Department for Environment Food & Rural Affairs

Air Pollution in the UK 2023

September 2024

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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 are reported on the UK-AIR website at https://uk-air.defra.gov.uk. This report continues the series of annual compliance reporting against the UK's Air Quality Standards Regulations (2010) and details progress towards meeting the two 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. It then summarises the UK's ambient air quality assessment for 2023, 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 2023 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 the limit value for annual mean concentration of $PM_{2.5}$ particulate matter. Subtraction of natural source contribution is not allowed in the case of $PM_{2.5}$.

- The UK continues to meet its 2020 national exposure reduction target for $PM_{2.5}$, based on the Average Exposure Indicator (AEI) statistic (explained in **Sections 4 and 5** of this report). In 2023, the three-year running mean AEI was 8 µg 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 µg m^{-3} for annual mean $PM_{2.5}$ concentrations to be achieved by 2040. Legal compliance is assessed using measurements from monitoring stations in England of all site types. One monitoring station in England exceeded this target in 2023 (London Marylebone Road, a roadside site in central London). In 2023 no monitoring stations exceeded the interim target of 12 µg m^{-3}, 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. An interim target of 22% is to be met by January 2028. The population exposure value for 2023 was 7.88 µg m^{-3}, which constitutes a reduction of 22% from the 2018 value. Therefore in 2023 England met the interim PERT of 22%.

- For ozone, there are two target values (which are being met) and two long term objectives (where there are exceedances).

    - All zones met both the target value based on the daily maximum eight-hour mean, which was set for the protection of human health.

    - All zones met the target value based on the AOT40 statistic (explained in **Sections 4 and 5** of this report), which was set for the protection of vegetation.

    - One zone out of 43 was compliant with the more stringent long-term objective for ozone, set for the protection of human health. This is based on the daily maximum eight-hour mean.

    - 13 zones out of 43 were compliant with the more stringent 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.

- There were 26 measured exceedances of the ozone population information threshold of 180 µg m^{-3} in 2023.

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

- Three zones out of 43 have exceeded the target value for nickel.

- Two zones out of 43 have exceeded the target value for benzo[a]pyrene.

A summary of the air quality assessment for 2023, 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 2023. It features periods of high particulate and ozone pollution in June and September 2023.

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. An 8-hour mean is only valid if there are at least six hours of data within the 8-hour period (75% data capture).

Arsenic (As). A 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 hydrocarbon compound, whose chemical formula is $C_6 H_6$. As an air pollutant, benzene can be emitted from domestic and industrial combustion processes, and road vehicles.

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.

Cadmium (Cd). A 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 8-hour means 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 these consecutive 8-hour averages is taken as the daily maximum 8-hour mean. A daily maximum 8-hour mean is only valid if there are at least 18 valid 8-hour means within the day, each with at least six hours of data (75% data capture).

Digitel^{TM} 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).***

Emissions. Pollutants released into the air from any source: these can result from human activities (such as industrial processes or vehicle exhaust, tyre and brake wear), or natural sources (such as wildfires or wind-blown dust). The UK's estimated emissions of a range of pollutants are quantified in the ***National Atmospheric Emissions Inventory (NAEI)***.

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 2018 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 metallic element that can be an air pollutant. The main sources include industrial production processes, and vehicle tyre and brake wear.

Leckel SEQ™. 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' (LTOs) for ozone concentration. A Long-Term Objective means "*a level to be attained in the long term, save where not achievable through proportionate measures, with the aim of providing effective protection of human health and the environment*". For both target values and LTOs, the legal requirement for the UK is to take all necessary measures not entailing disproportionate costs to meet them, but achievement is not legally mandatory. The ozone LTOs are based on the same statistics as the ozone target values but are more stringent: unlike target values, the legislation does not specify a date by which LTOs should be met.

Mercury (Hg). A 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 (µg m^{-3} or µg/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.

National Atmospheric Emissions Inventory (NAEI): a database of estimated UK annual pollutant ***emissions*** from 1970 to the most current publication year for a wide range of pollutants: https://naei.energysecurity.gov.uk/ .

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 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 combines with oxygen to form nitrogen dioxide.

Nitrogen Dioxide (NO_2). One of the oxides of nitrogen formed in combustion processes.

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.

Objective Estimation. The process of estimating whether a zone or agglomeration is likely to be compliant with a given limit or target value, based on available evidence. The methods used depend on the pollutant: these are explained in the Technical Report on UK supplementary modelling assessment under the Air Quality Standards Regulations (2010). (Pugsley, K. L. et al., 2024).

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.

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.

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. 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. $PM_{2.5}$ 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. 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 $PM_{2.5}$ (based on measurements 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. 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 while the UK must take all necessary measures not entailing disproportionate costs to meet the target values by the specified date, achievement is not legally mandatory. 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 2023*' continues this series, and has two aims:

- To provide a summary of the UK's 2023 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 2023 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 2023 and looks at how ambient concentrations have changed in recent years (**Section 5**).
- Explains noteworthy pollution events that occurred during 2023 (**Section 6**). This year, Section 6 looks at episodes of high particulate matter in the winter (January) and summer (September), also episodes of high ozone concentration in April, June and September.
- 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 such as The Environmental Permitting (England and Wales) Regulations 2016 and the Clean Air Act, regulating emissions from specific sources. 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 and international shipping) 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 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.

For ozone, there are also **Long-Term Objectives (LTOs)** as well as target values. These are based on the same statistics as the ozone target values but are more stringent and have no specified date by when they should be met. As with target values, the UK is legally required to take all necessary measures not entailing disproportionate costs to meet the long-term objectives, but achievement is not legally mandatory.

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) (which is explained in **Section 2.1.2**). Unlike the “target values”, 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 targets apply to England only, and are as follows:

- **The annual mean concentration target (AMCT),** requires 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”).

- **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”).

The AMCT will be considered 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. All monitoring stations will be included in the assessment, if they have met the minimum annual data capture requirement of 85% of the year.

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 specifies 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) set interim targets (for England only) 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. The assessment method for the interim targets is the same as described above for the long-term targets.

The Environment Act (2021) established 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 2020-29 and 2030. 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). Regulations 9 and 10 of the National Emissions Ceilings Regulations and Commission Implementing Decision 2018/1522 concerning the preparation and publication of a National Air Pollution Control Programme (NAPCP) were revoked at the end of 2023 under the provisions of the Retained EU Law Act[2].

The Gothenburg Protocol (United Nations Economic Commission for Europe (UNECE), 1999) was revised in May 2012 to set emission reduction commitments (ERCs) for 2020 (from the 2005 baseline) for NO_X, NMVOC, NH_3, SO_X and $PM_{2.5}$. 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.

In 2022 (the most recent year for which data have been reported), the UK met domestic and international 2020-2029 emission reduction commitments for emissions of fine particulate matter as $PM_{2.5}$, NO_x, 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 are for the year 2022 and can be found here: https://naei.energysecurity.gov.uk/data/.

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 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).

[2] Retained EU Law (Revocation and Reform) Act 2023 (legislation.gov.uk)

Under the EPR, industrial facilities must obtain an environmental permit which sets out conditions including limits on allowable emissions and ongoing monitoring requirements. Permit conditions are based on the application of Best Available Techniques (BAT). BAT means the economically and technically viable techniques or technologies which are the best for preventing or minimising emissions and impacts on the environment as a whole. The UK is committed to maintaining high environmental standards and has put in place a process for determining future BAT for the largest industries. 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.

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 2022 (the most recent year for which data are available), UK estimated emissions of nitrogen oxides have fallen by 78%, UK estimated emissions of PM_{10} particulate matter have fallen by 82% and UK estimated emissions of $PM_{2.5}$ particulate matter have fallen by 88% (Defra, 2024a).

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.

The Environment (Air Quality and Soundscapes) (Wales) Act 2024 (Welsh Government, 2024) received Royal Assent on 14th February 2024. The Act includes provisions for a national air quality target setting framework, with specific duties for Welsh Ministers to set a short or long-term target for the annual mean level average concentration of $PM_{2.5}$ in ambient air by February 2027 and to set an additional long-term target in respect of one of the following listed pollutants: ammonia; PM_{10}; ground level ozone; nitrogen dioxide; carbon monoxide; and sulphur dioxide. The Act requires that regulations setting a $PM_{2.5}$ target are laid before Senedd Cymru within three years of the Act receiving Royal Assent, and that regulations setting a long-term target in respect of one of the listed pollutants are laid before Senedd Cymru within six years of the Act receiving Royal Assent. The Act also includes powers for Welsh Ministers to set long-term targets in respect of any matter relating to air quality in Wales.

The Act builds on our commitments in the Clean Air Plan for Wales; Healthy Air, Healthy Wales, enhancing existing legislation and delivering air quality improvements. This will improve the quality of our air environment and reduce the impacts of air and noise pollution on human health, biodiversity, the natural environment and our economy.

2.5.1 Environmental Improvement Plan 2023

The Environmental Improvement Plan 2023 (EIP) (Defra, 2023a) was the first five-yearly statutory review[3] of the 25 Year Environment Plan. The EIP applies to England only and set out how Government will improve all aspects of the environment. The clean air chapter of the EIP updated the 2019 Clean Air Strategy. On 30 July 2024 Government announced[4] a rapid review of the Environmental Improvement Plan (EIP), to be completed by the end of the year, to ensure it will deliver its legally binding targets. Government will develop a new, statutory plan to protect and restore our natural environment with delivery plans to meet its Environment Act targets including the $PM_{2.5}$ concentration 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 a national 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. 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. In addition, the Scottish Government's Cleaner Air for Scotland 2 strategy sets out the current air quality policy framework in Scotland (Scottish Government, 2021). 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 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 the Government expects local authorities to take in support of achieving our long-term air quality goals, including the new Environment Act $PM_{2.5}$ 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

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

[4] Government launches rapid review to meet Environment Act targets - GOV.UK (www.gov.uk)

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 finalising Northern Ireland's first Clean Air Strategy, driven by the need to protect public health. 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, along with the Discussion Document, can be viewed at: https://www.daera-ni.gov.uk/clean_air_strategy_discussion_document. Now that the Executive has returned, DAERA is working with the other departments to finalise this important cross-cutting Strategy.

DAERA held a public consultation on the draft Ammonia Strategy for Northern Ireland from January to March 2023. Responses to the consultation are being used to inform a reworked draft Ammonia Strategy. A High-Level Report and a Summary Report of responses to the consultation on the draft Ammonia Strategy have been published[5].

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

[5] https://www.daera-ni.gov.uk/consultations/draft-ammonia-strategy-northern-ireland-consultation

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

Government has provided over £550 million to help local authorities tackle NO_2 exceedances and achieve compliance with legal limits for NO_2 in the shortest possible time. 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, including 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 have all implemented Clean Air Zones between 2021 and 2023. The support provided to local authorities includes funding 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.

Government assesses whether a local authority has successfully delivered sustained compliance with NO_2 legal limit values, and whether this is likely to be maintained if the local authority wishes to remove measures. At this point the legal obligation to continue with measures will expire 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. Measures delivered include property demolition to open up a street canyon and city centre infrastructure schemes to reduce general vehicle access and enhance active travel and public transport connections. Reduced 50mph speed limits, with average speed enforcement, have been applied on the motorway and trunk road network to help lower emissions where NO_2 exceedances were identified. 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, with local grace periods of between 12 and 24 months in place prior to enforcement starting. In Glasgow, a LEZ restriction for buses began in 2018: enforcement for other vehicle types started on 1st June 2023 (a year later for residents within the zone). LEZ enforcement began on 30th May 2024 in Dundee, and on 1st June 2024 in Edinburgh and Aberdeen.

To help lower income households and small businesses adapt to LEZs The Scottish Government has provided financial support towards the disposal of non-compliant vehicles. A total of £13.1m has been paid out through a LEZ support scheme since 2019 that has seen over 4,000 non-compliant high polluting vehicles disposed of. A further £3m is allocated for 2024/25.

A separate LEZ Retrofit Fund has provided over £4m grant funding for taxi retrofits in Scotland since 2019. This has seen over 560 taxis retrofitted to Euro 6 standard. A further £2m is allocated for 2024/25.

A total of £24m in grants has been awarded by the Scottish Government through the Bus Emission Abatement Retrofit (BEAR) programme, allowing over 1100 midlife buses/coaches to be retrofitted since 2018.

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 £1.8 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 2021 reports are the most recent in the series. The 2022 reports will be published in December 2024.

2.5.6 Air Quality Accredited Official Statistics and Indicators

For many years, the UK has reported the following two indicators as Accredited Official Statistics for ambient air quality:

- **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 sites.

The Air Quality Accredited Official Statistics for 2023 were released on 30th April 2024 and are 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 2022, is 5.82%.

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.

2.5.7 Accredited Official Statistics - Emissions

The UK reports annual emissions of the following pollutants via an annual Accredited Official Statistics Release, available at https://www.gov.uk/government/statistics/emissions-of-air-pollutants. This is a large publication comprising multiple sections: there is a summary section and a background section, as well as individual sections for each pollutant which are summarised 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 Accredited Official Statistics Release covers 1970 to 2022 (the most recent year for which emission statistics are available). The main conclusions are as follows:

- *'Emissions of sulphur dioxide have decreased by 98 per cent since 1970, to 120 thousand tonnes in 2022. This was driven by a decline in coal use in the energy sector. Emissions from coal in the energy sector decreased by 9 per cent from 1970 to 1991. From 1991, emissions decreased more rapidly, by 83 per cent between 1991 and 2005 and then by a further 99 per cent from 2005 to 2022. Stricter limits being placed on the sulphur content of liquid fuels has also reduced emissions in the long-term. Emissions of SO_2 have increased by 2 per cent from 2021 to 2022 after having reached the lowest level in the time series in 2021. However, emissions have remained lower than pre-2021 levels.' (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 NO_X have decreased by 78 per cent since 1970, to 643 thousand tonnes in 2022. This trend was driven by a decline in coal use in power stations and by the modernisation of the road transport fleet. Emissions of NO_X decreased by 4 per cent between 2021 and 2022. This is similar to the change since 1990 as total emissions have decreased by an average of 4 per cent per year between 1990 and 2022'. (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 NMVOCs decreased by 69 per cent since 1970, to 756 thousand tonnes in 2022. Emissions decreased by 5 per cent between 2021 and 2022. NMVOC emissions reached the highest point in the time series in 1990 and then decreased on average by 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. However, more recently annual changes have been much smaller, emissions decreased on average by 2 per cent per year since 2009. From 1990 to 2022, NMVOC emissions decreased by 73 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 decreased by 16 per cent since 1980, to 259 thousand tonnes in 2022. The majority of this reduction occurred between 1980 and 2008. Emissions of ammonia then remained relatively stable from 2008 to 2013. Annual ammonia emissions reached the lowest in the time series in 2013 at 256 thousand tonnes. Since then, emissions have been higher, but have remained below the levels seen prior to the mid-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 decreased by 82 per cent since 1970, to 127 thousand tonnes in 2022. They have increased by 1 per cent between 2021 and 2022. Annual emissions of $PM_{2.5}$ have decreased by 88 per cent since 1970, to 65 thousand tonnes in 2022. They have decreased by 2 per cent between 2021 and 2022. In the UK $PM_{2.5}$ emissions decreased by 41 per cent between 2005 and 2022. Therefore, in 2022, the UK did meet the 30 per cent emission reduction commitment required between 2020 to 2029 as set out in the NECR. Levels of both pollutants generally decreased between 1970 and the late-2000s. There are many reasons for this long-term decrease, which covers most emissions sources, 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 PM have generally continued to fall, but the rate of change has reduced. Compared to earlier decades, emission levels have been relatively steady with small annual fluctuations. Considerable decreases in emissions from some sources (e.g. from road transport and energy industries) 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 based -fuels). In 2020 PM emissions reached the lowest level since estimates began due to reduced economic activity during the COVID-19 pandemic.’ (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 2023 will be published in February 2025.

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 objectives prescribed in the Air Quality (England) Regulations (2000) (UK Government, 2000), Air Quality (Scotland) Regulations (2000) (Scottish Government, 2000), Environment (Air Quality and Soundscapes) (Wales) Act (2024) (Welsh Government, 2024), 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 for 2023 as part of the Round Eight cycle.

When the Review and Assessment process identifies an exceedance of an air quality objective, the local authority must declare an 'Air Quality Management Area' (AQMA) and develop an Action Plan to reduce pollutant concentrations 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. In England, excluding London, all local authorities are expected to take proactive action to improve air quality, whether or not they have an AQMA. Local authorities without an AQMA, should specify proactive measures they will take in their Air Quality Strategy.

Information on the UK's AQMAs is summarised in **Table 2-1** below. At the time of writing (August 2024), 251 Local Authorities – 69.5% 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 AQMAs (as of August 2024.)

Region	Total LAs	LAs with AQMAs	AQMAs for NO_2	AQMAs for PM_{10}	AQMAs for SO_2
England (outside London)	265	170	434	22	5
London	33	33	36	29	0
Scotland	32	13	23	23	1
Wales	22	11	43	1	0
Northern Ireland	11	9	17	2	0
TOTAL	**363**	**236**	**545**	**75**	**6**

Most AQMAs in the UK are in urban areas and have been established to address the contribution to air pollution from roadside 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 August 2024)

Source	England	Wales	Scotland	Northern Ireland	London
County or Unitary Authority Road	157	21	4	0	1
Domestic Heating	1	0	0	1	0
Strategic Road Network	35	2	0	0	0
Industrial Source	8	1	1	0	0
Mixture of Road Types	65	5	1	1	2
Not Defined	1	0	1	2	0
Railways	1	0	0	0	0
Road Transport (unspecified)	163	15	23	15	28
Transport and Industrial Source	10	0	2	0	4
Transport, Industrial and Domestic Sources	4	0	2	0	1

Data 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). 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 and effects (both on human health and the environment) 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.energysecurity.gov.uk/ (National Atmospheric Emissions Inventory, 2024a) 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 in relation to 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, with combustion from industry, passenger cars and other transport being the most important UK sources (National Atmospheric Emissions Inventory, 2024a).

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 often 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 sources such as 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 (and other pollutants which contribute to its formation) 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, which 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 the more stringent 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; agriculture; waste treatment, 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 in England 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 rapidly, making short-term exposure to peak concentrations important (COMEAP, 2011) (WHO, 2021).

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, 2024a).

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. It is a hydrocarbon (i.e. composed of carbon and hydrogen) and is a natural component of fossil fuels like crude oil and coal. 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). No safe level can be specified for benzene in ambient air; however, the risk increases with increased 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 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, 2024a). 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).

Inhalation of lead 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. 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 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, 2024a). A small number of UK zones continue to regularly exceed applicable target values for annual mean Ni, due to local industrial emissions. There are annual plans published which report the actions and measures already taken or planned, to help the UK meet the target values in the future (Defra, 2023c).

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 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, 2024a). 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 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 2% of the UK 2022 total (National Atmospheric Emissions Inventory, 2024a). 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, 2024a).

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 central nervous system and kidneys (UK Health Security Agency, 2022b). Chronic inhalation of mercury vapour may cause tremor, fatigue, headaches, depression, irritability and hallucinations (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 and PAHs in the UK are residential, commercial and industrial fuel combustion (National Atmospheric Emissions Inventory, 2024a). A small number of UK zones continue to exceed applicable target values for B[a]P, as has been the case for many years. There are annual plans published which report the actions and measures already taken or planned, to help the UK meet the target values in the future (Defra, 2023d).

PAHs are persistent, organic compounds with toxic and carcinogenic effects. Exposure to PAHs can lead to a range of respiratory effects, heart disease, dermatitis and effects on the immune system. 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.

3.2 Assessment of Air Quality in the UK

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 the national 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[6]. By contrast, Local Air Quality Management (LAQM) modelling is different in scope, purpose and methodology from the national modelling. The level of detail and resolution of LAQM modelling can be 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 3.3** for more details on the modelling carried out for compliance assessment.

The $PM_{2.5}$ targets set under the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) (UK Government, 2023) are assessed using fixed measurements from the national Automatic Urban Rural Network (AURN) only: modelling is not used in this case. The $PM_{2.5}$ monitoring network is currently being expanded to support the assessment.

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

3.2.1 Current UK Air Quality Monitoring

During 2023 there were 630 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 630 because some sites belong to more than one network. This table shows the number of sites in operation during part or all of 2023.

Table 3-1 The UK's Air Quality Monitoring Networks in 2023

Network	Pollutants	Number of Sites operating in 2023
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.)	**160** **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	**36**
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**

Network	Pollutants	Number of Sites operating in 2023
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**
UK Eutrophying and Acidifying Pollutants: AGANet	HNO_3, HONO, SO_2, Ca, Cl, Mg, Na, NO_2, NO_3 and SO_4	**28**
UK Eutrophying and Acidifying Pollutants: NAMN	NH_3 and/or NH_4	**113**
UK Eutrophying and Acidifying Pollutants: PrecipNet	Major ions in rainwater	**48**
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.	**345**

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 monitoring for dissemination of up-to-date data. 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 2023 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 that collect daily samples onto a filter for subsequent weighing (the reference method) at two sites only. 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 24 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. Two new sites started in 2023: Margam Youth Centre (in Port Talbot) and Portsmouth.

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 2023, 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 London 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 2023 the Acid Gas and Aerosol Network (AGANet) comprised a total of 28 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 Monitoring Network (NAMN) is used to quantify temporal and spatial changes in air concentrations and deposition in ammonia (NH_3) and ammonium (NH_4^+) on a long term basis using both passive samplers (Alpha Samplers) and low volume denuders (Delta Samplers). 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 2023 to include an additional 16 Alpha samplers which also form part of Natural England's Long Term Monitoring Network.

- The Precipitation Network (PrecipNet), measuring major ions in precipitation at 48 rural sites. Fifteen of these sites form part of the Long Term Monitoring Network managed by Natural England - seven of these sites started in 2023. 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 2023, 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. More information can be found from https://uwmn.uk.

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 caps. During 2023 monitoring was undertaken at approximately 300 sites.

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., 2024) (the latest versions of these can be found in the Library section of Defra's UK-AIR website, uk-air.defra.gov.uk.

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; 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, 2024)) 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 2023

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 2023

4.2 Air Quality Assessment for 2023

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., 2024)). 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.

An objective estimation method has been applied for the 2023 reporting year in zones for which the maximum annual mean NO_2 concentration is determined by including UUNN measurements with 9 or 10 months of data for the reporting year (as opposed to the usual UUNN data capture requirement of 11 months). This is to ensure that available evidence that is representative of annual mean NO_2 concentrations is used in the air quality assessment to determine the compliance status of these reporting zones.

Compliance with the $PM_{2.5}$ targets set in the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) 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 the Roadside

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 2023 are summarised in the tables below. The tables have been completed as follows:

- Where all measurements were within the relevant limit values in 2023, 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 2023, 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 2023. The 2023 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., 2024). This is underpinned by NAEI emission trends, AURN measurement trends and historical modelling assessments.

Nitrogen dioxide (NO_2): in 2023, 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 2023, 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; 2023 is the fourth consecutive year in which all zones have been compliant.

34 zones met the annual mean limit value for NO_2 (40 µg m^{-3}) in 2023. 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
- Nottingham Urban Area
- Bristol Urban Area
- Coventry/Bedworth
- The South East.

Table 4-2 Results of Air Quality Assessment for Nitrogen Dioxide in 2023

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	OK	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	> LV (s only)	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.

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. In the following year, 2021, 10 zones exceeded this limit value. In 2022, nine zones exceeded this limit value, and in 2023 also, nine zones exceeded this limit value.

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.

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 2023 there were no modelled exceedances of either the 24-hr or annual mean limit values prior to any natural source correction. (Pugsley, K. L. et al., 2024).

Table 4-3 Results of Air Quality Assessment for PM_{10} in 2023

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 2023. 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 annual mean limit value (20 µg m^{-3} to have been achieved by 1st Jan 2020).

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

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[7].

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

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., 2024).

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.

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

- 2021: 8 µg m^{-3}
- 2022: 8 µg m^{-3}
- 2023: 7 µg m^{-3}

The three-year running mean AEI for 2023 (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 2023.

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[7] 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 2023

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

Subtraction of natural source contribution is not permitted for $PM_{2.5}$.

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.
- 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.

The Annual Mean Concentration Target will be considered 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.

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. One AURN site in England exceeded the AMCT of 10 µg m^{-3} in 2023. This was London Marylebone Road, a roadside site in central London.

All AURN sites met the ***interim*** AMCT in 2023. 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. PEIbase is 10.09 µg m^{-3}. 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.

PEI2023 is 7.88 µg m^{-3}. The reduction in population exposure from 2018 to 2023 is 22%: England therefore met the ***interim*** PERT of 22% in 2023, though not the long-term target of 35% to be met by December 2040. **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 2023 (the larger the size of the circle, the more sites with this measurement)

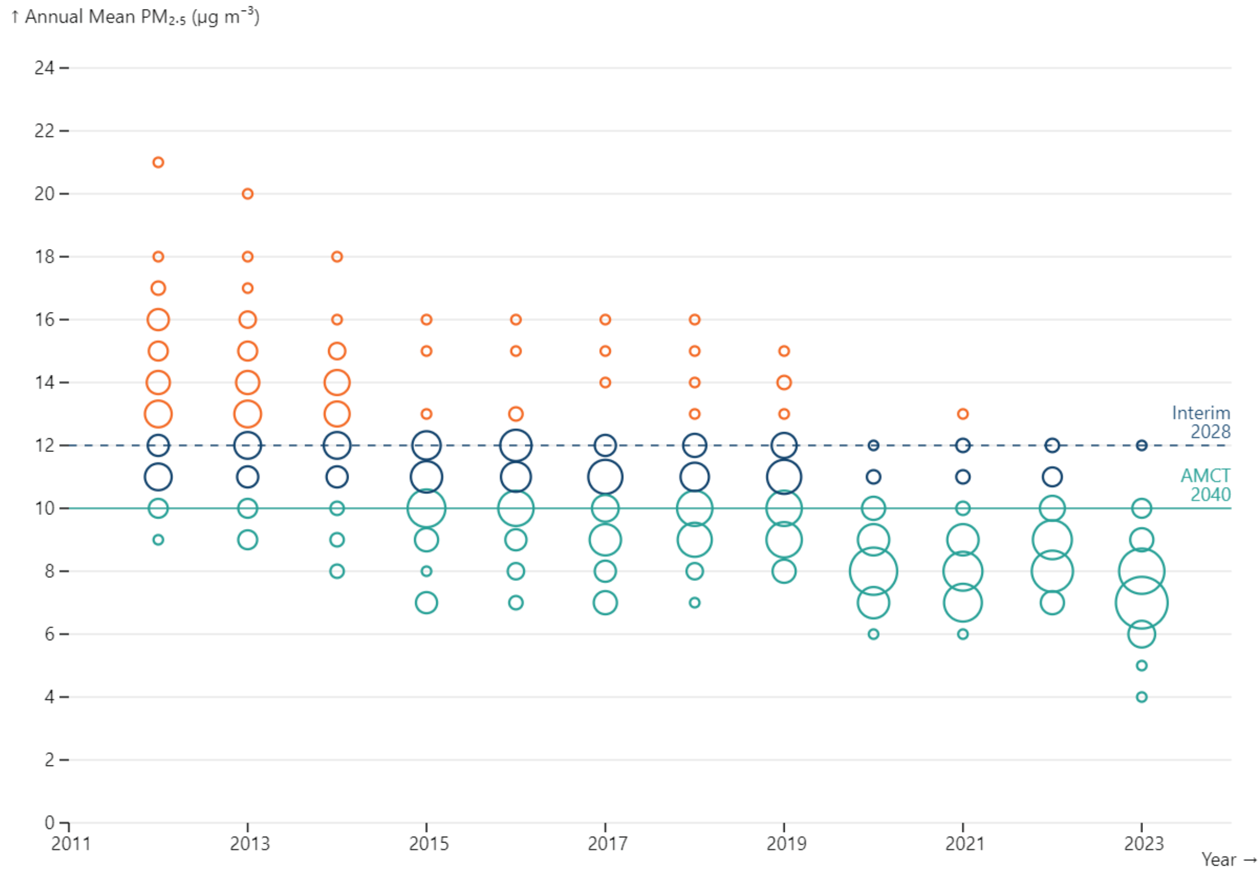
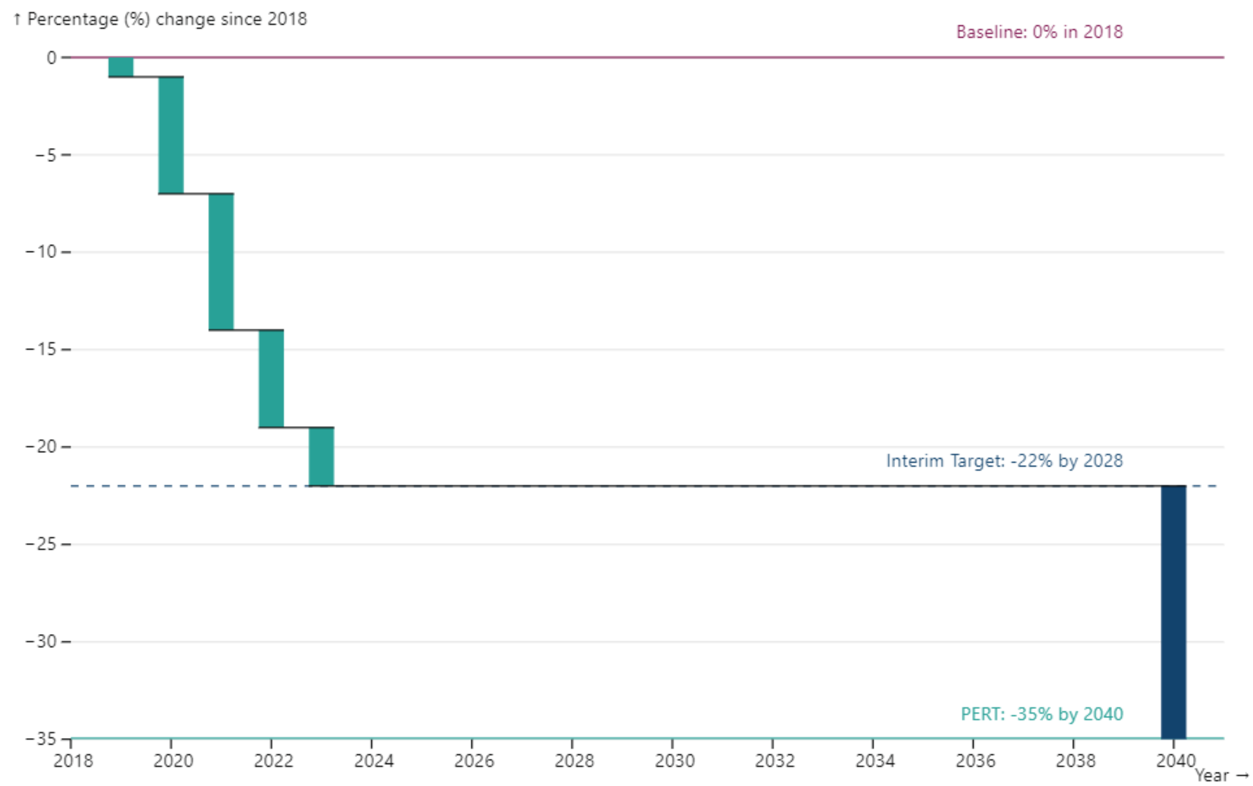


Figure 4-3 PERT progress from 2018 to 2023



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 more stringent long-term objective for protection of human health, also based on the maximum daily 8-hour mean. Only one of the 43 zones and agglomerations was compliant with the long-term objective (LTO) for health in 2023: Edinburgh Urban Area.

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 more stringent long-term objective, for protection of vegetation, also based on the AOT40 statistic; 30 zones exceeded this long-term objective for vegetation in 2023. The UK met all target values for O_3 in 2023 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 (travelling long distances across countries) and its formation is influenced by meteorological factors. Ozone is not emitted from sources in the same way as most other air pollutants. It is the product of chemical reactions between other pollutants in the air, both human-made and from natural sources, that occur more frequently during hot and sunny weather. The year 2023 contained two notable periods of high ozone concentration, during hot, sunny weather in June and September. There were more exceedances of the LTO for vegetation in 2023 than in 2022.

In 2023 there were 26 measured exceedances of the ozone population information threshold of 180 µg m^{-3}, considerably fewer than the 88 exceedances reported in 2022. There were 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 and early autumn weather. These were as follows:

- 10^{th}, 11^{th}, 13^{th} and 14^{th} June 2023. Measured ozone concentrations exceeded the population information threshold during the afternoons and early evenings of these days at several sites in the South East of England, London, Essex and Bournemouth.
- 7^{th} – 9^{th} September 2023. Exceedances of the population information threshold occurred in the afternoons of these days at several sites in London, the South East of England, Reading and East Anglia.

Table 4-5 Results of Air Quality Assessment for Ozone in 2023

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	Met TV, > LTO
Greater Manchester Urban Area	UK0003	Met TV, > LTO	Met TV, > LTO (s only)
West Yorkshire Urban Area	UK0004	Met TV, > LTO	Met TV, > LTO (s only)
Tyneside	UK0005	Met TV, > LTO (s only)	OK
Liverpool Urban Area	UK0006	Met TV, > LTO	Met TV, > LTO (s only)
Sheffield Urban Area	UK0007	Met TV, > LTO	Met TV, > LTO
Nottingham Urban Area	UK0008	Met TV, > LTO	Met TV, > LTO (s only)
Bristol Urban Area	UK0009	Met TV, > LTO	Met TV, > LTO (s only)
Brighton/Worthing/Littlehampton	UK0010	Met TV, > LTO	Met TV, > LTO (s only)
Leicester Urban Area	UK0011	Met TV, > LTO	Met TV, > LTO (s only)
Portsmouth Urban Area	UK0012	Met TV, > LTO	Met TV, > LTO
Teesside Urban Area	UK0013	Met TV, > LTO (s only)	OK
The Potteries	UK0014	Met TV, > LTO	Met TV, > LTO (s only)
Bournemouth Urban Area	UK0015	Met TV, > LTO	Met TV, > LTO
Reading/Wokingham Urban Area	UK0016	Met TV, > LTO	Met TV, > LTO (s only)
Coventry/Bedworth	UK0017	Met TV, > LTO	Met TV, > LTO (s only)
Kingston upon Hull	UK0018	Met TV, > LTO	Met TV, > LTO (s only)
Southampton Urban Area	UK0019	Met TV, > LTO	Met TV, > LTO (s only)
Birkenhead Urban Area	UK0020	Met TV, > LTO	Met TV, > LTO (s only)
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	OK
Edinburgh Urban Area	UK0025	OK	OK
Cardiff Urban Area	UK0026	Met TV, > LTO	Met TV, > LTO
Swansea Urban Area	UK0027	Met TV, > LTO	Met TV, > LTO (s only)
Belfast Metropolitan Urban Area	UK0028	Met TV, > LTO	OK
Eastern	UK0029	Met TV, > LTO	Met TV, > LTO
South West	UK0030	Met TV, > LTO	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	Met TV, > LTO
Yorkshire & Humberside	UK0034	Met TV, > LTO	Met TV, > LTO
West Midlands	UK0035	Met TV, > LTO	Met TV, > LTO
North East	UK0036	Met TV, > LTO (s only)	Met TV, > LTO (s only)
Central Scotland	UK0037	Met TV, > LTO (s only)	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	Met TV, > LTO (s only)
North Wales	UK0042	Met TV, > LTO	Met TV, > LTO (s only)
Northern Ireland	UK0043	Met TV, > LTO	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 2023

Site name	Zone name	Number of 1-hour exceedances of information threshold	Maximum 1-hour concentration (µg m^{-3})
Bournemouth	Bournemouth Urban Area	5	191
Rochester Stoke	South East	5	190
London Harlington	Greater London	4	190
London N. Kensington	Greater London	3	188
Canterbury	South East	2	187
St Osyth	Eastern	2	184
London Bloomsbury	Greater London	1	184
London Haringey Priory Park South	Greater London	1	182
Lullington Heath	South East	1	181
Reading New Town	Reading/Wokingham Urban Area	1	184
Sibton	Eastern	1	186

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 µg m^{-3} but less than 180.5 µg 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 Sheffield Urban Area, Swansea Urban Area 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 2023

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
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
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, lead, benzene and CO**, the UK has been compliant with all Air Quality Standards Regulations (2010) limit values since 2008. For **$PM_{2.5}$**, the UK has been compliant with the AQSR limit value (20 µg m^{-3} to have been achieved by 1st Jan 2020) since 2015. 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 2023. 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 2023.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.

This is only the second year in which compliance against the $PM_{2.5}$ targets of the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) has been reported so no table is included for $PM_{2.5}$.

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.

Table 4-8 Non-Compliances with Limit Values for Nitrogen Dioxide, 2008-2023

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: hence the apparent increase in zones exceeding in 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.
2023	None	9 zones	No time extensions in place.

Table 4-9 Non-Compliances with the Limit Values for PM_{10}, 2008-2023

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 > 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 > 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	-
2023	None	None	-

Table 4-10 Exceedances of Target Values for Ozone (Health) and Long-Term Objectives, 2008-2023

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
2023	None	None	42 zones	30 zones

Table 4-11 Zones Exceeding Target Values for As, Cd, Ni and B[a]P, 2008-2023

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, N. 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, N. 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)
2023	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 3.3** 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.

Reports in this series for years up to and including 2020 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 interactive maps will allow the viewer to see the modelled roadside concentrations in detail, and zoom in on 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. $\mu g\ m^{-3}$) 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 $\mu g\ m^{-3}$ per year (represented by the solid dark blue line) with a 95% confidence interval between -0.94 and -0.81 $\mu g\ m^{-3}$ (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.energysecurity.gov.uk/. The most recent year for which NAEI emission estimates are available is 2022. 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

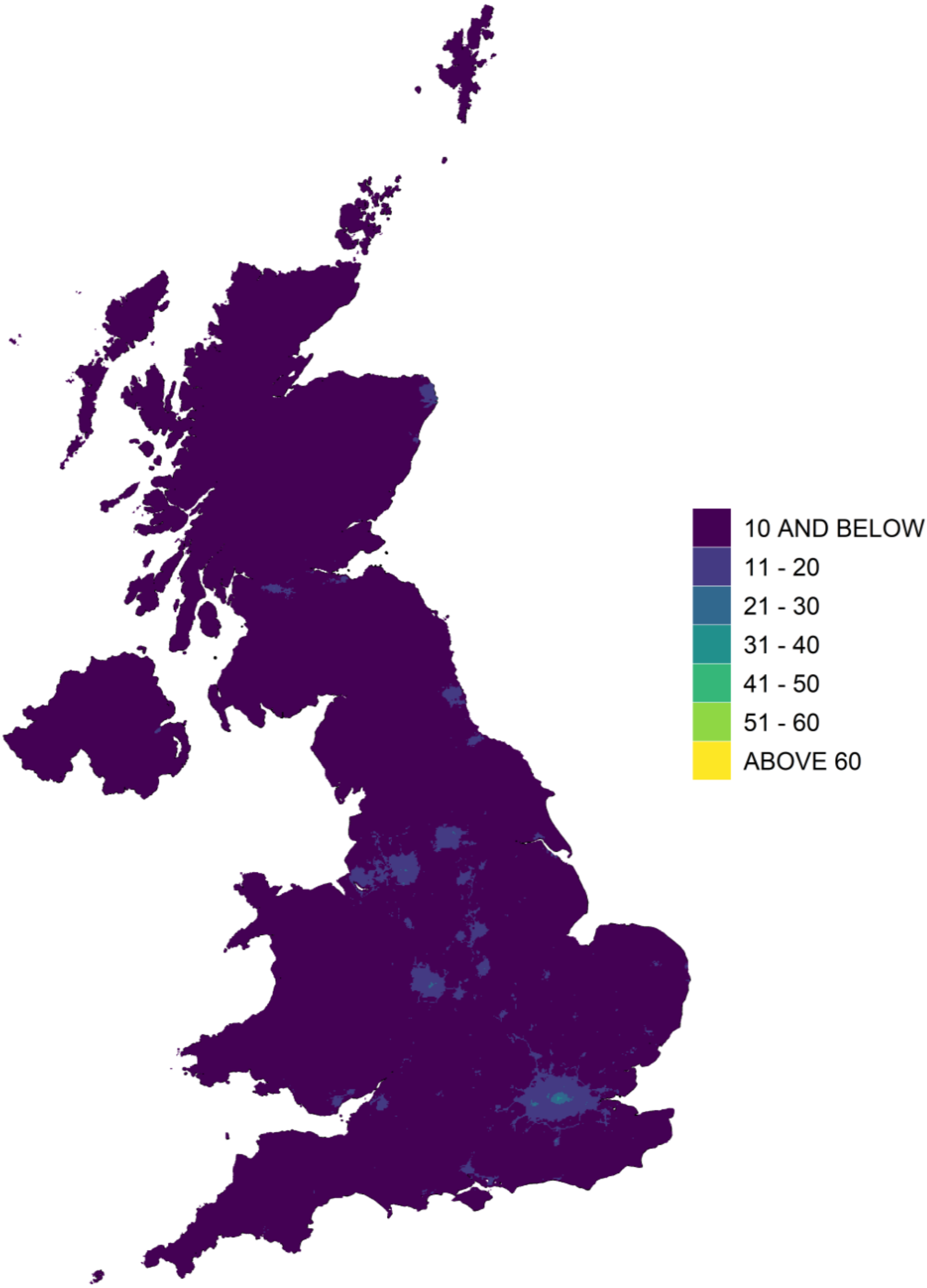
5.2.1 NO_2: Spatial Distribution in the UK

Figure 5-1 shows the modelled annual mean NO_2 concentrations for 2023, 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/.

As explained above, previous reports in this series (up to and including 2020) 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.

Figure 5-1 Annual Mean Background NO_2 Concentration, 2023 ($\mu g\ m^{-3}$)



An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/.

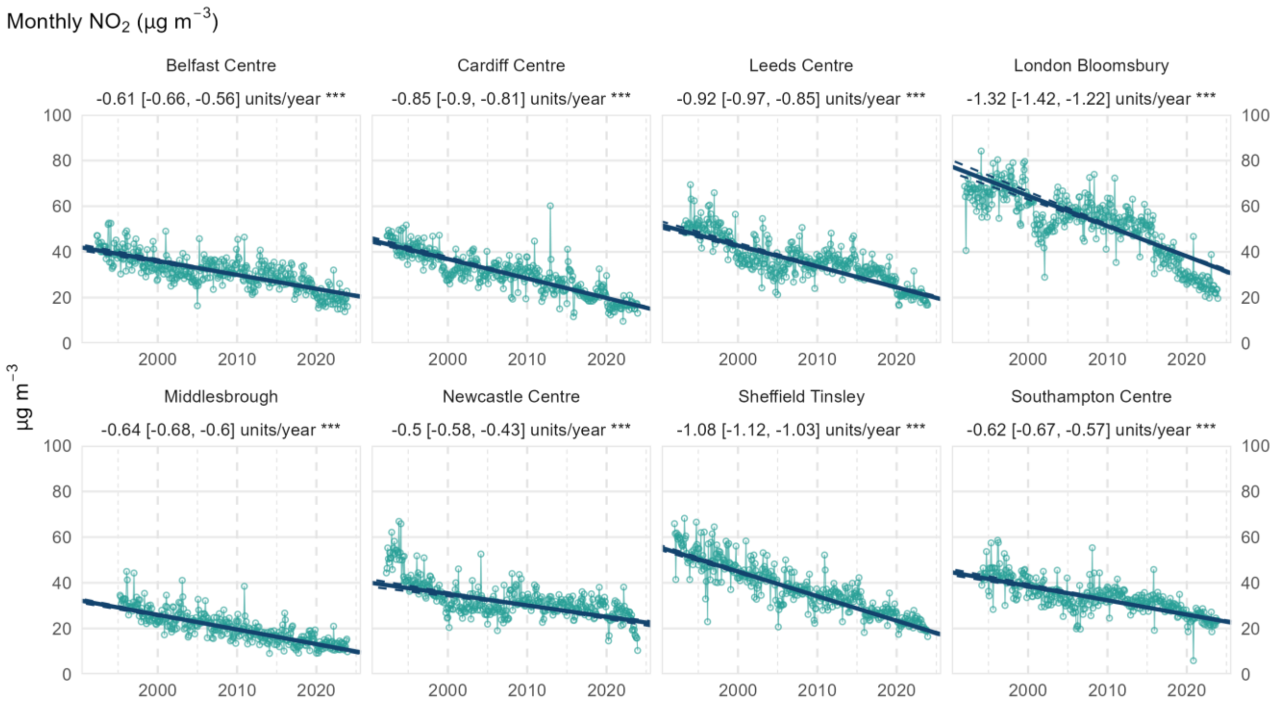
5.2.2 NO_2: Changes Over Time

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**); Cambridge Roadside, Camden Kerbside, 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 Eight Long-Running AURN Urban Background Sites, 1992-2023



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 -0.5 μg m^{-3} per year at Newcastle Centre to -1.32 μg 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 Eight Long-Running AURN Urban Traffic Sites, 1998-2023

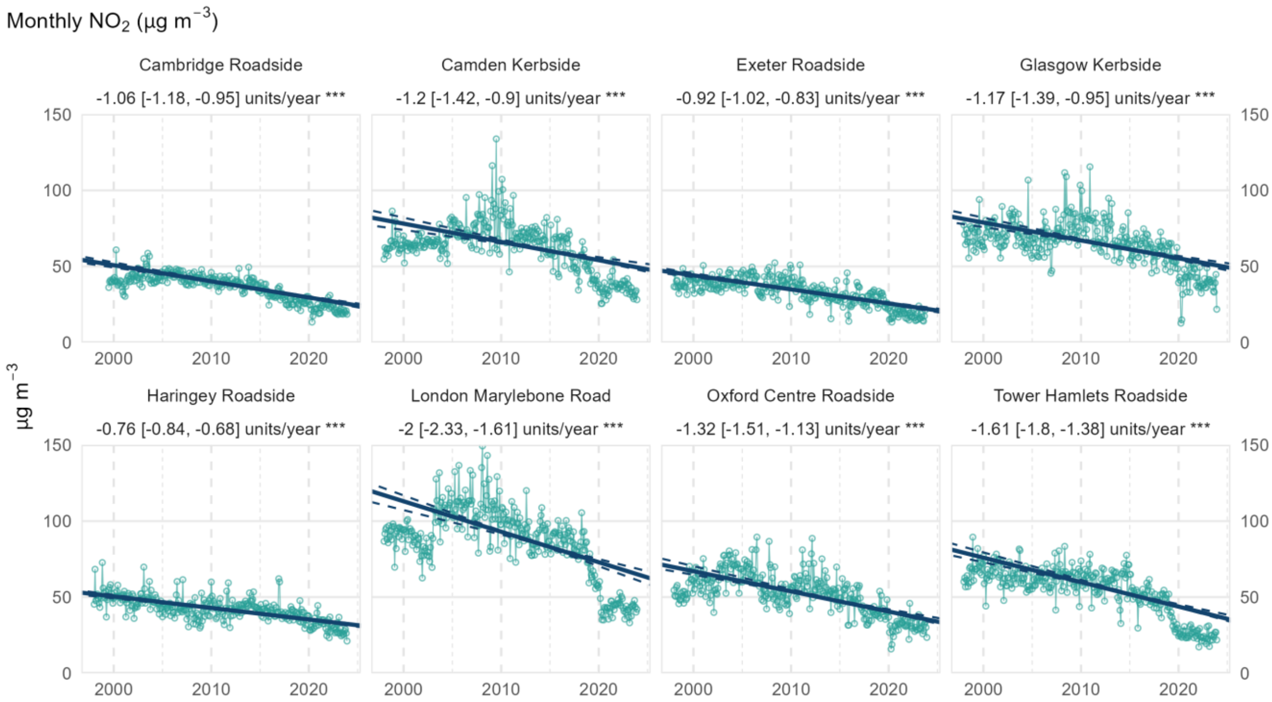


Figure 5-4 is taken from Defra's National Air Quality Statistics web page for NO_2, at https://www.gov.uk/government/statistics/air-quality-statistics/ntrogen-dioxide (Defra, 2024b). This shows annual mean NO_2 concentrations averaged over all included sites that had annual data capture greater than 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 2023. 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)***

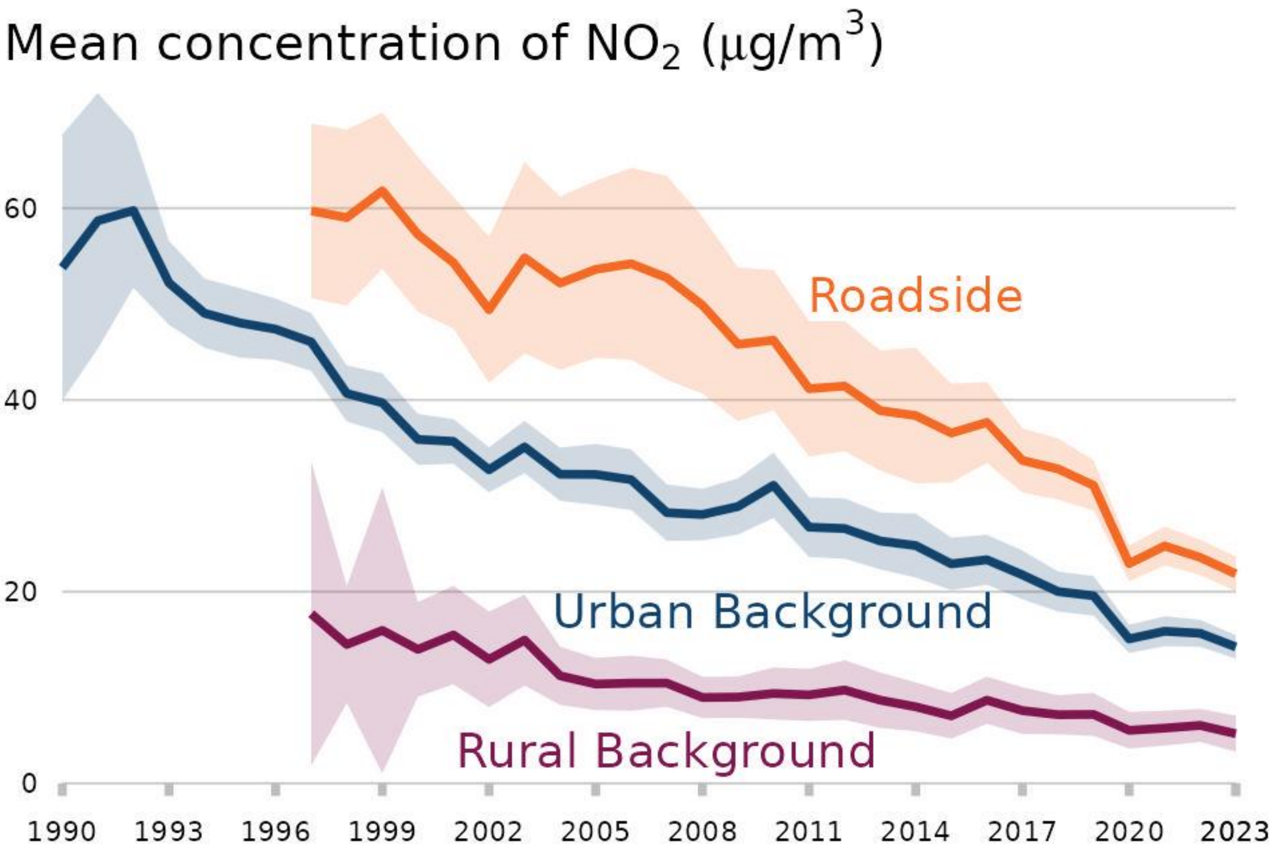
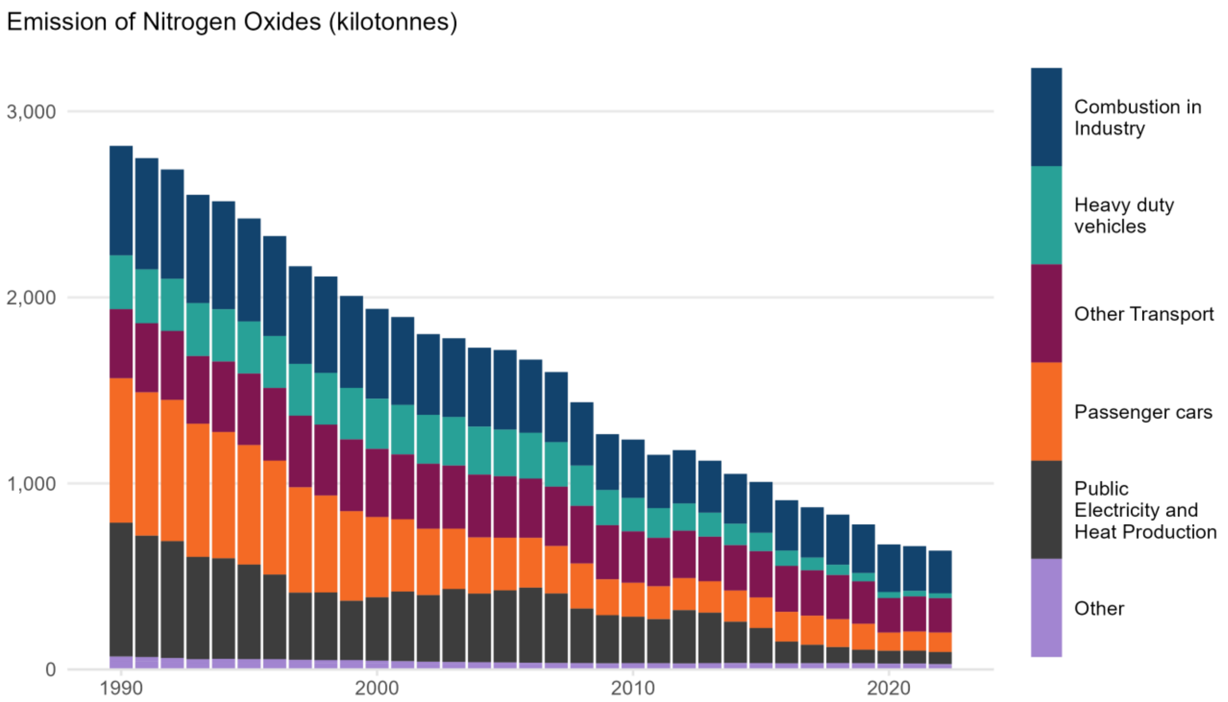


Figure 5-5 shows estimates of total UK annual emission of nitrogen oxides (NOx), in kilotonnes, from 1990 to 2022 (the most recent year for which emission estimates are available). The data are from the National Atmospheric Emissions Inventory (NAEI) website at: https://naei.energysecurity.gov.uk/. This 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.

For more information on UK emissions of NOx please visit the Accredited Official Statistics publication available here: https://www.gov.uk/government/statistics/emissions-of-air-pollutants.

Figure 5-5 Estimated Annual UK Emissions of Nitrogen Oxides (kt), 1990 – 2022 (Source: NAEI 2023)



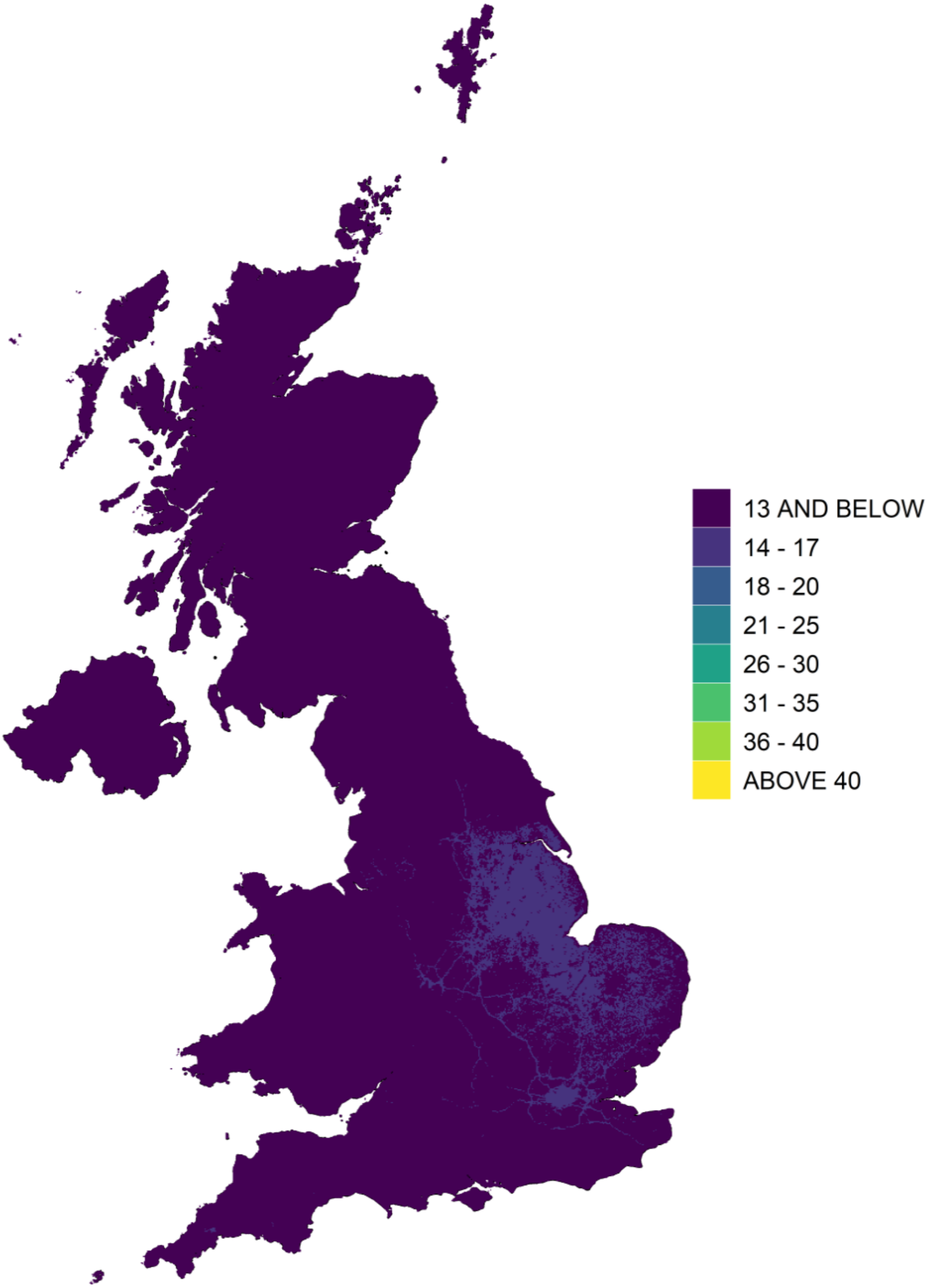
5.3 PM_{10} Particulate Matter

5.3.1 PM_{10}: Spatial Distribution

Figure 5-6 shows modelled annual mean background PM_{10} concentrations in 2023. 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/.

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.

Figure 5-6 Annual Mean Background PM_{10} Concentration, 2023 ($\mu g\ m^{-3}$)



An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/.

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 in magnitude (all are between 0 and -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 – 2023

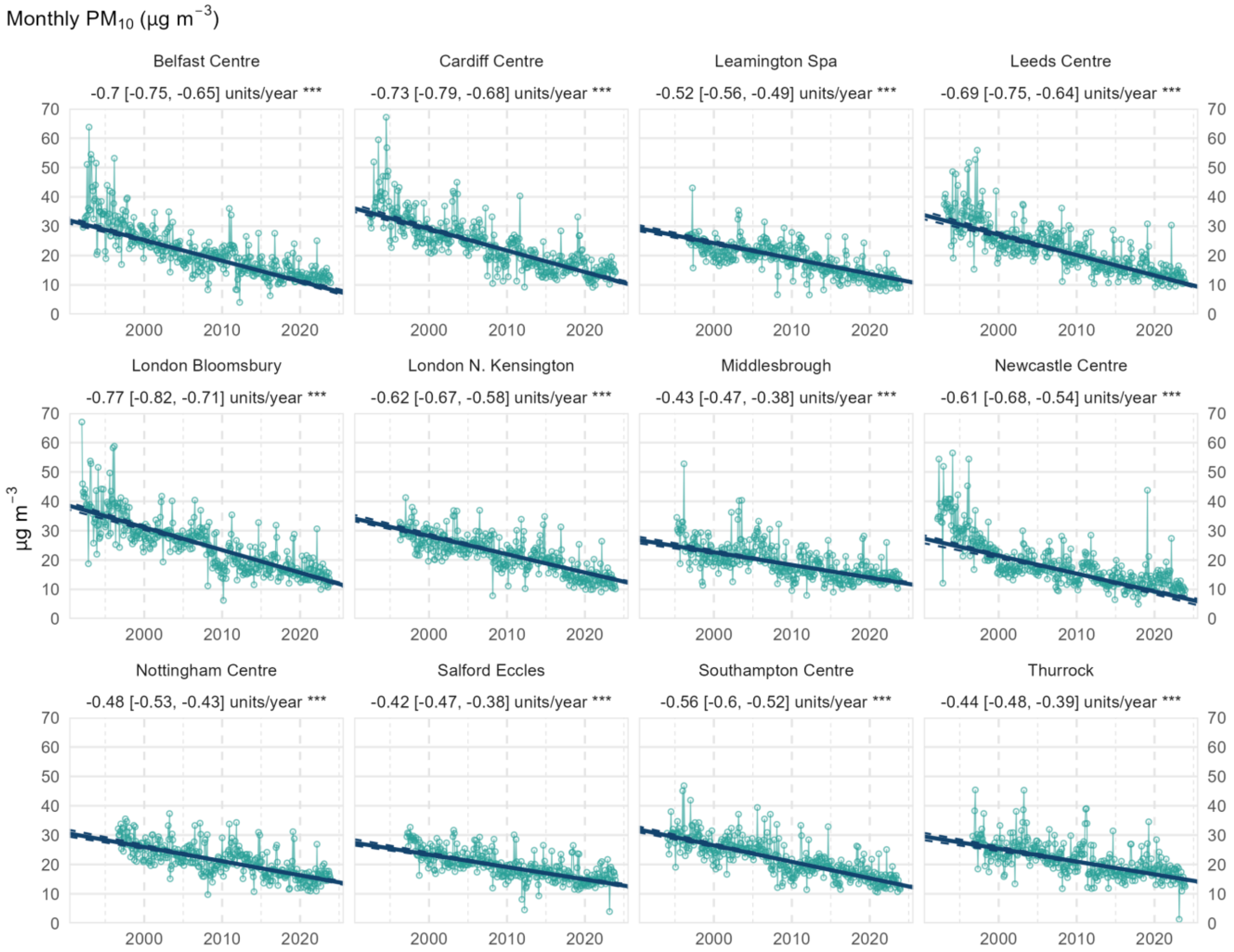


Figure 5-8 shows de-seasonalised trends in ambient PM_{10} concentration, based on 12 urban traffic AURN sites. There are few very long-running urban traffic PM_{10} sites: only three began monitoring PM_{10} before 2008. The sites shown here have been operating since the start of 2011 or earlier. The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

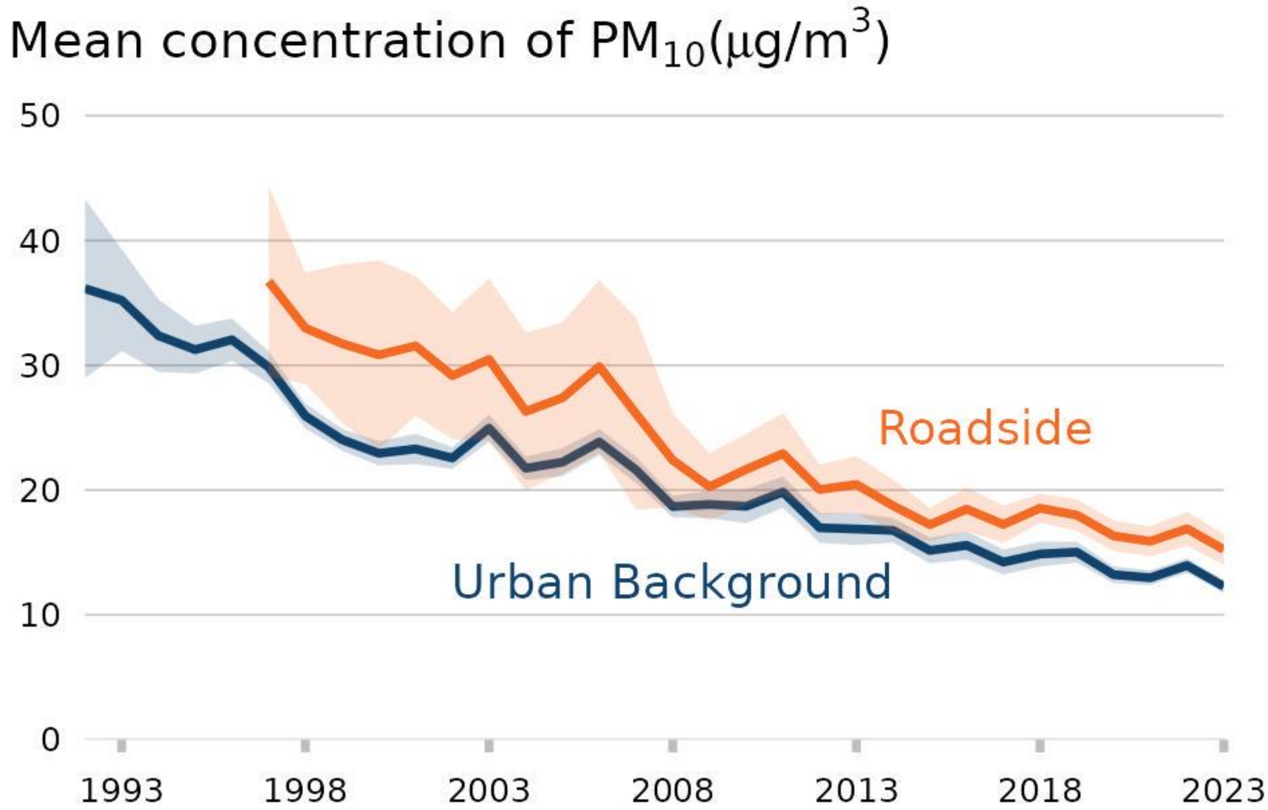
Eleven of these sites show a downward trend which is highly statistically significant (at the 0.001 confidence level). The exception is Swansea Roadside which shows no significant increasing or decreasing trend. As in the case of NO_2, it is likely that trends at urban traffic sites are influenced by 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 – 2023

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, 2024d). 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 2023. Shaded areas either side of each line show the 95% confidence interval of the mean.

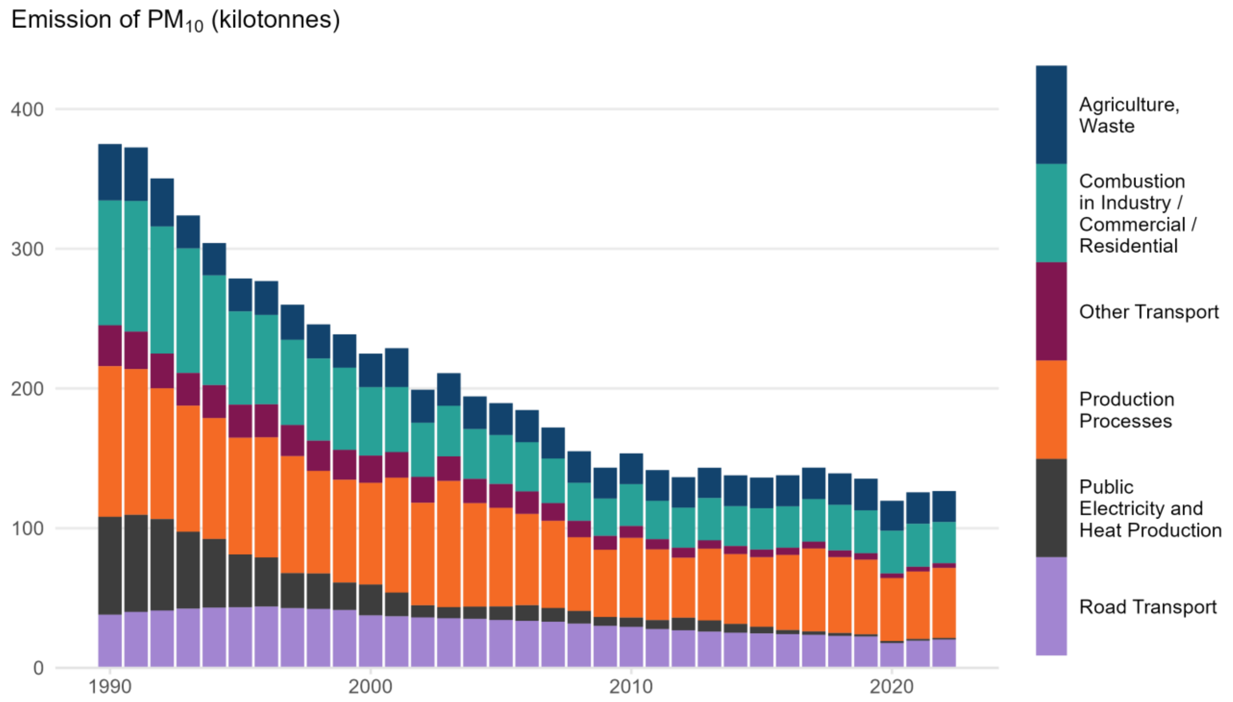


(Source: https://www.gov.uk/government/statistics/air-quality-statistics/concentrations-of-particulate-matter-pm10-and-pm25)

Figure 5-10 shows NAEI estimates of total UK annual emission of PM_{10} in kilotonnes, from 1990 to 2022 (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.energysecurity.gov.uk/node/51). 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.

For more information on UK emissions of PM_{10} please visit the Accredited Official Statistics publication available here: https://www.gov.uk/government/statistics/emissions-of-air-pollutants.

Figure 5-10 Estimated Annual UK Emissions of PM_{10} (kt), 1990 – 2022 (source: NAEI 2023)



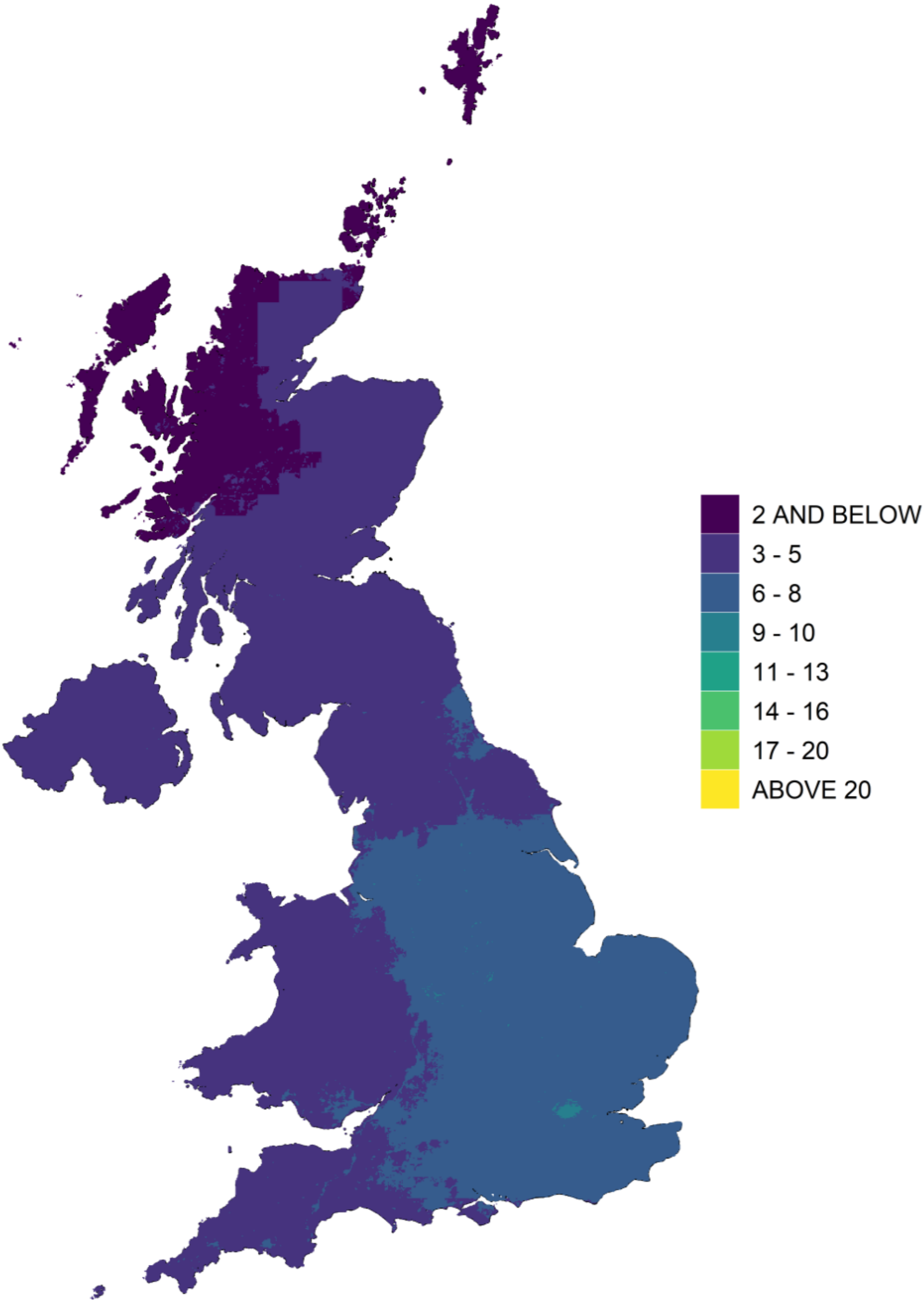
5.4 $PM_{2.5}$ Particulate Matter

5.4.1 $PM_{2.5}$: Spatial Distribution

Figure 5-11 shows modelled annual mean background $PM_{2.5}$ concentrations for 2023. 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 to 6-8 µg m^{-3} over most of southern and central England. Within London small parts of other cities, modelled concentrations were 9-10 µg m^{-3}, but everywhere in the UK was well within the annual mean 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/.

Figure 5-11 Annual Mean Background $PM_{2.5}$ Concentration, 2023 (µg m^{-3})



An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/.

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, 2009-2023. 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 2009-2023

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. All nine sites show decreasing trends, statistically significant at the 0.001 confidence level, between 2009 and 2023. Of note is Swansea Roadside: until 2021, this site showed an increasing trend in $PM_{2.5}$ concentration from 2009 onwards. In 2022 it showed a decreasing trend for the first time (though not statistically significant): 2023 is the first year in which it has shown a statistically significant downward trend.

Figure 5-13 De-seasonalised Trends in Ambient $PM_{2.5}$ Concentration, Nine Long-Running Urban Traffic AURN Sites 2009-2023

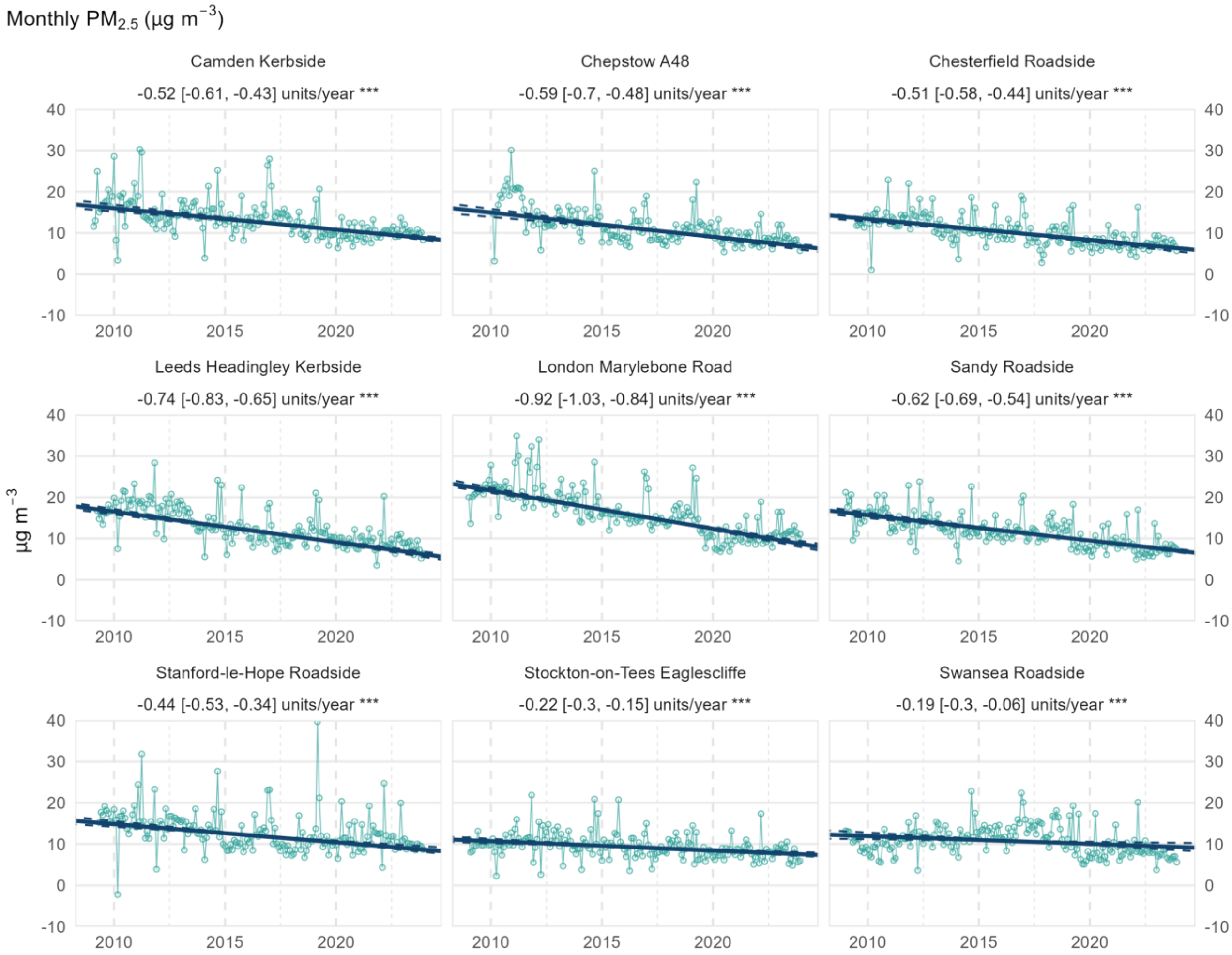
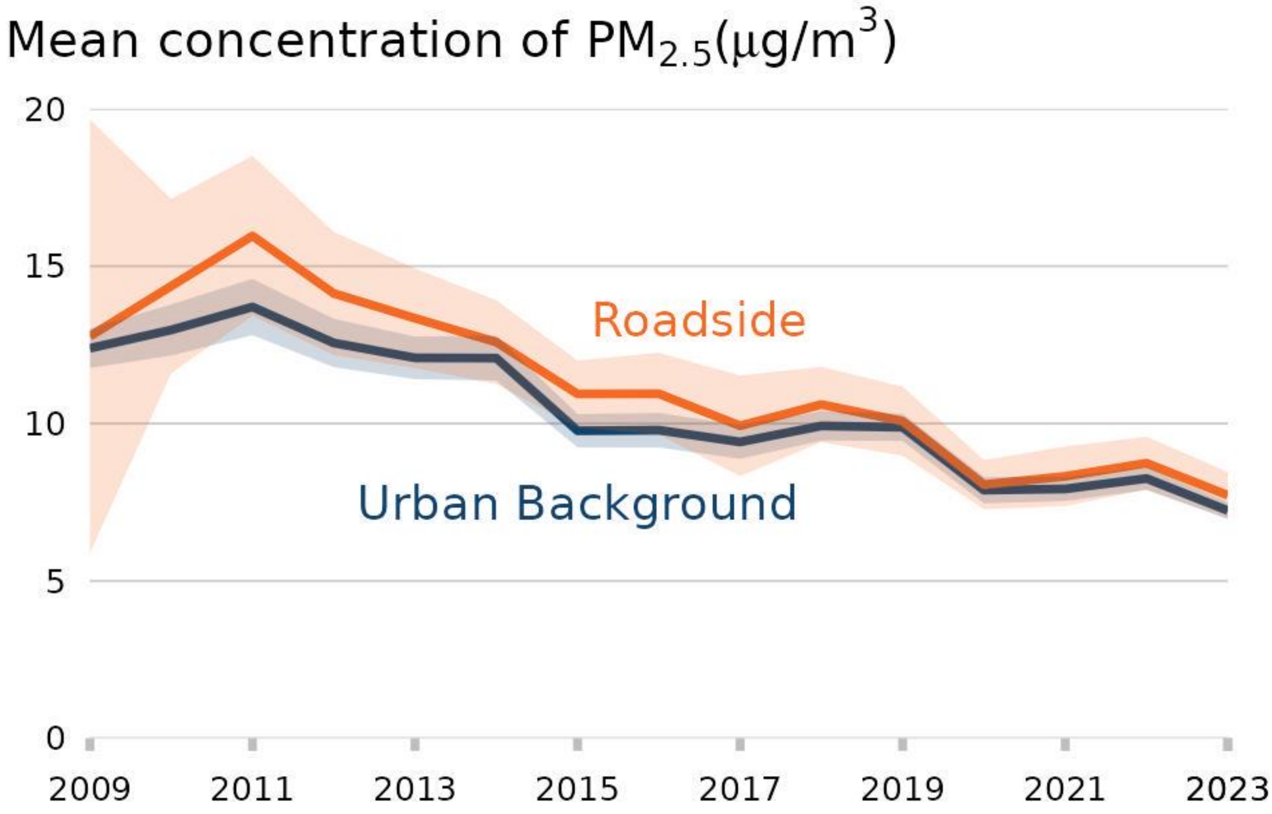


Figure 5-14 is taken from Defra's Air Quality Accredited Official Statistics web page for PM_{10} and $PM_{2.5}$, at https://www.gov.uk/government/statistics/air-quality-statistics/concentrations-of-particulate-matter-pm10-and-pm25 (Defra, 2024d). This shows annual mean $PM_{2.5}$ concentrations averaged 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 2023. Shaded areas either side of each line show the 95% confidence interval of the mean.

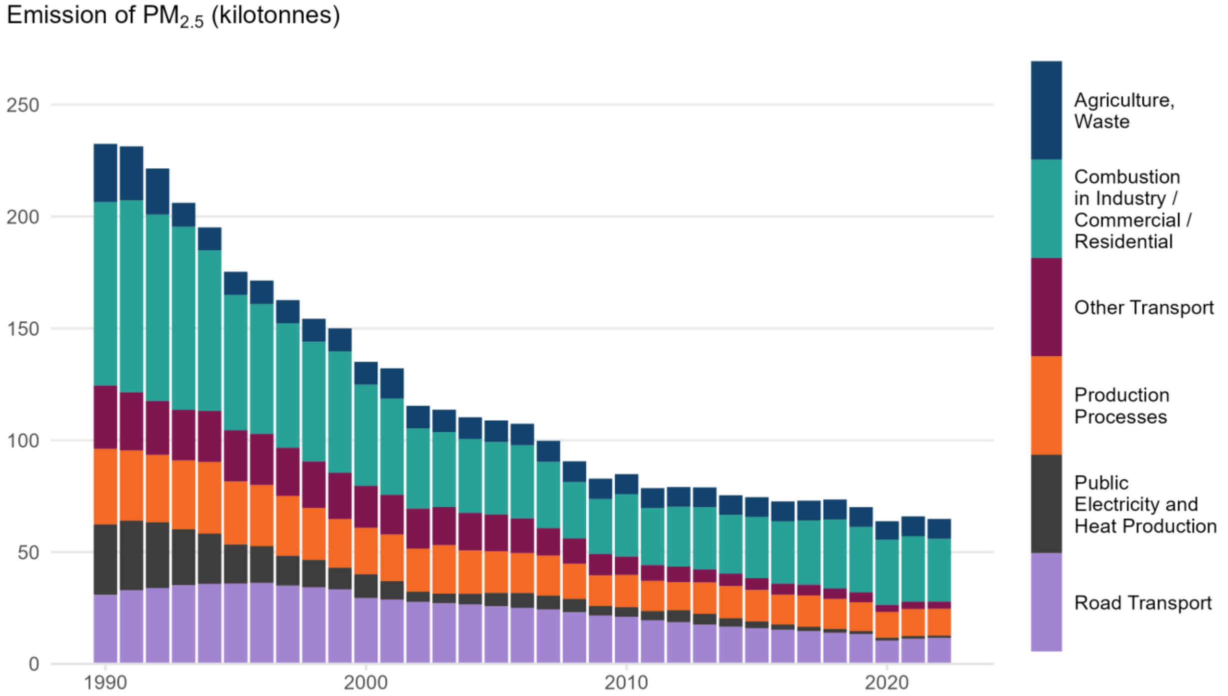


(Source: https://www.gov.uk/government/statistics/air-quality-statistics/concentrations-of-particulate-matter-pm10-and-pm25 .)

Finally, **Figure 5-15** shows the estimated annual emission of $PM_{2.5}$, from 1990 to 2022. 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 66% 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. For more information on UK emissions of $PM_{2.5}$ please visit the Accredited Official Statistics publication available here: https://www.gov.uk/government/statistics/emissions-of-air-pollutants.

Figure 5-15 Estimated Annual UK Emissions of $PM_{2.5}$ (kt), 1990 – 2022. (Source: NAEI 2023)



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 2021-2023. The number of such days was 6-10 throughout most of England, to the south of a line running roughly from Manchester to Middlesbrough, and in most of Wales. The number of such days was lower in further northern parts of England, Scotland, Northern Ireland and south west Wales. A small part of East Anglia had an average of 11-15 such days.

This map shows slightly lower values around some major conurbations including London, Birmingham, Manchester and the cities of West Yorkshire. 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 2023 only. This shows a similar pattern, 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, 2019-2023. 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 in the south, centre and east of the UK (outside of major cities), with lower values to the north and west. The 'scavenging' effect of NO is clearly visible: the outlines of some cities and major roads can be seen.

Figure 5-19 shows the same statistic, for 2023 only. AOT40 values for 2023 only were typically higher than the mean for the three-year period 2019-2023, although this period included 2020, which also had relatively high ozone concentrations. Highest AOT40 values in 2023 occurred in generally in the south-eastern part of the UK, as is typical: but particularly in parts of East Anglia and also the south west. Less typically, in 2023 Northern Scotland and the Northern Isles had higher AOT40 than central and southern Scotland.

Figure 5-16 Average Number of days with Maximum Daily Running 8h Mean O_3 Concentration > 120 µg m^{-3} 2020-2023

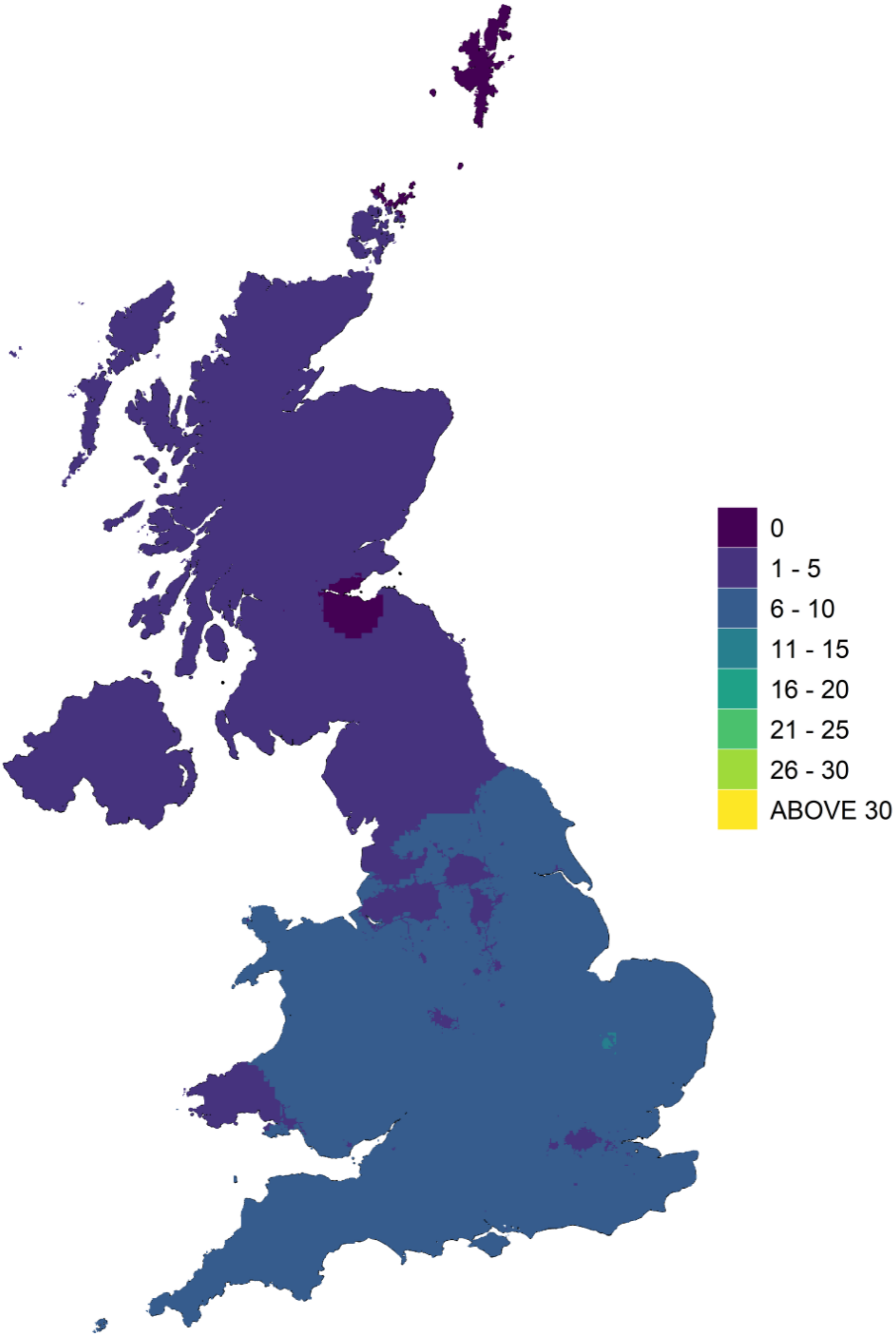
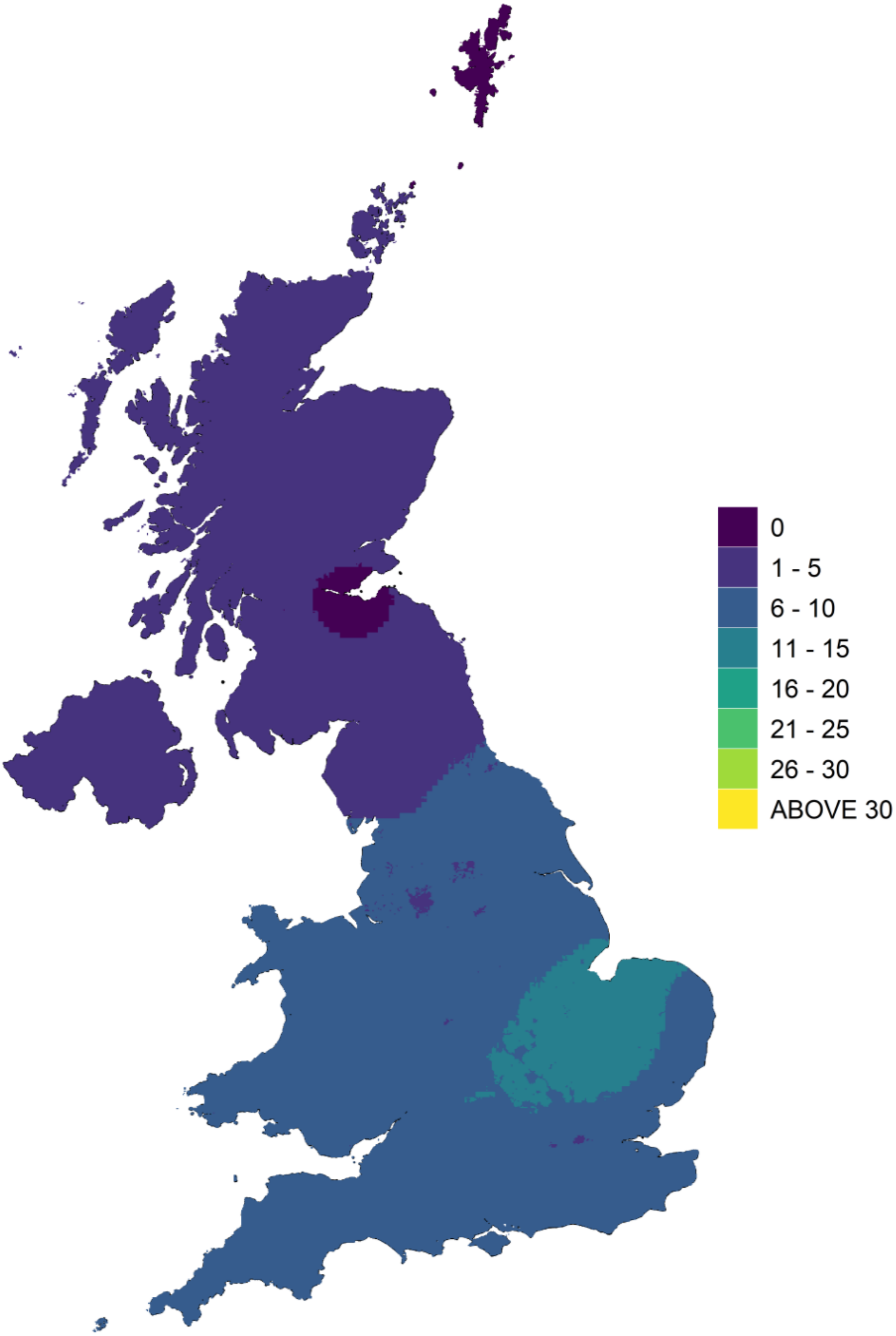


Figure 5-17 Days with Maximum Daily Running 8h Mean O_3 Concentration > 120 µg m^{-3}, 2023



An interactive map of this metric is available at https://uk-air.defra.gov.uk/data/gis-mapping/.

Figure 5-18 Average AOT40, 2018-2023 (μg m^{-3}.hours)

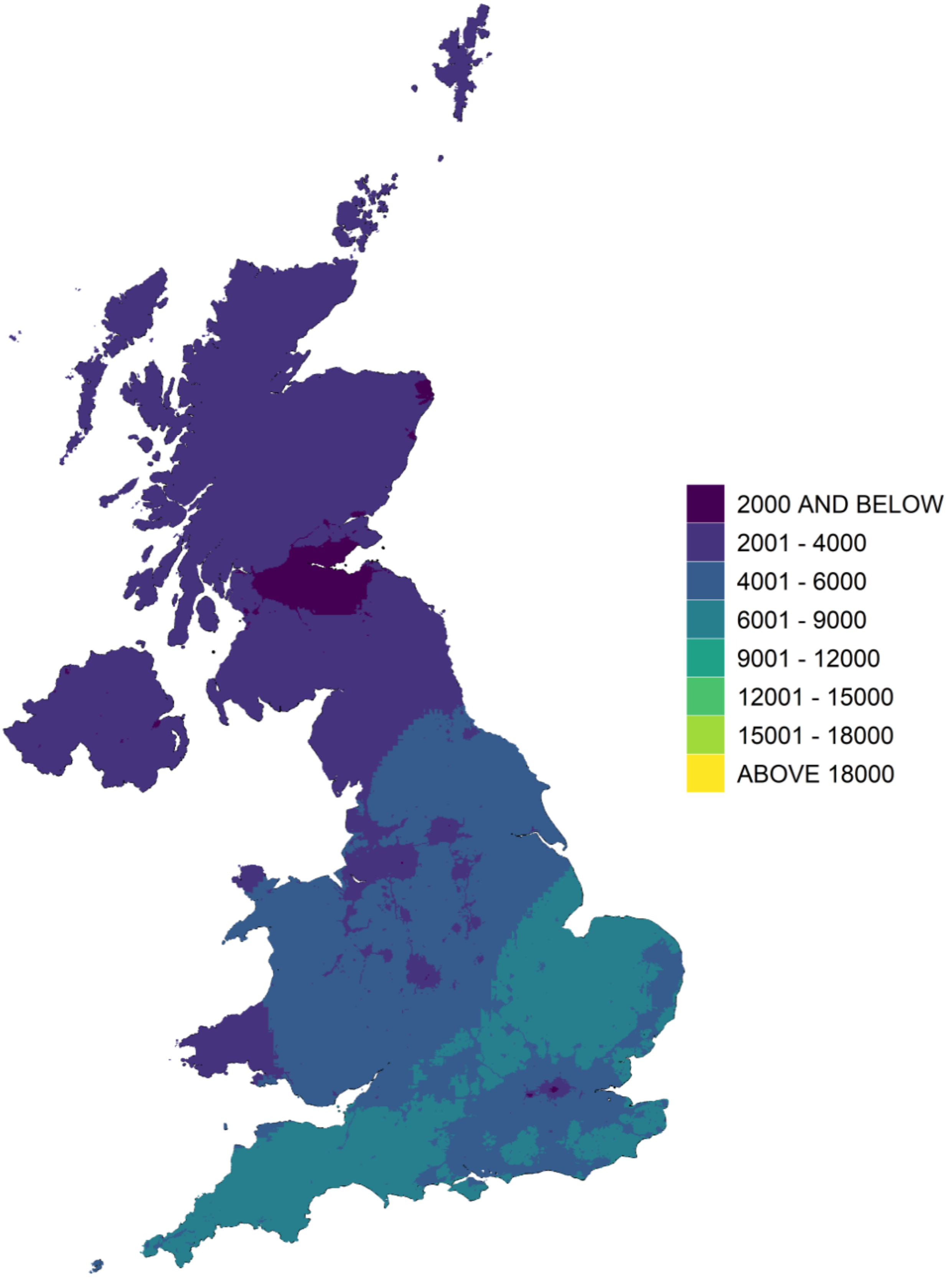
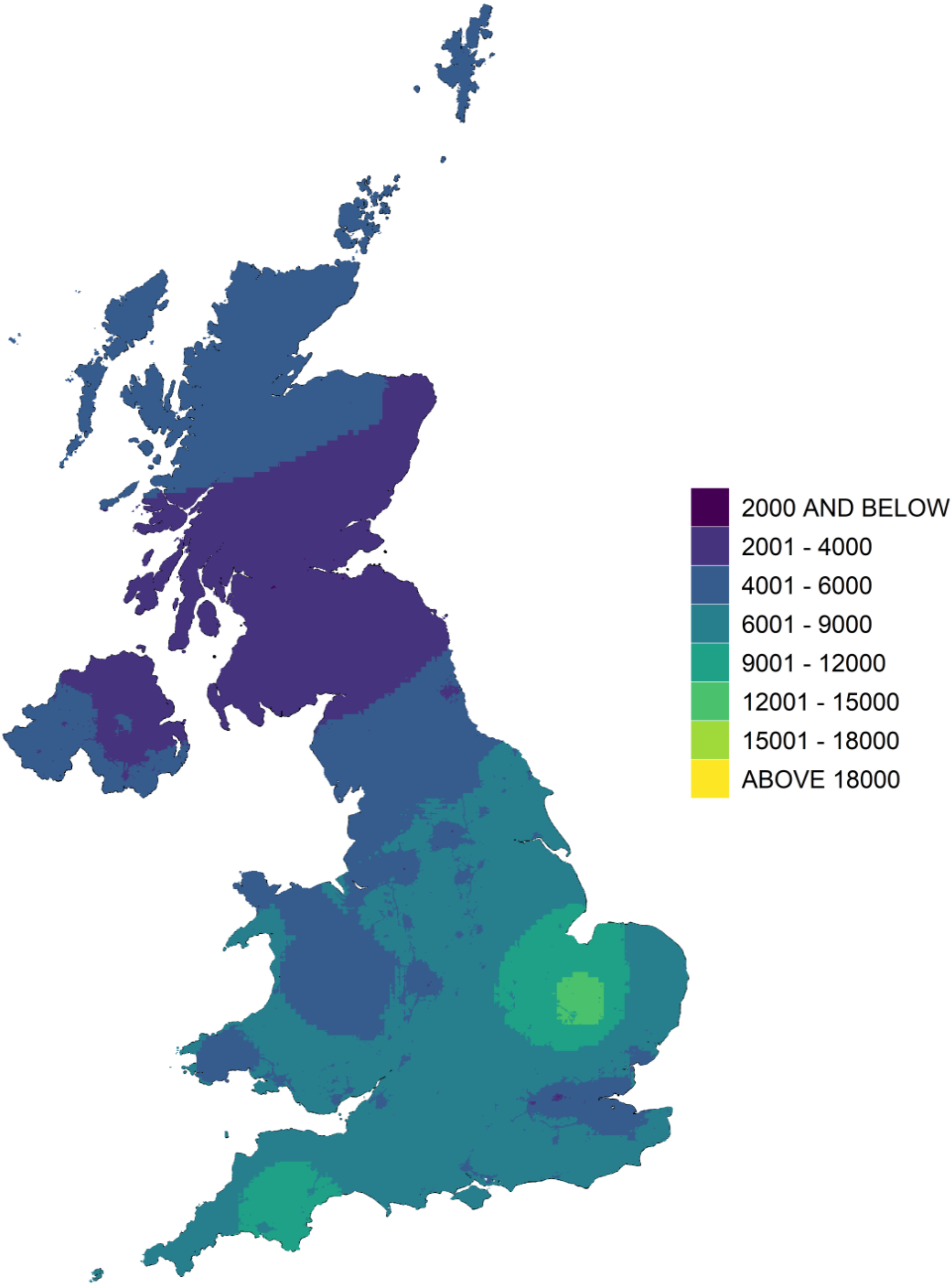


Figure 5-19 Average AOT40, 2023 (µg m^{-3}.hours)



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 1992-2023 (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.

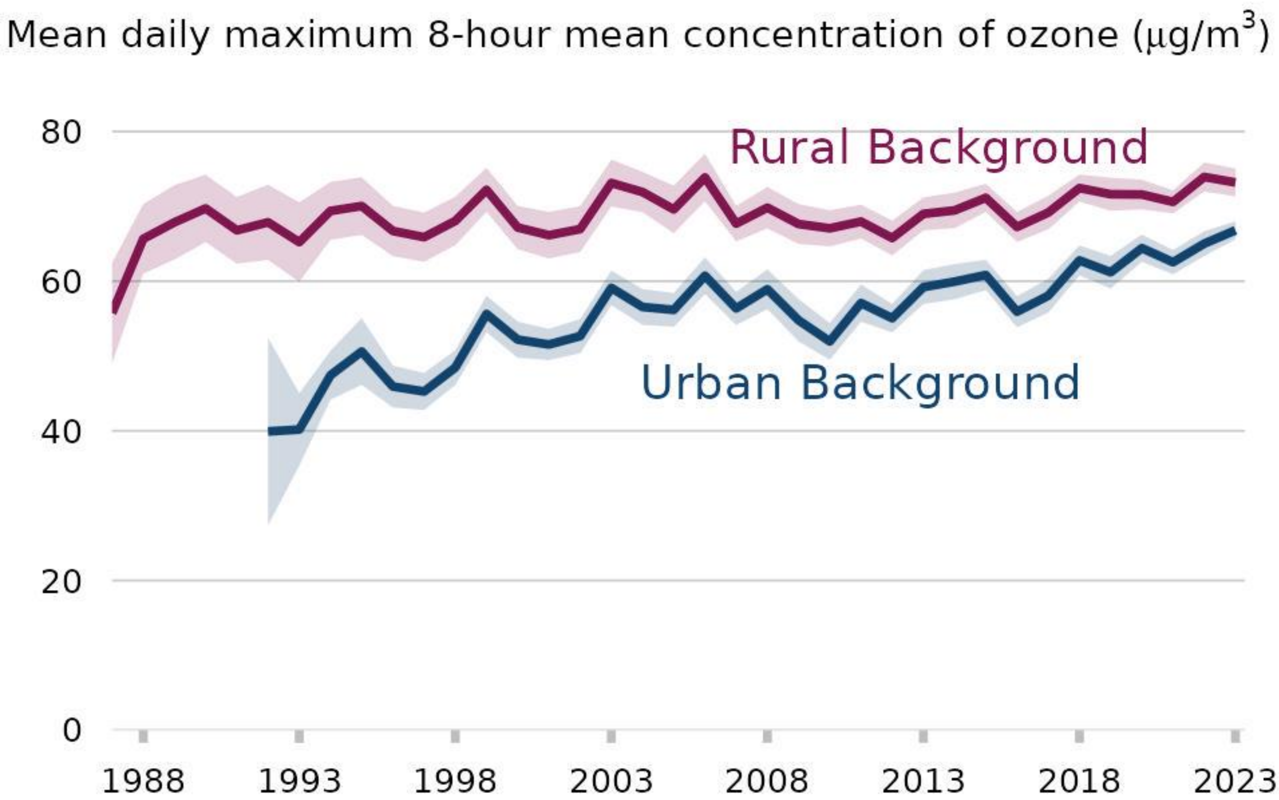
Eight sites (Aston Hill, Bush Estate, Eskdalemuir, High Muffles, Ladybower, Rochester Stoke, Sibton and Yarner Wood) show highly significant positive trends over this period. Two (Lough Navar and Strathvaich) show positive trends of lower significance. Two (Lullington Heath and Narberth) show no statistically significant trend. While there is no consistent pattern, upward trends are present at the majority 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 - 2023.

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, 2024c).

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 2023.



(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[8] of hourly mean sulphur dioxide concentration varied across the UK during 2023. 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 2023. 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.

[8] 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, 2023 ($\mu g\ m^{-3}$)

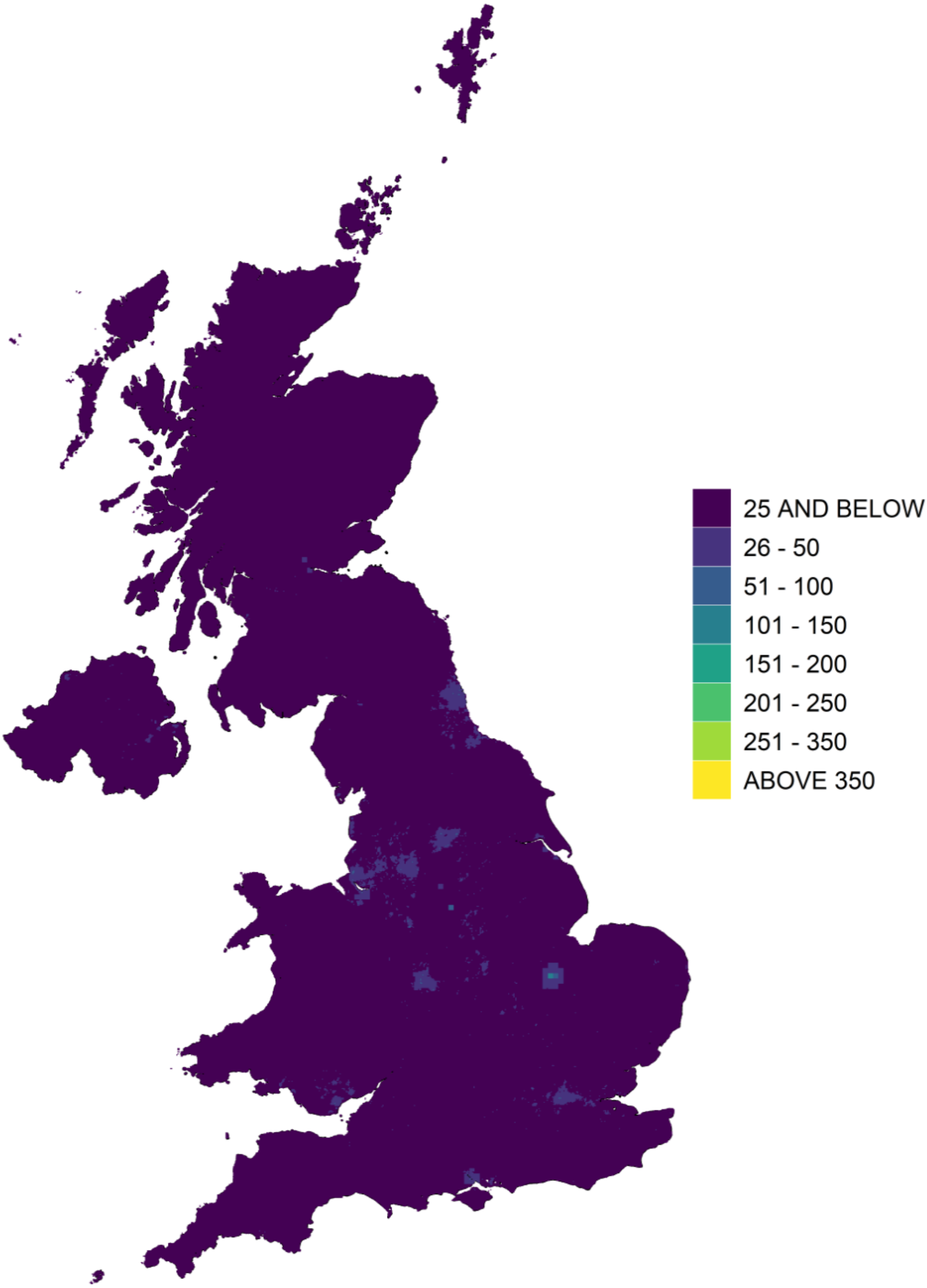
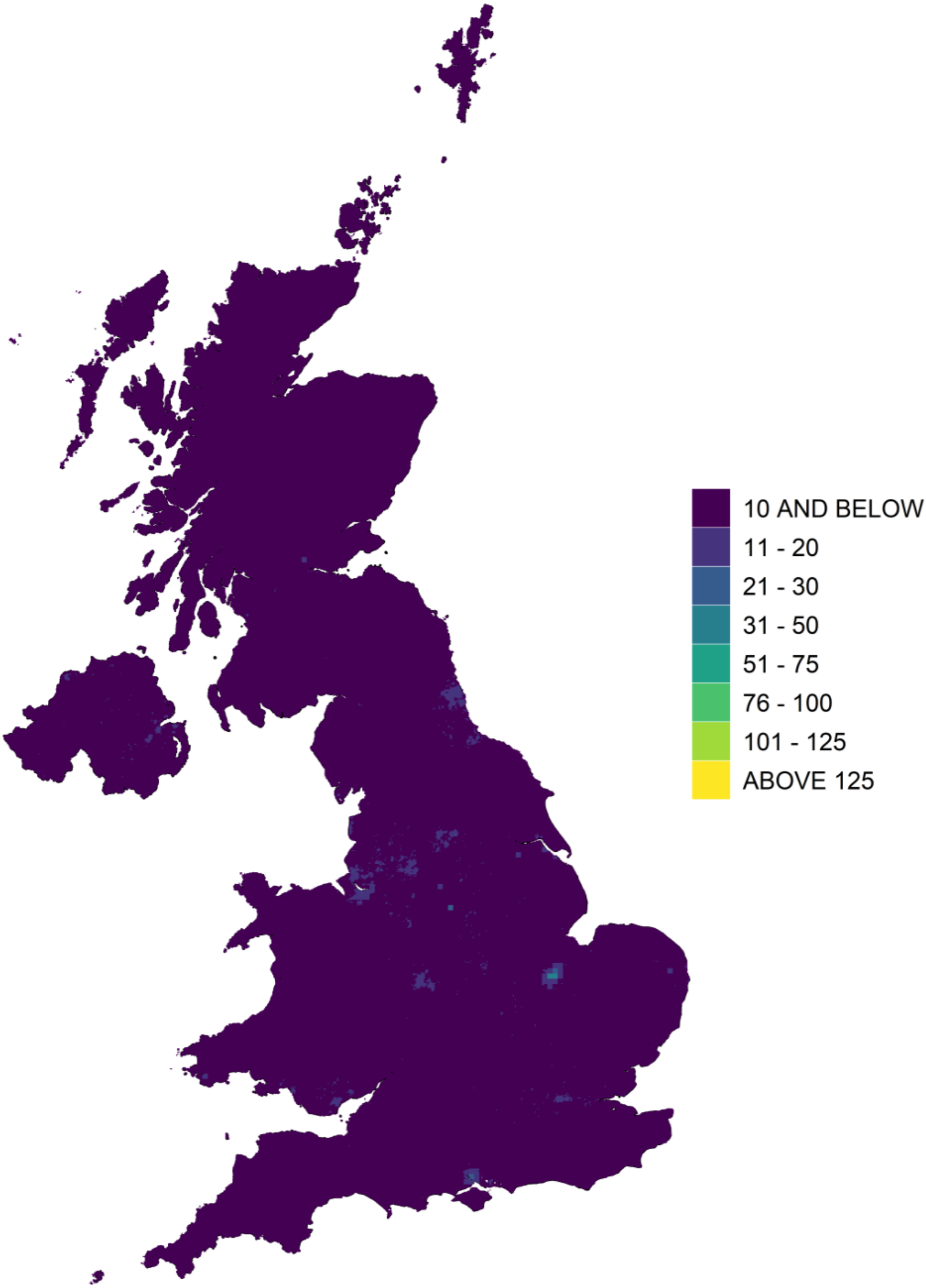


Figure 5-23 99.18th Percentile of 24-hour Mean SO_2 Concentration, 2023 ($\mu g\ m^{-3}$)



5.6.2 SO_2: Changes Over Time

Figure 5-24 shows how ambient concentrations have changed over the period 1992 to 2023, at the six AURN monitoring stations that have monitored this pollutant for the longest time and remained in operation in 2023. 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, 1992-2023 at Six Long-running AURN Sites

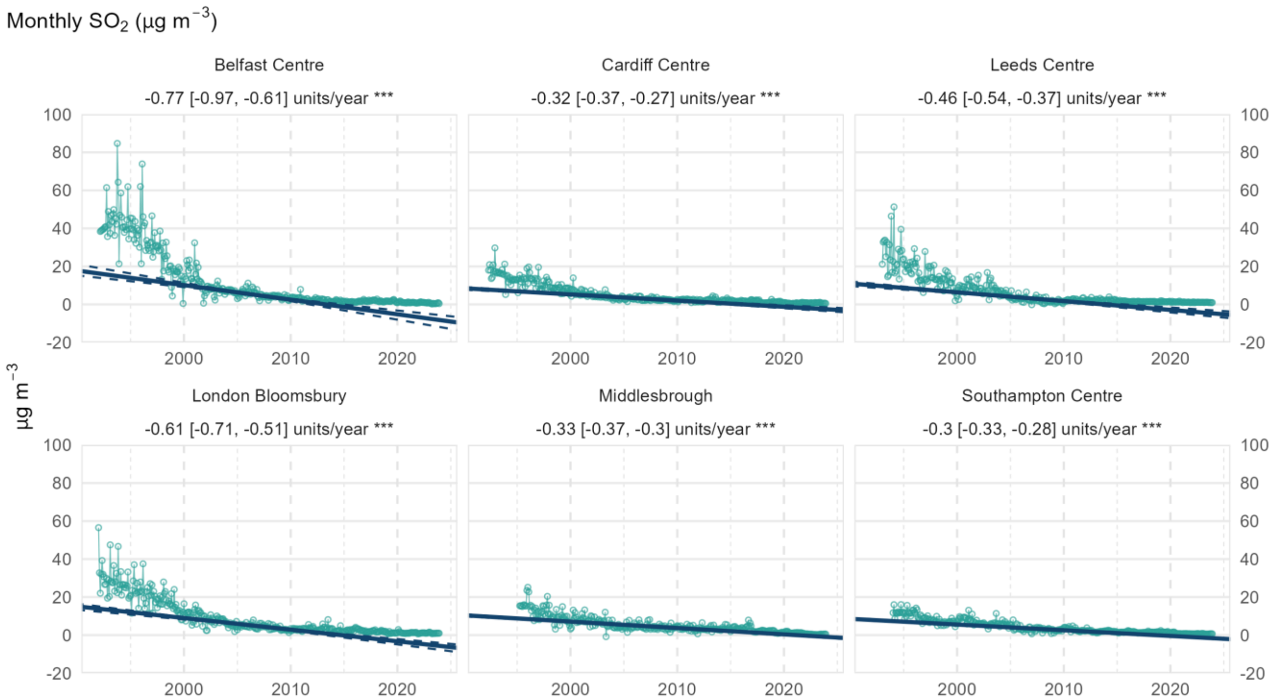


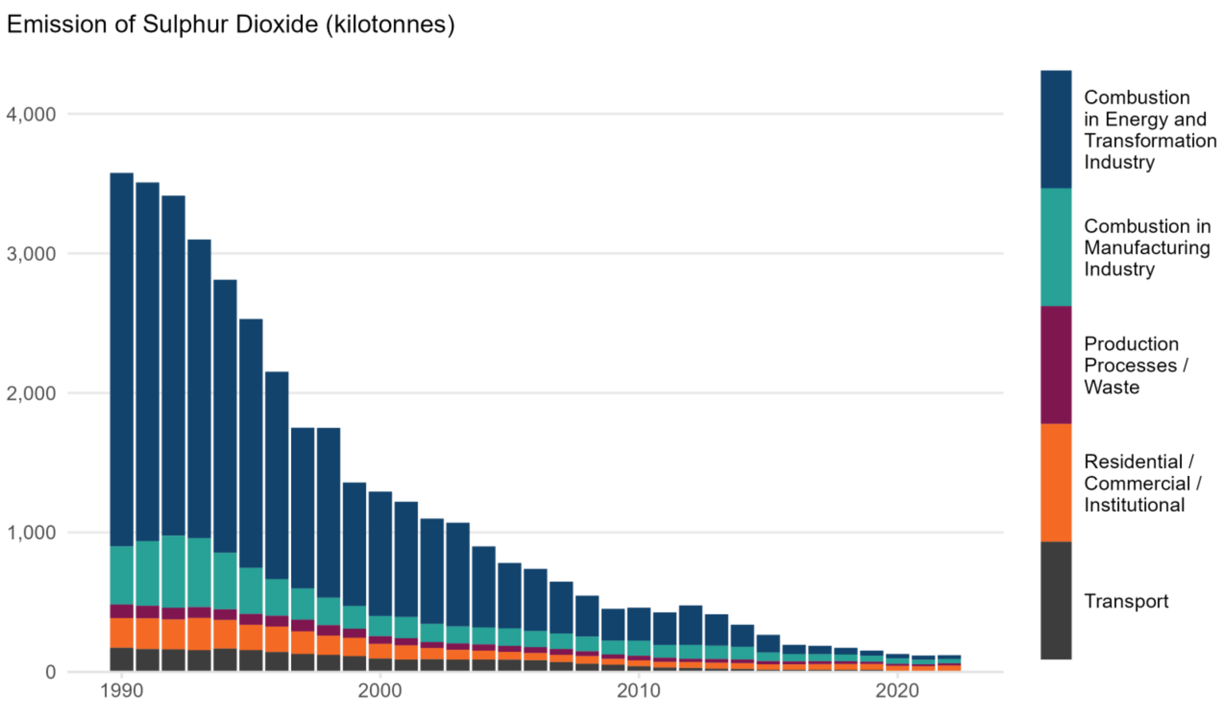
Figure 5-25 is based on data from the NAEI and shows the UK's estimated annual emissions of sulphur dioxide from 1990 to 2022 (the most recent year for which data are available). The decrease in emissions over time shown here is the continuation of an on-going trend observed by the NAEI throughout the 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.energysecurity.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.

For more information on UK emissions of SO_2 please visit the Accredited Official Statistics publication available here: https://www.gov.uk/government/statistics/emissions-of-air-pollutants.

Figure 5-25 Estimated Annual UK Emissions of SO_2 (kt), 1990 – 2022 (source: NAEI 2023)



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 2023. 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 1992-2023

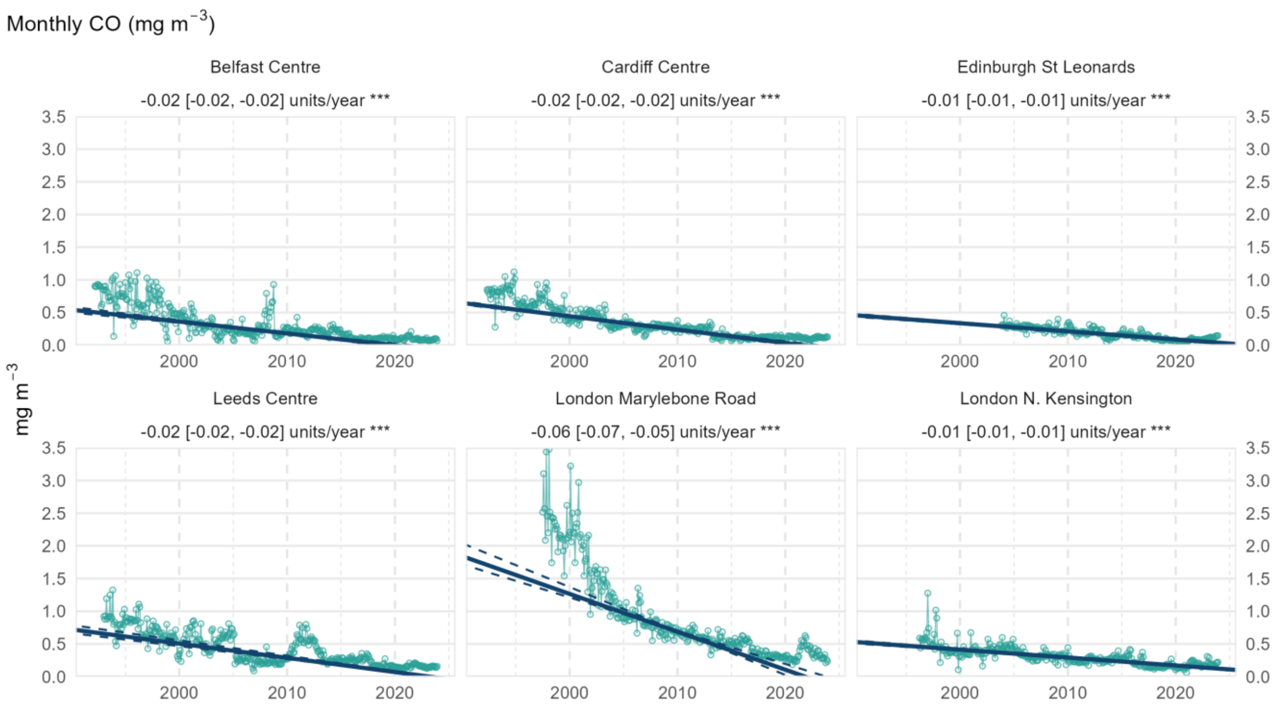
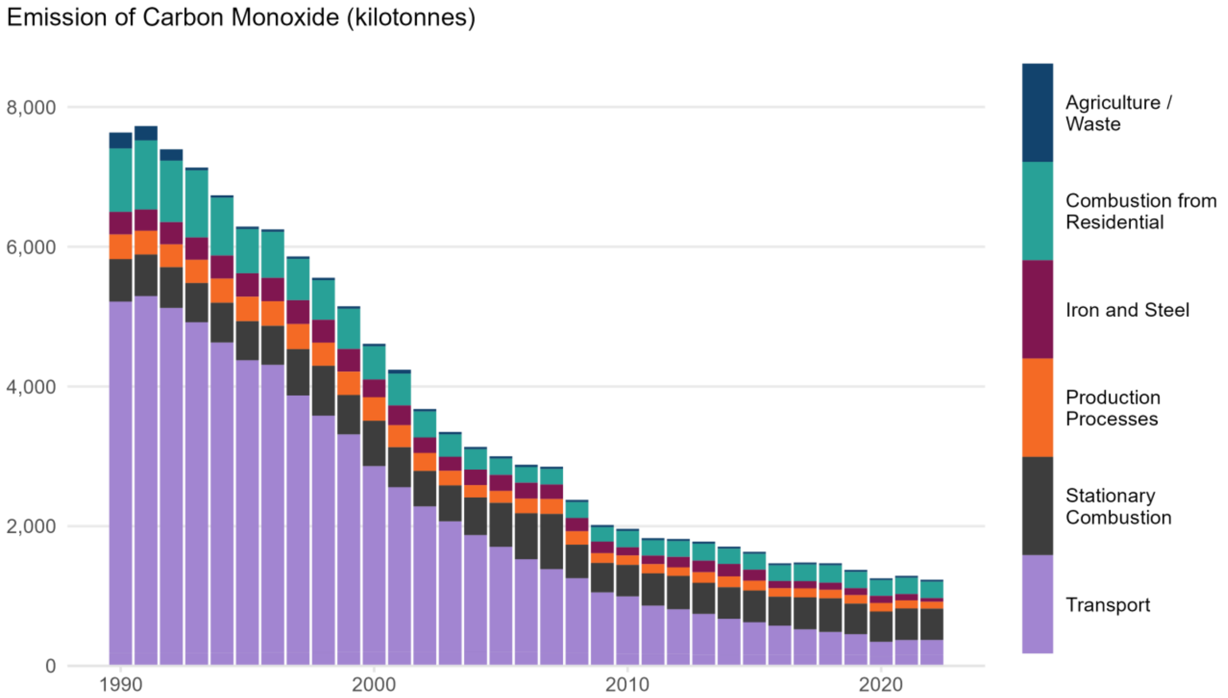


Figure 5-27 shows the estimated annual emissions of CO over the same period. The decreasing ambient concentrations reflect declining emissions over the last 25 years. The NAEI attributes the decrease in CO emissions to factors including EU-wide emission standards for road vehicles, a decline in industrial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

Figure 5-27 Estimated Annual UK Emissions of CO (kt), 1990 – 2022 (source: NAEI 2023)



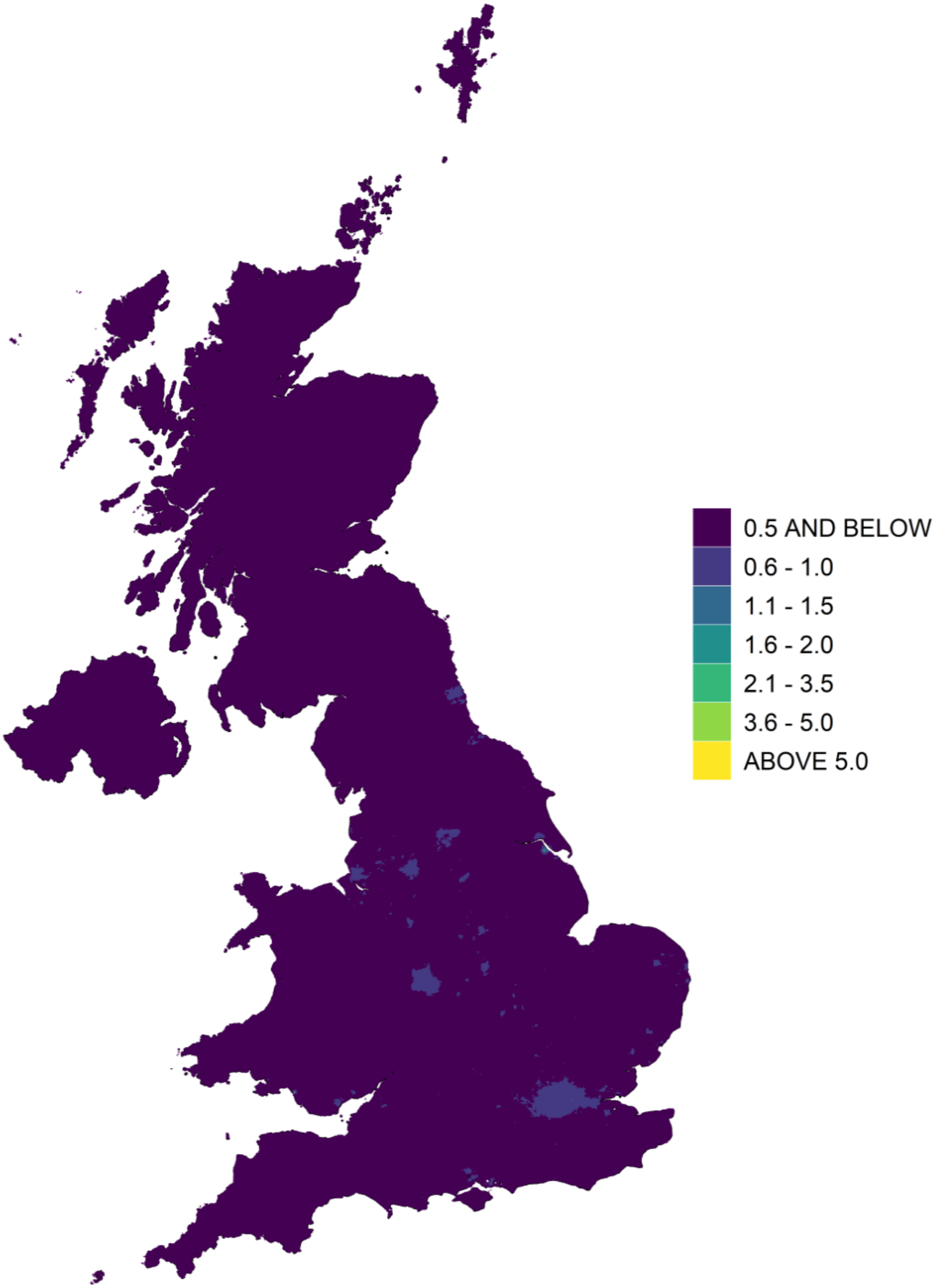
5.8 Benzene

5.8.1 Benzene: Spatial Distribution

Figure 5-28 shows the modelled annual mean background concentrations of benzene in 2023. Most areas outside major towns and cities had modelled benzene concentrations of 0.5 µg m^{-3} or below. Most urban areas had modelled concentrations of 1.0 µg m^{-3} or less, 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/.

Figure 5-28 Annual Mean Background Benzene Concentration, 2023 (µg m^{-3})



An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/.

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 2023. There appears to be a small rise in 2023 compared to 2021 and 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, 2002-2023

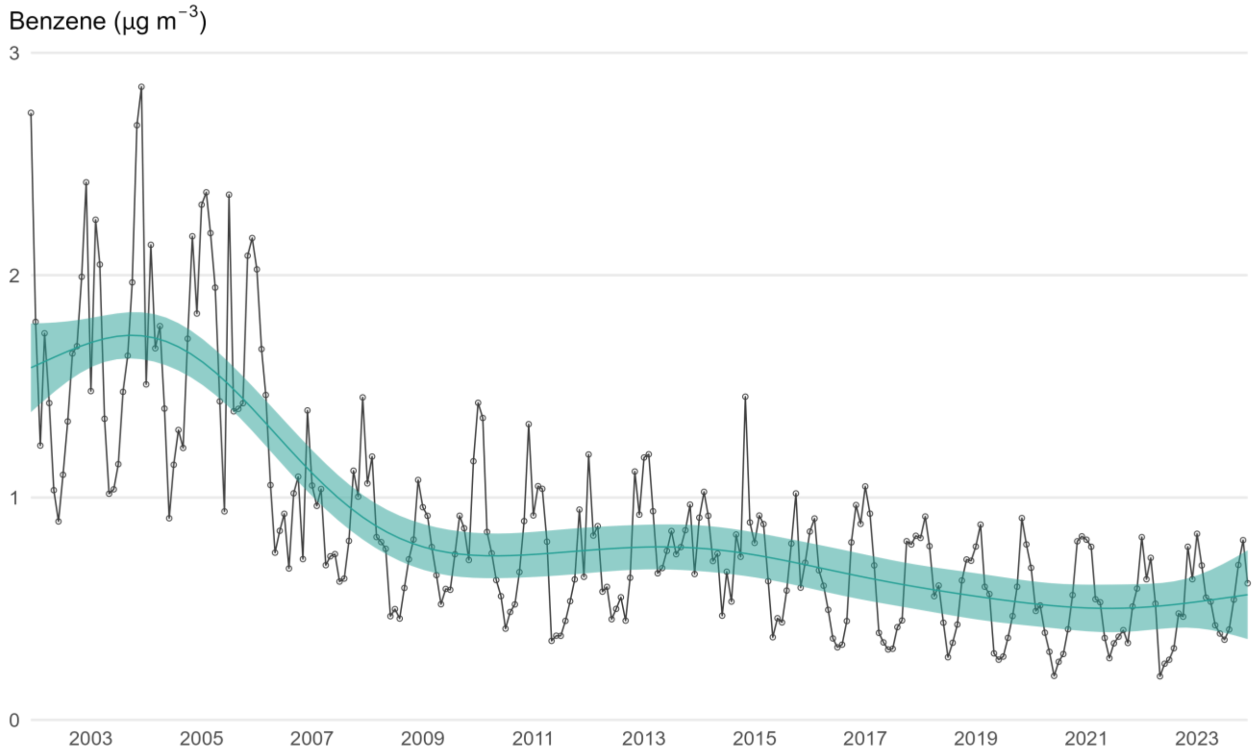
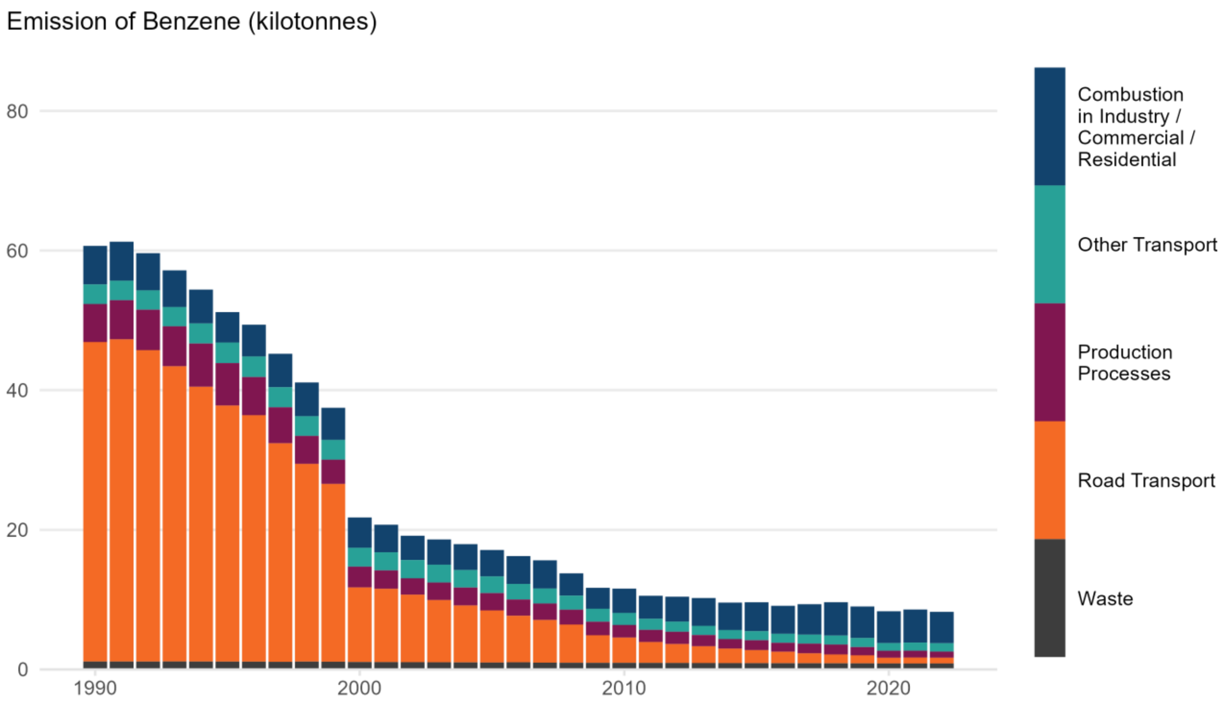


Figure 5-30 shows the estimated total annual UK emission of benzene (in kilotonnes), 1990 - 2022. The data are from the NAEI. The largest UK source of benzene is fuel combustion. Like the ambient concentrations, the estimated annual emissions also appear to have decreased over the period 2000 – 2010, but subsequently flattened off. 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 – 2022 (source: NAEI 2023)



5.9 1,3-Butadiene

5.9.1 1,3-Butadiene: Compliance with AQS Objective

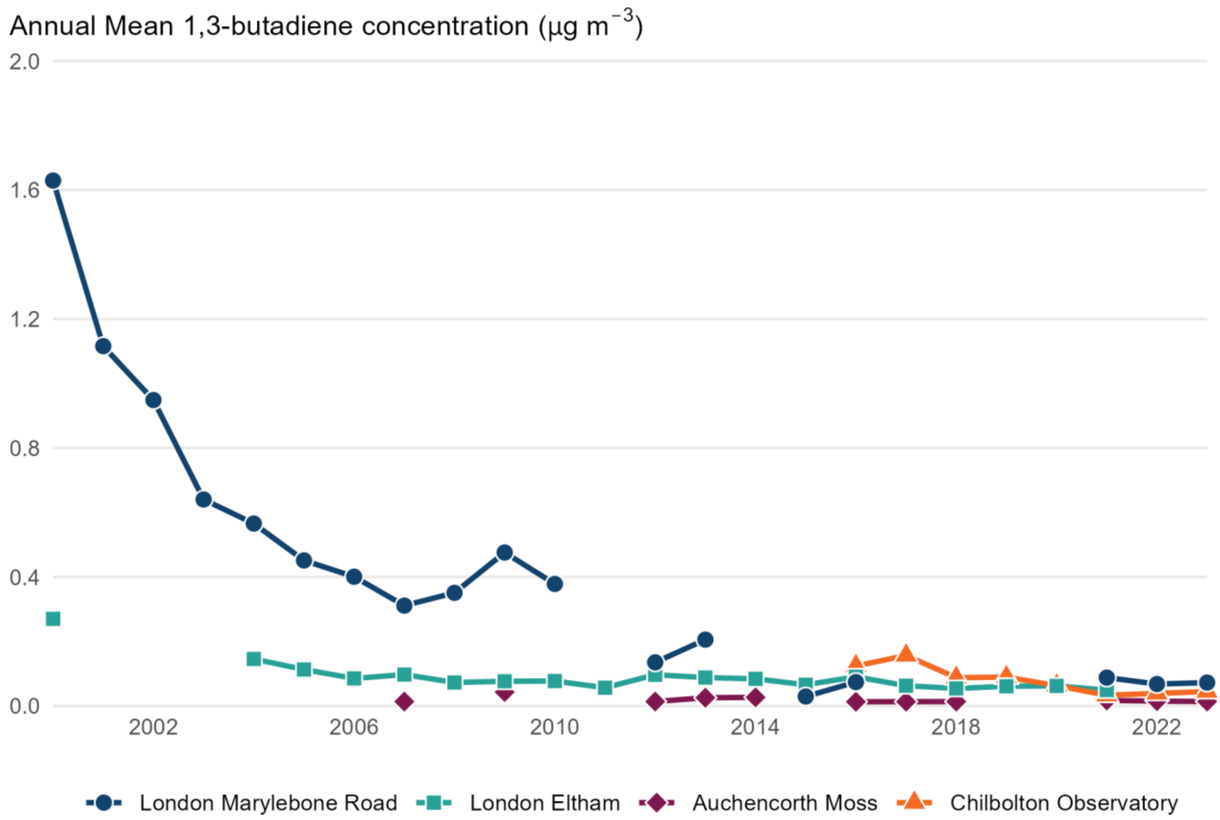
The UK Air Quality Strategy objective for 1,3-butadiene is 2.25 µg m^{-3}, as a maximum running annual mean. This objective was met throughout the UK by the due date of 31st December 2003. Modelled maps are not routinely produced for this pollutant.

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 2023.

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 2023 at the four automatic sites. (Minimum annual data capture for inclusion is 50% in this case.)

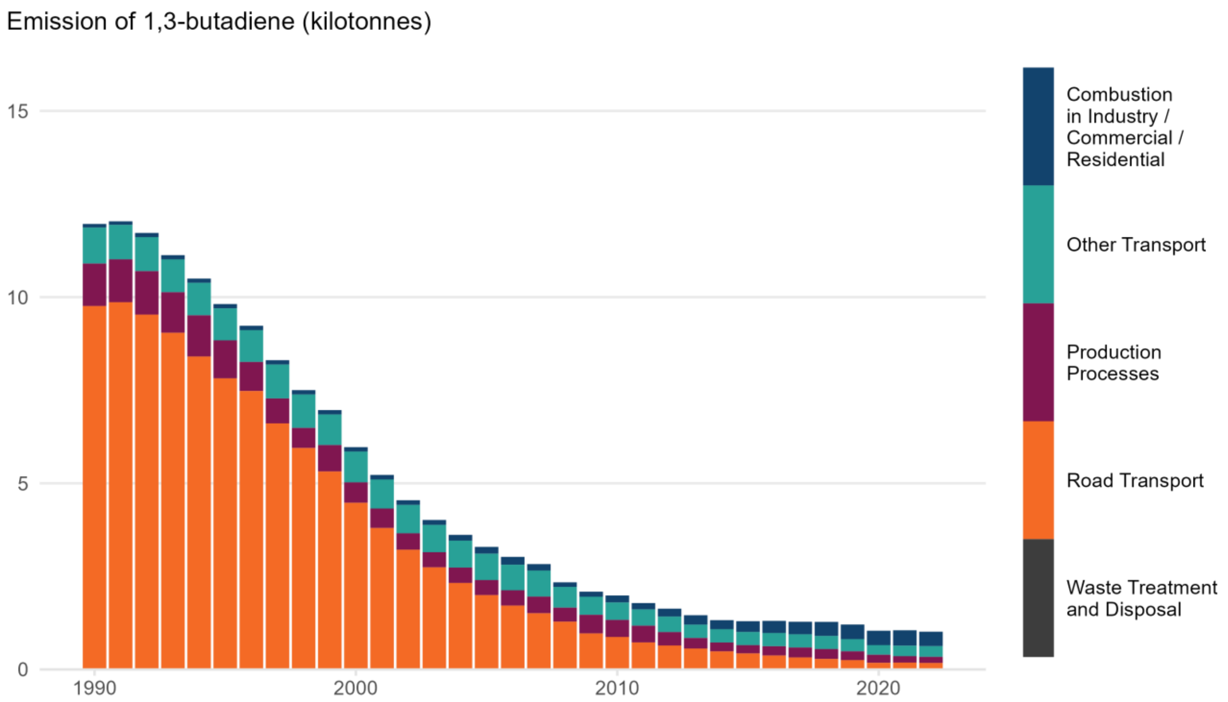
Figure 5-31 Time Series Graph of 1,3-Butadiene Concentration, 2000-2023



London Marylebone Road has historically had the highest concentrations of 1,3-butadiene, but these decreased substantially between 2000 and 2015. Chilbolton Observatory 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 than London Eltham (though the latter did not meet the data capture target in 2022 or 2023 and is currently out of action awaiting a relocation). All four sites, both urban and rural, are now measuring annual mean 1,3-butadiene 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 2022. 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. However, emissions from the ‘Combustion in Industry/Commercial/Residential’ category have increased over the past decade: this is attributed to an increase in the use of wood as a domestic fuel.

Figure 5-32 Estimated Annual UK Emissions of 1,3-Butadiene (kt), 1990 – 2022 (source: NAEI 2023)



5.10 Metallic Elements

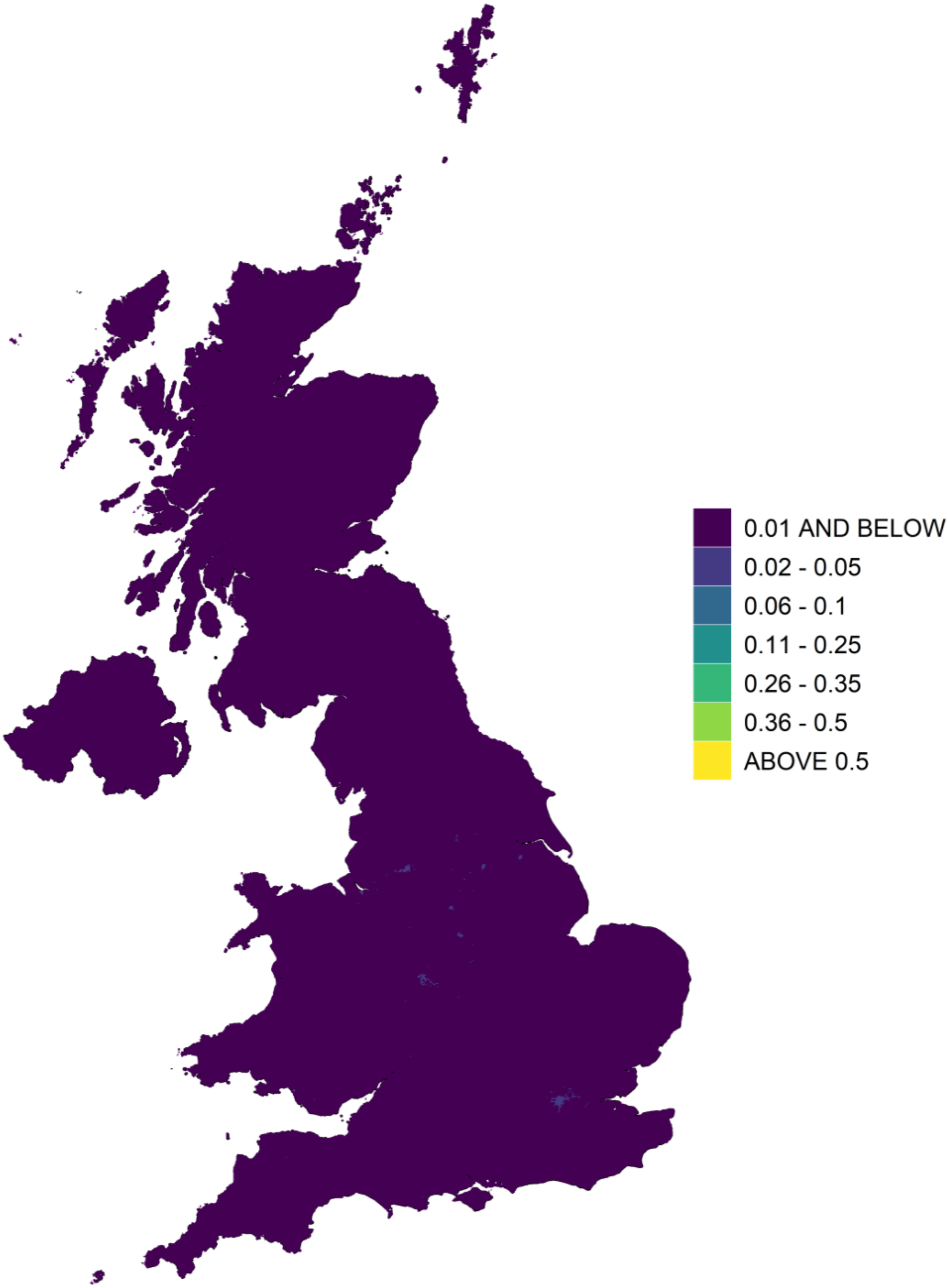
5.10.1 Metallic Elements: Spatial Distribution

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 2023. 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.

In recent previous years' reports, some small sections of major road routes have been visible on the map, with modelled concentrations in the 0.02 – 0.05 µg m^{-3} range. 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 did not feature strongly in the 2022 map and apart from a few in the Greater London area, are barely visible in the 2023 map.

Figure 5-33 Annual Mean Background Lead Concentration, 2023 (µg m^{-3})



An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/.

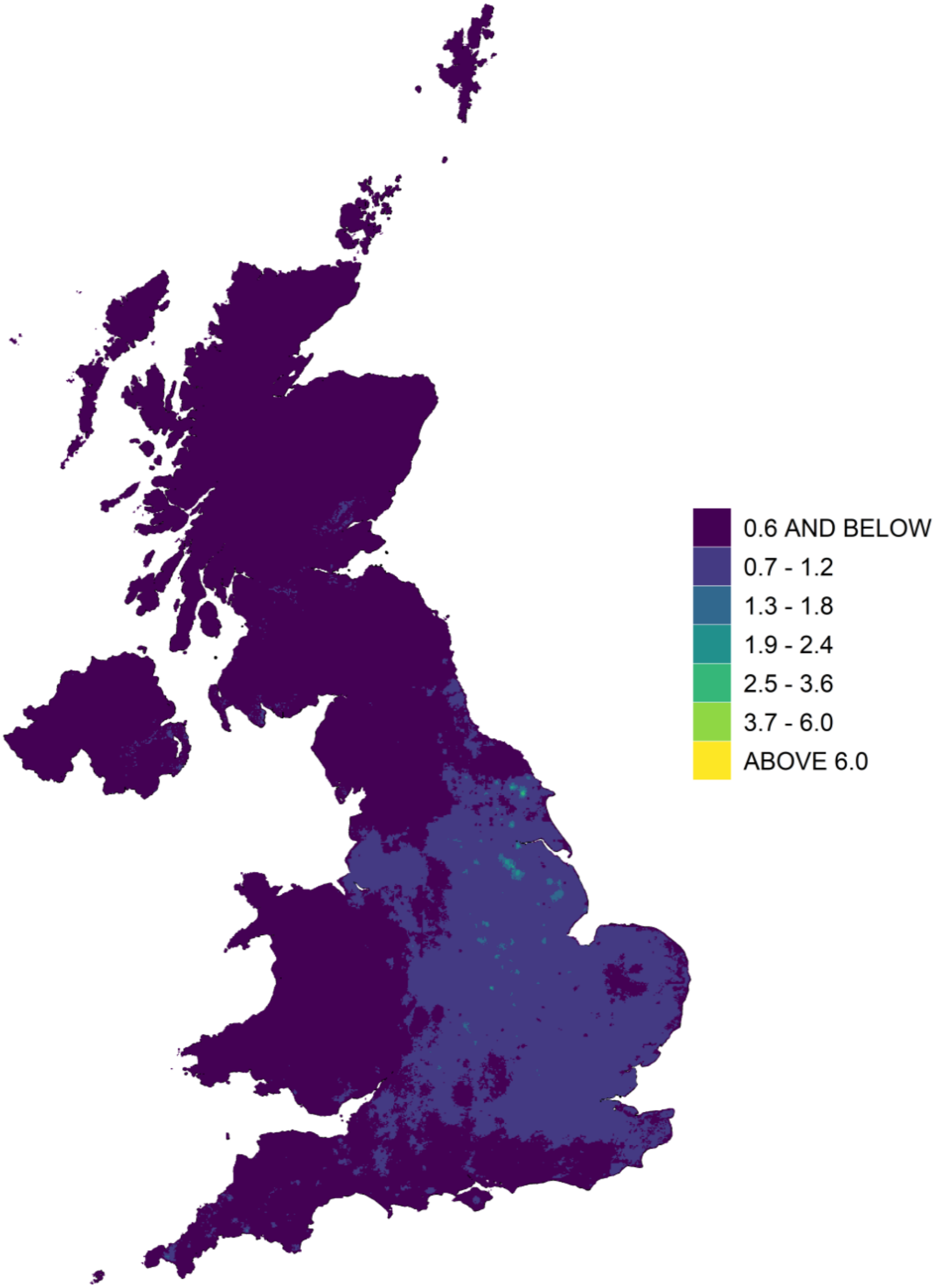
As: this toxic element is a metalloid rather than a metal but is nevertheless measured by the Heavy Metals Network. **Figure 5-34** shows that modelled annual mean background concentrations were 1.2 ng m^{-3} or less throughout most of the UK. Modelled concentrations were well within the limit value 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 2023 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}.

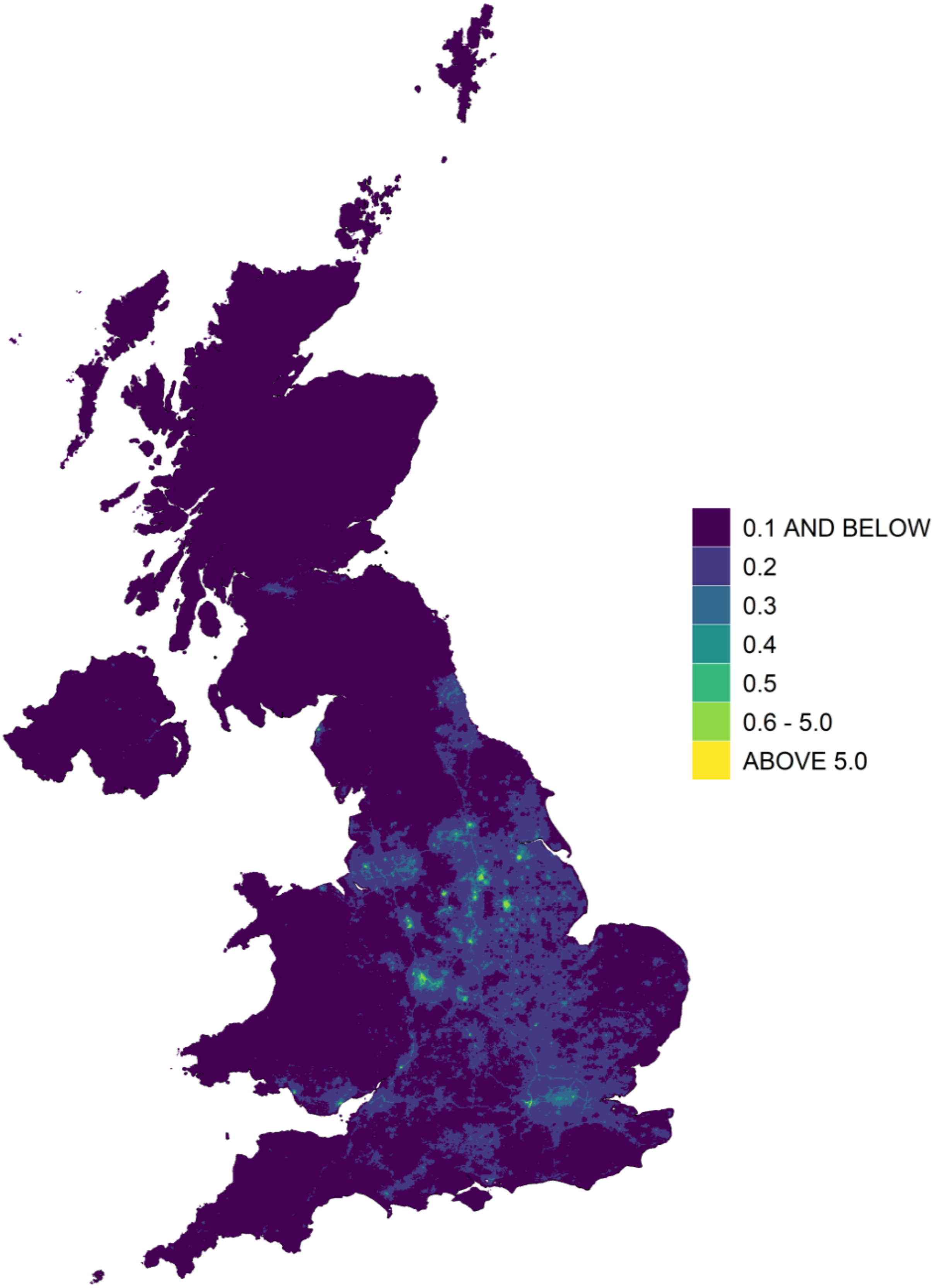
Ni: background concentrations of Ni were typically 2 ng m^{-3} or less, and usually 1 ng m^{-3} or less, away from urban areas (**Figure 5-36**). There were also a few small areas with higher concentrations due to industrial activity, including one location where modelled concentration exceeded the Ni target value of 20 ng m^{-3} in 2023: this is in the Sheffield Urban Area. The highest measured annual mean Ni concentration in 2023 was however just within the target value: 19 ng m^{-3} at Sheffield Tinsley. As reported in **Section 4**, three zones exceeded the target value for Ni in 2023: Sheffield Urban Area, Yorkshire and Humberside, and South Wales.

Figure 5-34 Annual Mean Background Arsenic Concentration, 2023 (ng m^{-3})



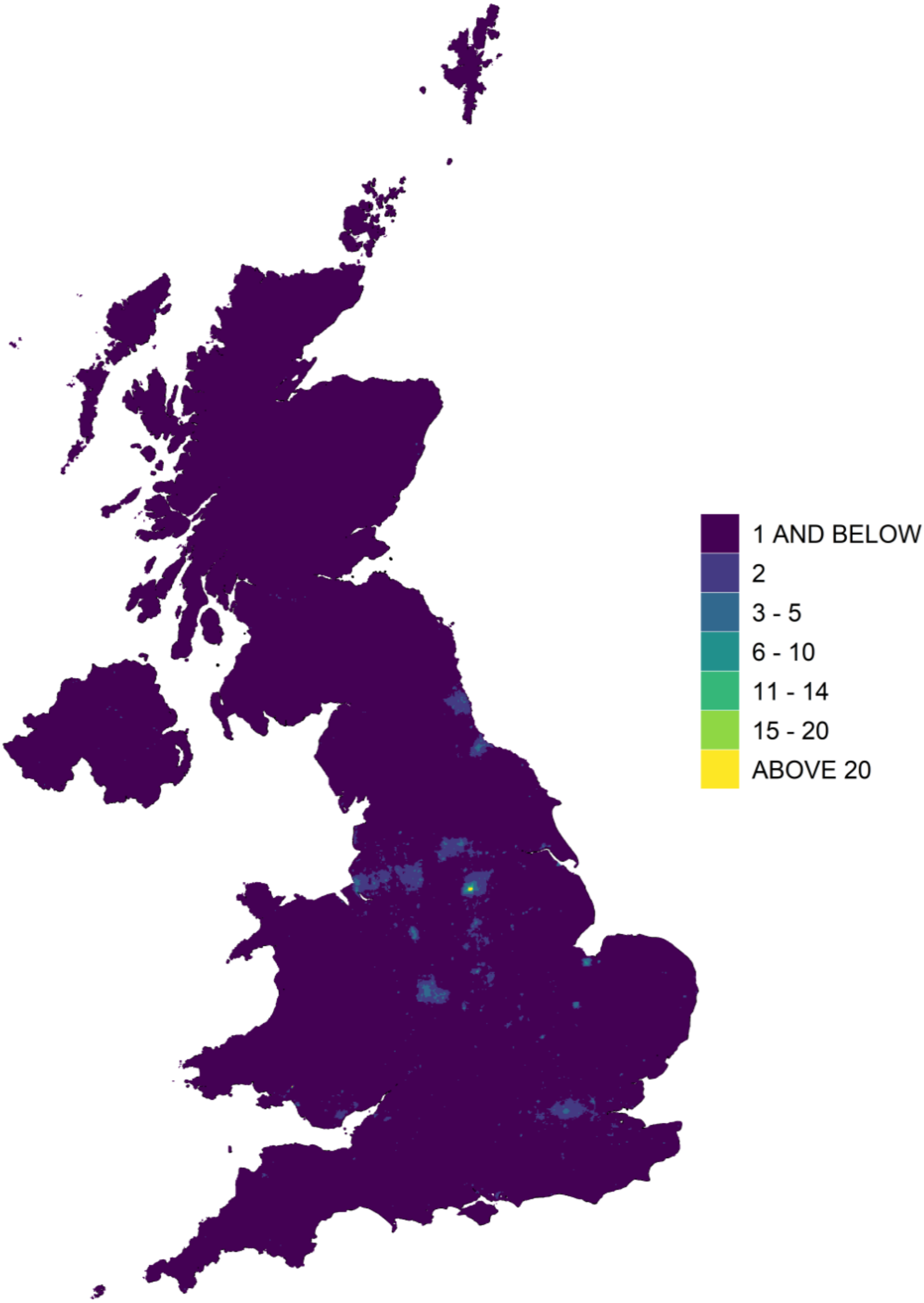
An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/.

Figure 5-35 Annual Mean Background Cadmium Concentration, 2023 (ng m^{-3})



An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/.

Figure 5-36 Annual Mean Background Nickel Concentration, 2023 (ng m^{-3})



An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/.

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 (50^{th} 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 2022. 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. A slight overall increase since 2020 is visible.

Figure 5-37 Ambient Concentrations of Pb in PM_{10}, 2004-2023

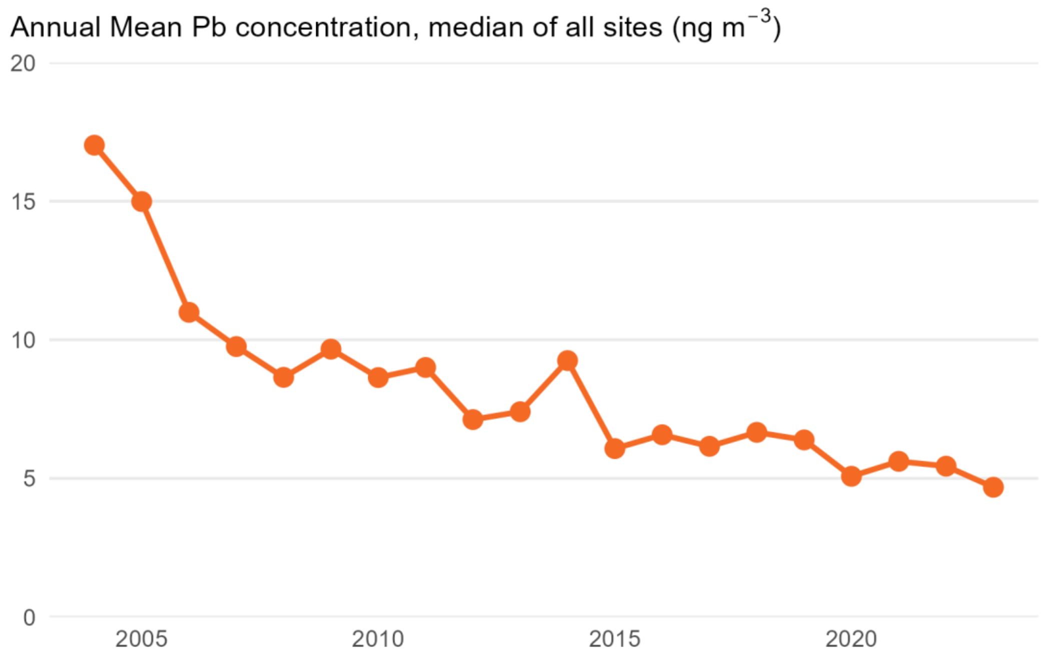
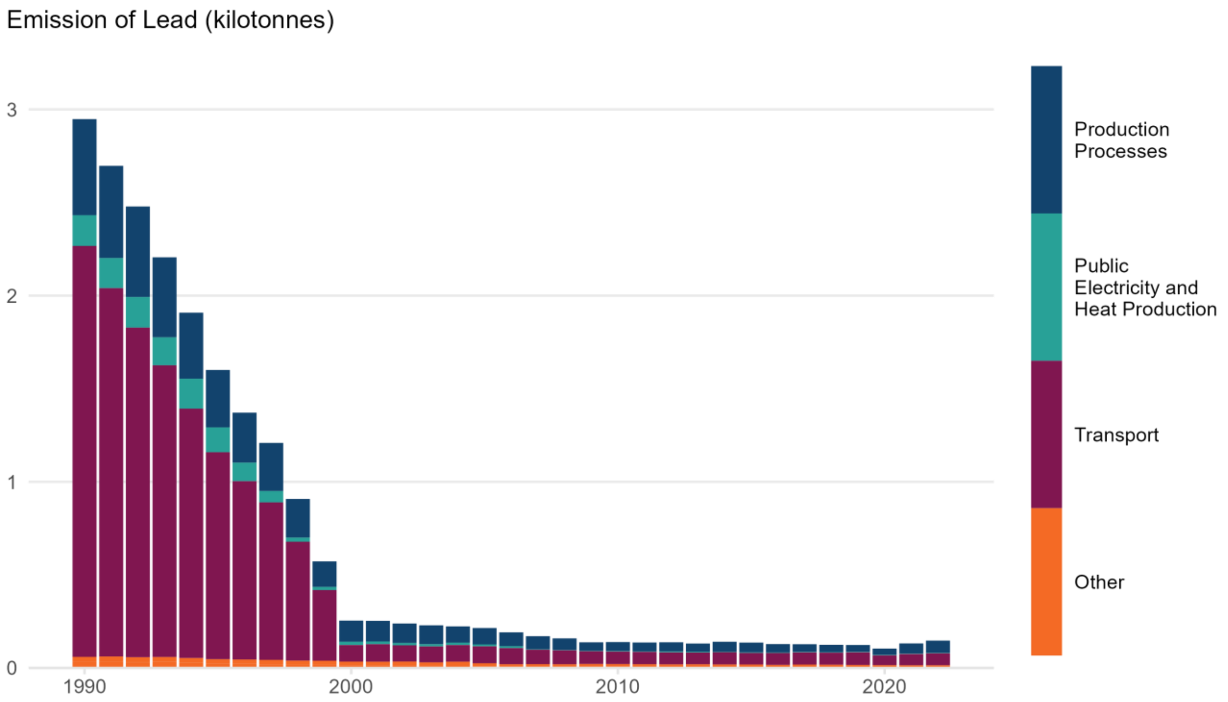


Figure 5-38 Estimated Annual UK Emissions of Pb (kt), 1990 – 2022 (source: NAEI 2023)



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 and 2023.

Figure 5-39 Ambient Concentrations of As in PM_{10}, 2004-2023

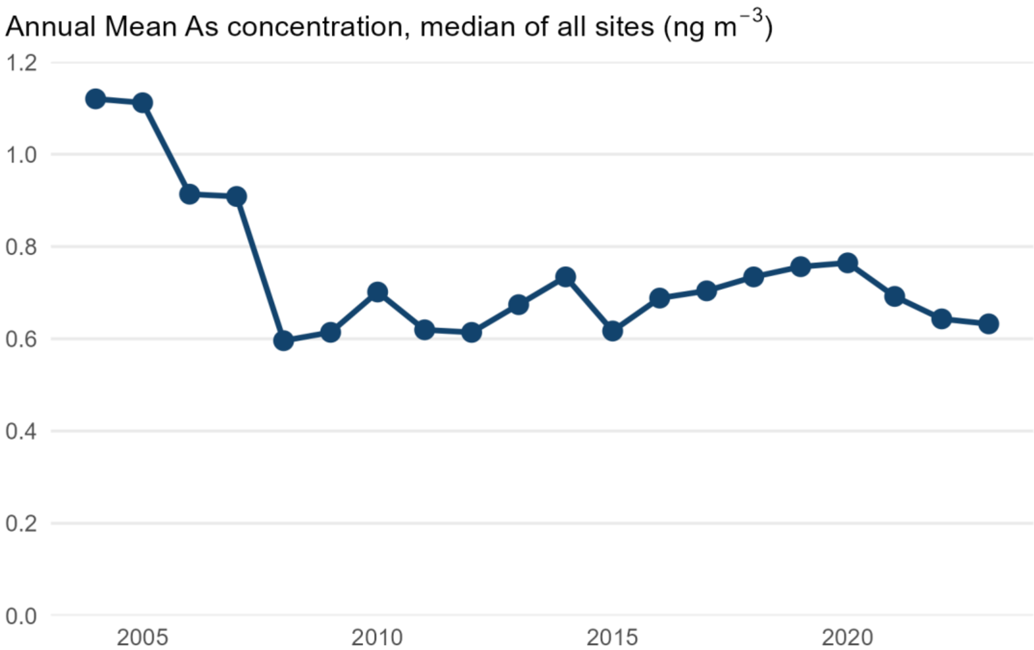
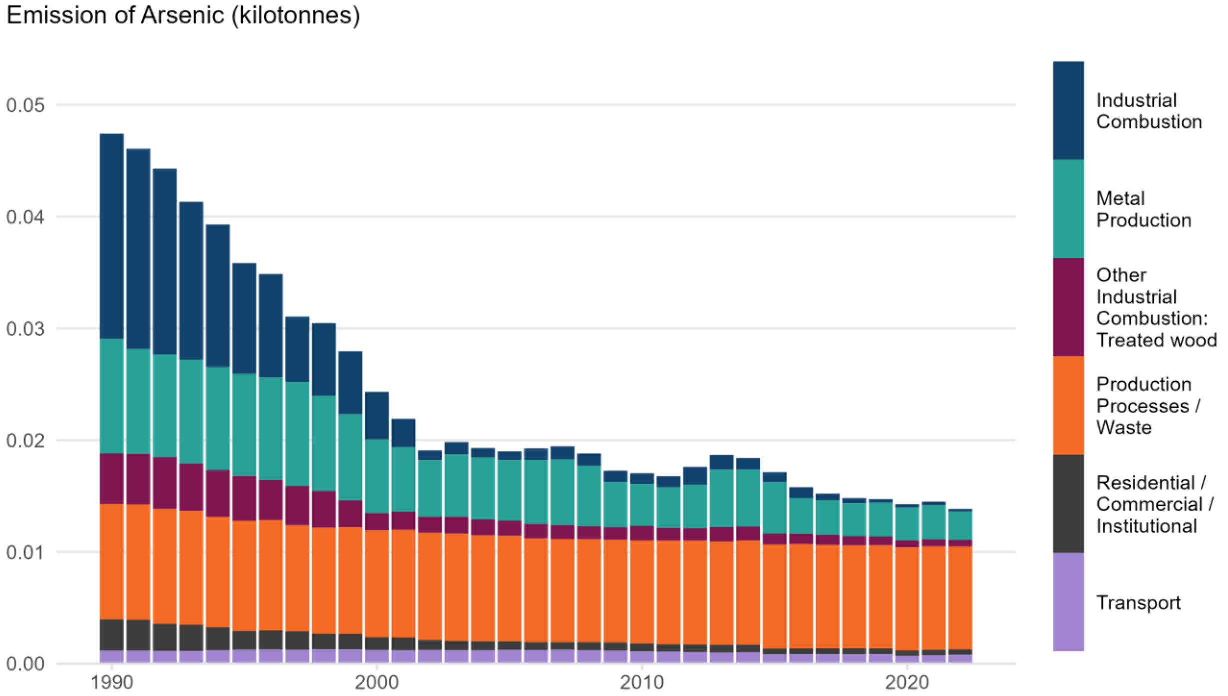


Figure 5-40 shows the UK's estimated total annual emission of As (from the NAEI), in kilotonnes, from 1990 to 2022. The largest human-made source of As emissions in the UK is the open burning of waste wood which has been treated with products containing As. This falls within the 'Production processes/waste' 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 – 2022 (source: NAEI 2023)



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 2023. 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 2022, 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 3% of the UK total.

Figure 5-41 Ambient Concentrations of Cd in PM_{10}, 2004 – 2023

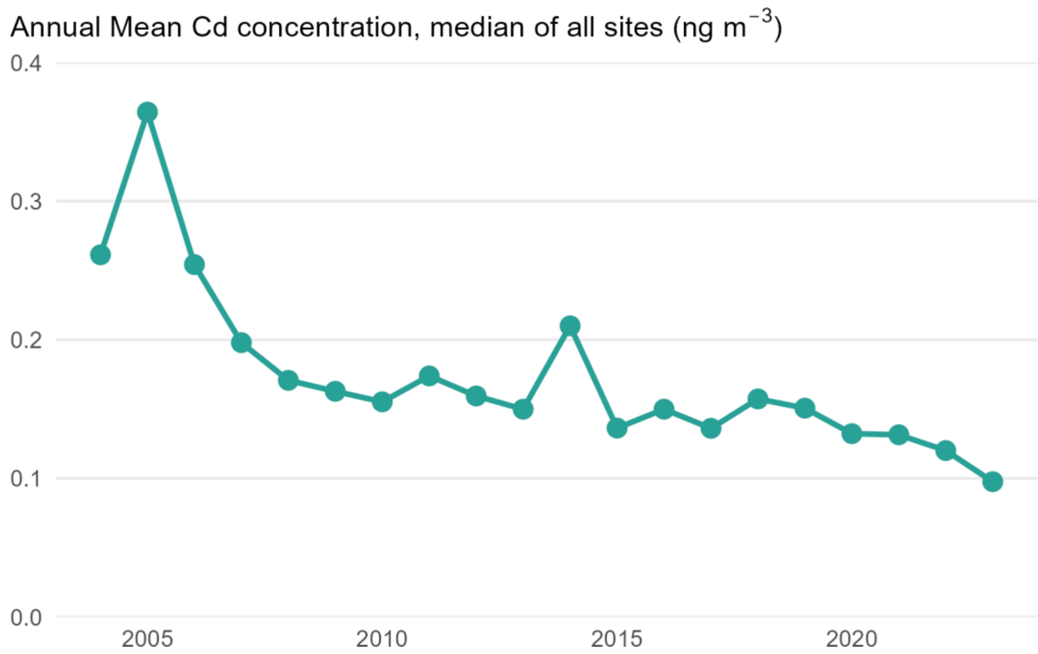
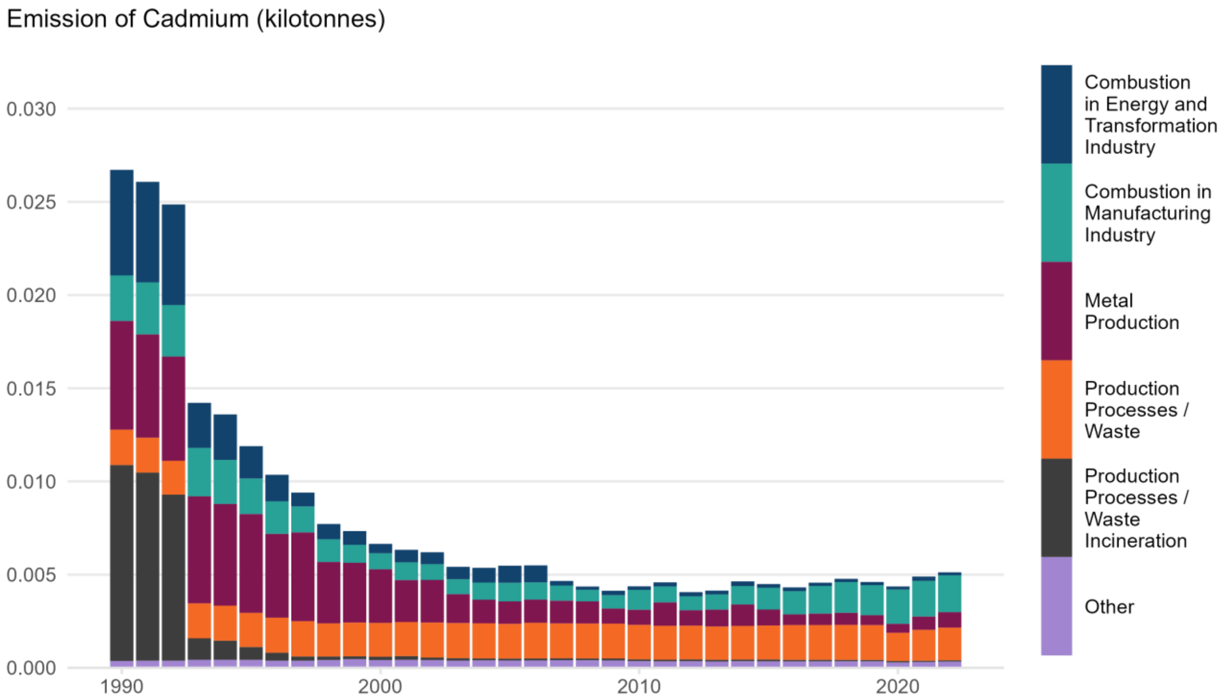


Figure 5-42 Estimated Annual UK Emissions of Cd (kt), 1990 – 2022 (source: NAEI 2023)



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 5-43 Ambient Concentrations of Ni in PM_{10}, 2004 – 2023

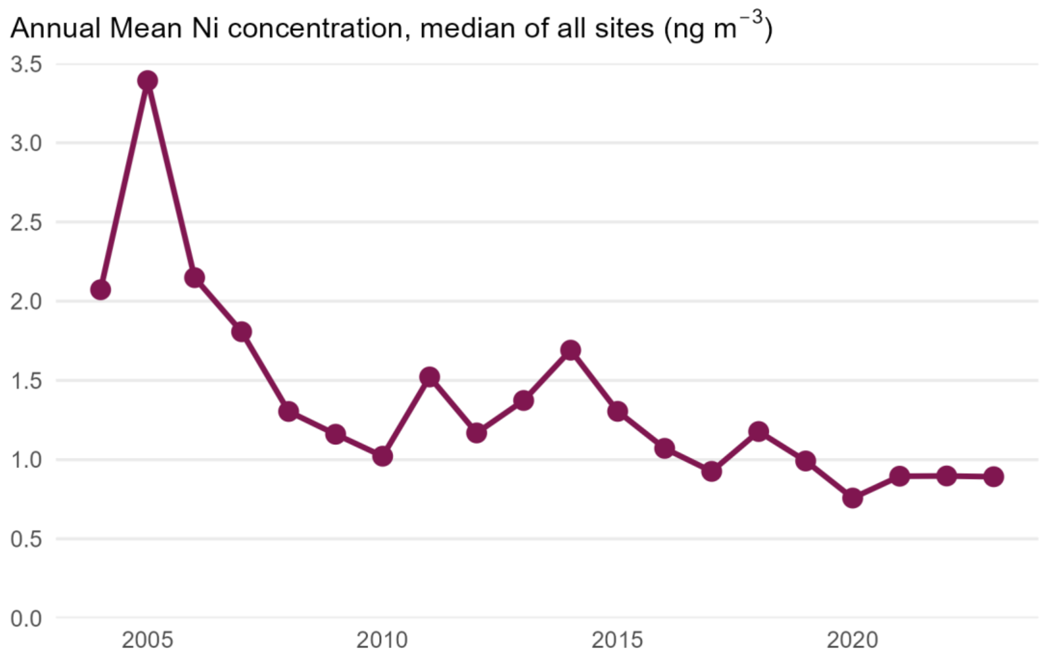
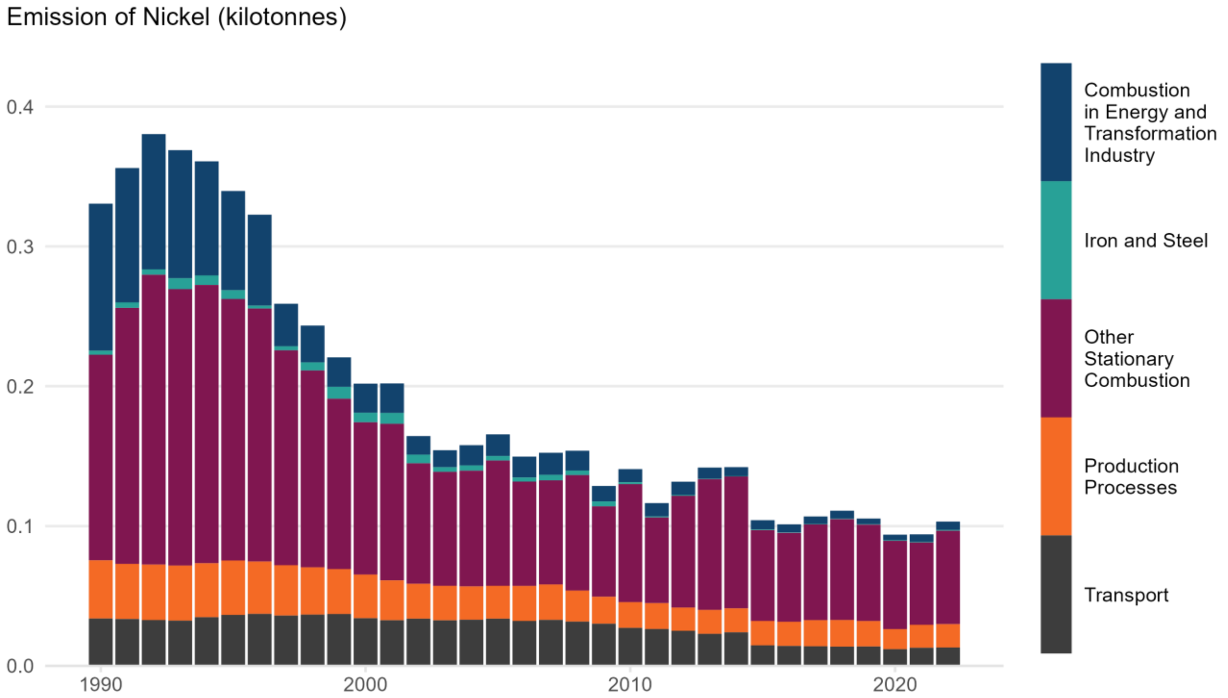


Figure 5-44 shows total estimated annual UK emissions of Ni, from the NAEI, from 1990 to 2022. Stationary combustion in industry (other than the energy production and transformation industry) is the major source. The NAEI data show a general – though not consistent - decrease in Ni emissions since 1990.

Figure 5-44 Estimated Annual UK Emissions of Ni (kt), 1990 – 2022 (source: NAEI 2023)



5.10.2.5 Mercury: Changes Over Time

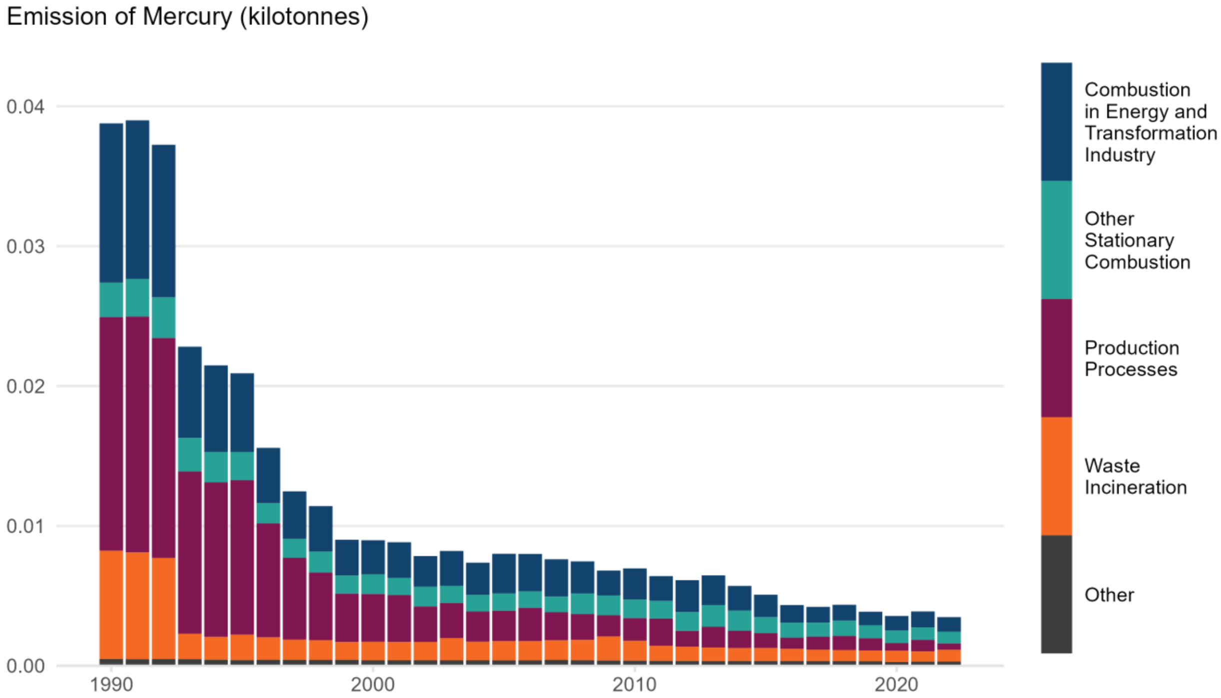
The Heavy Metals Network ceased measuring mercury (Hg) in PM_{10} at the end of 2013. Monitoring of Total Gaseous Mercury (TGM) continued at two sites (London Westminster and Runcorn Weston Point) until 2018. For information on previous years' measurements of mercury carried out by the Heavy Metals Network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

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 2022. 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 - 2022 (source: NAEI 2023)

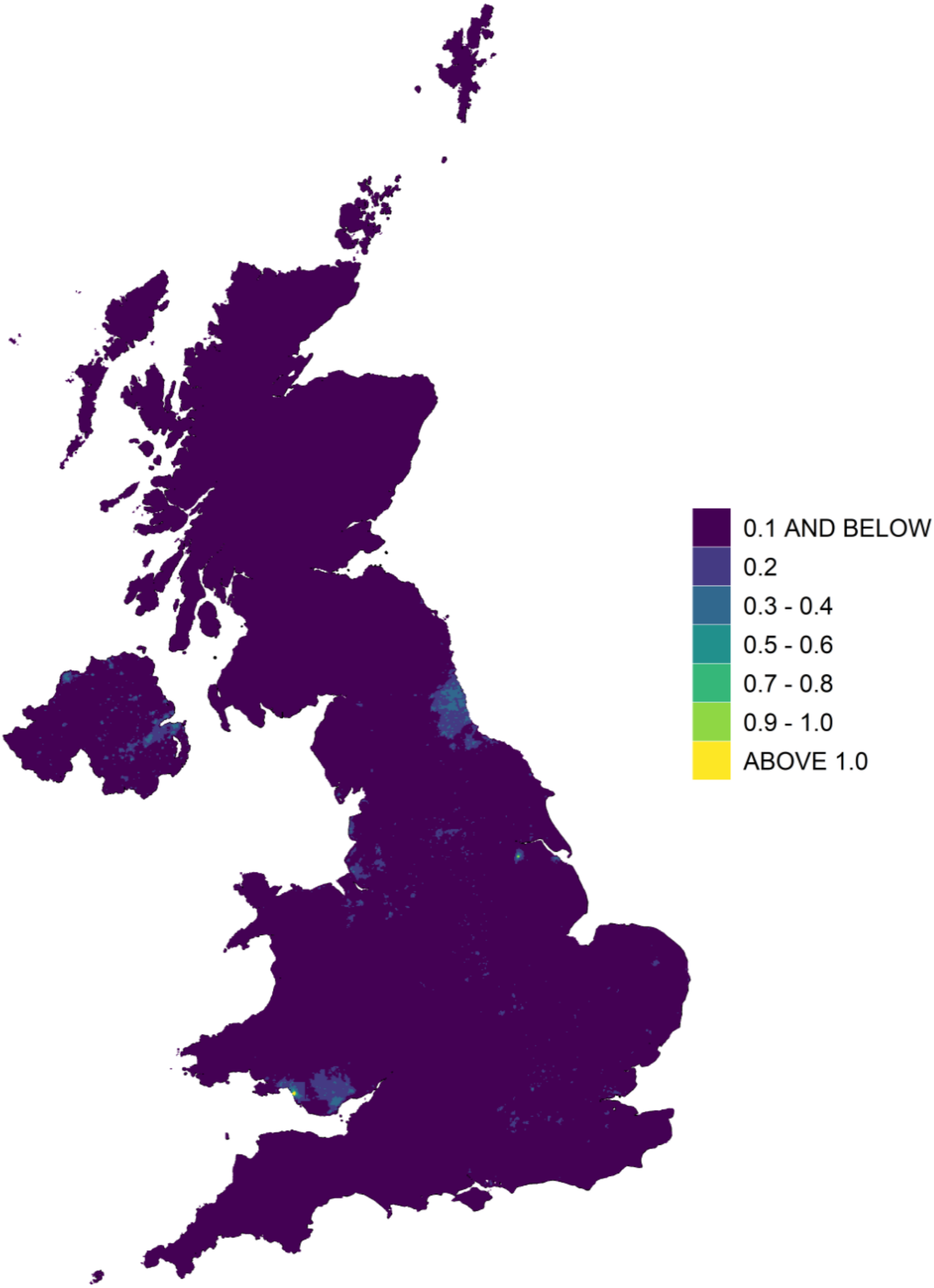


5.11 Benzo[a]pyrene

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 2023. 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. One small area of South Wales had annual mean B[a]P concentrations above the limit value of 1 ng m^{-3} in 2023: this reflects industrial sources in that area and has resulted in the exceedances reported for both Swansea Urban Area and the South Wales zone. Another small area of localised higher B[a]P concentrations is visible near Humberside, but this did not exceed the limit value of 1 ng m^{-3}.

Figure 5-46 Annual mean background B[a]P concentration, 2023 (ng m^{-3})



An interactive map is available at https://uk-air.defra.gov.uk/data/gis-mapping/.

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. Later, 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 2022. 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, 2008-2023

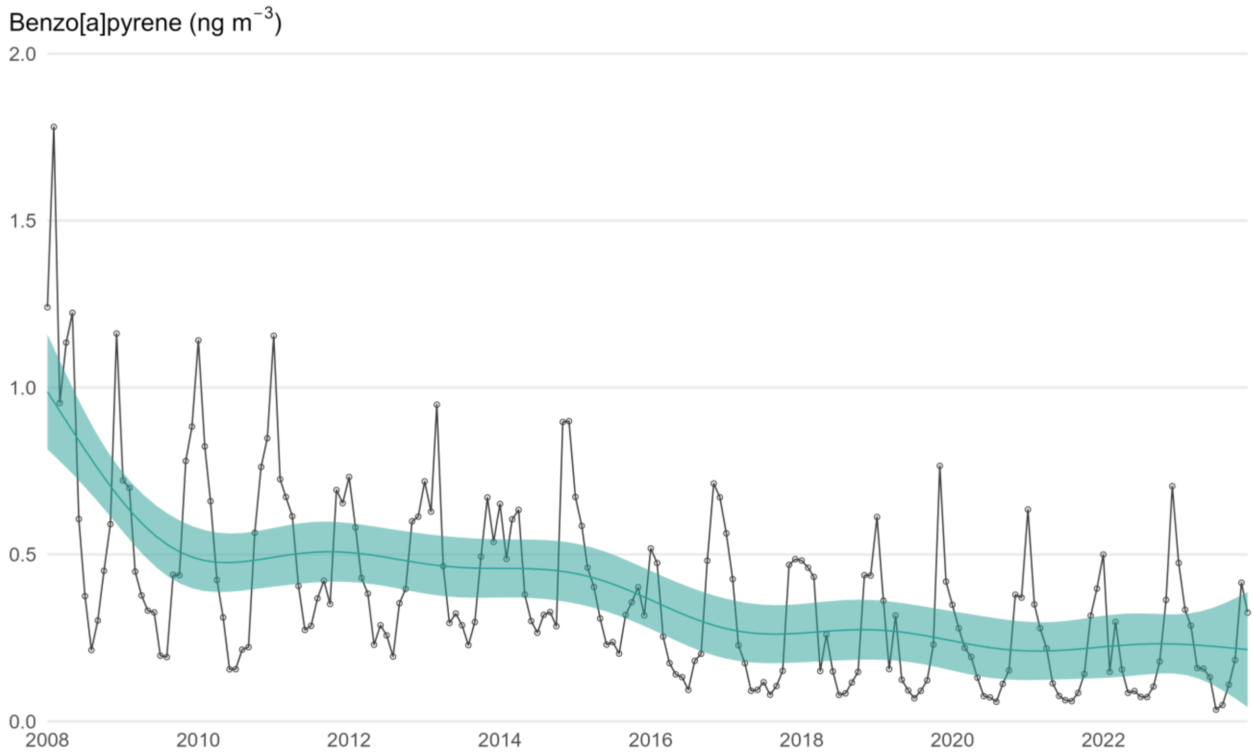
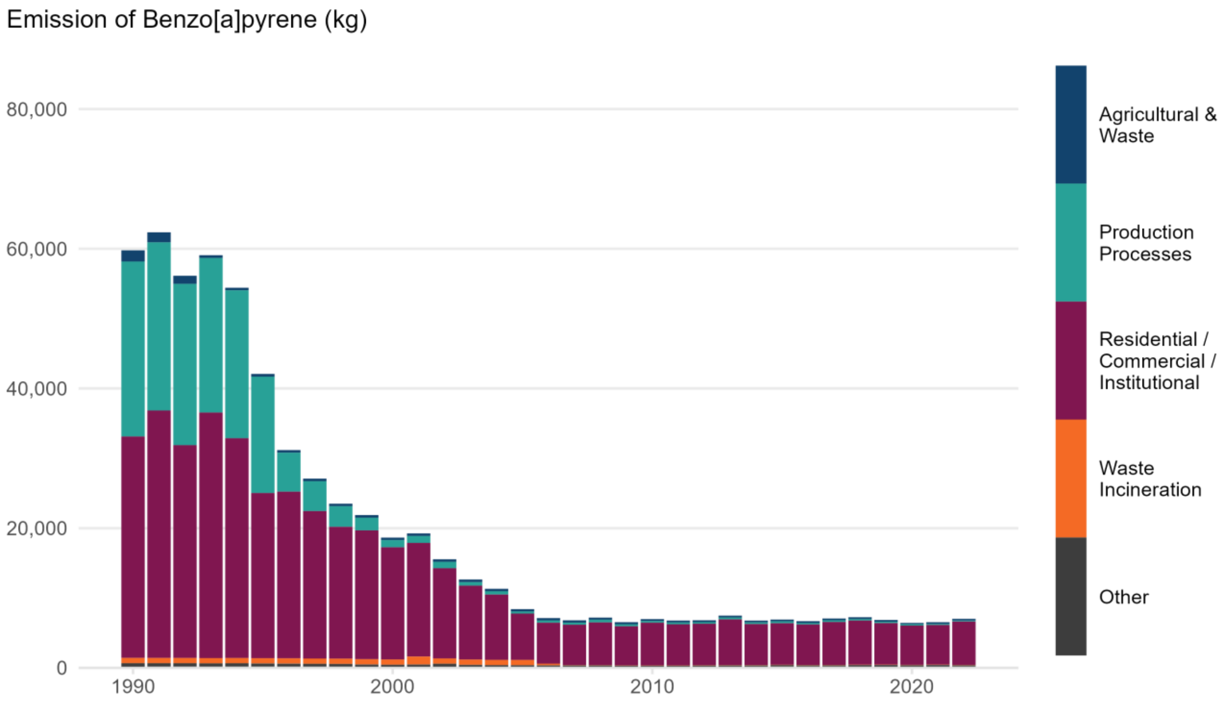


Figure 5-48 Estimated Annual UK Emissions of Benzo[a]pyrene (kg), 1990 – 2022 (source: NAEI)



6 Air Pollution Episodes in 2023

6.1 Particulate Pollution Episodes

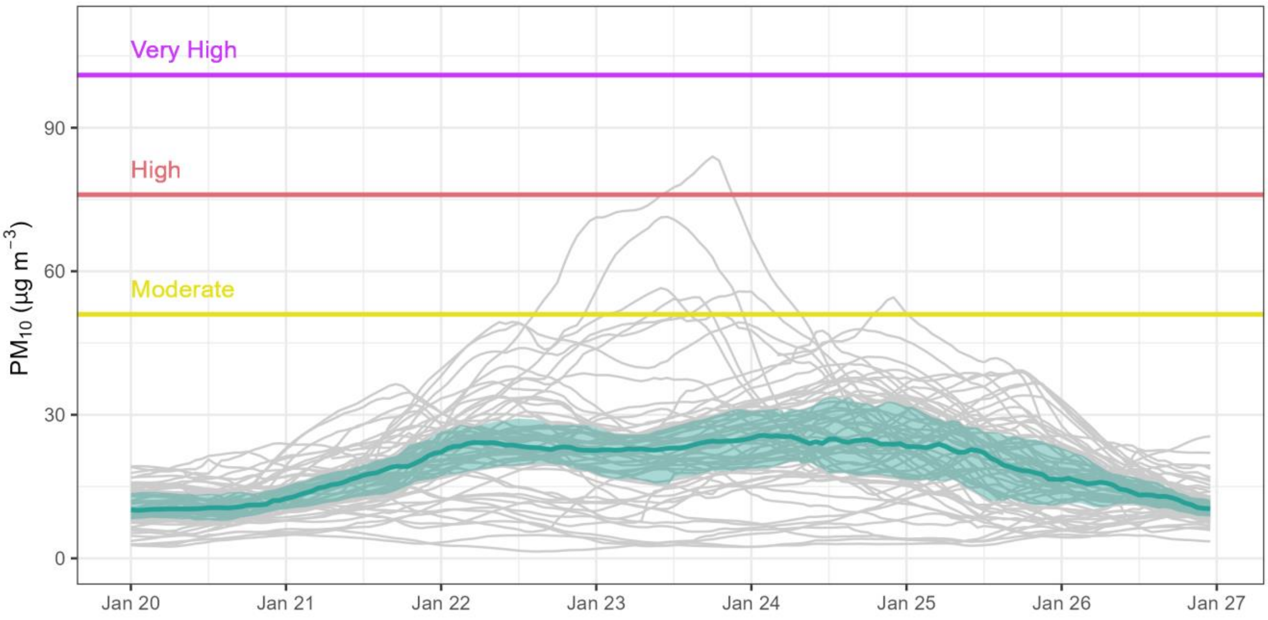
6.1.1 PM_{10} and $PM_{2.5}$ Episode January 22nd – 23rd

In January 2023 a particulate pollution episode was observed, which resulted in particulate matter (PM) concentrations reaching the Daily Air Quality Index (DAQI) Moderate band across eastern regions of the UK, and the DAQI High band in London.

Figure 6-1 and **Figure 6-2** show the running 24-hour mean of PM_{10} and $PM_{2.5}$ measured at urban background and rural background sites across the UK. PM_{10} concentrations reached the High band at London Teddington Bushy Park on January 23rd. On the same day, High $PM_{2.5}$ was also measured at London Teddington Bushy Park, London N. Kensington and London Westminster.

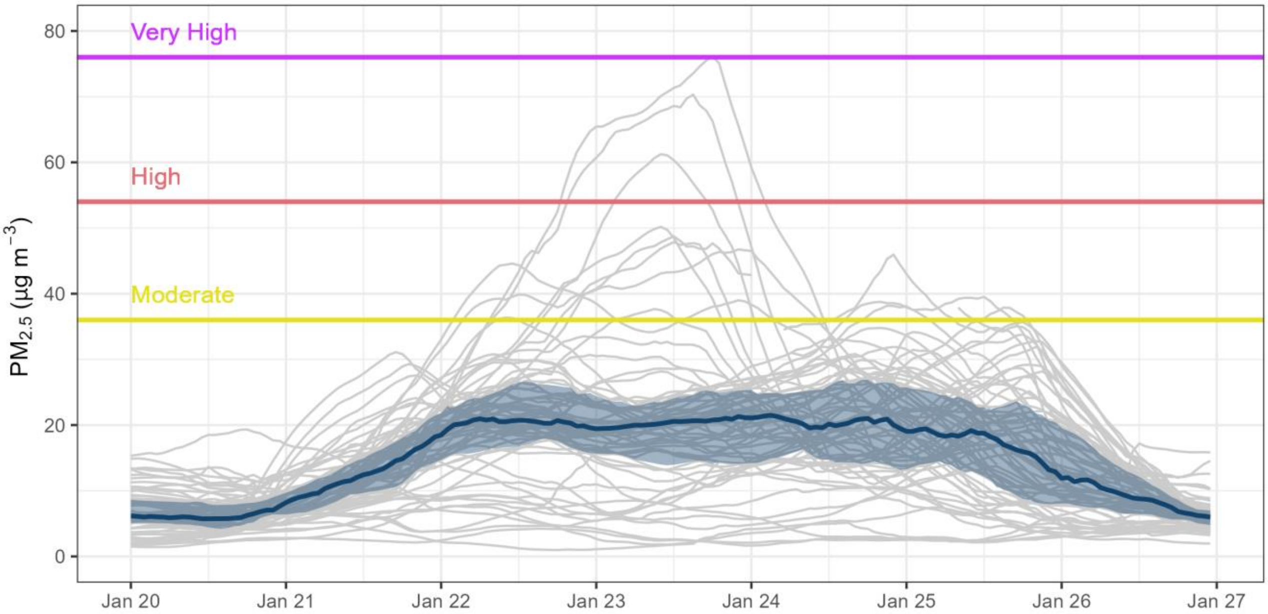
Moderate PM_{10} and/or $PM_{2.5}$ was also recorded in Yorkshire & Humberside, Eastern and South East regions on 22nd and 23rd January, as shown in **Figure 6-3**.

Figure 6-1 Running 24-hour mean PM_{10} measured at urban background and rural background sites between 20th and 27th January 2023.



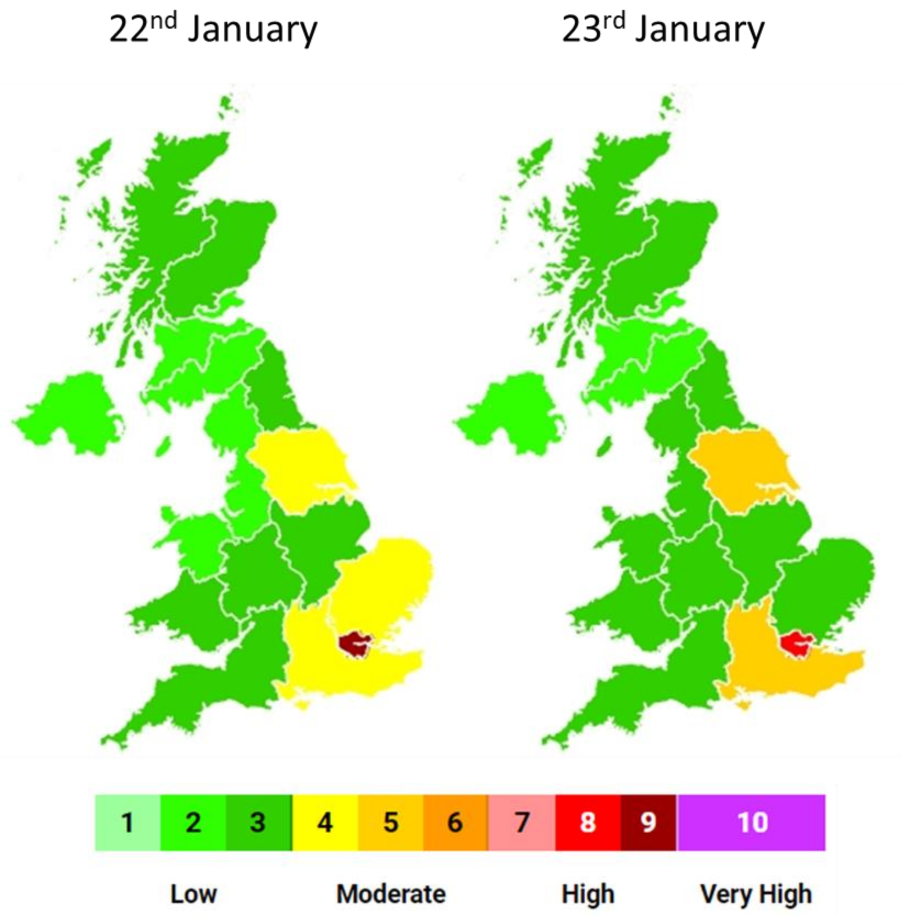
Footnote to Figure 6-1: The grey lines represent the time series for each site. The green coloured line represents the median of the running 24-hour mean concentrations across all sites, and the shaded region represents the range within the 25th and 75th percentiles.

Figure 6-2 Running 24-hour mean $PM_{2.5}$ measured at urban background and rural background sites between 20th and 27th January 2023.



Footnote to Figure 6-2: the grey lines represent the time series for each site. The blue coloured line represents the median of the running 24-hour mean concentrations across all sites, and the shaded region represents the range within the 25th and 75th percentiles.

Figure 6-3 Daily Air Quality Index (DAQI) on 22nd and 23rd January 2023.

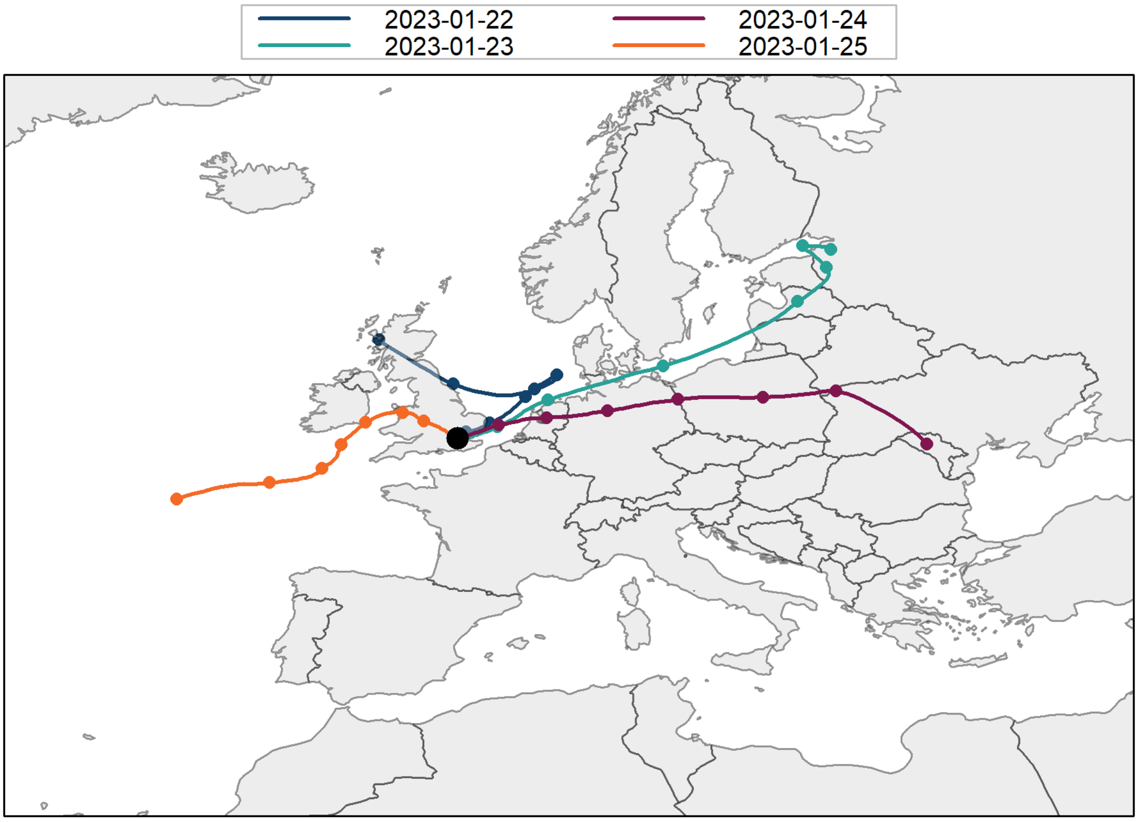


Back trajectories showing the origins of the air masses were calculated using the HYSPLIT Trajectory Model (https://www.ready.noaa.gov/HYSPLIT.php) from NOAA Air Resources Laboratory (ARL) and Global NOAA-NCEP/NCAR reanalysis data archives (Stein, et al., 2015), and plotted using the Openair package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

Figure 6-4 shows 96-hour back trajectories centred on London at an arrival time of 12 noon, from 22nd to 25th January 2023. The back trajectories on the 23rd and 24th January show air masses transported over Europe before arriving at the UK, potentially bringing polluted air from the continent to the east of the UK. On 25th January the air masses originated from the west, bringing cleaner air.

High particulate pollution observed in London over this period was likely due to a mixture of polluted air from Europe combined with locally emitted particulate matter. The weather conditions in London during this episode were described as '*settled, still and foggy conditions leading to a buildup of local pollutants, accentuated by temperature inversion caused by the cold nights*' (LondonAir, 2023). Such conditions can result in a build-up of pollutants from local sources, as dispersion is reduced.

Figure 6-4 Back Trajectories (96-hour) Showing Air Masses Arriving in London between 22nd and 25th January 2023.

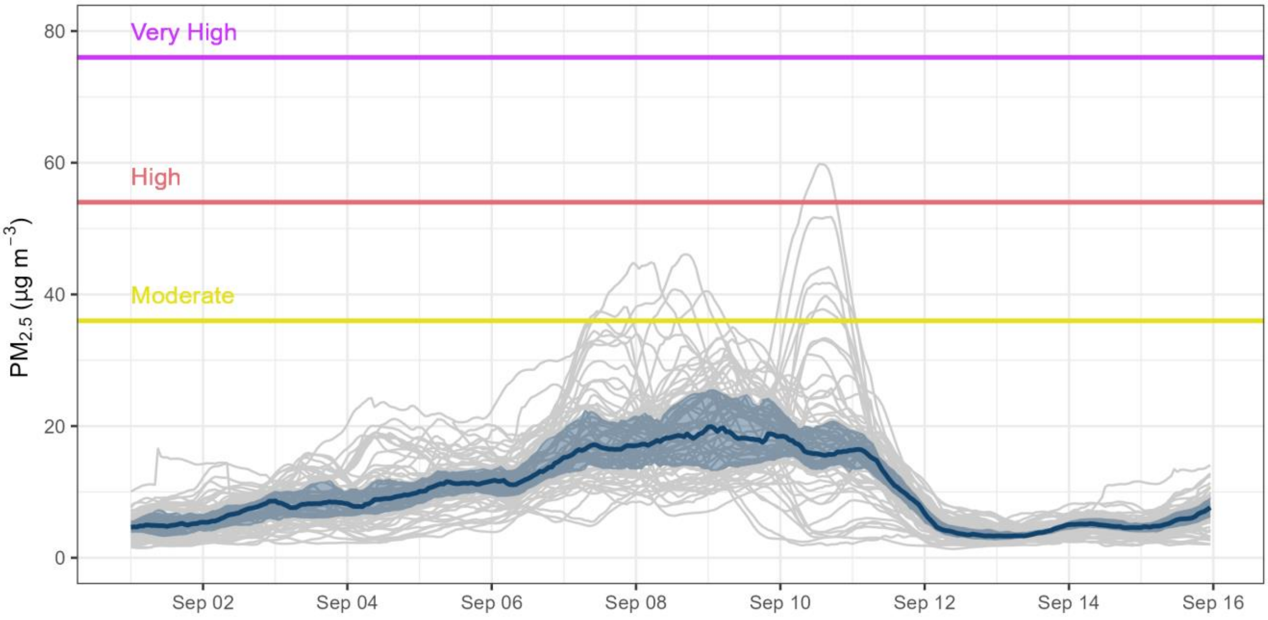


Footnote to Figure 6-4: the authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and READY website (http://www.ready.noaa.gov) used to prepare this figure.

6.1.2 $PM_{2.5}$ Episode 7th – 10th September

$PM_{2.5}$ also reached the High band at Rochester Stoke (a rural site in Kent) on 10th September (see **Figure 6-5**). Moderate $PM_{2.5}$ and PM_{10} at urban background and rural background sites were also observed at a number of sites from 7th to 10th September, coinciding with a period of elevated ozone and high temperatures. Unlike the pollution episode observed in January, which was likely due to local emissions building up under still, stable conditions, mixed with continental pollution, this $PM_{2.5}$ episode is more likely to have been related to an increase in secondary $PM_{2.5}$ formed during the period of high temperatures. Further information on the meteorological conditions during this period is provided in Section 6.2.1.2. More information on the secondary formation of $PM_{2.5}$ can be found in Section 3.1.3.

Figure 6-5 Running 24-hour mean of $PM_{2.5}$ measured at urban background and rural background sites, 2nd to 16th September 2023.



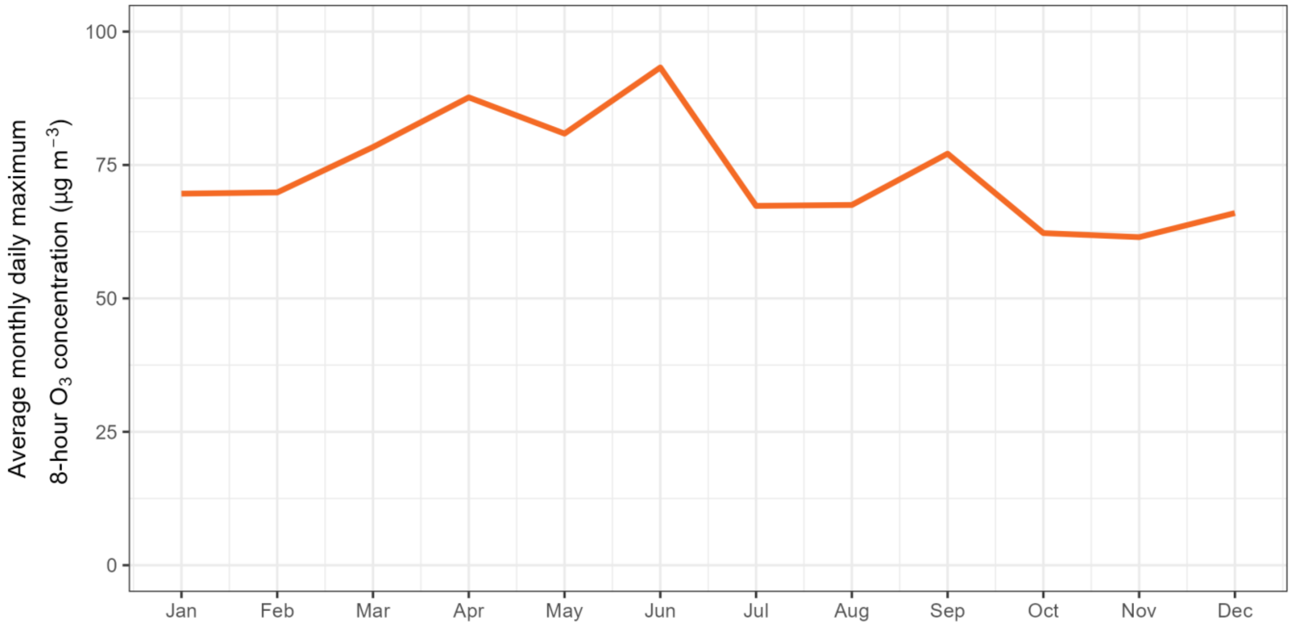
Footnote to Figure 6-5: the grey lines represent the time series for each site. The blue coloured line represents the median of the running 24-hour mean concentrations across all sites, and the shaded region represents the range within the 25th and 75th percentiles.

6.2 Widespread Ozone Events During Heatwaves

Ozone is a secondary pollutant, formed via the reaction between nitrogen oxides and volatile organic compounds (VOCs) in the presence of sunlight. Ozone concentrations are typically higher in the spring and summer, as a result of longer, sunnier days and stable conditions which allow ozone to build up, and higher temperatures which can increase the rate of ozone production.

In 2023 the average ozone measured at rural monitoring stations peaked in April, June and September (**Figure 6-6**). Springtime and summertime peaks are typical for ozone in the UK as the increase in radiation and abundance of ozone precursors results in an increase in ozone formation.

Figure 6-6 Monthly average of daily maximum 8-hour mean ozone concentrations at rural AURN sites, 2023.



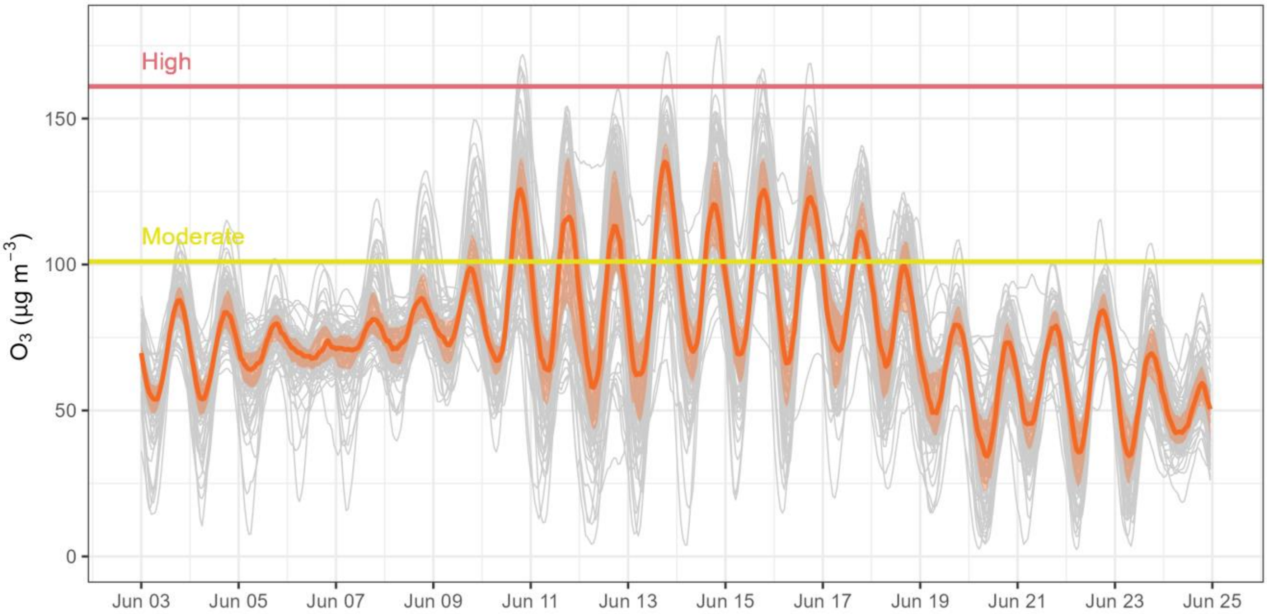
Footnote to Figure 6-6: monthly averages only included where data capture was ≥ 75% for that site and month.

6.2.1 High Ozone Events in 2023

6.2.1.1 Ozone Episode June 2023

Figure 6-7 shows the running 8-hour mean ozone concentrations measured at urban background and rural background sites between 3rd June and 25th June 2023. Ozone concentrations increased in the second week of June, and between 10th and 19th June Moderate ozone was observed across all of the UK, with some regions measuring ozone in the High band. During this period the UK experienced high temperatures, with a maximum of 32.3 °C measured in Surrey on 10th June (Met Office, 2023a).

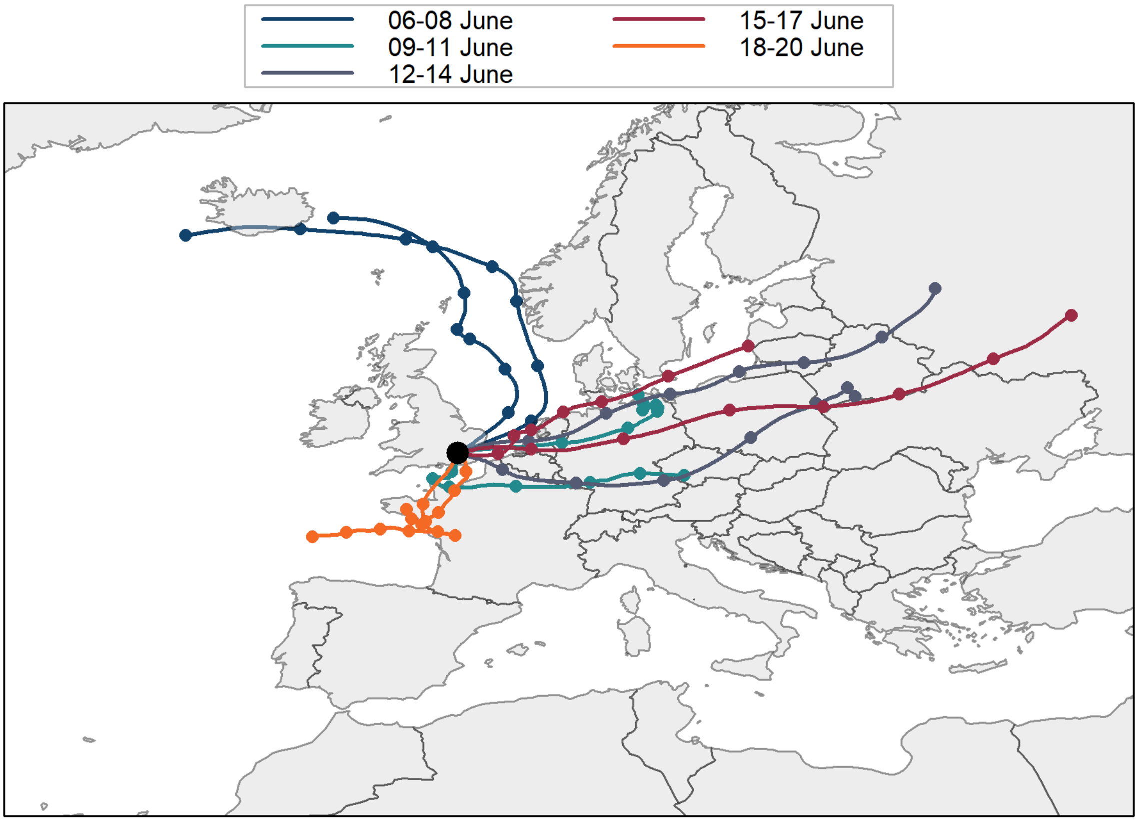
Figure 6-7 Running 8-hour mean O_3 measured at urban, suburban, and rural background sites from 3rd to 25th June 2023.



Footnote to Figure 6-7: 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 range within the 25th and 75th percentiles.

Back trajectories from 6th to 20th June 2023 (**Figure 6-8**) show the air masses being transported over Europe before reaching the UK from 9th to 17th June. The warm weather, coupled with air arriving from the continent, potentially transporting ozone precursors, was conducive to high ozone formation in the UK.

Figure 6-8 Back Trajectories (96-hour) Showing Air Masses Arriving in London between 6th and 20th June 2023.



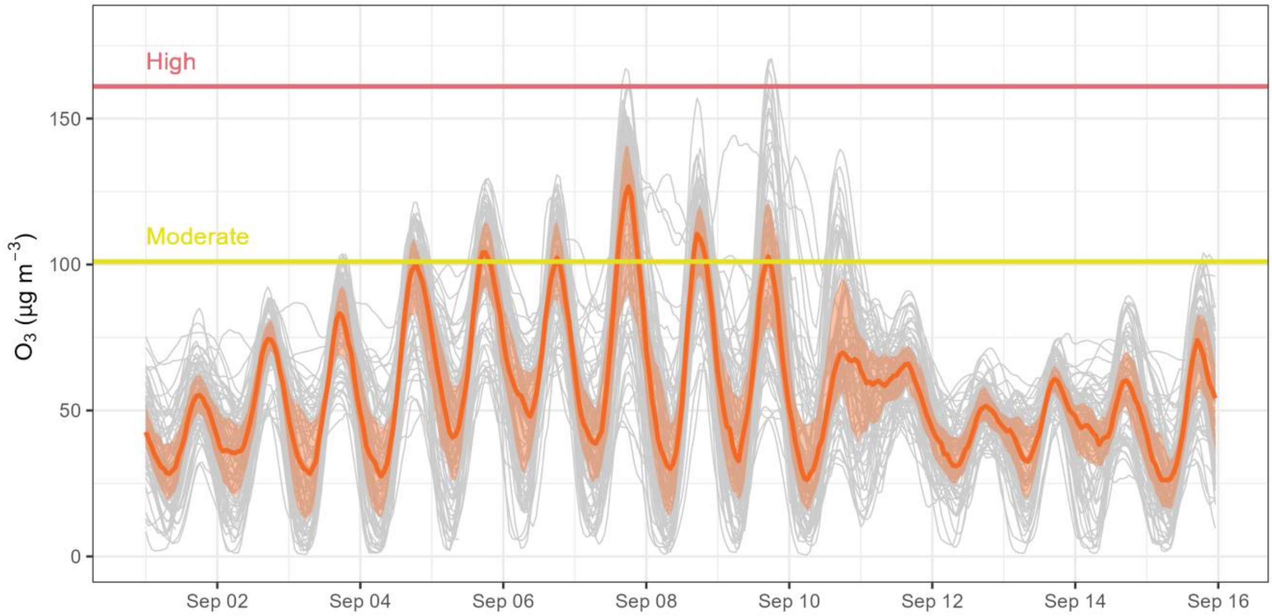
Footnote to Figure 6-8: the authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and READY website (http://www.ready.noaa.gov) used to prepare this figure.

6.2.1.2 Ozone Episode September 2023

From 4th to 9th September, Moderate ozone was observed across much of England and Wales, and on some days in Scotland. High ozone was reached in the south on 7th and 9th September, as shown in **Figure 6-9** and **Figure 6-10**.

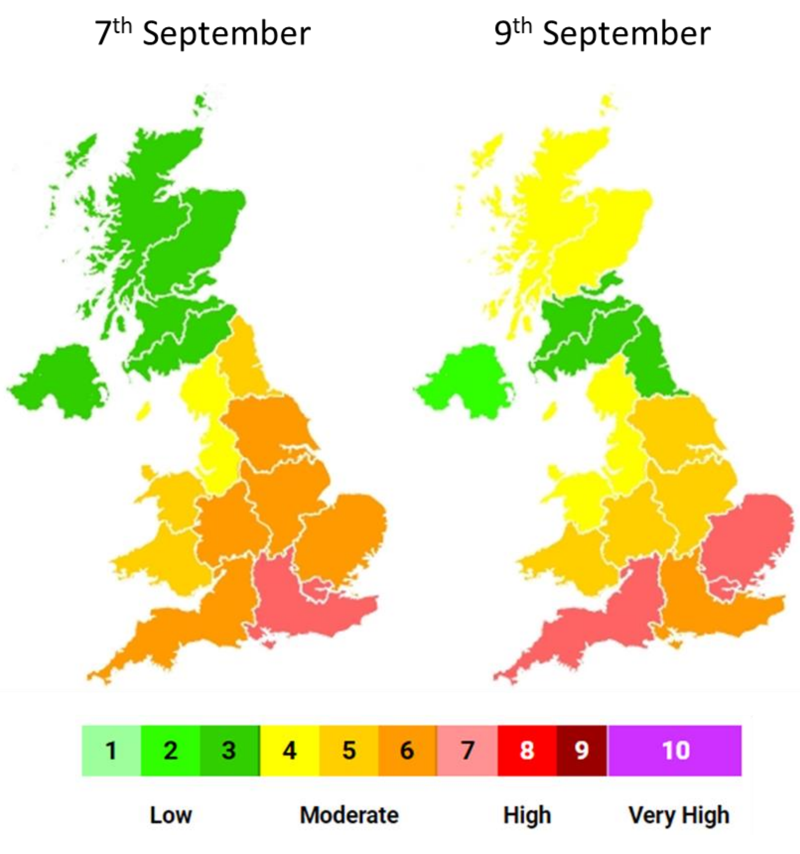
A heatwave occurred in the UK between 4th and 10th September, with temperatures above 30 °C recorded over a seven-day period (Met Office, 2023b). The wind was predominantly from the south/southeast during the early part of September. The sunny, hot conditions along with the transport of pollutant precursors from the continent resulted in the elevated ozone observed. As discussed in Section 6.1, elevated PM was also observed during this period, which is likely related to the long-range transport of pollutants and precursors.

Figure 6-9 Running 8-hour mean O_3 at urban, suburban, and rural background sites from 2nd to 14th September.



Footnote to Figure 6-9: 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 range within the 25th and 75th percentiles.

Figure 6-10 Daily Air Quality Index (DAQI) on 7th and 9th September 2023.



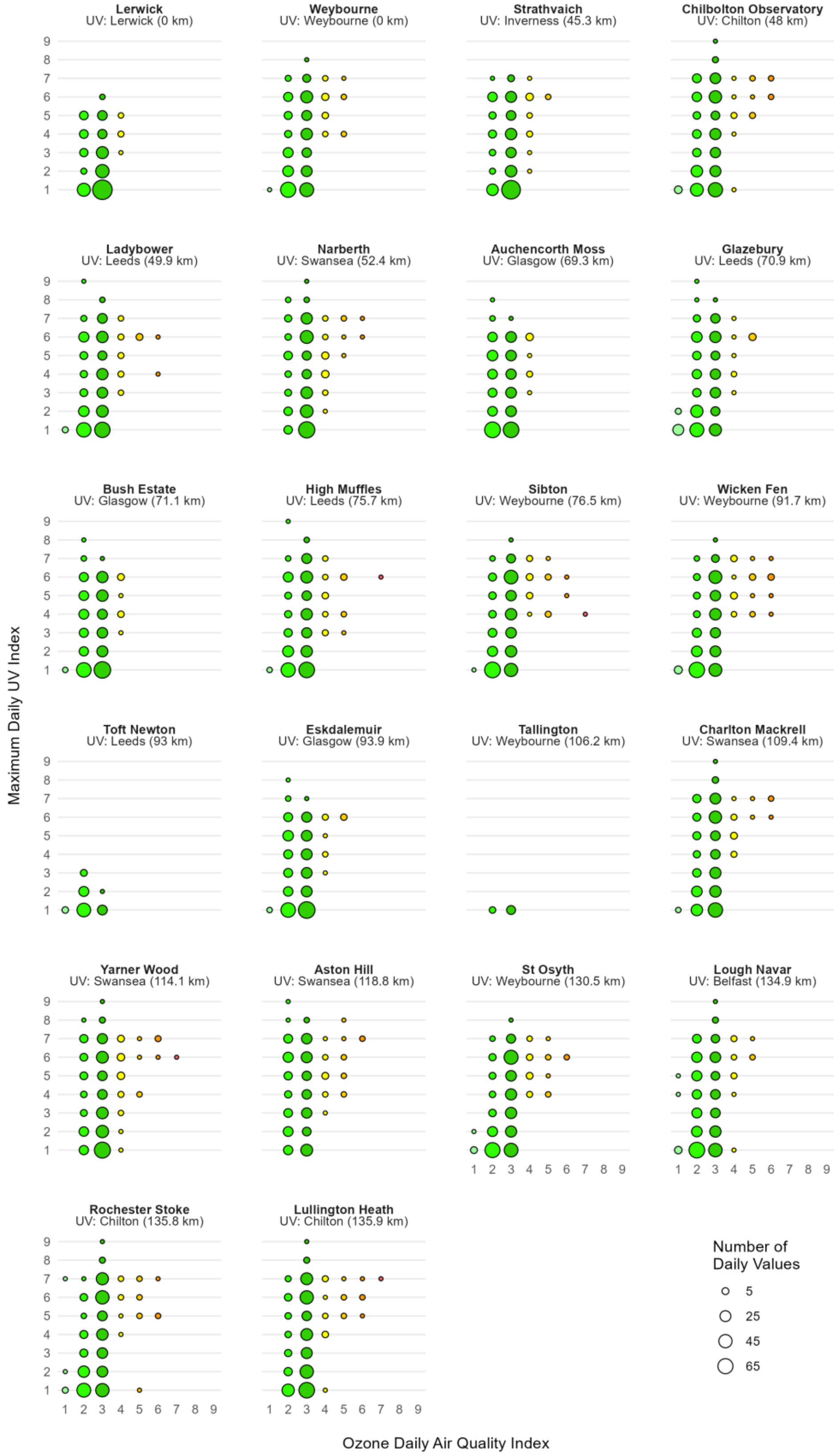
6.2.2 Relationship of Ozone Concentrations with Intensity of Sunlight

Ozone concentrations in rural areas tend to be higher during warm sunny days. **Figure 6-11** shows how the ozone Daily Air Quality Index (DAQI) varies with the intensity of the sunlight – represented by the daily UV index. Moderate to High ozone concentrations are associated with days when the UV index values are typically higher, reflecting the role of sunlight in ozone formation.

Higher temperatures can result in increased ozone concentrations as chemical reactions leading to the formation of ozone, and emissions of biogenic VOCs (precursor pollutants to ozone) also increase. **Figure 6-12** shows the relationship between 8-hour mean ozone with 8-hour mean temperature, at rural sites in 2023. The data show that at 8-hour mean temperatures above around 20º C there is a positive relationship between increases in temperature and increases in ozone.

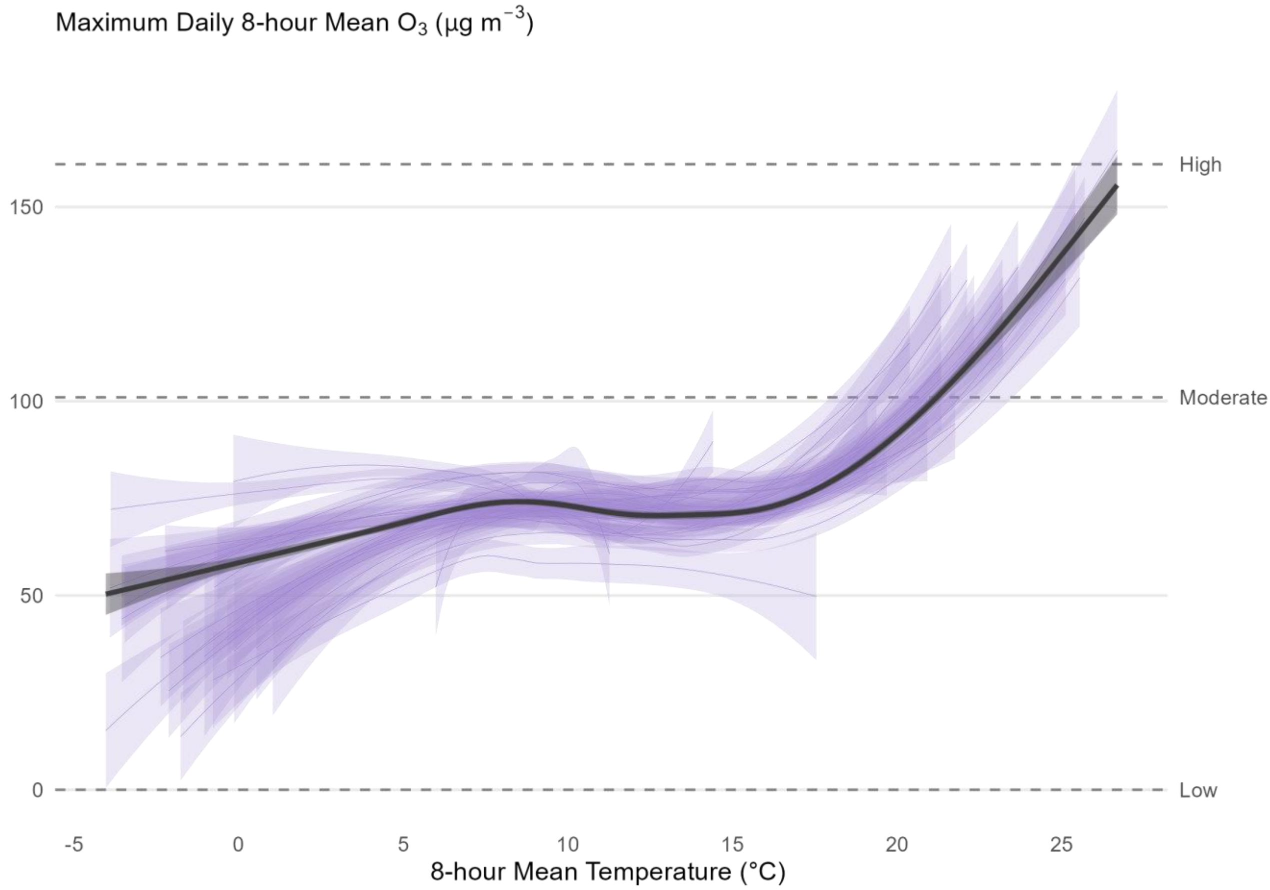
More information on the formation of ozone and its effects on health can be found in Section 3.1.2.

Figure 6-11 Distribution of ozone DAQI measured at rural monitoring sites versus the maximum daily UV index, for 2023.



Footnote to Figure 6-11: the size of the circle represents the number of days ozone was in each DAQI at the site. Produced using Data supplied from UK Health Security Agency under the Open Government Licence **(Defra, 2023b)**.

Figure 6-12 Variation of maximum daily 8-hour mean ozone with 8-hour mean temperature at rural sites in 2023.



Footnote to Figure 6-12: the purple lines represent the smoothed trend between temperature and ozone at each rural site and the black line represents all rural sites together. Shaded areas represent the 95% confidence intervals of the smoothed fit.

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.energysecurity.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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