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WHAT IS $PM_{2.5}$?

AN INTRODUCTION TO PARTICULATE MATTER IN THE ATMOSPHERE

Particulate matter (PM) is a term used to describe very small solid and liquid particles suspended in the air. These particles can be of natural or man-made origin and impact human health and the climate.

Airborne particles are described by their diameter, with PM_{10} indicating particles with a diameter of 10 µm or below and $PM_{2.5}$ indicating a diameter of 2.5 µm or below. Ultrafine particles are those with a diameter of less than 0.1 µm ($PM_{0.1}$).

A report from the WM-Air project

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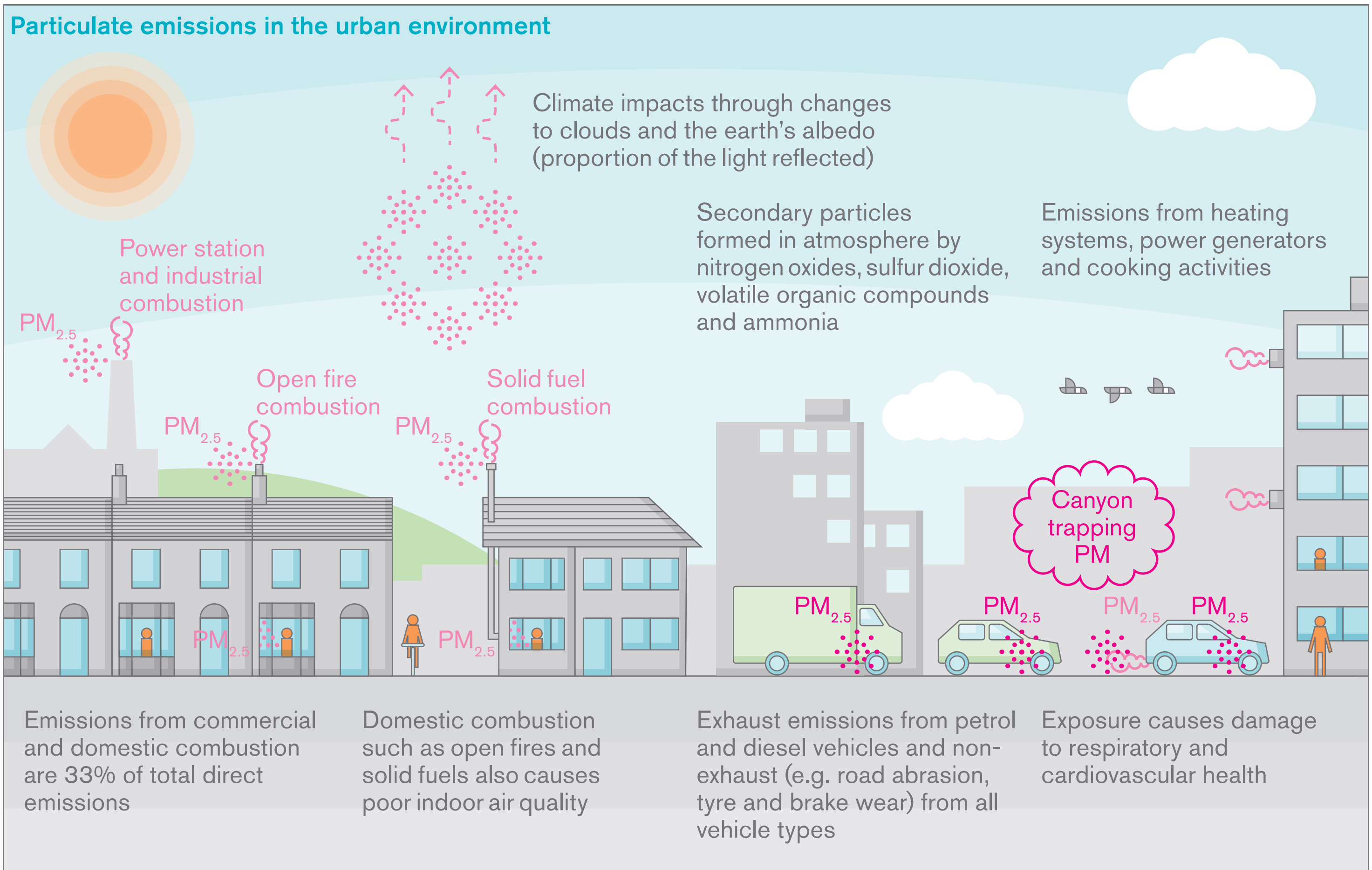

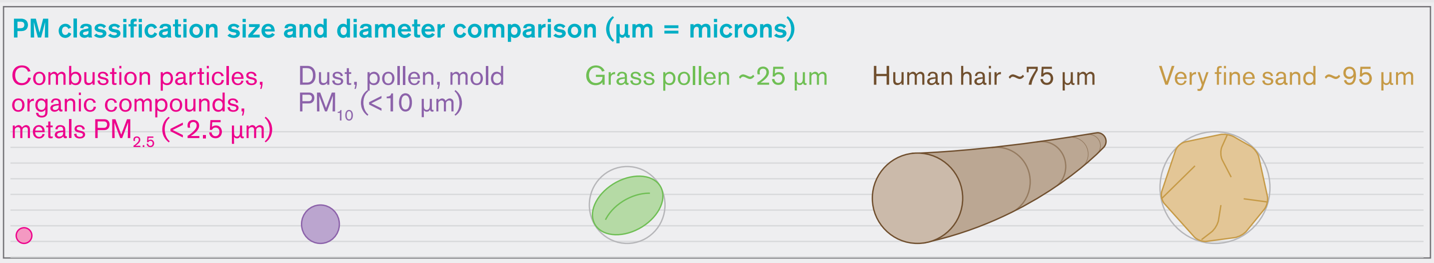

Health impacts

The health impacts caused by particulate matter are dependent on exposure (the total mass or number of particles inhaled), their size and their composition. Particle size is important as smaller particles penetrate deeper into the lungs and may enter the bloodstream. These particles are typically associated with greater negative health impacts (per unit mass) than larger particles.

The health effects of short- and long-term exposure to fine particles ($PM_{2.5}$) are well documented and include increased respiratory and cardiovascular morbidity and mortality. Exposure to $PM_{2.5}$ is also associated with low birthweights and increased risk of lung cancer. There is also emerging evidence of impacts on cognitive function. In the UK 28,000-36,000 premature deaths each year are attributable to exposure to air pollution[1].

The health impacts of ultrafine particles ($PM_{0.1}$) are not as well established as those of $PM_{2.5}$. However, research has shown that $PM_{0.1}$ causes more pulmonary inflammation than $PM_{2.5}$ and is retained longer in the lung[2].

Climate impacts

Air pollution and climate change are two separate but closely linked environmental problems. Air pollution – from species directly harmful to health – is caused by the local and regional emission of gases and particles with short atmospheric lifetimes (minutes to days) which impact the local environment. Climate change is driven by the emission of greenhouse gases such as CO_2; these compounds absorb and then emit infrared energy from the Earth, warming the planet's surface. Greenhouse gases often have long atmospheric lifetimes with carbon dioxide remaining in the atmosphere for hundreds of years. The dominant greenhouse gases, carbon dioxide and methane, do not directly impact human health at concentrations found in the atmosphere.

As well as impacting local air quality, particulate matter is one of the largest sources of uncertainty in predictions of future climate[3]. Particles generally remain in the atmosphere for days to weeks before being deposited onto surfaces or washed out of the atmosphere by rainfall. In the atmosphere particles can have both warming and cooling effects on the Earth's climate. In clear skies particles can reflect incoming radiation out of the atmosphere, cooling the planet. Particles can also act as cloud condensation nuclei (providing a surface for water condensation) increasing the amount of light reflected by clouds and so cooling the atmosphere. However, some particles such as black carbon (soot) absorb radiation trapping solar energy and warming the atmosphere.

PM Sources

Particulate matter has both primary and secondary sources. Primary sources are those which emit particles directly into the atmosphere, these include biomass (wood) burning, combustion, dusts and mechanically generated particles (e.g. from vehicle brake wear). Estimated sources of primary $PM_{2.5}$ in the UK are shown in Fig 2. A wide range of sources contribute to primary emission of $PM_{2.5}$ in the UK with the largest emissions from domestic and commercial combustion (33% of total direct emissions), production processes (16% of total emissions) and transportation, with road transport making up 14% of total direct emissions.

'The World Health Organisation issues non-binding guideline levels of air pollutants for the protection of human health. These are effectively the lowest concentration at which there is clear evidence of a risk to health ...

These guideline levels are exceeded in most urban areas in the UK.'

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Secondary particles are not emitted, but are formed in the atmosphere through chemical reactions. Precursors of secondary particulates include: nitrogen oxides (NO and NO_2), sulfur dioxide (SO_2), volatile organic compounds (VOCs), and ammonia (NH_3). These reactive gases are emitted from a broad range of sources including transportation (NO and NO_2), domestic and industrial combustion (SO_2), agriculture (NH_3), industrial processes (VOCs) and vegetation (VOCs). In this way the total influence of sectors such as road transport, combustion and agriculture on $PM_{2.5}$ concentrations is greater than indicated in Fig 2, below.

The contribution of secondary components to total $PM_{2.5}$ in the UK is highly dependent on location. It has been estimated that secondary particulates make up ~50% of roadside $PM_{2.5}$, with this contribution increasing to ~90% of $PM_{2.5}$ in rural areas[4].

Key sources

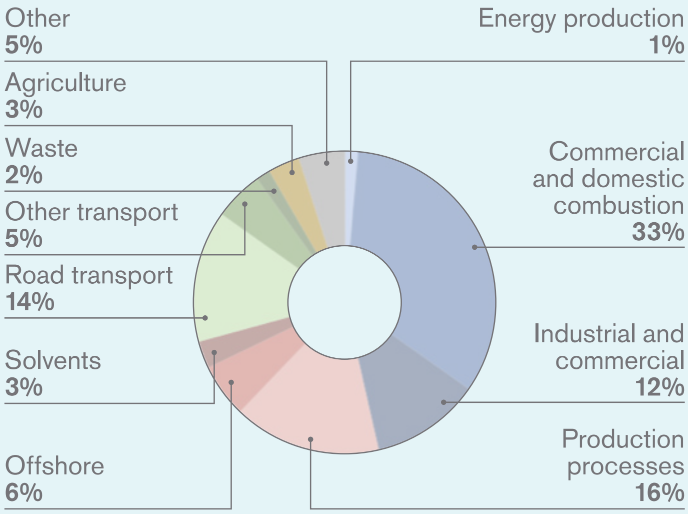
Fig 2 shows the broad range of sources contributing to the total $PM_{2.5}$ concentrations in the UK. In residential areas two key sources are domestic combustion and road traffic.

Domestic combustion is an important source of indoor and outdoor pollution[5]. The use of solid fuels such as wood and coal in domestic settings is a significant source of $PM_{2.5}$ emission in urban areas with emissions highest from open fires and older appliances. The moisture content of wood also impacts emission, with lower emissions from seasoned (dry) wood.

Emission of particulates from road traffic has reduced significantly over recent decades, driven by tightening emissions standards for vehicles. This has brought down exhaust emissions from both petrol and diesel vehicles. The introduction of electric vehicles, which have zero exhaust emissions, into the fleet will reduce total exhaust emissions further. Emissions from the resuspension of road dust, tyre and brake wear will mean that road traffic continues to be an important source of particulate emissions. Non-exhaust emissions currently account for at least 50% of $PM_{2.5}$ emissions from the UK road fleet overall[6].

'... two of the key sources of $PM_{2.5}$ are domestic combustion and road traffic.'

Fig 2. **$PM_{2.5}$ direct emissions**



Direct emissions of $PM_{2.5}$ from sources within the UK. This figure shows considers $PM_{2.5}$ directly emitted into the atmosphere and not secondary particles formed within the atmosphere. © Crown 2022 copyright Defra & BEIS via naei.beis.gov.uk, licenced under the Open Government Licence (OGL).

Table 1. **UK air quality targets (annual averages)**

UK urban areas	$PM_{2.5}$ guidelines/ target level (*interim target*)
Air quality objectives in England until December 2022	20 µg m^{-3}
Air quality objective for England to be achieved by 2040	10 µg m^{-3} (*12 µg m^{-3}*)
Air quality objectives in Wales	25 µg m^{-3}
Air quality objectives in Scotland	10 µg m^{-3}
2021 WHO guidelines	5 µg m^{-3} (*35/25/15/10 µg m^{-3}*)

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National and international guidance

In the UK, air quality targets are set at a national level with targets for short- and long-term concentrations set by the Scottish and Welsh parliaments and for England by the UK parliament (see Table 1). In England and Wales annual average concentration targets have (until recently) been set at 20 and 25 µg m^{-3} respectively. This concentration is rarely exceeded. Following the Environment Act, 2021, an annual average $PM_{2.5}$ target level for England of 10 µg m^{-3} to be achieved by 2040 has been announced[7] with an interim target of 12 µg m^{-3} to be achieved by January 2028[8]. This is currently the target level in Scotland. This target is exceeded in many urban areas in England (Fig 3). There is no current target for ultrafine particle concentrations.

The World Health Organisation issues non-binding guideline levels of air pollutants for the protection of human health. These are effectively the lowest concentration at which there is clear evidence of a risk to health. The WHO guidelines were updated in 2021 and include interim targets intended to guide reduction. The WHO $PM_{2.5}$ guideline level (5 µg m^{-3}) is exceeded in most urban areas in the UK.

Current $PM_{2.5}$ concentrations in the UK

The total concentration of a pollutant depends on the local sources (roads, industry etc.) and what has been transported to the region from upwind (transboundary) sources. In the UK $PM_{2.5}$ concentrations are highest in urban areas and the south and east of England. These high concentrations are driven by large emissions from major population centres, as can be seen in Fig 3, and transportation of particulates and their precursors from the European continent.

Higher spatial resolution modelling of $PM_{2.5}$ concentrations can be used to show the distribution of pollutants across an urban area. Fig 4 shows annual average $PM_{2.5}$ concentrations at street scale resolution from 2019 across the West Midlands metropolitan area. Concentrations peak along the major highways and in areas of high population density, driven by domestic and vehicular emissions.

> *'Non-exhaust emissions currently account for at least 50% of $PM_{2.5}$ from road traffic.'*

Fig 3. **$PM_{2.5}$ concentrations modelled by Imperial College for 2016**[9]

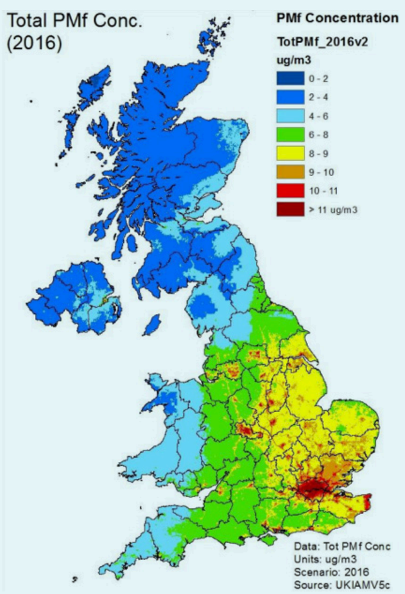
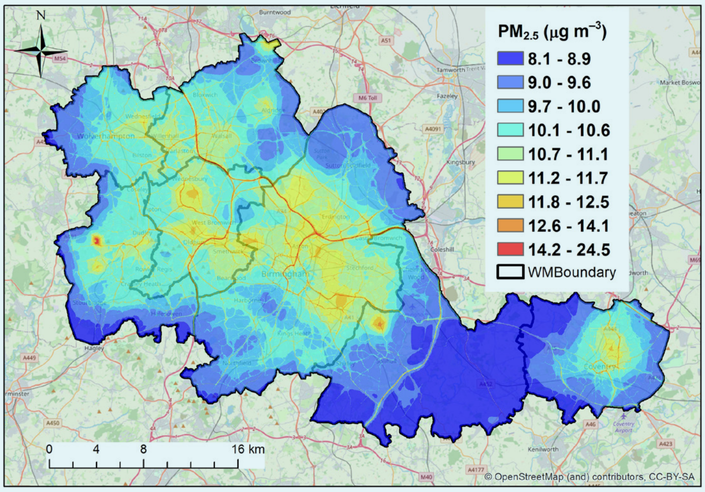


Fig 4. **Annual average $PM_{2.5}$ concentrations in the West Midlands for 2019**[10]



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