Department for Environment Food & Rural Affairs

Air Pollution in the UK 2020

September 2021

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Executive Summary

The UK's Air Quality Standards Regulations require reporting of ambient air quality data on an annual basis. Data are reported via the UK-AIR website at http://uk-air.defra.gov.uk/. This report provides background information on the pollutants covered by these Regulations and the UK's Air Quality Strategy: their sources and effects, the UK's statutory monitoring networks, and the UK's modelling methodology. The report then summarises the UK's ambient air quality assessment for 2020, 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, the UK is divided into 43 zones. The 2020 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. 2020 is the first year in which the UK has achieved full compliance with the hourly mean limit value, which came into force in 2008.
- 38 zones met the limit value for annual mean NO_2, with only five zones exceeding.
- The UK's full compliance with the hourly mean NO_2 limit value, and low number of zones exceeding the annual mean limit value, is largely attributed to the Covid-19 lockdown restrictions which substantially reduced traffic activity on many roads.
- All non-agglomeration zones complied with the critical level for annual mean NO_X concentration, set for protection of vegetation. (This has been the case in all years from 2008 onwards).
- All zones met the limit value for daily mean concentration of PM_{10} particulate matter, without the need for 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 subtraction of the contribution from natural sources.
- All zones met both limit values for annual mean concentration of $PM_{2.5}$ particulate matter: the Stage 1 limit value, which came into force on 1st January 2015, and the indicative Stage 2 limit value to be met by 2020.

- The UK has achieved its 2020 national exposure reduction target for $PM_{2.5}$, based on the Average Exposure Indicator (AEI) statistic.
- All zones met both the target values for ozone; the target value based on the maximum daily eight-hour mean, and the target value based on the AOT40 statistic.
- Three zones were compliant with the long-term objective for ozone, set for the protection of human health. This is based on the maximum daily eight-hour mean.
- 27 zones met the long-term objective for ozone, set for the protection of vegetation. This is based on the AOT40 statistic, which is explained in Section 4 and Section 5 of this report.
- All zones met the limit values for sulphur dioxide, carbon monoxide, benzene and lead.
- All zones met the target values for arsenic and cadmium.
- Four zones exceeded the target value for nickel.
- Three zones exceeded the target value for benzo[a]pyrene, as has been the case in the previous three years.

A summary of the air quality assessment for 2020, and a comparison with previous years' air quality assessments since 2008 can be found in Section 4 of this report.

Section 6 investigates the effects of the Covid-19 restrictions on UK air quality. These restrictions significantly reduced traffic flows on many UK roads, for much of the year. The data show this caused a decrease in urban ambient NO_2 concentrations, which has contributed to the improved compliance with limit values for this pollutant.

The pandemic restrictions appear to have substantially increased compliance with the limit values for nitrogen dioxide in 2020 compared to 2019. This does not mean concentrations of other pollutants were unaffected: however, the UK was already fully compliant with the limit values for other pollutants (PM_{10}, $PM_{2.5}$, SO_2, CO, benzene and lead), and target values for ozone, arsenic and cadmium.

Ozone is also of particular interest in the context of the Covid-19 restrictions. This pollutant is removed from the air by reaction with nitric oxide (NO), which is a component of vehicle emissions. The data suggest that traffic reductions may have allowed ozone concentrations in some urban areas to become higher than they otherwise would have. The UK met all target values for O_3 in 2020 as it has done for many years, but the number of zones exceeding the long-term objective for vegetation (16 zones) was relatively high compared with previous years.

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 http://uk-air.defra.gov.uk/, http://www.scottishairquality.scot/, https://airquality.gov.wales and www.airqualityni.co.uk.

Glossary

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. 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 are the legislation by which the UK fulfilled this requirement.

Air Quality Strategy. The United Kingdom's own National Air Quality Strategy, containing policies for assessment and management of air quality in the UK. This was first published in 1997, as a requirement of The Environment Act 1995.

Air Quality Strategy Objective. The Air Quality Strategy sets objectives for the maximum concentrations of eight pollutants. These are at least as stringent as the limit values of the Air Quality Directive and Air Quality Standards Regulations.

Ambient Air. Outdoor air.

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

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

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

Beta Attenuation Monitor (BAM). A type of instrument used for monitoring concentrations of particulate matter.

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

Carbon Monoxide (CO) a pollutant gas found 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.

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

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 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.

FDMS. This stands for 'Filter Dynamic Measurement System' and refers to a type of instrument for monitoring concentrations of particulate matter. The FDMS is a modified form of Tapered Element Oscillating Microbalance (TEOM).

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

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.

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.

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

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

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

Microgramme per cubic metre (µg m^{-3}). Unit often used to express concentration of a pollutant in air. 1 µg = 1 millionth of a gramme 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.

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

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

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

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

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

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

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

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

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

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

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

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

Secondary pollutant. A pollutant which is formed by chemical reactions from other pollutants in the atmosphere. Ozone, for example, is a secondary pollutant.

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

Target Value. As well as limit values, the ***Air Quality Standards Regulations*** set target values for some pollutants. These are similar to limit values but are not legally mandatory. The UK must take all necessary measures not entailing disproportionate costs to meet the target values.

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

A cleaner, healthier environment benefits people and the economy. 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.

The UK's Air Quality Standards Regulations (UK Government , 2010) 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 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 2020*' continues this series, and has two aims:

- To provide a summary of the UK's 2020 air quality assessment and findings. A separate Compliance Assessment Summary document is also published, based upon Section 4 of this report, and accompanies the UK's 2020 submission. This provides a concise summary aimed at the public.
- 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 2020 with the limit values, target values and long-term objectives set out in the Air Quality Standards Regulations (Section 4).

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

- Explains the spatial distribution of the main pollutants of concern within the UK during 2020 and looks at how ambient concentrations have changed in recent years (Section 5).

- Explains noteworthy pollution events that occurred during 2020 (Section 6). Typically, this section features episodes of high pollution: for the 2020 report, it looks at how the Covid-19 'lockdown' restrictions affected air quality in the UK.

- 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 http://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.

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; and

3) Legislation regulating emissions from specific sources such as UK legislation implementing the Environmental Permitting Regulations and the Clean Air Act.

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

2.1 The Air Quality Standards Regulations

2.1.1 Background to the Air Quality Standards Regulations

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

- 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 December 2016 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).

2.1.2 Provisions of the Air Quality Standards Regulations

The Air Quality Standards Regulations 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 are legally binding and 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).

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

The Air Quality Standards Regulations 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 The National Emission Ceilings Regulations 2002

The UK's National Emission Ceilings Regulations 2002 (UK Government, 2002) transposed the original 2001 National Emission Ceilings Directive (2001/81/EC) into UK legislation. The National Emission Ceilings Regulations set national emission limits or 'ceilings' for sulphur dioxide, oxides of nitrogen, ammonia and volatile organic compounds in the UK. The first three are the main air pollutants responsible for the acidification and eutrophication (nutrient enrichment) of the natural environment, and all four are significant in the formation of ground level ozone which impacts both human health and the environment. The ceilings had to be met by 2010 and have applied since. They reflect the ceilings agreed internationally in the 1999 Gothenburg Protocol to the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP). Emissions of these pollutants can impact either locally or across national borders: the latter is known as 'transboundary' air pollution.

The UK is compliant with all current emission ceilings set under the National Emission Ceilings Regulations which includes accepted adjustments for 2010 and 2012. To fulfil the reporting requirements under the CLRTAP and in the NECR, the UK compiles and reports its air pollutant emissions inventory on an annual basis, and the latest emissions data for 2019 can be found here: https://naei.beis.gov.uk/data/ .

The Gothenburg Protocol was revised in May 2012 to set emission reduction commitments (ERCs) for 2020 (from the 2005 baseline) for the same four pollutants and $PM_{2.5}$. The revised National Emission Ceilings Directive (European Parliament and Council of the European Union, 2016) came into force on 31st December 2016. This revised Directive was transposed into UK legislation in February 2018 via the National Emissions Ceilings Regulations 2018, and the new UK legislation came into force on 1st July 2018 (UK Government, 2018). Defra's Clean Air Strategy, published in January 2019, sets out how we will work towards these goals (see Section 2.4.2). In addition, the UK published its National Air Pollution Control Programme (Defra, 2019) on 1st April 2019 which detailed the potential policies and measures required to meet the 2020 and 2030 emission reduction targets. A revised National Air Pollution Control Programme (NAPCP) will be published in September 2022.

2.3 The Environmental Permitting Regulations (EPR 2016 & 2018)

UK's Environmental Permitting Regulations 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 – with the aim of achieving the environmental and human health benefits associated with reduction in pollution.

Under the EPR regulation, industries must use best available techniques (BAT) to reduce their emissions. These techniques, and the emissions limits associated with the use of those techniques, are set out in best available technique reference documents (known as BREFs). BREFs are reviewed regularly, to ensure an ongoing process of improvement to UK's air quality achieved through the continuous reduction of pollution. In addition, the regulation sets emission limits for the emission of pollutants from particular sectors.

The UK is committed to maintaining high environmental standards and will continue to apply the existing successful model of integrated pollution control. The UK government will put in place a process for determining future BAT for industrial emissions. This is being developed with the devolved administrations and competent authorities across the UK.

2.4 The UK Perspective

Poor air quality is the greatest environmental risk to public health in the UK. It is known to exacerbate the impact of pre-existing health conditions, such as respiratory and cardio-vascular illnesses, especially for the elderly and infants. 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 smogs caused by domestic and industrial coal burning, and significant progress has continued to improve air quality throughout subsequent decades. Between 2010 and 2019 (the most recent year for which data are available), UK estimated emissions of nitrogen oxides have fallen by 32%, UK estimated emissions of PM_{10} particulate matter have fallen by 10% and UK estimated emissions of $PM_{2.5}$ particulate matter have fallen by 11% (Defra, 2021 A).

The most immediate air quality challenge is tackling nitrogen dioxide concentrations. This is the only air pollutant for which the UK is currently failing to meet a statutory air quality limit value, with most exceedances occurring at roadside locations. NO_2 is associated with adverse effects on human health. Estimating the long-term impacts of NO_2 pollution is difficult, because of the challenge of separating its effects from those of other traffic-related pollutants. Although it has been more difficult to estimate the level of impact, there is enough evidence of such health effects to support the need to take action now.

Particulate matter is also of concern, although the UK has been compliant with limit values in recent years. In 2010, the Committee on the Medical Effects of Air Pollutants (COMEAP) produced a report on the mortality effects of long-term exposure to particulate air pollution in the United Kingdom. COMEAP estimated that the long-term impact of particulate pollution in the UK equated to 340,000 years of life lost (COMEAP, 2010).

We know there is more to do. The UK Parliament's landmark Environment Bill will establish a duty to set a legally binding target in England to reduce $PM_{2.5}$, alongside at least one further long-term target on air quality as part of the wider framework for setting legally binding environmental targets. The Bill will create a more strategic structure that will enable English local authorities to take more effective, co-ordinated actions to achieve their air quality objectives and deliver improvements to public health, and ensures local authorities have more effective powers to tackle emission from domestic burning, a key source of $PM_{2.5}$. Furthermore, the Bill introduces a new power to compel vehicle manufacturers to recall vehicles and non-road mobile machinery if they are found not to meet the environmental standards they were type approved to meet. This will enable government to ensure polluting vehicles are removed from the road and to hold non-compliant manufacturers to account.

2.4.1 The UK Air Quality Strategy

The Environment Act 1995 requires the UK Government and the Devolved Administrations for Scotland and Wales to produce a National Air Quality Strategy, containing standards, objectives and measures for improving ambient air quality; there is equivalent legislation in Northern Ireland. The Air Quality Strategy for England, Scotland, Wales and Northern Ireland was first published in March 1997 and subsequently updated in 2007 (Department for Environment, Food and Rural Affairs in partnership with the Scottish Executive, Welsh Assembly Government and Department of the Environment Northern Ireland, 2007), with a lighter touch update in 2011. The overall objectives of the Strategy are to:

- Map out future ambient air quality policy in the United Kingdom in the medium term.
- Provide best practicable protection to human health by setting health-based objectives for air pollutants.
- Outline measures which are to be taken by local authorities and other persons for the purpose of achieving those objectives
- Contribute to the protection of the natural environment through objectives for the protection of vegetation and ecosystems.
- Establish a framework to help identify what we all can do to improve air quality.

The Strategy has established objectives for eight key air pollutants, based on the best available medical and scientific understanding of their effects on health, as well as taking into account relevant developments in Europe and advice from the World Health Organisation (Department for Environment, Food and Rural Affairs in partnership with the Scottish Executive, Welsh Assembly Government and Department of the Environment Northern Ireland, 2007). These Air Quality Objectives are at least as stringent as the limit values of the relevant EU Directives and UK Air Quality Standards Regulations – in some cases, more so, e.g. for 8-hour mean ozone, annual mean lead and benzo[a]pyrene. The Strategy also covers an additional pollutant (1,3-butadiene), and includes an additional SO_2 objective, for the 15-minute mean. Scotland has adopted some tighter objectives for particulate matter and benzene.

The Environment Act 2021 requires the Secretary of State to undertake regular 5-yearly reviews of the Air Quality Strategy. The first review will be published in 2023.

2.4.2 The Clean Air Strategy 2019

Clean air is crucial for life, health, the environment and the economy. The UK Government's Clean Air Strategy for England (CAS) (Defra, 2018) sets out a range of policy actions that will help reduce air pollution, providing healthier air to breathe, enhancing the economy and protecting nature. The CAS begins by outlining our understanding of the problem, and the importance of a robust evidence base, backed by the most up to date science. It focuses on the five damaging pollutants for which the UK has ambitious reduction commitments:

- Fine particulate matter (as $PM_{2.5}$).
- Ammonia (NH_3).
- Nitrogen oxides (NO_X).
- Sulphur dioxide (SO_2).
- Non-methane volatile organic compounds (NMVOCs).

Ozone (O_3) is a pollutant which is not emitted but formed from chemical reactions in the air. By tackling all sources of pollution, we will continue to reduce the formation of ozone across the whole of the UK.

Next, it deals with **protecting the nation's health**. The health impacts (and their estimated costs to the UK) are summarised: actions are then set out for how public exposure to air pollution can be reduced.

Air pollution is not only a major risk to human health; it also has significant effects on the natural environment. It has damaging impacts on both plants and animal communities. The CAS devotes a chapter to **protecting the environment**.

The CAS highlights the importance of **securing clean growth and driving innovation**. Cleaning our air is about increasing productivity through improved air quality, effective use of resources and moving to a low carbon economy. Improving air quality is linked to tackling climate change, as the sources of 'greenhouse gases' implicated in climate change are in many cases also sources of air pollutants. The pathway to achieving the UK's NECR commitments in 2020 and 2030 needs to align with wider government policies such as Net Zero, ensuring co-benefits are maximised and unintended consequences avoided.

Air pollutants are released in large quantities from sources as diverse as domestic energy generation, industrial energy generation, industrial processes, road, air and rail transport, construction machinery, agriculture, and domestic cleaning and personal care products. The CAS contains subsequent chapters devoted to:

- Action to reduce emissions from **transport** (covering action already taken and action proposed for the future).

- Action to reduce emissions from **the home** (including domestic burning, and the use of products which release NMVOCs).

- Action to reduce emissions from **farming**: this focusses on reduction of emissions of ammonia (which reacts with nitrogen oxides and sulphur dioxide to form secondary particulate matter) and NMVOCs (which contribute to the formation of ozone).

- Action to reduce emissions from **industry** – setting out how we can build upon the existing strong framework and support continuous improvement.

The Strategy also addresses the issue of **leadership at all levels**: international (acknowledging that air pollution is not stopped at national borders, and UK emissions can have an impact across our country, the continent and worldwide); national (including improving the legislative framework); and local (enabling local authorities to take more effective, co-ordinated actions to achieve their air quality objectives). Focusing on the importance of co-operating with all parts of the UK, the document outlines the actions which are already underway throughout Northern Ireland, Scotland and Wales. These actions show how we can address the different sources of air pollution.

Finally, the Strategy summarises **progress -** there are several high-profile agreements to which the UK has signed up to, to improve air quality. Currently, the UK is compliant with ambient air quality limit values set by the Air Quality Standards Regulations 2010 for most pollutants. The annual mean limit value for nitrogen dioxide concentrations is the only statutory air quality limit that the UK is currently failing to meet. The 2017 UK plan for tackling roadside nitrogen dioxide (NO_2) concentrations (Defra, 2017) and 2018 supplement, sets out action to achieve compliance as swiftly as possible. It has been shown through analysis that the CAS can help meet the ambitious targets to reduce emissions.

In 2015, the Scottish Government published its air quality strategy '*Cleaner Air for Scotland – The Road to a Healthier Future*' or CAFS. (Scottish Government , 2015)**.** CAFS brings together into a single framework a number of Government policies impacting on air quality and sets out a series of 40 actions intended to deliver further air improvements. At the end of 2018, an independent review of CAFS was launched, with a remit to review progress to date and identify priorities for additional action. The review report was published in August 2019 and was used as the basis for developing a revised and updated strategy (Scottish Goverment, 2019)**.** The Scottish Government's new air quality strategy *'Cleaner Air for Scotland 2 – Towards a Better Place for Everyone'* (CAFS2) was published in July 2021 (Scottish Government, 2021) .

CAFS2 is structured around 10 general themes and sets out the air quality policy framework in Scotland to 2026. CAFS was largely concerned with transport emissions and, whilst this continues to be a key part of CAFS2, there is a stronger additional focus on other emissions sources, notably agriculture and domestic fuel combustion, along with a detailed consideration of the human health and wellbeing impacts of poor air quality. Co-ordination with other key Scottish Government plans and policies, such as the National

Transport Strategy 2, National Planning Framework 4, the Scottish Nitrogen Balance Sheet, the Climate Change Plan update and the Environment Strategy is a central thread running through CAFS2. The importance of public engagement and behaviour change is also a major theme.

In August 2020, the Welsh Government published its '*Clean Air Plan for Wales: Healthy Air, Healthy Wales*' (Welsh Government, 2020). This Plan sets out a 10-year pathway to achieving cleaner air in Wales. The Plan has been structured around four core themes:

- People: Protecting the health and well-being of current and future generations;
- Environment: Taking action to support our natural environment, ecosystems and biodiversity;
- Prosperity: Working with industry to reduce emissions, supporting a cleaner and more prosperous Wales; and
- Place: Creating sustainable places through better planning, infrastructure and transport.

The themes were designed through the lens of the Well-being of Future Generations (Wales) Act 2015 to enable collaborative and integrated approaches to improving air quality, across a range of policy areas and sectors. Information on this Act can be found online at https://www.futuregenerations.wales/about-us/future-generations-act/ .

In Northern Ireland DAERA is developing the first Clean Air Strategy for that administration. 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 are currently being reviewed. Preliminary findings will be discussed with the Minister and agreed proposals will then be more fully developed. Draft proposals will be included in a draft Clean Air Strategy for Northern Ireland which will be subject to consideration by the Northern Ireland Executive and a further public consultation to seek views on the proposals will be undertaken.

2.4.3 National Air Quality Statistics and Indicators

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

- **Annual average concentrations of particles and ozone**. These two types of air pollution are believed to have a significant impact on public health.
- **Number of days in the year when air pollution is 'Moderate' or higher**. This may relate to any one of five key air pollutants and is based on the UK's Daily Air Quality Index (see Section 2.4.5 which deals with forecasting). From the 1st January 2012, $PM_{2.5}$ particles replaced carbon monoxide in this suite of pollutants. The

thresholds used to define ‘Moderate’ and higher pollution levels in the air quality index were also revised at the beginning of 2012.

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

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

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

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

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

The National Air Quality Statistics summary for 2020 was released on 29th April 2021 and is available from the Defra website at https://www.gov.uk/government/statistics/air-quality-statistics .

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

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

This indicator is intended to enable Directors of Public Health to appropriately prioritise action on air quality in their local area. The indicator is calculated for each local authority in England based on modelled concentrations of fine particulate air pollution ($PM_{2.5}$). Estimates of the percentage of mortality attributable to long term exposure to particulate air pollution in local authority areas are available from the Public Health Outcomes Framework data tool at https://fingertips.phe.org.uk/profile/public-health-outcomes-framework. Current estimates at the time of writing, which are based on year 2019, range from 2.2% in the Isles of Scilly to 7% in some areas of London.

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. A toolkit aimed at helping public health professionals appropriately prioritise assessment and action on $PM_{2.5}$ on a local level is available here: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=18580 .

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 new national indicator under the Well-being of Future Generations (Wales) Act 2015 and the Welsh Public Health Outcomes Framework, which has now been published on StatsWales at https://statswales.gov.wales/Catalogue/Environment-and-Countryside/Air-Quality.

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

2.4.4 National Emissions Statistics

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

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

The most recent National Statistics Release covers 1970 to 2019 (the most recent year for which emission statistics are available). The main conclusions are as follows:

- *'Emissions of sulphur dioxide have fallen by 97 per cent since 1970, to 163 thousand tonnes in 2019. Emissions decreased by 8.4 per cent from 2018 to 2019, dropping to the lowest level in the time series. This was driven by a decline in coal use in power stations, continuing a long-term decrease in emissions from this source. Stricter limits being placed on the sulphur content of liquid fuels has also reduced emissions in the long-term.' (From Section 2 of 'Sulphur Dioxide' at https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-sulphur-dioxide-so2.)*

- *‘Emissions of nitrogen oxides have fallen by 71 per cent since 1970, to 839 thousand tonnes in 2019. There was a decrease of 3.1 per cent between 2018 and 2019. This is a smaller annual decrease than the long-term trend, since emissions have fallen by an average of 4.2 per cent per year between 1990 and 2019. This trend was driven by a decline in coal use in power stations and modernisation of the road transport fleet.’ (From Section 2 of ‘Nitrogen Oxides’ at https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-nitrogen-oxides-nox .)*

- *‘Emissions of non-methane volatile organic compounds (NMVOCs) have fallen by 66 per cent since 1970, to 812 thousand tonnes in 2019. There was a decrease in emissions of 0.97 per cent between 2018 and 2019. Emissions from many sources (including domestic solvent use) have been stable for several years, but there has been a recent increase in operator-reported emissions related to venting and flaring at oil and gas installations.’ (From Section 2 of ‘Non-methane volatile organic compounds (NMVOCs)’ at https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-non-methane-volatile-organic-compounds-nmvocs .)*

- *‘Emissions of ammonia have fallen by 12 per cent since 1980, to 272 thousand tonnes in 2019. There was a decrease of 0.72 per cent in emissions of ammonia between 2018 and 2019. Annual emissions of ammonia have remained relatively stable since 2017 following a short period of increasing emissions (2013 to 2017). Over the longer-term there was a gradual decrease in annual emissions of ammonia during the 1990s and 2000s. Changes in the trend of emissions of ammonia are largely driven by changes to farming practices, such as fertiliser application, and herd sizes.’ (From Section 2 of ‘Ammonia’ at https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-ammonia-nh3 .)*

- *‘Annual emissions of PM_{10} have fallen by 75 per cent since 1970, to 170 thousand tonnes in 2019. There was a decrease of 3.2 per cent between 2018 and 2019. Annual emissions of $PM_{2.5}$ have fallen by 80 per cent since 1970, to 109 thousand tonnes in 2019. There was a decrease of 2.7 per cent between 2018 and 2019. Levels of both pollutants generally decreased year-on-year between 1970 and the late-2000s. There are many reasons for this long-term decrease covering most emissions sectors, but the reduction in the burning of coal and improved emission standards for transport and industrial processes are major causes. Since the late 2000s, annual emissions have fluctuated year-on-year because significant decreases in emissions from some sectors are largely offset to increases in emissions from wood burning in a domestic setting and by solid fuel burning by industry (particularly use of biomass).’ (From Section 2 of ‘Particulate Matter (PM_{10} and $PM_{2.5}$) at https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-particulate-matter-pm10-and-pm25 .)*

The report also states that the UK met current emissions ceilings for sulphur dioxide, oxides of nitrogen, NMVOC and ammonia in 2019.

New emission statistics for 2020 will be published in February 2022.

2.4.5 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).

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, 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 provide automated updates on current and forecast air quality via Twitter @DefraUKAIR.

2.4.6 NO_2 Air Quality Plans

In July 2017, the UK Government published the *UK Plan for Tackling Roadside Nitrogen Dioxide Concentrations*, followed by a supplement in October 2018. The Plan and supplement set out how Government will achieve compliance with legal limits for NO_2 in the shortest possible time, supported by a £3.8 billion investment into air quality and cleaner transport. The investment set out in the 2017 plan included £495m specifically dedicated to supporting local authorities in England to take action to tackle NO_2 exceedances - this dedicated funding has since risen to £880m. This funding supports a wide range of measures, including Clean Air Zones, two of which have been implemented in 2021 - in Bath and Birmingham – with further zones planned to be introduced in other areas soon. The funding also includes a Clean Air Fund, accessible by those local authorities implementing measures to tackle NO_2 exceedances, to help them mitigate the impact of the plans on individuals and businesses. For example, this could provide help with the costs of upgrading to a cleaner vehicle where a Clean Air Zone is to be put in place.

The UK air quality plan for nitrogen dioxide, together with the supplement published in October 2018, is available at https://www.gov.uk/government/publications/air-quality-plan-for-nitrogen-dioxide-no2-in-uk-2017 .

Scotland’s first Low Emission Zone was established in Glasgow in December 2018. Further LEZs will be introduced in Aberdeen, Dundee and Edinburgh. 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 assessment to determine whether an LEZ would be an appropriate intervention in their areas.

The Scottish Government also provides a total of £4.5 million per year to support local authority air quality work, spends over £1 billion per year on public transport and increased its active travel budget to £500 million over five years from 2020/21.

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

The Air Quality Standards Regulations 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 2020 inclusive, except for 2017, when the nickel target value was not exceeded.

These exceedances are reported in September of the following years as part of the UK’s annual compliance assessment. For details of 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 2018. 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 are available at: https://uk-air.defra.gov.uk/library/bap-nickel-measures . At the time of writing, the 2018 report is the most recent in the series.

2.5 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), 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 to not be achieved.

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

With regards to LAQM statutory reporting requirements, in 2018 authorities in Wales adopted reporting in the form of an Annual Progress Report in line with the streamlined LAQM regime (Welsh Government, 2017). In England and Scotland, reporting in the form of the adopted Annual Status / Progress Reports has continued (Defra, 2016 A) (Scottish Government, 2017), whilst London authorities continued working against the revised London specific LLAQM policy guidance (Mayor of London, 2019) through the preparation of Annual Status Reports. Authorities in Northern Ireland commenced Round 7 of the Review and Assessment process in 2018, with appraisal of local air quality via Updating and Screening Assessments in line with the Round based approach to LAQM.

When the Review and Assessment process identifies an exceedance of an Air Quality Strategy objective, the Local Authority must declare an 'Air Quality Management Area' (AQMA) and develop an Action Plan to tackle problems in the affected areas. Action Plans formally set out the measures the Local Authority proposes to take to work towards meeting the air quality objectives. They may include a variety of measures such as congestion charging, traffic management, planning and financial incentives. Advice for Local Authorities preparing an Action Plan is available from the Defra LAQM web pages at https://laqm.defra.gov.uk/action-planning/aqap-supporting-guidance.html.

Information on the UK's AQMAs is summarised in Table 2-1 below. At the time of writing (August 2021), 253 Local Authorities – 67.5% 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.

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

Table 2-1 Current UK-wide status of Air Quality Management Areas (AQMAs) and Action Plans (as of August 2021.)

Region	Total LAs	LAs with AQMAs	AQMAs for NO_2	AQMAs for PM_{10}	AQMAs for SO_2
England (outside London)	277	186	502	28	5
London	33	33	34	29	0
Scotland	32	14	26	23	1
Wales	22	11	43	1	0
Northern Ireland	11	9	17	2	0
TOTAL	**375**	**253**	**622**	**83**	**6**

Note: the total number of LAs in the UK has decreased since 2020 due to some mergers.

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.

Road transport is specified as the main source in 96.4% of the AQMAs declared for NO_2. A further 2.0% of NO_2 AQMAs result from road transport mixed with industrial sources, 0.9% from a combination of road transport, industry and domestic sources, and the remaining less than 0.5% from other or unspecified sources.

Road transport is also the main source in the majority (76%) of AQMAs declared for PM_{10}. Road transport together with industry accounts for a further 11%. The proportion of AQMAs attributed to non-road sources is greater for PM_{10} than NO_2.

Five of the six AQMAs declared for SO_2 relate to industrial sources: the other is from domestic and 'other' sources.

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, date 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. 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 on ambient air quality. It describes the air pollutants which are of concern and how these are monitored and modelled in the UK.

3.1 Pollutants of Concern

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

The information on sources has largely been summarised from the National Atmospheric Emission Inventory (NAEI) pollutant information pages at https://naei.beis.gov.uk/ (UK National Atmospheric Emissions Inventory, 2021) 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). COMEAP has estimated that long-term exposure to the air pollution mixture in the UK has an annual effect equivalent to 28,000 to 36,000 deaths (COMEAP, 2018).

3.1.1 Oxides of Nitrogen

There are several oxides of nitrogen. The ones of most interest for air quality are nitric oxide (NO) and nitrogen dioxide (NO_2). Together, they are often referred to as NO_X. Nitrogen oxides are emitted from combustion processes. Combustion in industry, passenger cars and other transport are the most important UK sources (National Atmospheric Emissions Inventory, 2021).

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). It has been difficult to identify the direct health effects of NO_2 at ambient concentrations, because it is emitted from the same sources as other pollutants such as particulate matter (PM). However, the WHO's REVIHAAP study (WHO, 2013), COMEAP's 2015 statement, (COMEAP, 2015) and COMEAP's 2018 report on associations of mortality with NO_2 have reported increasing evidence that NO_2 itself is responsible for health effects. NO is not considered harmful to human health 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 and objectives, except at some congested urban roadside sites. Annual mean limit values and objectives are frequently exceeded at roadside sites in the UK, and in many other countries, although the extent of these exceedances was substantially reduced in 2020 in comparison with previous years (see section 6 for details).

3.1.2 Ozone

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

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

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

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

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

PM_{10} can be ‘primary’ (emitted directly to the atmosphere) or ‘secondary’ (formed by the chemical reaction of other pollutants in the air such as SO_2 or NO_2). The main source of primary particulate emissions is combustion, e.g. vehicles, domestic burning and power stations. Other man-made sources include quarrying and mining, industrial processes 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 and has the same sources. Research shows a range of health effects, including respiratory and cardiovascular illness and mortality, associated with PM_{10}. 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 environmental effects of particulate pollution are associated with two components of PM: black carbon, which is implicated in climate change, and secondary PM includes sulphate, nitrate and ammonium, 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 is currently power generation. Other important sources include industry, commercial fuel use, and residential fuel use in some areas. It is a respiratory irritant that can cause constriction of the airways, and people with asthma are considered to be particularly sensitive. Health effects can occur very rapidly, making short-term exposure to peak concentrations important (WHO, 2005), (WHO, 2018), (COMEAP, 2011).

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). Road transport is still the most significant source of this pollutant (National Atmospheric Emissions Inventory, 2021).

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

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

3.1.6 Benzene (C_6H_6)

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

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

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

3.1.7 Lead (Pb)

Lead (Pb) is a very toxic metallic element. Historically, lead was used as an additive in petrol, and road vehicles were the main source. Leaded petrol was phased out in 1999, resulting in a 98% reduction of pre-1999 UK emissions. Today, the main sources are metal production and industrial combustion of lubricants containing small amounts of lead. (National Atmospheric Emissions Inventory, 2021) . However, recent research has found that airborne particulate matter in cities is still ‘enriched’ with lead, likely due to emissions from historic combustion of leaded petrol (Resongles, et al., 2021).

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

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

3.1.8 Nickel (Ni)

Nickel (Ni) is a toxic metallic element found in ambient air as a result of releases from oil and coal combustion, metal processes, manufacturing and other sources. Currently the main source is the combustion of heavy fuel oil, the use of coal having declined (National Atmospheric Emissions Inventory, 2021). A small number of UK zones continue to exceed applicable target values for annual mean Ni, as has been the case for many years.

Nickel compounds are human carcinogens by inhalation exposure. Ni can cause irritation to the nose and sinuses and allergic responses and can lead to the loss of the sense of smell. Long-term exposure may lead to respiratory diseases and cancers (WHO, 2018).

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

3.1.9 Arsenic (As)

Arsenic (As) is a toxic metalloid which occurs naturally in the environment. Arsenic is emitted into the atmosphere in the form of particulate matter. Historically the largest source was coal combustion, but as this has declined, the use of wood treated with preservatives containing As has become the most significant component of As emissions (EPAQS, 2009). The UK has been compliant with applicable target values for As for many years. Inhalation of air containing high levels of As can cause lung damage, shortness of breath, chest pain and cough (Public Health England, 2019 A). Arsenic compounds may be corrosive and can cause burns to the skin or eyes on contact. Long term inhalation exposure is associated with genotoxic and carcinogenic effects. Arsenic can also pollute soil and water, leading to exposure via these routes. Arsenic in water or soil can be taken up by plants or fish. Food is the largest source of arsenic exposure for most people in the general population.

3.1.10 Cadmium (Cd)

Cadmium (Cd) is a toxic metallic element. The main sources are energy production, non-ferrous metal production, iron and steel manufacture as well as other forms of industrial combustion (National Atmospheric Emissions Inventory, 2021). 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 (WHO, 2018) or cause a build-up of Cd in the kidneys that can lead to kidney disease. 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, 2021).

Acute exposure to high levels of Hg can cause chest pain and shortness of breath and affect the CNS and kidneys. Chronic exposure leads to CNS disorders, kidney damage and stomach problems.

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

3.1.12 Polycyclic Aromatic Hydrocarbons (PAH)

Polycyclic aromatic hydrocarbons (PAHs) are a large group of chemical compounds which usually occur as complex mixtures rather than as individual compounds. One particular PAH, **Benzo[a]pyrene (B[a]P)** is used as a 'marker' for this group of compounds. The main sources of B[a]P in the UK are residential, commercial and industrial fuel combustion. (National Atmospheric Emissions Inventory, 2021). A small number of UK zones continue to exceed applicable target values for B[a]P, as has been the case for many years.

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

3.2 Assessment of Air Quality in the UK

The evidence base for the annual assessment of compliance is based on a combination of measurements from the UK national monitoring networks 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.

UK compliance assessment modelling is undertaken using national models known as the Pollution Climate Mapping (PCM) models. The PCM models have been designed to assess compliance with limit values, target values and long-term objectives at locations defined within the Air Quality Standards Regulations. 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) become available and the reporting deadline 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[1]. By contrast, Local Air Quality Management (LAQM) modelling is different in scope, purpose and methodology from the national modelling and will usually output contour plots showing dispersion away from the source, on a fine resolution grid. The level of detail and resolution of LAQM modelling is therefore much greater in order to focus on local exposure and hotspots and does not necessarily meet the requirements for air quality assessment under the Air Quality Standards Regulations. See **Section 3.5** for more details on the modelling carried out for compliance assessment.

3.2.1 Current UK Air Quality Monitoring

During 2020 there were 424 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. 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 424 because some sites belong to more than one network). This table shows the number of sites in operation during part or all of 2020.

Table 3-1 The UK's Air Quality Monitoring Networks in 2020

Network	Pollutants	Number of Sites operating in 2020
Automatic Urban and Rural Network (AURN)	CO, NO_x, NO_2, SO_2, O_3, PM_{10}, $PM_{2.5}$.	**172**
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	**23**

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

Network	Pollutants	Number of Sites operating in 2020
	Total gaseous mercury	
Non-Automatic Hydrocarbon	Benzene	**35**
Automatic Hydrocarbon	Range of volatile organic compounds (VOCs)	**5**
Polycyclic Aromatic Hydrocarbons (PAH).	23 PAH species including benzo[a]pyrene	**32**
European Monitoring and Evaluation Programme (EMEP)	Wide range of parameters relating to air quality, precipitation, meteorology and composition of aerosol in PM_{10} and $PM_{2.5}$.	**2**
Particle Numbers and Concentrations Network	Total particle number, concentration, size distribution, anions, EC/OC, speciation of PM_{10} and $PM_{2.5}$.	**4**
Toxic Organic Micropollutants	Range of toxic organics including dioxins and dibenzofurans.	**6**
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	**27**
UK Eutrophying and Acidifying Pollutants: NAMN	NH_3 and/or NH_4	**72**
UK Eutrophying and Acidifying Pollutants: PrecipNet	Major ions in rain water	**41**
Black Carbon	Black Carbon	**14**
Upland Waters Monitoring Network	Chemical and biological species in water	**10**

Network	Pollutants	Number of Sites operating in 2020
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.	**177**

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

Table 3-2 AURN Measurement Techniques

Pollutant	Method used, including details of CEN Standard Methods
O_3	EN 14625:2012 'Ambient air quality – standard method for the measurement of the concentration of ozone by ultraviolet photometry' (CEN, 2005)
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 , 2005)
SO_2	EN 14212:2012 'Ambient air quality – Standard method for the measurement of the concentration of sulphur dioxide by UV fluorescence' (CEN, 2005)
CO	EN 14626:2012 'Ambient air quality - Standard method for the measurement of the concentration of carbon monoxide by non-dispersive infrared spectroscopy' (CEN , 2005)
PM_{10} and $PM_{2.5}$	EN 12341:2014 '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, 2014) The AURN uses four methods which are equivalent for one or both metrics: the Fidas 200, an optical technique; the Beta-Attenuation Monitor (BAM) which measures the attenuation of beta rays passing through a paper filter tape on which particulate matter from sampled air has been collected; the Filter Dynamic Measurement System (FDMS), which determines particulate concentration by continuously weighing particles deposited on a filter, and the Partisol – a gravimetric sampler that collects daily samples onto a filter for subsequent weighing.

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, 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, 2005). Metals (As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, V and Zn) in PM_{10} are measured at 23 sites. The network stopped measuring mercury in PM_{10} in 2014.

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

The network stopped measuring total gaseous mercury in August 2018.

3.2.1.3 Non-Automatic Hydrocarbon Network

In this network, ambient concentrations of benzene are measured by the CEN standard method (CEN, 2005). 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 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 also require measurement and reporting of ozone precursor substances (29 species), which include volatile organic compounds (VOCs). The Air Quality Standards Regulations 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 as a pollutant in its own right.

3.2.1.5 PAH Network

The PAH Network monitors compliance with the Air Quality Standards Regulations, 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.

3.2.1.6 EMEP

EMEP (European Monitoring and Evaluation Programme) 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 Lothian (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 analyses 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 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 2020, the network consisted of four measurement sites; two rural sites (Auchencorth Moss and Chilbolton Observatory), and two in London (London Marylebone Road and London Honor Oak Park; the latter site replaced North Kensington in November 2018).

Among the parameters measured are:

- Total particle numbers per cubic centimetre of ambient air,
- Particle numbers in different particle size fractions,
- Major ions in $PM_{2.5}$
- 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 2019.

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 also 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.

3.2.1.8 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 six sites: Auchencorth Moss, Hazelrigg, High Muffles, 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 http://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 2020, the Acid Gas and Aerosol Network (AGANet) comprised a total of 27 sites. The network measures a range of gases and aerosol components. Samples are collected monthly and are analysed by either inductive coupled plasma optical emission spectrometry (ICP-OES) or ion chromatography.

- The National Ammonia Monitoring Network (NAMN) which characterizes ammonia and ammonium concentrations using both passive samplers (Alpha Samplers) and low volume denuders (Delta Samplers) at 72 locations.

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

3.2.1.10 Black Carbon Network

Black carbon is fine, dark carbonaceous particulate matter produced from the incomplete combustion of materials containing carbon (such as coal, oil, and biomass such as wood). It is of concern due to health effects, and also as a suspected contributor to climate change. In 2020, 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 Network) 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 original selection of eleven lakes and eleven streams was based on covering a wide deposition gradient, required minimal point source pollution and minimal catchment disturbance beyond those caused by traditional upland land use practices such as sheep grazing or forestry, and included forest-moorland pairs of sites. More recently additional stream sites have been added to broaden the acid-sensitivity gradient, while thermistor loggers have been 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. A range of other biological parameters, including algae and higher aquatic plants, invertebrates and fish, in addition to lake sediment biology and chemistry, were also measured routinely up until 2016. While biological sampling continued beyond this point, most new biological samples were archived but not analysed.

In April 2019, the Centre for Ecology & Hydrology (now UKCEH) took over management of the UWMN from ENSIS Ltd. Recently, most of the archived invertebrate and diatom samples have been analysed, and Defra are supporting collection and analysis of biological samples in 2021-22. In addition to this contribution, the UK UWMN is funded by the UK Centre for Ecology & Hydrology (UKCEH), Scottish Natural Heritage, the Welsh Government, Natural Resources Wales and Forest Research. It also receives considerable in-kind support for sampling and survey activity from UCL, Queen Mary University of London, SEPA, the Department of Agriculture, Environment and Rural Affairs in Northern Ireland, and several private volunteers.

3.2.1.12 Rural Mercury Monitoring

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

3.2.1.13 UK Urban NO_2 Network

The UK Urban NO_2 Network (UUNN) was established in December 2019 with monitoring beginning in January 2020. The objective of the network is to provide additional local roadside NO_2 measurements to enhance the UK's national compliance assessment. Monitoring of NO_2 is undertaken on the UUNN using Palmes-type diffusion tubes with wind protection membranes. During 2020 monitoring was undertaken at 177 locations across England and Wales: the network expanded further at the start of 2021 and now comprises just over 300 sites across Great Britain.

3.2.1.14 Air Pollution Impacts on Ecosystem Networks (APIENs)

The following information about UK APIENs is summarised from the APIS website at http://www.apis.ac.uk/APIENsWebinarSeries. 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. Integrated data from APIENs will provide the evidence to determine the state of UK ecosystems, and provide 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.

- Consistent with Data Quality Objectives. The uncertainty requirements of the Air Quality Standards Regulations are specified as data quality objectives. In the UK, all air quality data meet the data quality requirements of the Air Quality Standards Regulations in relation to uncertainty.

- Consistent with methodology guidance defined in the Air Quality Standards Regulations 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.

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:

- Coverage of the whole UK rather than specific locations where there is a monitoring site. 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.
- Providing information about the sources of pollutants to inform policy development.
- A reduction in the number of fixed continuous monitoring locations required for compliance with the UK Air Quality Standards Regulations – freeing up resources and ensuring value for money.
- Providing a framework within which to assess different air quality scenarios – for example projecting concentrations forward to assess levels in future years, in order to develop policies 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 (Brookes, D. M. et al., 2021) (the latest versions of these can be found in the Library section of Defra's UK-AIR website (Defra, 2021)).

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 – 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 (UK Government , 2010) as relevant for air quality assessment.

3.3.3 Background Air Quality

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

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

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

3.3.4 Roadside Air Quality

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

For each of the road links that are modelled, there are emission estimates for each pollutant from the National Atmospheric Emissions Inventory (NAEI, (UK National Atmospheric Emissions Inventory, 2021)) 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, 2021) 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 now includes a new Compliance Dashboard which displays all underlying data used in the compliance assessment. The Compliance Dashboard can be found at https://uk-air.defra.gov.uk/compliance-data.

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 2020

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 2020

4.2 Air Quality Assessment for 2020

The air quality assessment for each pollutant is derived from a combination of measured pollutant concentrations and supplementary assessment (that is, modelling, supplementary NO_2 diffusion tube measurements or objective assessment). Where both measurements and supplementary assessment results are available, the assessment of compliance for each zone is based on the higher concentration of the two.

The air quality compliance assessment for each calendar year must be published by Defra by 30th September the following calendar year. The results of the air quality assessment for 2020 are summarised in the tables below. The tables have been completed as follows:

- Where all measurements were within the relevant limit values in 2020, the table shows this as 'OK'.
- In the above cases, where compliance was determined by supplementary assessment, this is indicated by '(s)', i.e. 'OK (s)'.
- 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)', 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 2020, 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 2020.

The 2020 compliance assessment for CO has been based on objective estimation, as explained in Defra's technical report on UK air quality assessment (Brookes, D. M. et al., 2020). This is underpinned by NAEI emission trends, AURN measurement trends and historical modelling assessments.

Nitrogen dioxide (NO_2): in 2020 not all zones and agglomerations were compliant with 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 2020, 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, 2020 is the first year in which all zones have been compliant.

Thirty-eight zones met the annual mean limit value for NO_2 (40 µg m^{-3}) in 2020. The five zones that exceeded this limit value were:

- Greater London Urban Area
- West Midlands Urban Area
- Greater Manchester Urban Area
- Bristol Urban Area
- South Wales.

2020 saw a large reduction in the number of zones exceeding the annual mean limit value. For comparison, 33 zones exceeded in 2019. This large increase in the number of compliant zones is attributed to the reduced road traffic flows brought about by the Covid-19 pandemic lockdown restrictions.

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 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. Defra are working to develop and improve the national NO_2 compliance assessment to better reflect local level NO_2 concentrations. This includes establishing the UUNN to provide more local NO_2 measurement data.

Table 4-2 Results of Air Quality Assessment for Nitrogen Dioxide in 2020

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

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

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, 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 2020 there were no modelled exceedances of either the 24-hr or annual mean limit values, so no subtraction of contribution from natural sources has been carried out.

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

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

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

The AEI for the reference year (2010) was used to determine the National Exposure Reduction Target (NERT), to be achieved by 2020. The UK's reference year AEI was 13 µg m^{-3}; on this basis, the Air Quality Standards Regulations set an exposure reduction target of 15%. This equates to reducing the AEI to 11 µg m^{-3} by 2020. (The detailed methodology and results of this calculation are presented in Defra's technical report on UK air quality assessment (Brookes, D. M. et al., 2020).)

Table 4-3 Results of Air Quality Assessment for PM_{10} in 2020

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)	OK (s)
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)	OK (s)
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)	OK (s)
South Wales	UK0041	OK	OK
North Wales	UK0042	OK	OK
Northern Ireland	UK0043	OK	OK

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

Table 4-4 Results of Air Quality Assessment for $PM_{2.5}$ in 2020

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

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

The AEI for the reference year 2015 was set at 20 µg m^{-3} as an Exposure Concentration Obligation (ECO) in the Air Quality Standards Regulations. The UK met this obligation. There were no obligations or target values for the years *between* 2010, 2015 and 2020, but the running AEIs for these intervening years were used to give an indication of progress towards the 2020 target. The running AEI for 2020 was calculated as follows:

- 2018: 10 µg m^{-3}
- 2019: 10 µg m^{-3}
- 2020: 8 µg m^{-3}

The mean of these three values (to the nearest integer) is 9 µg m^{-3}. The AEI for 2020 itself is 8 µg m^{-3}. Thus, the UK has achieved the National Exposure Reduction Target (NERT), of reducing the AEI to below the 2020 exposure reduction target of 11 µg m^{-3} by 2020.

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

For ozone (O_3), there is a target value based on the maximum daily 8-hour mean. All 43 zones and agglomerations were compliant with this target value. There is also a long-term objective for protection of human health, based on the maximum daily 8-hour mean. Only three of the 43 zones and agglomerations were compliant with the long-term objective (LTO) for health in 2020.

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) and 80 µg m^{-3} over a given period using only the hourly mean values measured between 08:00 and 20:00 Central European Time each day. All 43 zones and agglomerations met the target value based on the AOT40 statistic. There is also a long-term objective, for protection of vegetation, based on this statistic; 16 zones and agglomerations exceeded this long-term objective for vegetation in 2020.

The UK met all target values for O_3 in 2020 as it has done for many years, but the number of zones exceeding the long-term objective for vegetation (16) was relatively high compared with most previous years.

Ozone concentrations – and hence the number of zones exceeding the LTOs - fluctuate from year to year as ozone is a transboundary pollutant and its formation is influenced by meteorological factors. However, as discussed in Section 6, the measurement data suggest O_3 concentrations in 2020 may have been affected by the Covid-19 restrictions. Ozone is removed from air by reaction with nitric oxide (NO), a component of vehicle emissions: the observed reductions in road traffic may have allowed ozone concentrations in some urban areas to become higher than they otherwise would have.

Table 4-5 Results of Air Quality Assessment for Ozone in 2020

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

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

In 2020 there were 98 measured exceedances of the ozone population information threshold of 180 µg m^{-3} (at 23 sites), but no exceedances of the population warning threshold of 240 µg m^{-3}. The population information threshold exceedances are detailed in **Table 4-6**. All occurred in the afternoons and evenings of the following dates: 9th May, 24th – 25th June, 31st July and 8th -12th August, typically between 14:00 – 21:00.

Table 4-6 Measured Exceedances of the Ozone Information Threshold Value in 2020

Site name	Zone code	Number of 1-hour exceedances of information threshold	Maximum 1-hour concentration (µg m^{-3})
St Osyth	UK0029	15	217
Wicken Fen	UK0029	11	193
Sibton	UK0029	10	216
Lullington Heath	UK0031	9	205
London N. Kensington	UK0001	8	217
Norwich Lakenfields	UK0029	6	202
Weybourne	UK0029	5	207
Canterbury	UK0031	4	214
Reading New Town	UK0016	4	201
Rochester Stoke	UK0031	4	198
Yarner Wood	UK0030	4	201
London Haringey Priory Park South	UK0001	3	211
Northampton Spring Park	UK0032	3	188
London Bloomsbury	UK0001	2	188
Thurrock	UK0029	2	203
Aston Hill	UK0042	1	187
Bournemouth	UK0015	1	182
Chilbolton Observatory	UK0031	1	183
Leamington Spa	UK0035	1	182
Leeds Centre	UK0004	1	181
London Eltham	UK0001	1	188
London Harlington	UK0001	1	187
London Hillingdon	UK0001	1	181

Table 4-6 shows the exceedances of the ozone information threshold in the verified dataset.

The air quality assessment 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 or benzo[a]pyrene.

Table 4-7 Results of Air Quality Assessment for As, Cd, Ni and B[a]P in 2020

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

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

Concentrations of Ni exceeded the target value in Sheffield Urban Area, Swansea Urban Area, Yorkshire and Humberside and South Wales. These exceedances are attributed to emissions from industrial sources. Concentrations of benzo[a]pyrene were above the target value in three zones; Yorkshire and Humberside, Swansea Urban Area and South Wales.

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 – came into force.)

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

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

For nitrogen dioxide, **Table 4-8** summarises the results of the air quality assessment in years from 2008 to 2020. 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 2020.There are notes in the right-hand column explaining the effects of the time extensions which were in place up to the end of 2011 for some zones.

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

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

Table 4-8 Non-Compliances with Limit Values for Nitrogen Dioxide, 2008-2020

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

Table 4-9 Non-Compliances with the Limit Values for PM_{10}, 2008-2020

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

Table 4-10 Exceedances of Target Values for Ozone (Health) and Long-Term Objectives, 2008-2020

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

Table 4-11 Zones Exceeding Target Values for As, Cd, Ni and B[a]P, 2008-2020

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

5 Spatial Variation and Changes Over Time

This section looks at the spatial distribution of pollutants across the UK, based upon the modelled maps of ambient pollutant concentration discussed in **Section 3.5** of this report, "Modelling". For some traffic-related pollutants such as NO_2, roadside and background concentrations are discussed separately.

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 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, in most cases, 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.

For pollutants monitored using continuous automatic techniques, trend analysis has been carried out using Openair: a free, open-source software package of tools for analysis of air pollution data. 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. A range of Openair functions are available on UK-AIR: 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. This uses the Theil-Sen statistical method to determine trends in pollutant concentrations over several years. 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 most pollutants, particularly those that show a seasonal pattern; SO_2, NO_2, particulate matter, CO and ozone - but not 1,3-butadiene. Where the 'de-seasonalise' option has been used, this is indicated in the graph title. The trend line is shown by a solid red line, with 95% confidence intervals for the trend shown by dotted red lines. The trend is given at the top of the graph in green, with confidence intervals shown in square brackets. The trend is given as units (e.g. $\mu g\ m^{-3}$) per year, over the period shown. This may be followed by a number of symbols, with + indicating that the trend is 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. 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.

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 http://naei.beis.gov.uk/. (The most recent year for which NAEI emission estimates are available is 2019). The NAEI dataset shows emissions split between various emission source categories (these source categories 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.

5.1 Nitrogen Dioxide

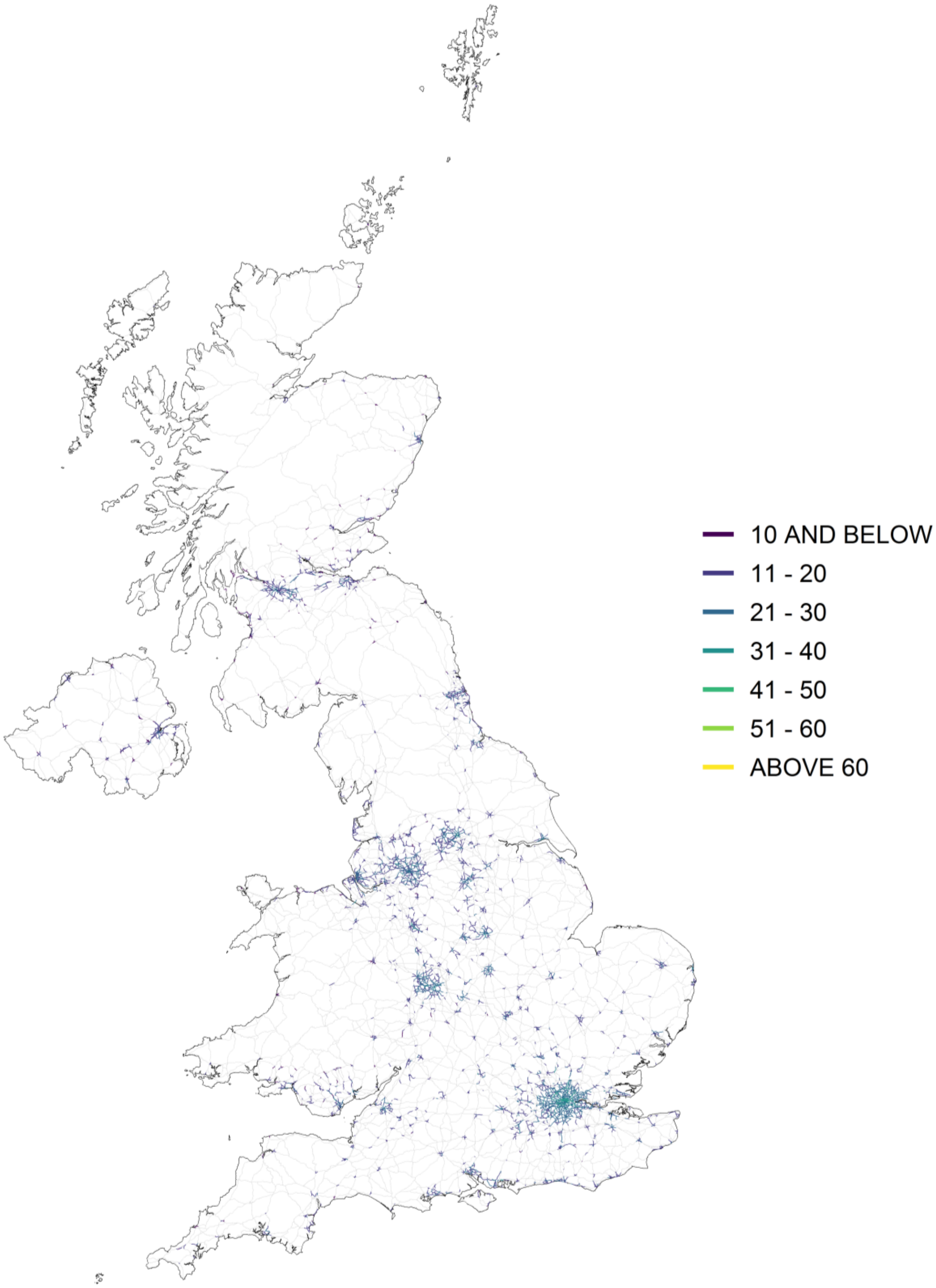
5.1.1 NO_2: Spatial Distribution in the UK

Figure 5-1 shows the modelled annual mean NO_2 concentrations for 2020, at *urban roadside* locations only. Although not every road link is clearly visible, some road links in urban areas are shaded in the lighter colours, indicating higher concentrations. Some road links in London have modelled annual mean concentrations above the annual mean limit value of 40 µg m^{-3}, but no road links are shaded yellow (which would indicate they had annual mean NO_2 concentrations in excess of 60 µg m^{-3}).

Figure 5-2 shows the modelled annual mean *background* NO_2 concentrations for 2020. Most background locations were within the limit value of 40 µg m^{-3}, with the exception of a small area within London, which is indicated by the lighter coloured shading (green and yellow).

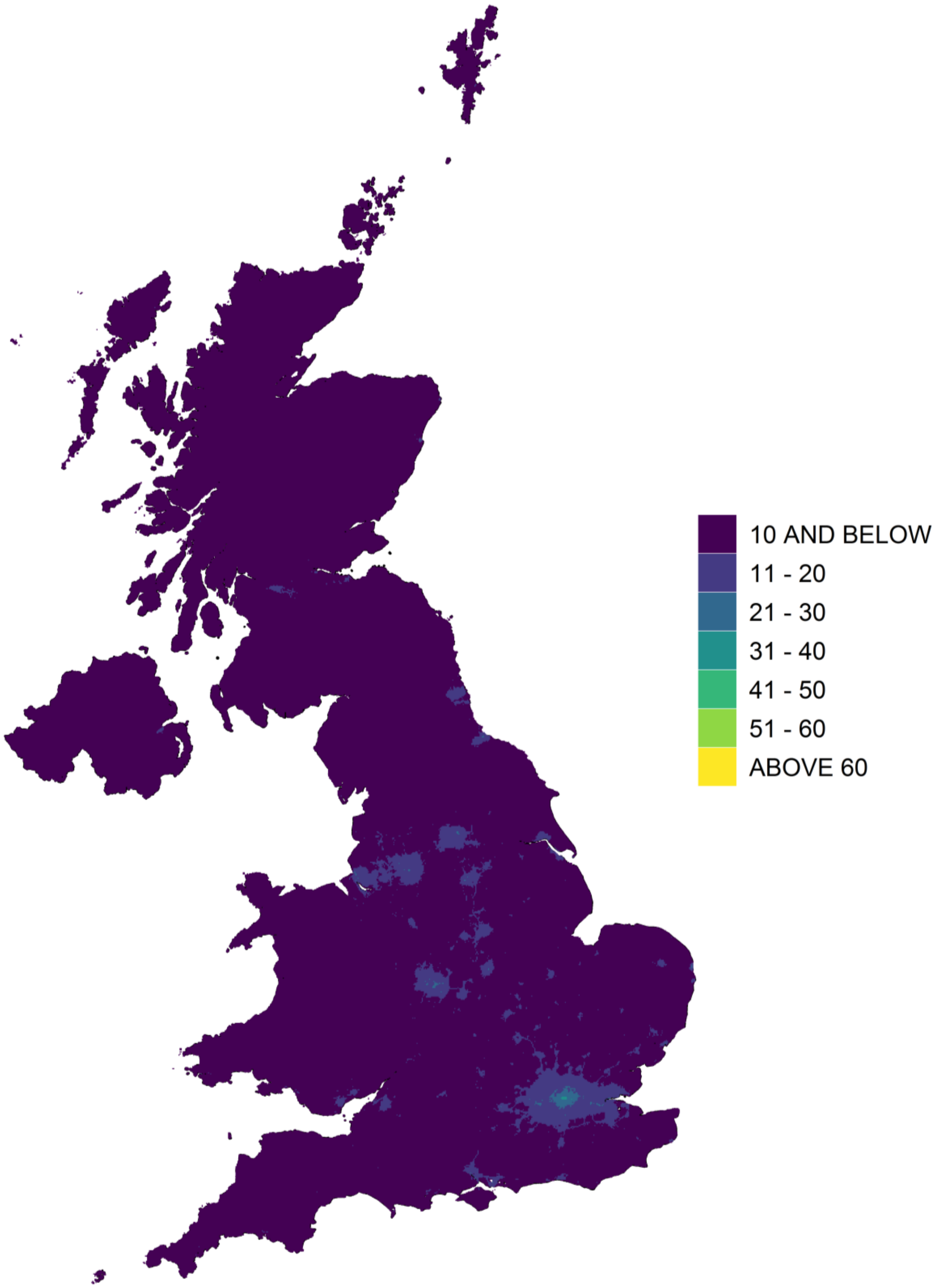
These maps for NO_2, and those for other pollutants in subsequent sections, are intended to provide an illustration of spatial variation in pollutant concentrations across the UK. To see detail for specific areas or individual road links, please use the UK Ambient Air Quality Interactive Map provided by UK-AIR at https://uk-air.defra.gov.uk/data/gis-mapping/. (Please note, the online interactive map uses a different colour scheme.)

Figure 5-1 Annual Mean Roadside NO_2 Concentration by Major Urban Roads, 2020 (µg m^{-3})



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

Figure 5-2 Annual Mean Background NO_2 Concentration, 2020 ($\mu g\ m^{-3}$)



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

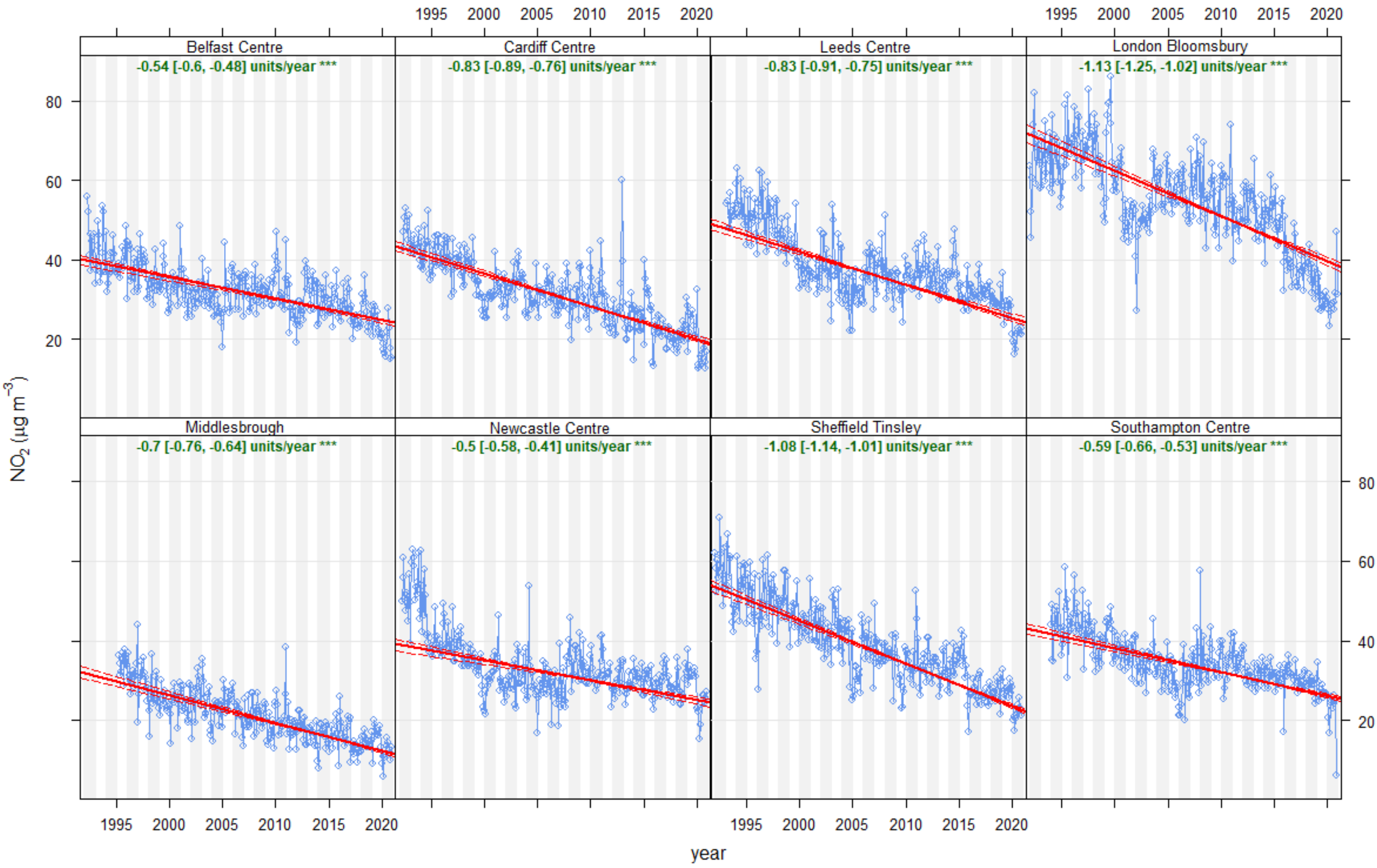
5.1.2 NO_2: Changes Over Time

Figure 5-3 and **Figure 5-4** 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 annual mean 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 5-3**); Belfast Centre, Cardiff Centre, Leeds Centre, London Bloomsbury, Middlesbrough, Newcastle Centre, Sheffield Tinsley and Southampton Centre. (These are all urban background, except Middlesbrough which is urban industrial).

- Eight urban traffic sites operating since 1999 or earlier (**Figure 5-4**); Camden Kerbside, Cambridge Roadside, Exeter Roadside, Glasgow Kerbside, Haringey Roadside, London Marylebone Road, Oxford Centre Roadside and Tower Hamlets Roadside. (Cambridge Roadside replaces the Bath Roadside site used in previous reports in this series, which closed in 2019.)

Figure 5-3 De-seasonalised Trends in NO_2 Concentration, at 8 Long-Running AURN Urban Non-Roadside* Sites, 1992-2020



**Urban Background, except for Middlesbrough which is urban industrial.*

All eight long-running urban non-roadside sites in **Figure 5-3** show a decreasing trend in NO_2. While the magnitude of the year-on-year decrease varies (ranging from -1.13 µg m^{-3}

to -0.5 µg m^{-3} per year), 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 5-4** 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 now sites show a downward trend statistically significant at the 0.001 level. This includes Camden Kerbside: although this site has shown a statistically significant downward trend in previous years, 2020 is the first year in which the trend has been significant at the 0.001 level as indicated by the three asterisks (***) on the plot. Several of the sites show a clear decrease in 2020, which is likely to be due at least in part to the Covid-19 restrictions.

Figure 5-4 De-seasonalised Trends in NO_2 Concentration at 8 Long-Running AURN Urban Traffic Sites, 1998-2020

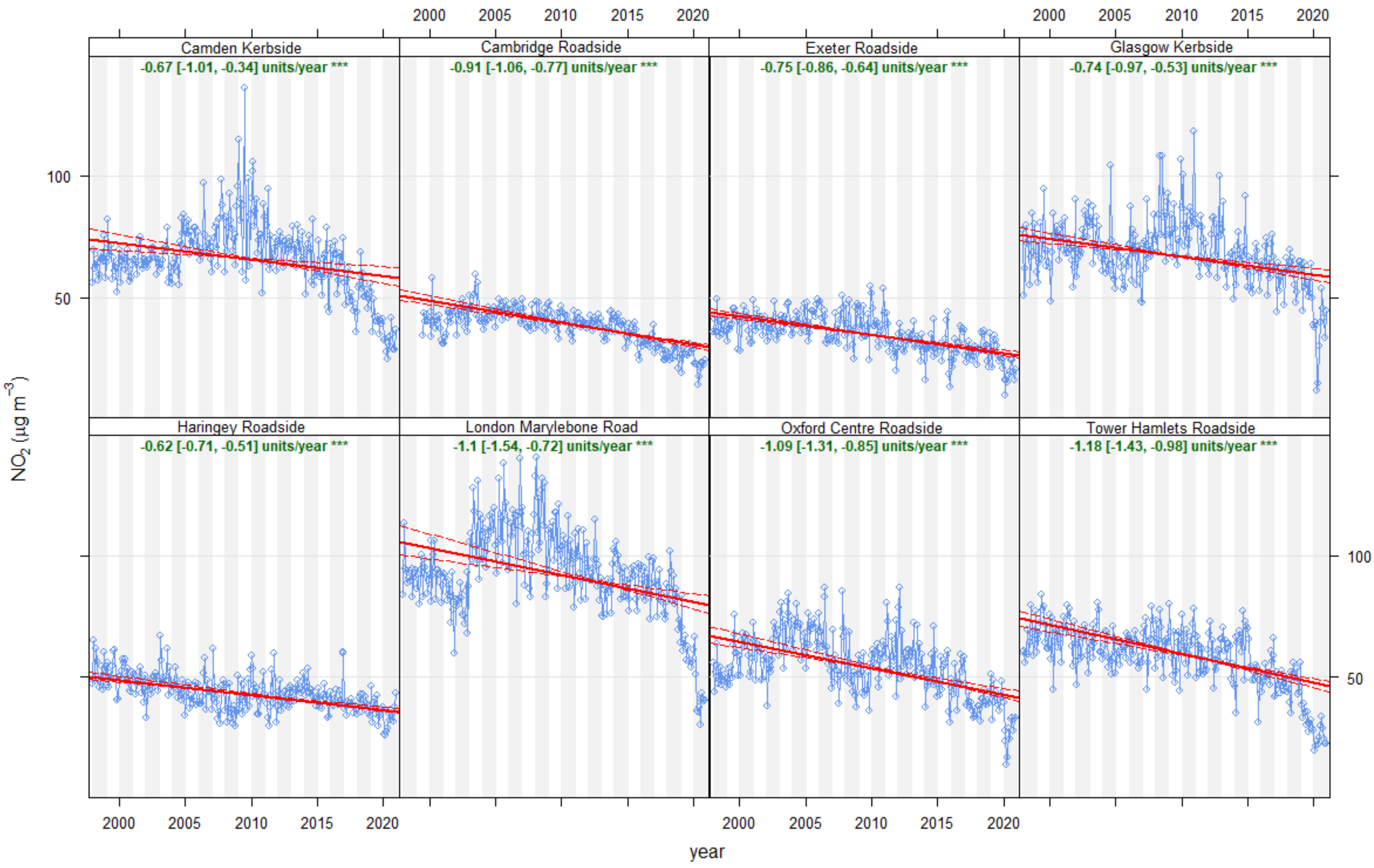
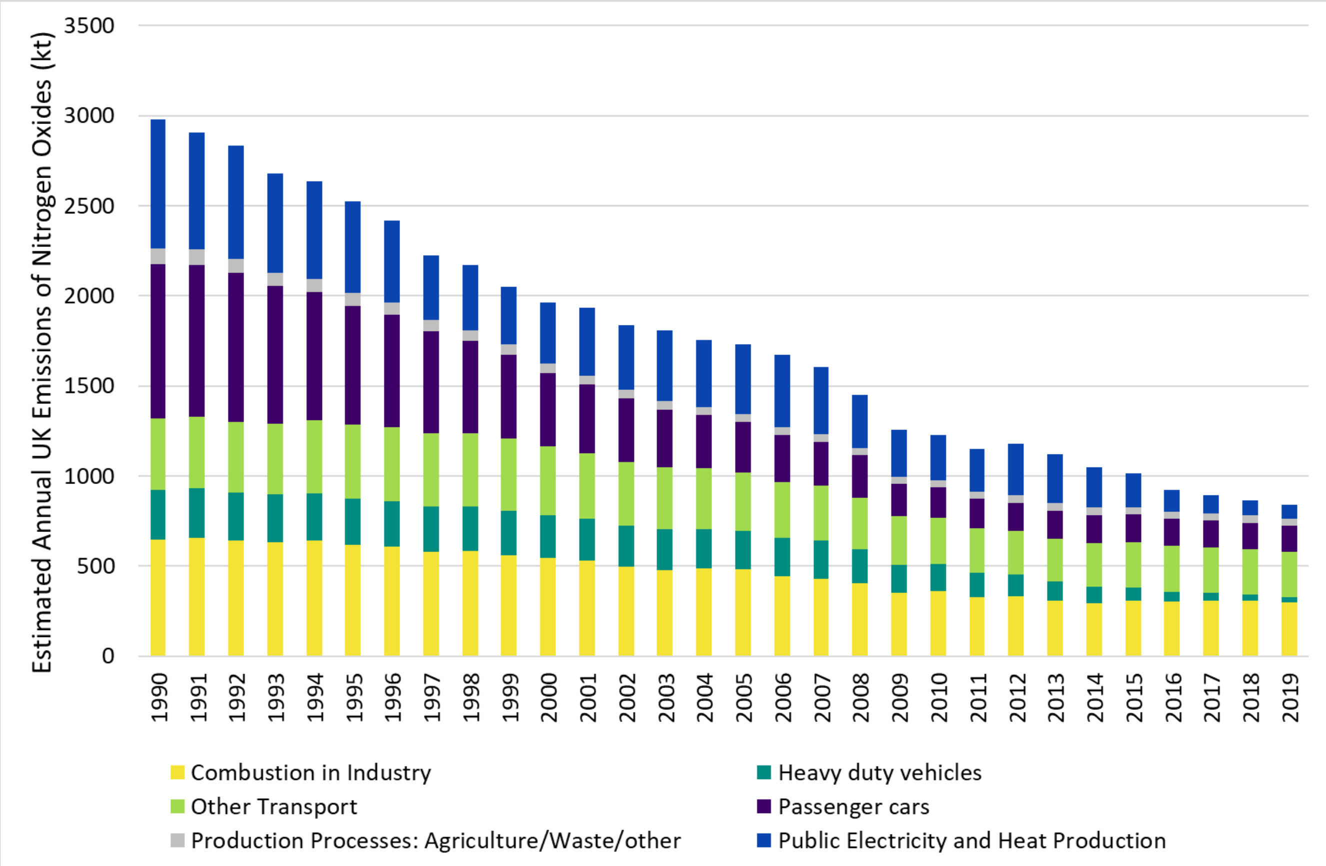


Figure 5-5 shows estimates of total UK annual emission of oxides of nitrogen, in kilotonnes, from 1990 to 2019 (the most recent year for which emission estimates are available). The data are from the National Atmospheric Emissions Inventory (NAEI) website at https://naei.beis.gov.uk/. This shows that total NO_X emissions have decreased substantially over this period and are now less than one third of the total emissions in 1990. Emissions from several specific sources, notably public energy and heat production, passenger cars and heavy-duty vehicles, have also shown substantial decreases over the same period.

Figure 5-5 Estimated Annual UK Emissions of Nitrogen Oxides (kt), 1990 – 2019 (Source: NAEI 2019)



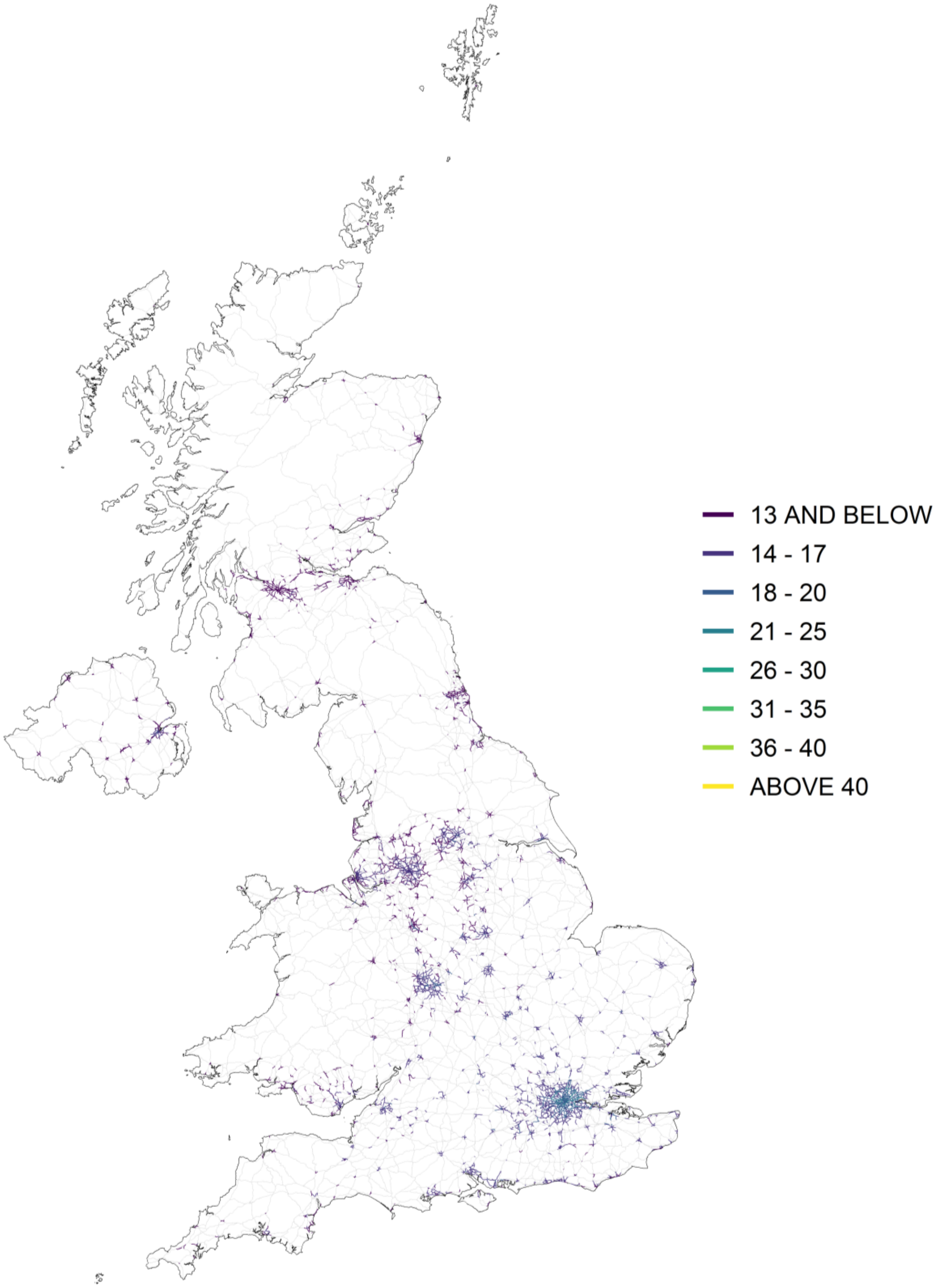
5.2 PM_{10} Particulate Matter

5.2.1 PM_{10}: Spatial Distribution

Figure 5-6 shows modelled annual mean urban roadside PM_{10} concentrations in 2020. No roadside locations had an annual mean concentration greater than the limit value of 40 µg m^{-3}. This is consistent with the compliance assessment reported in **Section 4**.

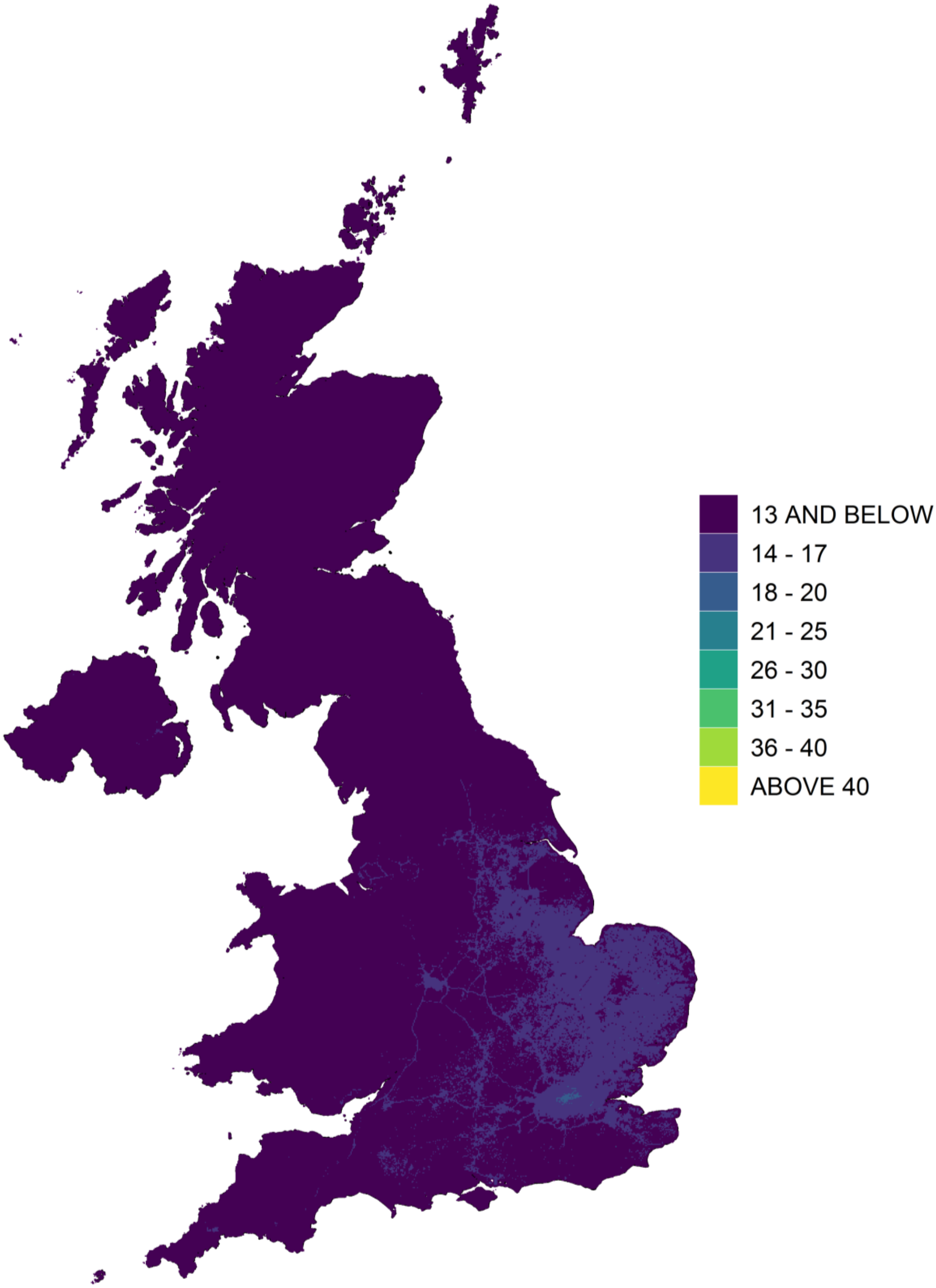
Figure 5-7 shows modelled annual mean background PM_{10} concentrations in 2020. Most parts of the UK had relatively low background concentrations (13 µg m^{-3} and below), shown by the darkest blue shading. Background concentrations were higher in the southern and eastern parts of the country; this is a typical pattern, because these regions receive a larger transboundary contribution of particulate pollution from mainland Europe. The elevated levels of PM_{10} associated with urban areas – particularly London, and some of the cities in the east of England - can also be seen. Also, the routes of some major roads are just visible in the Midlands.

Figure 5-6 Annual Mean Roadside PM_{10} Concentration by Urban Major Roads, 2020 ($\mu g\ m^{-3}$)



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

Figure 5-7 Annual Mean Background PM_{10} Concentration, 2020 ($\mu g\ m^{-3}$)



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

Where the annual mean PM_{10} concentration exceeds 31.5 µg m^{-3}, it is likely also that the 24-hour mean has exceeded the daily mean limit value of 50 µg m^{-3} on more than the permitted 35 occasions. **Figure 5-8** shows roads where the modelled annual mean roadside PM_{10} concentration is less than or equal to this threshold coloured dark blue, and roads where the annual mean exceeds this threshold coloured yellow. There are no yellow roads, indicating that there are unlikely to be any roadside locations where the 24-hour mean has exceeded the daily mean limit value of 50 µg m^{-3} on more than the permitted 35 occasions.

Similarly, **Figure 5-9** shows areas where the modelled annual mean background PM_{10} concentration is less than or equal to 31.5 µg m^{-3} in dark blue, and areas where the annual mean exceeds this threshold in yellow. There are no yellow shaded areas, which indicates that the 24-hour mean limit value of 50 µg m^{-3} is not exceeded on more than the permitted 35 occasions at any background locations. (Note: the value of 31.5 µg m^{-3} is specific to 2020: this threshold is calculated each year on the basis of the measured data. It may therefore change from year to year.)

Figure 5-8 Compliance with the 24-hour limit value for PM_{10} for major urban roads, 2020 (estimated to be compliant below an annual mean concentration of 31.5 µg m^{-3})

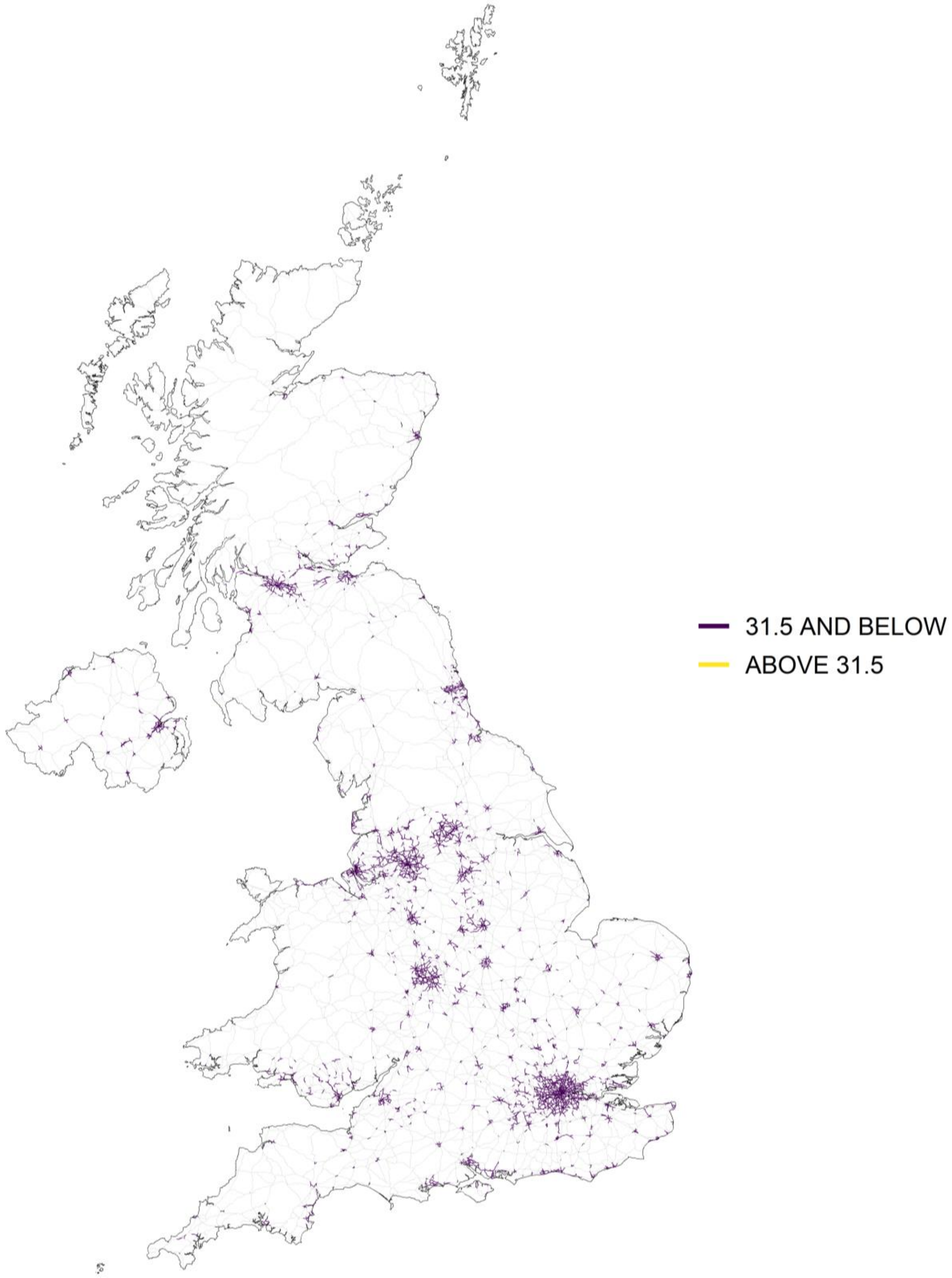
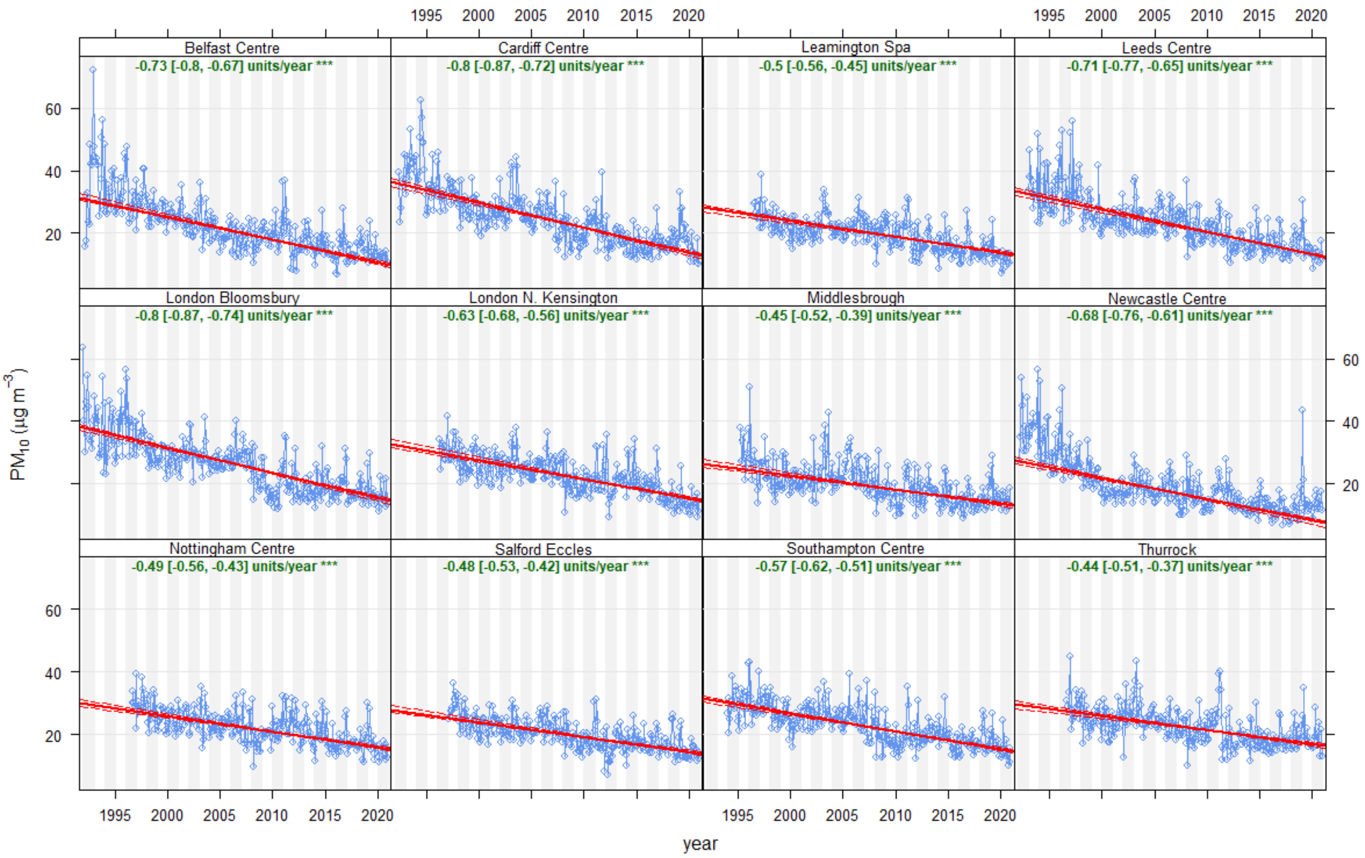


Figure 5-9 Compliance with the 24-hour limit value for PM_{10} at background locations, 2020 (estimated to be compliant below an annual mean concentration of 31.5 µg m^{-3})

5.2.2 PM10 Changes Over Time

Figure 5-10 shows de-seasonalised trends in ambient PM_{10} concentration, based on 12 urban non-roadside 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 is urban industrial, the others are urban background). All 12 sites show a downward trend for PM_{10} over their period of operation, highly statistically significant (at the 0.001 confidence level).

Figure 5-10 De-seasonalised Trends in Ambient PM_{10}, 12 Long-Running Urban Non-Roadside* AURN Sites 1992 – 2020



**Middlesbrough is urban industrial, the others are urban background.*

Figure 5-11 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 2009 or earlier. The sites are; Armagh Roadside, Camden Kerbside, Carlisle Roadside, Chepstow A48, Chesterfield Roadside, Leeds Headingley Kerbside, London Marylebone Road, Sandy Roadside, Stanford-le-Hope Roadside, Stockton-on-Tees Eaglescliffe, Swansea Roadside and York Fishergate. *(Note: Carlisle Roadside was excluded from the UK's compliance reporting from 2019 onwards, as it was within 25m of a major junction. The site has now been relocated. However, it is included here for consistency with previous years' reports.)*

Most of these sites show a statistically significant downward trend in PM_{10} concentration over this period (with varying degrees of significance). However, this is not the case for all sites: York Fishergate shows no significant trend and Swansea Roadside shows a statistically significant increase. As in the case of NO_2, it is possible that trends at urban traffic sites are influenced by changes in the volume and type of traffic on the adjacent road.

Figure 5-11 De-seasonalised Trends in Ambient PM_{10}, 12 Long-Running Urban Traffic AURN Sites 2009 – 2020

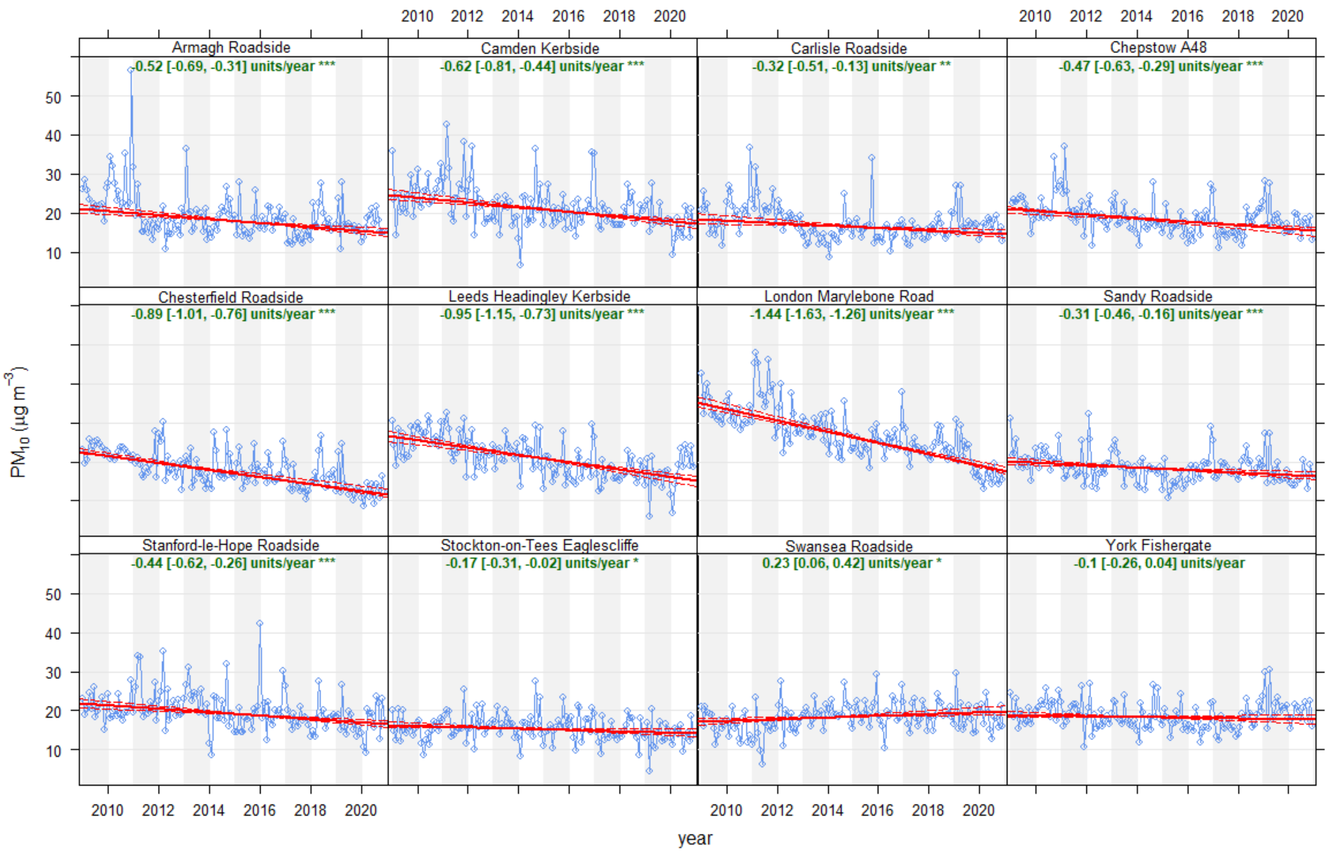
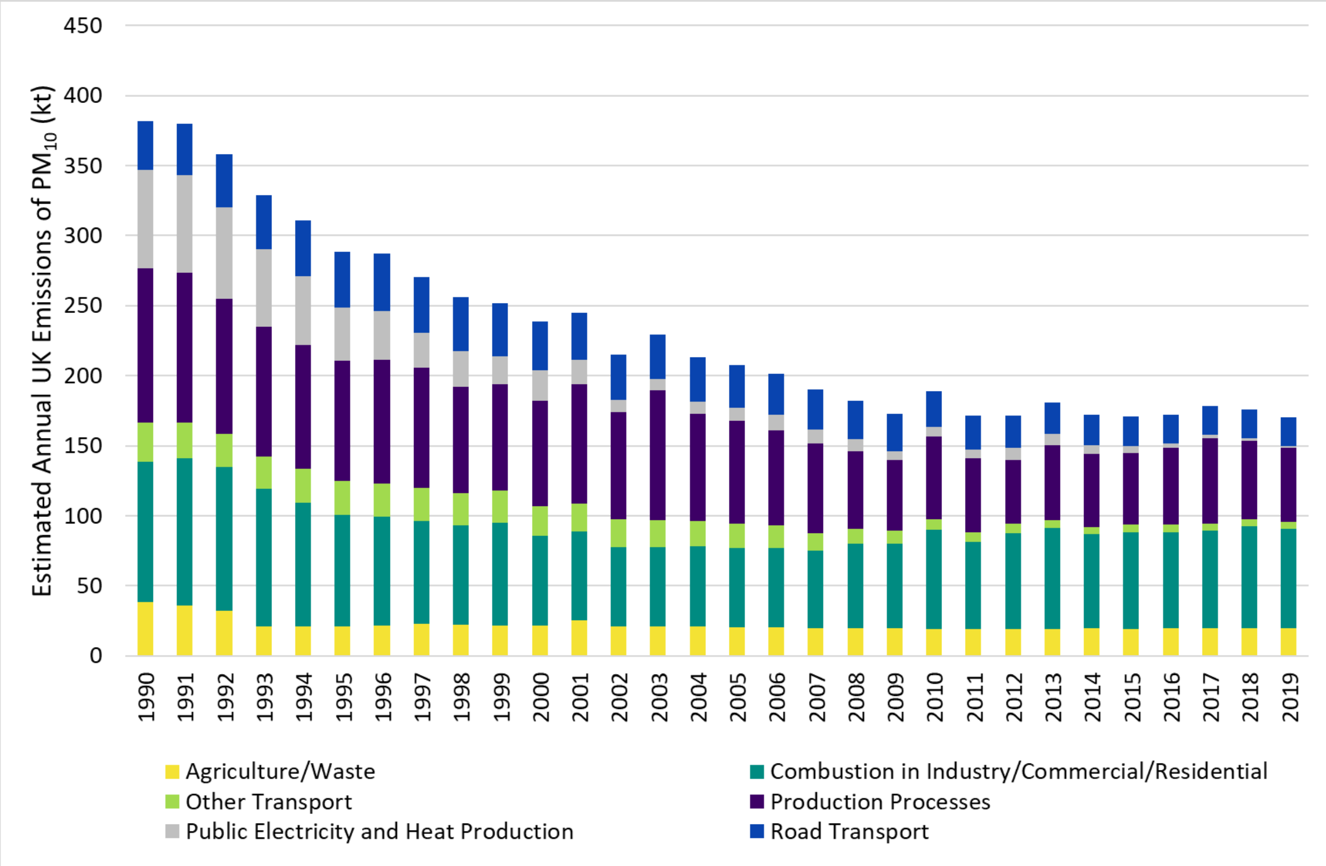


Figure 5-12 shows NAEI estimates of total UK annual emission of PM_{10} in kilotonnes, from 1990 to 2019 (the most recent year for which emission estimates are available). Total PM_{10} emissions have steadily decreased over all this period, although in more recent years the rate of decrease has slowed, flattening off after around 2010. Two sectors appear to be increasing over the past decade: production processes, and combustion in industry, commercial and residential settings. The NAEI says *"Emissions from residential sector combustion have grown both in real terms and in terms of the contribution to the UK total. This is because of strong growth in the use of wood as a domestic fuel, which has offset reductions that have occurred due to decreasing use of coal and other solid mineral fuels."* (https://naei.beis.gov.uk/overview/pollutants?pollutant_id=24). By contrast, estimated emissions from road traffic alone have continued to decrease steadily.

Figure 5-12 Estimated Annual UK Emissions of PM_{10} (kt), 1990 – 2019 (source: NAEI 2019)



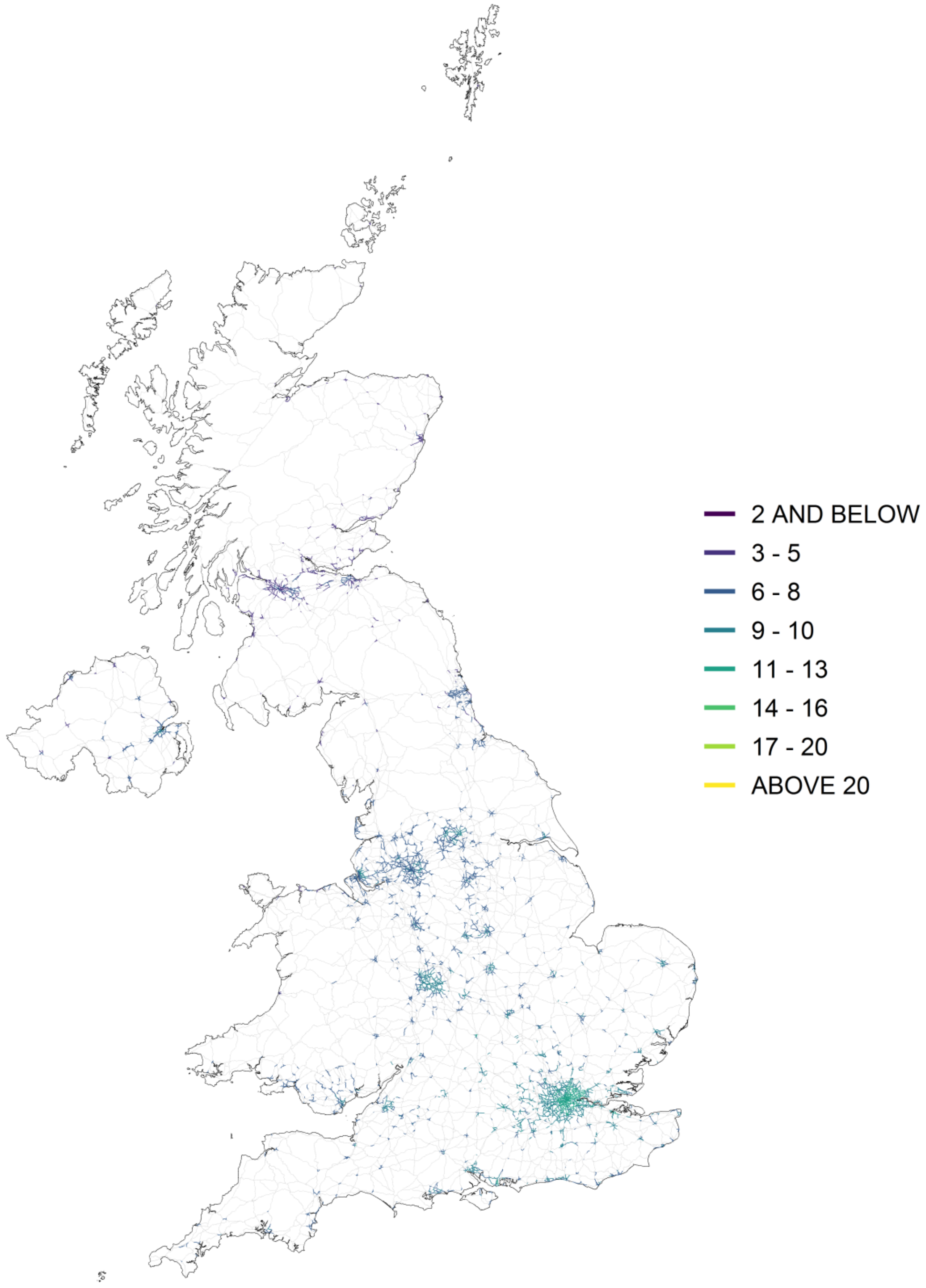
5.3 $PM_{2.5}$ Particulate Matter

5.3.1 $PM_{2.5}$: Spatial Distribution

Figure 5-13 shows the modelled annual mean urban roadside $PM_{2.5}$ concentrations in 2020. No roadside locations had annual means greater than the Stage 2 limit value of 20 µg m^{-3}; even in London, the highest was in the range 16 - 20 µg m^{-3}. This is consistent with the compliance assessment reported in **Section 4**.

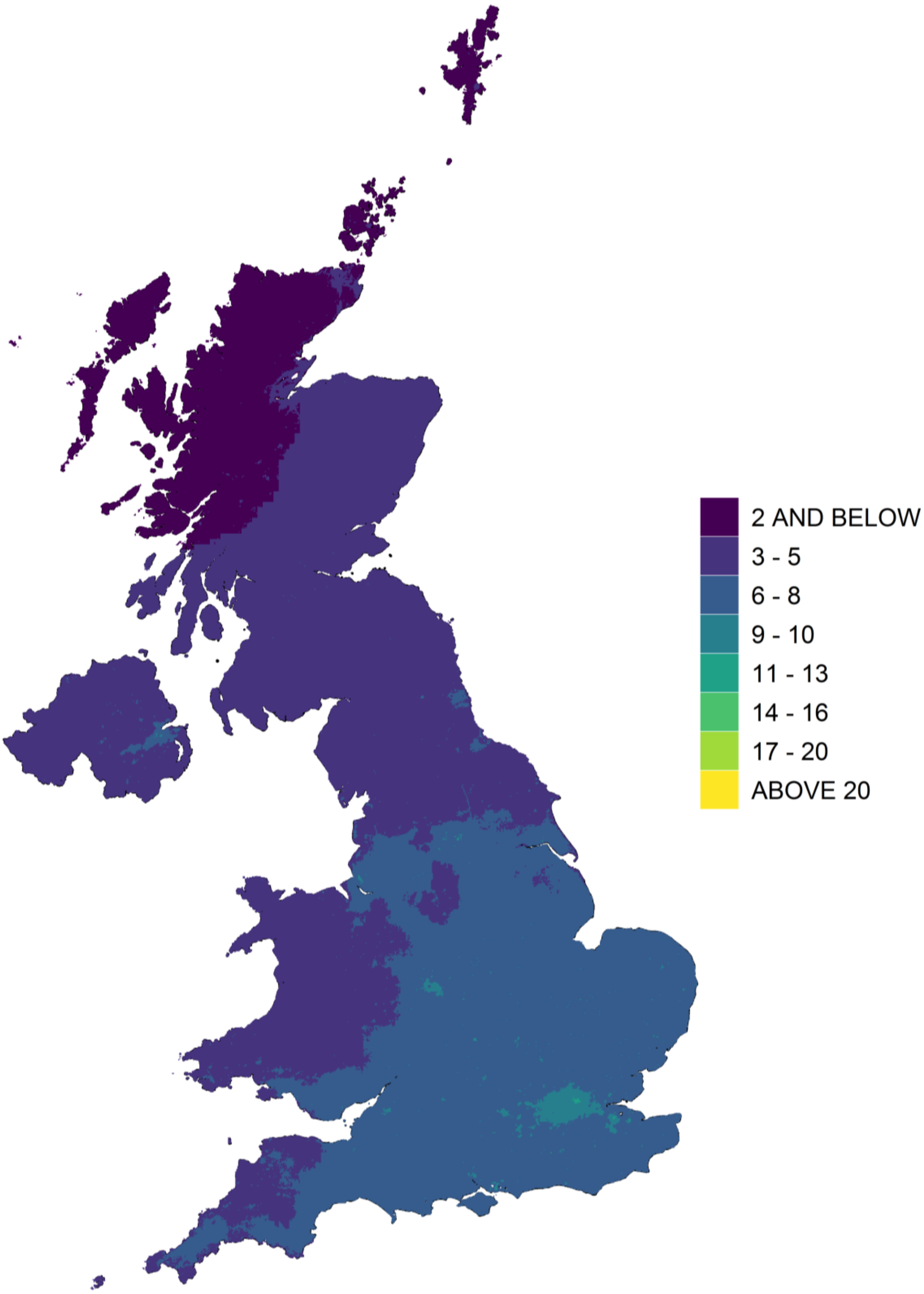
Figure 5-14 shows modelled annual mean background $PM_{2.5}$ concentrations in 2020. Modelled concentrations were lowest (less than 2 µg m^{-3}) in northern Scotland. The rest of Scotland, Northern Ireland, Wales and much of the north of England was in the range 3 - 5 µg m^{-3}. Concentrations were higher in most of the rest of England (6 - 10 µg m^{-3}). The areas with the highest modelled concentrations for 2020 were in London and the cities of the Midlands and the south; some urban centre locations had modelled concentrations in the range 13 - 15 µg m^{-3}, but none exceeded 20 µg m^{-3}. The whole UK was within the Stage 2 limit value of 20 µg m^{-3}, as reported in **Section 4**.

Figure 5-13 Annual Mean Roadside $PM_{2.5}$ Concentration, Urban Major Roads, 2020 (µg m^{-3})



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

Figure 5-14 Annual Mean Background $PM_{2.5}$ Concentration, 2020 ($\mu g\ m^{-3}$)



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

5.3.2 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 widespread. **Figure 5-15** shows trends in PM$_{2.5}$ concentration at 12 long-running urban background AURN sites, 2009-2020. All 12 sites show a statistically significant downward trend in PM$_{2.5}$ concentration: in all but one case, the trend is at the 0.001 confidence level.

Figure 5-15 De-seasonalised Trends in Ambient PM$_{2.5}$ Concentration, 12 Long-Running Urban Background AURN Sites 2009-2020

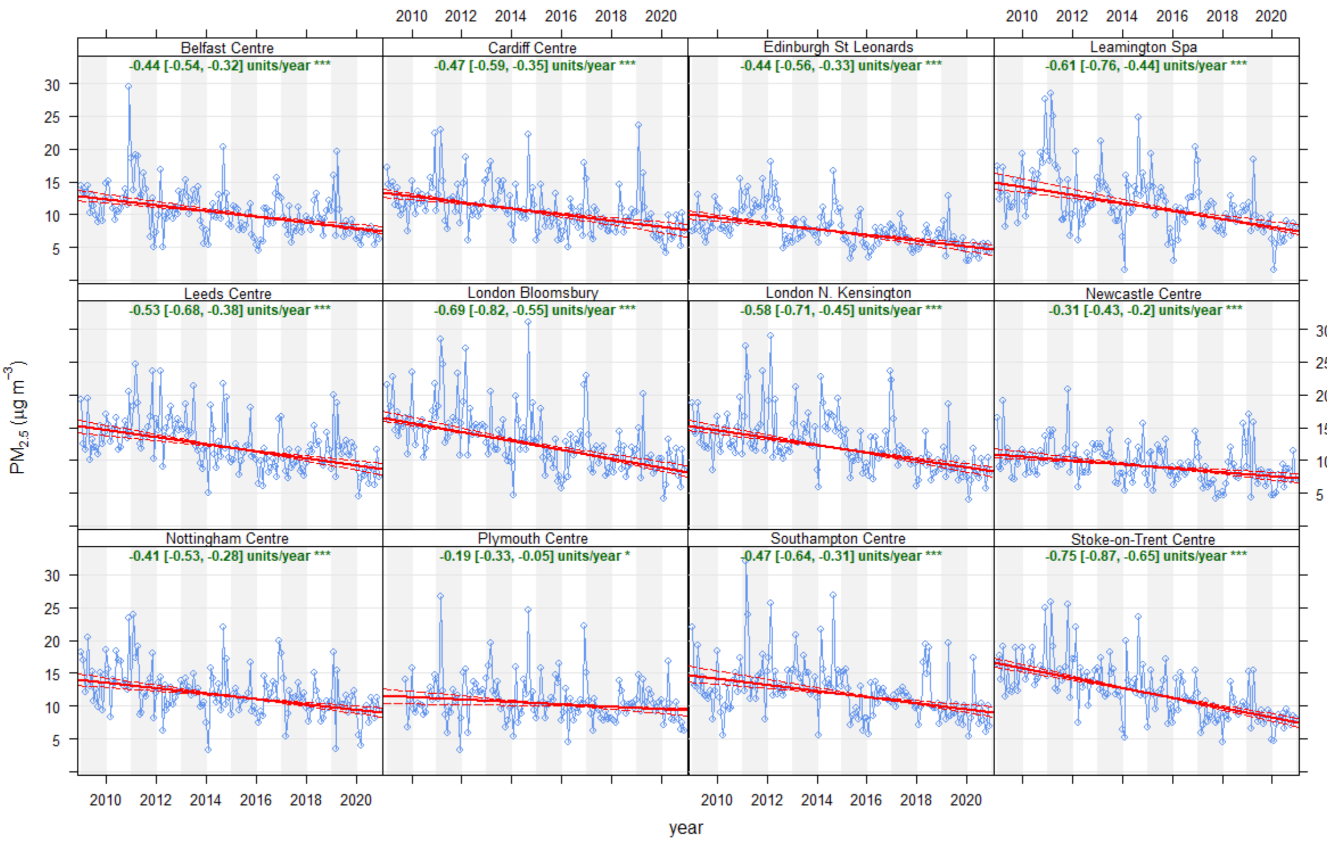
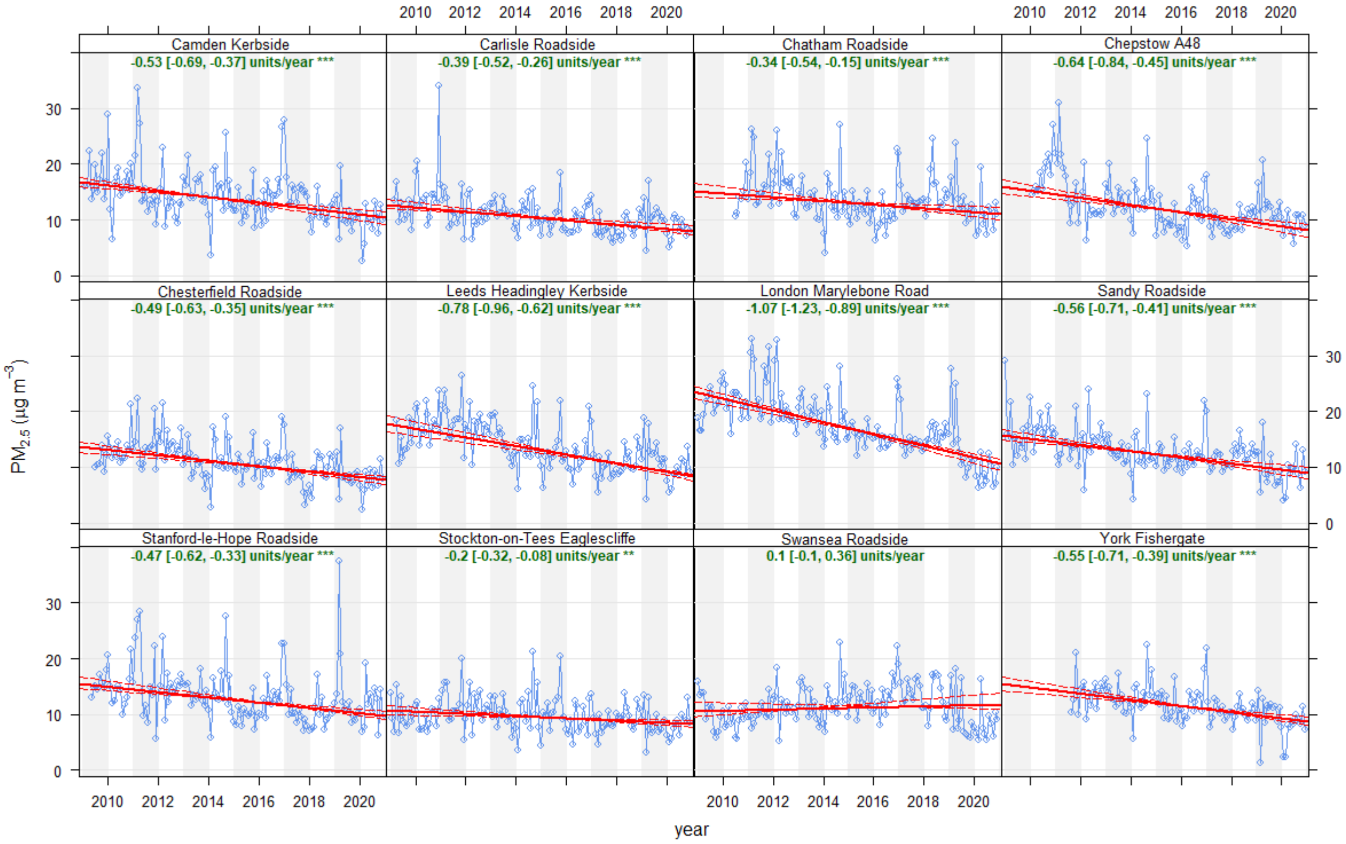


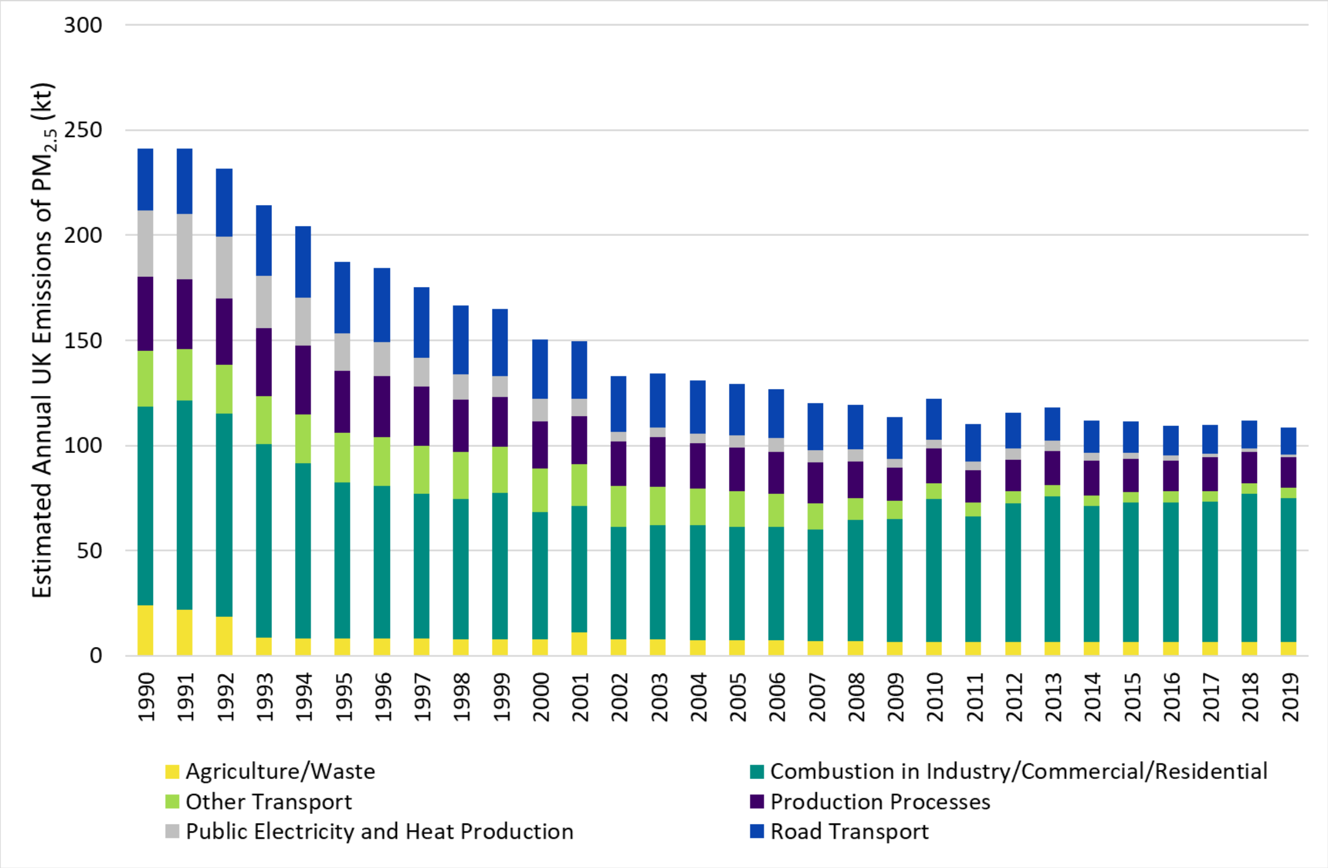
Figure 5-16 shows trends over the same period for PM$_{2.5}$ at 12 urban traffic AURN sites. (As for PM$_{10}$, Carlisle Roadside has been included for consistency with previous years' trend investigations, despite being excluded from the compliance assessment because it is located on a major junction. It has since been relocated elsewhere in Carlisle.) The majority of the sites (10 out of 12) show decreasing trends, statistically significant at the 0.001 confidence level. This includes Camden Kerbside, which until 2017 showed no significant trend. The two exceptions are Stockton-on-Tees Eaglescliffe (where the downward trend is still significant but only at the 0.01 confidence level) and Swansea Roadside, which shows an *increasing* trend in PM$_{2.5}$ concentration, as it also does for PM$_{10}$, though for PM$_{2.5}$ this is not statistically significant.

Figure 5-16 De-seasonalised Trends in Ambient $PM_{2.5}$ Concentration, 12 Long-Running Urban Traffic AURN Sites 2009-2020



Finally, **Figure 5-17** shows the estimated annual emission of $PM_{2.5}$, from 1990 to 2019. The graph shows that emissions have decreased in a similar manner to emissions of PM_{10}, with a steady decrease from the early 1990s, a clear levelling off, and no further consistent decrease after around 2010. The largest source category for $PM_{2.5}$ is combustion in industry, residential and commercial premises. Emissions from this source have increased over the past decade. The NAEI again notes the role of increased domestic wood burning: "*Residential sector emissions fell between 1990 (44kt) to 2002 (27kt), reflecting declining coal use. However, emissions from this source are now back at around 1990 levels due to increased use of wood as a fuel for homes (wood contributed 87% of domestic combustion emissions in 2018, compared with 13% in 1990). Industrial use of biomass fuels is also increasing and has, as a result, become a more significant contributor to UK emissions – 10% of UK emissions of $PM_{2.5}$ in 2019.*" (https://naei.beis.gov.uk/overview/pollutants?pollutant_id=122)

Figure 5-17 Estimated Annual UK Emissions of $PM_{2.5}$ (kt), 1990 – 2019. (Source: NAEI 2019)



5.4 Ozone

5.4.1 O_3: Spatial Distribution

Figure 5-18 shows the average number of days per year with ozone concentration > 120 µg m^{-3}, over the **three** years 2018-2020. The average number of days was highest (in the range 11-15 days) predominantly in the area to the south of a line running roughly from the Wash to the Bristol Channel. Elsewhere there were ten or fewer such days.

Figure 5-19 shows the number of days per year with ozone concentration > 120 µg m^{-3}, for 2020 only. Ozone concentrations in 2020 were generally lower than the three-year average in Scotland, but higher than the three-year average in parts of south and south-west England. Highest concentrations, with 16-20 days above 120 µg m^{-3}, occurred near the south coast of England and in the south west, including large parts of Devon.

Figure 5-18 Average Number of days with O_3 Concentration > 120 µg m^{-3} 2018-2020

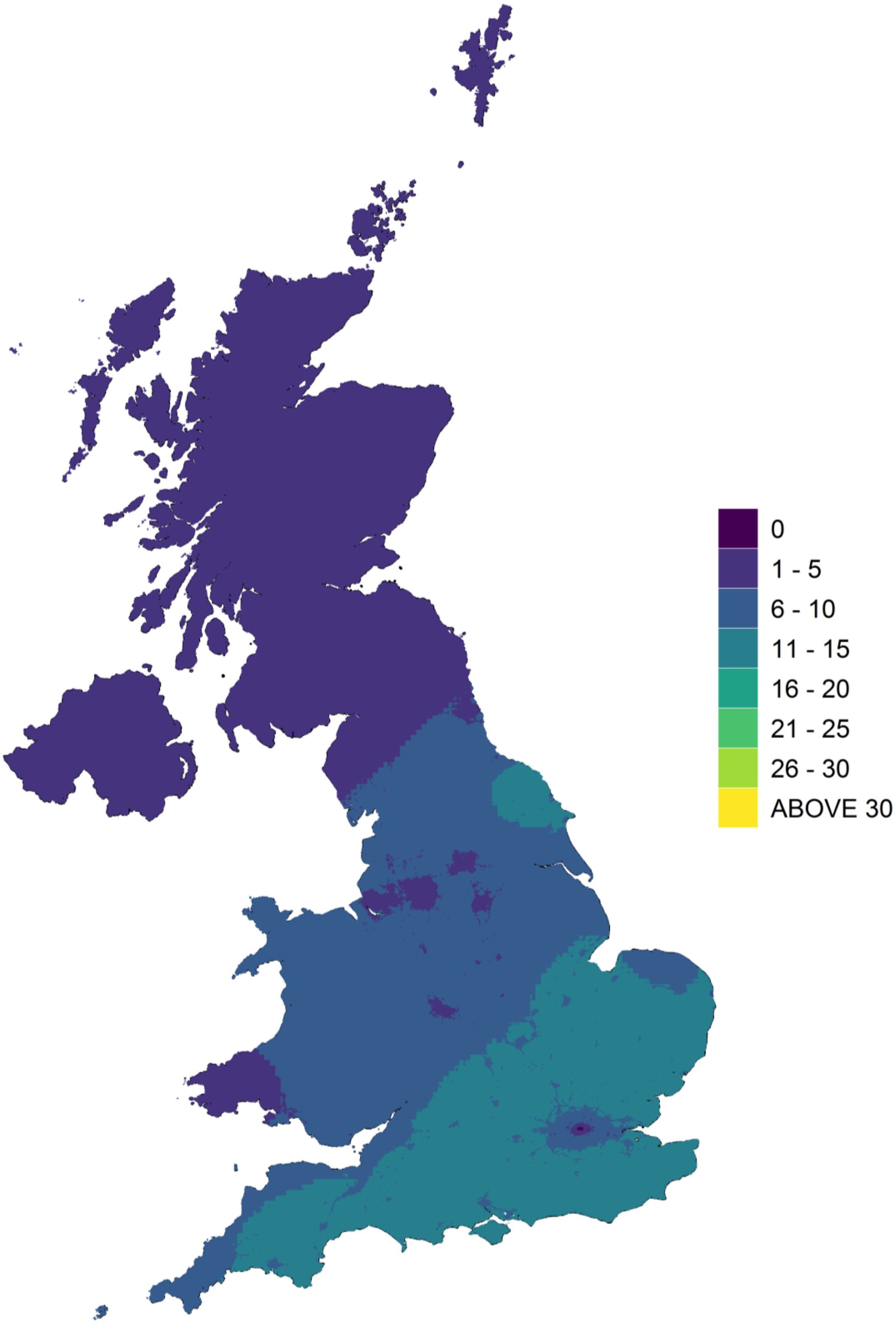
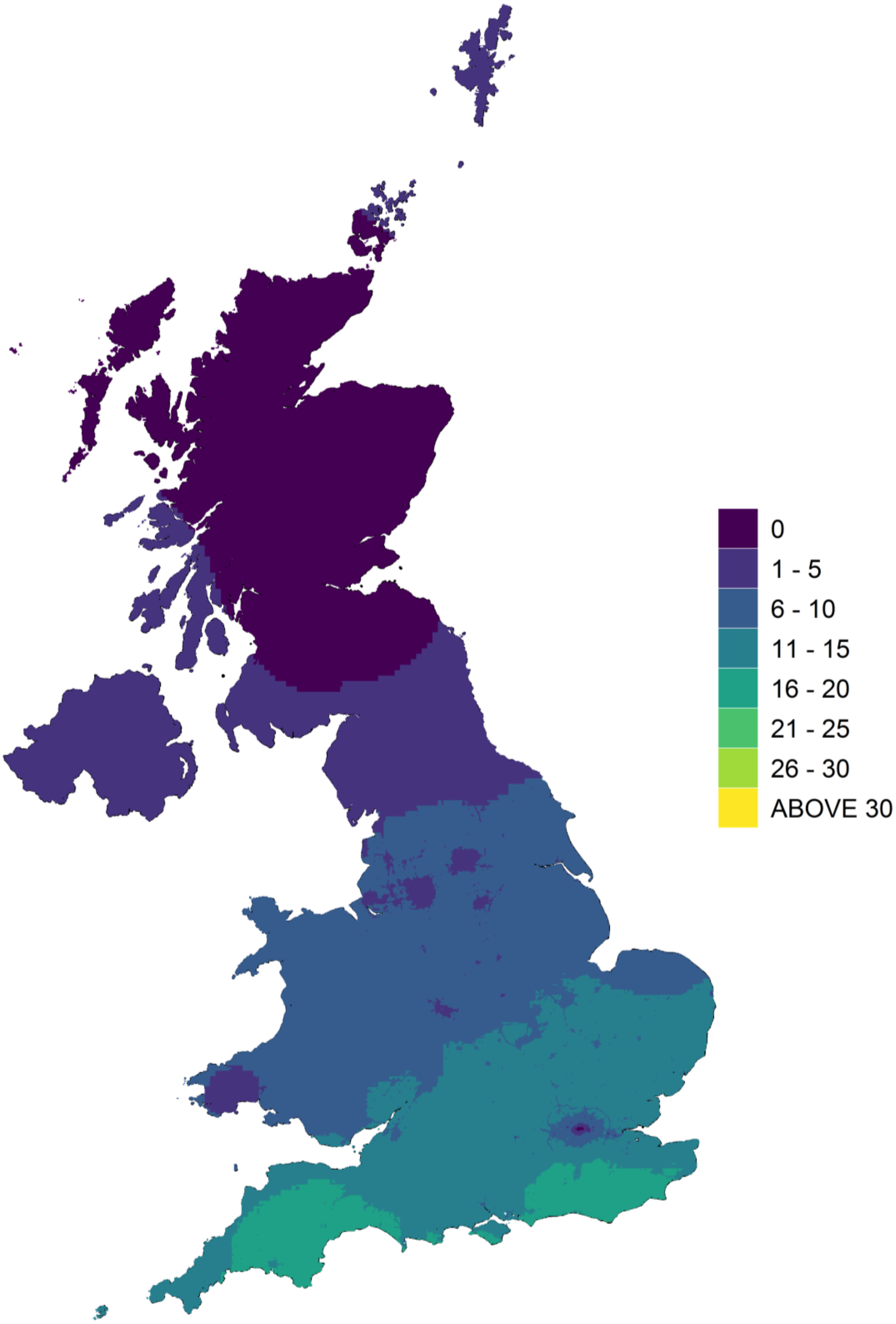


Figure 5-19 Days with O_3 Concentration > 120 µg m^{-3}, 2020



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

Figure 5-20 shows the AOT40 statistic, averaged over the past **five** complete years, 2016-2020. 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. Highest average AOT40 values can be seen in the south and west of England, with a small area also around North Yorkshire. Areas of lower concentration can be seen around cities such as London: this is because vehicle emissions (nitric oxide and other pollutants) react with ozone and thereby remove it from the air.

Figure 5-21 shows the same statistic, for 2020 only. The pattern is similar to that shown in **Figure 5-19** for days > 120 µg m^{-3}. Highest AOT40 values in 2020 occurred in the south and South West of the UK, to the south of a line running approximately from the Wash to the Bristol Channel. One small area in Devon had AOT0 values in the range 9,001 – 12,000. Again, areas of lower concentration are visible around London and some other cities, due to the ozone 'scavenging' effects of other pollutants.

Figure 5-20 Average AOT40, 2016-2020 (µg m^{-3}.hours)

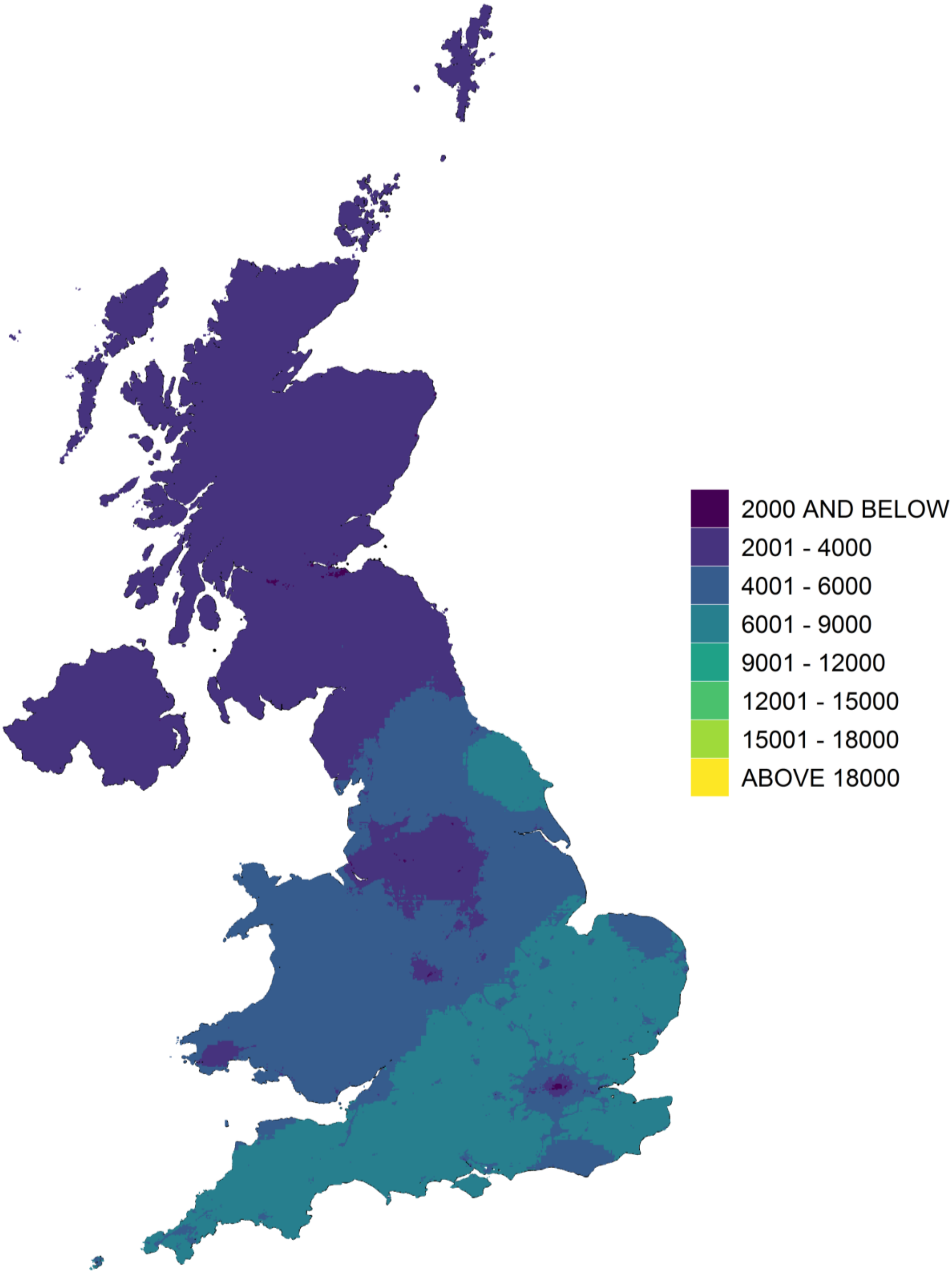
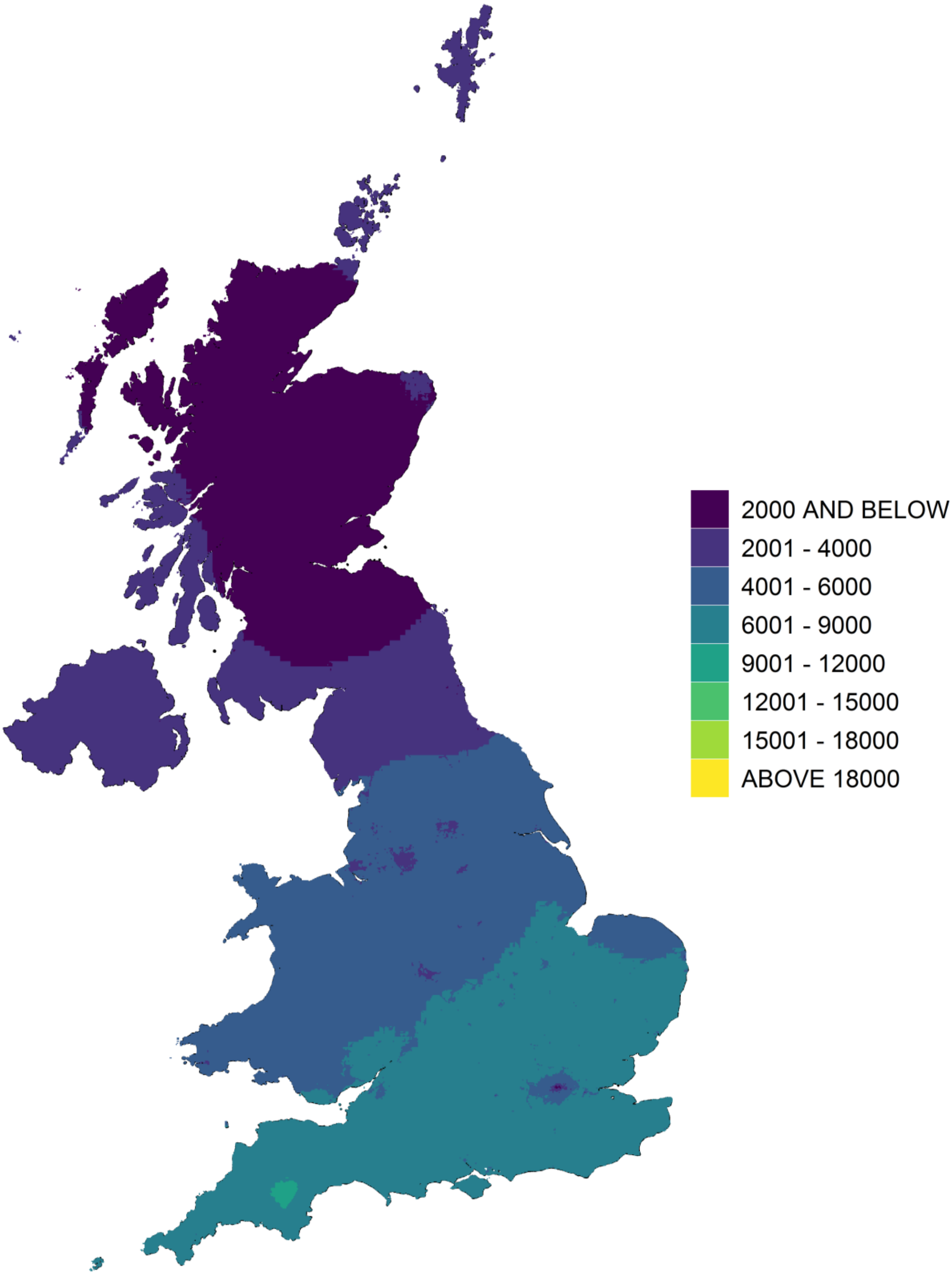


Figure 5-21 Average AOT40, 2020 (µg m^{-3}.hours)

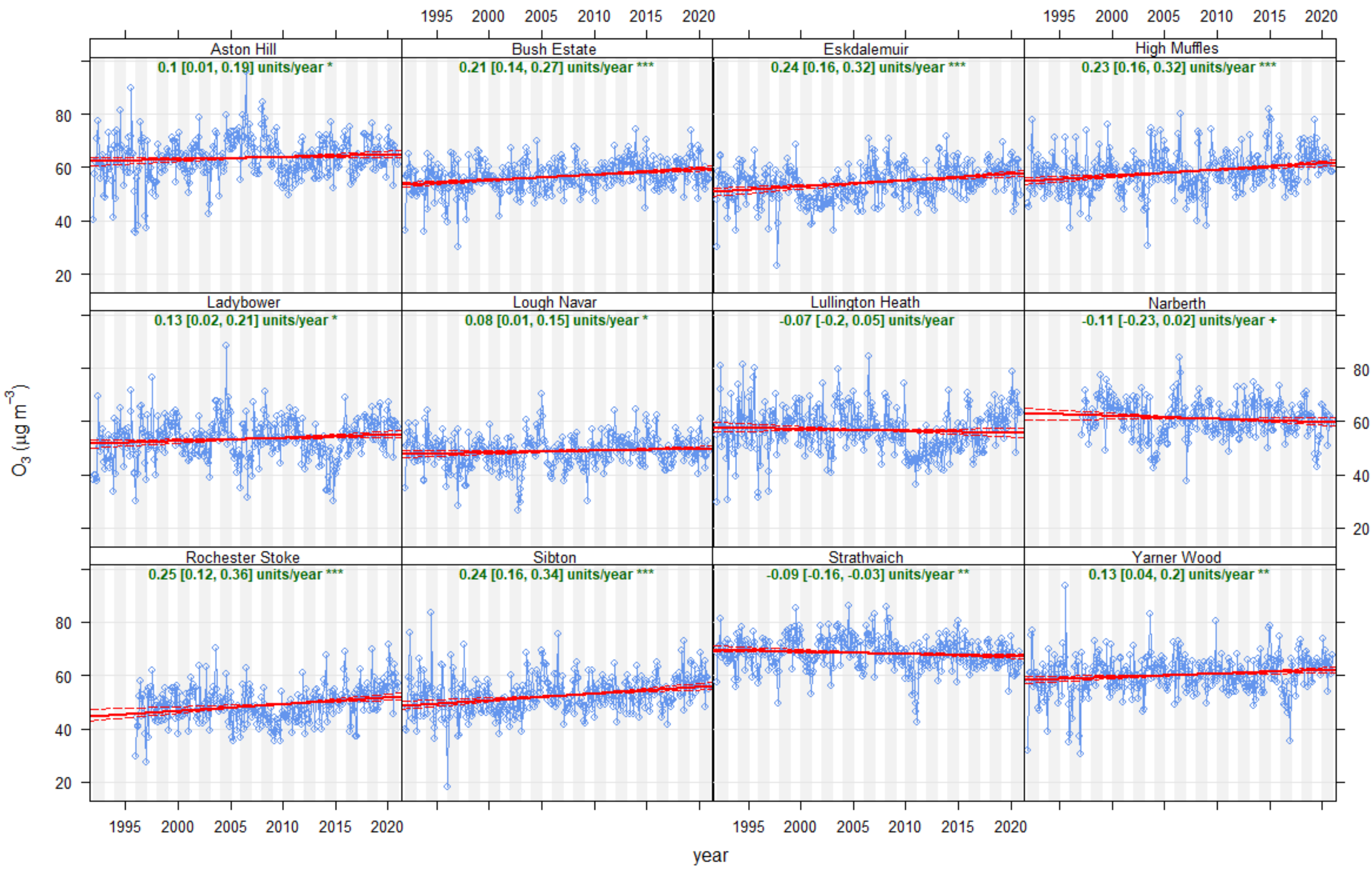


5.4.2 O_3: Changes Over Time

Figure 5-22 shows a trend plot of hourly mean ozone concentrations at 12 long-running rural AURN sites over the period 1992-2020 (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.

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

Figure 5-22 De-seasonalised Trends in Ozone Concentration at 12 Long-Running Rural AURN sites, 1992 - 2020.



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.

5.5 Sulphur Dioxide

5.5.1 SO_2: Spatial Distribution in the UK

Figure 5-23 shows how the modelled 99.73rd percentile[2] of hourly mean sulphur dioxide concentration varied across the UK during 2020. 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 5-24 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 2020.

[2] 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 5-23 99.73rd Percentile of 1-hour Mean SO_2 Concentration, 2020 ($\mu g\ m^{-3}$)

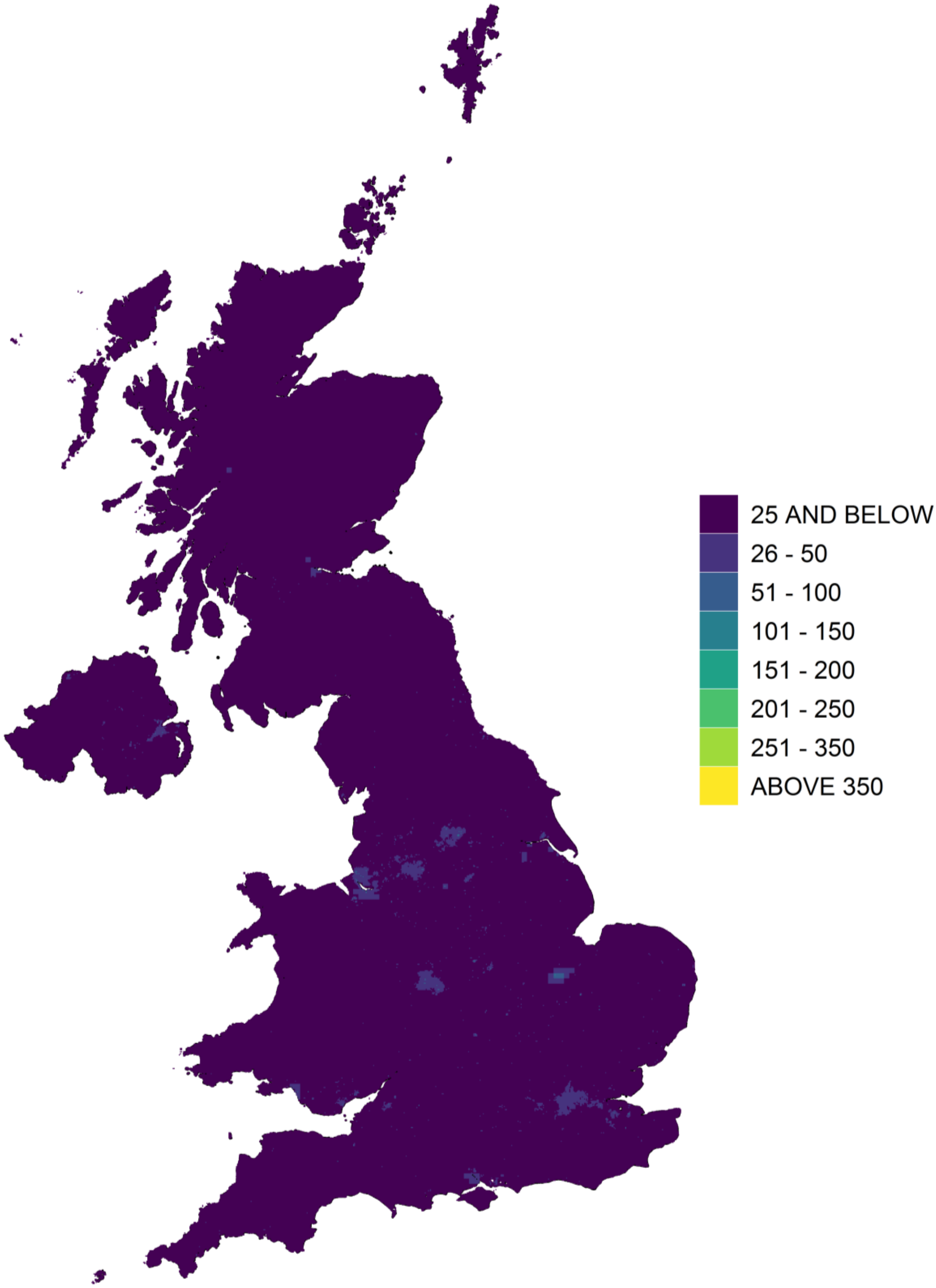
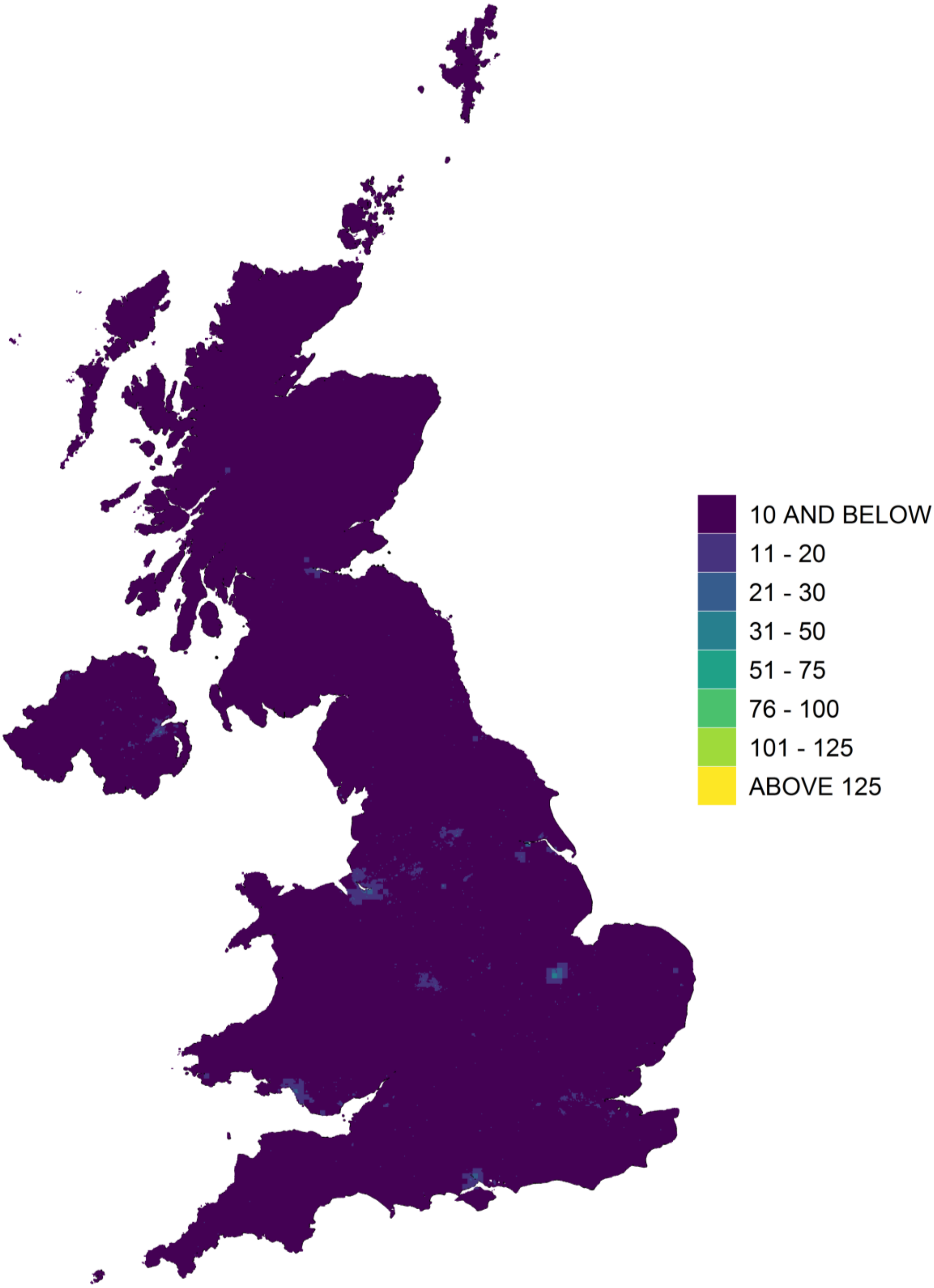


Figure 5-24 99.18th Percentile of 24-hour Mean SO_2 Concentration, 2020 (µg m^{-3})



An interactive map of annual mean SO_2 is available at https://uk-air.defra.gov.uk/data/gis-mapping/).

5.5.2 SO_2: Changes Over Time

Figure 5-25 shows how ambient concentrations have changed over the period 1992 to 2020, at the six AURN monitoring stations that have monitored this pollutant for the longest time and remained in operation in 2020. All six stations show a downward trend that is statistically significant at the highly significant 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 5-25 De-seasonalised Trends in SO_2 Concentration, 1992-2020 at 6 Long-running AURN Sites

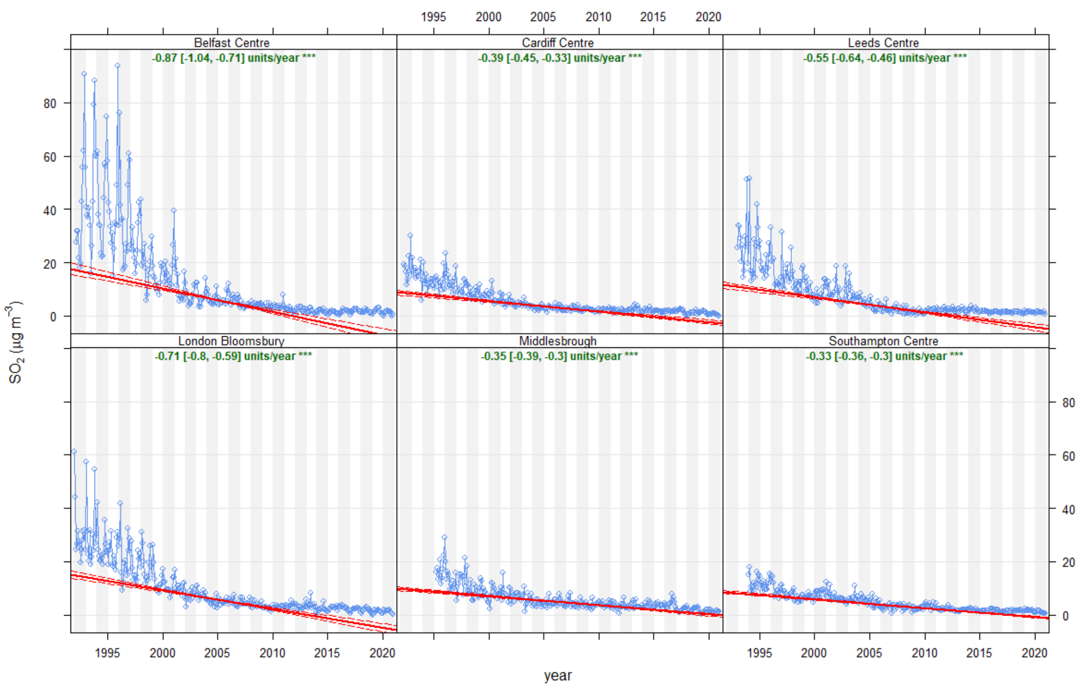
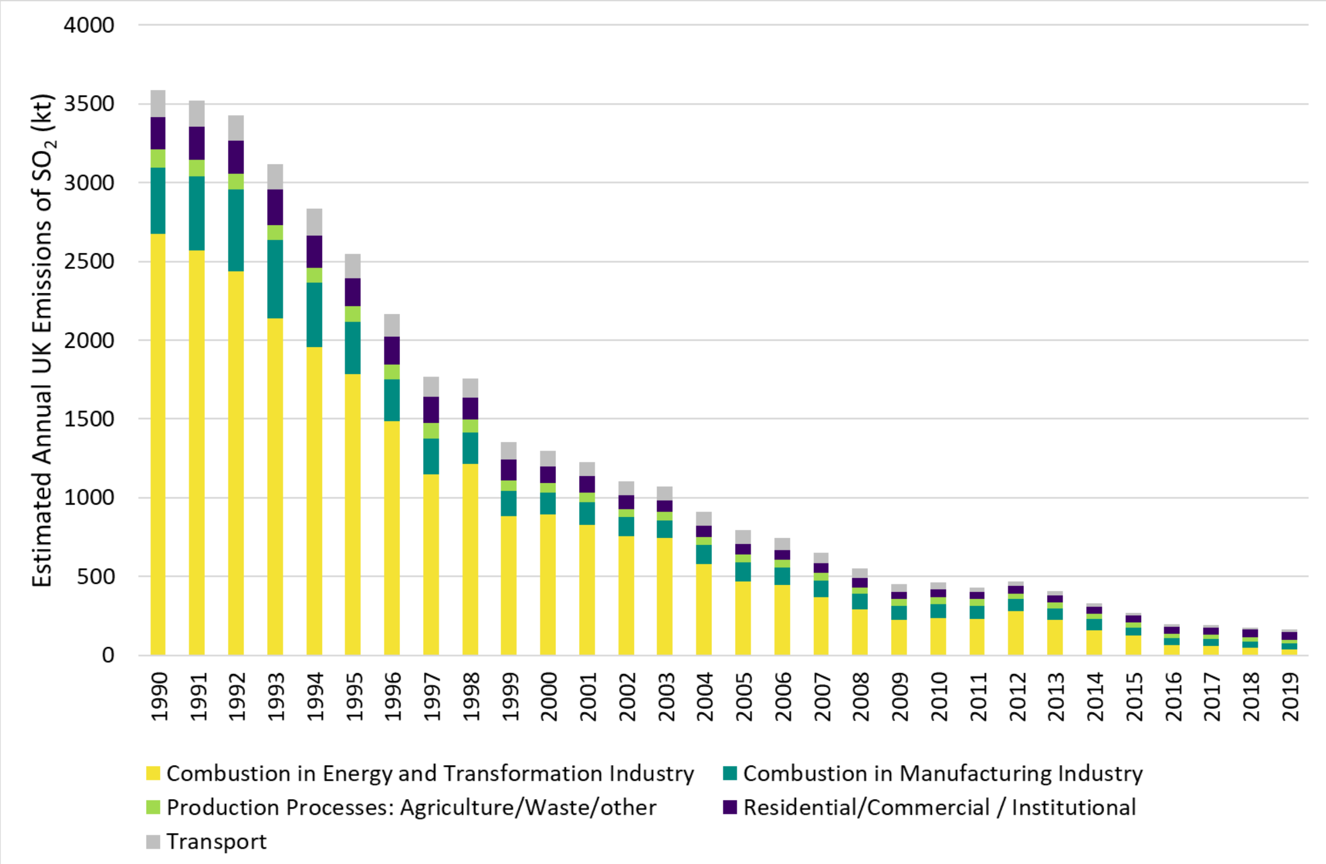


Figure 5-26 is taken from the NAEI and shows the UK's estimated annual emissions of sulphur dioxide from 1990 to 2019 (the most recent year for which data are available). The decrease in emissions over time shown here is the continuation of an on-going trend observed by the NAEI throughout the 1970s 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 http://naei.beis.gov.uk/overview/pollutants?pollutant_id=8) explains this as follows: "*As a result of the economic downturn the drive to cut energy costs has resulted in an increase in solid fuel use, particularly in 2012 some coal-sensitive pollutants have seen a significant* *rise in coal burning emissions*." Following 2012, the downward trend in SO_2 emissions continues.

The UK's total estimated emissions of SO_2 in 2019 were 50% below the UK's targets for 2020, set by the National Emission Ceilings Directive and the Gothenburg Protocol.

Figure 5-26 Estimated Annual UK Emissions of SO_2 (kt), 1990 – 2019 (source: NAEI 2019)



5.6 Carbon Monoxide

5.6.1 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.

5.6.2 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 5-27 shows de-seasonalised trends at these six long-running AURN sites, from 1992 to 2020. All six show a highly significant downward trend over the period.

Figure 5-27 De-seasonalised Trends in CO Concentration, 6 Long-Running AURN Sites 1992-2020

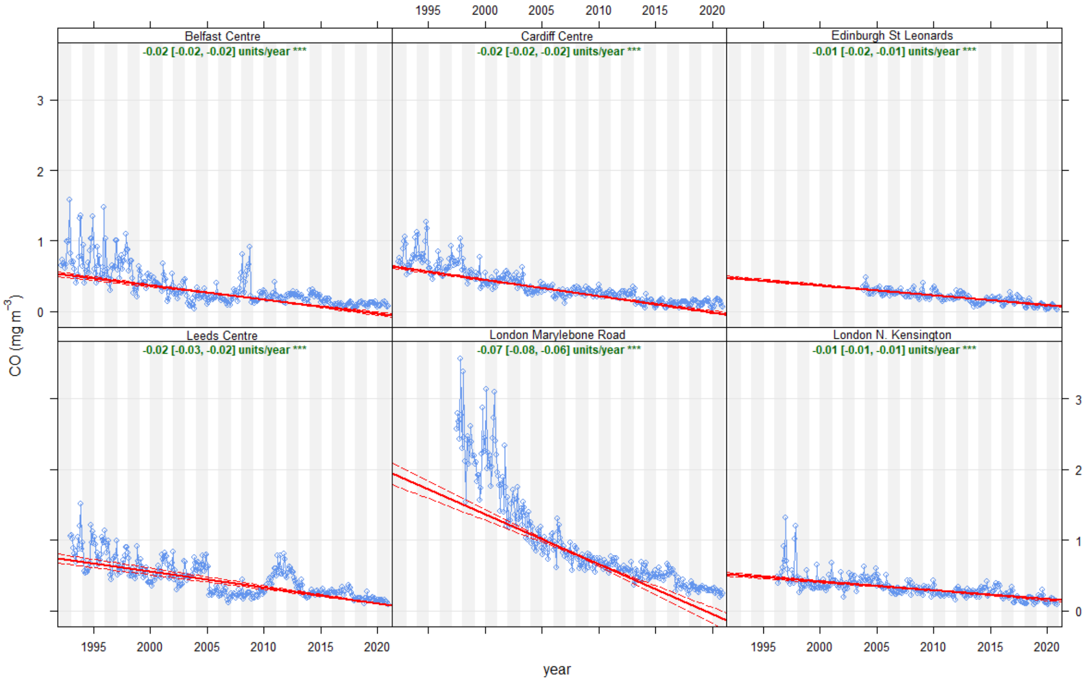
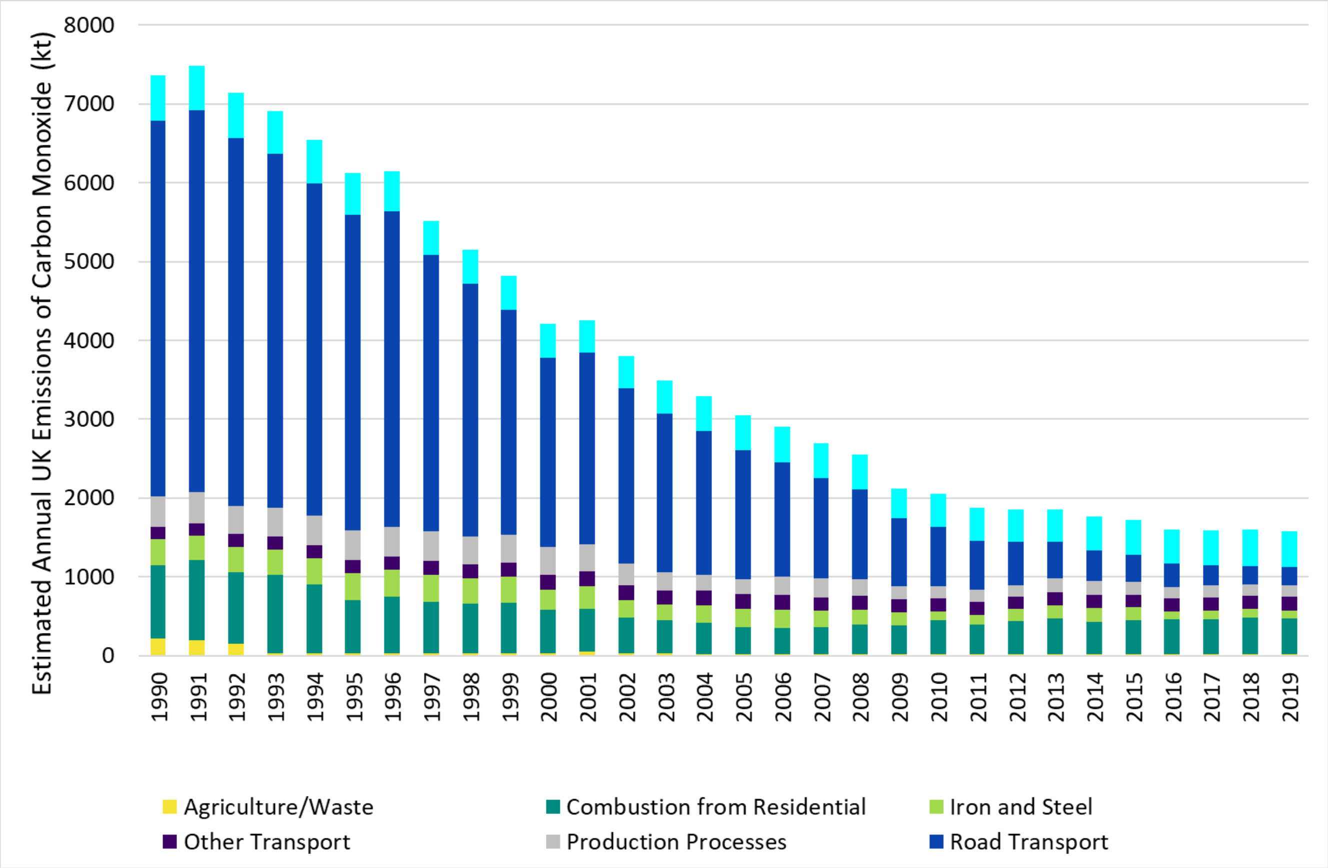


Figure 5-28 shows the estimated annual emissions of CO over the same period: a steady, almost linear year-on-year decrease to 2011 is followed by two years in which estimated emissions remained stable, before decreasing further. The decreasing ambient concentrations reflect declining emissions over the last 25 years. The NAEI attributes the decrease in CO emissions to factors including EU-wide emission standards for road vehicles, a decline in industrial use of solid fuels, and a decline in the production of steel and non-ferrous metals (https://naei.beis.gov.uk/overview/pollutants?pollutant_id=4).

Figure 5-28 Estimated Annual UK Emissions of CO (kt), 1990 – 2019 (source: NAEI 2019)

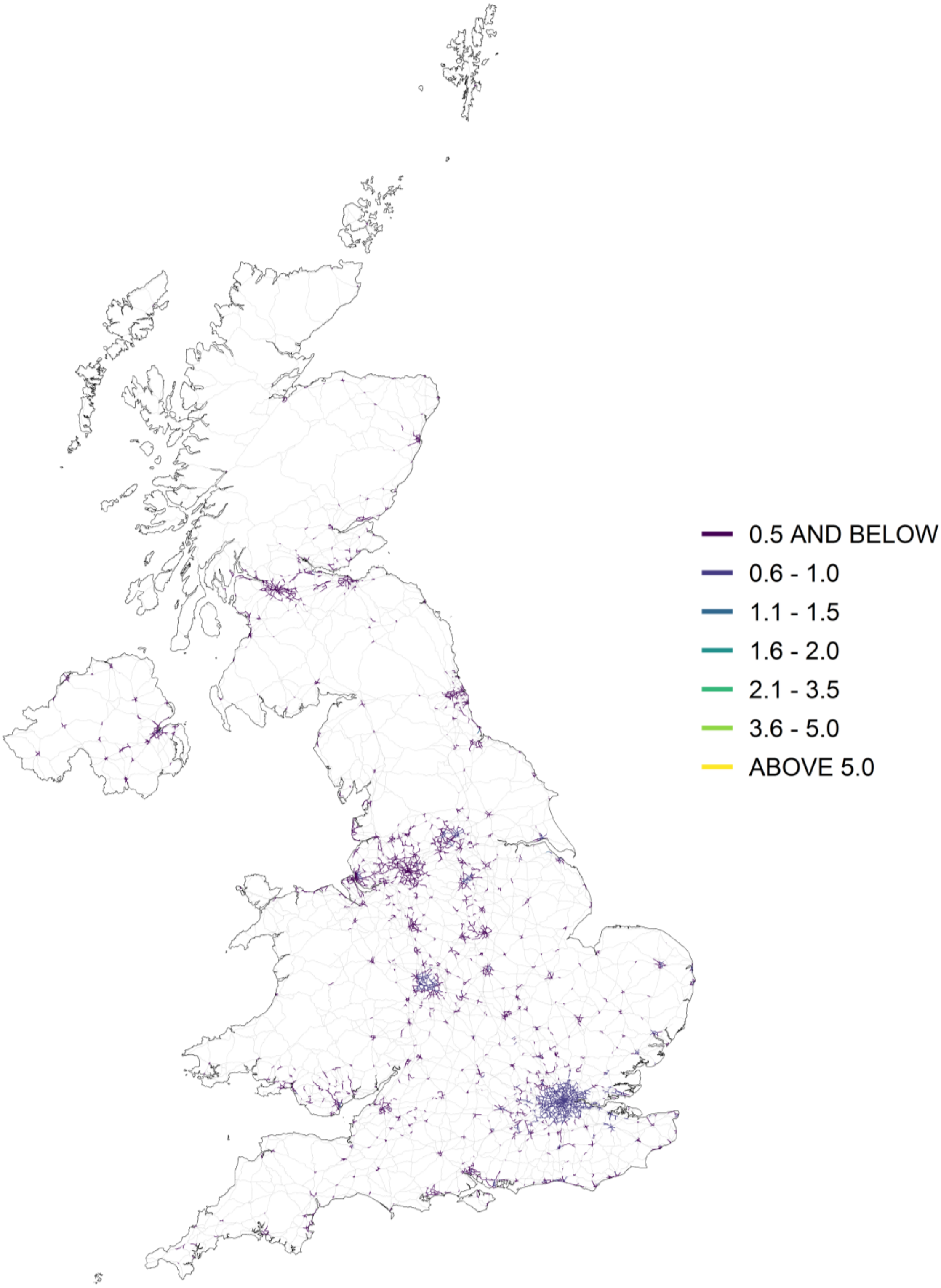


5.7 Benzene

5.7.1 Benzene: Spatial Distribution

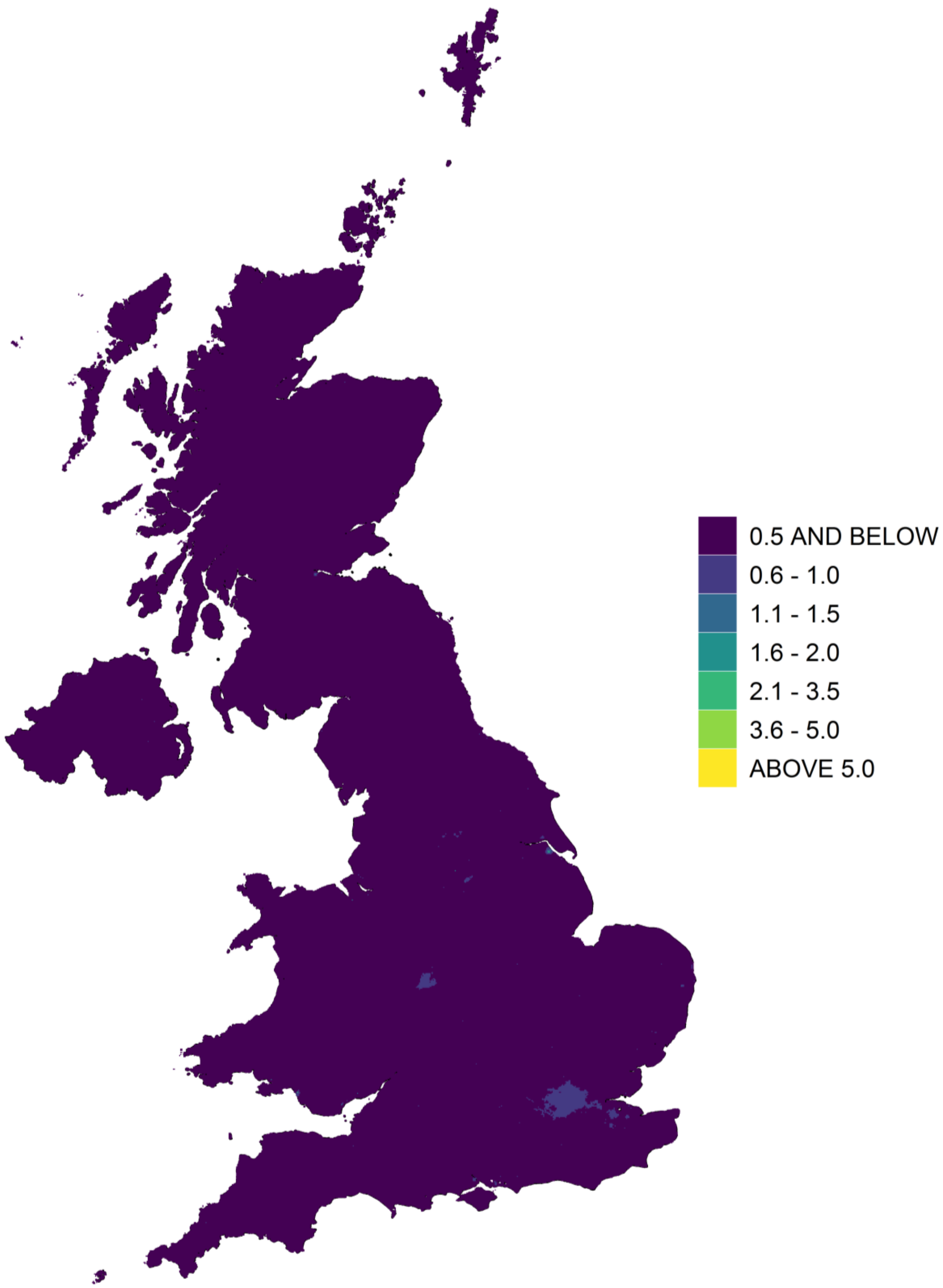
Benzene is found in petrol and in vehicle emissions, therefore higher levels may be expected at roadside locations. However, almost all road links had modelled concentrations below 1.0 µg m^{-3}. **Figure 5-29** shows modelled annual mean benzene concentrations at roadside locations in 2020, and **Figure 5-30** shows the modelled annual mean background concentrations of benzene in 2020. Modelled background concentrations were below 0.5 µg m^{-3} over most of the UK, marginally higher in some urban areas. A few very small areas had concentrations in excess of 1 µg m^{-3} (in Humberside and Grangemouth areas): these are too small to be clearly seen on the map. Background concentrations everywhere were well below the limit value of 5 µg m^{-3} for benzene.

Figure 5-29 Annual Mean Roadside Benzene Concentration for Major Urban Roads, 2020 (µg m^{-3})



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

Figure 5-30 Annual Mean Background Benzene Concentration, 2020 (µg m^{-3})



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

5.7.2 Benzene: Changes Over Time

Figure 5-31 shows a smoothed trend plot 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.

Figure 5-32 shows the estimated total annual UK emission of benzene (in kilotonnes), 1990 - 2019. 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.

Figure 5-31 Smoothed Trend Plot of Ambient Benzene Concentration, 14 Long-Running Non-Automatic Sites, 2002-2020

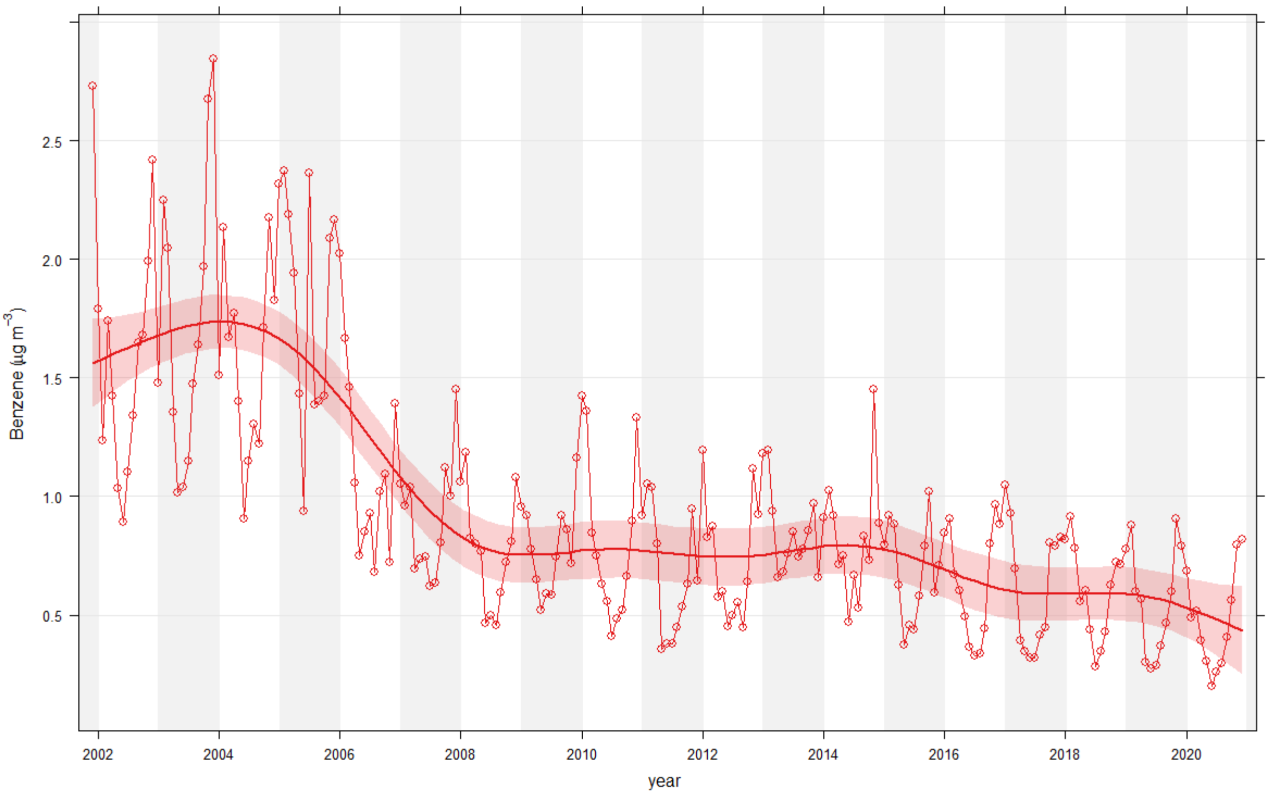
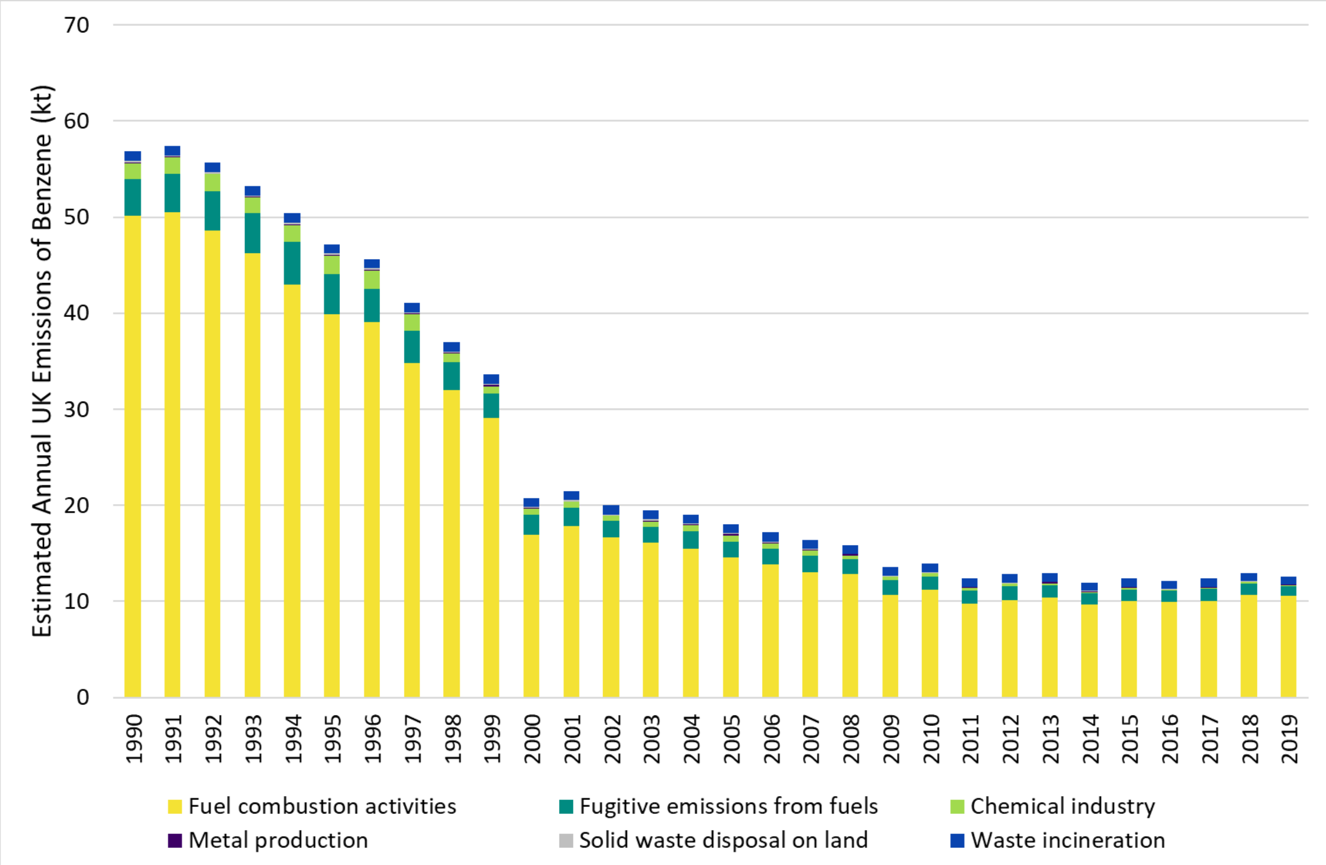


Figure 5-32 Estimated Annual UK Emissions of Benzene (kt), 1990 – 2019 (source: NAEI 2019)



5.8 1,3-Butadiene

5.8.1 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.

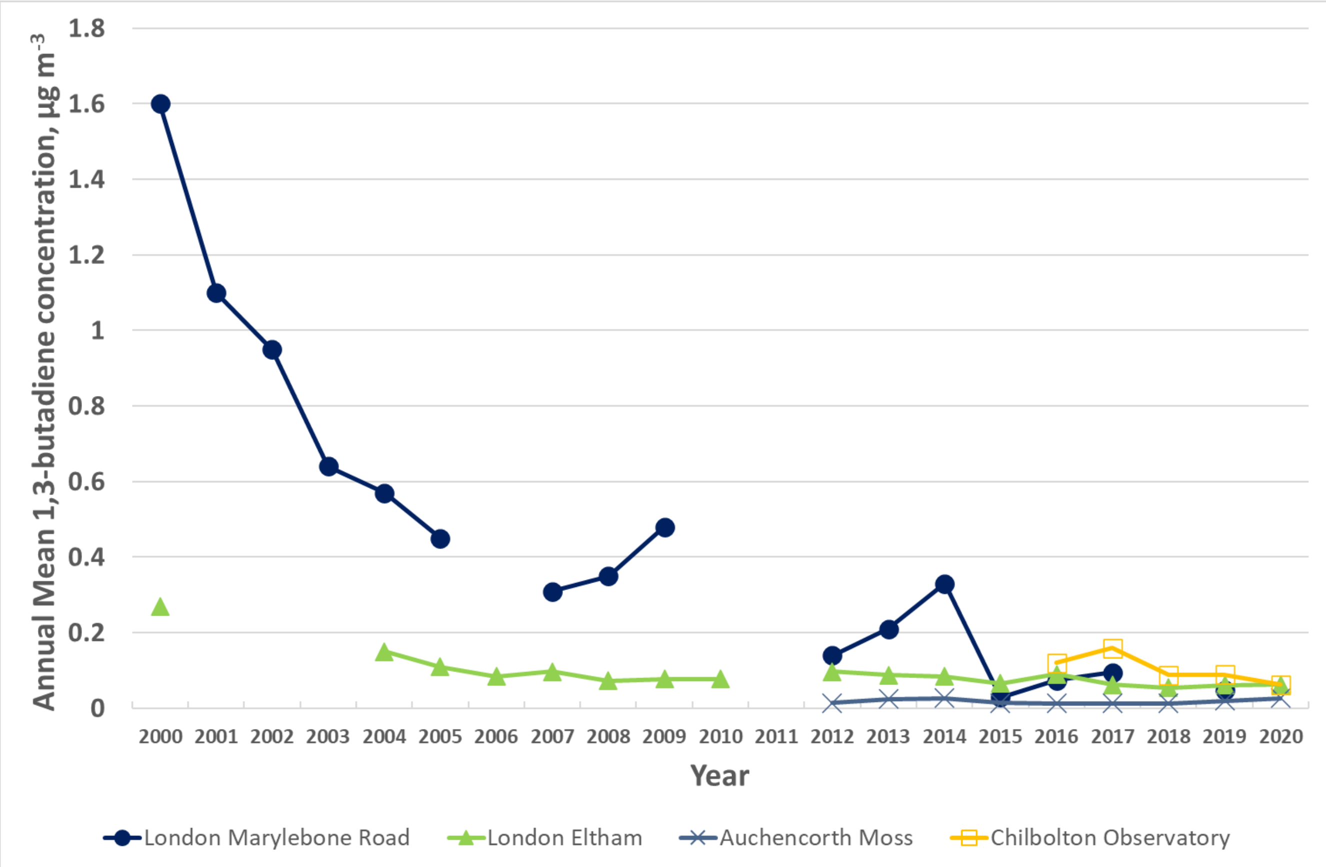
The Automatic Hydrocarbon Network monitors 1,3-butadiene at four sites: London Marylebone Road (urban traffic), London Eltham (urban background), Auchencorth Moss in Lothian (rural background), and Chilbolton Observatory in Hampshire (also rural background). Chilbolton Observatory replaced a previous 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 2020.

5.8.2 1,3-Butadiene: Changes Over Time

Figure 5-33 shows a time series chart of annual mean ambient 1,3-butadiene concentration between 2000 and 2020 at the four automatic sites. Although Auchencorth Moss has been monitoring this pollutant since 2006, data capture was low in years 2006-

2011. Therefore only annual means for 2012 onwards are shown for this site. Chilbolton Observatory has now been in operation five years, which is considered long enough for air quality trends to be evaluated. In this graph, annual means are only shown if data capture was at least 50%.

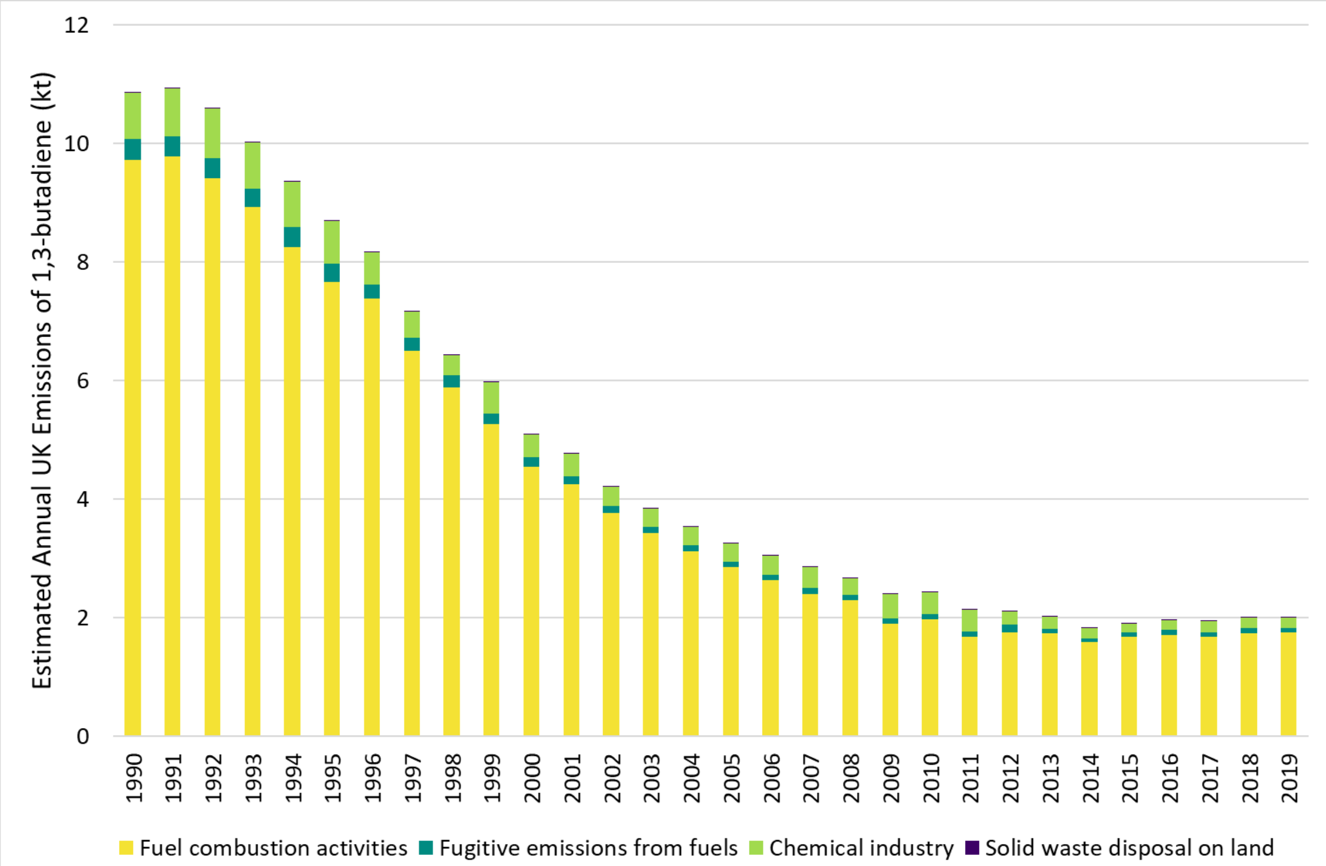
Figure 5-33 Time Series Graph of 1,3-Butadiene Concentration, 2000-2020



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

Figure 5-34 shows the total estimated UK annual emission of this compound, in kilotonnes, between 1990 and 2019. 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.

Figure 5-34 Estimated Annual UK Emissions of 1,3-Butadiene (kt), 1990 – 2019 (source: NAEI 2019)

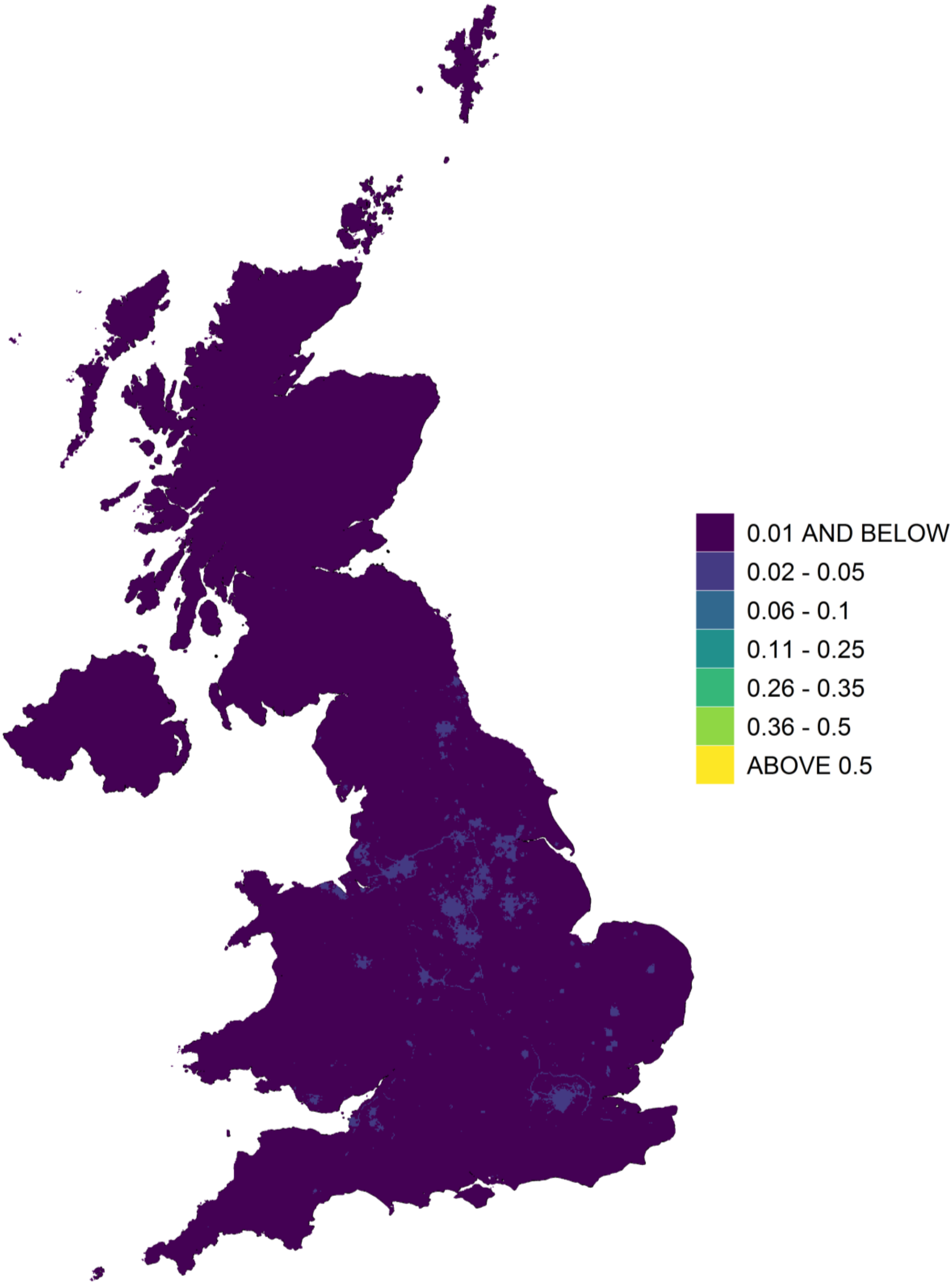


5.8.3 Metallic Elements: Spatial Distribution

Figure 5-35, **Figure 5-36**, **Figure 5-37** and **Figure 5-38** show modelled annual mean background concentrations of lead (Pb), arsenic (As), cadmium (Cd) and nickel (Ni) respectively in 2020. The spatial distribution patterns are discussed below.

Pb: background concentrations were 0.01 µg m^{-3} or less over most of the UK. (The map shows concentrations in microgrammes per cubic metre, as this is the unit used for the Air Quality Standards Regulations limit value.) There were some small areas (mostly industrial areas) where higher concentrations in the range 0.02 – 0.05 µg m^{-3} were modelled; however this is well within the limit value of 0.5 µg m^{-3} throughout the UK.

Figure 5-35 Annual Mean Background Lead Concentration, 2020 (µg m^{-3})



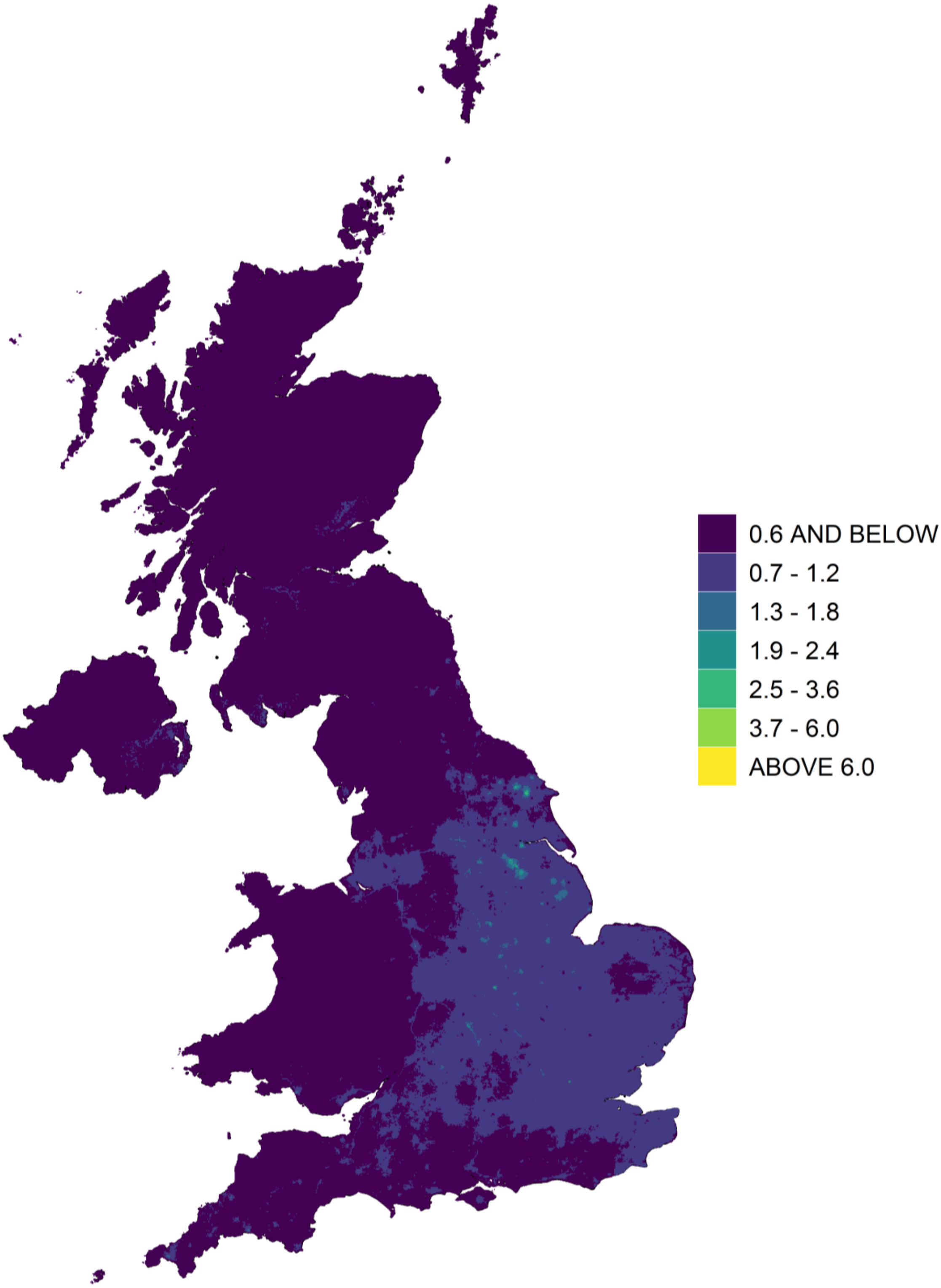
(An interactive version of this map is available at https://uk-air.defra.gov.uk/data/gis-mapping/).

As: this toxic element is a metalloid rather than a metal but is nevertheless measured by the Heavy Metals Network. Background concentrations were less than 6.0 ng m^{-3} over the whole UK, and 1.2 ng m^{-3} or less over most of the country. However, concentrations in the range 2.5 – 3.6 ng m^{-3} and above 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. Some major road routes are visible: this is due to re-suspended road dust. Some small areas had modelled concentrations greater than 0.6 ng m^{-3}; these were associated with specific point sources. However, no locations exceeded the target value of 5 ng m^{-3}.

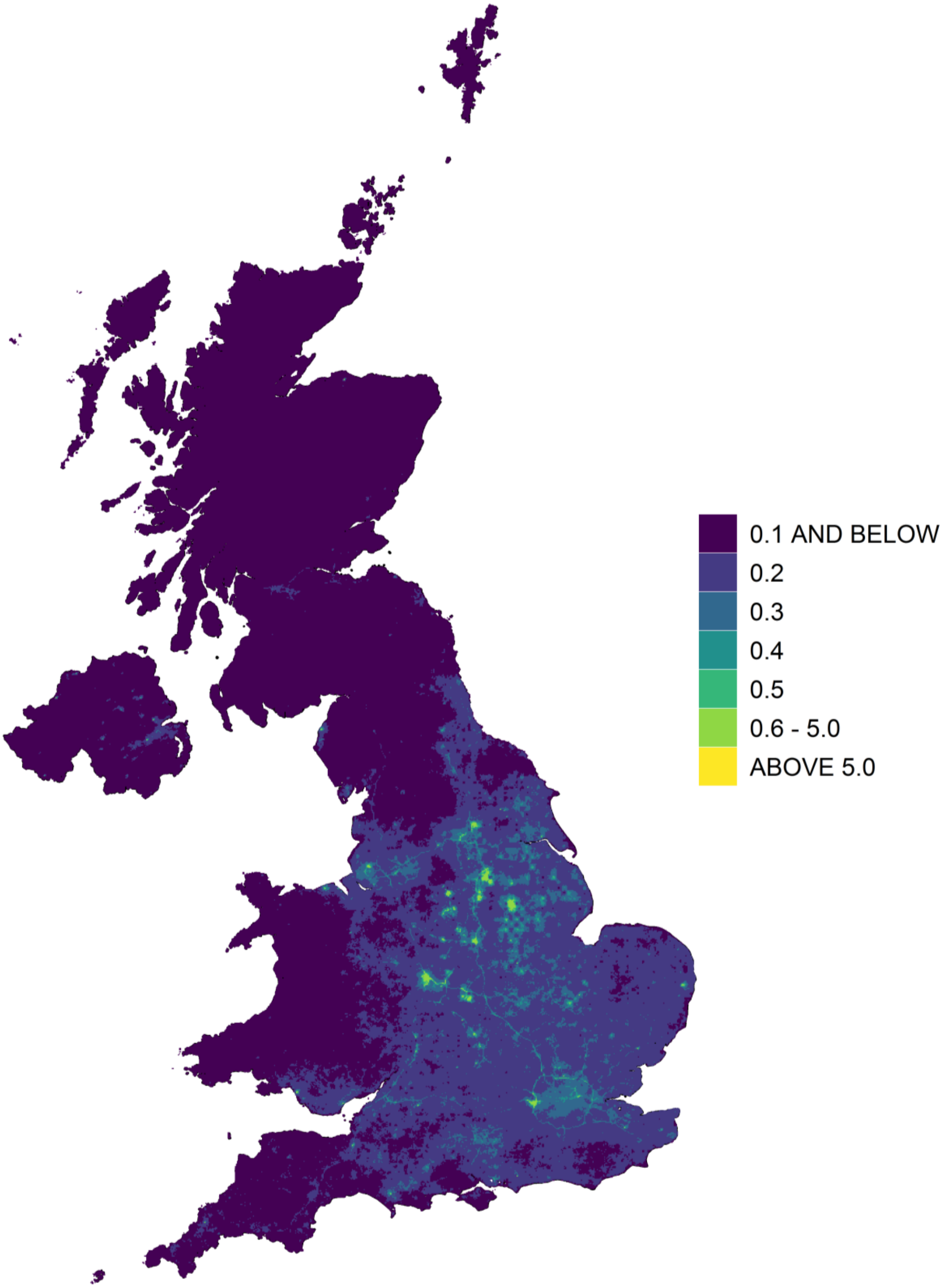
Ni: background concentrations of Ni were typically 2 ng m^{-3} or less (and usually 1 ng m^{-3} or less, away from urban areas). Like As and Cd, Ni is found in suspended road dust; it is often possible to see the paths of some major road routes, though these do not feature strongly on the 2020 map. There are also some small areas with higher concentrations due to industrial activity. Modelled concentrations exceeded the Ni target value of 20 ng m^{-3} in 2020 in Sheffield Urban Area, Yorkshire and Humberside and South Wales. However, apart from the one in Sheffield, these areas are too small to be clearly visible on the map. (The exceedance reported for Swansea Urban Area in **Section 4** was measured rather than modelled.)

Figure 5-36 Annual Mean Background Arsenic Concentration, 2020 (ng m^{-3})



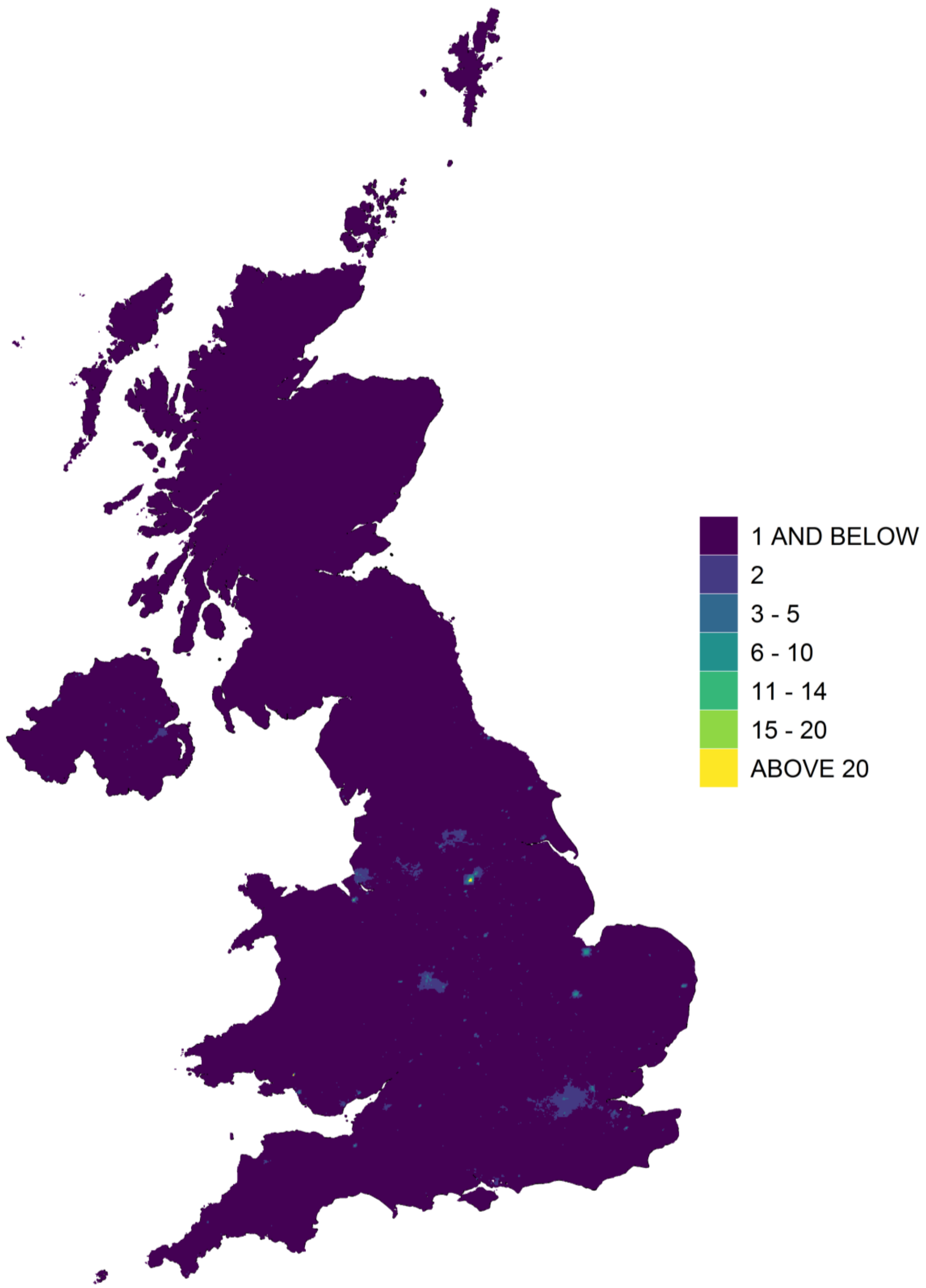
(An interactive version of this map is available at https://uk-air.defra.gov.uk/data/gis-mapping/).

Figure 5-37 Annual Mean Background Cadmium Concentration, 2020 (ng m^{-3})



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

Figure 5-38 Annual Mean Background Nickel Concentration, 2020 (ng m^{-3})



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

5.8.4 Lead: 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, 2016). 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.)

Figure 5-39 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 5-40 shows NAEI estimated total annual UK emissions of this metal from 1990 to 2019. Since the phasing-out of lead in petrol in the 1990s, the largest sources of lead in the UK have been production processes and other industrial combustion.

Figure 5-39 Ambient Concentrations of Pb in PM_{10}, 2004-2020

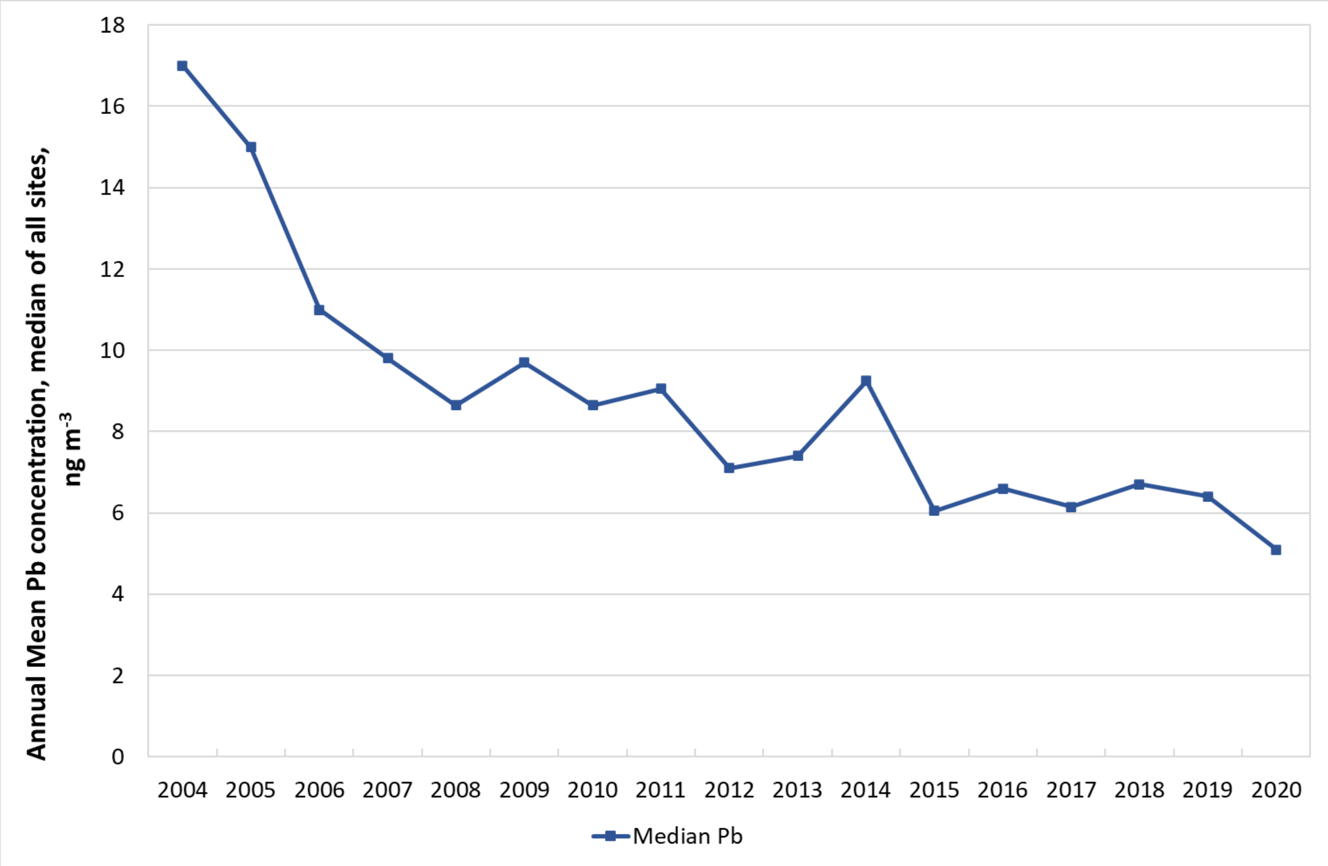
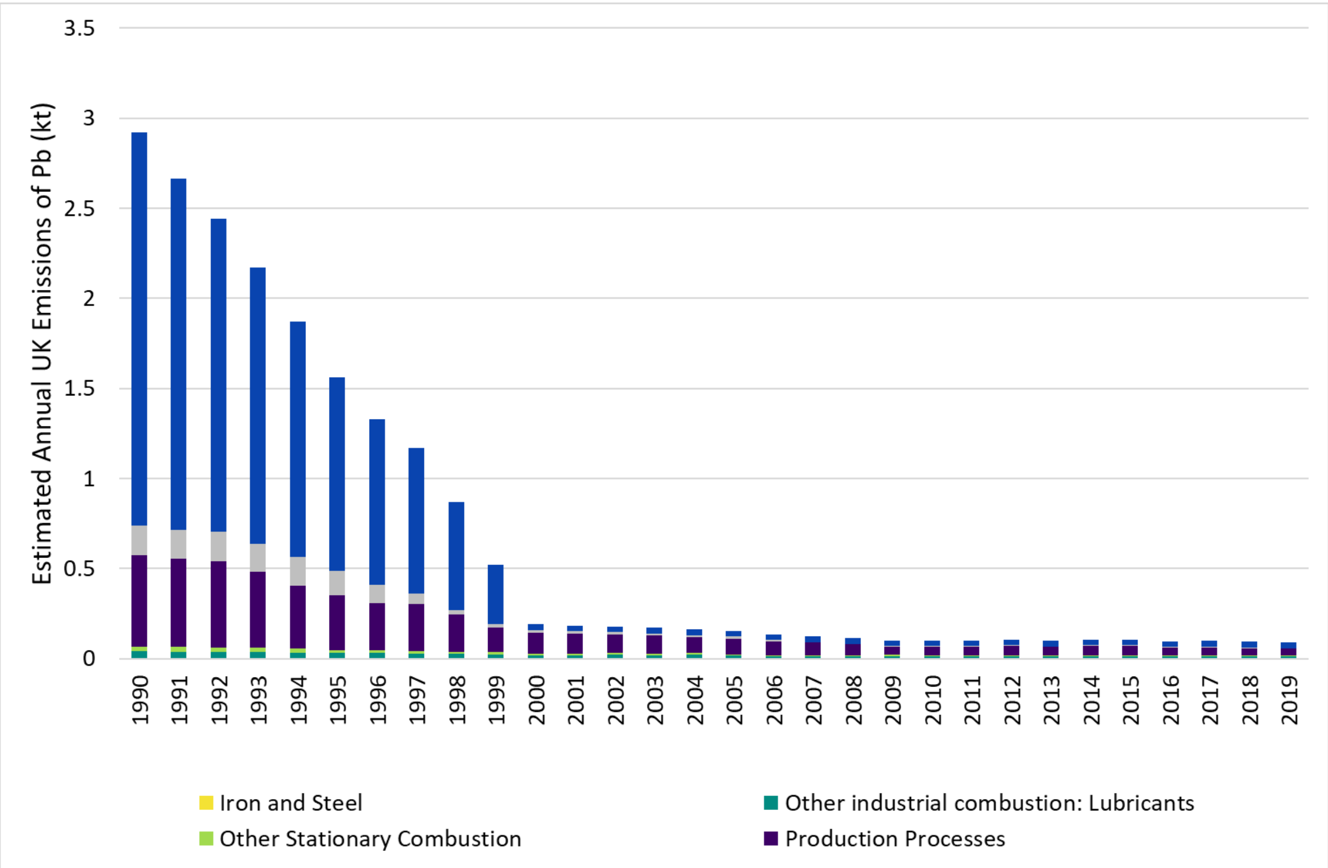


Figure 5-40 Estimated Annual UK Emissions of Pb (kt), 1990 – 2019 (source: NAEI 2019)



5.8.5 Arsenic: Changes Over Time

Figure 5-41 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.

Figure 5-42 shows the UK's estimated total annual emission of As (from the NAEI), in kilotonnes, from 1990 to 2019. The largest human-made sources of As are production processes, waste (particularly the open burning of treated wood), and metal (iron and steel) production processes.

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 5.8.3** above – wind-blown dust is a major natural source of airborne arsenic in some areas.

Figure 5-41 Ambient Concentrations of As in PM_{10}, 2004-2020

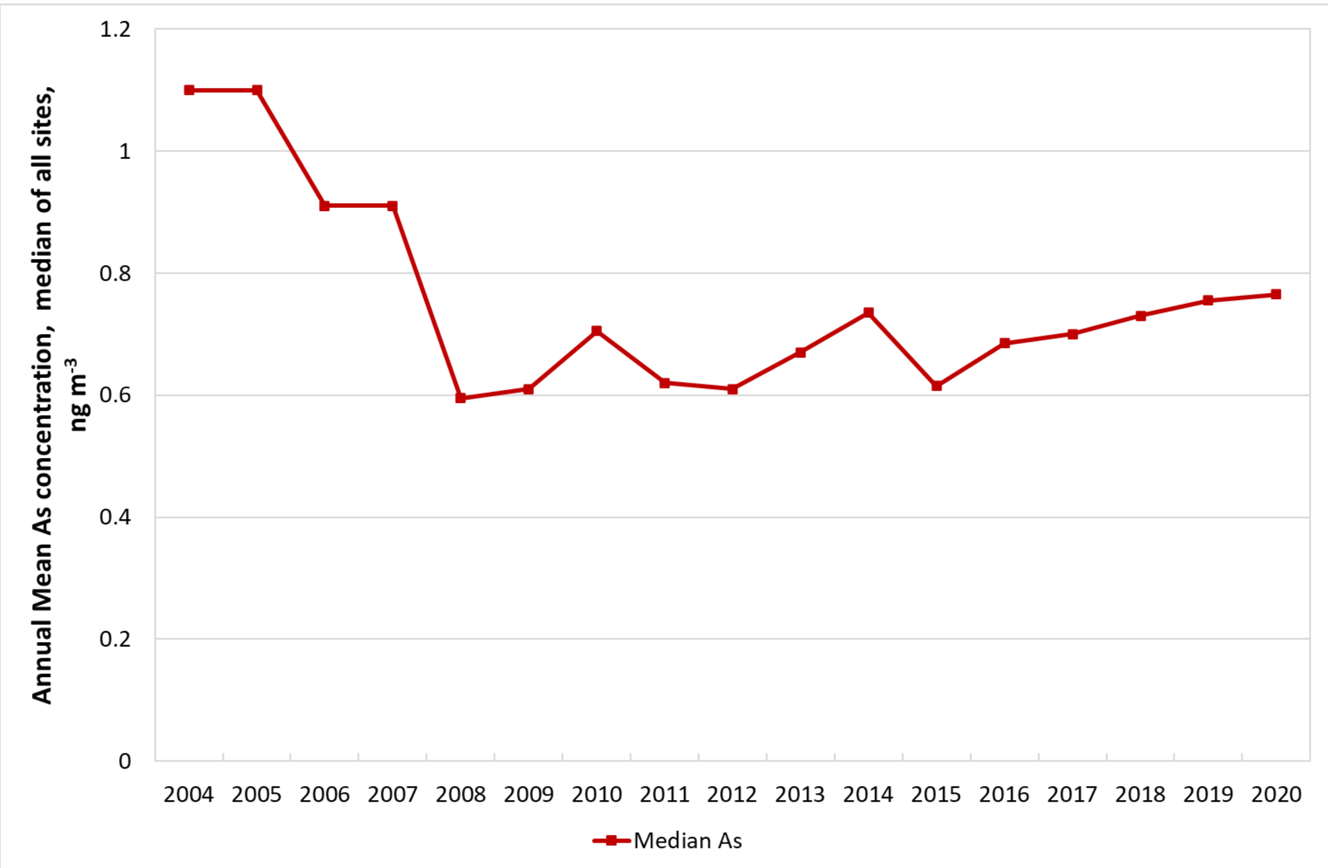
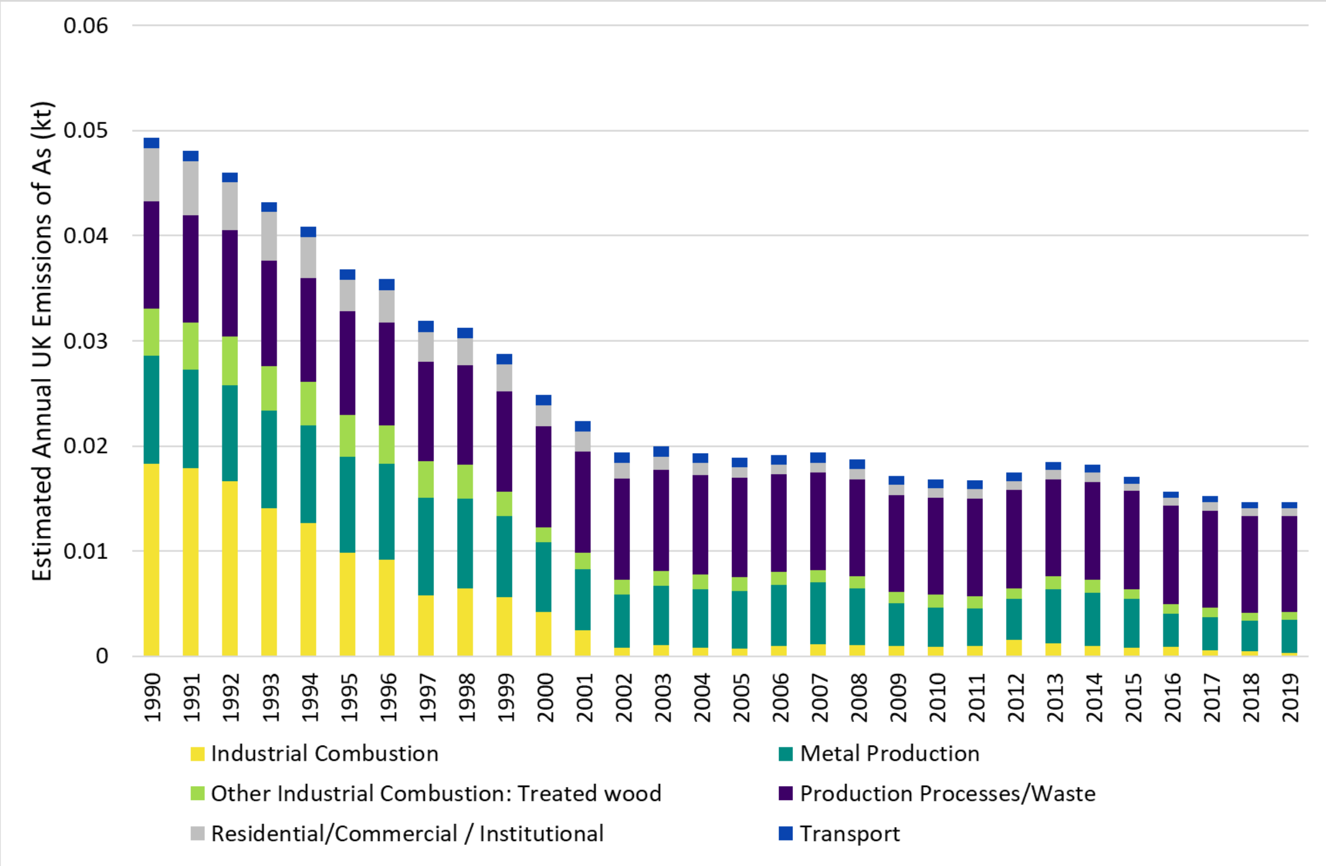


Figure 5-42 Estimated Annual UK Emissions of As (kt), 1990 – 2019 (source: NAEI 2019)



5.8.6 Cadmium: Changes Over Time

Figure 5-43 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 24 sites in operation during 2020. 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 5-44 shows the UK's estimated total annual emission of Cd (in kilotonnes), 1990 to 2019, from the NAEI. The main human-made sources of Cd are combustion in manufacturing industry, production processes and waste incineration, and metal production.

Figure 5-43 Ambient Concentrations of Cd in PM_{10}, 2004 – 2020

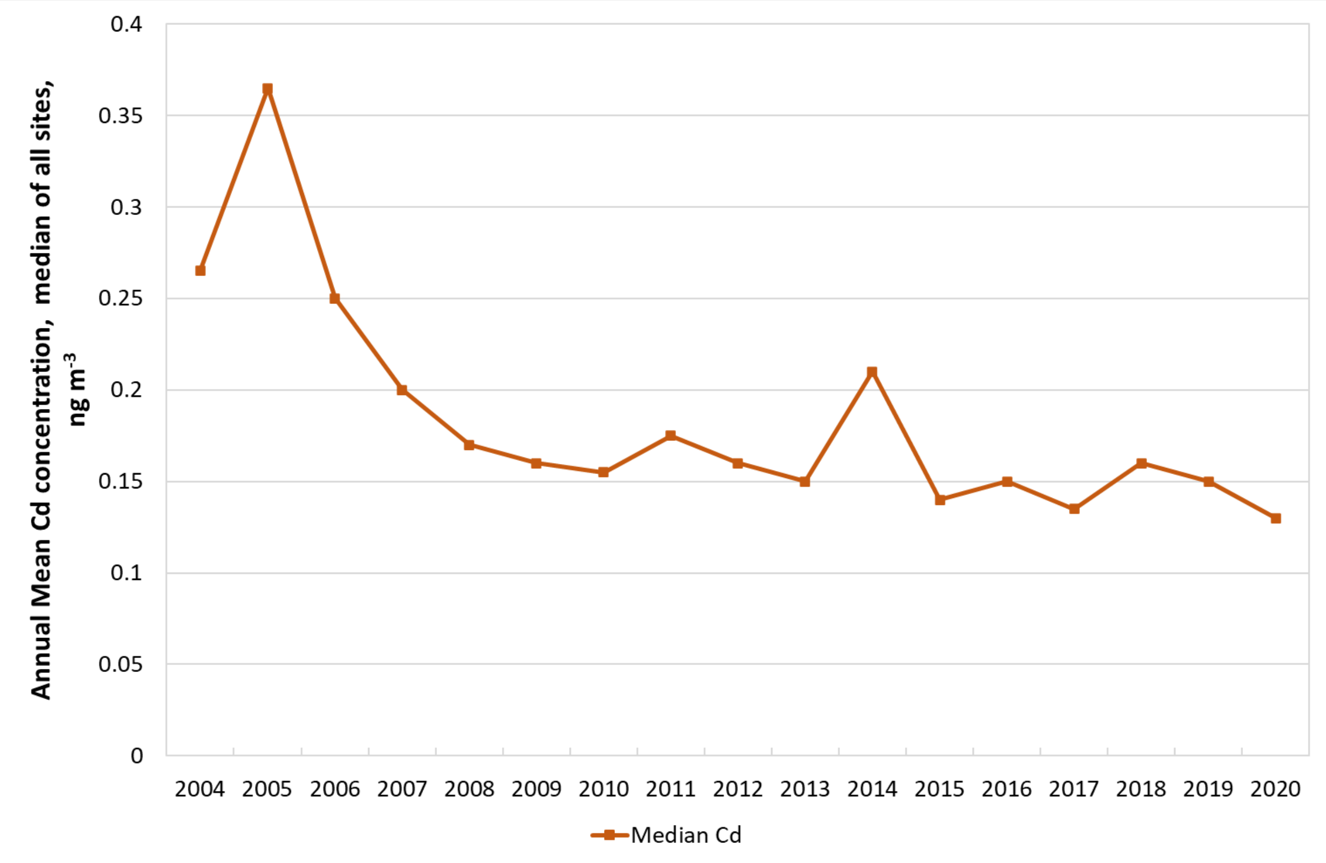
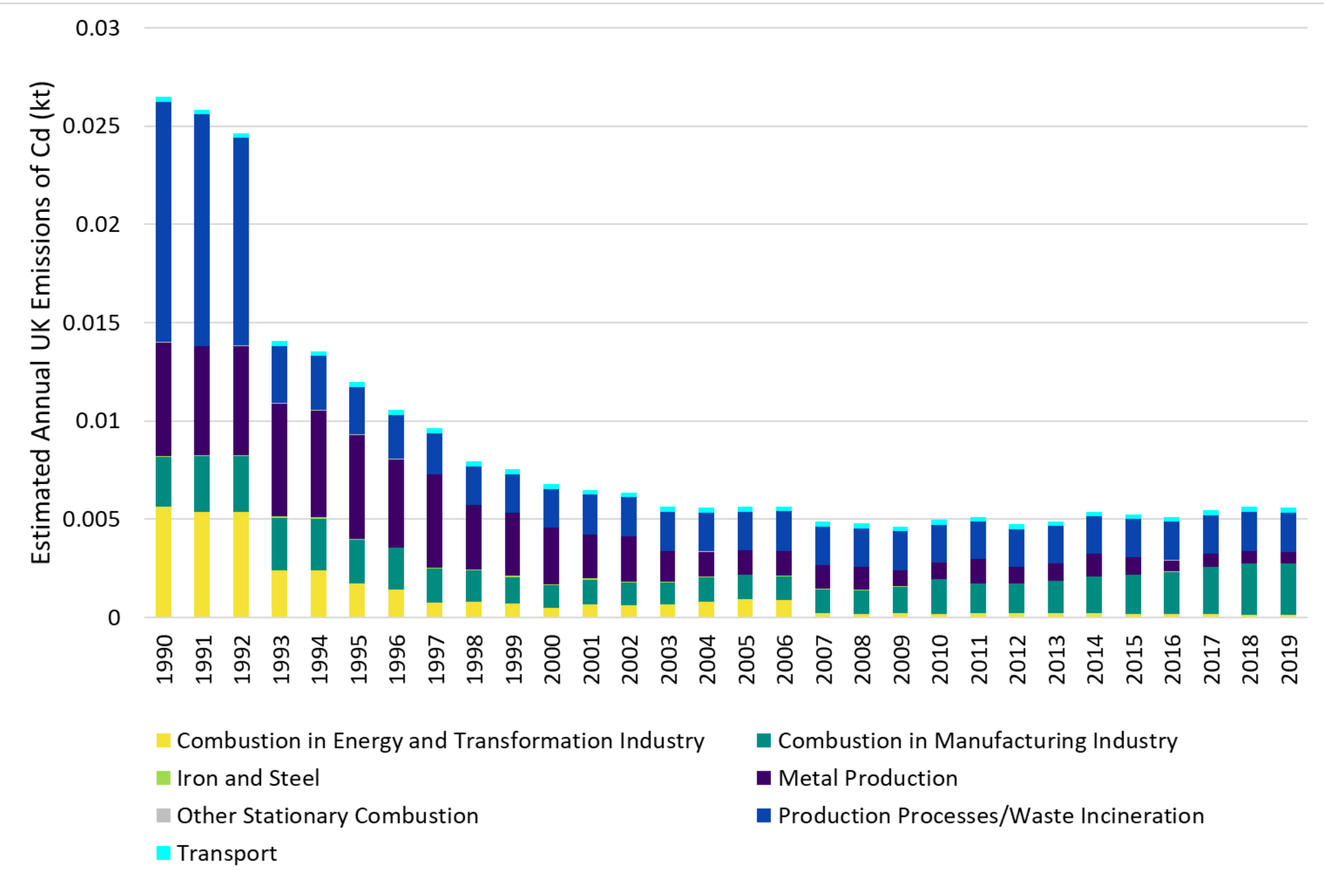


Figure 5-44 Estimated Annual UK Emissions of Cd (kt), 1990 – 2019 (source: NAEI 2019)



5.8.7 Nickel: Changes Over Time

Figure 5-45 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 5-46 shows total estimated annual UK emissions of Ni, from the NAEI, from 1990 to 2019. Stationary combustion in industry is the major source. The NAEI data appear to show a general decrease in Ni emissions over the period for which ambient measurements are available (2004 onwards).

Figure 5-45 Ambient Concentrations of Ni in PM_{10}, 2004 – 2020

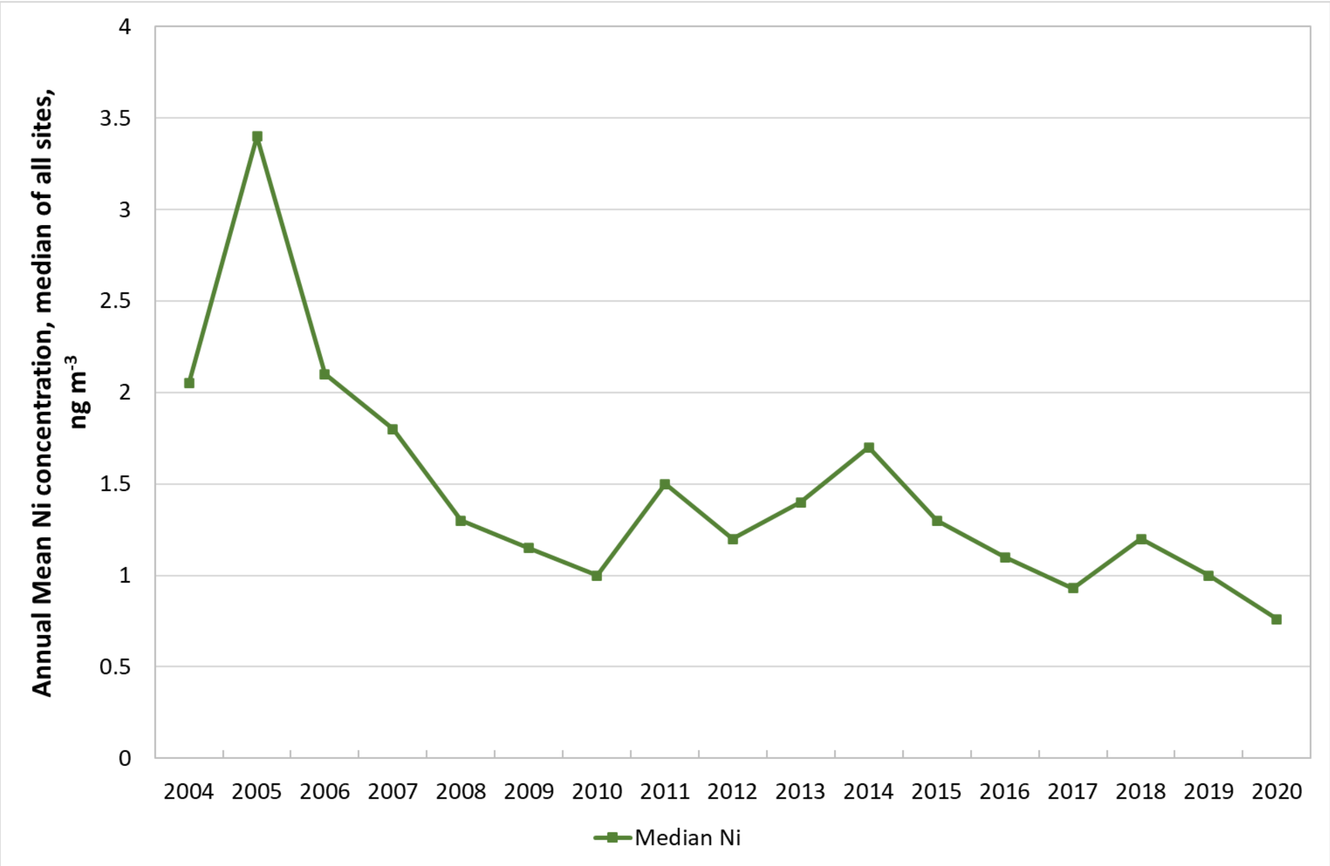
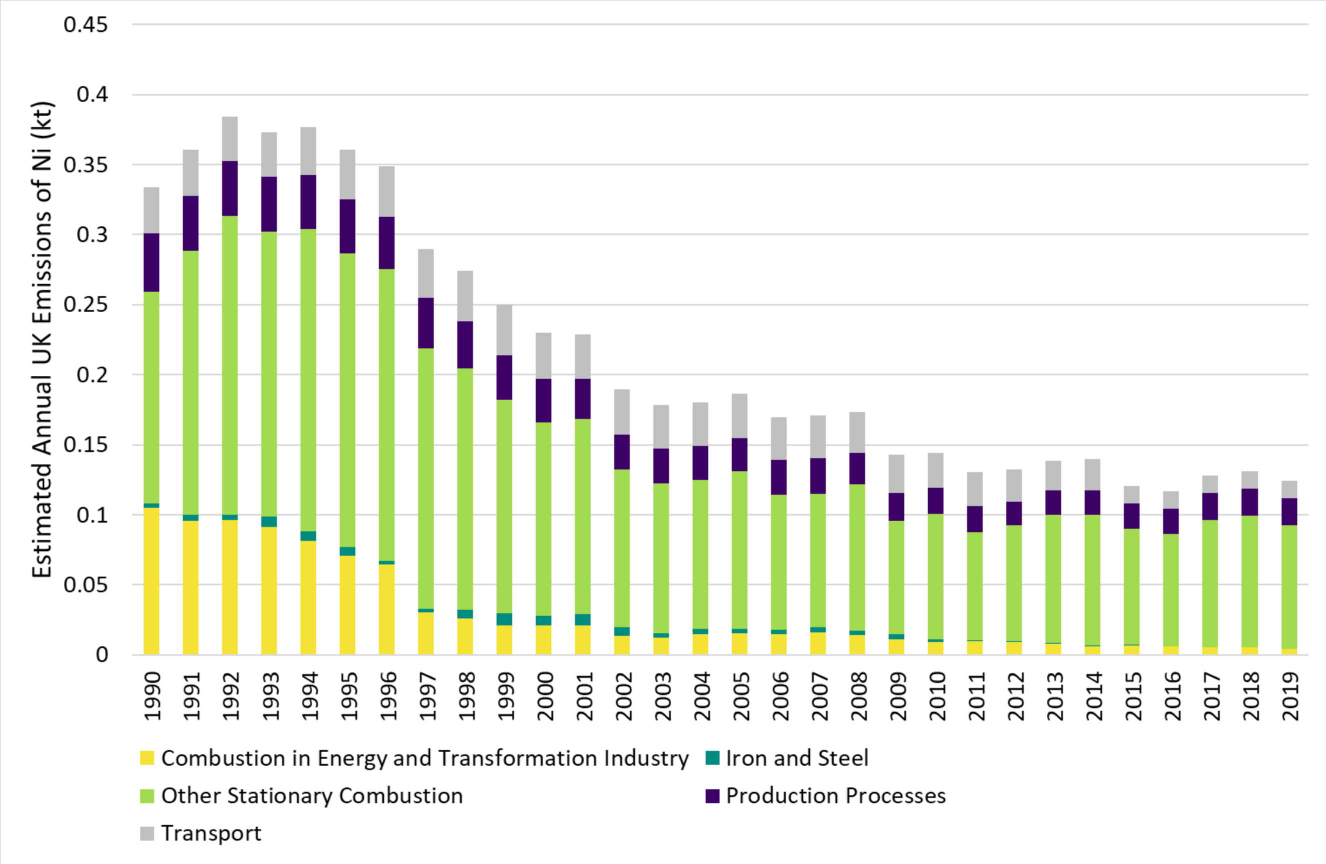


Figure 5-46 Estimated Annual UK Emissions of Ni (kt), 1990 – 2019 (source: NAEI 2019)



5.8.8 Mercury: Changes Over Time

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

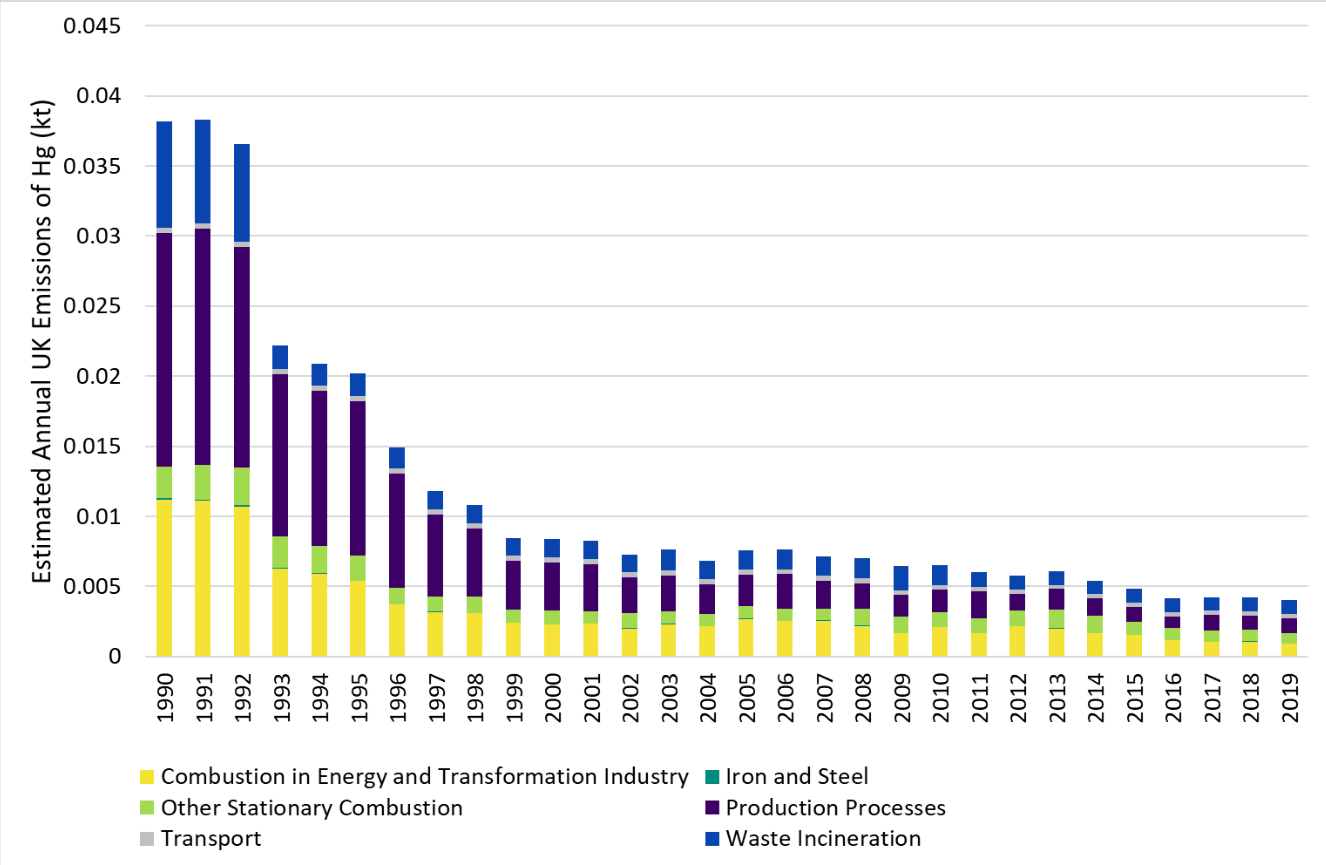
Mercury deposition (dry deposition and deposition in precipitation) is still carried out at several rural sites (see Section 3). However, ambient concentrations of Hg in air are now only measured at two rural sites: Chilbolton Observatory in Hampshire (which measures TGM), and Auchencorth Moss in Lothian. 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**).

Chilbolton Observatory has only been in operation since 2016, which is not considered long enough to evaluate trends. Auchencorth Moss has monitored the above Hg metrics since 2010, but data annual capture has been consistently less than 50%.

Annual mean concentrations of elemental Hg, for Auchencorth Moss only, are available from UK-AIR and have consistently been in the range 1.3 – 1.4 ng m^{-3} since monitoring of this metric began in 2010. There is no clear trend.

Figure 5-47 shows estimated annual UK emissions of Hg, from 1990 to 2019. 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 5-47 Estimated Annual UK Emissions of Hg, 1990 - 2019 (source: NAEI 2019)



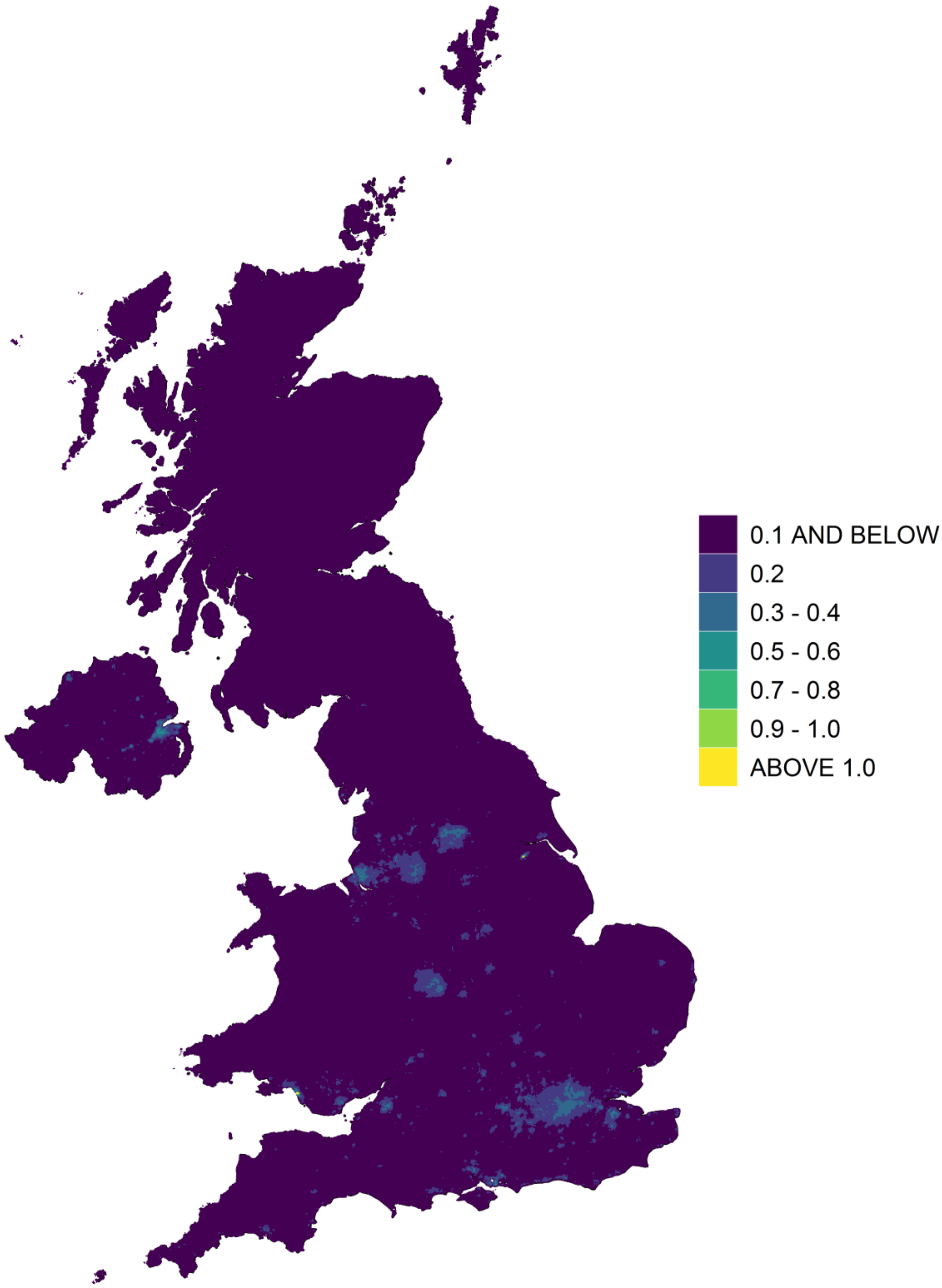
5.9 Benzo[a]pyrene

5.9.1 B[a]P: Spatial Distribution

Figure 5-48 shows the modelled annual mean background concentration of benzo[a]pyrene (B[a]P). The areas of highest concentration reflect the distribution of industrial sources; also, areas where there is widespread domestic use of oil and solid fuels for heating. The latter have historically included the Belfast area and other urban parts of Northern Ireland: also, parts of Yorkshire, Humberside and South Wales.

The only reporting zones with modelled annual mean B[a]P concentrations in excess of 1 ng m^{-3} in 2020 were Yorkshire and Humberside, Swansea Urban Area and South Wales (as also reported in **Section 4**). However, these areas, which are associated with industrial sources, are too small to be clearly seen on the map.

Figure 5-48 Annual mean background B[a]P concentration, 2020 (ng m^{-3})



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

5.9.2 B[a]P: Changes Over Time

The PAH monitoring network began operation in 1991, comprising a small number of sites, which increased to over 20 in the late 1990s. However, during the years 2007-2008, the network underwent a further major expansion and re-organisation, including a change of sampling technique. The newer sampling technique used at most sites from 2008 onwards (the “Digitel” PM_{10} sampler) was found to give higher results than the older method. The reason for this is likely to be due to a number of factors, predominantly the newer 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 5-49** shows how the average annual 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. The composition of the PAH network has changed little since 2008, so it is considered appropriate here to use the data from all sites.

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. However, since then, ambient concentrations appear to have remained relatively stable.

Figure 5-50 shows estimated total UK emissions of B[a]P, 1990 to 2019. Emissions have decreased substantially in recent decades compared to the early 1990s, due in part to measures such as the banning of stubble burning.

Emissions of B[a]P at the present time are dominated by domestic combustion of solid fuels, and the NAEI data indicate that this source (described as “residential/commercial/institutional”) is stable, or even slightly increasing.

Figure 5-49 Smoothed Trend Plot of Ambient Concentrations of Particulate Phase B[a]P, 2008-2020

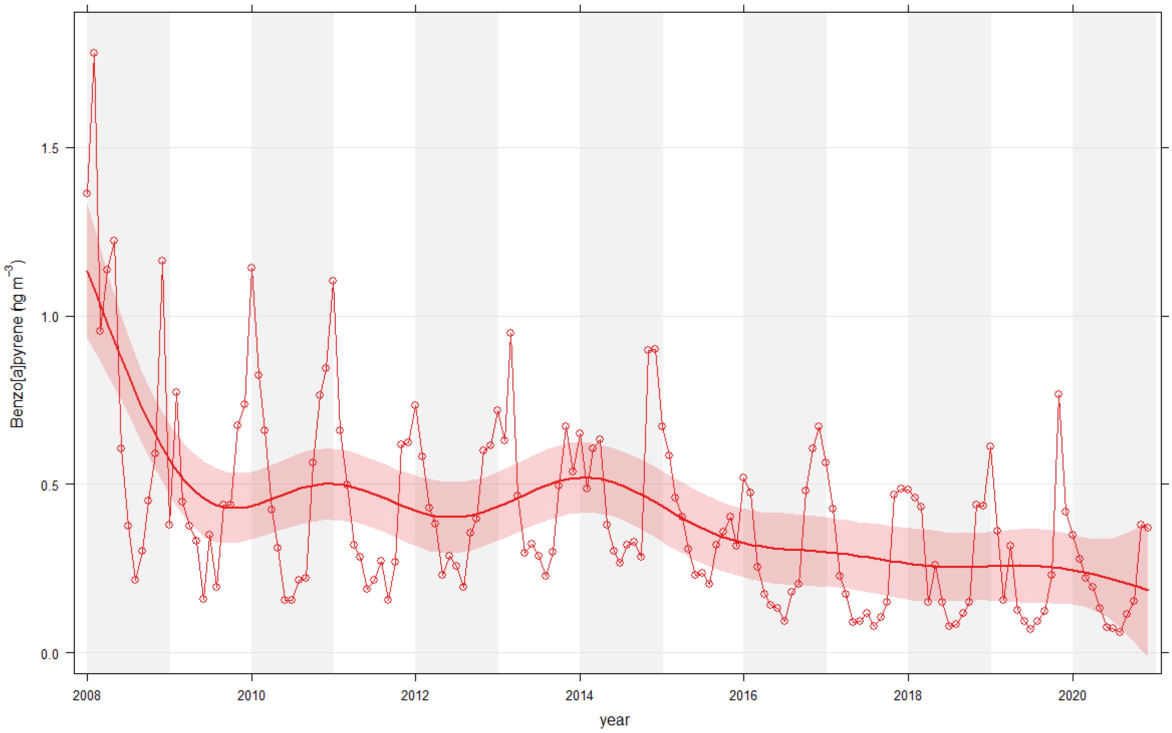
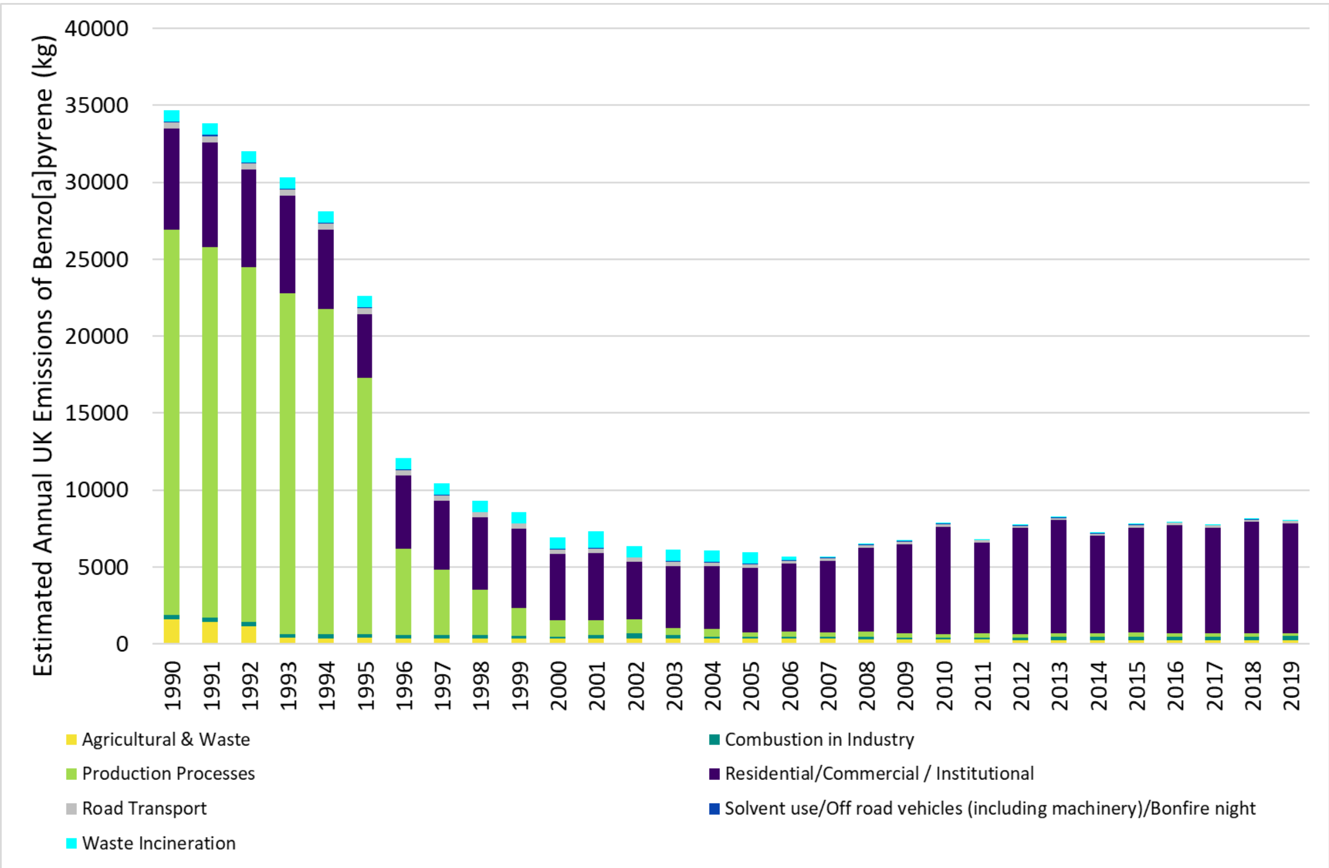


Figure 5-50 Estimated Annual UK Emissions of Benzo[a]pyrene (kg), 1990 – 2019 (source: NAEI)



6 Effects of Covid-19 Restrictions on Air Quality

In previous editions, section 6 of ‘Air Pollution in the UK’ covers noteworthy pollution events in the preceding year. However, 2020 was an unusual year, due to the Covid-19 pandemic and the ‘lockdown’ measures imposed. Therefore, section 6 of this 2020 report focuses mainly on the Covid-19 ‘lockdown’ restrictions, and their observed effects on air quality. A short sub-section at the end of the chapter summarises the other important air pollution events during 2020.

Key dates in the timeline of the UK’s response to the pandemic are as follows:

- Significant Covid-19 cases began to affect the UK from February 2020.
- On 16th March 2020, the Prime Minister issued guidance to begin social distancing, by stopping non-essential contact and travel.
- The first UK national lockdown began on 23rd March. People were instructed to leave home only for essential reasons such as work (if they could not work from home), daily exercise, and shopping for food and other essentials. Schools, pubs, non-essential shops and entertainment venues were closed.
- The lockdown restrictions remained in place throughout April and May, and were gradually lifted throughout the summer, though some areas remained in local lockdown.
- As case numbers rose again in the autumn, new restrictions came into force. These included limits on the size of social gatherings and renewed advice to work from home if possible.
- A second national lockdown was imposed in England, for the four weeks from 5th November to 2nd December 2020.
- Some restrictions continued into 2021, with a third lockdown period for England beginning on 6th January 2021.
- In Scotland, the first lockdown ran from 24th March to 18th June inclusive, with a second lockdown from 5th January to 15th April 2021.
- In Wales, a short “firebreak” lockdown was imposed from 23rd October to 9th November. Wales returned to lockdown on 26th December, with restrictions continuing into 2021.
- Northern Ireland had a second lockdown from 16th October to 20th November, with restrictions continuing into 2021, and a third lockdown period from 26th December into April 2021.

These restrictions affected home life, education, business, industry and travel. These activities are all sources of air pollutants, so the lockdown restrictions might be expected to affect air quality. In this section of the report, we look at the concentrations of four important pollutants - NO_2, O_3, PM_{10} and $PM_{2.5}$ - and assess the impact of lockdown measures on these pollutants across the UK.

This report concentrates on the first UK lockdown, which began on 23rd March 2020. There is a particular focus on this period because the sudden onset of lockdown in March 2020 provided a clear change point to focus on, in terms of ‘before and after’ analysis.

However, aside from the lockdown restrictions themselves, the pandemic caused far-reaching changes in many aspects of life in the UK, some of which will have impacted on air quality. These are likely to have ongoing effects beyond the lockdown period.

6.1 Statistical Modelling

Air quality on any given day depends not only on how much pollution is being emitted in the local area, but also on weather conditions on that day and preceding days. Weather conditions are a particularly important factor for secondary pollutants (that is, pollutants formed from reactions in the atmosphere rather than emitted from source). Ozone is almost entirely a secondary pollutant; PM_{10} and $PM_{2.5}$ include a proportion of secondary material. Therefore, when investigating the possible effects of lockdown restrictions on air quality, it is important to consider the weather conditions at the time. This process of taking into account the variation in pollutant concentrations due to changes in meteorology is called ‘meteorological normalisation’ or sometimes ‘deweathering’ (Air Quality Expert Group, 2020).

Here, this has been done using statistical modelling techniques (Grange & Carslaw, 2019), (Carslaw & Taylor, 2009). The ‘deweather’ R package[3] has been used to predict what the daily concentrations of pollutants would have been in 2020, given the actual weather conditions, but if 2020 had been an ordinary year with no lockdown. This is called the ‘counterfactual’, often informally referred to as the ‘Business as Usual’ (BAU) scenario. The statistical models used previous years’ hourly pollution measurements from the Automatic Urban and Rural Network (AURN), and meteorological data from the Weather Research and Forecasting (WRF) regional scale model. The models were tested by comparing their predictions with real pre-lockdown monitoring data (which had not been used in preparing the model).

These models were then used to predict daily average counterfactual or ‘BAU’ concentrations from 1st March to 31st December 2020 throughout the UK. (Daily averages were used in this case, as there were too many UK sites to run the model for hourly averages). The measured concentrations from the AURN sites were then compared with the modelled BAU scenario, and the differences quantified. Please note that there are uncertainties in data analyses of this type. While this data analysis gives a useful

[3] The model used here uses the ‘deweather’ package in R (https://github.com/davidcarslaw/deweather), and is based on the boosted regression tree (BRT) technique.

indication of how Covid-19 restrictions affected air quality, individual locations will have been affected differently.

In the following sub-sections, we firstly summarise the meteorological conditions during the first lockdown, and how they would be expected to influence air quality. This is followed by discussion of the findings for oxides of nitrogen, ozone, and particulate matter in turn. The final sub-section deals with 2020's other important air pollution events.

Reports on the effects of the Covid-19 lockdown restrictions on air quality in Wales (Ricardo Energy & Environment, 2020) Scotland (Ricardo Energy & Environment, 2021) and Northern Ireland (Ricardo Energy & Environment, 2021) have been produced on behalf of these Devolved Administrations. They are available via the air quality websites for Wales and Scotland and Northern Ireland: the Northern Ireland report is also available on the DAERA website.

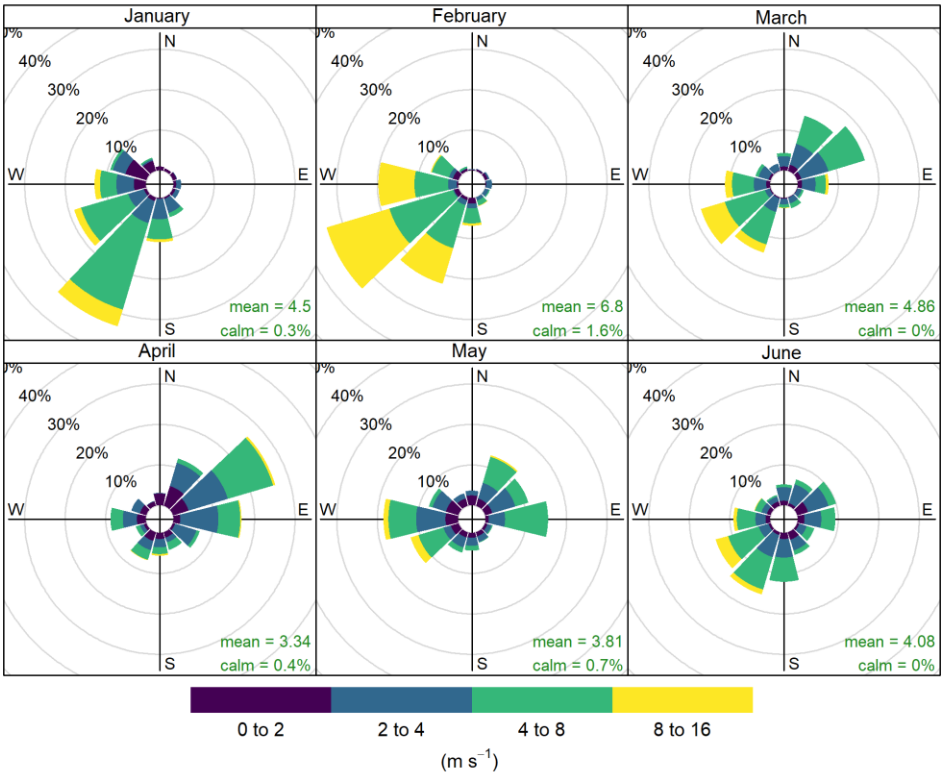
During the implementation of the UK plan for tackling roadside nitrogen dioxide concentrations, complementary models for meteorological normalisation have also been developed. These evaluate the impact of interventions such as clean air zones or other measures on air quality, whilst meeting requirements that differ from this publication. They too can be used to estimate Covid-19 impacts locally or more widely.

6.2 Meteorological Changes and Back Trajectories

To provide context, this section describes the weather conditions prevailing during the first lockdown period. **Figure 6-1** illustrates these using monthly wind rose charts for a weather station at Heathrow Airport, from January to June 2020. (Wind roses show the proportion of time the wind was coming from various directions, and at what speed.)

In January and February 2020, UK weather was dominated by strong winds from a westerly/south westerly direction. In February, strong winds and heavy rain, associated with Storm Ciara and Storm Dennis, occurred across much of the UK, with mean wind speeds of 6.8 ms^{-1} measured at the Heathrow weather station. However, by April, the mean wind speed had dropped to 3.3 ms^{-1} and winds were predominantly from an easterly direction. The point at which the change occurred was around the time of the start of lockdown on 23rd March.

Figure 6-1 Monthly wind roses for Heathrow Airport from January to June 2020. Data source: NOAA Integrated Surface Database (ISD)(2016) https://www.ncdc.noaa.gov/isd

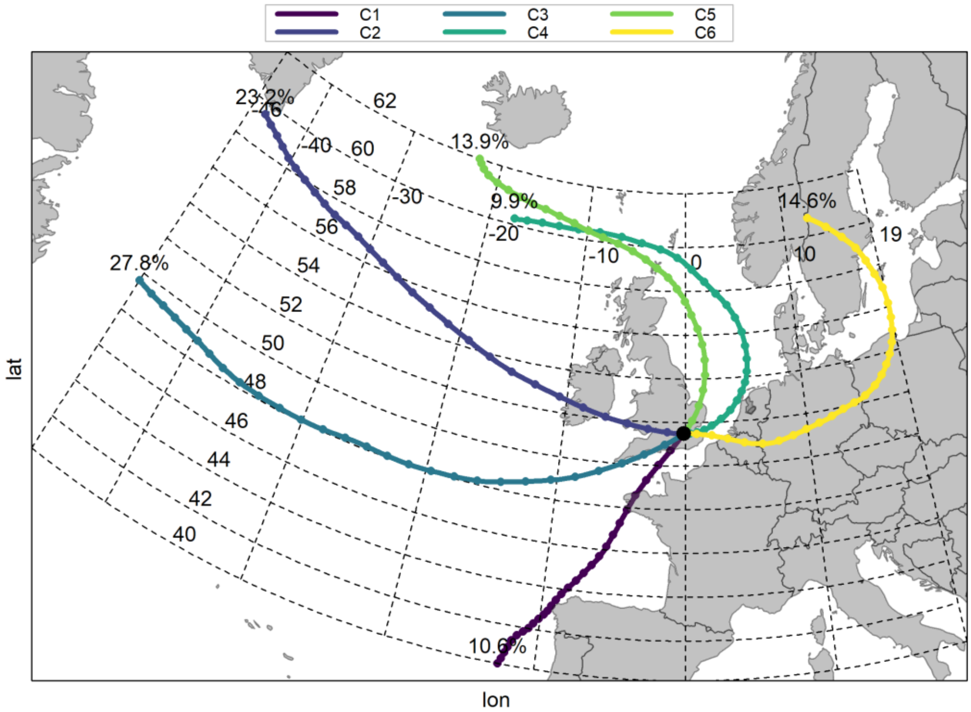


These changes in meteorology are likely to have had an impact upon measured concentrations of pollutants. Westerly winds typically bring clean air to the UK from the Atlantic, whereas easterly winds can import pollutants from the continent, in particular particulate matter and ozone.

To investigate the impact of meteorological changes on PM in more detail, a 'back trajectory analysis' was used. This involves determining where the air masses arriving in the UK on a particular day have originated, and the route they have taken to get here.

This was done using the HYSPLIT Trajectory Model from NOAA Air Resources Laboratory (ARL) (NOAA Air Resource Laboratory, 2016) (Rolph, et al., 2017) (Stein, et al., 2015) and Global NOAA-NCEP/NCAR reanalysis data archives. The trajectories were run for 96 hours, centred on London at an arrival time of 12 noon, and plotted using the Openair package for R (Carslaw & Ropkins, 2012) (Team, 2017) for the period 1st January to 31st May. The back trajectory plot is shown in **Figure 6-2.**

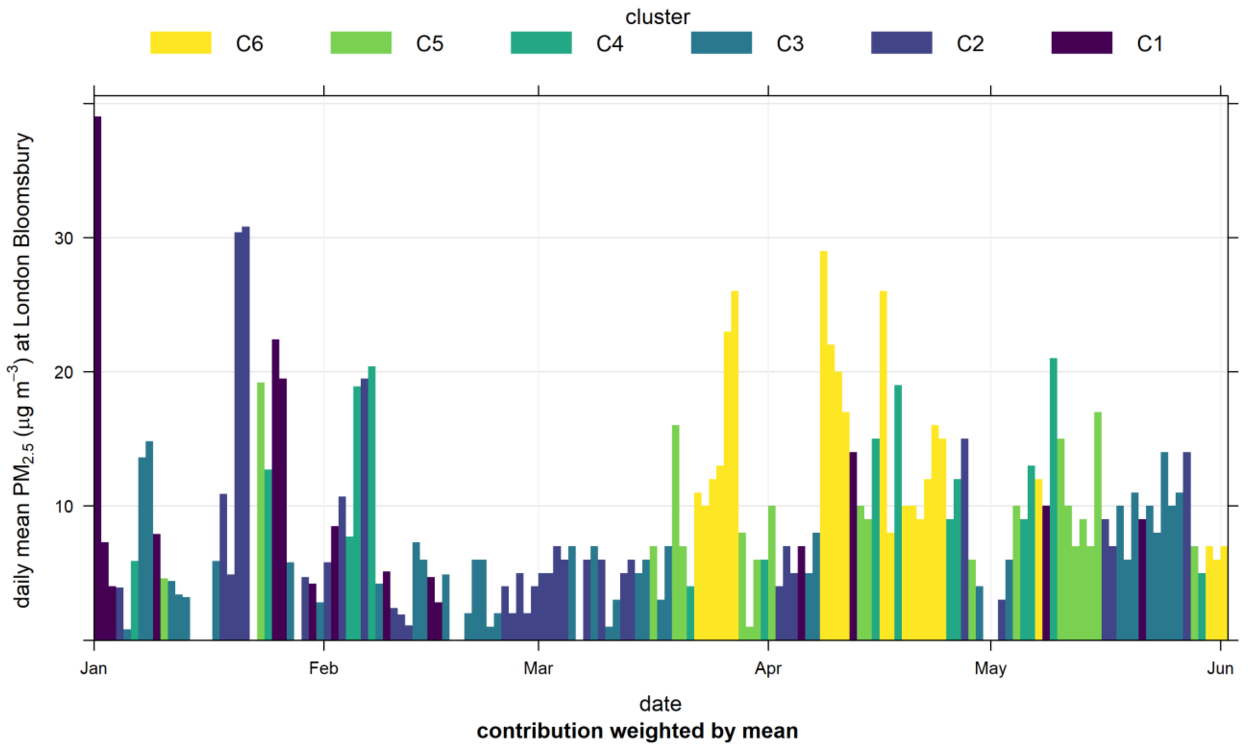
Figure 6-2 Cluster analysis of air mass origins centred on London, during the period 1st January to 31st May 2020. The numbers show the percent of time the air was from each cluster.



Each day's trajectory was grouped into one of 6 'clusters' (C1 to C6), according to its air mass origin. The trajectory clusters were then linked to the $PM_{2.5}$ concentrations measured at the London Bloomsbury AURN monitoring station. (This is an urban background site and therefore is unlikely to be directly influenced by any specific nearby sources.)

During January and February, on most days the arriving air masses came from the west and south west of the UK (clusters C1 to C4) bringing relatively clean air from over the Atlantic Ocean. But in mid-March, around the time lockdown began, air masses began to come in from continental Europe (clusters C5 and C6), potentially bringing higher concentrations of particulate pollution (shown in **Figure 6-3**). The highest daily mean concentrations during late March and April are associated with the 'C6' cluster of trajectories, i.e. air that has travelled over mainland Europe before reaching the UK.

Figure 6-3 Daily mean $PM_{2.5}$ concentrations measured at London Bloomsbury, coloured by air mass origin. Colours are the same as those used in Figure 6-2.



6.3 Nitrogen Oxides (NOx and NO_2)

6.3.1 Road and aircraft traffic

One of the biggest contributors to urban ambient NO_X is emissions from road traffic. This is a particularly important source because the emissions often happen in populated areas. In this section we look at how lockdown affected traffic levels, and whether this had an impact on ambient concentrations of NO_X.

The Department for Transport (DfT) publishes statistics on estimated transport use during the COVID-19 pandemic. Details on the methodology and full statistics can be found here: (https://www.gov.uk/government/statistics/transport-use-during-the-coronavirus-covid-19-pandemic). **Figure 6-4** shows the estimated change in daily traffic volume in Great Britain, as a percentage, compared to equivalent day during the first week in February (i.e. before lockdown began).

This shows that traffic flow on Britain's roads fell to approximately 30% of pre-pandemic levels at the start of the first national lockdown. It then rose steadily through the spring and early summer but did not reach pre-pandemic levels. There was another (smaller) downward step change when the second England lockdown was imposed in November, and a third sharp decrease just before the third England lockdown at the new year.

Figure 6-4 Estimated change in the daily volume of motor vehicles on all roads in Great Britain from 1st March to 31st December 2020, compared to the equivalent day in the first week of February 2020. The green lines represent weekends.

During lockdown periods, weekend traffic was lower than weekday traffic - reflecting the fact that leisure travel was reduced during lockdown. The opposite can be seen during the summer when restrictions were lifted; weekend traffic numbers are higher than those on weekdays. This may reflect the fact that with overseas travel greatly restricted, more people were holidaying in the UK.

Restrictions on travel during the first lockdown resulted in a large impact on air passenger traffic. **Figure 6-5** shows monthly data from the Civil Aviation Authority on international and domestic air passenger traffic from January 2019 to November 2020, indexed to February 2020. (i.e. the February 2020 value is shown as 100.) There is a clear drop in air passenger traffic during the lockdown, with levels in April falling to below 2% of February levels. The large reduction in air passenger traffic will likely also to have an impact on the levels of road traffic around the airports.

Figure 6-5 International and domestic air passenger traffic, non-seasonally adjusted, indexed to February 2020 (i.e. February 2020 = 100%). Source: Civil Aviation Authority. Data accessed from https://www.ons.gov.uk/ .

6.3.2 Ambient NO_2 Concentrations During Lockdown

Figure 6-6 shows the monthly mean difference between measured values and modelled counterfactual ("business as usual" or BAU) daily mean concentrations, in units of µg m^{-3}, at urban traffic monitoring sites in the AURN. There appears to have been a substantial reduction in ambient concentration of NO_2 at these sites, during the lockdown period. This decrease in ambient NO_2 at roadside sites during the lockdown period shows a similar pattern to that of the decrease in traffic (**Figure 6-4**): it is therefore likely to have been caused, at least to some extent, by the reduction in road traffic. The average decreases in roadside NO_2 compared to the counterfactual were in the range 10 – 20 µg m^{-3} in April 2020 in most regions, although there was some local variability in the level of reduction. (Please also note that not all locations within a region will have been affected to the same extent.)

Figure 6-6 Mean monthly difference in measured and counterfactual (“BAU”) NO_2 concentrations at urban traffic sites, for each region. Green bars represent measurements greater than modelled BAU concentrations and blue bars represent measurements lower than modelled BAU concentrations.

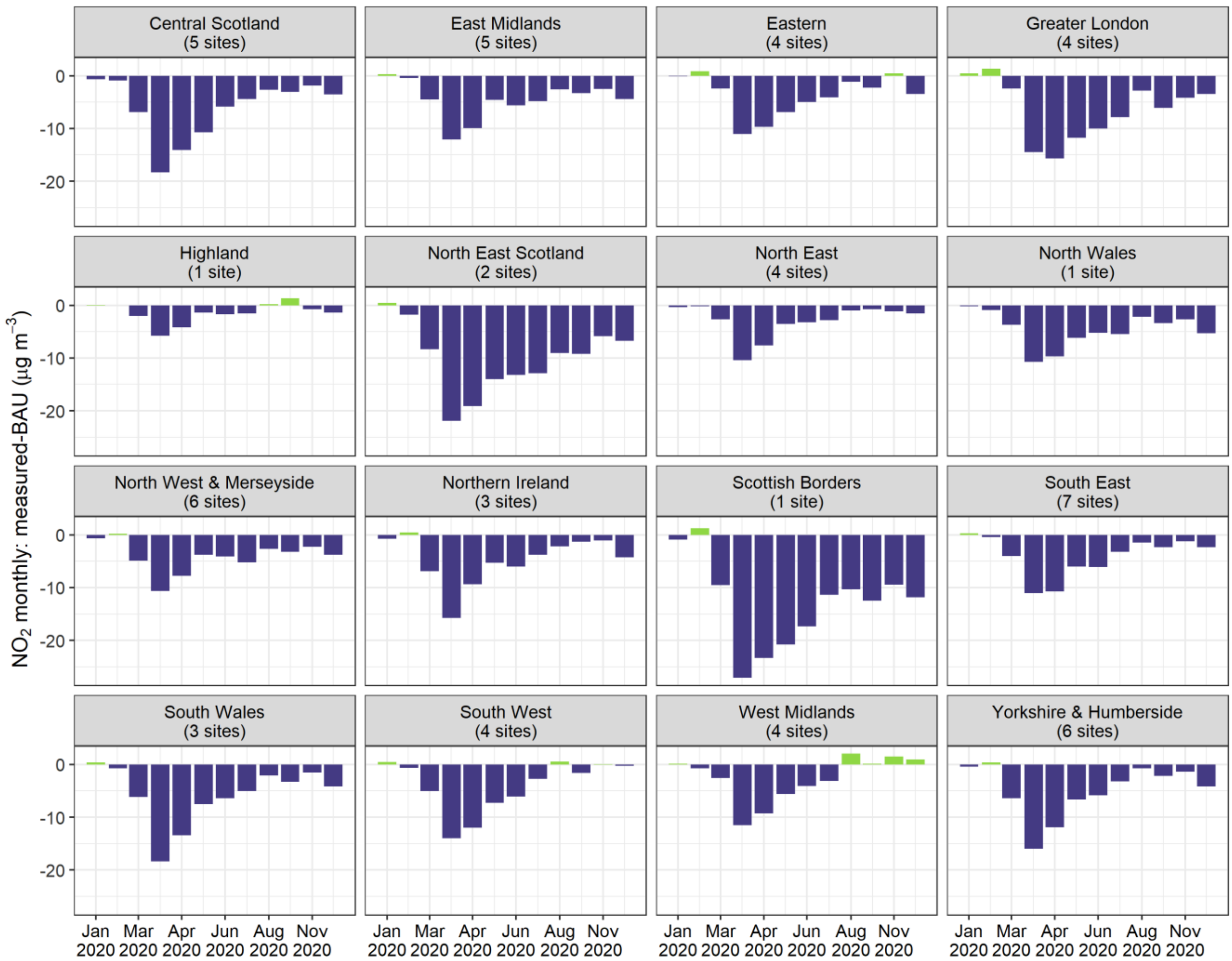


Figure 6-7 is a similar graph, showing the monthly mean difference between daily averaged measured values and modelled counterfactual daily mean concentrations for urban background AURN monitoring sites. The decrease in ambient NO_2 was smaller at urban background sites than at urban traffic sites (note the different y-axis). This is likely to reflect the fact that while roadside NO_2 concentrations are strongly influenced by traffic emissions on the adjacent road, urban background concentrations are determined by a mix of sources.

Figure 6-7 Mean monthly difference in measured and counterfactual ("BAU") NO_2 concentrations at urban background and suburban sites, for each region. Green bars represent measurements greater than modelled BAU concentrations and blue bars represent measurements lower than modelled BAU concentrations.

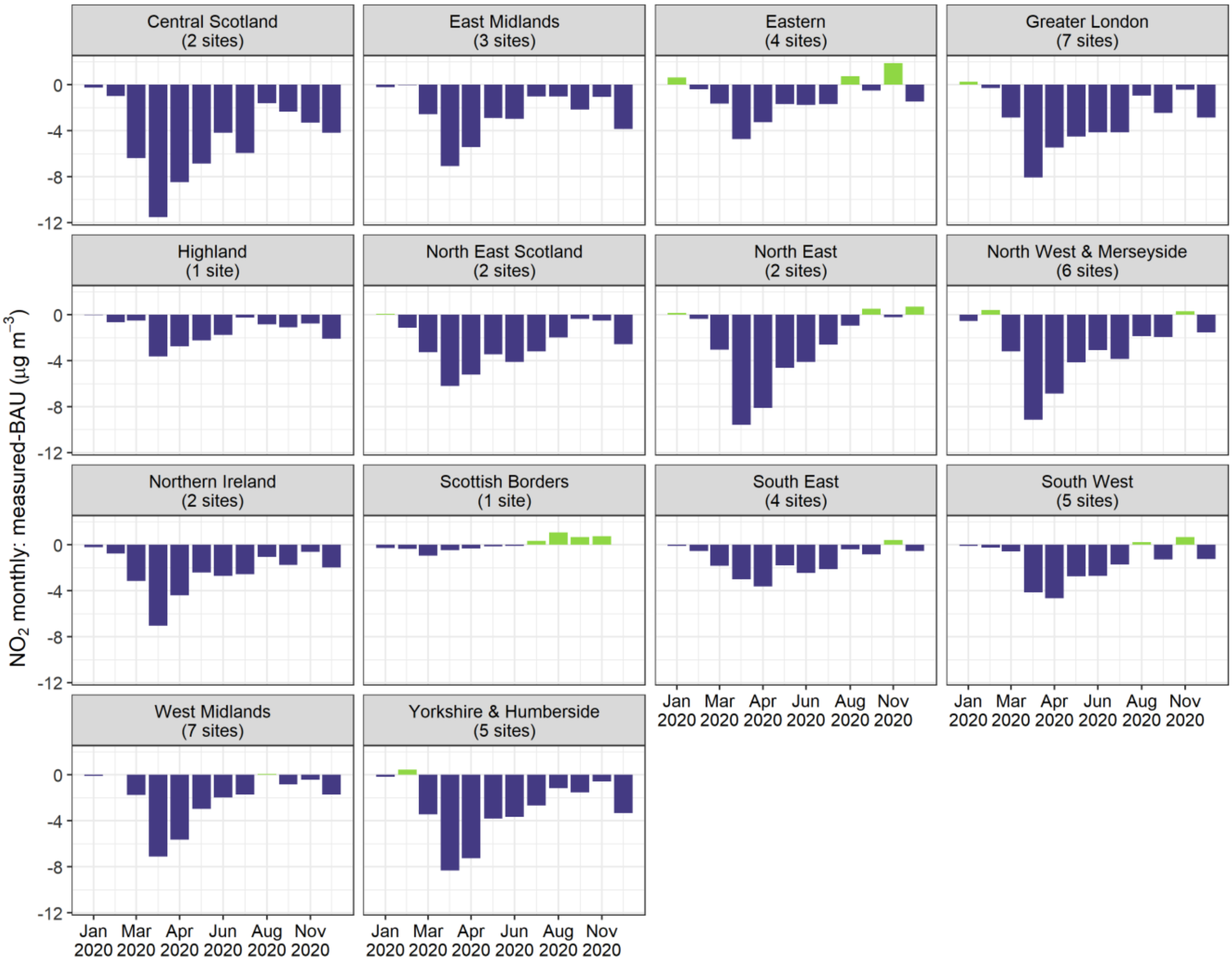
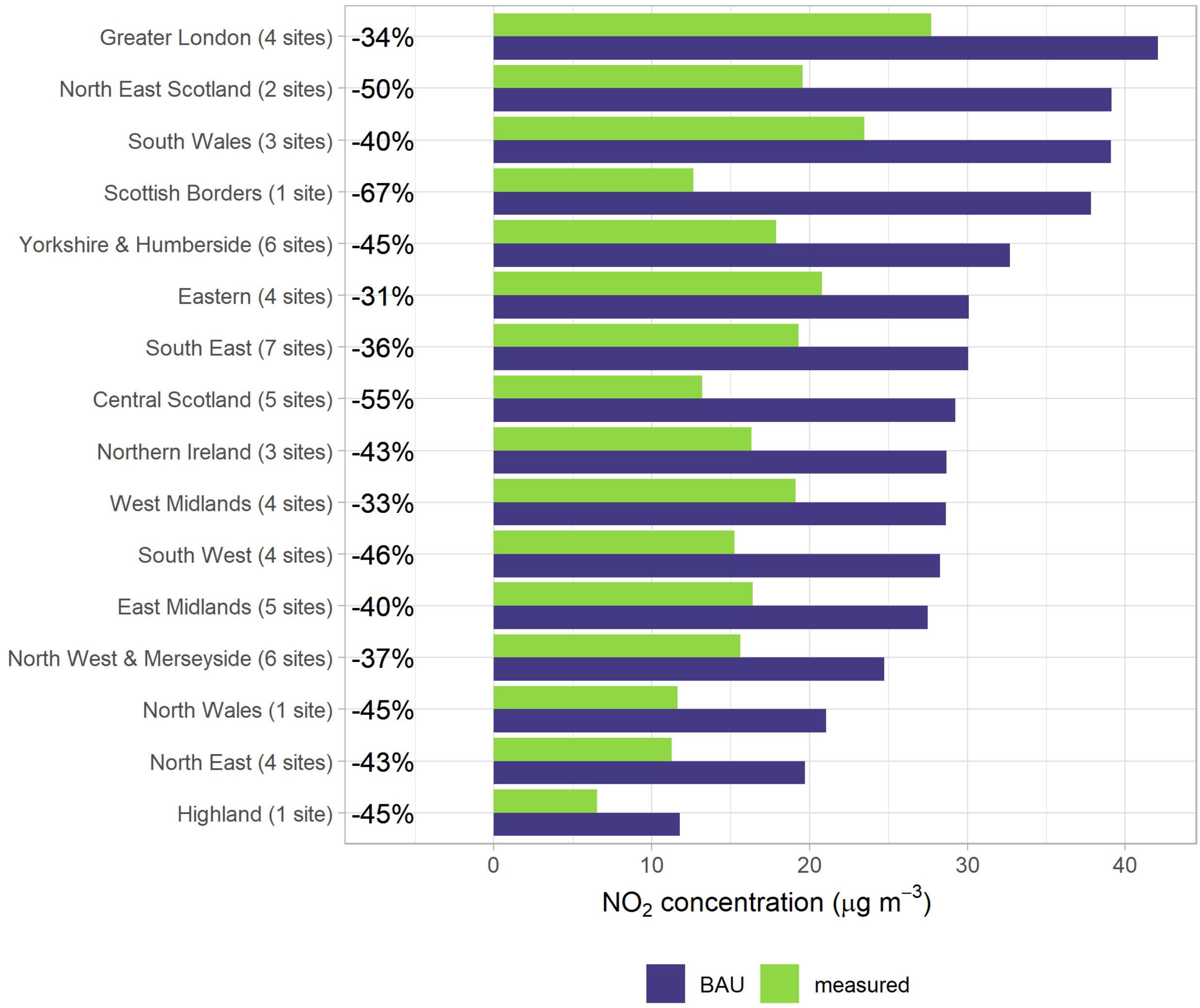


Figure 6-8 shows a comparison between measured and counterfactual (BAU) NO_2 concentrations measured at urban traffic AURN sites, during the first national lockdown from 23rd March to 31st May 2020, for each region. In this graph, the decrease is shown in percentage terms. In all regions, measured roadside NO_2 concentrations were lower than BAU, ranging from -31% to -67%. At the majority of measurement sites, roadside NO_2 concentrations remained lower than BAU throughout the remainder of 2020, although there continued to be considerable local level variability in the level of reduction.

Figure 6-8 Measured (green) and modelled counterfactual "BAU" (blue) NO_2 concentrations, at urban traffic sites for different regions, averaged over the period 23rd March to 31st May 2020. The numbers on the left show the percentage change in concentration relative to the counterfactual.



6.4 Ozone (O_3)

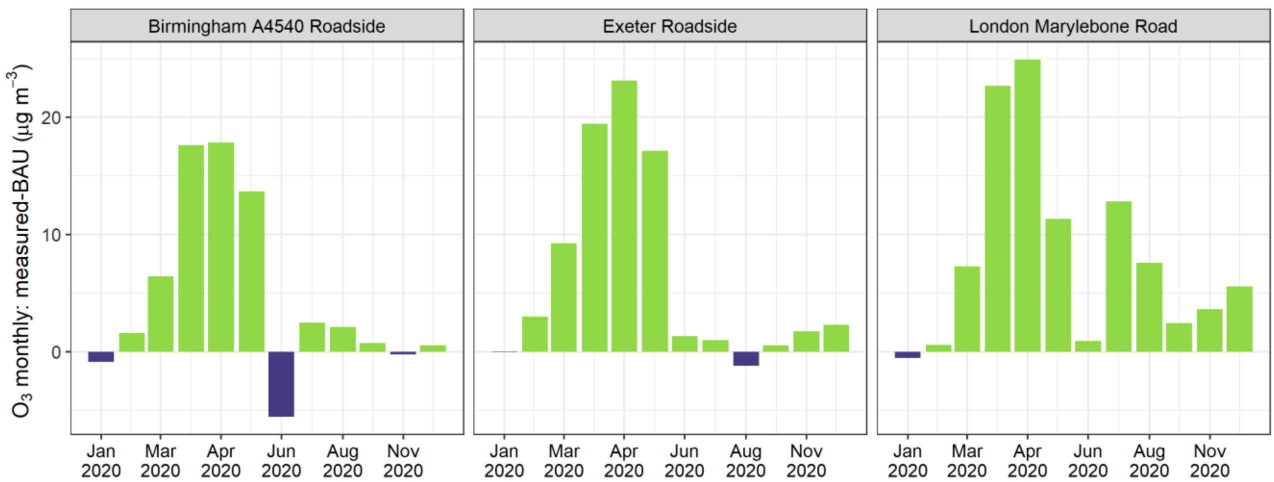
Ozone concentrations are typically higher in the spring and summer months, compared to winter. 'Episodes' of high ozone and/or particulate pollution often occur at this time of year. This was the case in 2020: as explained in Section 6.2, the start of lockdown coincided with the start of a period of fairly settled weather, with above average sunshine and temperatures and predominantly easterly winds (Met Office, 2020 (Apr)). These conditions are conducive to ozone formation, and significant high ozone episodes, driven by changes in meteorology, were observed during the first lockdown period. The episodes themselves are discussed in more detail in Section 6.6 below.

This section looks at the possible influence of lockdown. As we have seen, the observed reductions in road traffic during the first lockdown period led to a decrease in ambient NO_2 concentrations. However, it is possible that the reduction in traffic may have had the opposite effect for ozone. In urban areas, close to roadside, measured ozone concentrations are typically low, as ozone readily reacts with nitric oxide (NO) to form NO_2. The reduction in NOx emissions may therefore have caused an increase in urban ambient ozone concentrations, as there was less NO available to ‘scavenge’ ozone from the air.

This has been investigated by comparing measured concentrations with the modelled counterfactual or “business as usual” (BAU) scenario. **Figure 6-9** shows the monthly mean difference between daily averaged measured values and modelled BAU concentrations, in units of µg m^{-3}, at the three urban traffic monitoring sites in the AURN which measure O_3.

At all three sites there was an increase in ozone during the lockdown period in spring 2020, compared to BAU. The observed increase may have been, in part, due to the reduction in road traffic and resulting decrease in NOx emissions.

Figure 6-9 Mean monthly difference in measured and counterfactual or “BAU” O_3 concentrations for the AURN’s three urban traffic sites. Green bars represent measurements greater than modelled concentrations and blue bars represent measurements lower than modelled concentrations.



6.5 Particulate matter

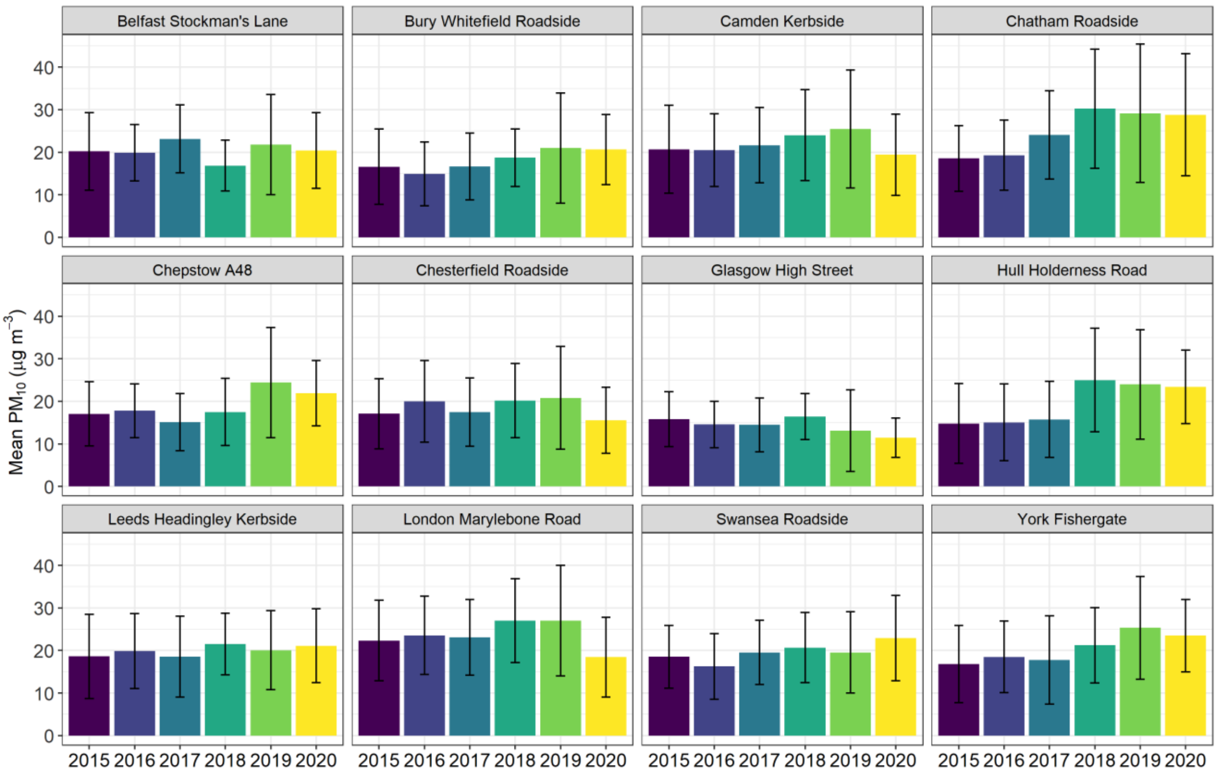
Assessing the impact of lockdown on particulate matter (PM) concentrations is challenging, because PM comprises a mixture of locally emitted pollution and continental pollution. The challenge is to separate effects of lockdown-related changes in local emissions from weather-related changes to continental pollution. One method is to look at the *urban increment* in PM. This is difference between PM_{10} or $PM_{2.5}$ concentration as measured at urban monitoring sites, and the same measurement at nearby rural monitoring sites.

There are five rural sites in the AURN where PM_{10} and $PM_{2.5}$ are measured. However, only three of these sites have been monitoring $PM_{2.5}$ for long enough to have sufficient measurements to enable modelling of the counterfactual and analysis of the urban increment in $PM_{2.5}$. As there are few rural sites, the concentrations at these sites do not necessarily represent the background concentrations in other parts of the UK, therefore we have not used the ‘deweathering’ BAU modelling method for assessing changes in PM.

Instead, we have assessed the change in PM_{10} and $PM_{2.5}$ during the lockdown periods by comparing the concentrations measured during the lockdown period in 2020 with mean concentrations measured during the same period over the previous five years. This is a less robust approach, as it does not take into account the effects of weather, as the deweathered BAU approach, used above for NO_2 and O_3, does.

The comparison for PM_{10} is shown as a bar chart in **Figure 6-10**. Only those sites with over 75% data capture for PM_{10} in all six years from 2015 to 2020 have been included in the analysis here.

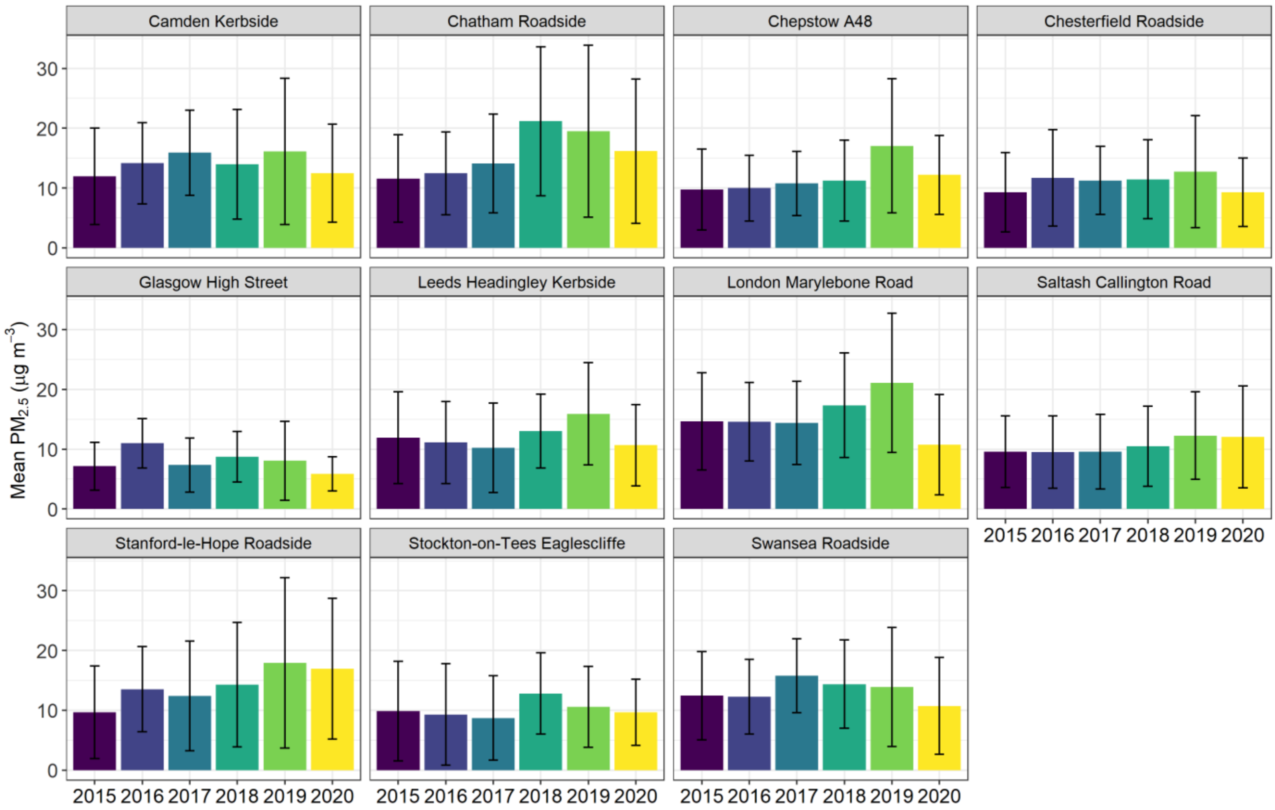
Figure 6-10 Average of the daily mean PM_{10} concentrations for the lockdown period in 2020 (weeks 13 to 22 of the year), compared with the mean concentrations over the same period for each year from 2015 to 2019, for urban traffic sites in the UK. Error bars represent the standard deviation of the means.



With the exception of Leeds Headingley Kerbside and Swansea Roadside, the mean PM_{10} concentrations for weeks 13 – 22 of the year were similar or lower in 2020 than in 2019. However, of these, at only four of the sites were the PM_{10} concentrations lower than those for all years from 2015 to 2019.

A similar comparison was performed for $PM_{2.5}$, as shown in **Figure 6-11**.

Figure 6-11 Average of the daily mean $PM_{2.5}$ concentrations for the lockdown period in 2020 (weeks 13 to 22 of the year), compared with the mean concentrations over the same period for each year from 2015 to 2019, for urban traffic sites in the UK. Error bars represent the standard deviation of the means.



The mean $PM_{2.5}$ concentrations for weeks 13 – 22 were consistently lower in 2020 than in 2019 for all these sites. However, only at five of the sites was this value lower in 2020 than in *any* of the preceding five years.

Figure 6-12 and **Figure 6-13** show a comparison of the average daily mean PM_{10} and $PM_{2.5}$ concentrations over the period 23rd March to 31st May 2020, with the average of all the daily means for the same period, from 2015 to 2019.

The Mann-Whitney U statistical test (Wilcoxon, 1945) (Mann & Whitney, 1947) was used to determine the statistical significance of the differences between 2020 and previous years. For PM_{10}, four sites (Camden Kerbside, Chesterfield Roadside Glasgow High Street London Marylebone Road) showed a significant decrease ($p < 0.01$) in PM_{10} concentrations in 2020, when compared to the same period in the previous 5 years.

Of the 11 urban traffic sites shown in **Figure 6-13**, only three sites (Glasgow High Street, London Marylebone Road and Swansea Roadside) showed a significant decrease ($p < 0.01$) in $PM_{2.5}$ concentrations in 2020, when compared to the same period in the previous 5 years.

Figure 6-12 Average of the daily mean PM_{10} concentrations for the lockdown period in 2020, compared with the average concentrations from 2015 to 2019, over the same period, for urban traffic sites in the UK. Error bars represent the standard deviation in the means.

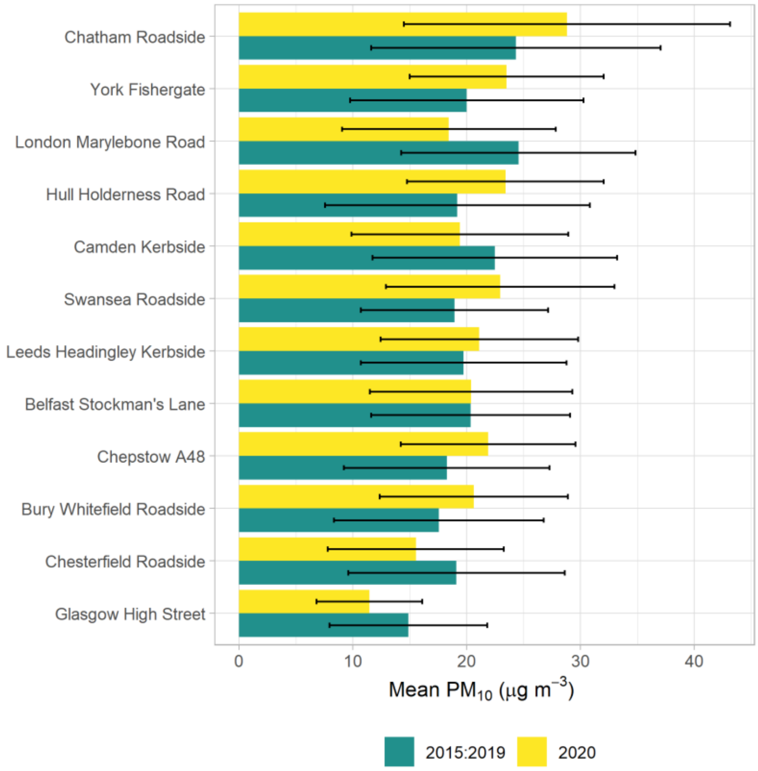
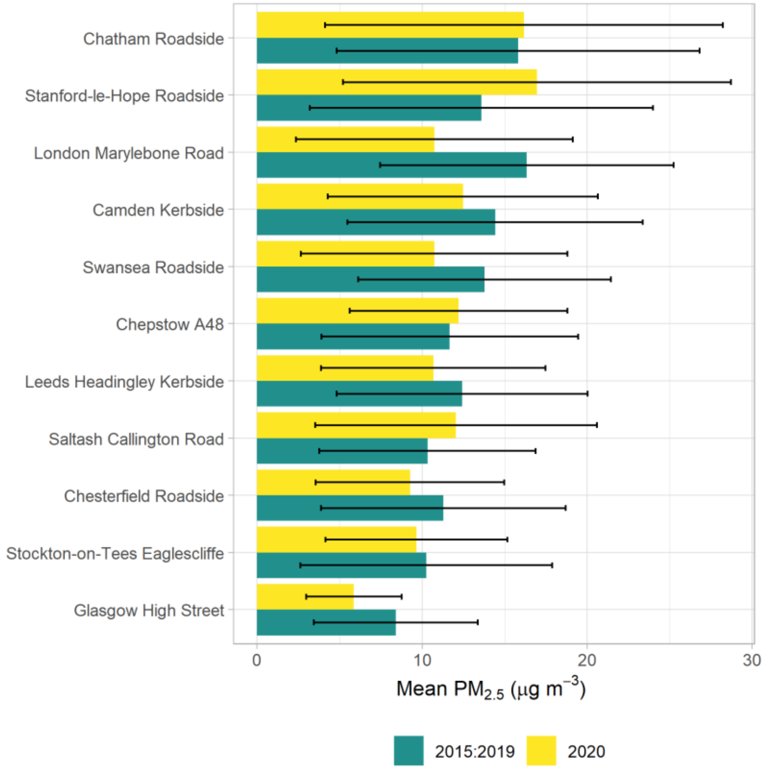


Figure 6-13 Average of the daily mean $PM_{2.5}$ concentrations for the lockdown period in 2020, compared with the average concentrations from 2015 to 2019, over the same period, for urban traffic sites in the UK. Error bars represent the standard deviation in the means.



The above data analyses therefore do not suggest that concentrations of PM_{10} and $PM_{2.5}$ at roadside sites were consistently reduced in the lockdown period. This may be because of the mix of sources contributing to ambient PM concentrations. Also, the weather conditions prevailing through the first spring lockdown period, which would have been favourable to both the long-range transport of particulate pollution from the continent of Europe, and the formation of secondary particulate matter (see section 6.2). This type of weather pattern often causes particulate pollution episodes in spring and early summer. It may be that the effects of meteorology outweighed any decrease in ambient PM caused by lockdown restrictions.

6.6 Other Significant Pollution Episodes in 2020

6.6.1 Ozone and Particulate Pollution - April 2020

During April 2020, the UK experienced settled weather in general, with above average sunshine and temperatures and predominantly easterly winds (Met Office, 2020 (Apr)). These conditions are conducive to pollution episodes, particularly for particulate matter and ozone. Therefore, despite the reduced emissions from traffic and other local sources caused by lockdown, conditions were right for an episode of PM and ozone pollution.

The Daily Air Quality Index (DAQI) is used to inform the public about levels of air pollution and provides recommended actions and health advice. The index is numbered 1-10 and divided into four bands, ‘Low’ (1-3), ‘Moderate’ (4-6), ‘High’ (7-9) and ‘Very High’ (10), to provide detail about air pollution levels in a simple way (Defra, 2013). The DAQI reached the ‘Moderate’ band in many regions across the UK during April, and in the Eastern and South Eastern Regions the ‘High’ index band was reached.

Figure 6-14 shows the daily max PM_{10} and $PM_{2.5}$, and daily max 8-Hour running mean ozone for the Eastern and South East regions from 1st to 25th April 2020. The DAQI thresholds for the ‘Moderate’ and ‘High’ bands for each pollutant are also shown. Particulate matter peaked on April 9th with concentrations in the ‘High’ index band for PM_{10} and $PM_{2.5}$ in the Eastern region and ‘High’ $PM_{2.5}$ in the South East. A second smaller peak in PM_{10} and $PM_{2.5}$ concentrations was also observed on 16th April for these two regions.

Moderate ozone levels were also recorded on many days across the UK during April 2020. The only regions where ozone did not reach the moderate band on at least one day in April were North East and North East Scotland.

Figure 6-14 Daily max PM_{10} and $PM_{2.5}$ concentrations for the Eastern and South East regions from 1st to 25th April 2020. The solid horizontal lines represent the "moderate" DAQI band and the dashed lines the "high" DAQI band, for each pollutant.

6.6.2 High Ozone Episodes Summer 2020

High levels of ozone often occur in the spring and summer months, when the weather is warm, still, and sunny - conditions which allow ozone levels to build up. The lifetime of ozone in rural areas can be of the order of a few days, therefore, ozone events are often widespread. Furthermore, the transport of ozone and its precursors from continental Europe can also add to the pollution in the UK. During summer 2020 there were four significant ozone events, where levels in some regions reached the DAQI "High" band, and exceeded the **EC Directive Ozone Population Warning Threshold** of 180 µg m^{-3}. These occurred on the following dates:

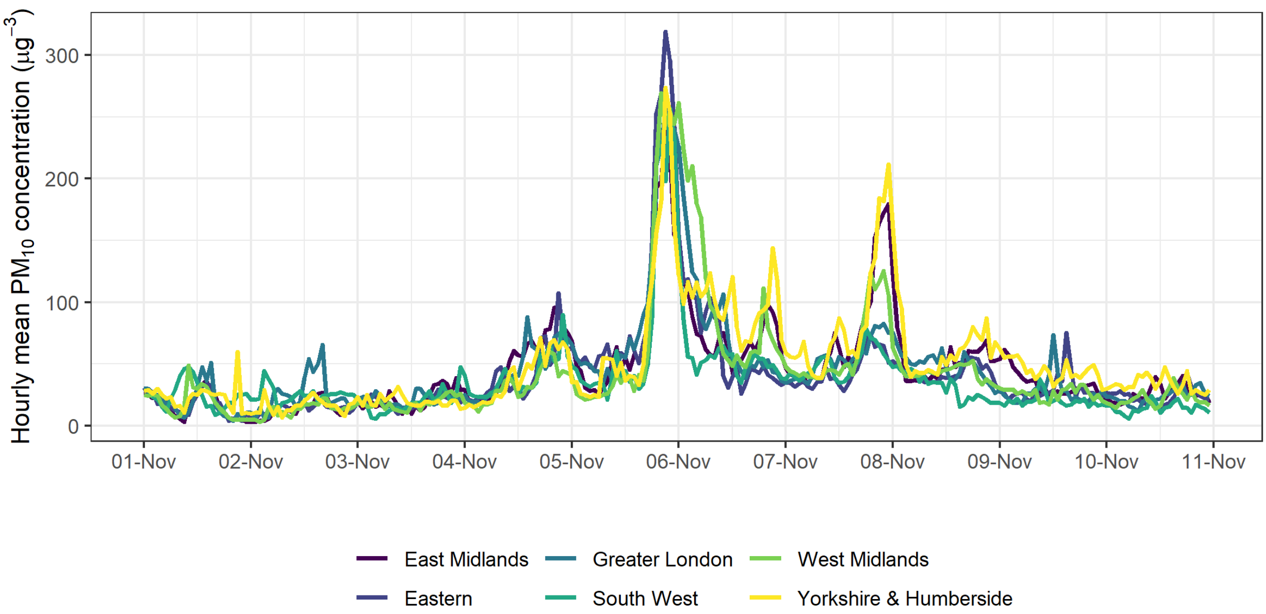
- 9th May – South West region reached the "High" ozone band.
- 24th to 25th June – East Midlands, South East, Greater London, Eastern, and Yorkshire & Humberside all reached the "High" ozone band.
- 31st July – Eastern region reached the "High" ozone band.
- 8th to 12th August – East Midlands, West Midlands, South East, Greater London and Eastern regions all reached the "High" ozone band.

6.6.3 High Particulate Episode – Bonfire Night

Most organised bonfire nights were cancelled in 2020 as a result of Covid-19 restrictions, however some celebrations still occurred, albeit on a much smaller scale. Given the lack of large bonfire night events, it might be expected that there would be less pollution during this period than in normal years. However, there was a high pressure system over the UK during this period (Met Office, 2020 (Nov)), which caused settled weather. This may have inhibited dispersion of particulates.

Between 5th and 7th November, the DAQI reached the “High” or “Very High” band in six different regions in England. **Figure 6-15** shows the average PM_{10} concentration measured at the AURN sites for each of the six regions identified. PM_{10} peaked on the evening of 5th November and remained high well into the following morning. Smaller peaks in PM_{10} were also observed the following two evenings on 6th and 7th November.

Figure 6-15 Average Hourly Mean PM_{10} concentrations for six regions in England, from 1st November to 11th November 2020.



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 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:

- The Welsh Air Quality Archive at https://airquality.gov.wales/
- The Scottish Air Quality Archive at http://www.scottishairquality.scot/
- The Northern Ireland Archive 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 regions. 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 Twitter (see https://uk-air.defra.gov.uk/twitter). Latest forecasts are issued daily, at https://uk-air.defra.gov.uk/forecasting/.

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

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

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

- The Scottish Government Air Quality web page at http://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/ .

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