 2019) In the environment, Cd can pollute soil and water, leading to exposure via these routes.

3.1.11 Mercury (Hg)

Mercury (Hg) is released to the air by human activities. The main current UK sources are coal use in public electricity and heat production and industrial combustion, iron and steel production processes, cremation, and emissions from the disposal of products containing mercury (National Atmospheric Emissions Inventory, 2022).

Acute exposure to high levels of Hg can cause a wide range of symptoms including chest pain, nausea, vomiting, muscle pains, and shortness of breath and affect the CNS and kidneys. (UK Health Security Agency, 2022b)

In the environment, Hg can also pollute soil, freshwater and sea water. Exposure to contaminated soil and water may then become a health risk. Mercury may accumulate in other organisms such as fish, and be passed up the food chain.

3.1.12 Polycyclic Aromatic Hydrocarbons (PAH)

Polycyclic aromatic hydrocarbons (PAHs) are a large group of chemical compounds which usually occur as complex mixtures rather than as individual compounds. One particular PAH, **Benzo[a]pyrene (B[a]P)** is used as a 'marker' for this group of compounds. The main sources of B[a]P in the UK are residential, commercial and industrial fuel combustion (National Atmospheric Emissions Inventory, 2022). A small number of UK zones continue to exceed applicable target values for B[a]P, as has been the case for many years.

PAHs are persistent, bio-accumulative, organic compounds with toxic and carcinogenic effects. The International Agency for Research on Cancer (IARC) has classified several PAH, including B[a]P, as causing cancer in humans (Public Health England, 2018). B[a]P is currently considered the most carcinogenic PAH. As PAHs can bio-accumulate they can be passed up the food chain.

3.2 Assessment of Air Quality in the UK

The $PM_{2.5}$ targets set under the Environment Act (2021) are assessed using fixed measurements from the UK national monitoring networks. The $PM_{2.5}$ monitoring network is being expanded to support the assessment.

The evidence base for the annual assessment of compliance against the Air Quality Standards Regulations (2010) is based on a combination of measurements and the results of modelling assessments. The use of models enables air quality to be assessed at locations without monitoring sites and reduces the number of monitoring stations required. It has the added benefit of providing additional information on source apportionment and projections to support the development and implementation of air quality policies.

Modelling is undertaken using national models known as the Pollution Climate Mapping (PCM) models. The PCM models have been designed to assess compliance with limit values, target values and long-term objectives at locations defined within the Air Quality Standards Regulations (2010). Modelled compliance assessments are undertaken for 11 air pollutants each year. This assessment needs to be completed each year in the relatively short period between the time when the input data (including ratified monitoring data and emission inventories) becomes available and the publication date at the end of September.

It is important to understand the differences between modelling carried out for compliance assessment purposes, and that carried out for Local Air Quality Management. National air quality modelling for the UK focuses on two components: pollutant concentrations at background locations, on a 1x1 km grid square basis, and roadside pollutant concentrations, at four metres from the kerb of urban major road links[3]. By contrast, Local Air Quality Management (LAQM) modelling is different in scope, purpose and methodology from the national modelling and will usually output contour plots showing dispersion away from the source, on a fine resolution grid. The level of detail and resolution of LAQM modelling is therefore much greater in order to focus on local exposure and hotspots and does not necessarily meet the requirements for air quality assessment under the Air Quality Standards Regulations (2010). See **Section 3.5** for more details on the modelling carried out for compliance assessment.

3.2.1 Current UK Air Quality Monitoring

During 2022 there were 538 national air quality monitoring sites across the UK, comprising several networks, each with different objectives, scope and coverage. This section provides a brief description of those used to monitor compliance with the Air Quality Standards Regulations (2010). A summary of the UK national networks is provided in **Table 3-1**: the number of sites shown in this table amounts to considerably more than 538 because some sites belong to more than one network. This table shows the number of sites in operation during part or all of 2022.

[3] A road link is a section of road that is greater than 100m in length.

Table 3-1 The UK's Air Quality Monitoring Networks in 2022

Network	Pollutants	Number of Sites operating in 2022
Automatic Urban and Rural Network (AURN) Automatic London Network (part of AURN)	CO, NO_x, NO_2, SO_2, O_3, PM_{10}, $PM_{2.5}$. (Not all sites measure all these pollutants.)	**154** **16**
UK Heavy Metals Network	Metals in PM_{10} including: As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, V, Zn. Measured deposition including: Al, As, Ba, Be, Cd, Co, Cr, Cs, Cu, Fe, Li, Mn, Mo, Ni, Pb, Rb, Sb, Sc, Se, Sn, Sr, Ti, U, V, W, Zn. Hg deposition Total gaseous mercury	**24**
Non-Automatic Hydrocarbon	Benzene	**34**
Automatic Hydrocarbon	Range of volatile organic compounds (VOCs)	**5**
Polycyclic Aromatic Hydrocarbons (PAH).	27 PAH species including benzo[a]pyrene	**35**
European Monitoring and Evaluation Programme (EMEP)	Wide range of parameters relating to air quality, precipitation, meteorology and composition of aerosol in PM_{10} and $PM_{2.5}$.	**2**
Particle Numbers and Concentrations Network	Total particle number, concentration, size distribution, anions, elemental carbon, organic carbon, speciation of PM_{10} and $PM_{2.5}$.	**4**
Toxic Organic Micropollutants	Range of toxic organics including dioxins and dibenzofurans.	**8**
UK Eutrophying and Acidifying Pollutants: NO_2Net (rural diffusion tubes)	NO_2 (rural)	**24**

Network	Pollutants	Number of Sites operating in 2022
UK Eutrophying and Acidifying Pollutants: AGANet	HNO_3, HONO, SO_2, Ca, Cl, Mg, Na, NO_2, NO_3 and SO_4	**27**
UK Eutrophying and Acidifying Pollutants: NAMN	NH_3 and/or NH_4	**99**
UK Eutrophying and Acidifying Pollutants: PrecipNet	Major ions in rainwater	**41**
Black Carbon	Black Carbon	**14**
Upland Waters Monitoring Network	Chemical and biological species in water	**10**
Rural Mercury Network	Tekran analyser used to measure mercury in $PM_{2.5}$, reactive mercury and elemental mercury at Auchencorth Moss, and total gaseous mercury at Chilbolton Observatory.	**2**
UK Urban NO_2 Network	Diffusion tubes with wind-protection membranes measuring NO_2 monthly at urban traffic-related sites.	**295**

3.2.1.1 The Automatic Urban and Rural Network (AURN)

The AURN is currently the largest automatic monitoring network in the UK and forms a large part of the UK's statutory compliance monitoring evidence base. Data from the AURN are available on Defra's online UK Air Information Resource, UK-AIR at https://uk-air.defra.gov.uk/. The Automatic London Network (ALN) is a subset of sites in the AURN which also form part of the wider London Air Quality Network (LAQN). In this report, 'AURN' includes the whole network, i.e. including the ALN subset of sites.

The techniques used for monitoring gaseous pollutants within the AURN are the reference measurement methods defined in the Air Quality Standards Regulations (2010). For particulate matter the AURN uses methods which have demonstrated equivalence to the reference method, but which (unlike the reference method) allow continuous on-line monitoring. Details are provided in **Table 3-2**.

Table 3-2 AURN Measurement Techniques

Pollutant	Method used, including details of CEN Standard Methods
O_3	EN 14625:2012 'Ambient air quality – standard method for the measurement of the concentration of ozone by ultraviolet photometry' (CEN, 2005a)
NO_2/NO_x	EN 14211:2012 'Ambient air quality - Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence' (CEN, 2005b)
SO_2	EN 14212:2012 'Ambient air quality – Standard method for the measurement of the concentration of sulphur dioxide by UV fluorescence' (CEN, 2005c)
CO	EN 14626:2012 'Ambient air quality - Standard method for the measurement of the concentration of carbon monoxide by non-dispersive infrared spectroscopy' (CEN, 2005d)
PM_{10} and $PM_{2.5}$	EN 12341:2023 'Ambient air quality - Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2.5}$ mass fraction of suspended particulate matter' (BS EN, 2023) In 2022 the AURN used three methods which are equivalent to the reference method for one or both metrics: the Fidas™ 200, an optical technique, the Beta-Attenuation Monitor (BAM) and gravimetric samplers (at two sites) that collect daily samples onto a filter for subsequent weighing. Descriptions of these methods are given in the Glossary of this report.

3.2.1.2 The UK Heavy Metals Network

The UK Heavy Metals Network forms the basis of the UK's compliance monitoring for the Air Quality Standards Regulations (2010), which cover lead, arsenic, cadmium, nickel and mercury.

At the end of 2013 Defra merged the existing Urban and Industrial Network with the Rural Network to form the UK Heavy Metals Network. The merged network monitors a range of elements (not all of which are classified as heavy metals) at urban, industrial and rural sites, using a method equivalent to the CEN standard method (CEN, 2005e). Metals (As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, V and Zn) in PM_{10} are measured at 23 sites. The network stopped measuring mercury in PM_{10} in 2014.

Metal deposition (Al, As, Ba, Be, Cd, Co, Cr, Cs, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Rb, Sb, Se, Sn, Sr, Ti, U, V, W, Zn) was measured at the following rural sites: Auchencorth Moss, Chilbolton Observatory, Heigham Holmes and Yarner Wood. The same metals were measured at Lough Navar with the exception of mercury.

The network stopped measuring total gaseous mercury in August 2018.

3.2.1.3 Non-Automatic Hydrocarbon Network

In this network, ambient concentrations of benzene are measured by the CEN standard method (CEN, 2005f). This involves pumping air through an adsorption tube to trap the compound, which is later analysed in a laboratory. This network monitors compliance with the Air Quality Standards Regulations (2010) limit value for benzene. All sites in the Non-Automatic Hydrocarbon Network are co-located with AURN sites.

3.2.1.4 Automatic Hydrocarbon Network

The Air Quality Standards Regulations (2010) also require measurement and reporting of ozone precursor substances (29 species), which include volatile organic compounds (VOCs). The Air Quality Standards Regulations (2010) refer to Annex X (ten) of the Air Quality Directive which provides a list of compounds recommended for measurement.

Ozone precursor measurement is carried out by the Automatic Hydrocarbon Network. Automatic hourly measurements of a range of hydrocarbon species (including all those specified in Annex X of the Air Quality Directive (European Parliament and Council of the European Union, 2008) except formaldehyde and total non-methane hydrocarbons), are made at four sites using automated pumped sampling with *in-situ* gas chromatography. The VOCs monitored include benzene, which is covered by the Air Quality Standards Regulations (2010) as a pollutant in its own right.

3.2.1.5 Polycyclic Aromatic Hydrocarbons (PAH) Network

The PAH Network monitors compliance with the Air Quality Standards Regulations (2010), which include a target value of 1 ng m^{-3} for the annual mean concentration of benzo[a]pyrene as a representative PAH. Samples are collected on filters using the PM_{10} ‘Digitel’ sampler. Samples are subsequently analysed in a laboratory for 23 PAH compounds.

Three new sites started in 2022: Armagh Roadside, Plymouth Centre and Preston. One site (Lynemouth 2) closed.

3.2.1.6 European Monitoring and Evaluation Programme (EMEP)

EMEP is a programme set up to provide governments with qualified scientific information on air pollutants, under the UNECE Convention on Long-range Transboundary Air Pollution. There are currently two EMEP ‘supersites’, at Auchencorth Moss in Midlothian (representing the north of the UK) and at Chilbolton Observatory in Hampshire (representing the south). The site at Chilbolton replaced the long running site at Harwell at the start of 2016. A representativeness analysis showed that both sites were similar in their rural background nature. A very wide range of measurements are taken at EMEP sites, supplemented by data from other UK networks which are co-located.

Monitoring includes:

- Hourly meteorological data,
- Soil and vegetation measurements,
- Metallic elements in PM_{10} and precipitation,
- Deposition of inorganic ions,
- Major ions in $PM_{2.5}$ and PM_{10}, as well as HCl, HNO_2, HNO_3, NH_3 and SO_2,
- Trace gases (ozone, NO_X and SO_2),
- Black carbon, organic carbon (OC) and elemental carbon (EC),
- Ammonia (monthly),
- Daily and hourly PM_{10} and $PM_{2.5}$ mass,
- Volatile Organic Compounds,
- Carbonyls,
- CH_4 and N_2O fluxes.

3.2.1.7 Particle Numbers and Concentrations Network

The Air Quality Standards Regulations (2010) require that the chemical composition of $PM_{2.5}$ is characterised at background locations in the United Kingdom. The Particle Numbers and Concentrations Network sites contribute to this statutory requirement. During 2022, the network consisted of four measurement sites; two rural sites (Auchencorth Moss and Chilbolton Observatory), and two in London (London Marylebone Road and London Honor Oak Park; the latter site replaced North Kensington in November 2018).

Among the parameters measured are:

- Total particle numbers per cubic centimetre of ambient air,
- Particle numbers in different particle size fractions,
- Major ions (ammonium, nitrate and sulphate) in $PM_{2.5}$ and PM_1.
- Total carbon, organic carbon (OC) and elemental carbon (EC) concentrations in $PM_{2.5}$.

PM_{10} speciation was replaced by $PM_{2.5}$ speciation in 2018. PM_1 speciation began at the London sites in 2020.

As well as its statutory function, this network provides data on the chemical composition of particulate matter, primarily for the use of researchers of atmospheric processes, epidemiology and toxicology.

Measurements of elemental carbon (EC) and organic carbon (OC) began at Auchencorth Moss at the start of 2011 and Chilbolton Observatory at the start of 2016. EC and OC measurements were made using a thermal/optical method involving both reflectance and transmission correction methods. Comparing both correction methods aims to provide valuable understanding of the measurement process for EC and OC.

A multi-metal monitoring system measuring 40 metals in $PM_{2.5}$ and PM_{10} was installed in 2022 at London Marylebone Road and London Honor Oak Park.

3.2.1.8 Toxic Organic Micropollutants (TOMPs) Network

This research-based network monitors a range of toxic organic micropollutants (compounds that are present in the environment at very low concentrations but are highly toxic and persistent). These include dioxins, dibenzofurans and polychlorinated biphenyls. The TOMPs Network consists of eight sites across the UK: Auchencorth Moss, Cardiff Lakeside, Hazelrigg, High Muffles, Kilmakee Leisure Centre, London Nobel House, Manchester Law Courts and Weybourne.

The purpose of the TOMPs Network is to provide data on these air pollutants, and to support the development of policy to protect the environment and human health. Further information on the TOMPs Network can be found on UK-AIR at https://uk-air.defra.gov.uk/networks/network-info?view=tomps. However, this network is not used for compliance monitoring and will not be discussed further in subsequent sections of the report.

3.2.1.9 UK Eutrophying and Acidifying Pollutants Network

The UK Eutrophying and Acidifying Atmospheric Pollutants (UKEAP) network provides information on deposition of eutrophying and acidifying compounds in the UK and assessment of their potential impacts on ecosystems. The UKEAP network is an ‘umbrella’ project covering four groups of sites:

- The UKEAP rural NO_2 diffusion tube network (NO_2Net). This measures NO_2 concentrations at 24 locations as required for input to the rural NO_x concentration field in the Pollution Climate Model.

- In 2022 the Acid Gas and Aerosol Network (AGANet) comprised a total of 27 sites. The network measures a range of gases and aerosol components. Samples are collected monthly and are analysed by either inductive coupled plasma optical emission spectrometry (ICP-OES) or ion chromatography.

- The UKEAP: National Ammonia Network is used to quantify temporal and spatial changes in air concentrations and deposition in NH_3 and NH_4^+ on a long term basis. The monitoring provides a baseline in the reduced nitrogen species (NH_3 + NH_4^+), which is necessary for examining responses to changes in the agricultural sector and to verify compliance with targets set by international agreements. The network was expanded in 2022 to include an additional 25 sampling sites in Northern Ireland and now comprises 99 sites in total.

- The Precipitation Network (PrecipNet), measuring major ions in precipitation at 41 rural sites. Eight of these sites form part of the Long-Term Monitoring Network managed by Natural England. The UKEAP network allows estimates of sulphur and nitrogen deposition. Samples are collected fortnightly at all sites and daily at two sites.

3.2.1.10 Black Carbon Network

Black carbon is fine, dark carbonaceous particulate matter produced from the incomplete combustion of materials containing carbon (such as coal, oil, and biomass such as wood). It is of concern due to health effects, and also as a suspected contributor to climate change. In 2022, the Black Carbon Network measured black carbon at 14 sites using the Aethalometer™ automated instrument. The Aethalometer™ measures black carbon directly, using a real-time optical transmission technique. The objectives of the network are as follows:

- To maintain coverage of black carbon measurements across the whole UK;
- To maintain continuity of historic datasets;
- To gather data for epidemiological studies of black carbon and health effects;
- To gather information about black carbon PM sources in the UK;
- To assess PM reductions from air quality management interventions;
- To quantify the contribution of wood burning to black carbon and ambient PM in the UK; and
- To gather data to address future policy considerations including black carbon and climate change.

3.2.1.11 UK Upland Waters Monitoring Network (UK UWMN)

The UK Upland Waters Monitoring Network (UWMN) was set up in 1988 (then called the Acid Waters Monitoring Network) by ENSIS Ltd, at University College London (UCL) under funding from the then Department of the Environment (later DETR and Defra). Its objective was to assess the chemical and biological response of acidified lakes and streams in the UK to the planned reduction in emissions. It was initially designed to provide chemical and biological data on the extent and degree of surface water acidification in the UK uplands and underpin the science linking acid deposition to water quality and aquatic ecosystem health. In recent years it has been adapted to address a wider range of questions, particularly with respect to understanding impacts of nitrogen enrichment, the influence of climate change and land use on upland waters, and interactions between these drivers and recovery from acidification.

The eleven lakes and eleven streams were originally selected to cover a wide deposition gradient and included forest-moorland pairs of sites. Sites were required to be subject to minimal point source pollution and catchment disturbance beyond that caused by traditional upland land use practices such as sheep grazing or forestry. Additional stream sites have recently been added to broaden the acid-sensitivity gradient, while thermistor loggers are now deployed to continuously monitor water temperature. Water chemistry has been monitored monthly in streams and quarterly in lakes ever since the inception of the network to the present. Biological monitoring involves annual assessment of algae (diatoms), higher aquatic plants and macroinvertebrates. Fish monitoring was discontinued in 2015 due to budget cuts. In April 2019, the Centre for Ecology & Hydrology (now UKCEH) took over management of the UWMN from ENSIS Ltd. After a significant funding hiatus from 2016, Defra are again supporting collection and analysis of biological samples as of 2021. Currently, UKCEH conduct all water chemical analysis while Queen Mary University of London (QMUL) provide all biological sampling and taxonomic analysis.

The UK UWMN also receives funding from the National Environment Research Council (NERC) via the UK Centre for Ecology & Hydrology (UKCEH), NatureScot, the Welsh Government, Natural Resources Wales, Forest Research and Moors for the Future, and has also benefited, or continues to benefit, from considerable in-kind support for sampling and survey activity from UCL, QMUL, the Scottish Environment Protection Agency (SEPA), the Department of Agriculture, Environment and Rural Affairs (DAERA) in Northern Ireland, and several private volunteers.

3.2.1.12 Rural Mercury Monitoring

The Tekran instrument at Auchencorth Moss measures the mercury composition of $PM_{2.5}$ as well as mercury in its elemental and reactive forms, whereas at Chilbolton Observatory it measures just total gaseous mercury.

3.2.1.13 UK Urban NO_2 Network

The UK Urban NO_2 Network (UUNN) was established in December 2019 with monitoring beginning in January 2020. The objective of the network is to provide additional local roadside NO_2 measurements to enhance the UK's national compliance assessment. Monitoring of NO_2 is undertaken using Palmes-type diffusion tubes with wind protection membranes. During 2020 monitoring was undertaken at 177 locations across England and Wales: the network expanded further at the start of 2021 and now comprises 290 sites across Great Britain.

3.2.1.14 Air Pollution Impacts on Ecosystem Networks (APIENs)

The following information about UK APIENs is summarised from the APIS website at https://www.apis.ac.uk/APIENs. The purpose of UK APIENs is to monitor and report the negative impacts of air pollution (e.g. acidification, eutrophication, ozone damage or changes in biodiversity) on ecosystems that are representative of freshwater, natural and semi-natural habitats and forests in the UK. It was formed in 2018 by integrating UK national air quality and ecosystem monitoring networks and surveys, to meet UK monitoring and reporting obligations under the EU National Emissions Ceilings Directive. The Directive was transposed into the UK National Emissions Ceilings Regulations (NECR) (2018). The duty to monitor the negative impacts of air pollution across the UK is set out in Part 5 of the Regulations. Integrated data from APIENs will provide evidence to determine the state of UK ecosystems and provide a baseline against which any changes and potential recovery can be compared.

3.2.2 Quality Assurance and Quality Control

Air quality monitoring in the UK is subject to rigorous procedures of validation and ratification. The well-established monitoring networks each have a robust and documented Quality Assurance and Quality Control (QA/QC) programme designed to ensure that measurements meet the defined standards of quality with a stated level of confidence. Essentially, each programme serves to ensure that the data obtained are:

- Representative of ambient concentrations existing in the various areas under investigation.
- Sufficiently accurate and precise to meet specified monitoring objectives.
- Comparable and reproducible. Results must be internally consistent and comparable with international or other accepted standards, if these exist.
- Consistent over time. This is particularly important if long-term trend analysis of the data is to be undertaken.
- Representative over the period of measurement; for most purposes, a yearly data capture rate of not less than 90% is usually required for determining compliance with limit values where applicable. An allowance of 5% is made in some cases for down-time due to planned maintenance. This is the same data capture requirement as specified in the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) for at least 85% of the hours in a year.
- Consistent with Data Quality Objectives. The uncertainty requirements of the Air Quality Standards Regulations (2010) are specified as data quality objectives. In the UK, all air quality data meet the data quality requirements of the Air Quality Standards Regulations (2010) in relation to uncertainty.
- Consistent with methodology guidance defined in the Air Quality Standards Regulations (2010) for relevant pollutants and measurement techniques. The use of tested and approved analysers that conform to Standard Method (or equivalent) requirements and harmonised on-going QA/QC procedures allows a reliable and consistent quantification of the uncertainties associated with measurements of air pollution.

Most UK networks use a system of regular detailed audits of all monitoring equipment at every site. These audits supplement more regular calibrations and filter changes and test all critical parameters of the measuring equipment including, where appropriate, linearity, converter efficiency (in the case of NO_X analysers) response time, flow rate etc.

Data verification is the process of checking and validating the data. (The term 'ratification' is used in some networks). Data uploaded to the Defra UK Air Information Resource (UK-AIR at https://uk-air.defra.gov.uk/) in near real time are provided as provisional data. All these data are then carefully screened and checked via the verification process. The verified data then overwrite the provisional data on the website. It should, however, be noted that there are occasionally circumstances where data which have been flagged as 'Verified' could be subject to further revision. This may be for example where:

- A QA/QC audit has detected a problem which affects data from earlier verification periods.
- Long-term analysis has detected an anomaly between expected and measured trends which requires further investigation and possible data correction.
- Further research comes to light which indicates that new or tighter QA/QC criteria are required to meet the data quality objectives. This may require review and revision of historical data by applying the new criteria.

Only verified data are included in the UK's assessment of compliance with the Air Quality Standards Regulations (2010) and the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023).

Further details on the QA/QC procedures appropriate to each network can be obtained from the annual reports of the relevant monitoring networks, and from the report '*Quality Assurance and Quality Control (QA/QC) Procedures for UK Air Quality Monitoring under 2008/50/EC and 2004/107/EC)*' available from Defra's UK-AIR website (Defra, 2016).

3.3 Modelling

3.3.1 Why Do Modelling?

The UK's monitoring programmes are supplemented by air quality modelling. There are several benefits of using modelling to complement the monitoring data gathered across the UK national monitoring networks:

- Modelling allows an assessment of levels of pollutants where monitoring does not take place. Whilst our monitoring network is extensive, a monitoring site might not fully represent the wider region in which it is located due to local characteristics such as buildings affecting dispersion, localised or temporary sources.

- Modelling provides information about the sources of pollutants to inform policy development.
- Modelling enables an assessment of levels of pollutants both now and in future years in order to develop policies across government to continue to improve air quality in the UK.

3.3.2 How the Models Work

The national modelling methodology varies between pollutants. The detailed methodology is explained in a technical report (Pugsley, K. L. et al., 2022) (the latest versions of these can be found in the Library section of Defra's UK-AIR website (Defra, 2022b)).

Defra's air quality national modelling assessment for the UK consists of two components:

- Background concentrations – on a 1x1km resolution, representing ambient air quality concentrations at background locations.
- Roadside concentrations for some pollutants – concentrations at the roadside of urban major road links throughout the UK (i.e. motorways and major A-roads). There are approximately 9,000 of these urban major road links.

Roadside concentrations are not modelled for CO, SO_2, ozone, benzo[a]pyrene and metals as these are deemed not to have significant traffic-related sources.

The models have been designed to assess compliance at locations defined by the Air Quality Standards Regulations (2010) (UK Government, 2010) as relevant for air quality assessment.

3.3.3 Background Air Quality

The 1x1 km background maps are made up of several components which are modelled separately and then added together to make the final grid of the UK. These individual components (supplemented by some additional components for certain pollutants) are:

- Large point sources (e.g. power stations, steel works and oil refineries),
- Small point sources (e.g. boilers in town halls, schools or hospitals and crematoria),
- Distant sources (characterised by the rural background concentration),
- Local area sources (e.g. road traffic, domestic and commercial combustion and agriculture).

In order to ensure that these ambient concentrations from area sources are representative of the real-world situation, they are validated against measurements taken from the national networks (including the AURN). After the validation has been completed the large points, small points, distant sources and area source components are added together to provide the final background concentrations.

3.3.4 Roadside Air Quality

Roadside concentrations are determined by using a roadside increment model which estimates the contribution from road traffic sources and adds this to the modelled background concentrations discussed above.

For each of the road links that are modelled, there are emission estimates for each pollutant from the National Atmospheric Emissions Inventory (NAEI), (UK National Atmospheric Emissions Inventory, 2023)) and road traffic counts from the Department for Transport. A measured roadside increment concentration is calculated for road links with a roadside monitoring station by subtracting the link's modelled background concentration (from the 1x1 km modelled maps) from the relevant measured roadside concentration. A roads kernel model (RKM) is used to calculate a modelled roadside increment concentration for each road link by applying the NAEI emissions and road traffic counts (annual average daily traffic flow) in a dispersion model. The RKM is calibrated by comparing the measured roadside increment concentrations at roadside monitoring stations with the modelled roadside increment concentrations for these road links. The application of the RKM ensures that a process-based modelling approach is used to determine the local component of roadside concentrations, including factors influencing dispersion at the roadside, e.g. road orientation, width, and additional vehicle induced turbulence.

3.4 Access to Assessment Data

Data from the UK's air quality monitoring networks and annual compliance modelling is available under the Open Government Licence (UK Government, 2022b) from UK-AIR.

Defra has produced a searchable online catalogue of air quality and emissions datasets which allows people to browse the extent of data available and access key metadata. This is available at https://uk-air.defra.gov.uk/data/data-catalogue.

Historical monitoring data can be accessed through the data selector tools in UK-AIR, at https://uk-air.defra.gov.uk/data/. Modelled data from the Pollution Climate Mapping model are available as .csv files for download from the modelled air quality data pages at https://uk-air.defra.gov.uk/data/modelling-data or can be accessed through the Ambient Air Quality Interactive Map at https://uk-air.defra.gov.uk/data/gis-mapping - a GIS (geographical information system) based tool which provides enhanced visualisation capability and access to roadside concentration data.

UK-AIR also houses a Compliance Dashboard which displays all the underlying data used in the compliance assessment against the Air Quality Standards Regulations (2010). The Compliance Dashboard can be found at https://uk-air.defra.gov.uk/compliance-data and is made up of three parts:

- **Interactive GIS Compliance map** – a streamlined viewer facilitating summaries of compliance status across different geographies for different pollutant metrics based on modelled background data, modelled roadside data and measurements.

- **Compliance data hub** – a comprehensive data catalogue and extraction tool for underlying data that serves the compliance app. This allows users to acquire the data behind the compliance status either for a specific zone/agglomeration or Local Authority or for the whole of the UK in one process.

- **XML file library – a catalogue of download links for the machine-readable XML formats of the compliance data.**

Data used to assess compliance with the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) are also published on the UK AIR website, available here: https://uk-air.defra.gov.uk/pm25targets/calculation.

4 Assessment of Compliance

4.1 Definition of Zones

The UK is divided into 43 zones for air quality assessment. There are 28 agglomeration zones (large urban areas) and 15 non-agglomeration zones. Each zone has an identification code (**Table 4-1**). Zones are shown in **Figure 4-1**.

Table 4-1 UK Zones for Ambient Air Quality Reporting 2022

Zone	Zone code	Zone type
Greater London Urban Area	UK0001	Agglomeration
West Midlands Urban Area	UK0002	Agglomeration
Greater Manchester Urban Area	UK0003	Agglomeration
West Yorkshire Urban Area	UK0004	Agglomeration
Tyneside	UK0005	Agglomeration
Liverpool Urban Area	UK0006	Agglomeration
Sheffield Urban Area	UK0007	Agglomeration
Nottingham Urban Area	UK0008	Agglomeration
Bristol Urban Area	UK0009	Agglomeration
Brighton/Worthing/Littlehampton	UK0010	Agglomeration
Leicester Urban Area	UK0011	Agglomeration
Portsmouth Urban Area	UK0012	Agglomeration
Teesside Urban Area	UK0013	Agglomeration
The Potteries	UK0014	Agglomeration
Bournemouth Urban Area	UK0015	Agglomeration
Reading/Wokingham Urban Area	UK0016	Agglomeration
Coventry/Bedworth	UK0017	Agglomeration
Kingston upon Hull	UK0018	Agglomeration
Southampton Urban Area	UK0019	Agglomeration
Birkenhead Urban Area	UK0020	Agglomeration
Southend Urban Area	UK0021	Agglomeration
Blackpool Urban Area	UK0022	Agglomeration
Preston Urban Area	UK0023	Agglomeration
Glasgow Urban Area	UK0024	Agglomeration
Edinburgh Urban Area	UK0025	Agglomeration
Cardiff Urban Area	UK0026	Agglomeration
Swansea Urban Area	UK0027	Agglomeration
Belfast Metropolitan Urban Area	UK0028	Agglomeration
Eastern	UK0029	Non-agglomeration
South West	UK0030	Non-agglomeration
South East	UK0031	Non-agglomeration
East Midlands	UK0032	Non-agglomeration
North West & Merseyside	UK0033	Non-agglomeration
Yorkshire & Humberside	UK0034	Non-agglomeration
West Midlands	UK0035	Non-agglomeration
North East	UK0036	Non-agglomeration
Central Scotland	UK0037	Non-agglomeration
North East Scotland	UK0038	Non-agglomeration
Highland	UK0039	Non-agglomeration
Scottish Borders	UK0040	Non-agglomeration
South Wales	UK0041	Non-agglomeration
North Wales	UK0042	Non-agglomeration
Northern Ireland	UK0043	Non-agglomeration

Figure 4-1 UK Zones for Ambient Air Quality Reporting 2022

4.2 Air Quality Assessment for 2022

The air quality assessment for compliance against the Air Quality Standard Regulations (2010) is derived from a combination of measured pollutant concentrations from the Automatic Urban and Rural Network (AURN) and supplementary assessment (that is, modelling using the Pollution Climate Mapping (PCM) model, supplementary NO_2 diffusion tube measurements from the UK Urban Nitrogen Dioxide Network - the UUNN - or objective estimation, as explained in Defra's technical report on UK air quality assessment (Pugsley, K. L. et al., 2022)). Where both measurements and supplementary assessment results are available for a zone, the assessment of compliance for each zone is based on the higher concentration of the two.

In the case of NO_2, an additional rule was introduced in 2021. This is used where there is roadside monitoring (an AURN monitoring site, a UUNN diffusion tube monitoring site, or both) on a major urban road, which is also modelled by the PCM model. This rule determines the order of precedence of these data sources when used in compliance assessment and is described in **Section 4.2.1** below.

Compliance with the $PM_{2.5}$ targets set in the Environment Act (2021) is based only on measured pollutant concentrations from the Automatic Urban and Rural Network (AURN) and modelling is not included in the assessment.

4.2.1 Approach for Nitrogen Dioxide at Roadside, 2021 Onwards

In compliance assessments for years up to and including 2020, the approach taken when assessing NO_2 concentrations at roadside locations where both modelled and measured concentrations were available was to report all concentrations, but to always use the highest concentration to determine the compliance status, whether measured or modelled. This was a conservative approach in which an exceedance was always reported if any of the data indicated one, but it did not consider the quality of the evidence available. The availability of a new source of evidence - measurements from the UUNN, which was established in 2020 - prompted a review of the approach for NO_2.

A study led by Defra working closely with members of their independent Air Quality Expert Group (AQEG) compared the quality of modelled NO_2 concentrations from the PCM model to measured concentrations from the UUNN and AURN. This concluded that the AURN provides the most accurate assessment of NO_2 concentrations, followed by the UUNN, and then the PCM model.

The method for determining compliance with the annual mean limit value for NO_2 was therefore adjusted to reflect this. As of 2021, all modelled and measured NO_2 concentrations are still reported as part of the assessment, but the order of precedence, for any given major urban road, is as follows:

1. If AURN measurements are available, these have been used to assess compliance in preference to values from the UUNN and/or the PCM model for the same major urban road.

2. If UUNN measurements (but not AURN measurements) are available, the UUNN measurements have been used to assess compliance in preference to values from the PCM model for the same major urban road.

3. If no AURN or UUNN measurements are available, concentrations from the PCM model have been used to assess compliance.

This order of precedence only applies to results for the same major urban road. Therefore, the NO_2 compliance status of a given zone could in theory still be determined on the basis of modelling, if the highest concentration for that zone was a modelled value for a location without co-located monitoring.

No change has been made to the method for determining compliance for other pollutants. This means that the most appropriate evidence-based approach is taken for each pollutant.

4.2.2 Compliance Summary

The results of the air quality assessment for 2022 are summarised in the tables below. The tables have been completed as follows:

- Where all measurements were within the relevant limit values in 2022, the table shows this as ‘OK’.
- In the above cases, where compliance was determined by supplementary assessment only, this is indicated by ‘(s only)’, i.e. ‘OK (s only)’.
- Where locations were identified as exceeding a limit value, target value or long-term objective, this is identified as ‘>LV’, '>TV’ or ‘>LTO’ as applicable.
- Where a non-compliance was determined by supplementary assessment, this is indicated by ‘(s only)’, as above.
- The abbreviation ‘n/a’ (not applicable) means that an assessment is not relevant for this zone, such as for the NO_X vegetation critical level in agglomeration zones.
- Zones that complied with the relevant limit values, targets or long-term objectives are shaded blue, while those that did not are shaded red. For ozone, zones that met the relevant target value but not the long-term objective are shaded purple.

There are no longer any zones where margins of tolerance apply.

Sulphur dioxide (SO_2): in 2022, all zones and agglomerations within the UK complied with the limit values for 1-hour mean and 24-hour mean SO_2 concentration, set for protection of human health. All non-agglomeration zones within the UK also complied with the critical levels for annual mean and winter mean SO_2 concentration, set for protection of ecosystems (these are not applicable to built-up areas).

Carbon monoxide (CO), benzene and lead: all zones and agglomerations were compliant with the limit values for these three pollutants in 2022. The 2022 compliance assessment for CO has been based on objective estimation, as explained in Defra's technical report on UK air quality assessment (Pugsley, K. L. et al., 2022). This is underpinned by NAEI emission trends, AURN measurement trends and historical modelling assessments.

Nitrogen dioxide (NO_2): in 2022 not every zone was compliant with all the limit values. The results of the air quality assessment for nitrogen dioxide for each zone are summarised in **Table 4-2**.

All zones and agglomerations were compliant with the 1-hour limit value (200 µg m^{-3}) in 2022, with none exceeding this limit value on more than the permitted 18 occasions. In recent years only a few zones (typically one or two) have exceeded this limit value; 2022 is the third consecutive year in which all zones have been compliant.

Thirty-four zones met the annual mean limit value for NO_2 (40 µg m^{-3}) in 2022. The nine zones that exceeded this limit value were:

- Greater London Urban Area
- West Midlands Urban Area
- Greater Manchester Urban Area
- West Yorkshire Urban Area
- Liverpool Urban Area
- Sheffield Urban Area
- Nottingham Urban Area
- Bristol Urban Area
- South East

The year 2020 saw a large reduction in the number of zones exceeding the annual mean limit value: just five zones exceeded in 2020 compared to 33 zones in 2019. This was attributed to the reduced road traffic flows brought about by the COVID-19 pandemic lockdown restrictions. The following year, 2021, 10 zones exceeded this limit value. In 2022, nine zones exceeded this limit value, which suggests that while NO_2 concentrations have increased compared to 2020, they remain lower than pre-pandemic levels.

All non-agglomeration zones within the UK complied with the critical level for annual mean NO_X concentration, set for protection of vegetation, as has been the case for many years.

Table 4-2 Results of Air Quality Assessment for Nitrogen Dioxide in 2022

Zone	Zone code	NO_2 LV for health (1hr mean)	NO_2 LV for health (annual mean)	NO_X critical level for vegetation (ann. mean)
Greater London Urban Area	UK0001	OK	> LV	n/a
West Midlands Urban Area	UK0002	OK	> LV (s only)	n/a
Greater Manchester Urban Area	UK0003	OK	> LV (s only)	n/a
West Yorkshire Urban Area	UK0004	OK	> LV (s only)	n/a
Tyneside	UK0005	OK	OK	n/a
Liverpool Urban Area	UK0006	OK	> LV (s only)	n/a
Sheffield Urban Area	UK0007	OK	> LV (s only)	n/a
Nottingham Urban Area	UK0008	OK	> LV (s only)	n/a
Bristol Urban Area	UK0009	OK	> LV (s only)	n/a
Brighton/Worthing/Littlehampton	UK0010	OK	OK	n/a
Leicester Urban Area	UK0011	OK	OK	n/a
Portsmouth Urban Area	UK0012	OK	OK	n/a
Teesside Urban Area	UK0013	OK	OK	n/a
The Potteries	UK0014	OK	OK	n/a
Bournemouth Urban Area	UK0015	OK	OK	n/a
Reading/Wokingham Urban Area	UK0016	OK	OK	n/a
Coventry/Bedworth	UK0017	OK	OK	n/a
Kingston upon Hull	UK0018	OK	OK	n/a
Southampton Urban Area	UK0019	OK	OK	n/a
Birkenhead Urban Area	UK0020	OK	OK	n/a
Southend Urban Area	UK0021	OK	OK	n/a
Blackpool Urban Area	UK0022	OK	OK	n/a
Preston Urban Area	UK0023	OK	OK	n/a
Glasgow Urban Area	UK0024	OK	OK	n/a
Edinburgh Urban Area	UK0025	OK	OK	n/a
Cardiff Urban Area	UK0026	OK	OK	n/a
Swansea Urban Area	UK0027	OK	OK	n/a
Belfast Urban Area	UK0028	OK	OK	n/a
Eastern	UK0029	OK	OK	OK
South West	UK0030	OK	OK	OK
South East	UK0031	OK	> LV (s only)	OK
East Midlands	UK0032	OK	OK	OK
North West & Merseyside	UK0033	OK	OK	OK (s only)
Yorkshire & Humberside	UK0034	OK	OK	OK
West Midlands	UK0035	OK	OK	OK (s only)
North East	UK0036	OK	OK	OK (s only)
Central Scotland	UK0037	OK	OK	OK (s only)
North East Scotland	UK0038	OK	OK	OK (s only)
Highland	UK0039	OK	OK	OK (s only)
Scottish Borders	UK0040	OK	OK	OK (s only)
South Wales	UK0041	OK	OK	OK
North Wales	UK0042	OK	OK	OK
Northern Ireland	UK0043	OK	OK	OK (s only)

LV = limit value, (s only) indicates the compliance or exceedance was determined by supplementary assessment only.

As part of the 2017 UK plan for tackling roadside nitrogen dioxide concentrations (Defra, 2017), local authorities in England with exceedances of the annual mean nitrogen dioxide limit value have been required to develop local plans or studies to consider measures to achieve the statutory limit value within the shortest possible time. These studies or plans may include local scale modelling and/or monitoring data, and in some cases the local data presents different results to the national air quality assessment. This is partly due to local monitoring being sited differently to national monitoring in order to target local pollution hotspots. Where possible, Defra is working to develop and improve the national NO_2 compliance assessment to better reflect local level NO_2 concentrations. This included establishing the UUNN in 2020, to provide more local NO_2 measurement data.

Particulate Matter as PM_{10}: all zones and agglomerations were compliant with the annual mean limit value of 40 µg m^{-3} for PM_{10}. All zones and agglomerations were also compliant with the daily mean limit value of 50 µg m^{-3}, which must not be exceeded more than 35 times a year. The results of the air quality assessment for PM_{10} for each zone, with respect to the daily mean and annual mean limit values, are summarised in **Table 4-3**.

Under the Air Quality Standards Regulations (2010), the UK is required to identify any exceedances of PM_{10} limit values which are due to natural sources (for example sea salt). Where this is the case, the exceedance does not count as non-compliance. Particulate matter from sea salt is modelled and has been used in the past to determine whether compliance with the limit values has been achieved after contribution from natural sources has been subtracted. However, in 2022 there were no modelled exceedances of either the 24-hr or annual mean limit values, so no subtraction of contribution from natural sources has been carried out (Pugsley, K. L. et al., 2022).

Table 4-3 Results of Air Quality Assessment for PM_{10} in 2022

Zone	Zone code	PM_{10} LV (daily mean)	PM_{10} LV (annual mean)
Greater London Urban Area	UK0001	OK	OK
West Midlands Urban Area	UK0002	OK	OK
Greater Manchester Urban Area	UK0003	OK	OK
West Yorkshire Urban Area	UK0004	OK	OK
Tyneside	UK0005	OK	OK
Liverpool Urban Area	UK0006	OK	OK
Sheffield Urban Area	UK0007	OK	OK
Nottingham Urban Area	UK0008	OK	OK
Bristol Urban Area	UK0009	OK	OK
Brighton/Worthing/Littlehampton	UK0010	OK (s only)	OK (s only)
Leicester Urban Area	UK0011	OK	OK
Portsmouth Urban Area	UK0012	OK	OK
Teesside Urban Area	UK0013	OK	OK
The Potteries	UK0014	OK	OK
Bournemouth Urban Area	UK0015	OK (s only)	OK (s only)
Reading/Wokingham Urban Area	UK0016	OK	OK
Coventry/Bedworth	UK0017	OK	OK
Kingston upon Hull	UK0018	OK	OK
Southampton Urban Area	UK0019	OK	OK
Birkenhead Urban Area	UK0020	OK	OK
Southend Urban Area	UK0021	OK	OK
Blackpool Urban Area	UK0022	OK	OK
Preston Urban Area	UK0023	OK	OK
Glasgow Urban Area	UK0024	OK	OK
Edinburgh Urban Area	UK0025	OK	OK
Cardiff Urban Area	UK0026	OK	OK
Swansea Urban Area	UK0027	OK	OK
Belfast Metropolitan Urban Area	UK0028	OK	OK
Eastern	UK0029	OK	OK
South West	UK0030	OK	OK
South East	UK0031	OK	OK
East Midlands	UK0032	OK	OK
North West & Merseyside	UK0033	OK	OK
Yorkshire & Humberside	UK0034	OK	OK
West Midlands	UK0035	OK	OK
North East	UK0036	OK	OK
Central Scotland	UK0037	OK	OK
North East Scotland	UK0038	OK	OK
Highland	UK0039	OK	OK
Scottish Borders	UK0040	OK (s only)	OK (s only)
South Wales	UK0041	OK	OK
North Wales	UK0042	OK	OK
Northern Ireland	UK0043	OK	OK

Subtraction of natural source contribution was not carried out for any zones in 2022. LV = limit value, (s only) indicates that the compliance or exceedance was determined by supplementary assessment only.

Particulate Matter as $PM_{2.5}$: all zones met the Stage 1 limit value (25 μg m^{-3} to be achieved by 1st Jan 2015) and the Stage 2 limit value (20 μg m^{-3} to be achieved by 1st Jan 2020). Both limit values apply to the annual mean, based on the calendar year.

The results of the air quality assessment for $PM_{2.5}$ for each zone are summarised in **Table 4-4**. Subtraction of $PM_{2.5}$ contributions due to natural sources was not necessary for any zone.

Under the Air Quality Standards Regulations (2010), the UK was required to achieve a National Exposure Reduction Target (NERT) for $PM_{2.5}$, over the period 2010 to 2020. The UK achieved the NERT in 2016, well before the 2020 target year, but has continued to report compliance annually, even after 2020, to demonstrate that it remains compliant.

Compliance is assessed on the basis of the Average Exposure Indicator (AEI) statistic. The AEI for the UK is calculated as follows:

(i) Each year, the annual arithmetic mean $PM_{2.5}$ concentration is calculated for the designated AEI subset of urban background sites[4].

(ii) The mean of the most recent three calendar years' values is taken as the AEI.

The AEI for the reference year (2010) was 13 μg m^{-3}; based on this, the Air Quality Standards Regulations (2010) set an exposure reduction target of 15%, which equated to reducing the AEI to 11 μg m^{-3} by 2020. (The detailed methodology and results of this calculation are presented in Defra's technical report on UK air quality assessment (Pugsley, K. L. et al., 2022).)

Most recent annual mean urban background $PM_{2.5}$ concentrations were as follows:

- 2020: 8 μg m^{-3}
- 2021: 8 μg m^{-3}
- 2022: 8 μg m^{-3}

The three-year running mean AEI for 2022 (calculated as the mean of the above annual values, to the nearest integer), is 8 μg m^{-3}. Therefore, the UK remained compliant with the NERT in 2022.

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[4] The sites used for calculation of the AEI are all the urban background $PM_{2.5}$ monitoring sites that were in operation in the baseline year. Urban background sites that started monitoring $PM_{2.5}$ later, or were not classified as urban background in the baseline year, are not included. (The exception is where the new site is the relocation of an existing AEI site that has been moved by a short distance, and to a similar environment). This means that the AEI is calculated on a largely consistent group of sites from year to year.

Table 4-4 Results of Air Quality Assessment for $PM_{2.5}$ in 2022

Zone	Zone code	$PM_{2.5}$ Stage 1 limit value (annual mean, for 1st Jan 2015)	$PM_{2.5}$ Stage 2 limit value (annual mean, for 1st Jan 2020)
Greater London Urban Area	UK0001	OK	OK
West Midlands Urban Area	UK0002	OK	OK
Greater Manchester Urban Area	UK0003	OK	OK
West Yorkshire Urban Area	UK0004	OK	OK
Tyneside	UK0005	OK	OK
Liverpool Urban Area	UK0006	OK (s only)	OK (s only)
Sheffield Urban Area	UK0007	OK	OK
Nottingham Urban Area	UK0008	OK	OK
Bristol Urban Area	UK0009	OK	OK
Brighton/Worthing/Littlehampton	UK0010	OK	OK
Leicester Urban Area	UK0011	OK	OK
Portsmouth Urban Area	UK0012	OK	OK
Teesside Urban Area	UK0013	OK	OK
The Potteries	UK0014	OK	OK
Bournemouth Urban Area	UK0015	OK	OK
Reading/Wokingham Urban Area	UK0016	OK	OK
Coventry/Bedworth	UK0017	OK	OK
Kingston upon Hull	UK0018	OK	OK
Southampton Urban Area	UK0019	OK	OK
Birkenhead Urban Area	UK0020	OK	OK
Southend Urban Area	UK0021	OK	OK
Blackpool Urban Area	UK0022	OK	OK
Preston Urban Area	UK0023	OK	OK
Glasgow Urban Area	UK0024	OK	OK
Edinburgh Urban Area	UK0025	OK	OK
Cardiff Urban Area	UK0026	OK	OK
Swansea Urban Area	UK0027	OK	OK
Belfast Metropolitan Urban Area	UK0028	OK	OK
Eastern	UK0029	OK	OK
South West	UK0030	OK	OK
South East	UK0031	OK	OK
East Midlands	UK0032	OK	OK
North West & Merseyside	UK0033	OK	OK
Yorkshire & Humberside	UK0034	OK	OK
West Midlands	UK0035	OK	OK
North East	UK0036	OK	OK
Central Scotland	UK0037	OK	OK
North East Scotland	UK0038	OK	OK
Highland	UK0039	OK	OK
Scottish Borders	UK0040	OK (s only)	OK (s only)
South Wales	UK0041	OK	OK
North Wales	UK0042	OK	OK
Northern Ireland	UK0043	OK	OK

Subtraction of natural source contribution was not carried out for any zones in 2022.

LV = limit value, (s only) indicates the compliance or exceedance was determined by supplementary assessment only.

Also, as explained in **Section 2.2**, the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) (UK Government, 2023) contain the following long-term targets for $PM_{2.5}$:

- An Annual Mean Concentration Target (AMCT) - to reduce maximum annual mean $PM_{2.5}$ concentrations in England to 10 µg m^{-3} by 2040. This Annual Mean Concentration Target applies to individual $PM_{2.5}$ monitoring stations, regardless of their classification.

- A Population Exposure Reduction Target (PERT), to reduce population exposure to $PM_{2.5}$ in England by 35% compared to 2018, by 2040. The PERT is based on an average of measurements from urban background and suburban background monitoring sites.

Compliance with the targets is a legal requirement from 2040 onwards, but progress against them and the interim targets (which are not legally mandatory) is reported below. The targets apply only in England. Six AURN sites in England exceeded the AMCT in 2022. They were as follows:

- Chatham Roadside (urban traffic) 12 µg m^{-3}
- Stanford-le-Hope Roadside (urban traffic) 12 µg m^{-3}
- Rochester Stoke (rural background) 11 µg m^{-3}
- Brighton Preston Park (urban background) 11 µg m^{-3}
- Christchurch Barrack Road (urban traffic) 11 µg m^{-3}
- London Marylebone Road (urban traffic) 11 µg m^{-3}

All AURN sites met the interim AMCT in 2022. This is a maximum of 12 µg m^{-3} to be achieved by January 2028. **Figure 4-2** shows how measured concentrations are changing over time and compares them to the long-term and interim targets.

Progress towards meeting the PERT is assessed using a 'Population Exposure Indicator' (PEIyear) - a measure of average population exposure in the three-year period ending on 31st December in a given year. The reduction in population exposure is found by comparing the PEIyear against the Baseline Population Exposure Indicator ('PEIbase') - the average for the three years 2016, 2017 and 2018. A statistical method to account for changes in the monitoring network is used in the calculation of the percentage reduction, so the comparison is not direct.

PEIbase is 10.09 µg m^{-3} and PEI2022 is 8.13 µg m^{-3}. The reduction in population exposure from 2018 to 2022 is 19%. This does not meet the interim PERT to be achieved by January 2028 which is 22% or the long-term target to be met by December 2040 which is 35%. **Figure 4-3** illustrates progress towards meeting the PERT and the interim target.

Information on progress towards meeting the $PM_{2.5}$ targets is available on UK-AIR, at https://uk-air.defra.gov.uk/pm25targets/progress and the full calculation methodology for the PERT and AMCT can be found here https://uk-air.defra.gov.uk/pm25targets/calculation.

Figure 4-2 AMCT progress from 2012 to 2022 (closed dots are PERT sites)

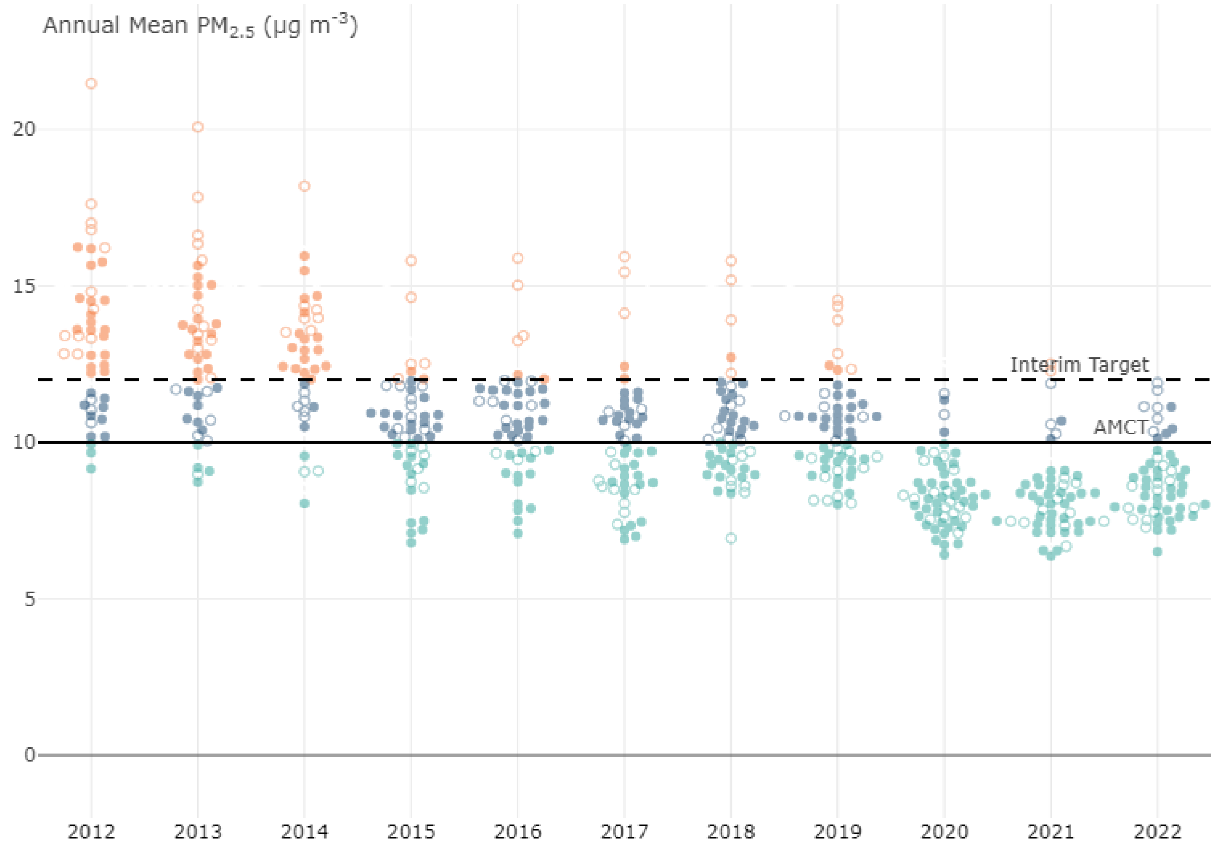
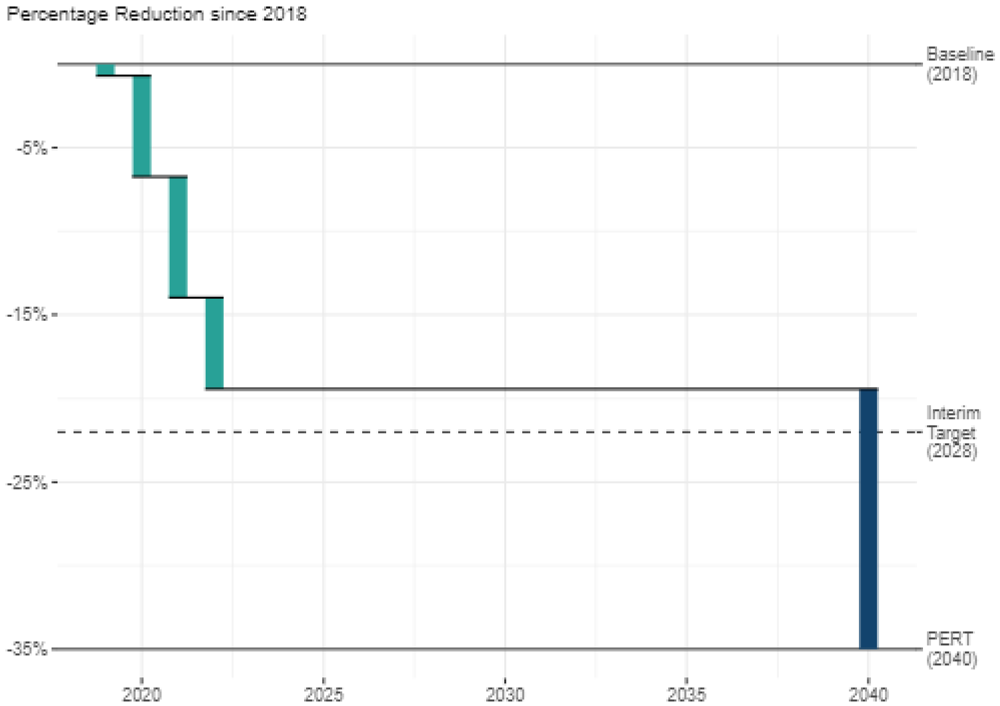


Figure 4-3 PERT progress from 2018 to 2022



Ozone: all zones and agglomerations met the target values for health and for protection of vegetation. The results of the air quality assessment for ozone are summarised in **Table 4-5**.

For ozone (O_3), there is a target value based on the maximum daily 8-hour mean. All 43 zones and agglomerations were compliant with this target value. There is also a long-term objective for protection of human health, based on the maximum daily 8-hour mean. None of the 43 zones and agglomerations were compliant with the long-term objective (LTO) for health in 2022.

There is also a target value based on the AOT40 statistic. The AOT40 statistic (expressed in µg m^{-3}.hours) is the sum of the difference between hourly concentrations greater than 80 µg m^{-3} (= 40 ppb) over a given period using only the hourly mean values measured between 08:00 and 20:00 Central European Time each day. All 43 zones and agglomerations met the target value based on the AOT40 statistic. There is also a long-term objective, for protection of vegetation, based on this statistic; 11 zones exceeded this long-term objective for vegetation in 2022. The UK met all target values for O_3 in 2022 as it has done for many years.

Ozone concentrations – and hence the number of zones exceeding the LTOs - fluctuate from year to year as ozone is a transboundary pollutant and its formation is influenced by meteorological factors. The year 2022 contained two notable periods of high ozone concentration, during heatwave conditions in July and August. There were considerably more exceedances of the LTO for vegetation than in 2021 (which was a relatively low year), and also considerably more exceedances of the population information threshold.

In 2022 there were 88 measured exceedances of the ozone population information threshold of 180 µg m^{-3}, but no exceedances of the population warning threshold of 240 µg m^{-3}. The population information threshold exceedances are detailed in **Table 4-6**. These occurred during two specific periods of hot summer weather.

The first was over the two days 17th – 18th July: first at 17:00 on 18th July, at Sibton and Weybourne (both in the Eastern zone) only. Then in the afternoon and evening of 19th July, exceedances were measured as late as 23:00. These were more widespread, with the Eastern zone most affected, but other sites such as Glazebury and Sunderland Silksworth also recorded exceedances.

The second was over the period 12th – 14th August. During the afternoon and early evening of 12th August exceedances were measured in the south west of England (at Charlton Mackrell and Yarner Wood), also at Chilbolton Observatory, Lullington Heath and Cardiff Centre. Further exceedances were measured in the afternoon and early evening of 13th August, in southern and central England, parts of Wales and the Midlands. Finally on the afternoon of 14th August, exceedances occurred in the south and east of England.

Table 4-5 Results of Air Quality Assessment for Ozone in 2022

Zone	Zone code	O_3 TV and LTO for health (8hr mean)	O_3 TV and LTO for vegetation (AOT40)
Greater London Urban Area	UK0001	Met TV, > LTO	Met TV, > LTO
West Midlands Urban Area	UK0002	Met TV, > LTO	OK
Greater Manchester Urban Area	UK0003	Met TV, > LTO	OK
West Yorkshire Urban Area	UK0004	Met TV, > LTO	OK
Tyneside	UK0005	Met TV, > LTO	OK
Liverpool Urban Area	UK0006	Met TV, > LTO	OK
Sheffield Urban Area	UK0007	Met TV, > LTO	OK
Nottingham Urban Area	UK0008	Met TV, > LTO	OK
Bristol Urban Area	UK0009	Met TV, > LTO	OK
Brighton/Worthing/Littlehampton	UK0010	Met TV, > LTO	Met TV, > LTO (s only)
Leicester Urban Area	UK0011	Met TV, > LTO	OK
Portsmouth Urban Area	UK0012	Met TV, > LTO	Met TV, > LTO (s only)
Teesside Urban Area	UK0013	Met TV, > LTO	OK
The Potteries	UK0014	Met TV, > LTO	OK
Bournemouth Urban Area	UK0015	Met TV, > LTO	Met TV, > LTO (s only)
Reading/Wokingham Urban Area	UK0016	Met TV, > LTO	Met TV, > LTO (s only)
Coventry/Bedworth	UK0017	Met TV, > LTO	OK
Kingston upon Hull	UK0018	Met TV, > LTO	OK
Southampton Urban Area	UK0019	Met TV, > LTO	Met TV, > LTO (s only)
Birkenhead Urban Area	UK0020	Met TV, > LTO	OK
Southend Urban Area	UK0021	Met TV, > LTO	OK
Blackpool Urban Area	UK0022	Met TV, > LTO	OK
Preston Urban Area	UK0023	Met TV, > LTO	OK
Glasgow Urban Area	UK0024	Met TV, > LTO (s only)	OK
Edinburgh Urban Area	UK0025	Met TV, > LTO (s only)	OK (s only)
Cardiff Urban Area	UK0026	Met TV, > LTO	OK
Swansea Urban Area	UK0027	Met TV, > LTO	OK
Belfast Metropolitan Urban Area	UK0028	Met TV, > LTO (s only)	OK
Eastern	UK0029	Met TV, > LTO	Met TV, > LTO
South West	UK0030	Met TV, > LTO (s only)	Met TV, > LTO
South East	UK0031	Met TV, > LTO	Met TV, > LTO
East Midlands	UK0032	Met TV, > LTO	Met TV, > LTO
North West & Merseyside	UK0033	Met TV, > LTO	OK
Yorkshire & Humberside	UK0034	Met TV, > LTO	OK
West Midlands	UK0035	Met TV, > LTO	Met TV, > LTO (s only)
North East	UK0036	Met TV, > LTO	OK
Central Scotland	UK0037	Met TV, > LTO	OK
North East Scotland	UK0038	Met TV, > LTO (s only)	OK
Highland	UK0039	Met TV, > LTO	OK
Scottish Borders	UK0040	Met TV, > LTO	OK
South Wales	UK0041	Met TV, > LTO	OK
North Wales	UK0042	Met TV, > LTO	OK
Northern Ireland	UK0043	Met TV, > LTO (s only)	OK

TV = target value, LTO = long-term objective, (s only) indicates that the compliance or exceedance was determined by supplementary assessment only.

Table 4-6 Measured Exceedances of the Ozone Information Threshold Value in 2022

Site name	Zone code	Number of 1-hour exceedances of information threshold	Maximum 1-hour concentration ($\mu g\ m^{-3}$)
Yarner Wood	UK0030	15	217
Charlton Mackrell	UK0030	12	217
St Osyth	UK0029	8	212
Sibton	UK0029	6	243
Chilbolton Observatory	UK0031	6	198
Northampton Spring Park	UK0032	6	188
Weybourne	UK0029	5	205
Norwich Lakenfields	UK0029	5	198
Lullington Heath	UK0031	4	188
Aston Hill	UK0042	4	183
Narberth	UK0041	3	198
Cardiff Centre	UK0026	3	188
Sunderland Silksworth	UK0005	2	192
Reading New Town	UK0016	2	188
London Harlington	UK0001	2	188
Rochester Stoke	UK0031	2	187
Glazebury	UK0033	2	186
Walsall Woodlands	UK0002	1	183

Table 4-6 shows the exceedances of the ozone information threshold in the verified dataset. The highest value is rounded to the nearest integer before counting, so values greater than 180 $\mu g\ m^{-3}$ but less than 180.5 $\mu g\ m^{-3}$ do not count towards the total.

Arsenic, cadmium, nickel and benzo[a]pyrene: the air quality assessments for arsenic (As), cadmium (Cd), nickel (Ni) and benzo[a]pyrene (B[a]P) are summarised in **Table 4-7**. All zones met target values for arsenic and cadmium, but some zones exceeded the target value for nickel and/or benzo[a]pyrene.

Concentrations of Ni exceeded the target value in three zones: Sheffield Urban Area, Yorkshire and Humberside and South Wales. These exceedances are attributed to emissions from industrial sources.

Concentrations of B[a]P were above the target value in two zones: Swansea Urban Area and South Wales. These exceedances are also attributed to emissions from industrial sources.

Table 4-7 Results of Air Quality Assessment for As, Cd, Ni and B[a]P in 2022

Zone	Zone code	As TV	Cd TV	Ni TV	B[a]P TV
Greater London Urban Area	UK0001	OK	OK	OK	OK
West Midlands Urban Area	UK0002	OK	OK	OK	OK
Greater Manchester Urban Area	UK0003	OK (s only)	OK (s only)	OK (s only)	OK
West Yorkshire Urban Area	UK0004	OK (s only)	OK (s only)	OK (s only)	OK
Tyneside	UK0005	OK (s only)	OK (s only)	OK (s only)	OK
Liverpool Urban Area	UK0006	OK (s only)	OK (s only)	OK (s only)	OK
Sheffield Urban Area	UK0007	OK	OK	> TV (s only)	OK
Nottingham Urban Area	UK0008	OK (s only)	OK (s only)	OK (s only)	OK
Bristol Urban Area	UK0009	OK (s only)	OK (s only)	OK (s only)	OK
Brighton/Worthing/Littlehampton	UK0010	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Leicester Urban Area	UK0011	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Portsmouth Urban Area	UK0012	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Teesside Urban Area	UK0013	OK (s only)	OK (s only)	OK (s only)	OK
The Potteries	UK0014	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Bournemouth Urban Area	UK0015	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Reading/Wokingham Urban Area	UK0016	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Coventry/Bedworth	UK0017	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Kingston upon Hull	UK0018	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Southampton Urban Area	UK0019	OK (s only)	OK (s only)	OK (s only)	OK
Birkenhead Urban Area	UK0020	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Southend Urban Area	UK0021	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Blackpool Urban Area	UK0022	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Preston Urban Area	UK0023	OK (s only)	OK (s only)	OK (s only)	OK
Glasgow Urban Area	UK0024	OK (s only)	OK (s only)	OK (s only)	OK
Edinburgh Urban Area	UK0025	OK (s only)	OK (s only)	OK (s only)	OK
Cardiff Urban Area	UK0026	OK (s only)	OK (s only)	OK (s only)	OK
Swansea Urban Area	UK0027	OK	OK	OK	> TV (s only)
Belfast Urban Area	UK0028	OK	OK	OK	OK
Eastern	UK0029	OK	OK	OK	OK
South West	UK0030	OK	OK	OK	OK
South East	UK0031	OK	OK	OK	OK
East Midlands	UK0032	OK	OK	OK	OK
North West & Merseyside	UK0033	OK (s only)	OK (s only)	OK (s only)	OK
Yorkshire & Humberside	UK0034	OK	OK	> TV (s only)	OK
West Midlands	UK0035	OK	OK	OK	OK (s only)
North East	UK0036	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Central Scotland	UK0037	OK	OK	OK	OK
North East Scotland	UK0038	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Highland	UK0039	OK (s only)	OK (s only)	OK (s only)	OK
Scottish Borders	UK0040	OK	OK	OK	OK (s only)
South Wales	UK0041	OK	OK	> TV (s only)	> TV (s only)
North Wales	UK0042	OK (s only)	OK (s only)	OK (s only)	OK (s only)
Northern Ireland	UK0043	OK (s only)	OK (s only)	OK (s only)	OK

TV = target value, (s only) indicates the compliance or exceedance was determined by supplementary assessment only.

4.3 Comparison with Previous Years

This section provides information on non-compliances in previous years from 2008 onwards. (2008 is the year that the Air Quality Directive - which was subsequently transposed into UK legislation by the Air Quality Standards Regulations (2010) – came into force.)

For **SO_2, $PM_{2.5}$, lead, benzene and CO**, the UK has been compliant with Air Quality Standards Regulations (2010) limit values (apart from the $PM_{2.5}$ Stage 2 indicative limit value) in all years since 2008. For information on compliance with the 1st and 2nd Daughter Directives for all pollutants in earlier years, please see the 2012 or earlier reports in this series, which can be found here: https://uk-air.defra.gov.uk/library/annualreport/.

The UK has been compliant with the limit values for both **lead** and **CO** since 2003, and for **benzene** since 2007: these limit values are the same as those contained in the 1st and 2nd Daughter Directives, which the Air Quality Directive (and therefore the Air Quality Standards Regulations (2010)) superseded.

For nitrogen dioxide, **Table 4-8** summarises the results of the air quality assessment in years from 2008 to 2022. This table shows the numbers of zones exceeding the limit value (plus any agreed margin of tolerance, in cases where a time extension had been granted). The right-hand column contains notes on the effects of any time extensions, the last of which ended on 1st January 2015.

All non-agglomeration zones within the UK have complied with the critical level for annual mean NO_X concentration, set for protection of vegetation, in years 2008 onwards.

For PM_{10}, **Table 4-9** summarises the results of the air quality assessment in years from 2008 to 2022.There are notes in the right-hand column explaining the effects of the time extensions which were in place up to the end of 2011 for some zones.

For ozone, **Table 4-10** summarises annual exceedances of the target value for human health (based on the maximum daily 8-hour mean), the target value for protection of vegetation (based on the AOT40 statistic), and the two long-term objectives (LTOs) based on these two metrics.

Finally, for the pollutants formerly covered by the Fourth Daughter Directive - arsenic (As), cadmium (Cd), nickel (Ni) and benzo[a]pyrene (B[a]P) - **Table 4-11** summarises the numbers of zones with exceedances of target values in previous years.

This is the first year in which compliance against the $PM_{2.5}$ targets has been reported.

Table 4-8 Non-Compliances with Limit Values for Nitrogen Dioxide, 2008-2022

Year	Zones Exceeding NO_2 LV for health (1hr mean)	Zones Exceeding NO_2 LV for health (annual mean)	Notes on Time Extensions
2008	3 zones (London, Glasgow, N.E. Scotland)	40 zones	-
2009	2 zones (London, Glasgow)	40 zones	-
2010	3 zones (London, Teesside, Glasgow)	40 zones	-
2011	3 zones (London, Glasgow, South East)	35 zones	A further 5 zones exceeded the annual mean NO_2 LV in 2011 but were covered by time extensions and within the LV+ Margin of Tolerance (MOT), therefore compliant.
2012	2 zones (London, South East)	34 zones	A further 4 zones exceeded the annual mean NO_2 LV in 2012 but were covered by time extensions and within the LV+ MOT, therefore compliant.
2013	1 zone (London)	31 zones	A further 7 zones exceeded the annual mean NO_2 LV in 2013 but were covered by time extensions and within the LV+ MOT, therefore compliant.
2014	2 zones (London, South Wales)	30 zones	A further 8 zones exceeded the annual mean NO_2 LV in 2014 but were covered by time extensions and within the LV+ MOT, therefore compliant.
2015	2 zones (London, South Wales)	37 zones	2015 was the first year with no time extensions for NO_2: this is the reason for the apparent increase in zones exceeding between 2014 and 2015.
2016	2 zones (London, South Wales)	37 zones	No time extensions in place.
2017	2 zones (London, South Wales)	37 zones	No time extensions in place.
2018	2 zones (London, South Wales)	36 zones	No time extensions in place.
2019	1 zone (South Wales)	33 zones	No time extensions in place.
2020	None	5 zones	No time extensions in place.
2021	None	10 zones	No time extensions in place.
2022	None	9 zones	No time extensions in place.

Table 4-9 Non-Compliances with the Limit Values for PM_{10}, 2008-2022

Year	PM_{10} LV (annual mean)	PM_{10} LV (daily mean)	Notes on Time Extensions and Subtraction of Natural contribution
2008	None	2 zones (1 zone after subtraction of natural contribution)	-
2009	None	3 zones (1 zone after subtraction of natural contribution)	-
2010	None	None (after subtraction of natural contribution)	One zone exceeded the daily mean PM_{10} limit value more than the permitted 35 times in 2010, after subtraction of natural contribution. This zone was covered by a time extension and was within the LV+MOT so was therefore compliant.
2011	None	None (after subtraction of natural contribution)	One zone exceeded the daily mean PM_{10} limit value more than the permitted 35 times in 2011, after subtraction of natural contribution. This zone was covered by a time extension and was within the LV+MOT so was therefore compliant.
2012	None	None (after subtraction of natural contribution. No time extension.)	-
2013	None	None (after subtraction of natural contribution. No time extension.)	-
2014	None	None (after subtraction of natural contribution. No time extension.)	-
2015	None	None (after subtraction of natural contribution. No time extension.)	-
2016	None	None	-
2017	None	None	-
2018	None	None	-
2019	None	None	-
2020	None	None	-
2021	None	None	-
2022	None	None	-

Table 4-10 Exceedances of Target Values for Ozone (Health) and Long-Term Objectives, 2008-2022

Year	8-Hour Mean Target Value	AOT40 Target Value	8-Hour Mean LTO	AOT40 LTO
2008	1 zone measured (Eastern)	None	43 zones	41 zones
2009	None	None	39 zones	10 zones
2010	None	None	41 zones	6 zones
2011	None	None	43 zones	3 zones
2012	None	None	41 zones	3 zones
2013	None	None	33 zones	8 zones
2014	None	None	32 zones	3 zones
2015	None	None	43 zones	1 zone
2016	None	None	42 zones	5 zones
2017	None	None	34 zones	None
2018	None	None	43 zones	38 zones
2019	None	None	43 zones	6 zones
2020	None	None	40 zones	16 zones
2021	None	None	39 zones	1 zone
2022	None	None	43 zones	11 zones

Table 4-11 Zones Exceeding Target Values for As, Cd, Ni and B[a]P, 2008-2022

Year	As	Cd	Ni	B[a]P
2008	None	None	2 (Swansea, South Wales)	6 (Yorks. & Humberside, Teesside, Northern Ireland, Swansea, South Wales, Belfast)
2009	None	None	2 (Swansea, South Wales)	6 (Yorks. & Humberside, Northern Ireland, Teesside, Swansea, North East, South Wales)
2010	None	None	2 (Swansea, South Wales)	8 (Yorks. & Humberside, Northern Ireland, Teesside, Belfast, W Midlands, North East, South Wales, North Wales.)
2011	None	None	2 (Swansea, South Wales)	7 (Yorks. & Humberside, N. Ireland, Teesside, Swansea, Belfast, North East, South Wales)
2012	None	None	2 (Swansea, South Wales)	8 (Yorks. & Humberside, Teesside, Swansea, Belfast, the North East, South Wales, North Wales, Northern Ireland.)
2013	None	None	2 (Swansea, South Wales)	6 (Yorks. & Humberside, Teesside, Swansea, East Midlands, North East, South Wales.)
2014	None	None	3 (Sheffield, Swansea, South Wales)	6 (Yorks. & Humberside, Teesside, Swansea, East Midlands, North East, and South Wales).
2015	None	None	2 (Swansea, South Wales)	5 (Yorks. & Humberside, Teesside, Swansea, the North East and South Wales).
2016	None	None	3 (Sheffield, Swansea, South Wales)	4 (Yorks. & Humberside, Swansea, South Wales and Northern Ireland).
2017	None	None	None	3 (Yorks. & Humberside, Swansea and South Wales)
2018	None	None	4 (Sheffield, Yorks. & Humberside, Swansea and South Wales)	3 (Yorks. & Humberside, Swansea and South Wales)
2019	None	None	4 (Sheffield, Yorks. & Humberside, Swansea and South Wales)	3 (Yorks. & Humberside, Swansea and South Wales)
2020	None	None	4 (Sheffield, Yorks. & Humberside, Swansea and South Wales)	3 (Yorks. & Humberside, Swansea and South Wales)
2021	None	None	4 (Sheffield, Yorks. & Humberside, Swansea and South Wales)	2 (Swansea and South Wales)
2022	None	None	3 (Sheffield, Yorks. & Humberside and South Wales)	2 (Swansea and South Wales)

5 Spatial Variation and Changes Over Time

5.1 About the Maps and Charts in this Section

Maps of Modelled Pollutant Concentration

This section looks at the spatial distribution of pollutants across the UK, based upon the modelled maps of ambient pollutant concentration discussed in **Section 3.5** of this report, "Modelling".

Modelled maps are included in this section to illustrate how background (i.e. non-roadside) concentrations of various pollutants vary across the UK. However, here they can only show general patterns and limited detail. To see modelled maps in more detail, and to zoom in on specific areas, it is recommended to view the UK Ambient Air Quality Interactive Maps, provided by UK-AIR at https://uk-air.defra.gov.uk/data/gis-mapping/.

Please note, the online interactive versions of the maps are not all identical to the versions used in this report. In some cases, the concentration bands may be different, and in the case of lead (Pb), different units are used. Also, the online interactive maps use a different default colour scale from the one used in this report. To view the online maps in the 'Viridis' colour scale used in this report, please change this via the accessibility settings as follows:

(i) At https://uk-air.defra.gov.uk/data/gis-mapping/, click on the link to "*About this ambient air quality map*" in the top right corner of the page.
(ii) Scroll down to the 'Accessibility Version' heading.
(iii) Select the 'Viridis' colour scale from the list.

Previous reports in this series have also included maps of modelled roadside concentrations of some traffic-related pollutants: NO_2, PM_{10}, $PM_{2.5}$ and benzene. However, these are no longer included, due to the difficulty of showing the modelled roadside concentrations in a clear and accessible way. Instead, the reader is recommended to refer to the interactive maps on UK-AIR using the link above. These will allow the viewer to see modelled roadside concentrations for individual road links.

Trend and Time Series Charts

For each pollutant, this section also discusses how ambient concentrations have changed over time, using data from the relevant ambient air quality monitoring networks: the Automatic Urban and Rural Network (AURN), the Automatic Hydrocarbon Network, the Non-Automatic Hydrocarbon Network, the Heavy Metals Network, and the Polycyclic Aromatic Hydrocarbons (PAH) Network.

The AURN has been in operation since 1992. Since that time, it has grown considerably in size, and the proportion of urban traffic ('roadside') monitoring sites has increased. Therefore, for most pollutants measured by the AURN, we have based our investigation of trends on data from sub-sets of long-running AURN monitoring sites, rather than the whole network. This is intended to show changes over time, without introducing any spurious effects due to changes in the number and distribution of the sites.

Trend analysis has been carried out using Openair (Carslaw & Ropkins, 2012). Openair provides free, open-source and innovative tools to analyse interpret and understand air pollution data using R; a free and open-source programming language designed for the analysis of data. The Openair package was primarily developed for the analysis of air pollution datasets and can handle high volumes of data; the AURN, with its long data record, lends itself to this. A further strength of the Openair tools is that they also allow data to be conditioned by one or more variables. For example, plots can be produced that show the inter-relationships between air pollutants and meteorological parameters, or temporal trends.

Openair was developed by King's College London with the University of Leeds. The Openair project is currently led by Dr David Carslaw, of Ricardo Energy & Environment and the University of York. The UK-AIR website provides simplified web access to a customised selection of the Openair tools, including tools that require meteorological measurements. For more information on the functions and how to use them, please refer to: https://uk-air.defra.gov.uk/data/openair.

The Openair 'TheilSen' function has been used here for NO_2, PM_{10}, $PM_{2.5}$, O_3, SO_2 and CO. This uses the Theil-Sen statistical method to quantify trends in concentrations over time. The trend analysis is based on monthly mean pollutant concentrations (at least 75% data capture is required for a valid monthly mean). The 'TheilSen' function includes an option to 'de-seasonalise' the data (i.e. statistically modify the plotted data to remove the influence of seasonal cycles, thus providing a clearer indication of the overall trend). The 'de-seasonalise' option has been used for the AURN pollutants, as indicated in the graph titles.

The trend line is shown by a solid dark blue line, with 95% confidence intervals for the trend shown by dotted dark blue lines. The trend is given at the top of the graph, in units (e.g. µg m^{-3}) per year, over the period shown. This is followed by the 95% confidence interval, shown in square brackets. This may be followed by a number of symbols, with + indicating that the trend is statistically significant at the 0.1 level, * indicating that the trend is statistically significant at the 0.05 level, ** indicating significance at the 0.01 level and *** indicating significance at the 0.001 level.

For example, "**-0.89 [-0.94, -0.81] units/year *****" appearing above a trend graph for NO_2 graph would indicate that there is a downward trend in NO_2 concentration of 0.89 µg m^{-3} per year (represented by the solid dark blue line) with a 95% confidence interval between -0.94 and -0.81 µg m^{-3} (represented by the dotted dark blue lines either side of it), and that this trend was statistically significant at the 0.001 level.

It should also be noted that the 'de-seasonalise' option fills in any gaps in the dataset using an interpolation method, so the datasets shown in these trend plots appear uninterrupted, though this is not necessarily the case.

For pollutants measured by the Hydrocarbons, PAH and Heavy Metals networks, time series or smoothed trend plots (not de-seasonalised) have been used to illustrate changes over time.

Estimated UK Emission Charts

These changes over time are compared to changes in estimated total UK emissions where appropriate. Estimated UK emissions data are taken from the National Atmospheric Emissions Inventory (NAEI) website at https://naei.beis.gov.uk/. (The most recent year for which NAEI emission estimates are available is 2021). The NAEI dataset shows emissions split between various emission source categories, which are different for different pollutants.

Please note that this section only aims to provide a general indication of changes in pollutant concentration over time, based in most cases on averages or groups of long-running sites. Patterns for specific regions or individual sites may be different.

5.2 Nitrogen Dioxide

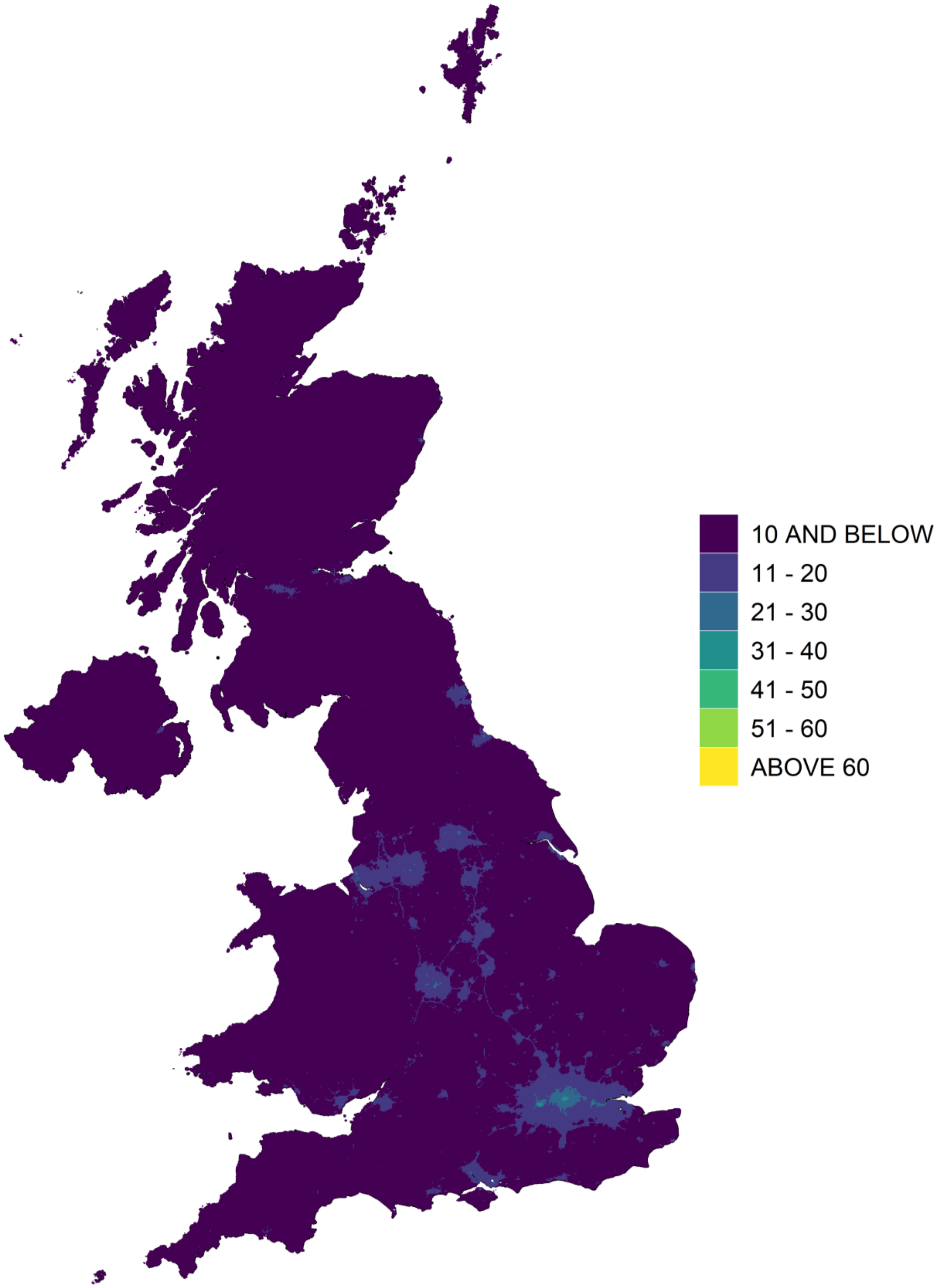
5.2.1 NO_2: Spatial Distribution in the UK

Figure 5-1 shows the modelled annual mean NO_2 concentrations for 2022, at all urban, suburban and rural background locations. Outside of major towns and cities, modelled annual mean concentrations of NO_2 were mostly 10 µg m^{-3} or below (shown as dark blue). In the UK's urban areas, modelled concentrations were higher (indicated by lighter colours), but all background locations were within the limit value of 40 µg m^{-3}.

To see detail for specific areas, and maps of modelled roadside concentrations, please use the UK Ambient Air Quality Interactive Map provided by UK-AIR at https://uk-air.defra.gov.uk/data/gis-mapping/. (Please note, the online interactive map defaults to a different colour scale unless 'Viridis' is specifically selected using the accessibility options).

As explained above, previous reports in this series have also included maps of modelled roadside concentrations of NO_2 and other traffic-related pollutants. However, these are no longer included, due to the difficulty of showing the modelled roadside concentrations in a clear and accessible way. Instead, the reader is referred to the above Interactive Maps to see the modelled roadside concentrations. In 2022, some road links had modelled annual mean concentrations above the annual mean limit value of 40 µg m^{-3}, but none had modelled annual mean concentrations above 60 µg m^{-3}.

Figure 5-1 Annual Mean Background NO_2 Concentration, 2022 (µg m^{-3})



(An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/. Please note the bands and default colour scale may be different to those used above.)

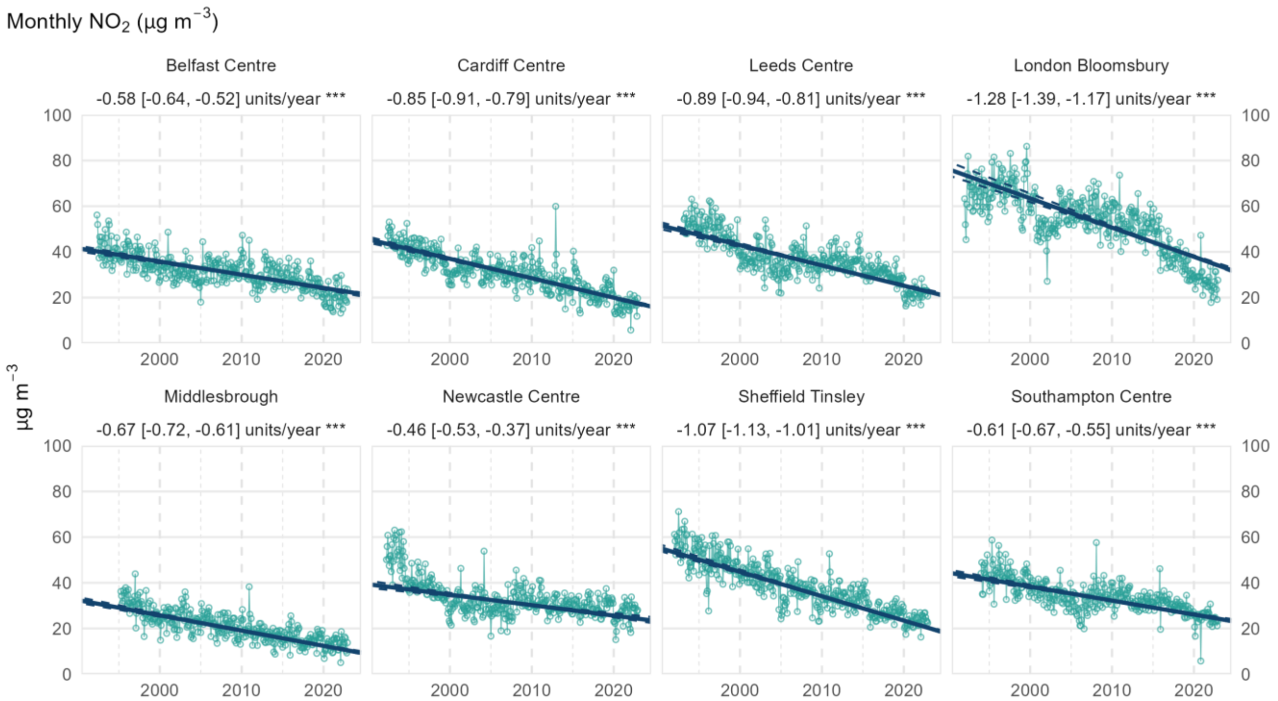
5.2.2 NO_2: Changes Over Time

Figure 5-2 and **Figure 5-3** show how ambient concentrations of NO_2 (as measured by the AURN) have decreased since 1992 (the Network's first year of operation). Time series charts of NO_2 concentration are shown for the following sub-sets of long-running sites:

- Eight urban non-roadside sites operating since 1995 or earlier (**Figure 5-2**); Belfast Centre, Cardiff Centre, Leeds Centre, London Bloomsbury, Middlesbrough, Newcastle Centre, Sheffield Tinsley and Southampton Centre. (These are all urban background: Middlesbrough was urban industrial but was re-classified in 2022 due to a reduction in industry in the area surrounding the site).

- Eight urban traffic sites operating since 1998 or earlier (**Figure 5-3**); Camden Kerbside, Cambridge Roadside, Exeter Roadside, Glasgow Kerbside, Haringey Roadside, London Marylebone Road, Oxford Centre Roadside and Tower Hamlets Roadside.

Figure 5-2 De-seasonalised Trends in NO_2 Concentration, at 8 Long-Running AURN Urban Background Sites, 1992-2022



All eight long-running urban background sites in **Figure 5-2** show a decreasing trend in NO_2 (shown by the numbers above each graph, which are in all cases negative). The decreasing trends vary from -0.46 $\mu g\ m^{-3}$ per year at Newcastle Centre to -1.28 $\mu g\ m^{-3}$ at London Bloomsbury. While the magnitude of the year-on-year decrease varies, the trend is statistically highly significant at the 0.001 level for all eight sites, as indicated by the three asterisks (***) on the plots.

For the urban traffic sites in **Figure 5-3** below, (for which the dataset is slightly shorter), the pattern of trends has historically been less consistent, as highlighted in previous reports in this series. However, all eight sites now show a downward trend statistically significant at the 0.001 level. Several of the sites (such as London Marylebone Road, Glasgow Kerbside and Tower Hamlets Roadside) show a dip in NO_2 concentration in 2020, which is likely to have been due at least in part to the COVID-19 restrictions.

Figure 5-3 De-seasonalised Trends in NO_2 Concentration at 8 Long-Running AURN Urban Traffic Sites, 1998-2022

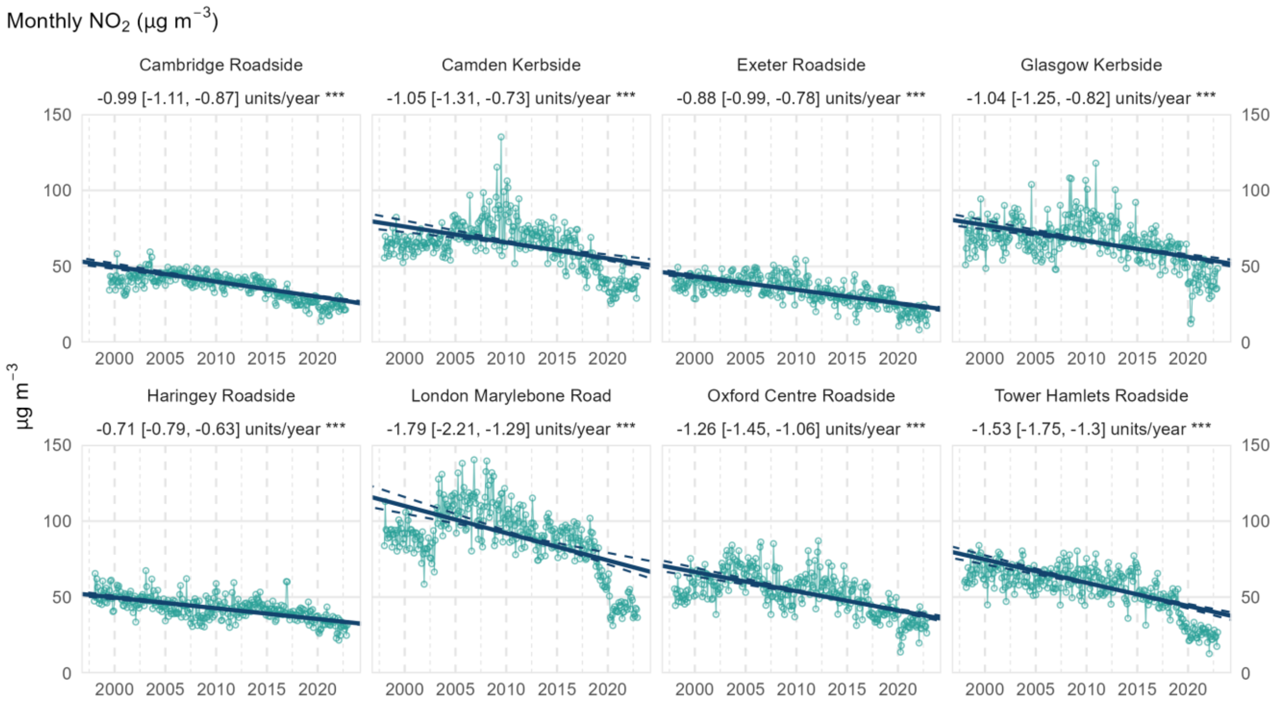


Figure 5-4 is taken from Defra's National Air Quality Statistics web page for NO_2, at https://www.gov.uk/government/statistics/air-quality-statistics/ntrogen-dioxide (Defra, 2023d). This shows annual mean NO_2 concentrations averaged over all included sites that had annual data capture greater than or equal to 75% in the relevant year. Roadside (urban traffic), urban background and rural sites are shown by separate, labelled, lines.

As explained at the start of this section, the number of sites in the network has increased substantially over the years. This introduces uncertainty when considering trends for the whole network. Therefore, this graph shows the 95% confidence interval of the annual mean for each site classification, as a shaded area either side of each line. The confidence intervals narrow over time because of an increase in the number of monitoring sites and a reduction in the variation between annual means at monitoring sites for NO_2.

For both urban traffic and urban background sites, there appears to be a dip in 2020, which is likely to be due at least in part to the reduction in traffic emissions caused by the COVID-19 pandemic restrictions in that year.

Figure 5-4 Annual mean concentrations of NO_2 in the UK, by AURN Site Classification, 1990 to 2022. Shaded areas either side of each line show the 95% confidence interval of the mean. ***(Source: https://www.gov.uk/government/statistics/air-quality-statistics/ntrogen-dioxide)***

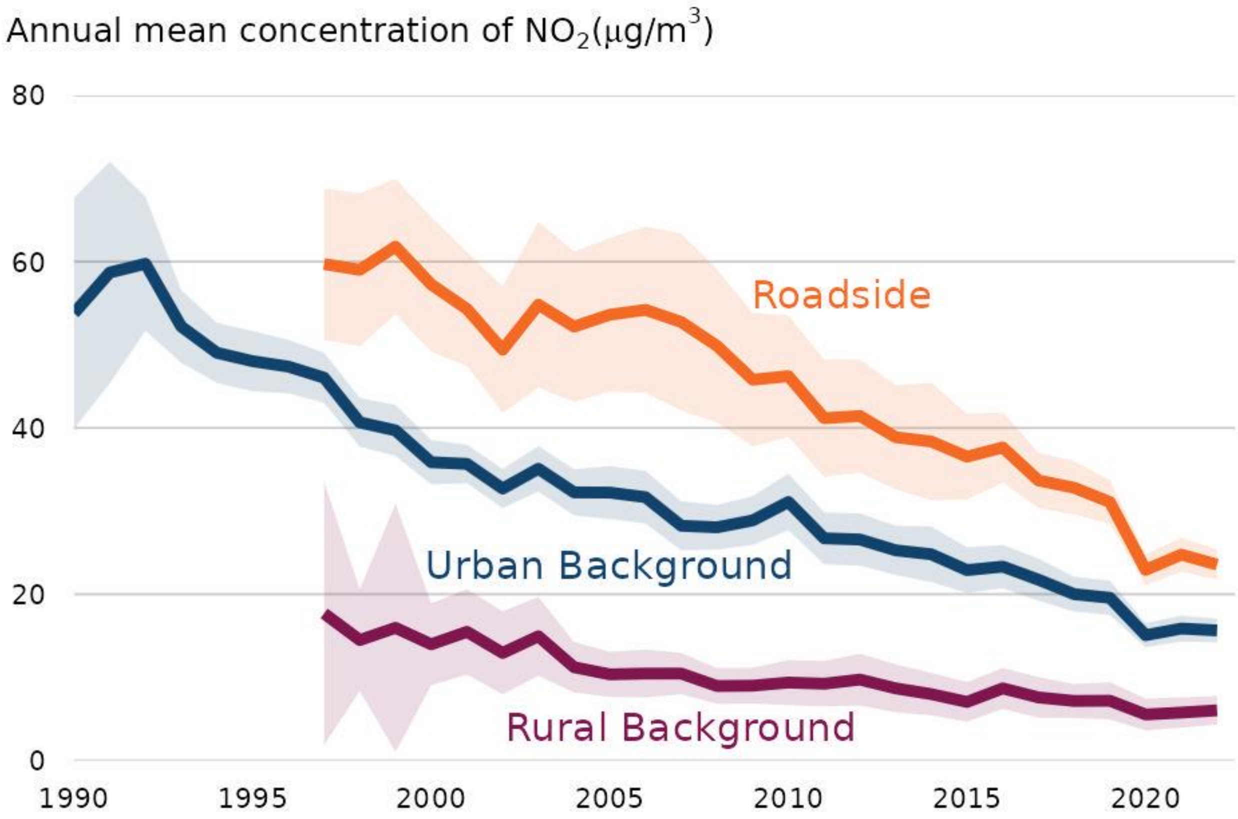
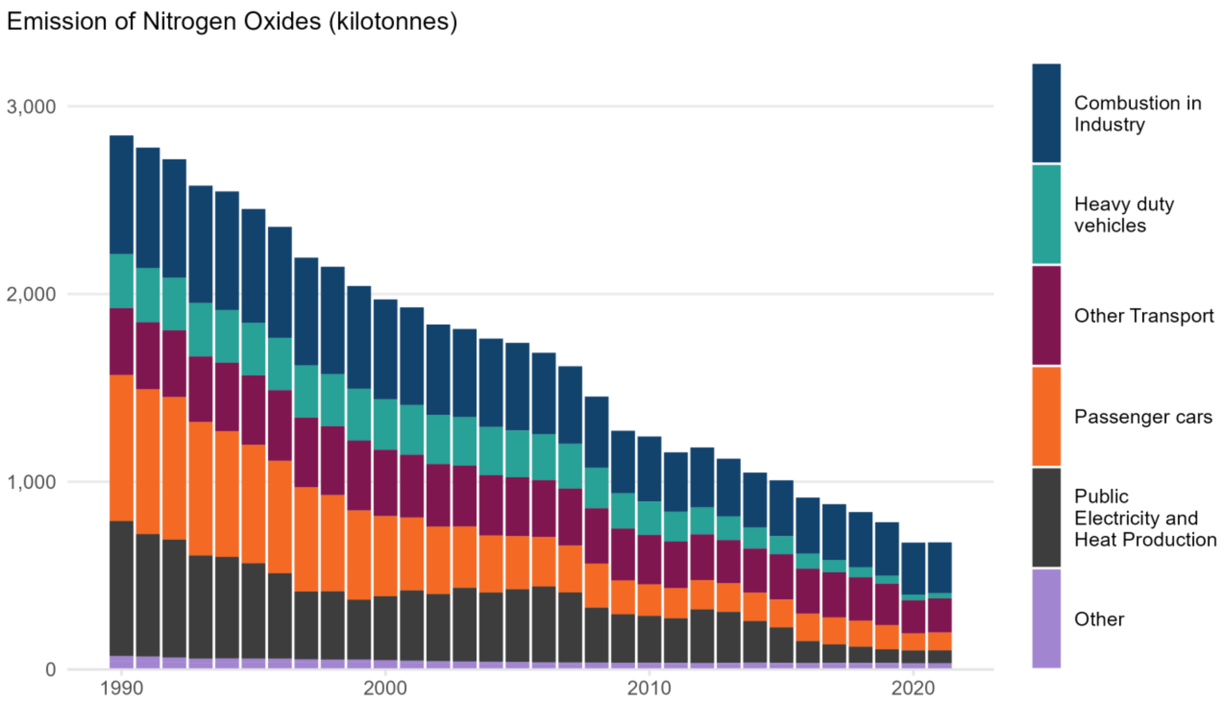


Figure 5-5 shows estimates of total UK annual emission of nitrogen oxides (NOx), in kilotonnes, from 1990 to 2021 (the most recent year for which emission estimates are available). The data are from the National Atmospheric Emissions Inventory (NAEI) website at: https://naei.beis.gov.uk/. This shows that total NOx emissions have decreased substantially over this period and are now less than one third of the total emissions in 1990. Emissions from several specific sources, notably public energy and heat production, passenger cars and heavy-duty vehicles, have also shown substantial decreases over the same period.

Figure 5-5 Estimated Annual UK Emissions of Nitrogen Oxides (kt), 1990 – 2021 (Source: NAEI 2023)



5.3 PM_{10} Particulate Matter

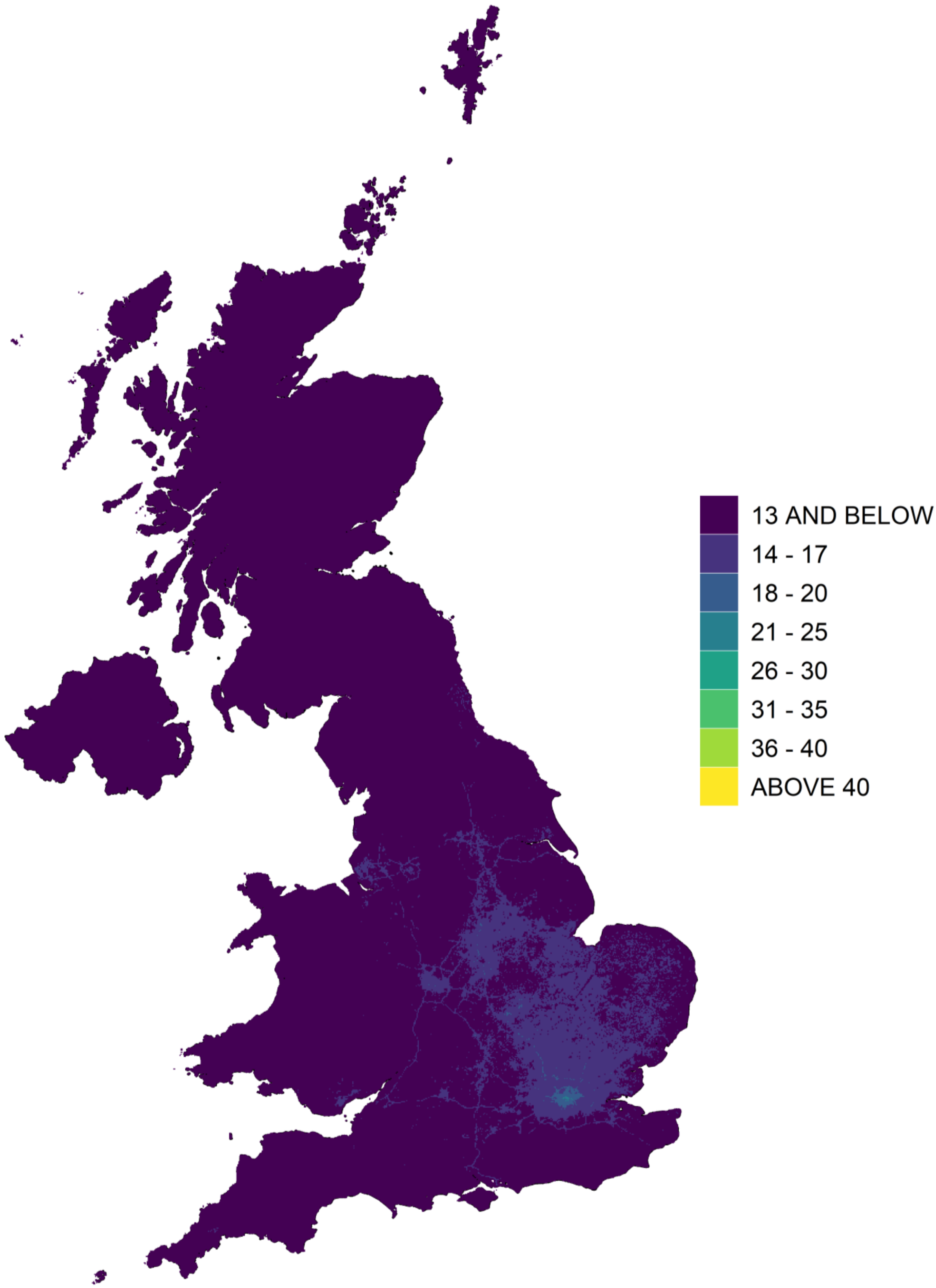
5.3.1 PM_{10}: Spatial Distribution

Figure 5-6 shows modelled annual mean background PM_{10} concentrations in 2022. No urban background locations had a modelled annual mean concentration greater than the limit value of 40 µg m^{-3}. An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/: please note the interactive maps use a different colour scale unless "Viridis" is selected using the accessibility options.

As in the case of NO_2 and other traffic-related pollutants, roadside concentrations are also modelled, but maps are no longer included in this report because of the difficulty of showing the information clearly. Instead, the reader is referred to the interactive maps of modelled concentrations of both roadside and background PM_{10} (at https://uk-air.defra.gov.uk/data/gis-mapping/) which allow the detail to be seen more clearly. No roadside locations had a modelled annual mean PM_{10} concentration greater than the limit value of 40 µg m^{-3}.

Where the annual mean PM_{10} concentration exceeds 31.5 µg m^{-3}, it is likely also that the 24-hour mean has exceeded the daily mean limit value of 50 µg m^{-3} on more than the permitted 35 occasions. No background or roadside locations had modelled annual mean PM_{10} concentrations greater than 31.5 µg m^{-3} in 2022.

Figure 5-6 Annual Mean Background PM_{10} Concentration, 2022 (µg m^{-3})



(An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/. Please note the bands and default colour scale may be different to those used above.)

5.3.1 PM_{10} Changes Over Time

Figure 5-7 shows de-seasonalised trends in ambient PM_{10} concentration, based on 12 urban background AURN sites, all of which have been operating since 1997 or earlier. The sites are; Belfast Centre, Cardiff Centre, Leamington Spa, Leeds Centre, London Bloomsbury, London North Kensington, Middlesbrough, Newcastle Centre, Nottingham Centre, Salford Eccles, Southampton Centre and Thurrock. (Middlesbrough was formerly urban industrial: it was re-classified in 2022 due to a decrease in industry in the area). All 12 sites show a downward trend for PM_{10} over their period of operation: although the decreasing trends are not large (all are less than 1 µg m^{-3}) they are all highly statistically significant (at the 0.001 confidence level) as indicated by the three asterisks (***).

Figure 5-7 De-seasonalised Trends in Ambient PM_{10}, 12 Long-Running Urban Background AURN Sites 1992 – 2022

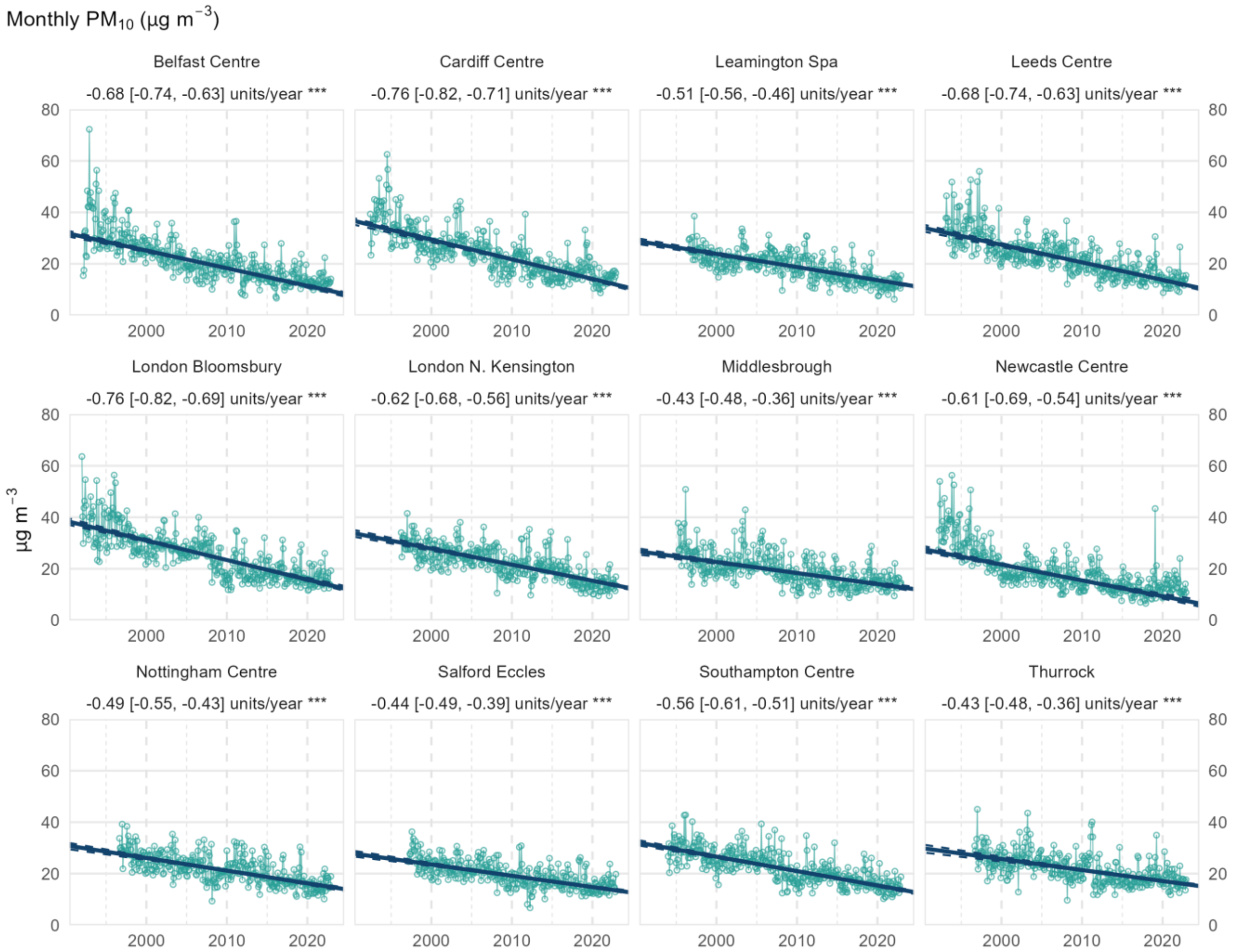


Figure 5-8 shows de-seasonalised trends in ambient PM_{10} concentration, based on 12 urban traffic AURN sites. There are few very long-running urban traffic PM_{10} sites: only three began monitoring PM_{10} before 2008. The sites shown here have been operating since the start of 2011 or earlier. The sites are; Armagh Roadside, Camden Kerbside,

Chatham Roadside, Chepstow A48, Chesterfield Roadside, Leeds Headingley Kerbside, London Marylebone Road, Sandy Roadside, Stanford-le-Hope Roadside, Stockton-on-Tees Eaglescliffe, Swansea Roadside and York Fishergate. *(Note: in previous reports, this sub-set of sites included Carlisle Roadside. Carlisle Roadside was closed and relocated elsewhere in Carlisle during 2021. Therefore, in* **Figure 5-8** *the next longest-running site, Chatham Roadside has been included instead.)*

Ten of these sites show a downward trend which is highly statistically significant (at the 0.001 confidence level). The exceptions are York Fishergate, which shows a downward trend significant at the 0.01 confidence level, and Swansea Roadside which shows a statistically significant increase. As in the case of NO_2, it is likely that trends at urban traffic sites are influenced by changes in the volume and type of traffic on the adjacent road.

Figure 5-8 De-seasonalised Trends in Ambient PM_{10}, 12 Long-Running Urban Traffic AURN Sites 2009 – 2022

Figure 5-9 is taken from Defra's National Air Quality Statistics web page for PM_{10} and $PM_{2.5}$, at https://www.gov.uk/government/statistics/air-quality-statistics/concentrations-of-particulate-matter-pm10-and-pm25 , (Defra, 2023e). This shows annual mean PM_{10} concentrations averaged over all included AURN sites that had annual data capture

greater than or equal to 75% in the relevant year. Roadside (urban traffic) and urban background sites are shown by separate, labelled, lines.

Shaded areas surrounding the lines show the 95% confidence interval of the annual mean for each site classification. The confidence intervals narrow over time, as the number of monitoring sites has increased: this is particularly the case for urban traffic (roadside) PM_{10} monitoring sites, which have almost doubled in number since 2008.

Figure 5-9 Annual mean concentrations of PM_{10} in the UK, by AURN Site Classification, 1992 to 2022. Shaded areas either side of each line show the 95% confidence interval of the mean. ***(Source: https://www.gov.uk/government/statistics/air-quality-statistics/concentrations-of-particulate-matter-pm10-and-pm25)***

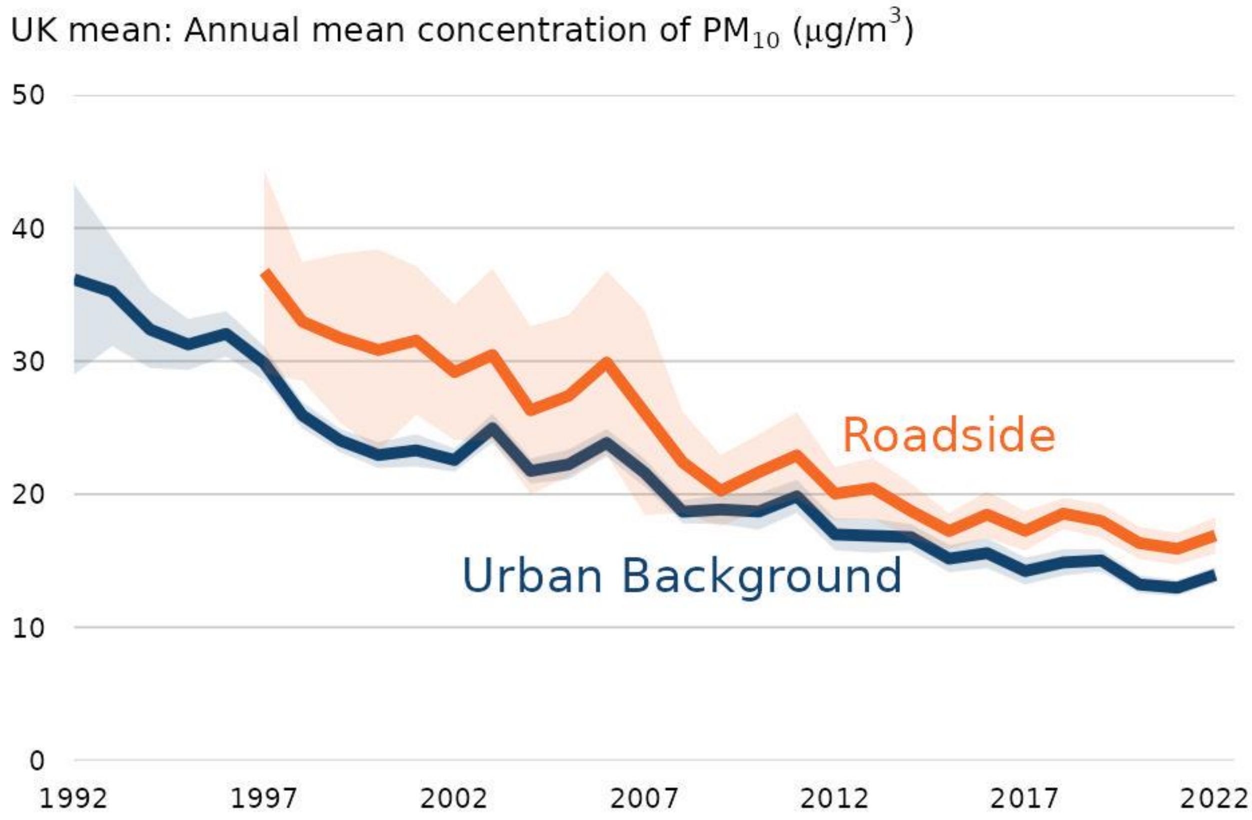
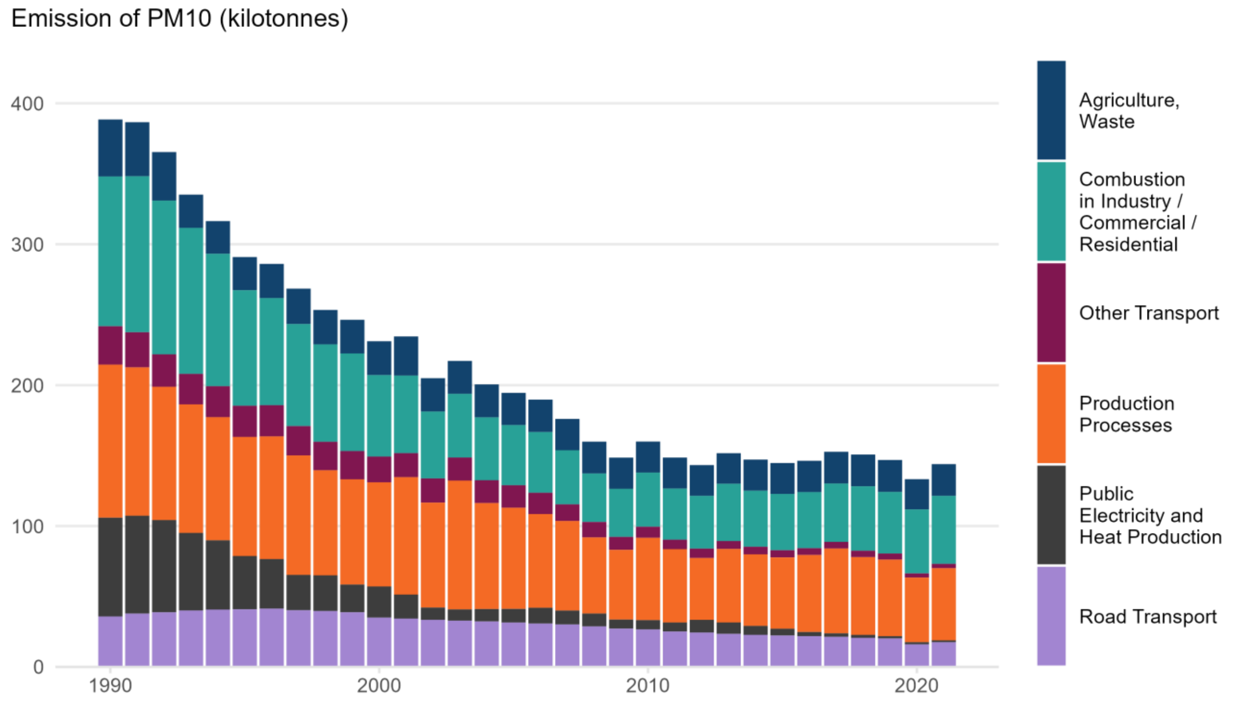


Figure 5-10 shows NAEI estimates of total UK annual emission of PM_{10} in kilotonnes, from 1990 to 2021 (the most recent year for which emission estimates are available). Total PM_{10} emissions have steadily decreased over all this period, although in more recent years the rate of decrease has slowed, flattening off after around 2010. Emissions from the *'combustion in industry, commercial and residential'* sector appears to have increased slightly over the past decade. The NAEI says *"Emissions from residential sector combustion have grown both in real terms and in terms of the contribution to the UK total. This is because of strong growth in the use of wood as a domestic fuel, which has offset reductions that have occurred due to decreasing use of coal and other solid mineral fuels."* (https://naei.beis.gov.uk/overview/pollutants?pollutant_id=24). By contrast, estimated emissions from road traffic alone have continued to decrease steadily. 2020

saw a sharp decrease in estimated emissions from road traffic and other traffic, as a result of the COVID-19 pandemic restrictions.

Figure 5-10 Estimated Annual UK Emissions of PM_{10} (kt), 1990 – 2021 (source: NAEI 2023)



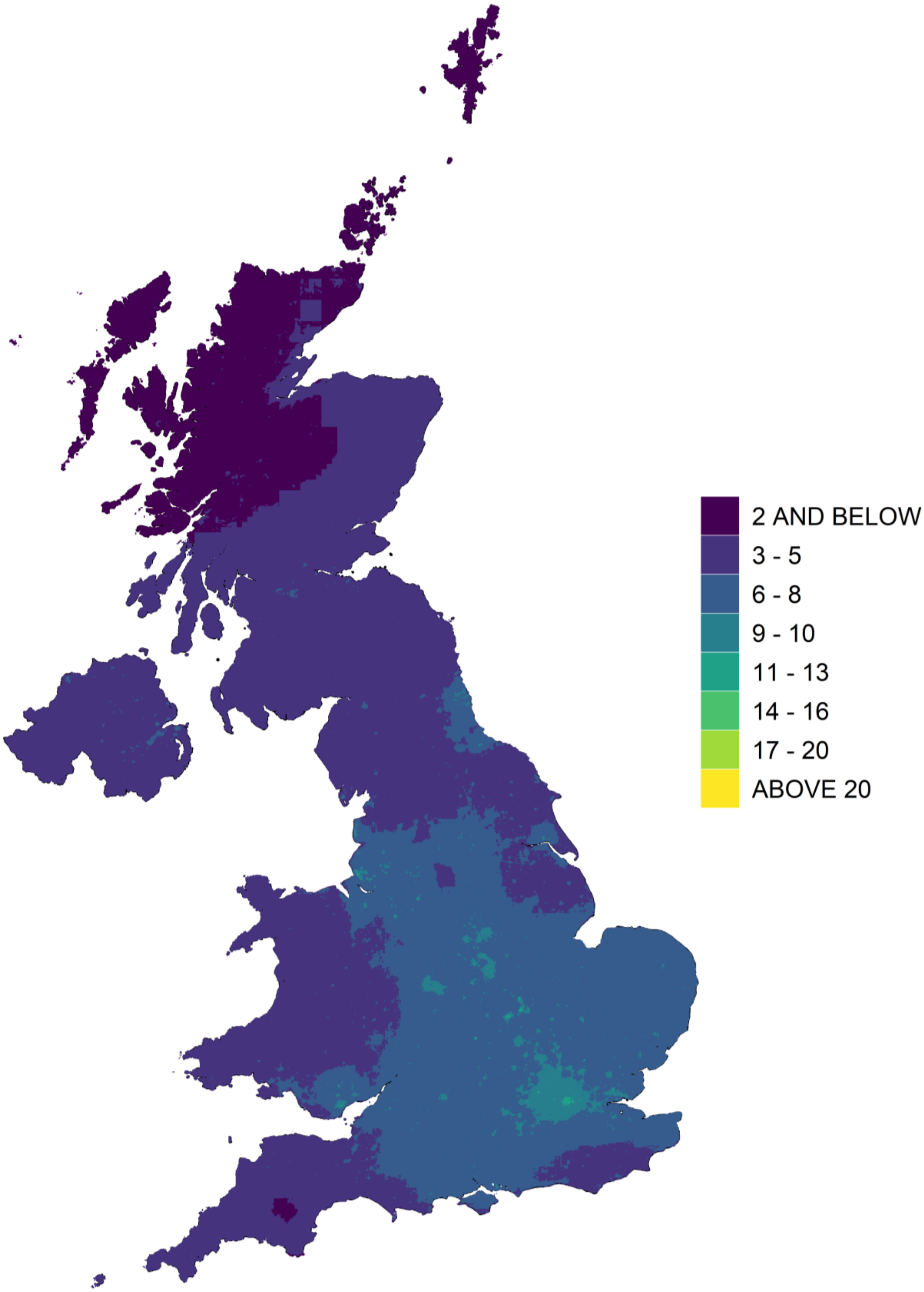
5.4 $PM_{2.5}$ Particulate Matter

5.4.1 $PM_{2.5}$: Spatial Distribution

Figure 5-11 shows modelled annual mean background $PM_{2.5}$ concentrations for 2022. These were highest in the centre, south and east of the UK, and lower in the north and west. Modelled concentrations ranged from 2 µg m^{-3} or less in northwest Scotland and a small area of Devon to 6-8 µg m^{-3} over most of southern and central England. Within cities such as London and Birmingham, modelled concentrations were higher, but everywhere in the UK was well within the Stage 2 limit value of 20 µg m^{-3}, as reported in **Section 4**.

As in the case of other traffic-related pollutants, maps of modelled annual mean roadside concentrations are also produced. However, they are no longer included in this series of reports because the detail can be seen much more clearly in the interactive versions of the maps, available on UK-AIR at https://uk-air.defra.gov.uk/data/gis-mapping/. No roadside locations had modelled annual mean $PM_{2.5}$ concentrations greater than the Stage 2 limit value of 20 µg m^{-3}; this is consistent with the compliance assessment reported in **Section 4**.

Figure 5-11 Annual Mean Background $PM_{2.5}$ Concentration, 2022 ($\mu g\ m^{-3}$)



(An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/. Please note the bands and default colour scale may be different to those used above.)

5.4.2 $PM_{2.5}$: Changes Over Time

Until 2008, routine monitoring of $PM_{2.5}$ within the AURN was confined to a small number of sites in London. Therefore, in this report, trend analysis for $PM_{2.5}$ concentrates on years 2009 onwards, during which $PM_{2.5}$ monitoring has been more widespread. **Figure 5-12** shows trends in $PM_{2.5}$ concentration at 12 long-running urban background AURN sites, 2009-2022. All 12 sites show a statistically significant downward trend in $PM_{2.5}$ concentration, significant at the 0.001 confidence level (as indicated by the three asterisks).

Figure 5-12 De-seasonalised Trends in Ambient $PM_{2.5}$ Concentration, 12 Long-Running Urban Background AURN Sites 2009-2022

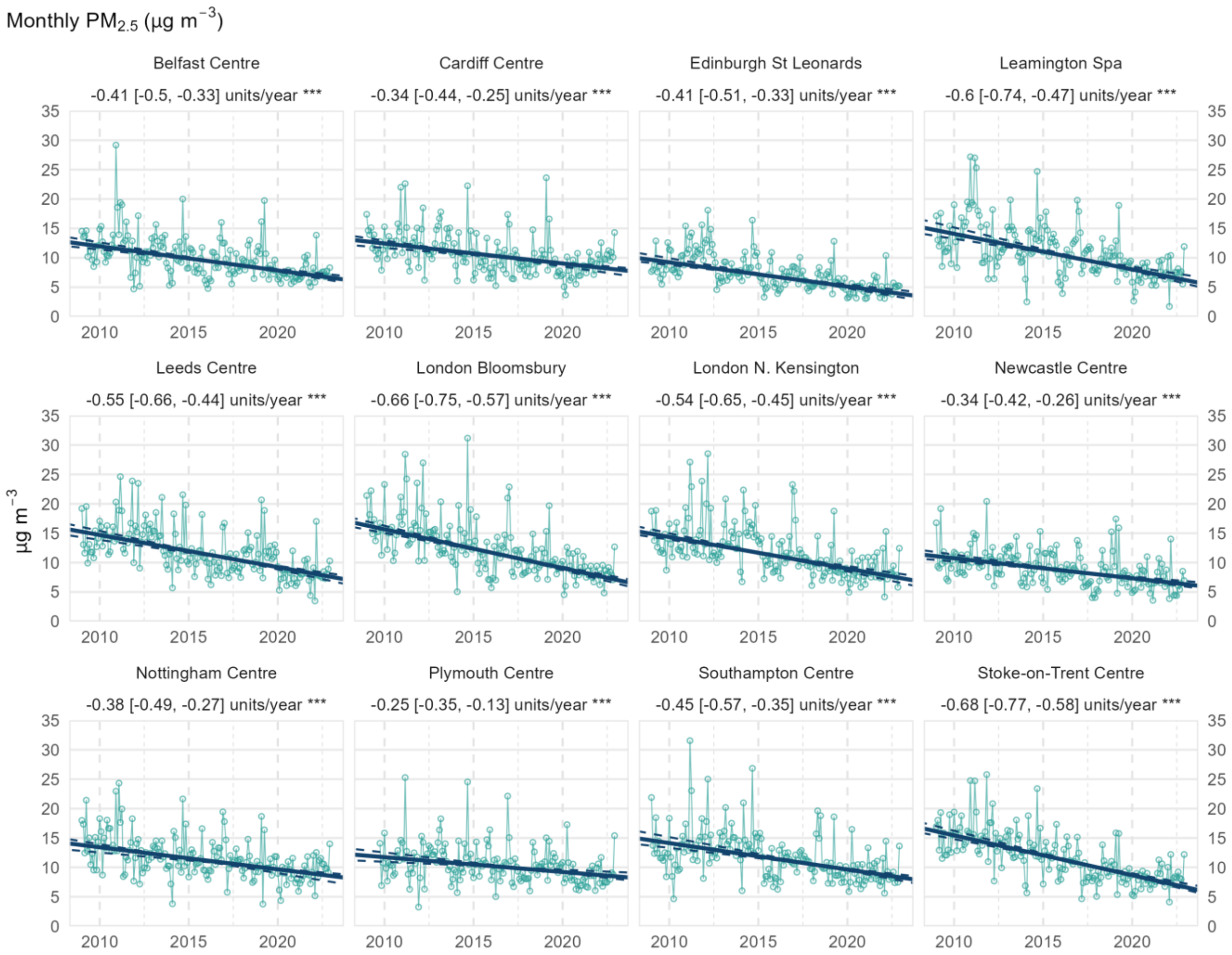


Figure 5-13 shows trends over the same period for $PM_{2.5}$ at nine long-running urban traffic AURN sites, all of which have been measuring this pollutant since 2010 or earlier. Eight of the nine sites show decreasing trends, statistically significant at the 0.001 confidence level, between 2009 and 2022. The exception is Swansea Roadside: in previous years, this site has shown an increasing trend in $PM_{2.5}$ concentration in the dataset from 2009 onwards (as it still does for PM_{10}). It now shows a decreasing trend although this is not statistically significant.

Figure 5-13 De-seasonalised Trends in Ambient $PM_{2.5}$ Concentration, Nine Long-Running Urban Traffic AURN Sites 2009-2022

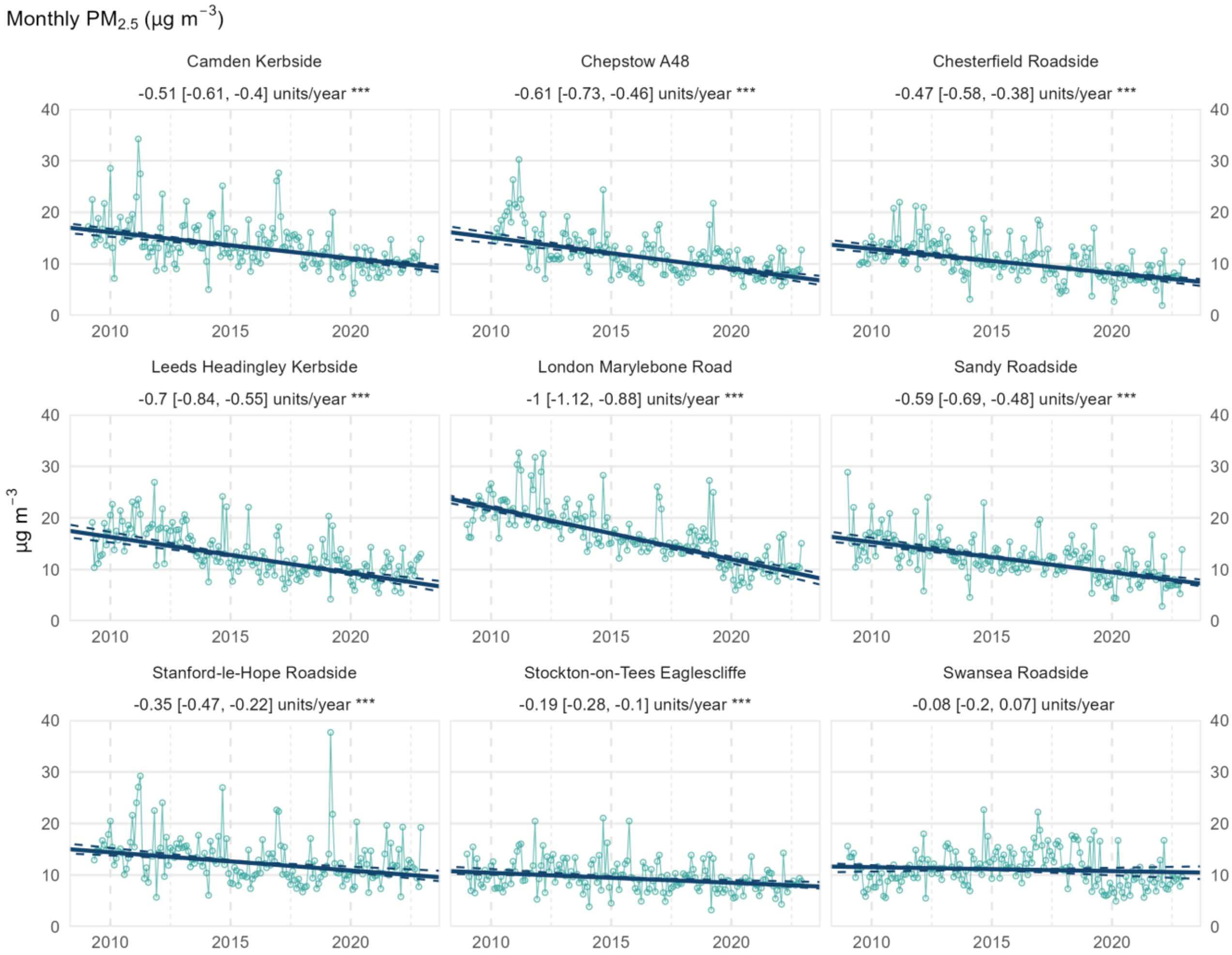
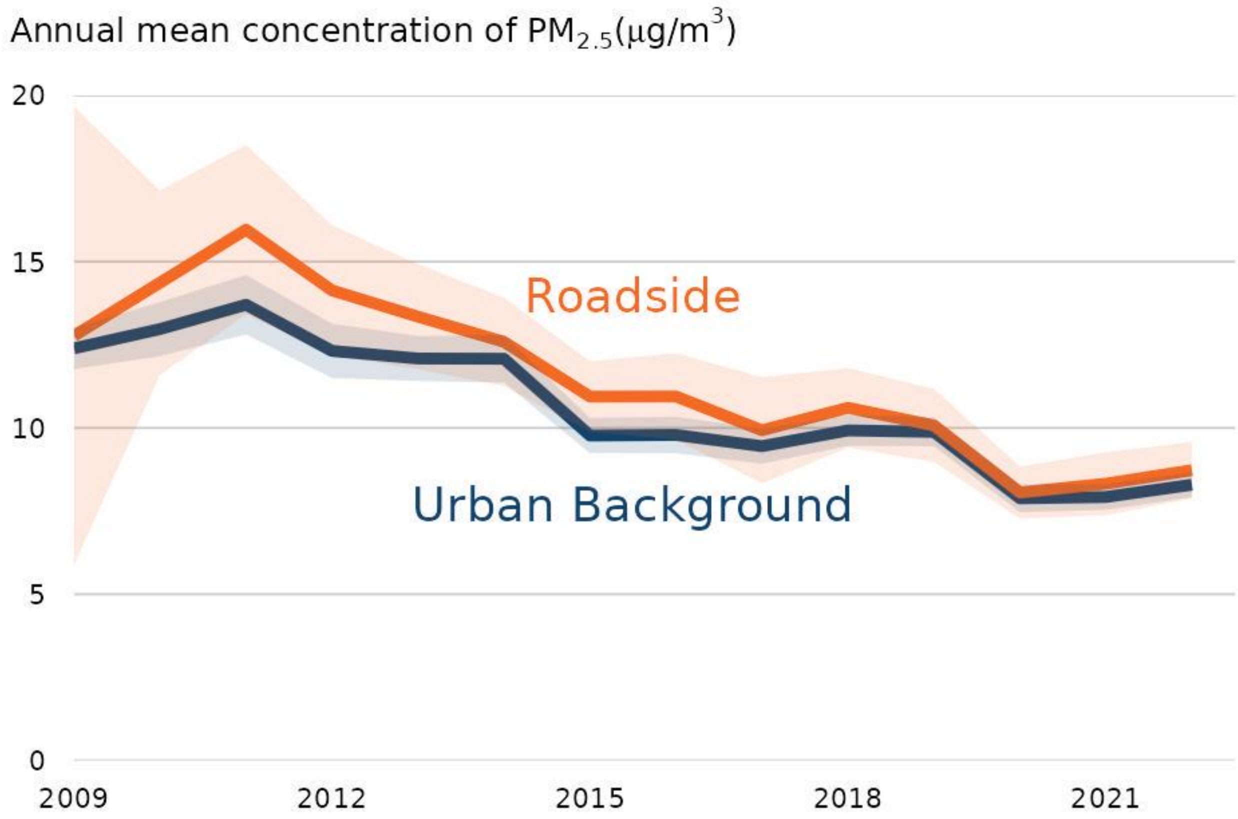


Figure 5-14 is taken from Defra's National Air Quality Statistics web page for PM_{10} and $PM_{2.5}$, at https://www.gov.uk/government/statistics/air-quality-statistics/concentrations-of-particulate-matter-pm10-and-pm25 (Defra, 2023e). This shows annual mean $PM_{2.5}$ concentrations averaged over all included AURN sites that had annual data capture greater than or equal to 75% in the relevant year. Roadside (urban traffic) and urban background sites are shown by separate, labelled, lines. This graph shows years from 2009 onwards: although there was some $PM_{2.5}$ monitoring before then, the number of sites was very small.

Shaded areas surrounding the lines show the 95% confidence interval of the annual mean for each site classification. The very wide confidence intervals in 2009 – 2011, especially for roadside sites, reflect the small number of sites measuring $PM_{2.5}$ in these early years.

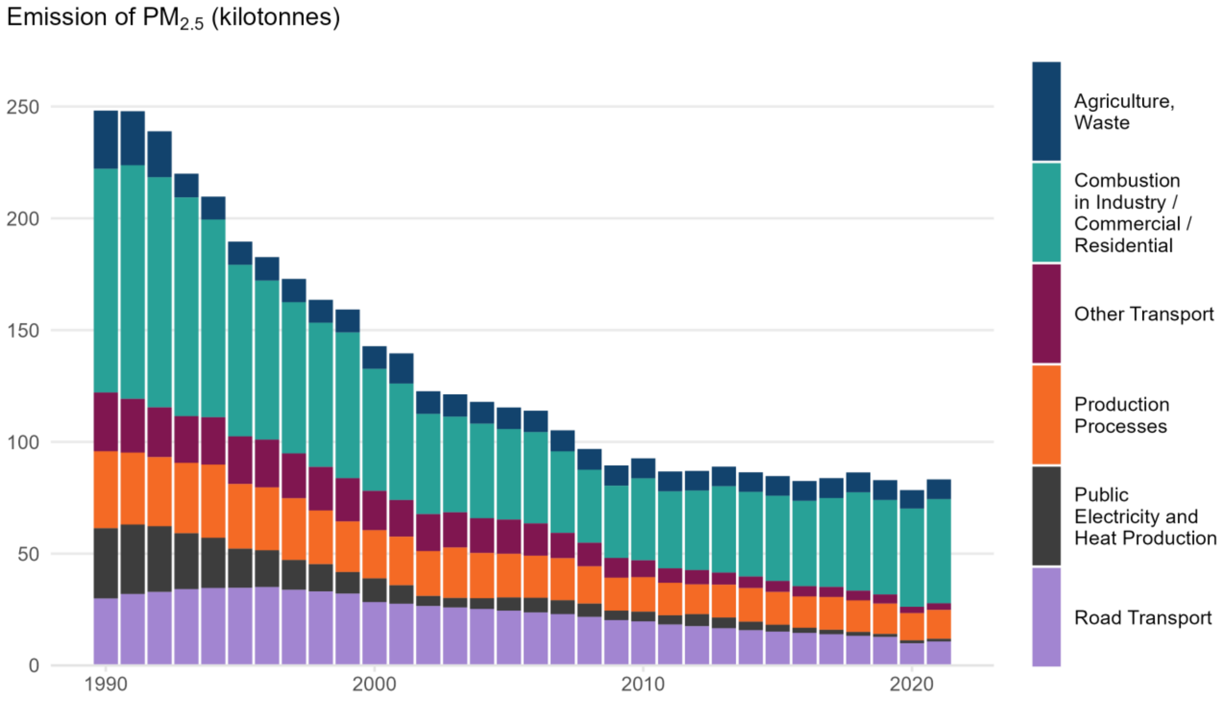
Figure 5-14 Annual mean concentrations of $PM_{2.5}$ in the UK, by AURN Site Classification, 2009 to 2022. Shaded areas either side of each line show the 95% confidence interval of the mean. ***(Source: https://www.gov.uk/government/statistics/air-quality-statistics/concentrations-of-particulate-matter-pm10-and-pm25)***



Finally, **Figure 5-15** shows the estimated annual emission of $PM_{2.5}$, from 1990 to 2021. The graph shows that emissions have decreased in a similar manner to emissions of PM_{10}, with a steady decrease from the early 1990s, and a clear levelling off around 2010 with no further consistent decrease until 2020. Estimated UK emissions of $PM_{2.5}$ have declined by 67% since 1990 due mainly to a reduction in coal use, and the banning of crop residue burning in 1993. Emissions from coal-fired power stations have also fallen by 99.9% since 1990. The largest source category for $PM_{2.5}$ is combustion in industry, residential and commercial premises. Estimated emissions from this source have increased over the past decade, both in real terms and as a proportion of the UK total. Residential and industrial combustion of wood and other biomass fuels have increased since 2000 and have become a substantial source of total $PM_{2.5}$ emissions.

Estimated $PM_{2.5}$ emissions from both road transport and other transport showed a dip in 2020, similar to that observed for PM_{10} and attributed to the travel restrictions resulting from the COVID-19 pandemic.

Figure 5-15 Estimated Annual UK Emissions of $PM_{2.5}$ (kt), 1990 – 2021. (Source: NAEI 2022)



5.5 Ozone

5.5.1 O_3: Spatial Distribution

Figure 5-16 shows the average number of days per year with maximum daily running 8-hour mean ozone concentration > 120 µg m^{-3}, over the **three** years 2020-2022. Highest concentrations occurred in two relatively small areas on England's south-east and south-west coasts. Apart from this, concentrations elsewhere showed a fairly typical pattern for the UK, being generally slightly higher in the south and east, and lower in more northern and western areas.

This map shows slightly lower values around some major conurbations (such as London, Birmingham, Nottingham, Derby and Hull). Ozone concentrations tend to be lower in built-up areas, due to the 'scavenging' effect of nitric oxide (NO), which reacts with ozone.

Figure 5-17 shows the number of days per year with maximum daily running 8-hour mean ozone concentration > 120 µg m^{-3}, for 2022 only. This 2022 value is higher over most of the UK than the 2020-2022 average, reflecting the fact that ozone concentrations in 2022 were generally higher than in the previous two years. Again, a fairly typical pattern can be seen, with the south and eastern areas generally experiencing more days with higher concentrations compared to the northern and western areas.

As in **Figure 5-16**, slightly lower values can be seen around some major cities, and in some cases, major routes between them are also just visible: again, due to the 'scavenging' effect of nitric oxide (NO) from local sources.

Figure 5-18 shows the AOT40 statistic, averaged over the past **five** complete years, 2018-2022. The AOT40 statistic (expressed in µg m^{-3}.hours) is the sum of the difference between hourly concentrations greater than 80 µg m^{-3} (= 40 ppb) and 80 µg m^{-3} over a given period using only the one-hour values measured between 0800 and 2000 Central European Time each day. This shows the same general pattern of higher AOT40 values to the south and east of the UK (outside of major cities), with lower values to the north and west.

Figure 5-19 shows the same statistic, for 2022 only. Although 2022 saw higher ozone concentrations than 2021, this map shows that the AOT40 statistic for 2022 was lower throughout most of the UK compared to the average of the most recent five years. The period 2018 to 2022 included 2018 and 2020, which also had relatively high ozone concentrations. Highest AOT40 values in 2022 occurred in the south-eastern part of the UK (south of a line approximately linking the Humber and Severn estuaries), but with lower concentrations in cities.

Figure 5-16 Average Number of days with Maximum Daily Running 8h Mean O_3 Concentration > 120 µg m^{-3} 2020-2022

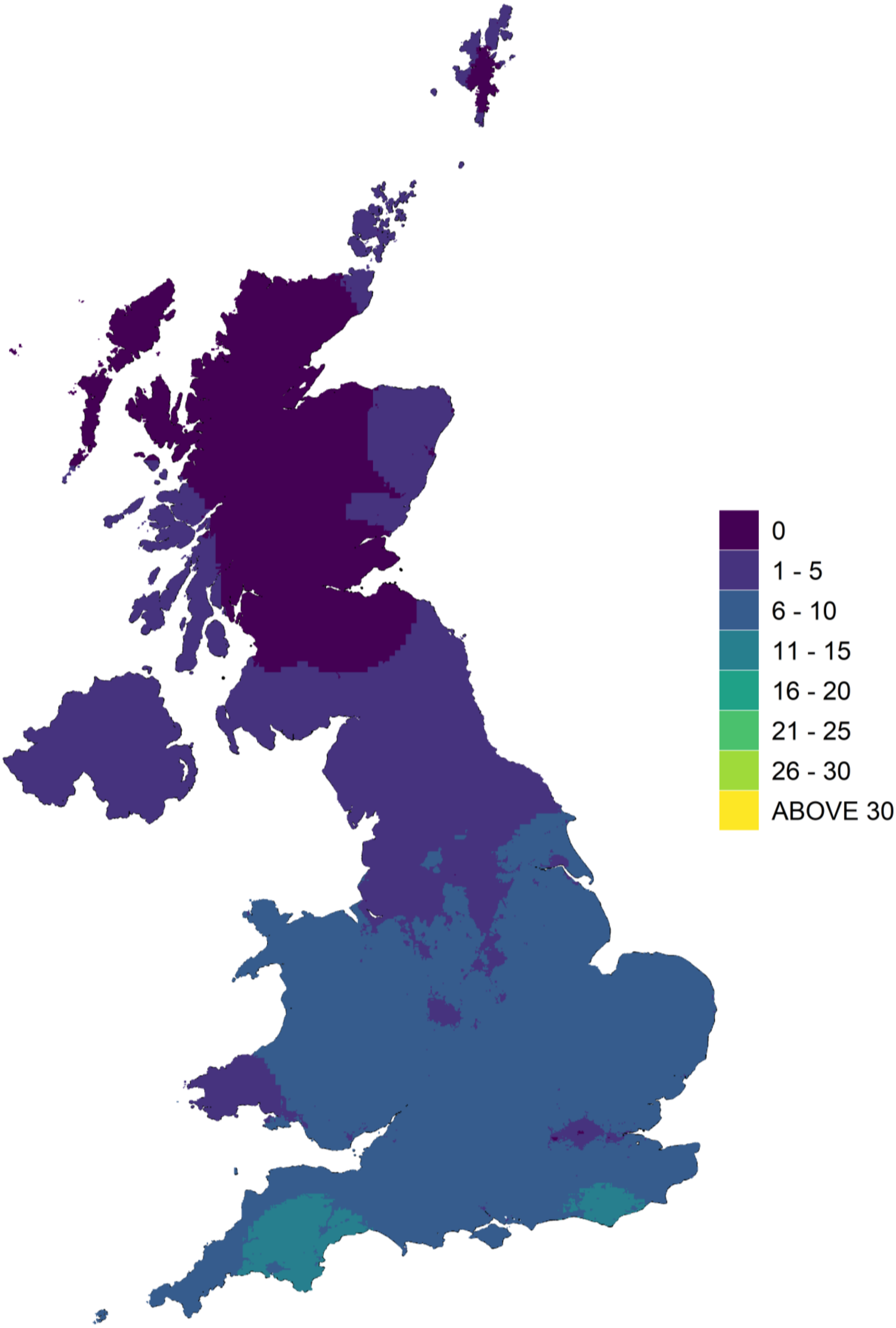
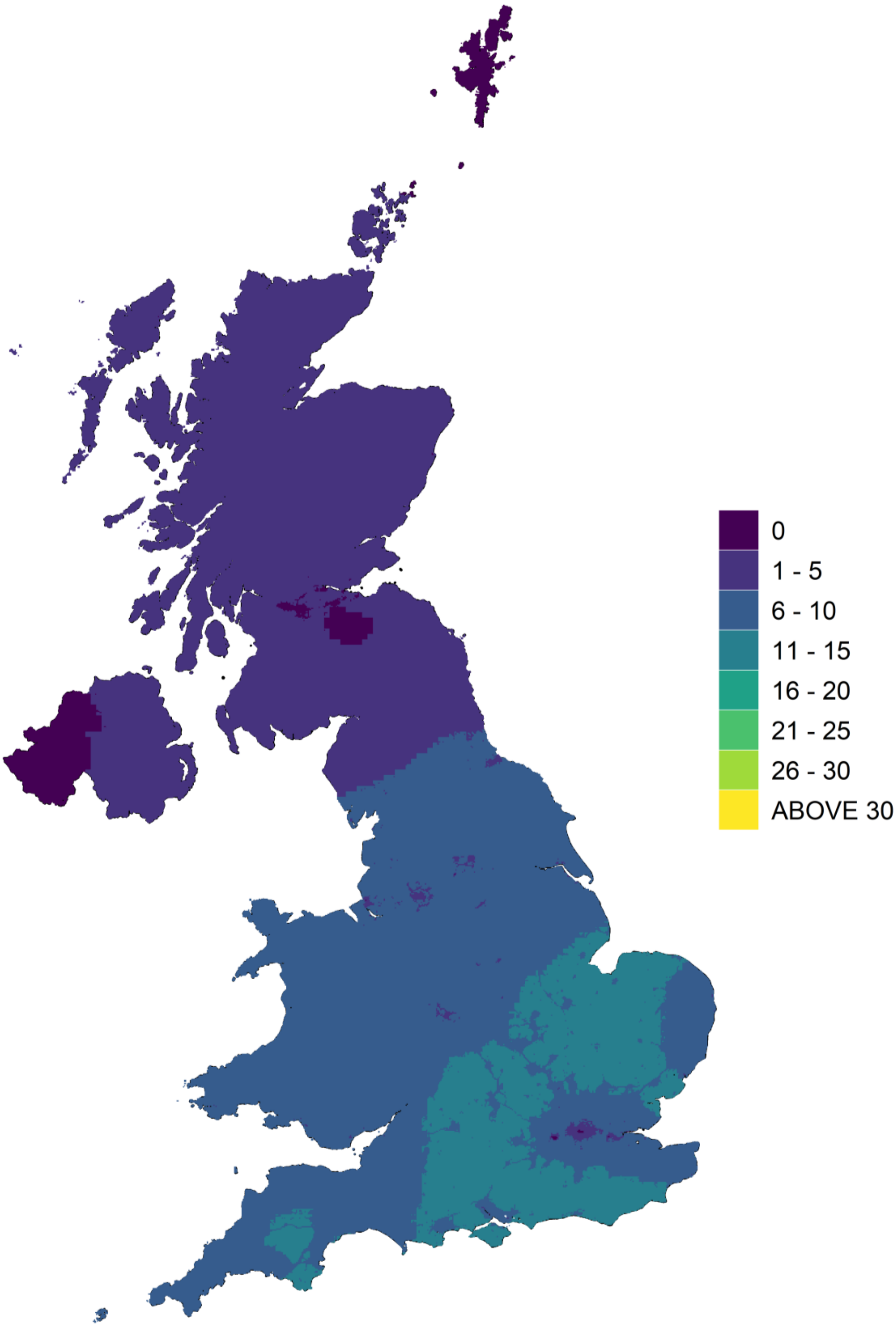


Figure 5-17 Days with Maximum Daily Running 8h Mean O_3 Concentration > 120 µg m^{-3}, 2022



(An interactive map of this metric is available at https://uk-air.defra.gov.uk/data/gis-mapping/. Please note the bands and default colour scale may be different to those used above.)

Figure 5-18 Average AOT40, 2018-2022 (µg m^{-3}.hours)

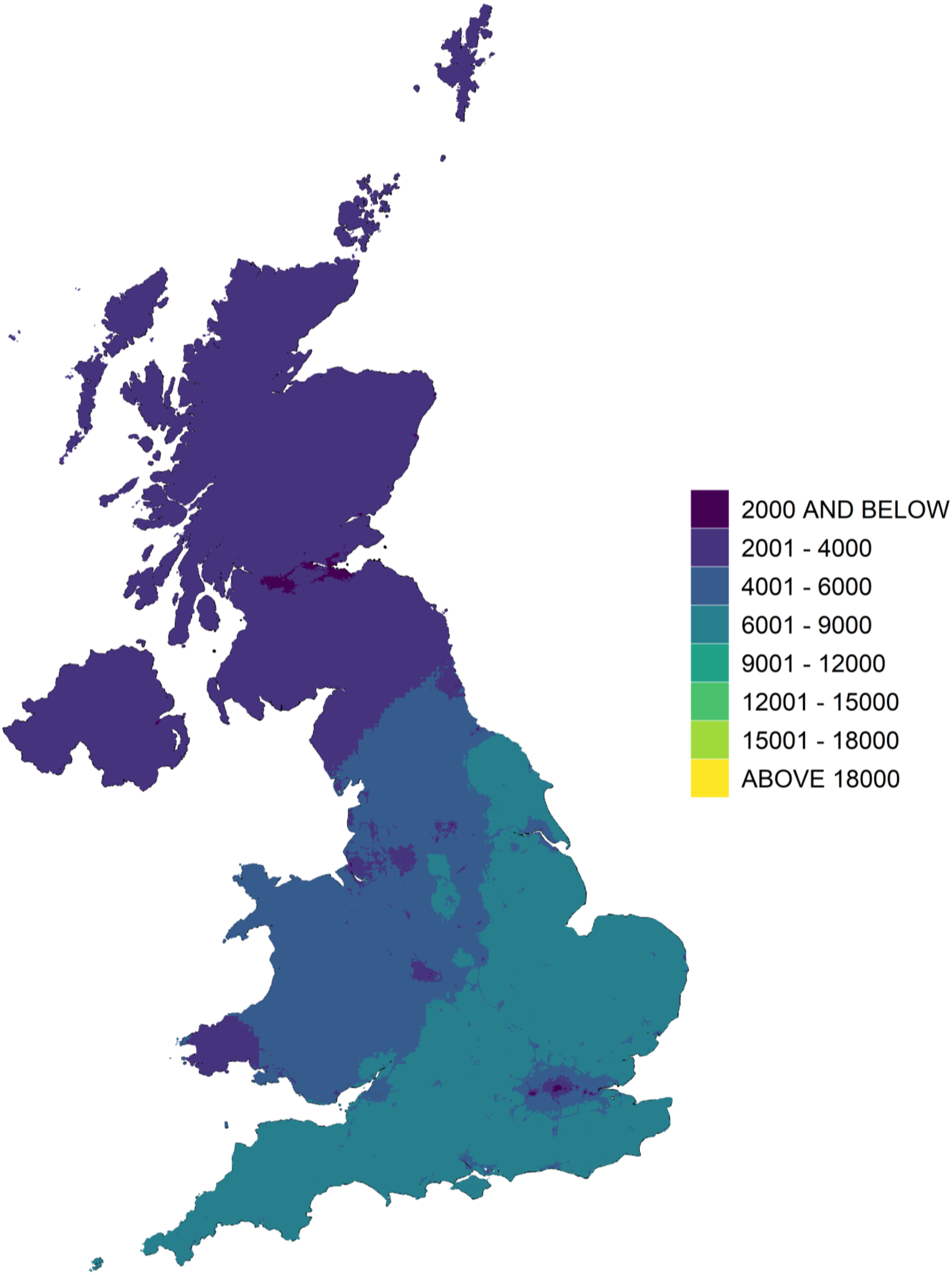
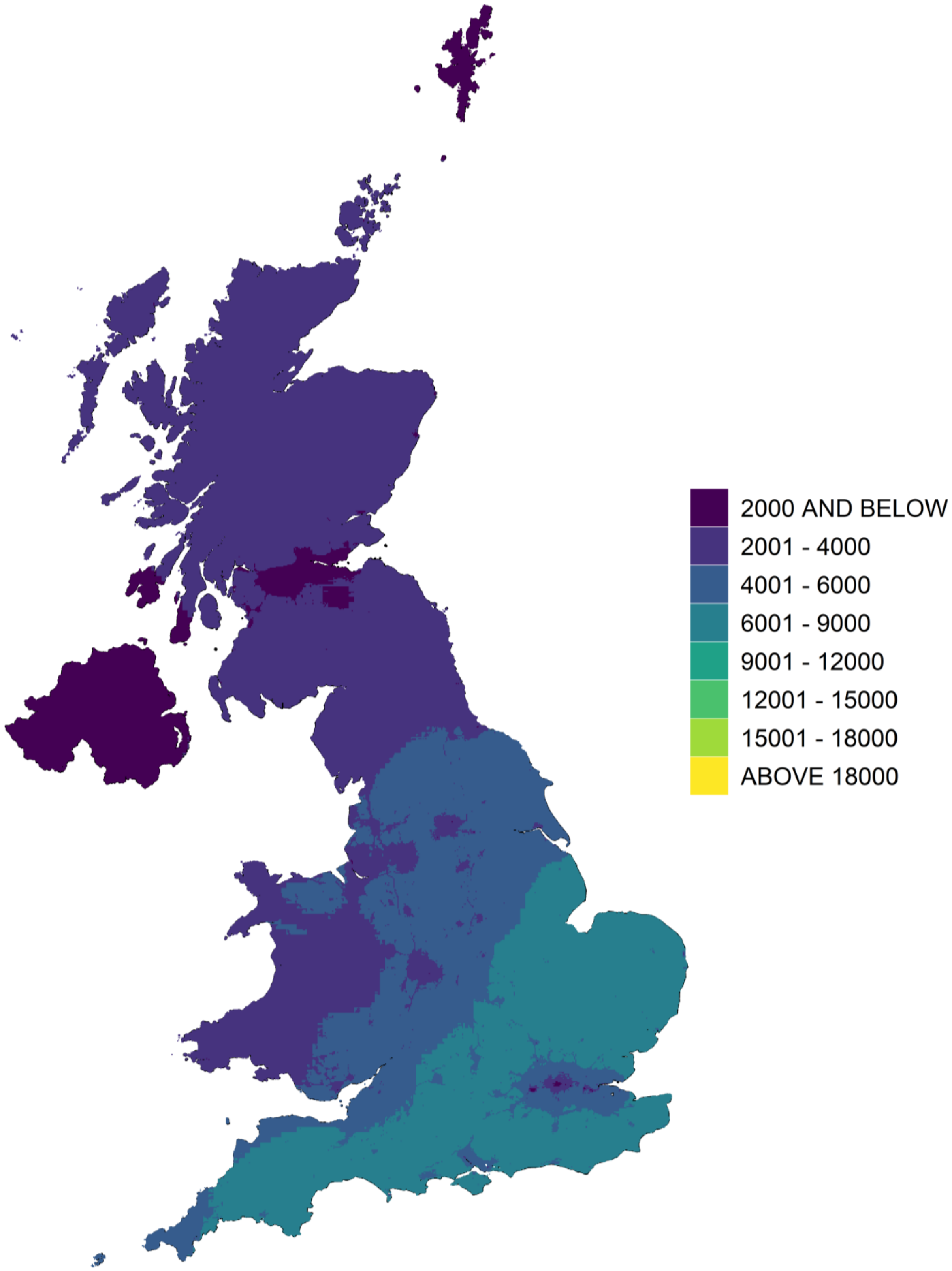


Figure 5-19 Average AOT40, 2022 (µg m^{-3}.hours)



5.5.2 O_3: Changes Over Time

Figure 5-20 shows a trend plot of ozone concentrations at 12 long-running rural AURN sites over the period 1992-2022 (Aston Hill, Bush Estate, Eskdalemuir, High Muffles, Ladybower, Lough Navar, Lullington Heath, Narberth, Rochester Stoke, Sibton, Strathvaich and Yarner Wood). Rural sites have been chosen because concentrations of ozone are typically highest in rural areas.

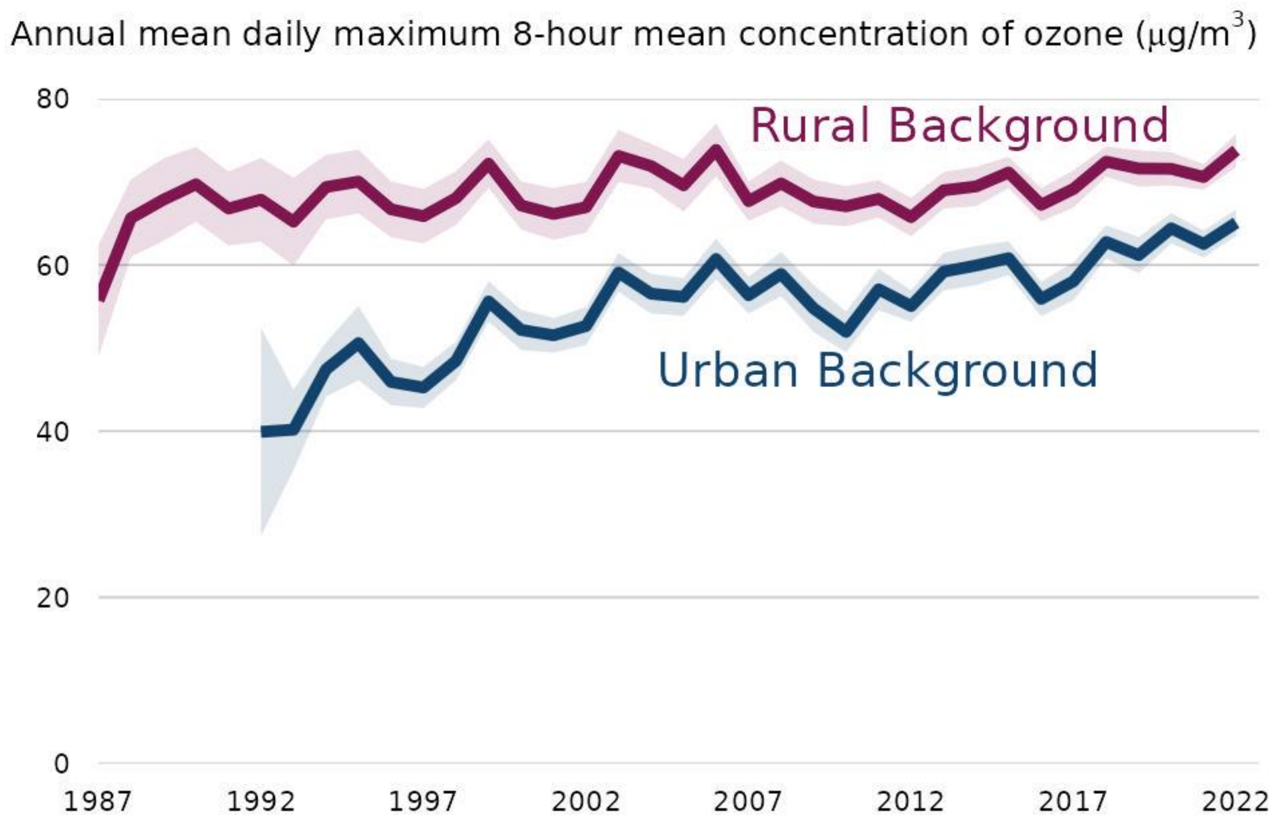
Seven sites (Bush Estate, Eskdalemuir, High Muffles, Ladybower, Rochester Stoke, Sibton and Yarner Wood) show highly significant positive trends over this period. Two (Aston Hill and Lough Navar) show positive trends of lower significance. Two (Lullington Heath and Narberth) show no statistically significant trend, and only one (Strathvaich) shows a statistically significant negative trend. While there is no consistent pattern, upward trends are present at more than half of these sites. There is evidence that the 'hemispheric background' ozone concentration has increased since the 1950s, and the observed trends may reflect this (Vinzargan, 2004).

Figure 5-20 De-seasonalised Trends in Ozone Concentration at 12 Long-Running Rural AURN Sites, 1992 - 2022.

This increasing trend in background ozone concentrations is also illustrated by **Figure 5-21**, taken from Defra's National Air Quality Statistics web page for ozone, at https://www.gov.uk/government/statistics/air-quality-statistics/concentrations-of-ozone , (Defra, 2023f).

This shows the annual mean of the daily maximum 8-hour mean, averaged over all sites that had annual data capture greater than or equal to 75%. Separate lines are shown for urban background sites and rural background sites, with the 95% confidence intervals shown as shaded areas either side of each line. Ozone has been monitored in the UK since the 1980s, and this graph shows years from 1987 onwards.

Figure 5-21 Annual mean daily maximum 8-hour mean O_3 concentrations in the UK, 1987 to 2022. ***(Source: https://www.gov.uk/government/statistics/air-quality-statistics/concentrations-of-ozone)***



Ozone is not emitted in significant quantities directly from any source in the UK (instead, it is formed from reactions involving other pollutants). Ozone is therefore not included in the NAEI, and trends in ozone emissions are not covered by this report.

5.6 Sulphur Dioxide

5.6.1 SO_2: Spatial Distribution in the UK

Figure 5-22 shows how the modelled 99.73rd percentile[5] of hourly mean sulphur dioxide concentration varied across the UK during 2022. This statistic corresponds approximately to the 25th highest hourly mean (in the case of a full year's data); if greater than the hourly mean limit value it indicates that the limit value was exceeded on more than the 24 permitted occasions. There were no areas in which this statistic exceeded the limit value of 350 µg m^{-3}.

Figure 5-23 shows the modelled 99.18th percentile of 24-hour means (which corresponds to the 4th highest day in a full year). If greater than the 24-hourly mean limit value of 125 µg m^{-3}, this would indicate that there were more than the permitted three exceedances in the year. There were no areas of the UK where this was the case in 2022. The modelled 99.18th percentile is 10 µg m^{-3} or less over most of the UK: it was higher in some small areas due to specific local industrial and other emissions.

The online interactive maps at https://uk-air.defra.gov.uk/data/gis-mapping/ include annual mean background SO_2 concentrations but not maps of the above metrics.

[5] Where the Directive allows exceedances on a number of occasions (i.e. limit value not to be exceeded more than a specified number of times per year), percentiles are used to illustrate this. These are simply the xth highest hourly mean divided by the number of hours in a year, or yth highest daily mean divided by the days in a year, expressed as a percentage.

Figure 5-22 99.73rd Percentile of 1-hour Mean SO_2 Concentration, 2022 ($\mu g\ m^{-3}$)

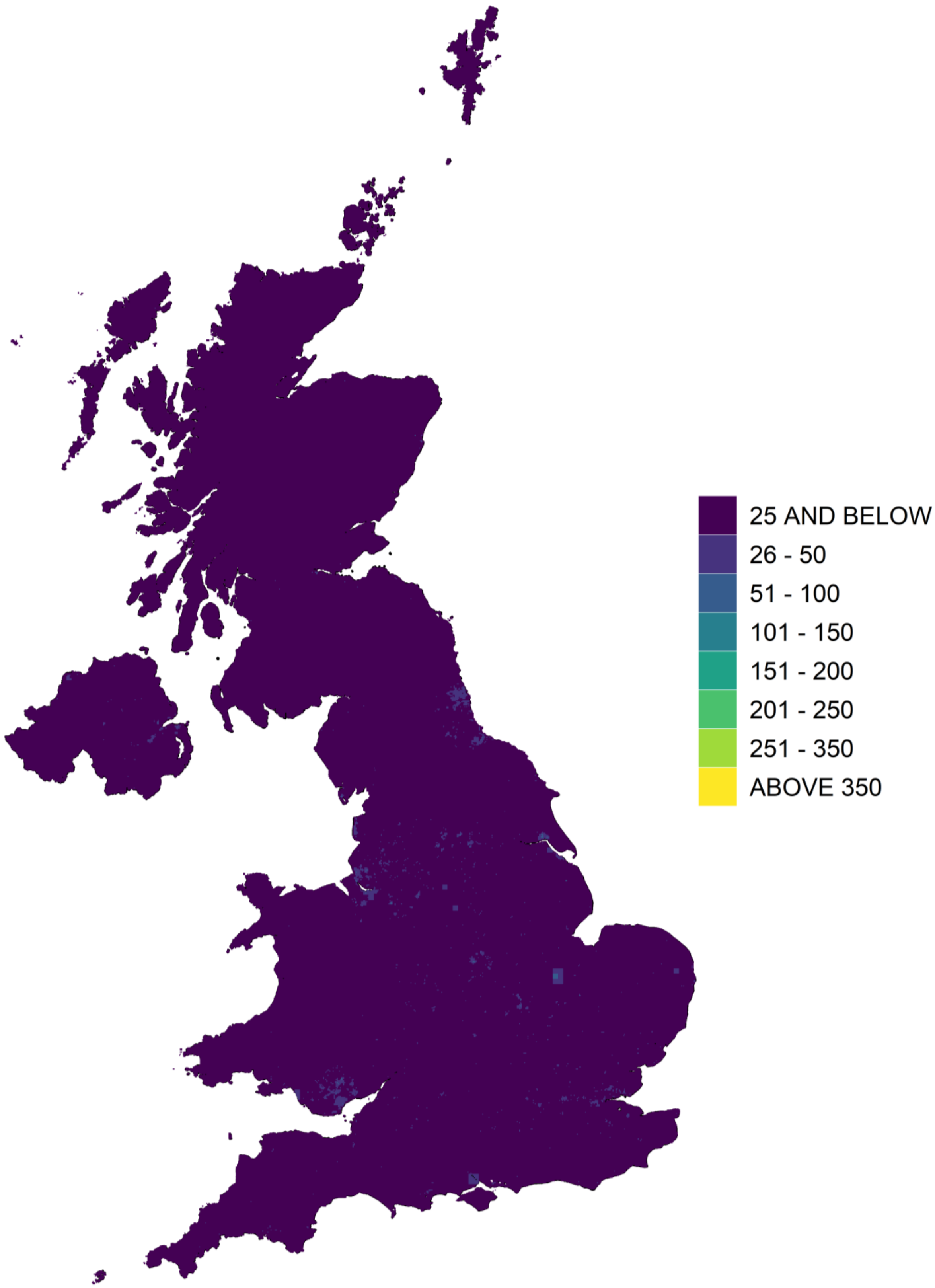
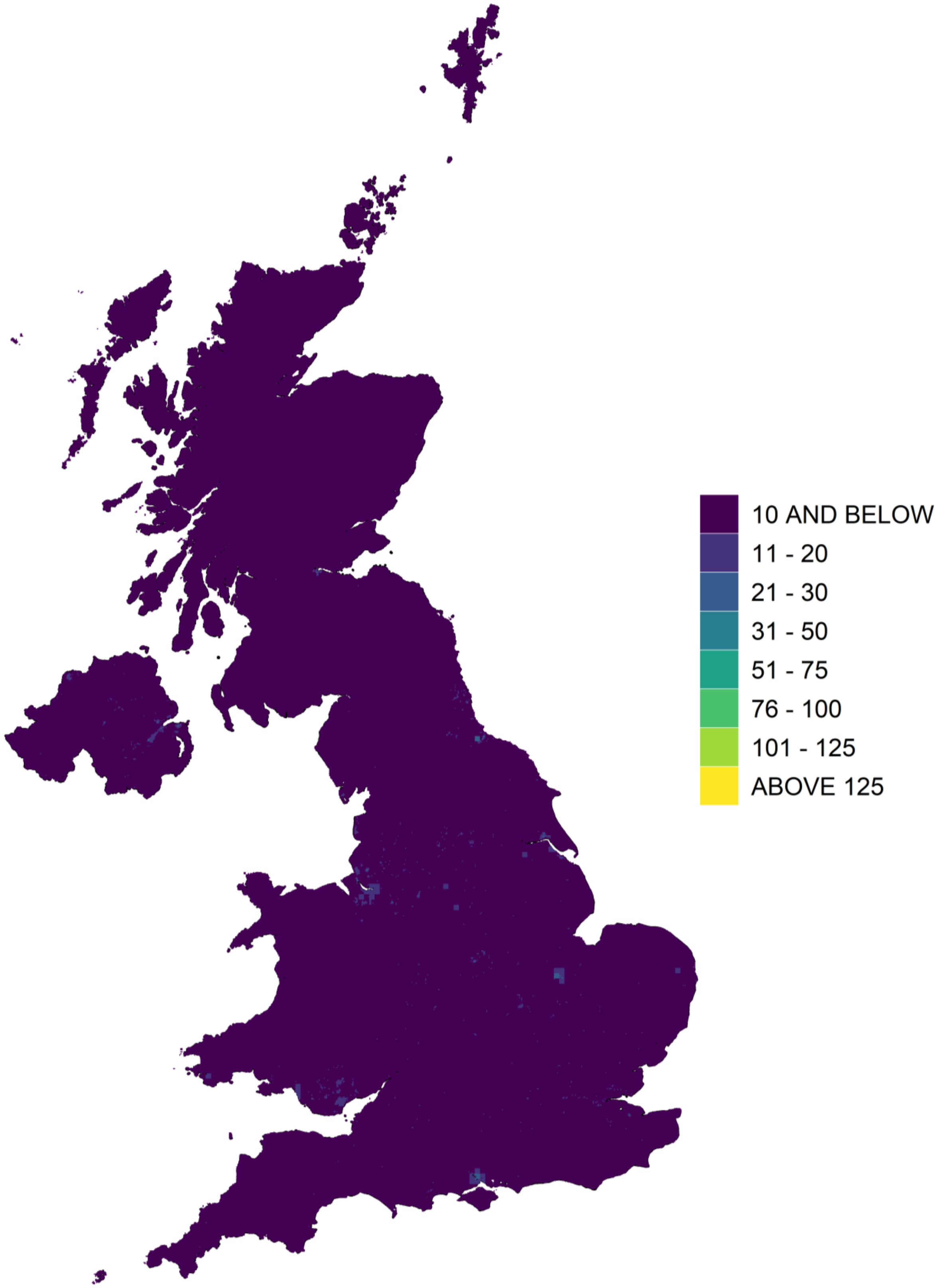


Figure 5-23 99.18th Percentile of 24-hour Mean SO_2 Concentration, 2022 ($\mu g\ m^{-3}$)



5.6.2 SO_2: Changes Over Time

Figure 5-24 shows how ambient concentrations have changed over the period 1992 to 2022, at the six AURN monitoring stations that have monitored this pollutant for the longest time and remained in operation in 2022. All six stations show a downward trend that is statistically highly significant at the 0.001 level.

However, the decrease has not been linear. At most of these sites, the downward trend is steepest for the 1990s and early 2000s: there is a clear flattening-off in more recent years from around 2010.The pattern observed in ambient SO_2 concentrations appears to reflect changes in national emissions.

Figure 5-24 De-seasonalised Trends in SO_2 Concentration, 1992-2022 at Six Long-running AURN Sites

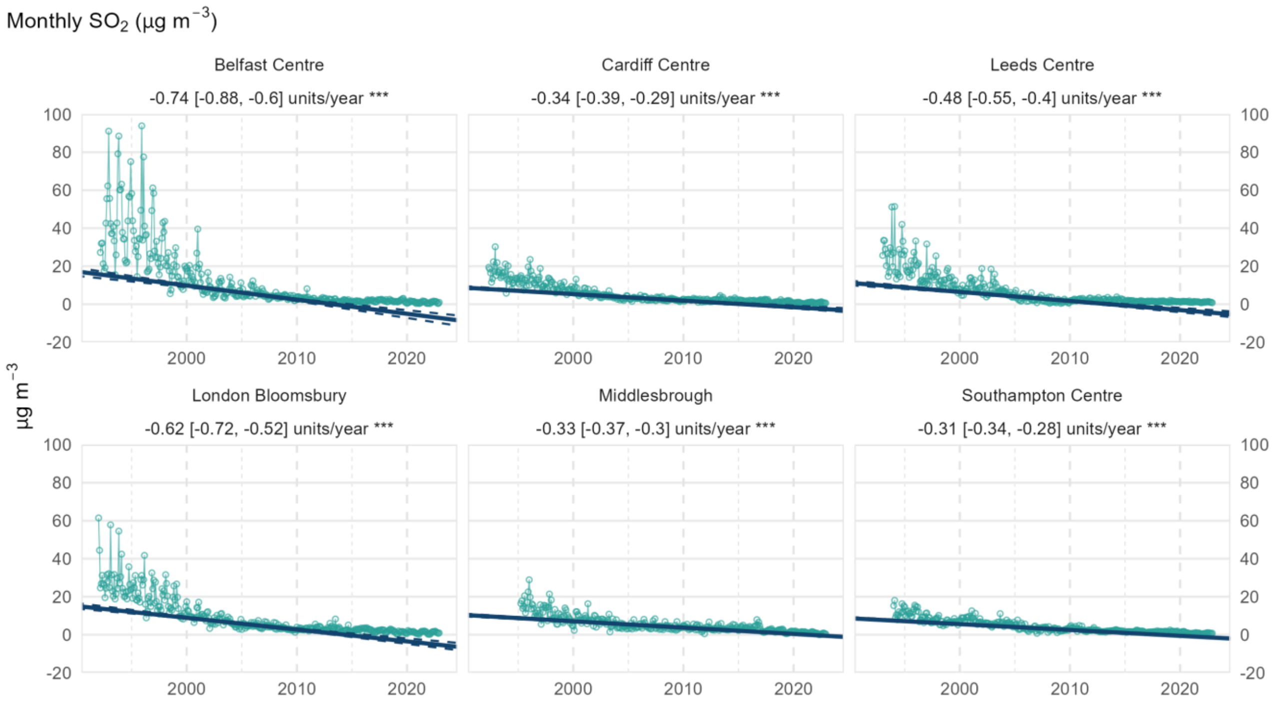


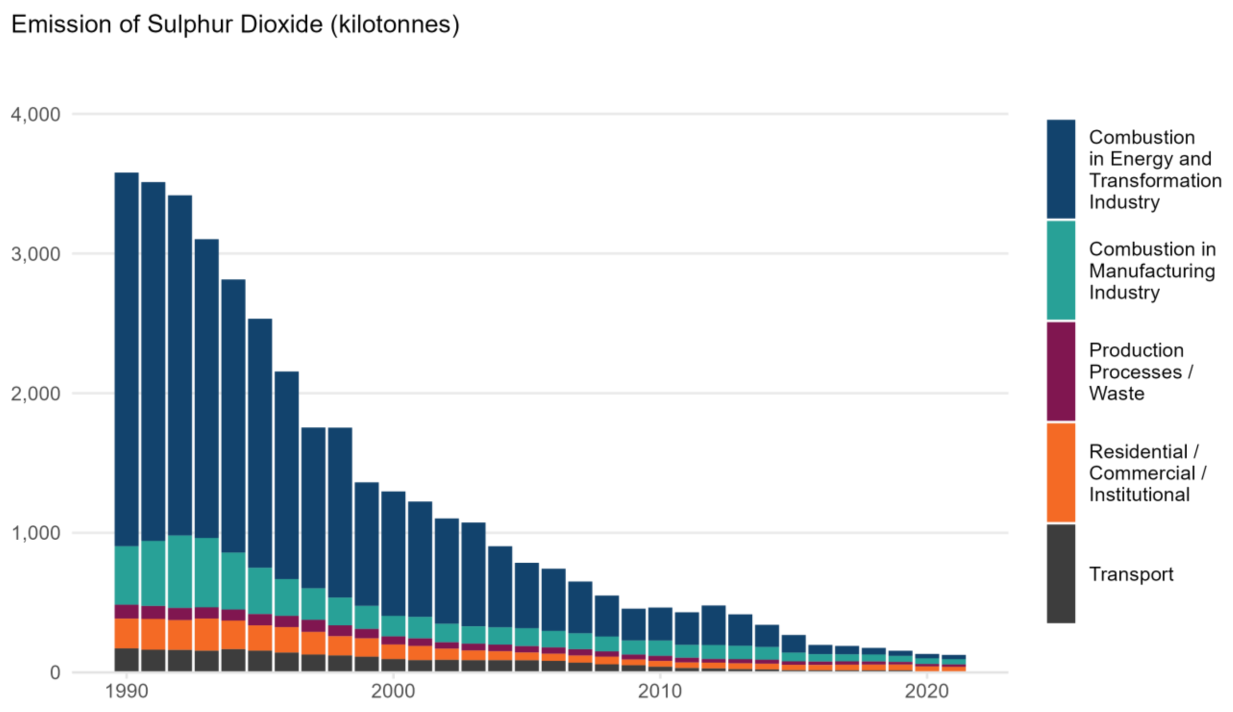
Figure 5-25 is based on data from the NAEI and shows the UK's estimated annual emissions of sulphur dioxide from 1990 to 2021 (the most recent year for which data are available). The decrease in emissions over time shown here is the continuation of an on-going trend observed by the NAEI throughout the 1970s and 1980s, partly due to the decline of the UK's heavy industry. The main source of this pollutant is fossil fuel combustion: SO_2 emissions in the UK have decreased substantially since 1990, due to reductions in the use of coal, gas and oil. More stringent legislation restricting the sulphur content of fuel oils and diesel fuel used in road vehicles has also helped to reduce emissions of SO_2.

Around 2009, the graph flattens off, and shows a slight upturn in total SO_2 emissions in 2012. The NAEI pollutant information page for SO_2 (at https://naei.beis.gov.uk/overview/pollutants?pollutant_id=8) explains this as follows: "*As a result of the economic downturn the drive to cut energy costs has resulted in an increase* *in solid fuel use, particularly in 2012 some coal-sensitive pollutants have seen a significant rise in coal burning emissions*."

Following 2012, the downward trend in SO_2 emissions continues: the NAEI pollutant information attributes the decrease between 2012 and 2018 to a decrease of over 40% in coal combustion in power stations.

The UK has met its targets for 2021, set by the National Emission Ceilings Directive (2016) and the Gothenburg Protocol. Latest projections suggest that emissions will need to be reduced further to meet 2030 Emission Reduction Commitments.

Figure 5-25 Estimated Annual UK Emissions of SO_2 (kt), 1990 – 2021 (source: NAEI 2022)



5.7 Carbon Monoxide

5.7.1 CO: Spatial Distribution

Ambient concentrations of CO throughout the UK have been well within the limit value for many years. Therefore, since 2010, maps of modelled concentration have no longer been routinely produced for CO.

5.7.2 CO: Changes over time

Because concentrations of CO are well within the limit value, relatively few monitoring sites are required. Seven urban AURN sites currently monitor this pollutant, of which six (Belfast

Centre, Cardiff Centre, Edinburgh St Leonards, Leeds Centre, London Marylebone Road and London North Kensington) have operated for at least 10 years.

Figure 5-26 shows de-seasonalised trends at these six long-running AURN sites, from 1992 to 2022. All six show a highly significant downward trend over the period.

Figure 5-26 De-seasonalised Trends in CO Concentration, Six Long-Running AURN Sites 1992-2022

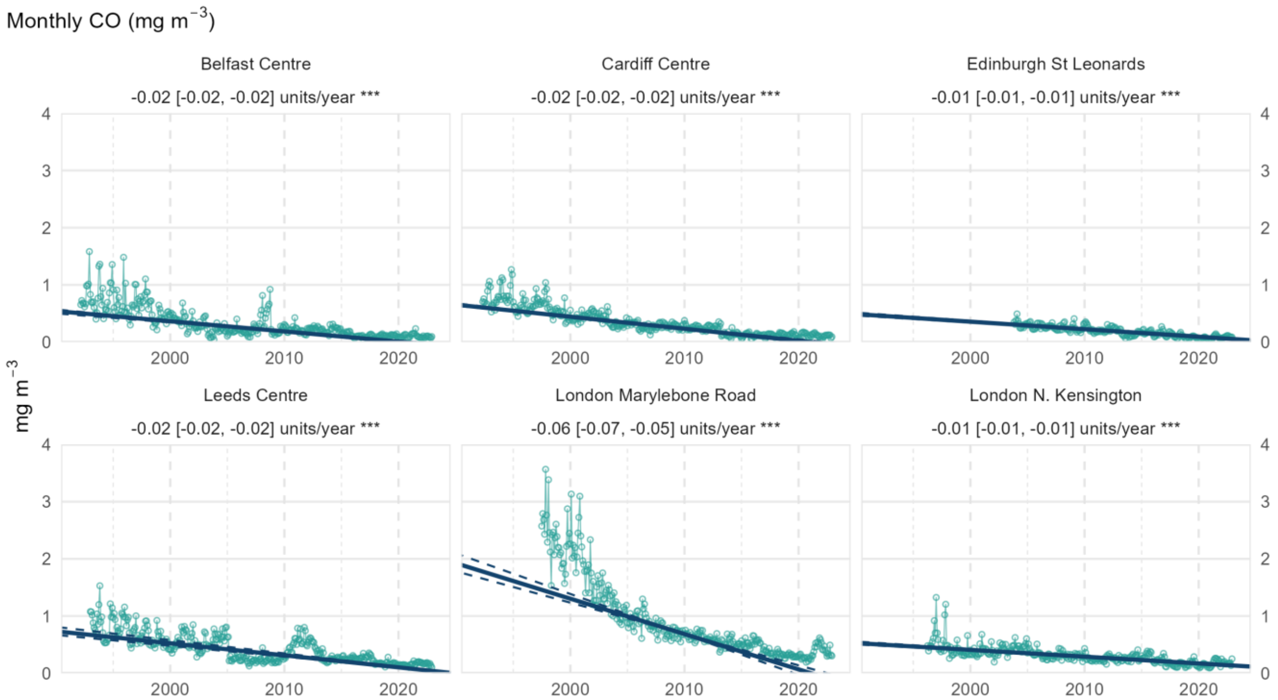
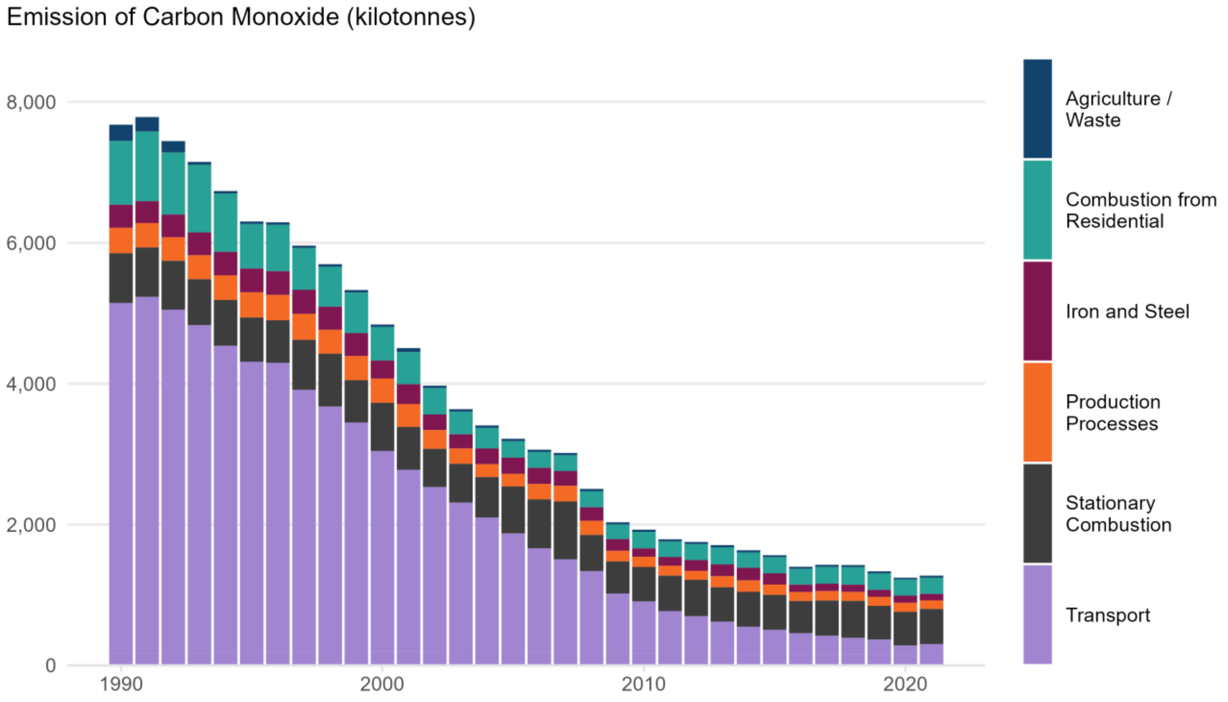


Figure 5-27 shows the estimated annual emissions of CO over the same period. The decreasing ambient concentrations reflect declining emissions over the last 25 years. The NAEI attributes the decrease in CO emissions to factors including EU-wide emission standards for road vehicles, a decline in industrial use of solid fuels, and a decline in the production of steel and non-ferrous metals (https://naei.beis.gov.uk/overview/pollutants?pollutant_id=4).

Figure 5-27 Estimated Annual UK Emissions of CO (kt), 1990 – 2021 (source: NAEI 2022)



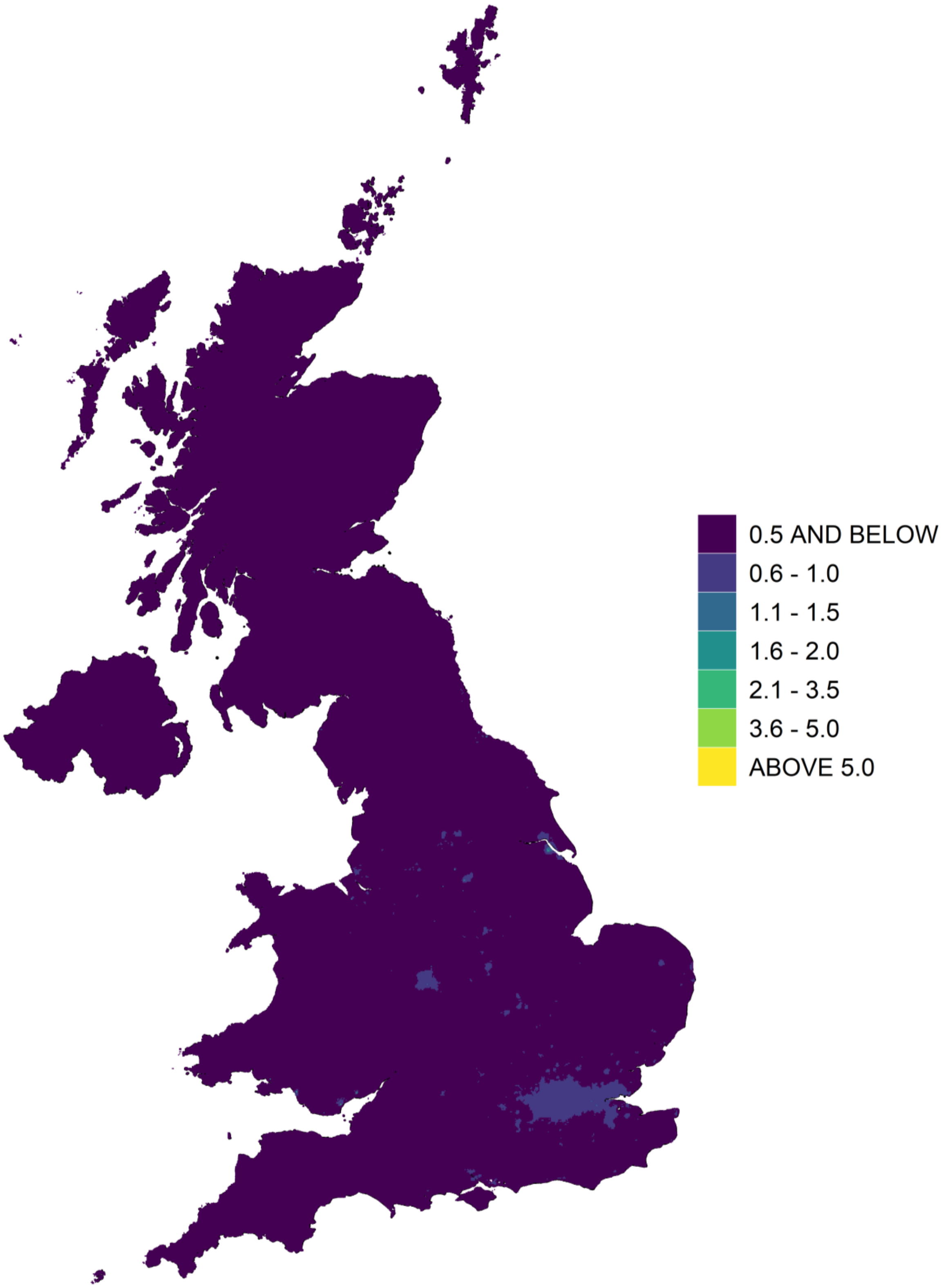
5.8 Benzene

5.8.1 Benzene: Spatial Distribution

Figure 5-28 shows the modelled annual mean background concentrations of benzene in 2022. Most areas outside major towns and cities had modelled benzene concentrations of less than 0.5 µg m^{-3}. Most urban areas had modelled concentrations below 1.0 µg m^{-3} with the exception of a few very small industrial areas. No locations in the UK exceeded the annual mean limit value of 5.0 µg m^{-3}.

Benzene is found in petrol and in vehicle emissions, therefore higher levels may be expected at roadside locations. Maps of modelled annual mean roadside benzene concentration are therefore also produced. However, as for other traffic-related pollutants, the detail in such maps can be difficult to see clearly, so these are no longer included in this series of reports. Instead, the reader is recommended to use the interactive version of the modelled roadside map, available on UK-AIR at https://uk-air.defra.gov.uk/data/gis-mapping/. Almost all road links had modelled concentrations below 1.0 µg m^{-3}: a very small number had higher modelled concentrations, but none were above 2.0 µg m^{-3}.

Figure 5-28 Annual Mean Background Benzene Concentration, 2022 (µg m^{-3})



(An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/. Please note the bands and default colour scale may be different to those used above.)

5.8.2 Benzene: Changes Over Time

Figure 5-29 shows a smoothed trend plot of ambient benzene concentration, based on the combined dataset from 14 long-running sites in the Non-Automatic Hydrocarbon Network, which have operated since 2002. These are: Barnsley Gawber, Belfast Centre, Haringey Roadside, Leamington Spa, Leeds Centre, Liverpool Speke, London Bloomsbury, Manchester Piccadilly, Middlesbrough, Newcastle Centre, Nottingham Centre, Oxford Centre Roadside, Southampton Centre and Stoke-on-Trent Centre.

The smoothed trend plot for these 14 sites shows a slight increase from 2002 to 2004, followed by a steep decrease between 2004 and 2008. From then on, the graph is much flatter, showing little further fall in ambient concentrations of benzene until 2012-2014 when there is a slight rise, followed by a further decrease in subsequent years to 2022. Benzene shows seasonal variation, which is illustrated by the graph (which is not de-seasonalised.)

Figure 5-29 Smoothed Trend Plot of Ambient Benzene Concentration, 14 Long-Running Non-Automatic Sites, 2002-2022

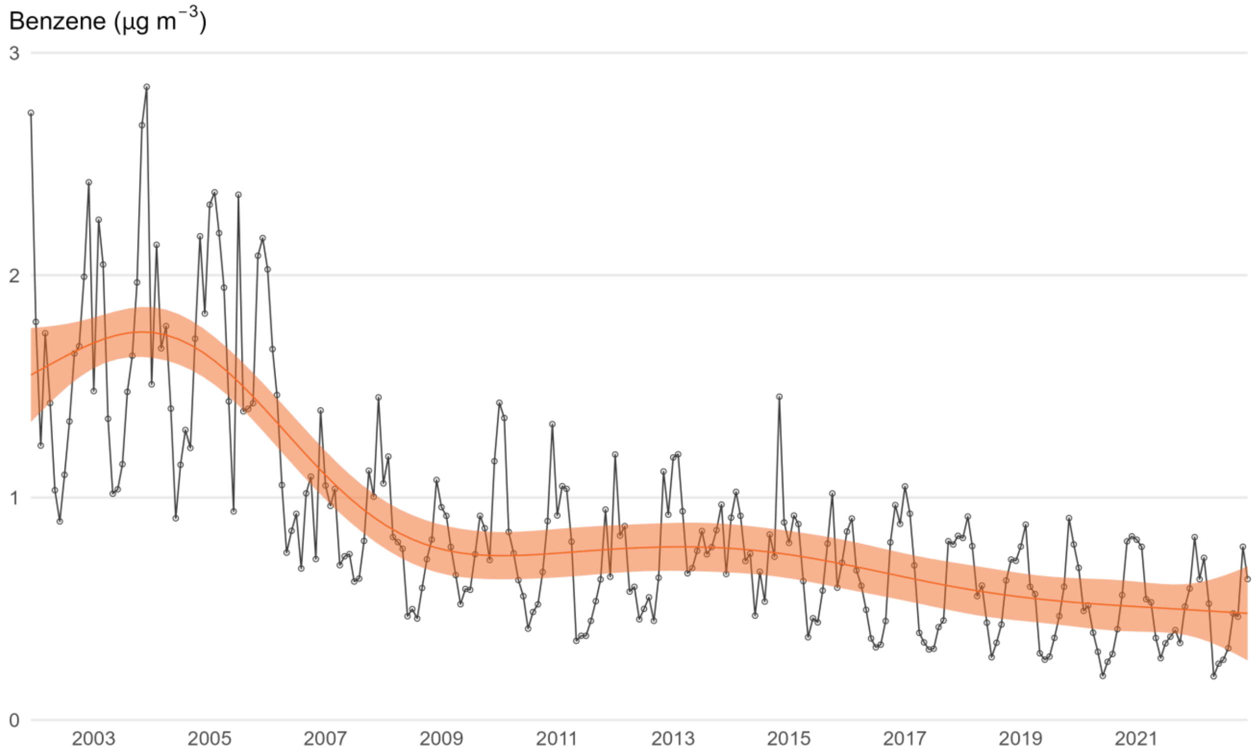
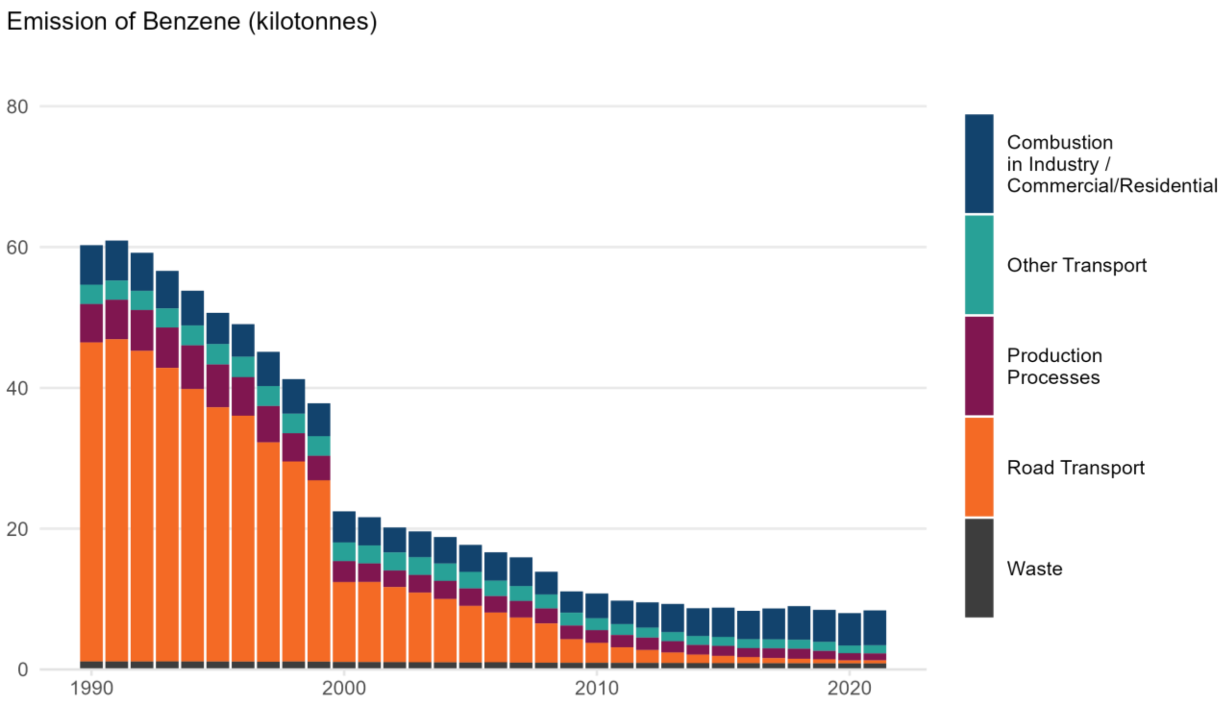


Figure 5-30 shows the estimated total annual UK emission of benzene (in kilotonnes), 1990 - 2021. The data are from the NAEI. The largest UK source of benzene is fuel combustion. Like the ambient concentrations, the estimated annual emissions also appear to have decreased over the period 2000 – 2010, but subsequently flattened off. However, the estimated total annual emission for 2020 was the lowest in the time series so far: there was a small increase in 2021. There is a downward step-change in benzene emissions from road transport in 2000: this is primarily attributed to reduction in benzene emissions from petrol vehicles.

Figure 5-30 Estimated Annual UK Emissions of Benzene (kt), 1990 – 2021 (source: NAEI 2022)



5.9 1,3-Butadiene

5.9.1 1,3-Butadiene: Compliance with AQS Objective

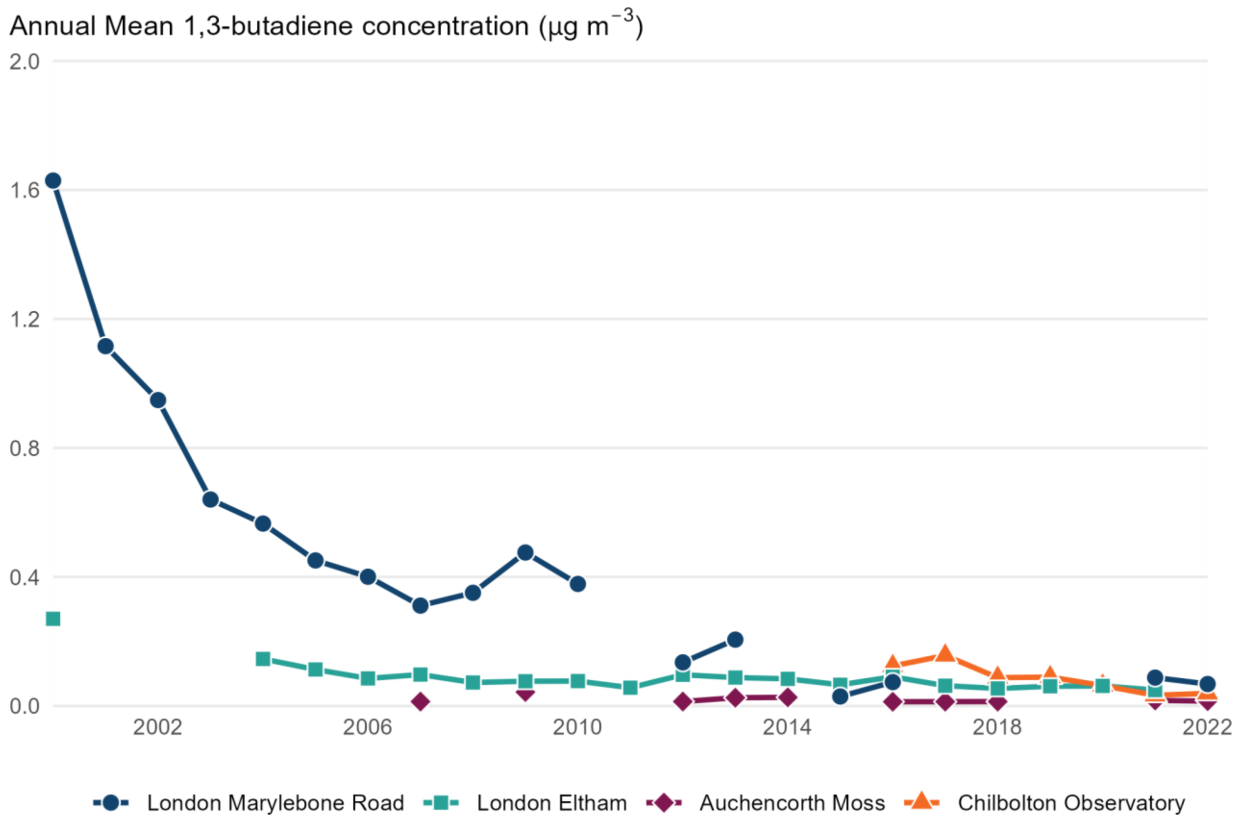
The UK Air Quality Strategy objective for 1,3-butadiene is 2.25 µg m^{-3}, as a maximum running annual mean. This objective was met throughout the UK by the due date of 31st December 2003. Modelled maps are not routinely produced for this pollutant.

The Automatic Hydrocarbon Network monitors 1,3-butadiene at four sites: London Marylebone Road (urban traffic), London Eltham (urban background), Auchencorth Moss in Midlothian (rural background), and Chilbolton Observatory in Hampshire (also rural background). Chilbolton Observatory replaced a previous rural site in Harwell (Oxfordshire) at the beginning of 2016. Measured concentrations of 1,3-butadiene at all three sites were well within the AQS objective in 2022.

5.9.2 1,3-Butadiene: Changes Over Time

Figure 5-31 shows a time series chart of ambient annual mean 1,3-butadiene concentration between 2000 and 2022 at the four automatic sites. (Minimum annual data capture for inclusion is 50% in this case.)

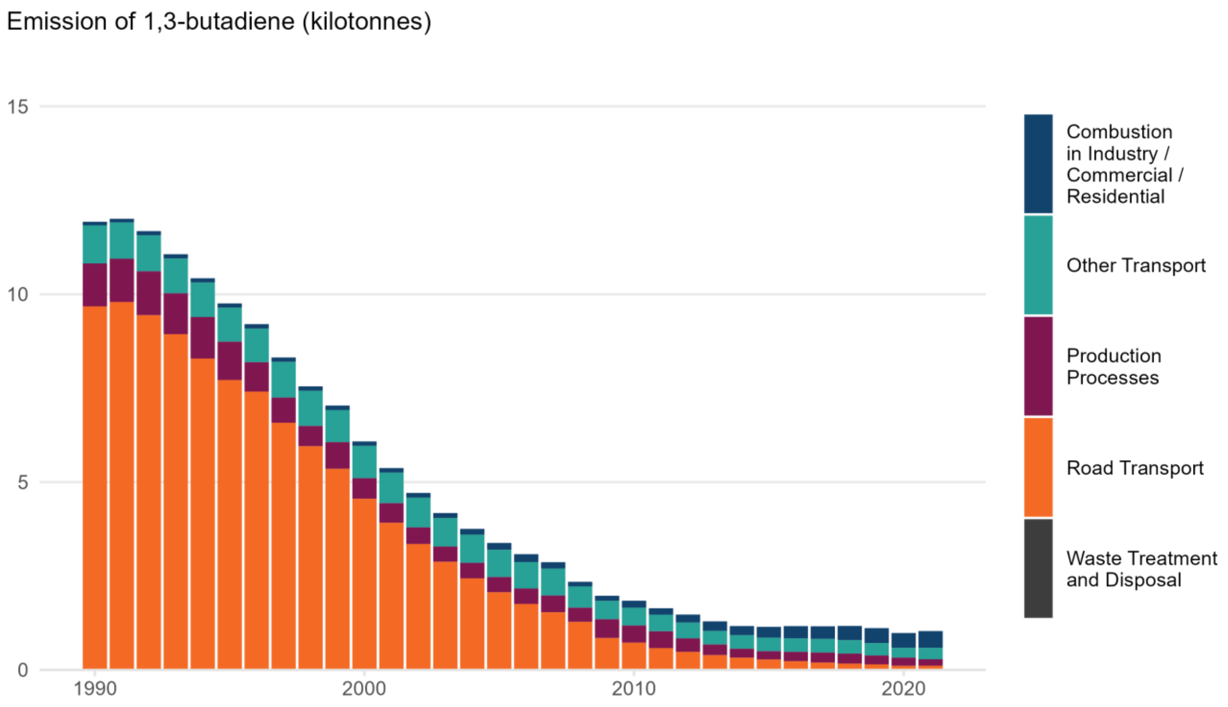
Figure 5-31 Time Series Graph of 1,3-Butadiene Concentration, 2000-2022



London Marylebone Road has historically had the highest concentrations of 1,3-butadiene, but these have decreased substantially between 2000 and 2015. London Eltham has also exhibited a decrease, although concentrations have always been lower than at London Marylebone. Chilbolton Observatory, despite its rural location, has typically reported slightly higher concentrations during its five years of operation than London Eltham. All four sites, both urban and rural, are now measuring annual mean concentrations of less than 0.1 µg m^{-3}.

Figure 5-32 shows the total estimated UK annual emission of this compound, in kilotonnes, between 1990 and 2021. This appears to have decreased steadily since 2000, though flattening off after 2014. The main source of 1,3-butadiene is vehicle emissions, and the use of catalytic converters since the early 1990s has substantially reduced emissions from this source. The estimated total annual emission for 2020 was the lowest in the time series so far: travel restrictions due to COVID-19 were likely a contributory factor.

Figure 5-32 Estimated Annual UK Emissions of 1,3-Butadiene (kt), 1990 – 2021 (source: NAEI 2022)



5.10 Metallic Elements

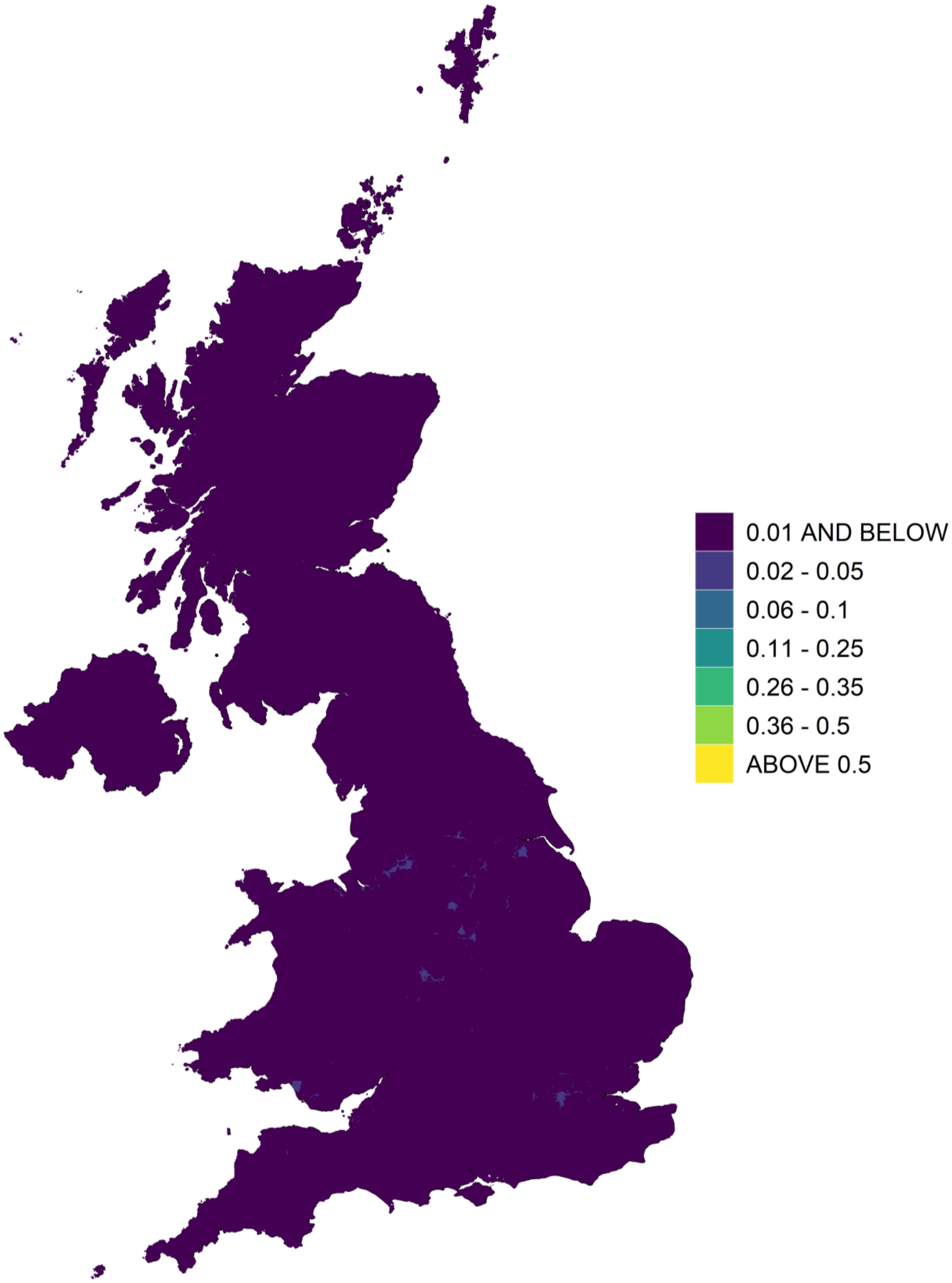
5.10.1 Metallic Elements: Spatial Distribution

Figure 5-33, Figure 5-34, **Figure 5-35** and **Figure 5-36** show modelled annual mean background concentrations of lead (Pb), arsenic (As), cadmium (Cd) and nickel (Ni) respectively in 2022. The spatial distribution patterns are discussed below.

Pb: background concentrations were 0.01 µg m^{-3} (that is, 10 ng m^{-3}) or less over almost all the UK. (The map shows concentrations in micrograms per cubic metre, as this is the unit used for the Air Quality Standards Regulations (2010) limit value.) Some small areas around major cities had concentrations in the 0.02 – 0.05 µg m^{-3} range. Modelled concentrations were well within the limit value of 0.5 µg m^{-3} throughout the UK.

Also, just visible on the map, with modelled concentrations in the 0.02 – 0.05 µg m^{-3} range, are small sections of some major road routes. This is not due to vehicle tailpipe emissions (leaded petrol having been phased out from general sale in the UK in 1999), but to re-suspended road dust - tyre and brake wear is now a significant source of Pb emissions in the UK. However, these do not feature strongly in the 2022 map.

Figure 5-33 Annual Mean Background Lead Concentration, 2022 (µg m^{-3})



(An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/. Please note the bands, default colour scale **and units** may be different to those used above.)

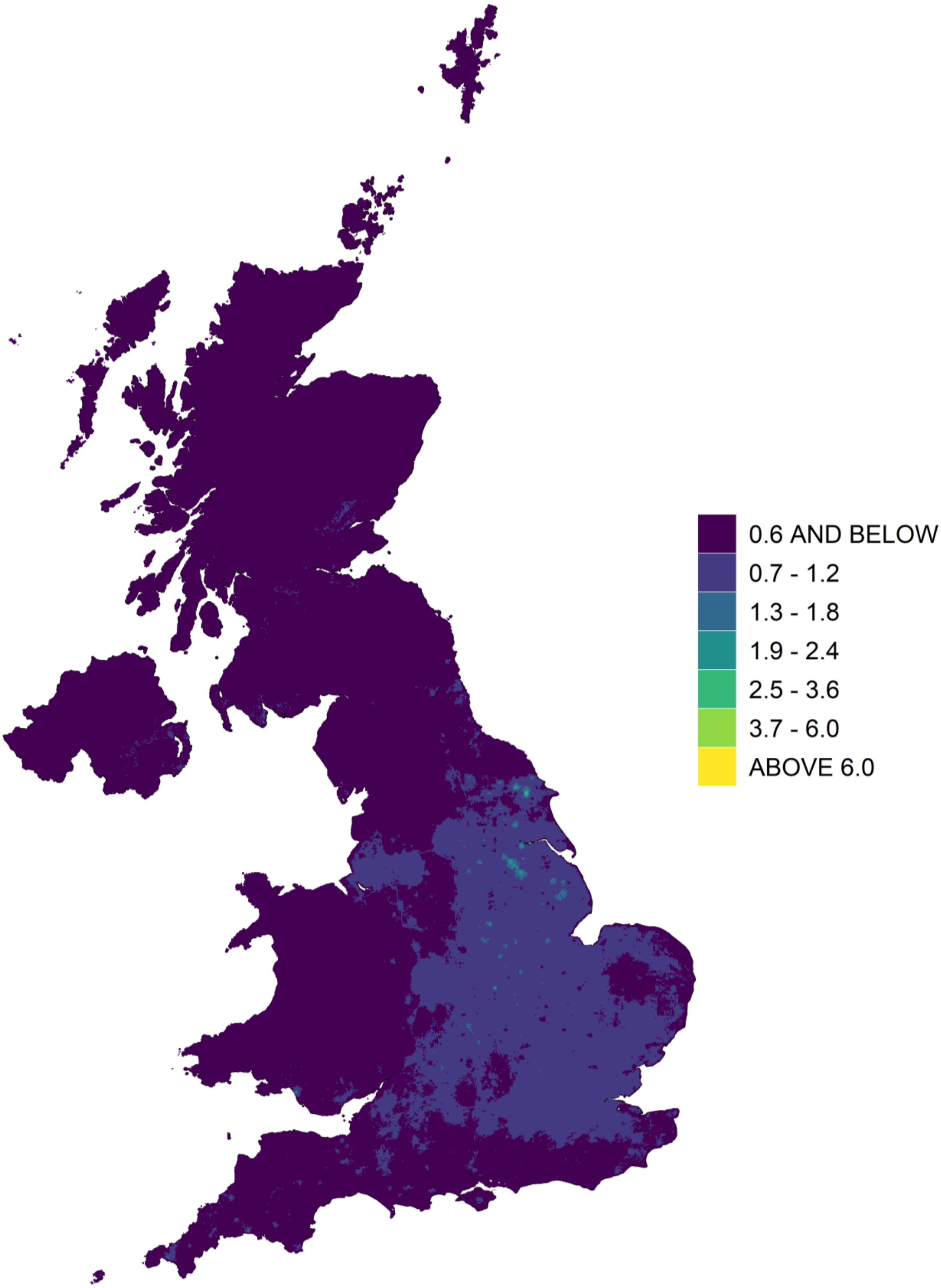
As: this toxic element is a metalloid rather than a metal but is nevertheless measured by the Heavy Metals Network. **Figure 5-34** shows that modelled annual mean background concentrations were 1.2 ng m^{-3} or less throughout most of the UK. Modelled concentrations were well within the limit value of 6 ng m^{-3} throughout the UK.

However, concentrations in the range 1.9 – 2.4 ng m^{-3} occurred in some small areas, particularly the north-eastern part of England, Yorkshire and Humberside. This pattern reflects the natural sources of airborne arsenic, particularly wind-blown dust. Modelled concentrations were therefore highest in areas where agricultural practices give rise to wind-blown dust (such as parts of eastern England) and where the natural arsenic content of the soil is relatively high.

Cd: background concentrations were less than 0.3 ng m^{-3} over most of the UK, as shown by **Figure 5-35**. Higher concentrations can be seen at numerous urban and industrial areas around the UK, which reflects the sources of cadmium which are primarily industrial. Higher concentrations are also visible along some major road routes: like lead, cadmium is a constituent of re-suspended road dust. In the 2022 maps, this feature is more clearly visible for cadmium than it is for lead. However, no parts of the UK had modelled concentrations greater than the annual mean limit value of 5 ng m^{-3}.

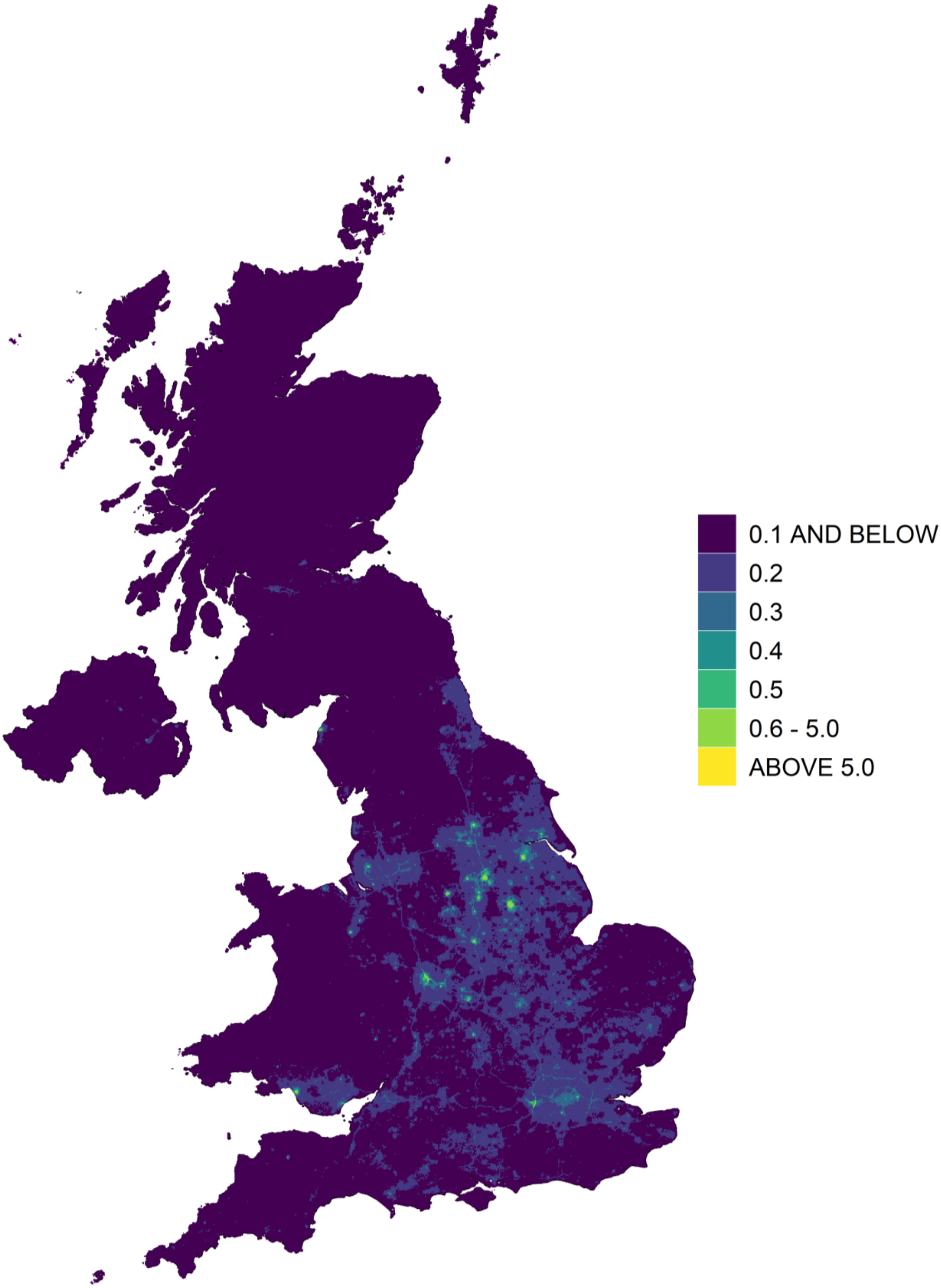
Ni: background concentrations of Ni were typically 2 ng m^{-3} or less, and usually 1 ng m^{-3} or less, away from urban areas (**Figure 5-36**). There were also a few small areas with higher concentrations due to industrial activity, including locations where modelled concentration exceeded the Ni target value of 20 ng m^{-3} in 2022: these are in the Yorkshire area and in South Wales. As reported in **Section 4**, three zones exceeded the target value for Ni in 2022: Sheffield Urban Area, Yorkshire and Humberside and the South Wales zone.

Figure 5-34 Annual Mean Background Arsenic Concentration, 2022 (ng m^{-3})



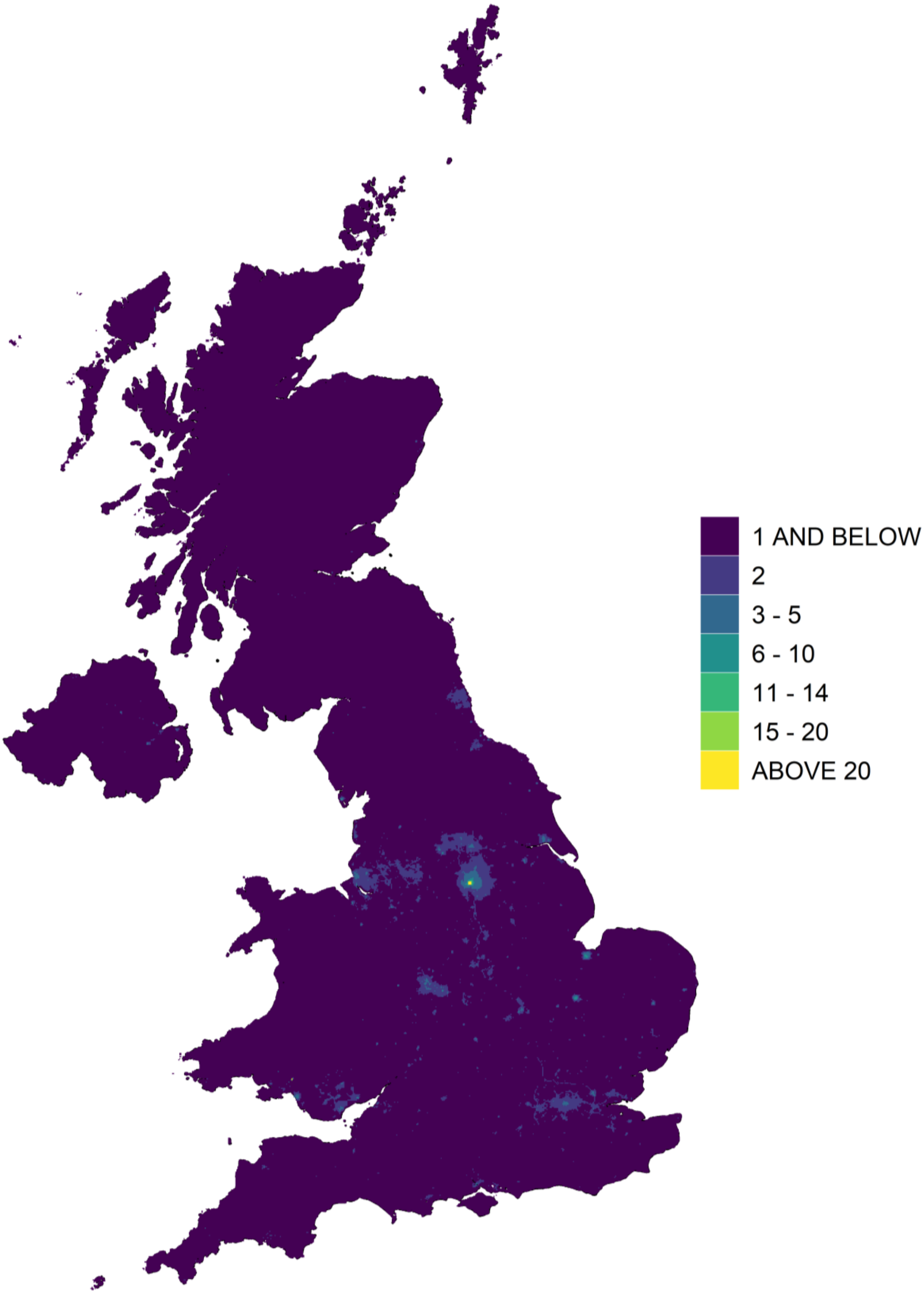
(An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/. Please note the bands and default colour scale may be different to those used above.)

Figure 5-35 Annual Mean Background Cadmium Concentration, 2022 (ng m^{-3})



(An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/. Please note the bands and default colour scale may be different to those used above.)

Figure 5-36 Annual Mean Background Nickel Concentration, 2022 (ng m^{-3})



(An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/. Please note the bands and default colour scale may be different to those used above.)

5.10.2 Metals: Changes Over Time

The Heavy Metals Network monitoring stations are very diverse, ranging from remote rural sites to urban industrial locations. The range of measured ambient concentrations reflects this diversity: annual mean concentrations can be an order of magnitude higher at some sites than at others. Consequently, if using a network average concentration to show changes over time, caution is needed. If the arithmetic mean is used, this statistic can be dominated by the sites with highest concentrations. If one of these sites starts or ceases operation, or if its measured concentrations change substantially (e.g. due to changes in local industry), this may cause a discontinuity in the time series.

Therefore, the time series graphs for metals Pb, As, Cd and Ni show the *median* (50th percentile), rather than the arithmetic mean, of the annual mean concentrations at all Heavy Metals Network sites. (This approach, used in '*Air Pollution in the UK*' reports for years 2017 onwards, is that used by the network operators, NPL, to investigate trends in ambient concentrations (NPL, 2020). However, please note that '*Air Pollution in the UK*' reports for years up to and including 2016 used a different approach; the metals graphs showed the arithmetic mean but included urban sites only.)

5.10.2.1 Lead: Changes Over Time

Figure 5-37 shows a time series of the median annual mean concentration of Pb in the PM_{10} particulate fraction, as measured from 2004 by the UK Heavy Metals Network, as described in **Section 3.1**. (Prior to 2004, Pb in the particulate phase was measured by the six sites comprising the former Multi-Element Network. For further information on this, please see earlier reports in this series. However please note that the sampling method used by the Multi-Element Network is not directly comparable with current sampling methods as it was not size-selective).

The median of the annual mean concentrations from all Heavy Metals Network sites, both urban and rural, is shown. (As highlighted above, this is a change from the 2016 and earlier reports in this series, which showed the arithmetic mean for urban sites only). ***Please also note that for clarity, this graph uses units of ng m^{-3}, rather than µg m^{-3} as used in the modelled maps.*** Ambient concentrations of Pb have decreased substantially, though not consistently, since 2004.

Figure 5-38 shows NAEI estimated total annual UK emissions of this metal from 1990 to 2021. The phasing-out of lead in petrol in the 1990s greatly reduced emissions of Pb from transport, which had previously been the largest UK source. However, Pb is a constituent of dust from tyre and brake wear, so transport remains a significant source, though emissions are now much lower. Production processes are also a significant source.

Figure 5-37 Ambient Concentrations of Pb in PM_{10}, 2004-2022

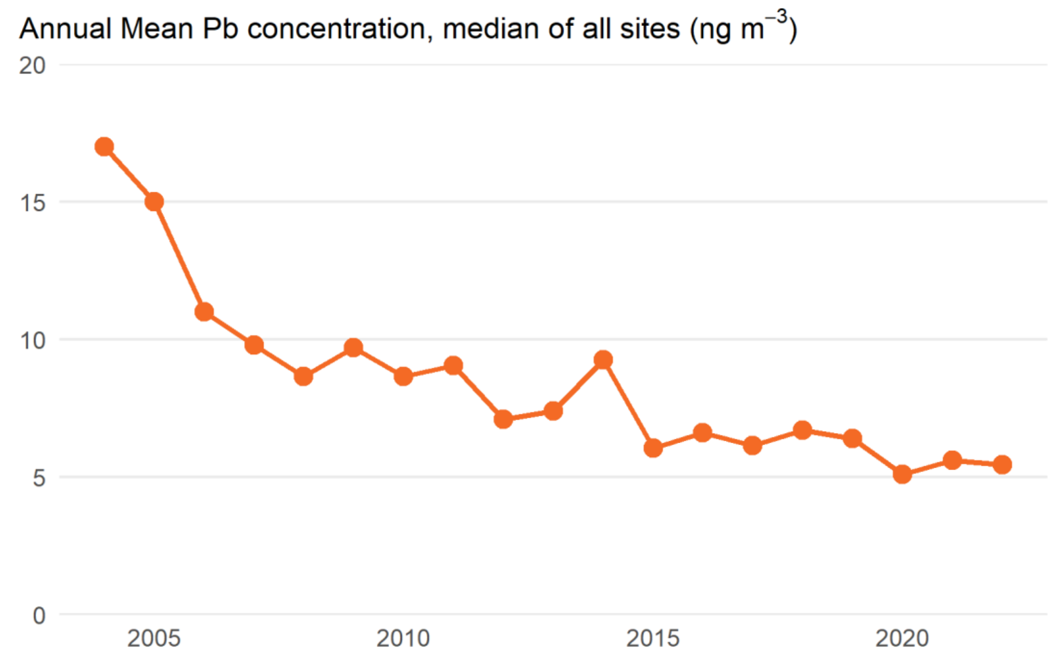
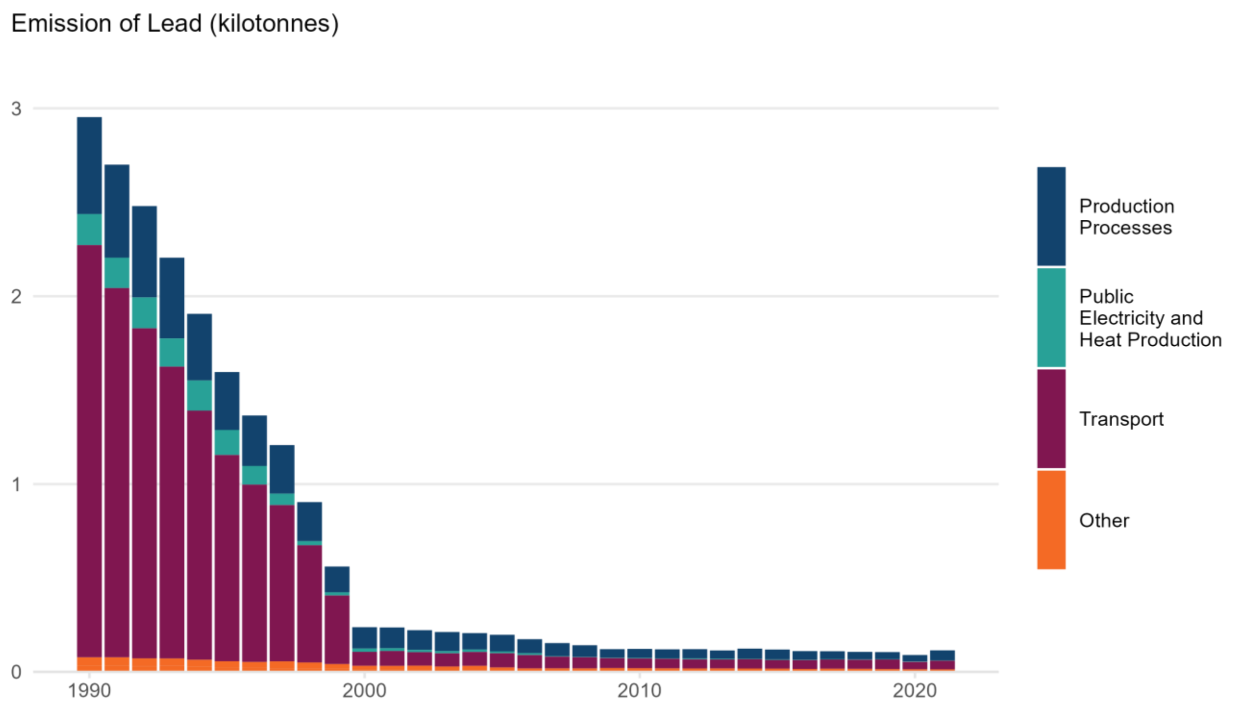


Figure 5-38 Estimated Annual UK Emissions of Pb (kt), 1990 – 2021 (source: NAEI 2022)



5.10.2.2 Arsenic: Changes Over Time

Figure 5-39 shows a time series of ambient concentration of arsenic (As) in the PM_{10} fraction, expressed as the median annual mean of all sites in UK Heavy Metals Network, as described in **Section 3.3.2**. (For pre-2004 non-size selective measurements from the Multi-Element Network, please see earlier reports in this series.)

The average used is the median of all sites' annual means, rather than the arithmetic mean, to avoid confounding effects due to changes at sites where concentrations are particularly high. All sites, both urban and rural have been included. Ambient concentrations of As appear to have decreased substantially between 2004 and 2008, remaining relatively stable until 2015 and from then on slightly increasing until 2021, when there was a further decrease, continued in 2022.

Figure 5-39 Ambient Concentrations of As in PM_{10}, 2004-2022

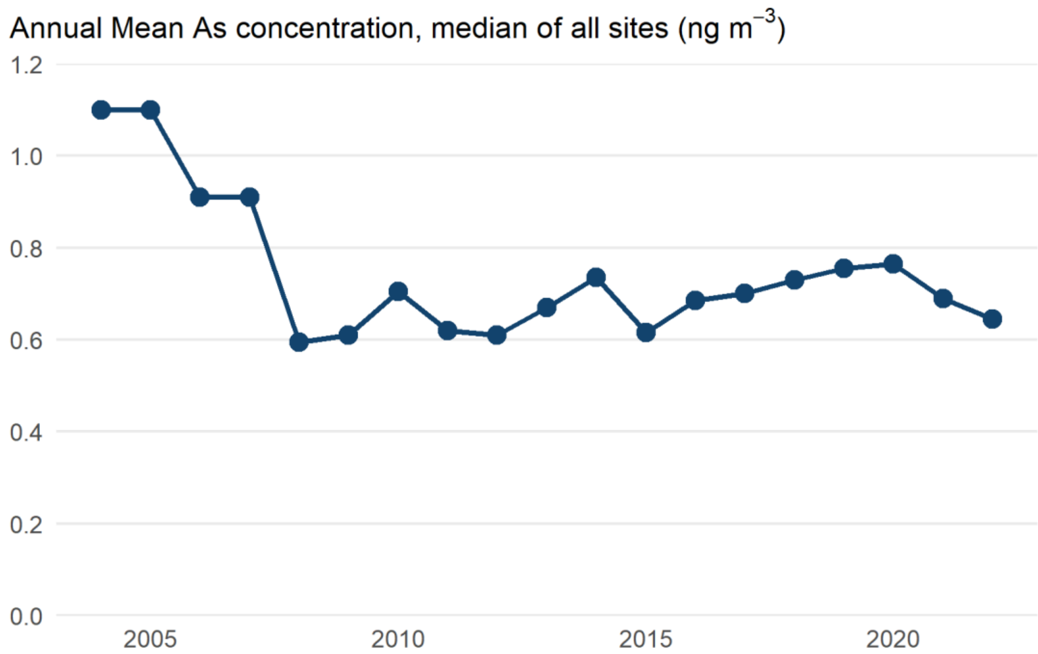
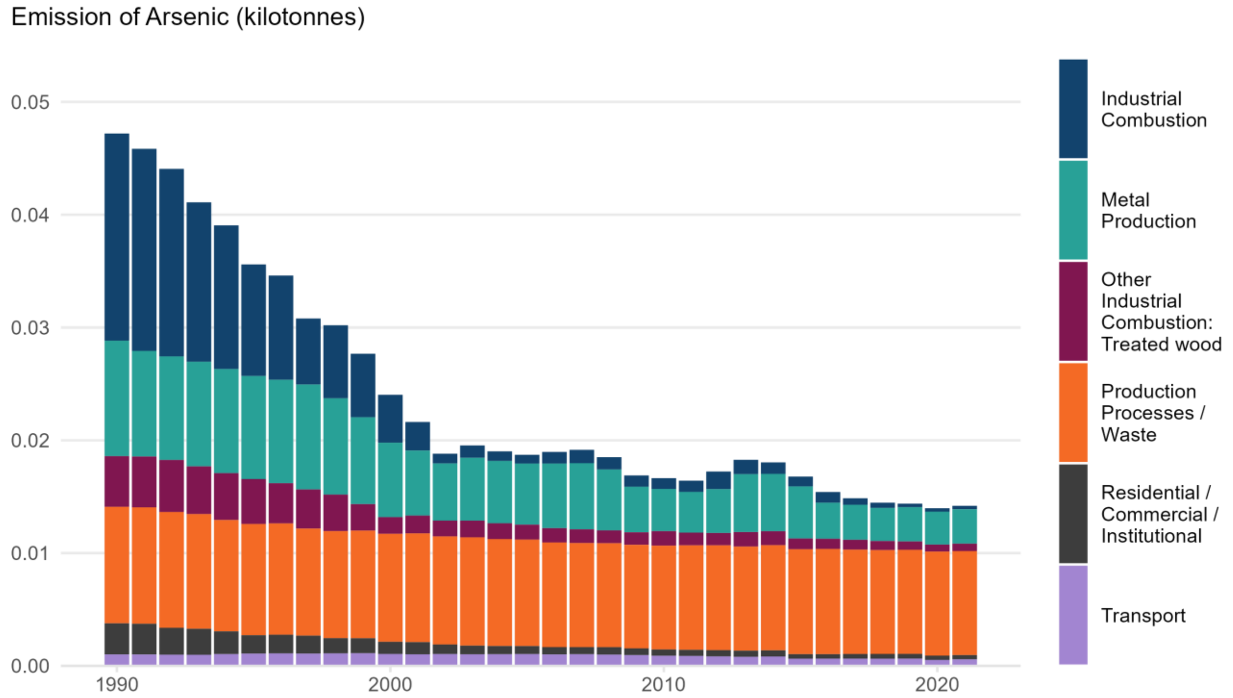


Figure 5-40 shows the UK's estimated total annual emission of As (from the NAEI), in kilotonnes, from 1990 to 2021. The largest human-made source of As emissions in the UK is the open burning of waste wood which has been treated with products containing As. This falls within the 'Production processes/waste' category. Metal (iron and steel) production processes also give rise to some emissions.

Changes in measured ambient As concentrations (since 2004) do not appear to reflect estimated total emissions. The reasons for this have not been investigated but it may be that the results from the monitoring sites reflect local rather than national trends. Furthermore – as mentioned in **Section 5.10.1** above – wind-blown dust is a major natural source of airborne arsenic in some areas.

Figure 5-40 Estimated Annual UK Emissions of As (kt), 1990 – 2021 (source: NAEI 2022)



5.10.2.3 Cadmium: Changes Over Time

Figure 5-41 shows a time series of ambient concentration of cadmium (Cd) in the PM_{10} fraction as measured by the UK Heavy Metals Network, described in **Section 3.3.2**. For pre-2004 non-size selective measurements from the Multi-Element Network, please see earlier reports in this series.

Again, the graph shows the median of all sites' annual means, rather than the arithmetic mean, to avoid confounding effects due to changes at sites where concentrations are particularly high. All sites – both urban and rural – have been included; there were 23 sites in operation during 2022. Over the network's years of operation there has been a decrease in ambient Cd concentrations, but it has not been consistent (for example, Cd shows an apparent increase in 2014, as does Pb).

Figure 5-42 shows the UK's estimated total annual emission of Cd (in kilotonnes), 1990 to 2021, from the NAEI. The main human-made sources of Cd are combustion in manufacturing industry and production processes. Waste incineration was once a large source until control of this source was improved in the 1990s: it now accounts for only 1% of the UK total.

Figure 5-41 Ambient Concentrations of Cd in PM_{10}, 2004 – 2022

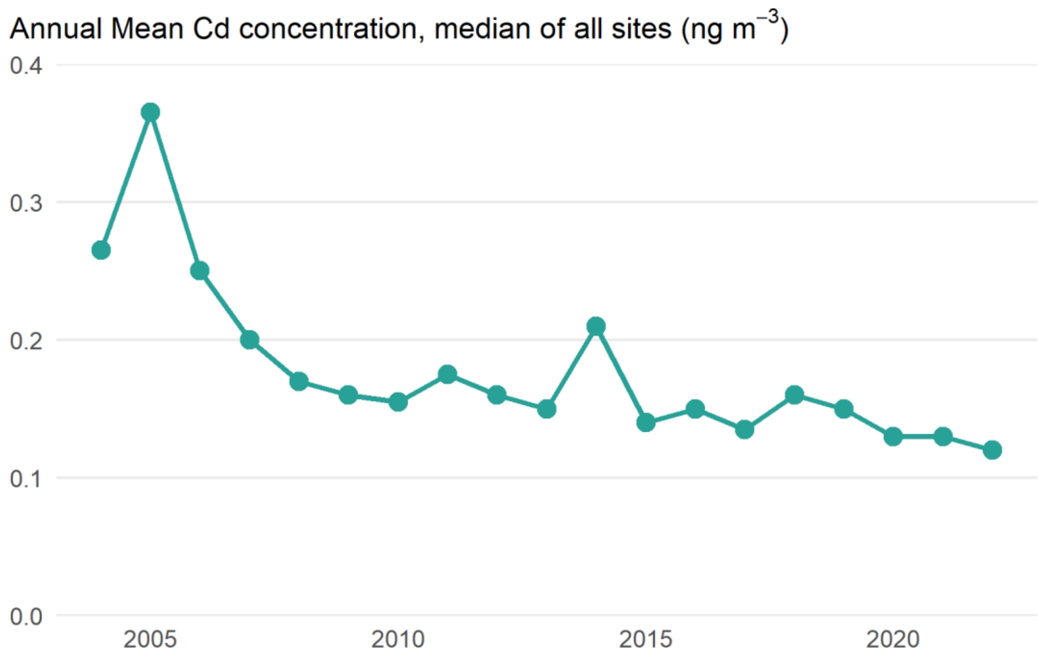
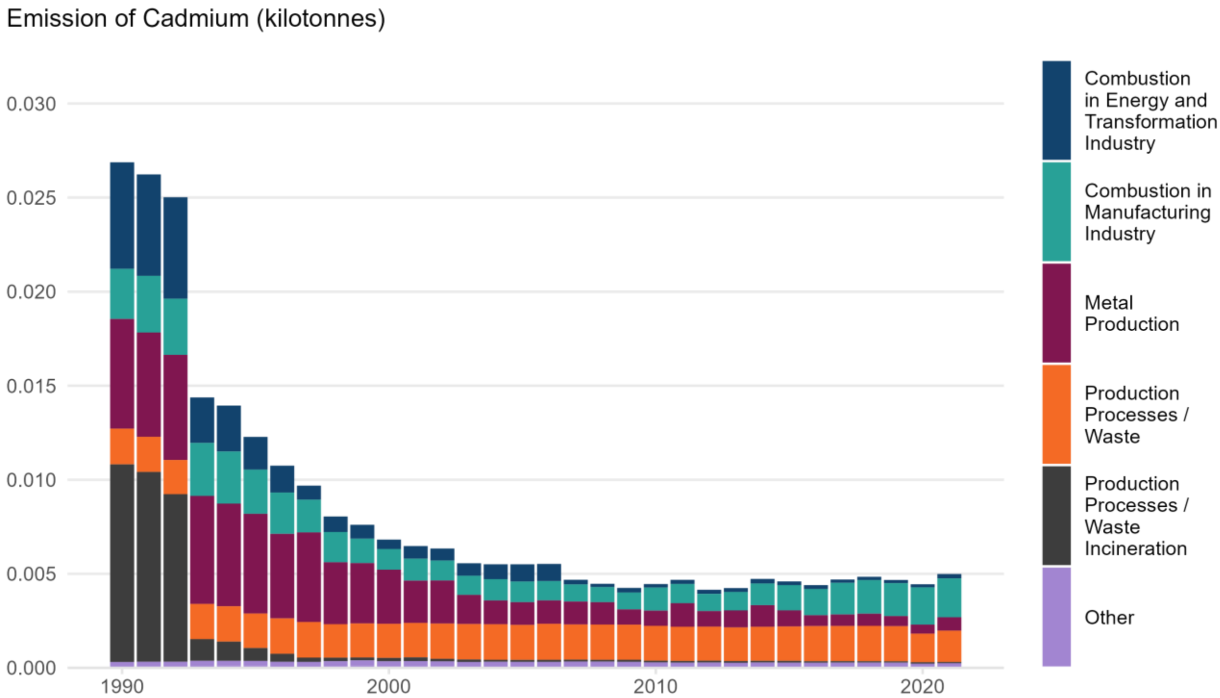


Figure 5-42 Estimated Annual UK Emissions of Cd (kt), 1990 – 2021 (source: NAEI 2022)



5.10.2.4 Nickel: Changes Over Time

Figure 5-43 shows a time series of median annual mean concentrations of nickel (Ni) in PM_{10}, as measured by all sites in the UK Heavy Metals Network. As with the other metals, information on non-size selective measurements from the older Multi-Element Network can be found in earlier reports in this series.

Again, the graph shows the median, rather than the arithmetic mean, of annual mean concentrations at all sites. This avoids confounding effects due to a small number of sites which measure ambient Ni concentrations very much higher than the others. Ambient concentrations also show a general (though not consistent) decrease over the period of operation of the network: the pattern is similar to that for Cd.

Figure 5-44 shows total estimated annual UK emissions of Ni, from the NAEI, from 1990 to 2021. Stationary combustion in industry (other than the energy production and transformation industry) is the major source. The NAEI data show a general – though not consistent - decrease in Ni emissions since 1990.

Figure 5-43 Ambient Concentrations of Ni in PM_{10}, 2004 – 2022

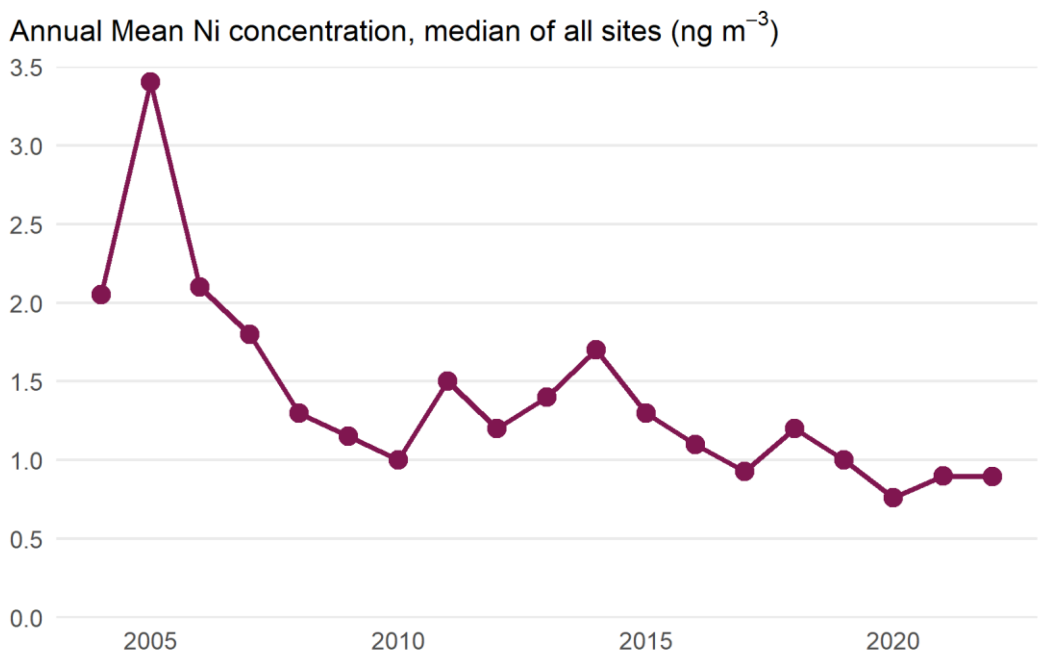
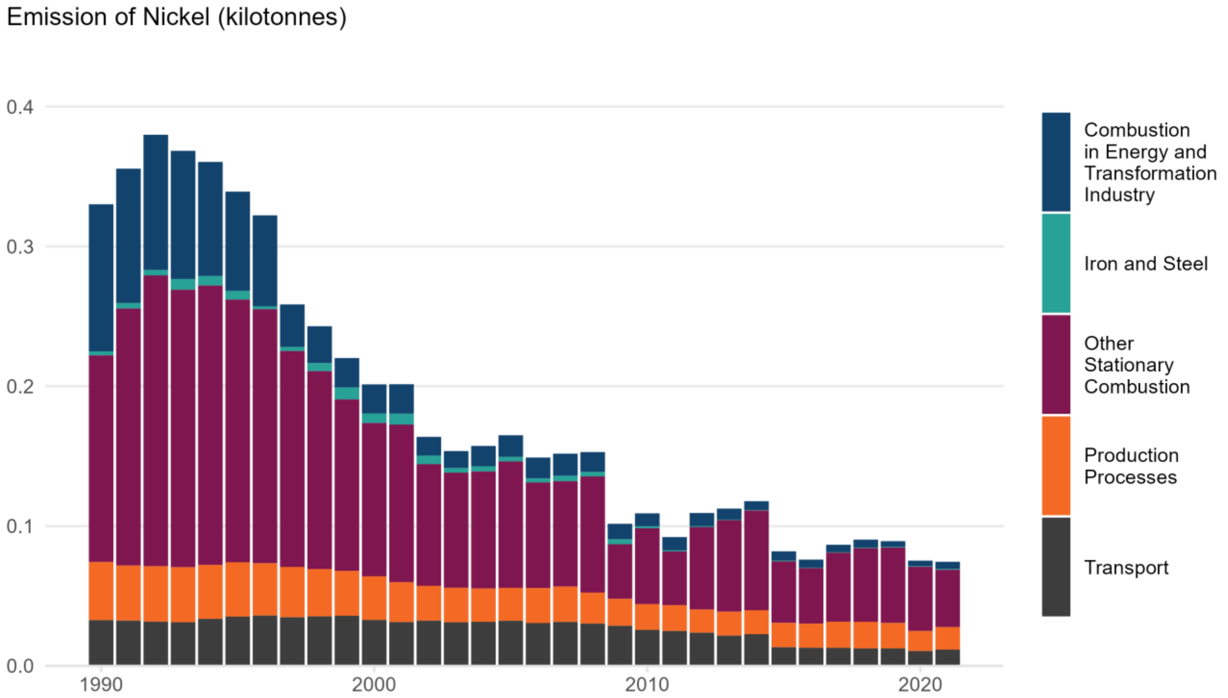


Figure 5-44 Estimated Annual UK Emissions of Ni (kt), 1990 – 2021 (source: NAEI 2022)



5.10.2.5 Mercury: Changes Over Time

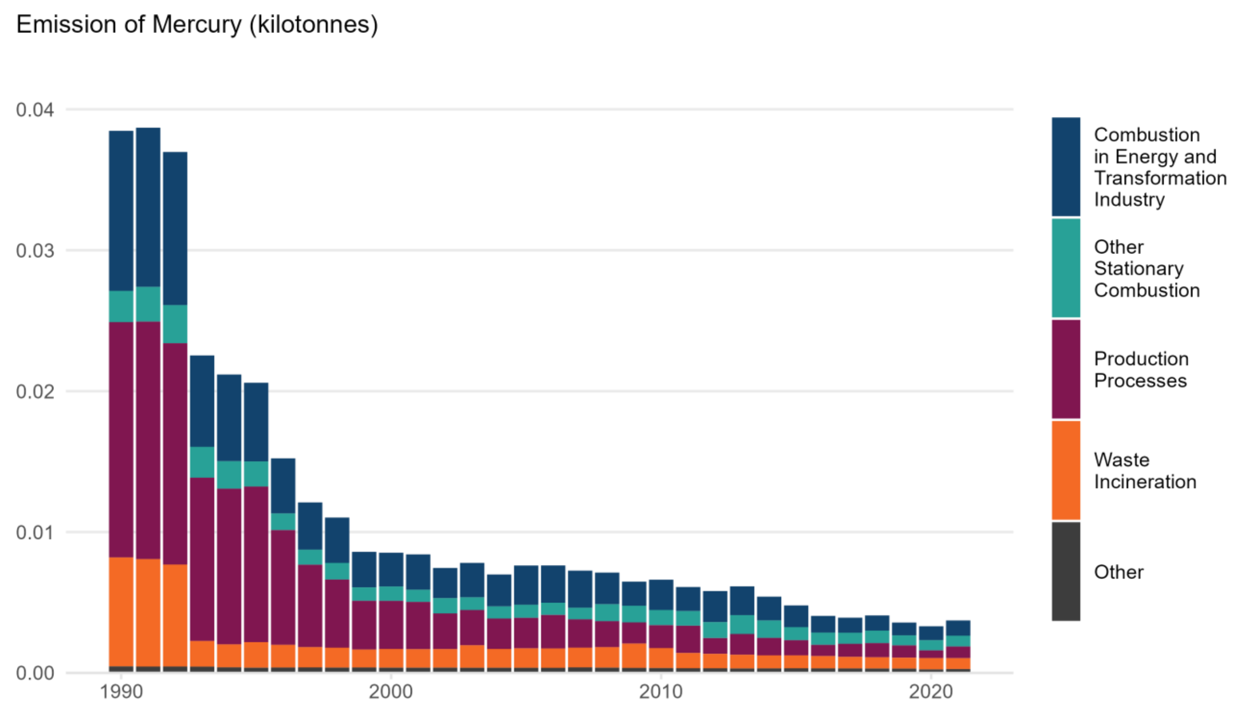
The Heavy Metals Network ceased measuring mercury (Hg) in PM_{10} at the end of 2013. Monitoring of Total Gaseous Mercury (TGM) continued at two sites (London Westminster and Runcorn Weston Point) until 2018. For information on previous years' measurements of mercury carried out by the Heavy Metals Network and its predecessors from 2004 to 2018, please refer to "*Air Pollution in the UK 2018*" and earlier reports in this series.

Mercury deposition (dry deposition and deposition in precipitation) is still carried out at several rural sites (see **Section 3**). However, ambient concentrations of Hg in air are now only measured at two rural sites: Chilbolton Observatory in Hampshire (which measures TGM), and Auchencorth Moss in Midlothian. The latter site measures Hg in $PM_{2.5}$, Elemental Gaseous Mercury and Reactive Hg in air. These measurements are carried out using the Tekran instrument, as part of the Rural Mercury Network (see **Section 3.3.12**).

Annual mean concentrations of elemental mercury at Auchencorth Moss from 2010 onwards and TGM at Chilbolton Observatory from 2016 onwards are available from UK-AIR. Annual mean elemental mercury concentrations at Auchencorth Moss have consistently been in the range 1.3 – 1.4 ng m^{-3} since monitoring of this metric began in 2010. Annual mean TGM concentrations at Chilbolton Observatory have consistently been in the range 1.3 – 1.6 ng m^{-3} since monitoring of this metric began in 2016. However, in both cases data capture has been very low (less than 50%) in several years, and there is no clear trend at either site.

Figure 5-45 shows estimated annual UK emissions of Hg, from 1990 to 2021. The main sources are combustion in industry, waste incineration and production processes. Mercury emissions have steadily decreased between 2006 and 2016, though the decrease appears to have flattened off in more recent years. The main sources are industrial, therefore trends in ambient Hg concentrations at the rural sites where monitoring of this element has continued would not necessarily be expected to reflect these emission trends.

Figure 5-45 Estimated Annual UK Emissions of Hg, 1990 - 2021 (source: NAEI 2022)

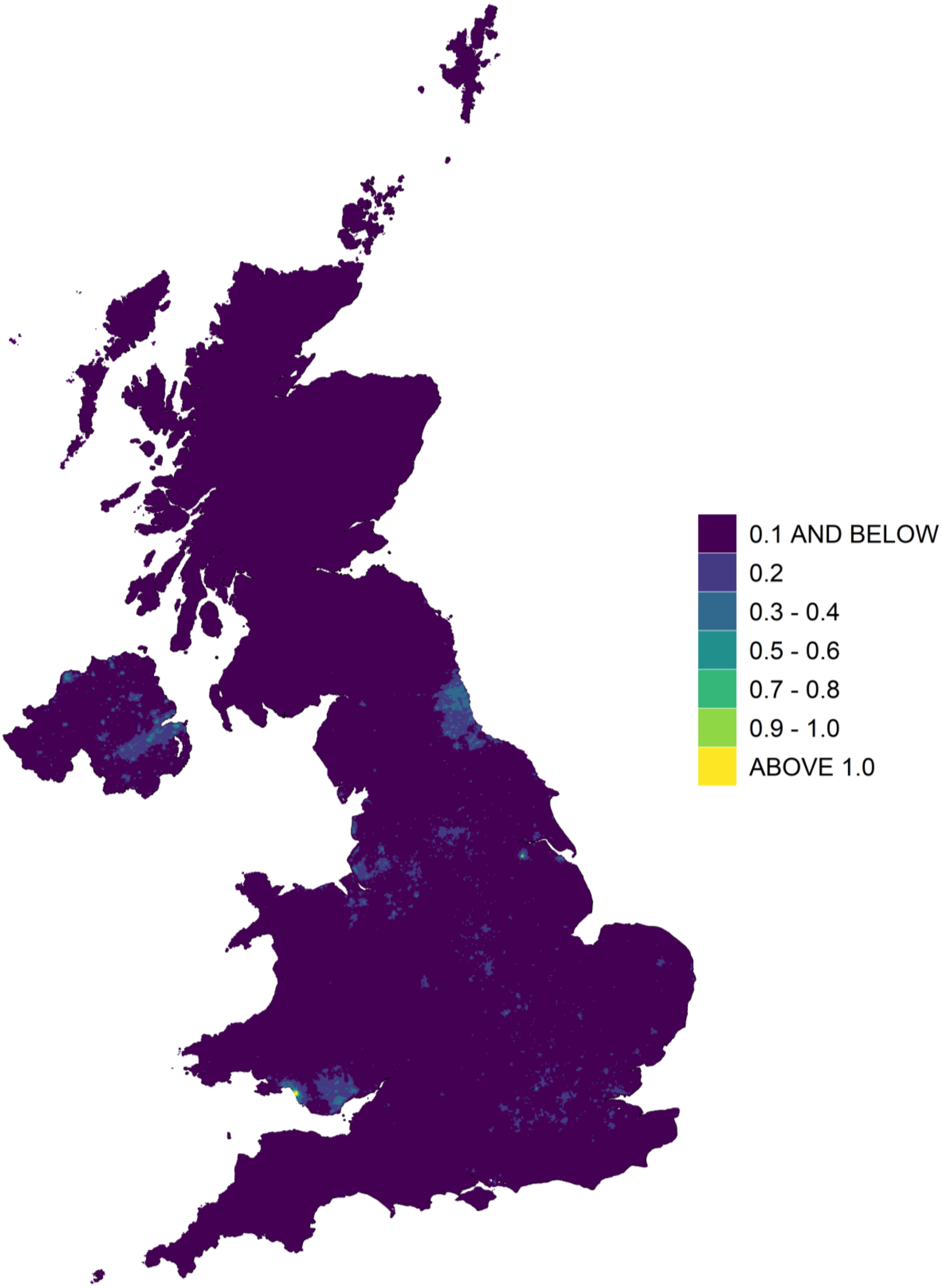


5.11 Benzo[a]pyrene

5.11.1 B[a]P: Spatial Distribution

Figure 5-46 shows the modelled annual mean background concentration of the polycyclic aromatic hydrocarbon compound, benzo[a]pyrene (B[a]P). Most of the UK had modelled concentrations of 0.1 ng m^{-3} or less in 2022: areas of higher concentration reflect the distribution of industrial sources, and areas where there is widespread domestic use of oil and solid fuels for heating. There was one small area of South Wales with annual mean B[a]P concentrations in excess of the limit value of 1 ng m^{-3} in 2022: this reflects industrial sources in that area and has resulted in the exceedance reported for both Swansea Urban Area and South Wales zone.

Figure 5-46 Annual mean background B[a]P concentration, 2022 (ng m^{-3})



An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/. Please note the bands and default colour scale may be different to those used above.

5.11.2 B[a]P: Changes Over Time

The Polycyclic Aromatic Hydrocarbon (PAH) monitoring network began operation in 1991. At that time, it comprised just a small number of sites, but increased in size to over 20 in the late 1990s. However, during the years 2007-2008, the network underwent a further major expansion and re-organisation, including a change of sampling technique. The newer sampling technique used at most sites from 2008 onwards (the "Digitel™" PM_{10} sampler) was found to give higher results than the older method. The reason for this is likely to be due to a number of factors, predominantly the Digitel™ samplers' shorter collection period. The shorter collection period is likely to decrease the degradation of the PAHs by ozone or other oxidative species (Sarantiridis, 2014).

Because of these changes in the composition of the network, and in particular the techniques used, temporal variation in PAH concentrations has only been analysed from 2008 in this report. **Figure 5-47** shows how the mean B[a]P concentration has changed in the years since 2008. This graph shows a smoothed trend plot, based on combined data from all sites in the PAH Network. This network takes monthly samples, and the graph shows the mean of all sites' measurements, for each month. The composition of the PAH network has changed little since 2008, so it is considered appropriate here to use the data from all sites. In recent years, results less than the limit of detection (LoD) have occurred at some sites: these results have been treated as half the LoD, for the purpose of calculating the averages shown here.

B[a]P shows a strong seasonal variation: this is illustrated by this graph (which is not de-seasonalised). Following a sharp drop in measured concentrations of B[a]P between 2008 and 2009, B[a]P concentrations then appear to have remained generally stable until 2014 when there was a further decrease. Since then, ambient concentrations appear to show a slight overall downward trend.

Figure 5-48 shows estimated total UK emissions of B[a]P, 1990 to 2021. Emissions have decreased substantially in recent decades compared to the early 1990s, due in part to measures such as the banning of stubble burning in agriculture.

At present, emissions of B[a]P are dominated by combustion of solid fuels in the home, and the NAEI data indicate that this source (part of the category described as "residential/commercial/institutional") has remained stable in recent years.

Figure 5-47 Smoothed Trend Plot of Average Ambient Concentrations of Particulate Phase B[a]P, 2008-2022

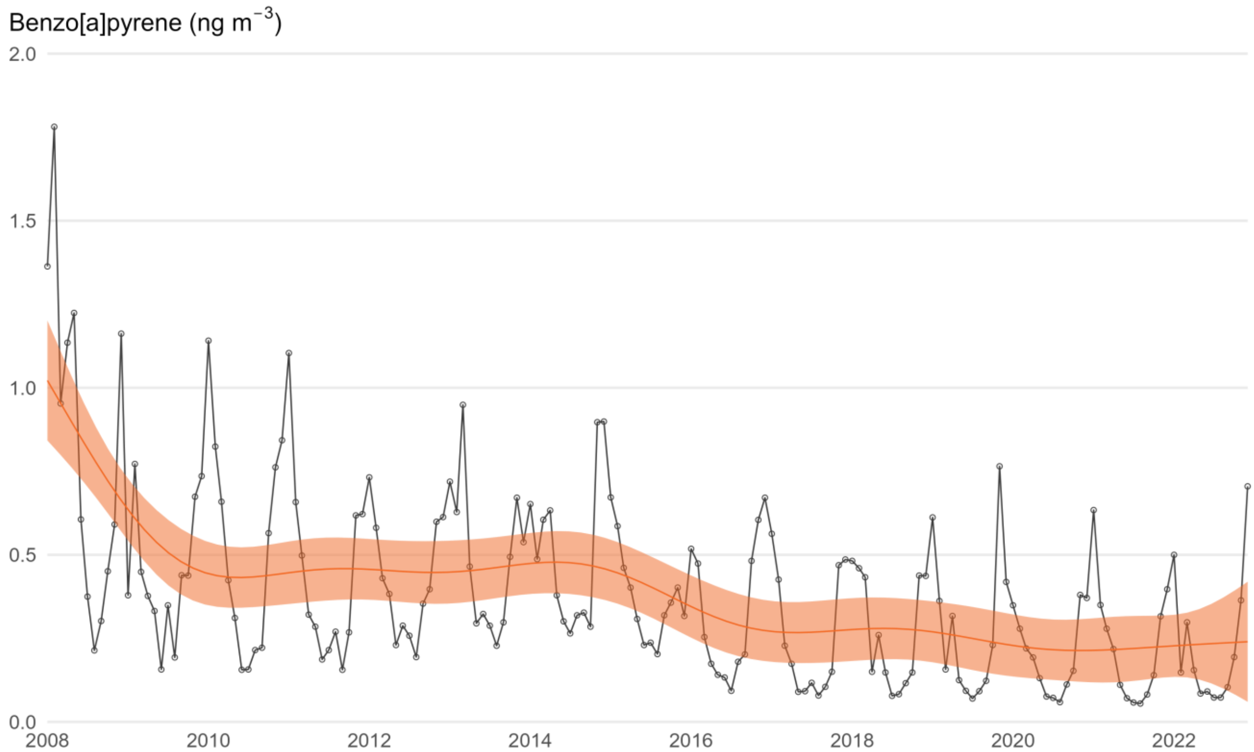
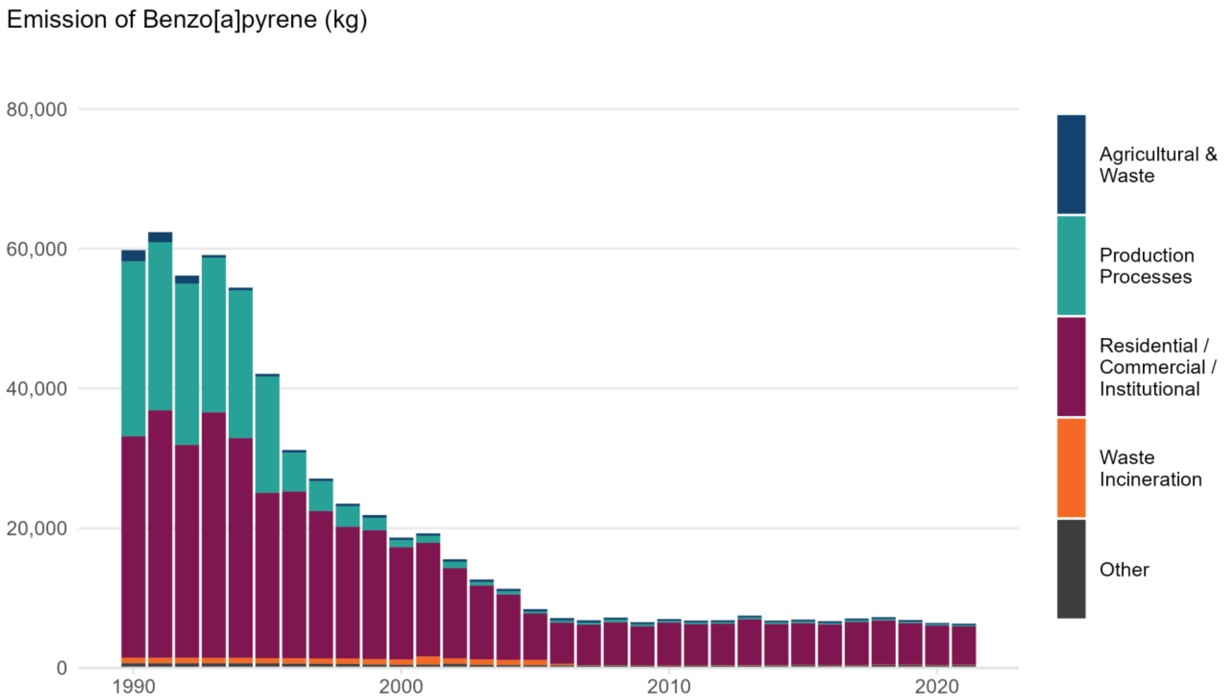


Figure 5-48 Estimated Annual UK Emissions of Benzo[a]pyrene (kg), 1990 – 2021 (source: NAEI)



6 Air Pollution Episodes in 2022

6.1 Particulate Pollution Episodes

During 2022 there was one significant widespread particulate pollution episode recorded. The episode occurred in spring and coincided with low wind speeds and air masses transported over Europe. Localised pollution events also occurred throughout the year. Bonfire Night in particular is a period when localised high PM often occurs.

6.1.1 Springtime Particulate Episode

During late March, much of the UK experienced a Moderate/High particulate pollution episode (as defined by the Daily Air Quality Index – DAQI), with some monitoring sites even recording concentrations in the Very High band. **Figure 6-1** and **Figure 6-2** show the running 24-hour mean PM_{10} and $PM_{2.5}$ concentrations, measured at urban background and rural background AURN sites. Widespread Moderate PM_{10} and $PM_{2.5}$ began on 21st March, with the episode ending on 27th March. The peak concentrations occurred around 23rd to 24th March.

Figure 6-1 Running 24-hour mean of PM_{10} measured at urban background and rural background AURN sites. The grey lines represent the time series for each site. The coloured line represents the median of the running 24-hour mean concentrations across all sites, and the shaded region represents the 25th and 75th percentiles.

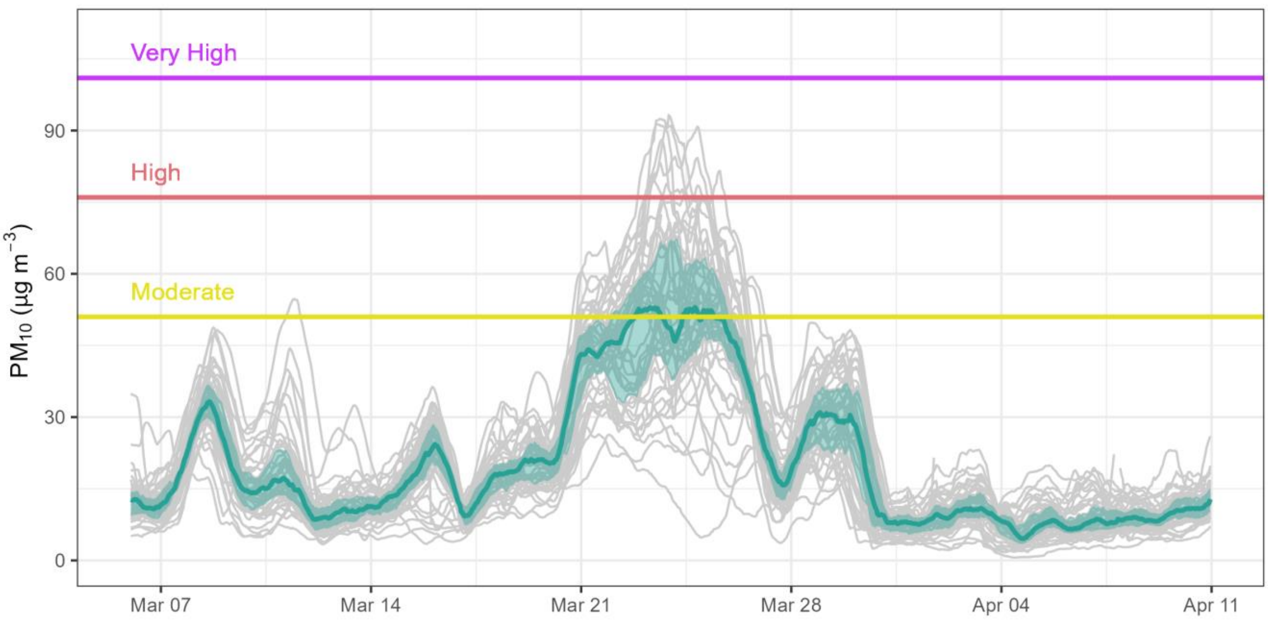
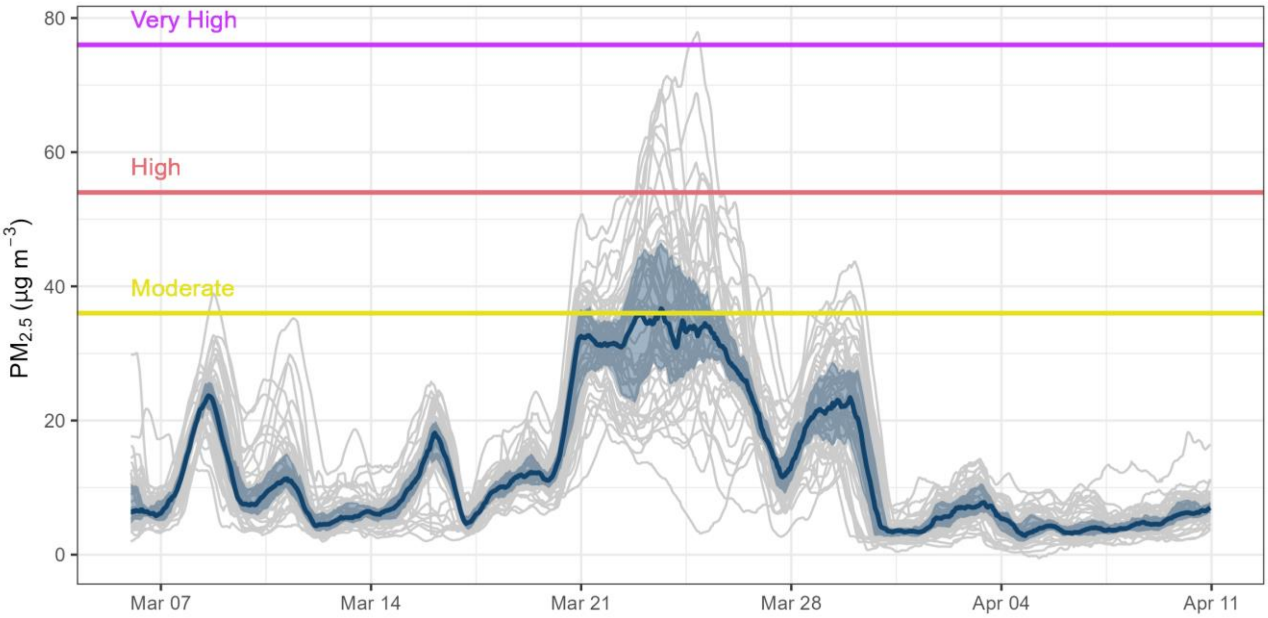


Figure 6-2 Running 24-hour mean of $PM_{2.5}$ measured at urban background and rural background AURN sites between 6th March and 11th April 2022. The grey lines represent the time series for each site. The coloured line represents the median of the running 24-hour mean concentrations across all sites, and the shaded region represents the 25th and 75th percentiles.

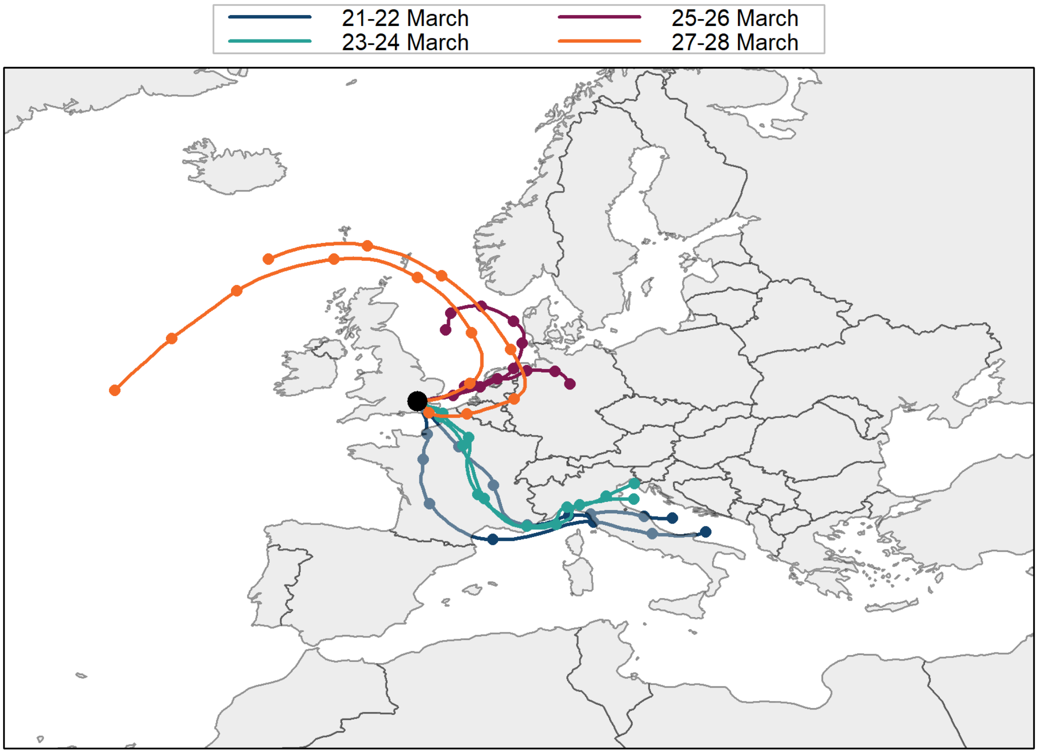


Back trajectories showing the origins of the air masses were calculated using the HYSPLIT Trajectory Model (https://www.ready.noaa.gov/HYSPLIT.php) from NOAA Air Resources Laboratory (ARL) and Global NOAA-NCEP/NCAR reanalysis data archives (Stein, et al., 2015), and plotted using the Openair package for R (R Core Team, 2019) (Carslaw & Ropkins, 2012).

Figure 6-3 shows 96-hour back trajectories centred on London at an arrival time of 12 noon, from 21st to 28th March. The back trajectories indicate that between 21st to 24th March the air masses arriving over the UK were transported over mainland Europe, bringing polluted air from these regions. On 25th March the trajectories changed, with cleaner air masses arriving from the North Sea. This coincided with lower PM concentrations being measured at the AURN sites.

The weather during the peak pollution period was generally settled (Met Office, 2022a). Such conditions can reduce dispersion, allowing local emissions to build up and adding to the pollution transported from Europe.

Figure 6-3 Back Trajectories (96-hour) Showing Air Masses Arriving in London between 21st and 26th March 2022. ***The authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and READY website (http://www.ready.noaa.gov) used to prepare this figure.***



6.1.2 Bonfire Night 2022

The activities associated with Bonfire Night on 5th November often have a measurable impact on air quality. **Figure 6-4** shows the hourly concentrations of PM_{10} and $PM_{2.5}$ measured across the AURN sites over the period 2nd to 10th November 2022. Peaks in PM occurred during the evening of Bonfire Night (5th November), which then decreased the following morning. On 5th and 6th November Moderate PM concentrations were observed in the North West & Merseyside and Yorkshire & Humberside areas, as shown in **Figure 6-5**.

The impact of Bonfire Night on measured PM concentrations depends on various factors, such as: local meteorological conditions; when organised events occurred; and how close the event is to a monitoring station. In 2022, Bonfire Night fell on a Saturday, therefore many events were likely to have occurred on the actual night, rather than spread over a few evenings (as may happen when it falls on a weeknight). The weather conditions on 5th and 6th November were unsettled in many areas, with some showers, which allows for dispersion of pollution. This may explain in part why Moderate pollution was only observed in a few areas.

Figure 6-4 Hourly PM_{10} and $PM_{2.5}$ measured at all sites in the AURN. The grey lines represent the time series for each site. The coloured line represents the median of the running 24-hour mean concentrations across all sites, and the shaded region represents the 25th and 75th percentiles.

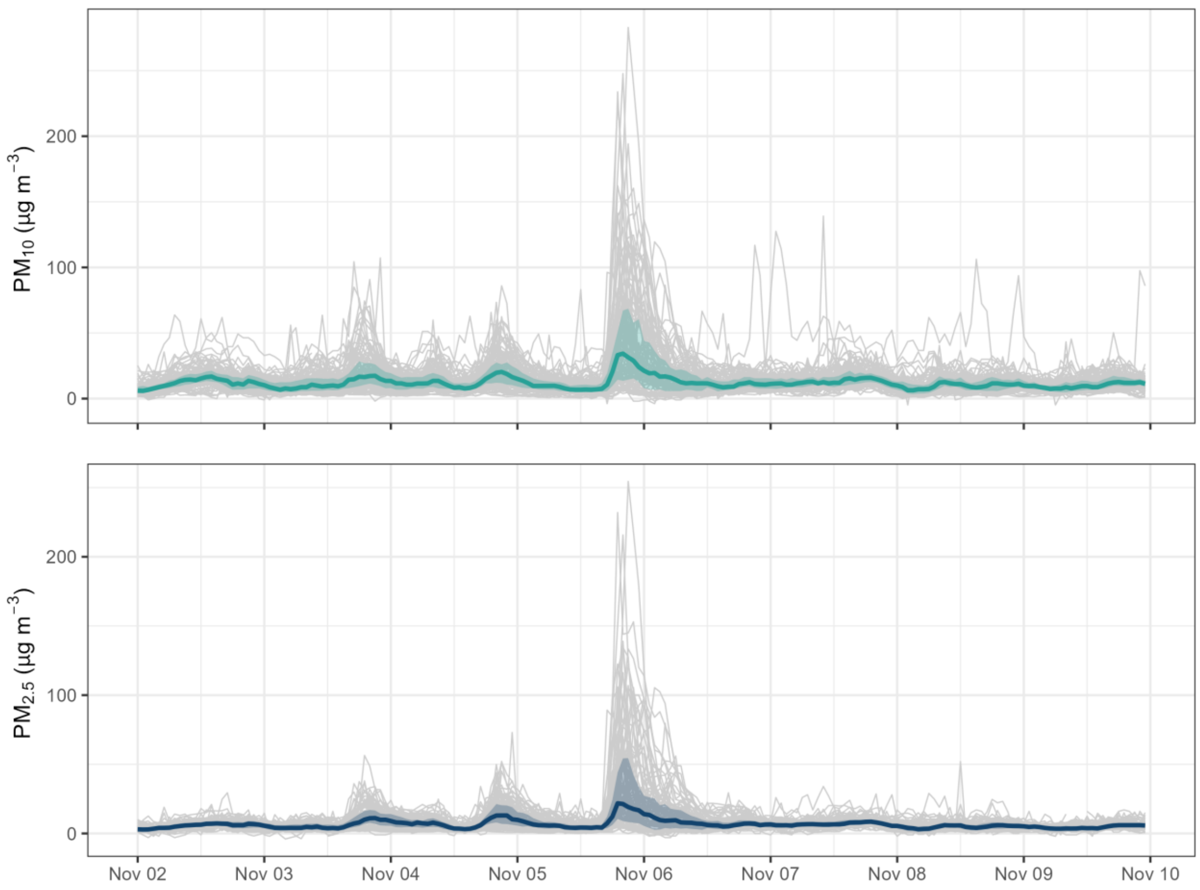
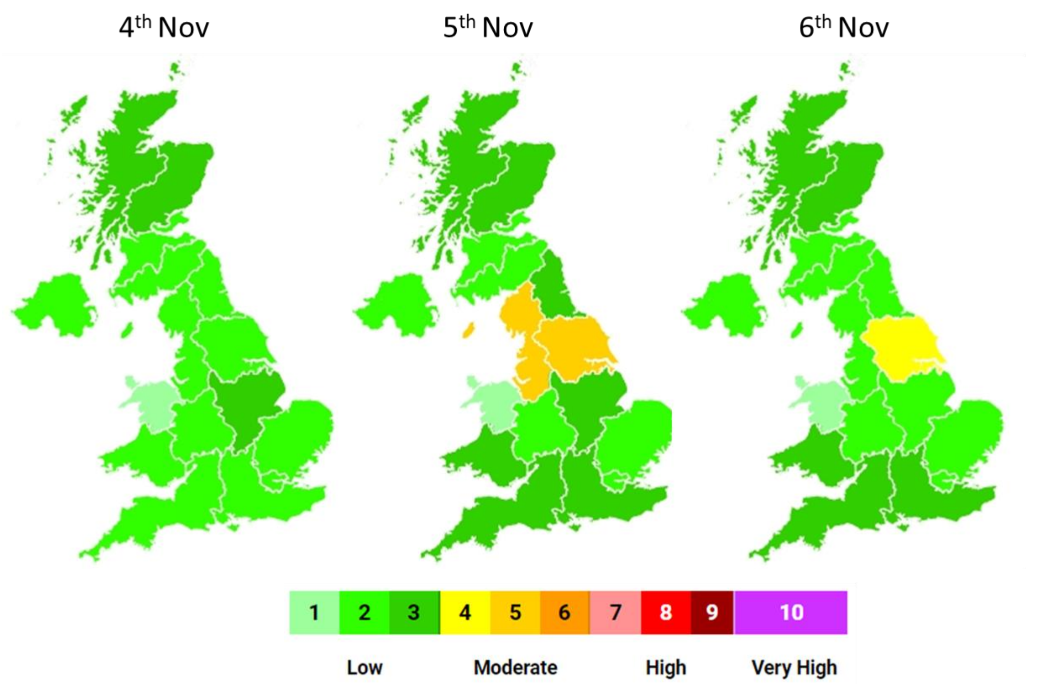


Figure 6-5 Daily Air Quality Index (DAQI) from 4th to 6th November 2022.



Fireworks are also a common feature of New Year's Eve festivities and emissions may impact local PM. However, analysis of the data from 2022 did not indicate any pollution episode linked to New Year's Eve.

6.2 Widespread Ozone Events During Heatwaves

Ozone is not directly emitted into the atmosphere. Instead, it forms through photochemical reactions involving precursor pollutants such as nitrogen oxides (NOx) and volatile organic compounds (VOCs), which can be emitted from vehicles, industrial processes, and natural sources like vegetation. Sunlight provides the energy needed to drive the chemical reactions, and higher temperatures accelerate the reaction rates. This means that ozone concentrations are typically higher in the spring and summer, whilst there are higher temperatures, longer sunnier days and stable conditions which allow ozone to build up.

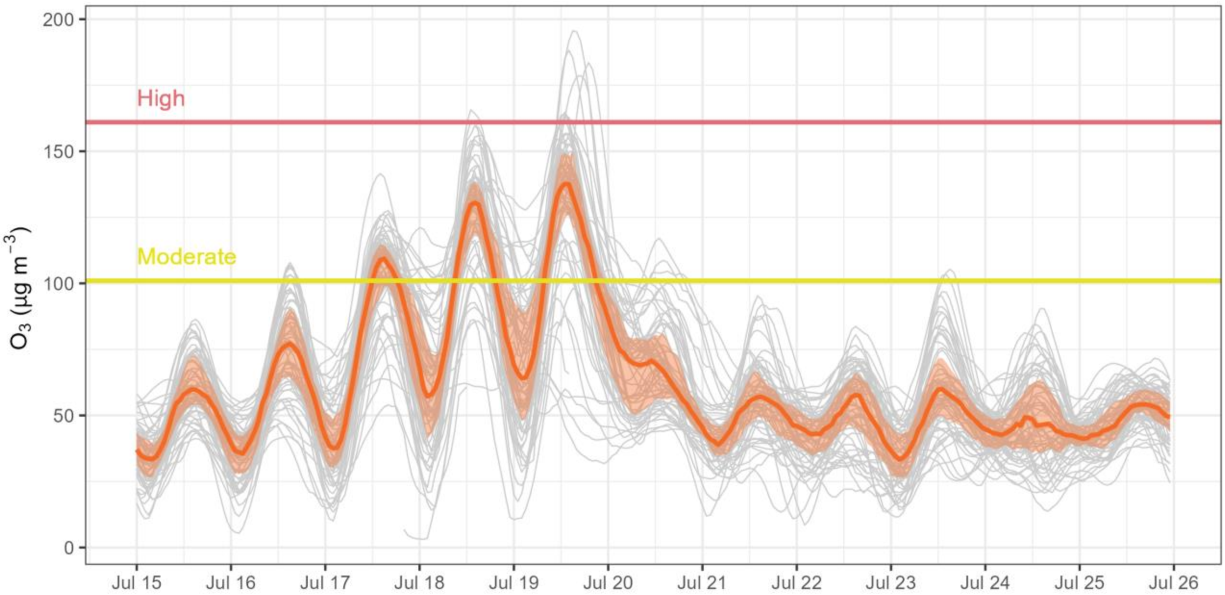
In 2022 most areas of the UK saw higher than average temperatures and sunshine during the summer months (Met Office, 2022b). Widespread Moderate ozone was recorded in June and September. July and August saw widespread High ozone events coinciding with extreme temperatures.

6.2.1 High Ozone Events

An extreme heatwave occurred between 16th and 19th July 2022. A record temperature of 40.3°C was recorded at Coningsby in Lincolnshire on 19th July and the Met Office issued amber and red alerts for extreme heat across England and Wales (Met Office, 2022c).

Figure 6-6 shows the running 8-hour mean ozone concentrations measured at urban, suburban and rural background AURN sites between 15th and 26th July 2022. The median ozone concentrations across all sites began to increase on 16th July, with some Moderate ozone recorded. It peaked on 19th July, with High ozone recorded at nine sites across the East of England and West Midlands.

Figure 6-6 Running 8-hour mean O_3 measured at urban, suburban, and rural background AURN sites from 15th – 26th July. The grey lines represent the time series for each site. The orange line represents the median of the 8-hour mean concentrations across all sites, and the shaded region represents the 25th and 75th percentiles.



Another heatwave occurred during mid-August. Although the temperatures were not as high as those in July, the duration of the heatwave was longer, with temperatures over 30°C recorded in England and Wales (Met Office, 2022d). Moderate and High ozone were recorded across England and Wales during the August heatwave, as shown in **Figure 6-7**. Pollution levels in Scotland and Northern Ireland during this period were generally low. Sixteen sites, across seven regions, recorded High ozone on August 13th (**Figure 6-8**).

Figure 6-7 Running 8-hour mean O_3 measured at urban, suburban, and rural background sites from 6th – 21st August. The grey lines represent the time series for each site. The orange line represents the median of the 8-hour mean concentrations across all sites, and the shaded region represents the 25th and 75th percentiles.

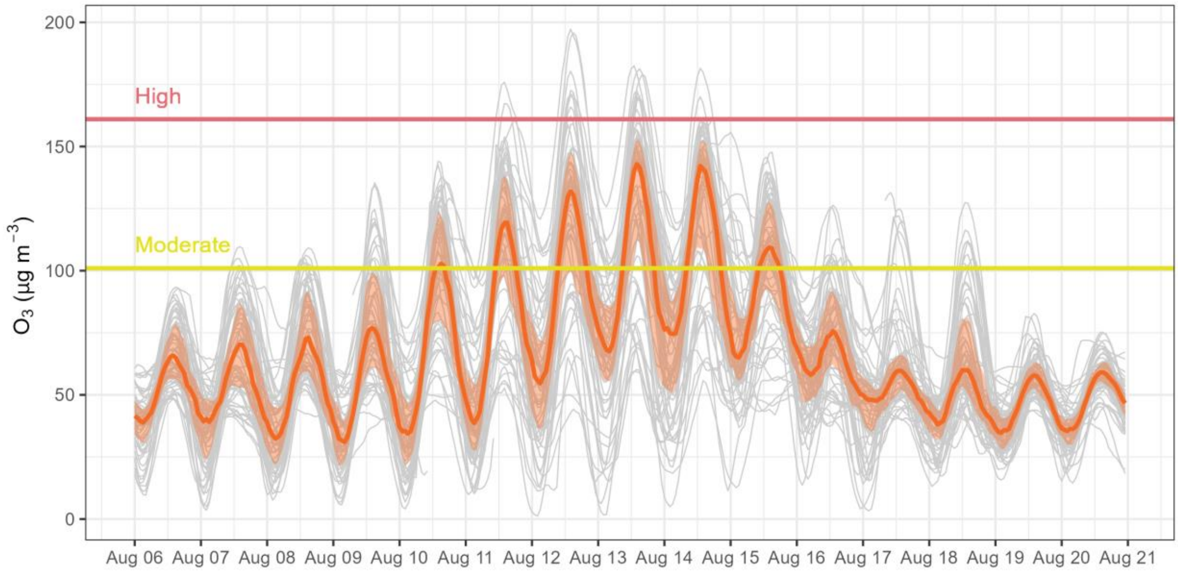
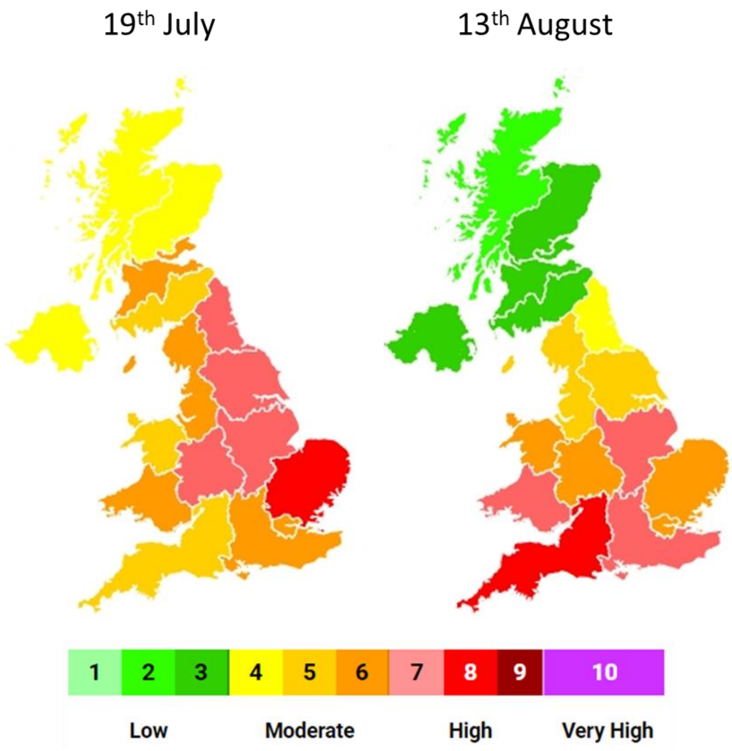


Figure 6-8 Daily Air Quality Index (DAQI) during the peak ozone episodes on 19th July and 13th August 2022.



6.2.2 Moderate Ozone Events

In addition to the High ozone events described above, there were three periods of widespread Moderate ozone during June and one in early September. All coincided with periods of warm weather. **Figure 6-9** shows the running 8-hour mean ozone measured at background sites across the UK in June. As shown in **Figure 6-10**, the moderate ozone events in June were observed across Southern England and Wales in early June, and then most of England and Wales, during the following two episodes.

Figure 6-9 Running 8-hour mean O_3 measured at urban background and rural background AURN sites from 1st – 29th June. The grey lines represent the time series for each site. The orange line represents the median of the 8-hour mean concentrations across all sites, and the shaded region represents the 25th and 75th percentiles.

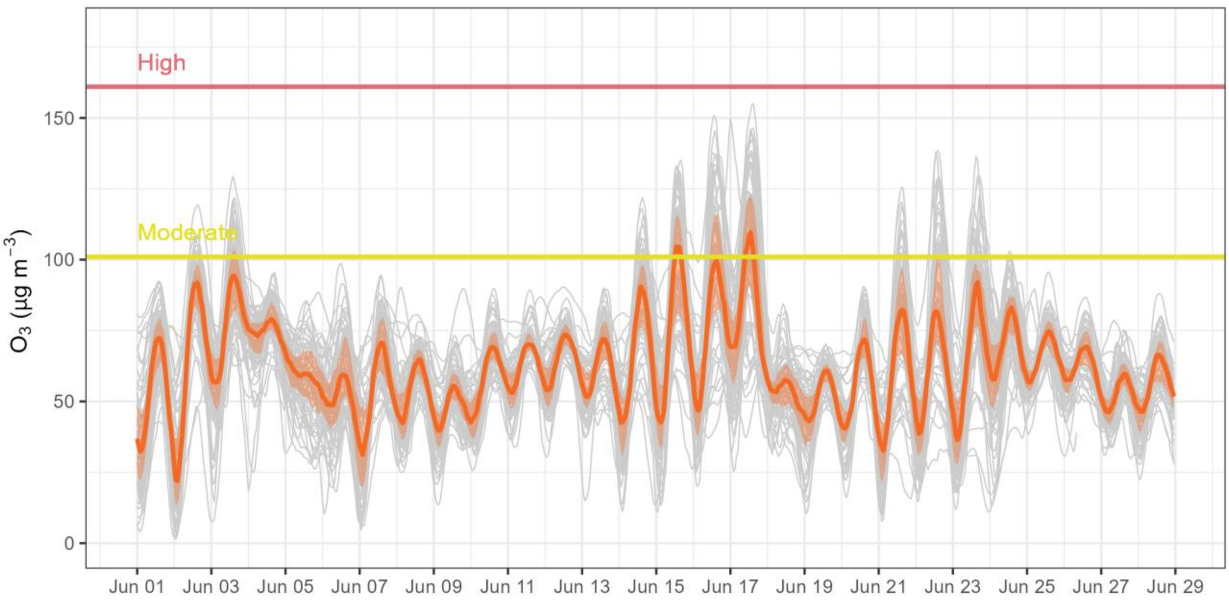
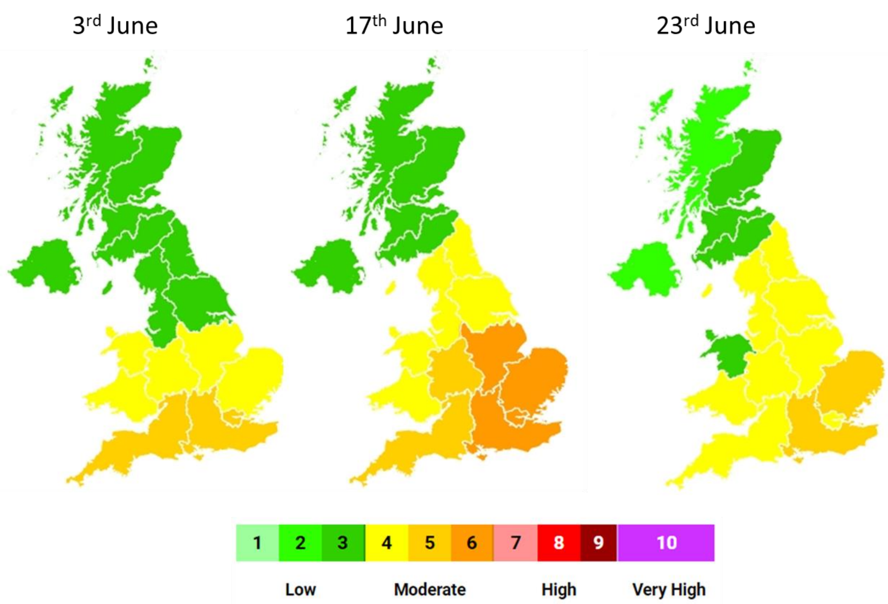


Figure 6-10 Daily Air Quality Index (DAQI) on 3rd, 17th, and 23rd June 2022.



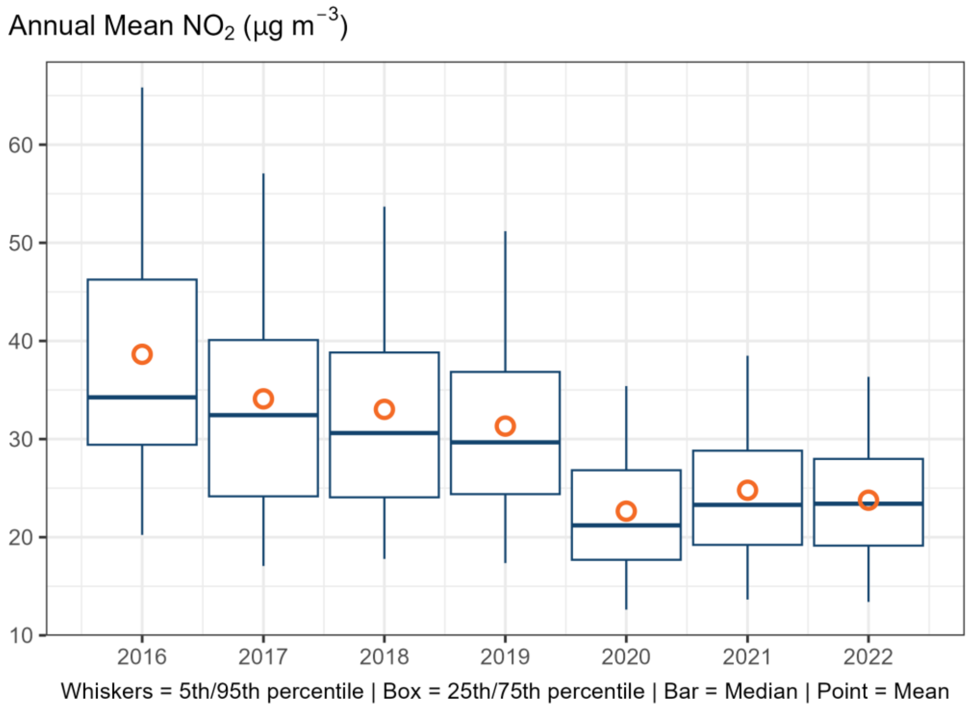
6.3 Post-COVID Air Quality

The 2020 and 2021 reports in this series included investigations of the effect of COVID-19 pandemic restrictions on air quality in the UK. In 2022 there were no longer any COVID-19 lockdown restrictions in place: this section assesses air quality after COVID-19 restrictions ended.

Figure 6-11 shows the distribution of annual mean NO_2 concentrations measured at urban traffic air quality monitoring sites in the UK, from 2016 to 2022. The boxes show the 25th to 75th percentile of each dataset, with the median (50th percentile) as a bar in the middle and the mean shown as a circle. The 'whiskers' extending from the top and bottom of the boxes represent the 5th to 95th percentile of each dataset.

Although there were no longer any travel restrictions during 2022, the average NO_2 concentration measured at urban traffic sites was similar to that in 2021 and has remained lower than pre-pandemic years.

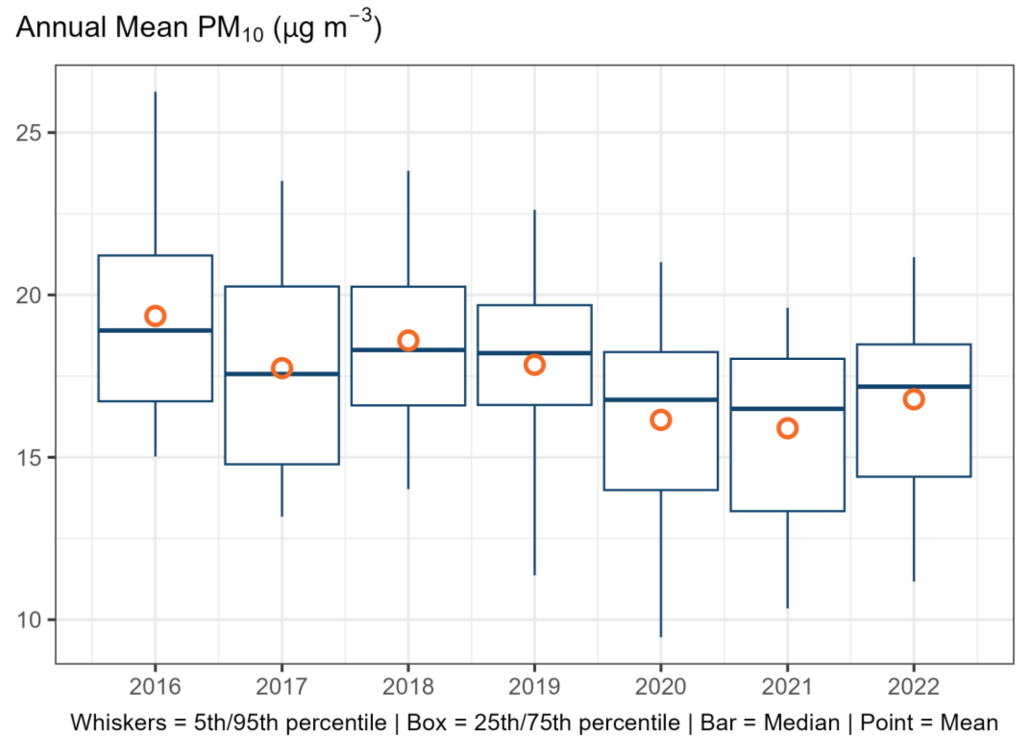
Figure 6-11 Box plot showing annual mean NO_2 concentrations measured at urban traffic AURN sites in the UK from 2016 to 2022.

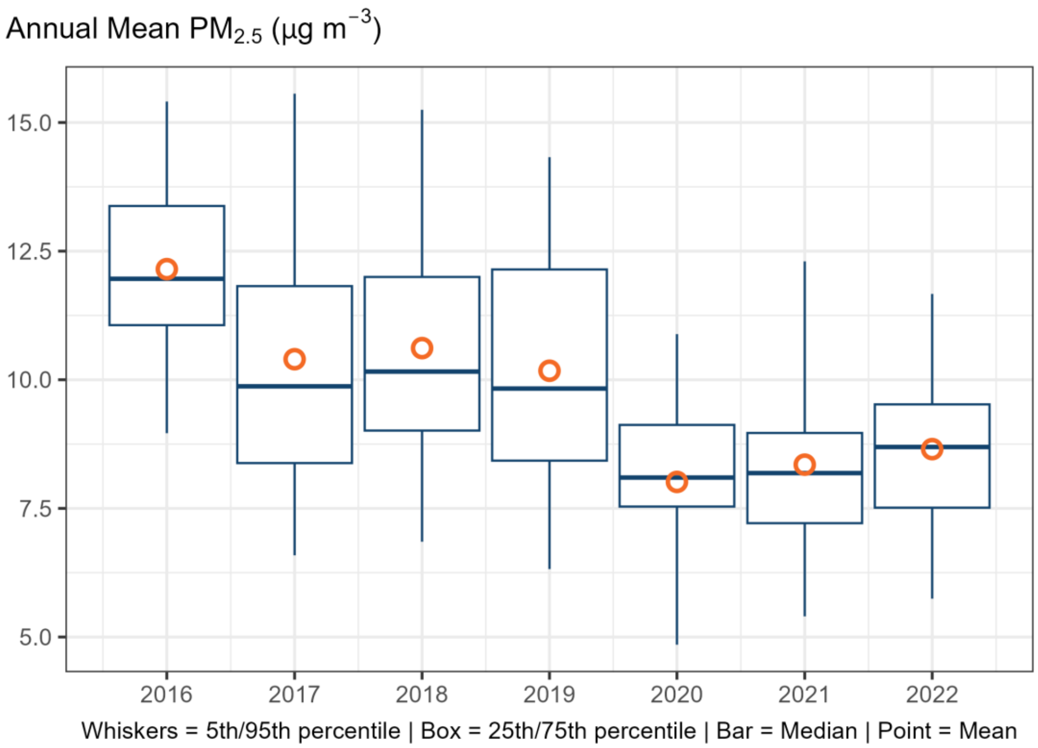


Estimated transport use on roads in Great Britain, published by the Department for Transport (DfT), shows that the overall number of vehicle miles driven in 2022 increased by 8.8% compared with 2021, but remained 4.4% lower than pre-COVID (2019) miles (DfT, 2023). The reduction in vehicle usage, along with a general decrease in NOx emissions from traffic, may explain why average NO_2 concentrations have remained below those measured pre-COVID.

Figure 6-12 shows the distribution of annual mean PM_{10} and $PM_{2.5}$ concentrations measured at urban traffic AURN air quality monitoring sites in the UK, from 2016 to 2022. A small increase in both PM_{10} and $PM_{2.5}$ is observed between 2021 and 2022. However, as PM is impacted by long range transport of pollution, it is challenging to separate the effects of local changes (such as changes in traffic volumes), from those of regional pollution.

Figure 6-12 Box plots showing annual mean PM_{10} and $PM_{2.5}$ concentrations measured at urban traffic AURN sites in the UK from 2016 to 2022.





7 Where to Find Out More

Defra's web pages relating to air quality can be found at https://www.gov.uk/government/policies/protecting-and-enhancing-our-urban-and-natural-environment-to-improve-public-health-and-wellbeing/supporting-pages/international-european-and-national-standards-for-air-quality. These provide details of what the UK is doing to tackle air pollution, and the science and research programmes in place.

Also, Defra has published a Guide to Air Pollution Information Resources, detailing the types of information that are made available and this can be found at https://uk-air.defra.gov.uk/assets/documents/reports/cat14/1307241318_Guide_to_UK_Air_Pollution_Information_Resources.pdf .

Information on the UK's air quality, now and in the past, is available on UK-AIR, the Defra online air quality resource at https://uk-air.defra.gov.uk/. UK-AIR is the national repository for historic ambient air quality data. It contains measurements from automatic measurement programmes, some dating back to 1972, together with non-automatic sampler measurements dating back to the 1960s. The data archive brings together into one coherent database both data and information from all the UK's measurement networks. Tools available on UK-AIR include the UK Ambient Air Quality Interactive Map at https://uk-air.defra.gov.uk/data/gis-mapping that allows you to look at outputs for the national modelling conducted for this compliance assessment, based on pollutant, background or roadside and geographical location.

Similar national online air quality resources have also been developed for Scotland, Wales and Northern Ireland:

- Air Quality in Wales at https://airquality.gov.wales/
- Air Quality in Scotland at https://www.scottishairquality.scot/
- Northern Ireland Air at https://www.airqualityni.co.uk/

Together, these four national websites provide a comprehensive resource for data and analyses covering all aspects of air quality throughout the UK and all its regions.

The Devolved Administrations each produce their own short annual report, providing more specific information on air quality in their parts of the UK. These reports are available from the above websites.

UK-AIR also provides a daily air quality forecast, which is further disseminated via e-mail, RSS feeds and X (formerly Twitter) (see https://twitter.com/DefraUKAir). Latest forecasts are issued daily, at https://uk-air.defra.gov.uk/forecasting/. Defra also provides a free telephone information service, with current air pollution levels and forecasts updated every hour. To use this service, call 0800 556677 and follow the instructions.

Detailed pollutant emission data for the UK are available from the National Atmospheric Emissions Inventory (NAEI) at https://naei.beis.gov.uk/.

The Clean Air Hub, at https://www.cleanairday.org.uk/pages/category/clean-air-hub, brings together information on air pollution, how it affects our health, and the actions we can take both to protect ourselves from it, and to help tackle it. There is also information on the annual Clean Air Day. The Clean Air Hub is coordinated by Global Action Plan: more information about Global Action Plan can be found at https://www.globalactionplan.org.uk/.

Additional information from the Devolved Administrations of Scotland, Wales and Northern Ireland can be found at:

- The Scottish Government Air Quality web page at https://www.scotland.gov.uk/Topics/Environment/waste-and-pollution/Pollution-1/16215

- The Welsh Government Environment and Climate Change web pages at https://gov.wales/environment-climate-change .

- The Northern Ireland Department of Agriculture, Environment and Rural Affairs (DAERA) web page at https://www.daera-ni.gov.uk/topics/protect-environment .

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