CLEAN AIR FUND

THE PATHWAY TO HEALTHY AIR IN THE UK

Demonstrating that the WHO interim target of 10 μg/m^3 for fine-particulate matter ($PM_{2.5}$) is necessary, beneficial and achievable by 2030

Imperial College London
Projects

ABOUT CLEAN AIR FUND

The Clean Air Fund (CAF) is a philanthropic initiative that seeks to tackle air pollution around the world. Launched at the United Nations Secretary-General's Climate Summit in 2019, CAF unites funders, researchers, policy makers and campaigners with the aim of promoting approaches and techniques that will provide clean air for all. CAF channels the money it receives into efforts to: monitor air quality; assess and communicate the health and economic impacts of air pollution; support ambitious policy makers and campaigners; and engage the public and private sectors.

ABOUT IMPERIAL COLLEGE LONDON

Imperial College London is among the top ten universities globally, with a world-class reputation in science, engineering, business and medicine. Imperial's Environmental Research Group (ERG) is part of the School of Public Health and is a leading provider of air quality information and research in the UK, combining science, toxicology and epidemiology to determine the impacts of air pollution on health, and the role specific pollutants play in causing disease and deaths. The ERG works closely with authorities responsible for air quality management, supporting policies and actions to minimise the negative effects of air pollution on health. The team from the ERG provided their independent analysis for this report via Imperial Projects.

This report summarises findings of a more detailed technical report available **here**.

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CONTENTS

EXECUTIVE SUMMARY

In 2022, the UK Government will set a new target for the annual average concentration of fine-particle matter ($PM_{2.5}$), a major component of air pollution. This matters to us all; the Committee on the Medical Effects of Air Pollutants (COMEAP) – an independent advisory committee to the UK Government – estimates that 28,000–36,000 people died in 2013 as a result of air pollution in the UK. Polluted air also places a considerable burden on the National Health Service and the UK economy.

The current annual average concentration target for $PM_{2.5}$ in the UK is set at 20 micrograms per cubic metre (µg/m^3). The World Health Organization (WHO) recommended annual average guideline level is now 5 µg/m^3 (WHO-5). The guideline value was revised in September 2021 in light of new scientific evidence on the health dangers of air pollution even at levels below the previous guideline of 10 µg/m^3 (WHO-10). WHO-10 has now been redefined as an interim target aimed at helping countries and regions struggling with high air-pollution levels. Large parts of the UK are still exposed to poor air quality; this report makes the case for the UK government's new $PM_{2.5}$ concentration target to be WHO-10, to be met by 2030 at the latest.

The report presents evidence from a study commissioned by the Clean Air Fund (CAF) in 2021, by researchers from the Environmental Research Group at Imperial College London and consultancy Vivid Economics. The study sought to determine whether WHO-10 would be achievable by 2030, to quantify the associated health benefits from the improved air quality, and to examine the likely policy costs.

The findings of that research, which modelled the potential impacts of existing UK policies and ongoing electrification of the UK vehicle fleet, indicate that:

- By 2030, the majority of the UK will comply with WHO-10, provided relevant policies that are planned and anticipated for the UK and London are successfully implemented.
- When weighted by the number of people at risk, 41% of local authorities had $PM_{2.5}$ exposure levels above WHO-10 in 2018. This should fall to less than 1% by 2030.
- 6.4% of the UK and 82.6% of London exceeded WHO-10 in 2018; these figures should reduce to 0.2% and 0.6%, respectively, in 2030.
- In 2030, some locations close to major roads in cities and industrial sites burning biomass may still exceed the target. Devolved powers could help cities take targeted action to help them meet WHO-10.
- Not only is achieving clean air possible, it is affordable too. In fact, we can get to much cleaner air with existing policies and plans – at virtually no additional cost.
- And there are huge benefits – longer,[a,b] and much healthier lives, including an average of 3,100 fewer new coronary heart disease cases, and 388,000 fewer reported asthma symptom days in children each year.
- The value of the total benefits gained is more than £380 billion. This justifies spending of up to £3.3 billion per year on existing and new policies to address air pollution.

ACHIEVING WHO-10 ACROSS THE UK BY 2030 WOULD RESULT IN:*

23% REDUCTION IN AVERAGE EXPOSURE TO $PM_{2.5}$

£384 BILLION OF ECONOMIC BENEFITS TO THE UK

8–9 WEEKS LONGER LIFE EXPECTANCY

~20 FEWER INFANT DEATHS PER YEAR

3,100 FEWER NEW CASES OF CORONARY HEART DISEASE PER YEAR

* More information on these statistics, their calculation methods and uncertainties are available below and in the technical report.

[a] 11.5 million UK life years gained between 2018 and 2134 (average 98,000 life years per year) including a gain of 8–9 weeks of life expectancy in those born in 2018.

[b] The target of WHO-10 proposed in this study was also recommended in the Prevention of Future Deaths report by the Coroner overseeing the inquest into the death of nine-year-old Ella Kissi-Debrah, who died as a result of air pollution.

NINE-POINT PLAN FOR POLICY MAKERS TO ACHIEVE CLEAN AIR

1. Commit the UK to becoming a world leader in air quality – to improve public health, reduce health inequalities and relieve pressure on the National Health Service – as the COVID pandemic continues to have an impact on communities around the country.
2. Set WHO-10 as the legally binding annual average concentration target for $PM_{2.5}$ – to be achieved by 2030 at the latest – recognising that pursuing $PM_{2.5}$ targets can bring about additional benefits by also reducing harmful PM_{10} (larger-particulate matter) and nitrogen dioxide (NO_2).
3. Ensure robust delivery of the new target through a clear framework for monitoring and evaluating progress. Take into account international efforts on target setting, such as the WHO working group on UN Sustainable Development Goal 11.6.2, and share methods to lead global collaboration on air quality target setting.
4. Set an ambitious population-exposure reduction target for $PM_{2.5}$ to support meeting the WHO-10 concentration target and to ensure there is continued action on clean air across the UK and not just in pollution hotspots.
5. Commit to implementing existing and anticipated air quality-related policies and the Climate Change Committee's recommendations for vehicle electrification to meet Net Zero carbon by 2050.
6. Provide city authorities with the powers and funding necessary to monitor air quality and address local sources of pollution.
7. Develop additional policies targeted at industrial biomass burning, to reduce localised exceedances of WHO-10.
8. Ensure that air-pollution considerations are integrated into Net-Zero plans, to maximise the health and economic benefits of achieving a zero-carbon future.
9. Make clear that WHO-10 is an interim target on the pathway to ultimately meeting WHO-5, by enhancing existing policies and designing new ones to achieve reductions above and beyond current commitments – for example in relation to domestic wood burning, and ammonia from agriculture.

SETTING WHO-10 AS THE UK TARGET FOR $PM_{2.5}$ IN 2022, AND MEETING IT BEFORE 2030, IS NECESSARY, BENEFICIAL AND ACHIEVABLE.

IT WILL SET US ON A PATHWAY TO CLEAN AIR ACROSS THE UK AND DELIVER CONTINUOUS IMPROVEMENTS FOR HEALTH, THE ECONOMY AND THE CLIMATE.

INTRODUCTION

The case for setting the WHO-10 target for $PM_{2.5}$ in the UK

This report summarises the findings of a study, conducted by researchers from Imperial College London and Vivid Economics, to determine the ambiant (outdoor) air quality improvements that could be made under existing and anticipated policies for the UK and London between 2018 and 2030. Commissioned by the Clean Air Fund, the study was designed to inform the planned target-setting process for fine-particulate matter ($PM_{2.5}$) – a particularly damaging component of air pollution – as part of the Environment Act 2021. Specifically, it sought to show whether meeting the World Health Organization (WHO) interim target of 10 micrograms per cubic metre ($\mu g/m^3$) per year (WHO-10) would be achievable, and to quantify the benefits that could be gained from doing so.

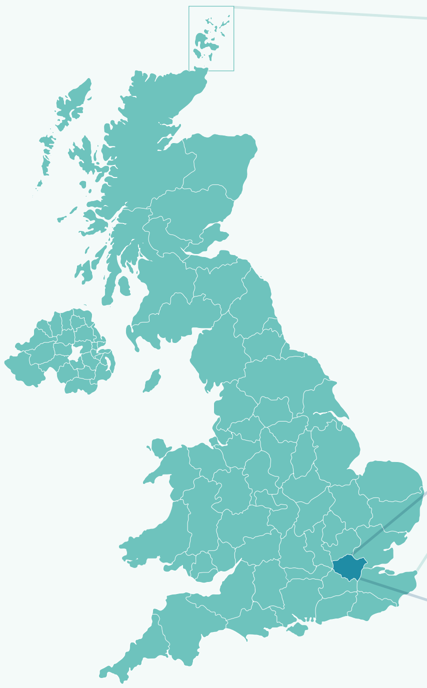
The Environment Act 2021 commits the UK government to setting a limited-based target in respect of the annual mean level of ($PM_{2.5}$) in ambient air by October 2022. The Government has also committed to introducing a long-term population exposure reduction target for ($PM_{2.5}$) through the wider environmental target framework[1].

The Department for Environment, Food and Rural Affairs (Defra) has confirmed that the proposed targets will be informed by evidence and analysis, including from independent experts, and will be put to public consultation.

With this in mind, researchers from Imperial College used sophisticated air quality modelling methods to forecast concentrations of $PM_{2.5}$ (along with nitrogen dioxide [NO_2] and larger-particulate matter [PM_{10}] for health analyses) for the UK for 2018 and 2030. They used a conservative Defra 'business as usual' (BAU) policy scenario, combined with reductions in road transport emissions outlined in the Balanced Net Zero Pathway (BNZP) proposed by the Climate Change Committee (CCC). The CCC recommendations were incorporated in response to publication of the UK government's Net Zero Strategy[2] in October 2021.

FIGURE 1: THE MODELLING FOR 2018 AND 2030 WAS UNDERTAKEN FOR THE UK AS A WHOLE BUT TOOK INTO ACCOUNT ADDITIONAL AIR QUALITY MEASURES FOR LONDON.

The two models used have been approved for use in Defra model intercomparison studies.



The UK model applied scientific first principles to data on emissions and meteorology to predict annual average concentrations of airborne gases and particles, including $PM_{2.5}$, at resolutions up to 20m.

- 1st model run: Used input data on emissions of diverse chemicals for 2018, this set the baseline conditions **(UK2018).**
- 2nd model run: With the 2018 data altered to reflect changes in emissions from existing and planned policies (from Defra and the CCC BNZP) this predicted future air quality across the UK **(UK2030)**. LS1 (below) replaced outcomes for the capital, giving the **UK2030+LS1** scenario.

The London model is quicker to run, facilitating more policy scenarios.

- 1st model run: Used London-specific emissions data to set baseline conditions in London in 2018 **(London2018)**.
- 2nd model run: **LS1**– reflects policies outlined in the London Environment Strategy and the Port of London Authority's emissions-reduction roadmap and air quality strategy.
- 3rd model run: **LS2** – built on LS1, with additional reductions from the Mayor of London's $PM_{2.5}$ roadmap.
- 4th model run: **LS3** – built on LS2, assuming a ban on domestic wood burning.

With the modelling showing London to have higher levels of $PM_{2.5}$, researchers from Imperial College – in collaboration with the Greater London Authority (GLA), Transport for London (TfL) and the Port of London Authority (PLA) – then developed three scenarios for the capital based on the London Environment Strategy and other published policy documents. The UK-wide policy scenario used in this report combines the Defra BAU and CCC BNZP with London Scenario 1 (LS1), and is hereafter referred to as UK2030+LS1. Defra was consulted on the development of the UK2030 scenario. Key policies within it, when assessed by the UK Government on a stand-alone basis, have been approved based on their costs and benefits. The scientists used the concentration changes indicated from modelling the UK2030+LS1 scenario (LS1), London Scenario 2 (LS2) and London Scenario 3 (LS3) to conduct health-benefit analyses.

The results indicate that the WHO-10 target is achievable almost everywhere across the UK by 2030 using only existing and anticipated policies – and could be attained everywhere with the introduction of minor additional actions. The modelling forecasts a 0.9–4 $\mu g/m^3$ reduction in people's exposure to $PM_{2.5}$ between 2018 and 2030. This has potential to enhance life expectancy, and improve outcomes for both cardiovascular and respiratory diseases. Fully implementing the planned and anticipated policies outlined in the UK2030 and London scenarios (which could also be used to guide action in other cities) will help to achieve cleaner air for all and continue the effort towards meeting WHO-5 in future – recognising that there is no safe level of air pollution.

CONTEXT

How air pollution is a threat to the UK

Air pollution is the biggest environmental threat to health in the UK. The UK government's Committee on the Medical Effects of Air Pollutants (COMEAP) estimates that 28,000–36,000 people died in 2013[c] as a result of air pollution in the UK.[3] Globally, the WHO considers that 'the burden of disease attributable to air pollution is now estimated to be on a par with other major global health risks such as unhealthy diet and tobacco smoking.'

$PM_{2.5}$ is the most damaging type of air pollution;[4] breathing it in for just a few hours or days is harmful, and exposure over months or years is particularly dangerous. It is associated with multiple causes of death – including dementia, diabetes, hypertension, lung cancer and pneumonia[5] – and with both cardiovascular and respiratory diseases. Children, pregnant women, the elderly, and people with heart and lung diseases are more susceptible to having their health affected by $PM_{2.5}$. Some disadvantaged societal groups are exposed to higher levels of air pollution and therefore also face a greater risk of adverse health effects.

BOX 1 WHAT IS $PM_{2.5}$ AND WHY IS IT OF CONCERN?

Particulate matter (PM) is a complex mixture of solid particles and liquid droplets, comprising primary and secondary particles. Primary particles include those from brake and tyre wear, black carbon, and semi-volatile and volatile organic compounds (VOCs). These particles are emitted by sources such as vehicle exhausts, tyres, brakes and resuspension; heating homes by burning wood and coal; and industrial processes. Secondary particles are created in the atmosphere through chemical reactions. They include sulphate, nitrate and secondary organic aerosols, which derive from the primary emissions from industry and transport. Ammonia from agriculture is also an important contributor to secondary PM, reacting with chemicals such as nitrate to form ammonium nitrate particles. In addition to anthropogenic sources of PM are natural sources, such as plants, dust and sea salt. This variety of sources, and the differing extents to which particles are transported once airborne, means the chemical composition of PM varies from place to place.

For air quality purposes, PM is defined by the size of its constituent parts rather than its chemical composition. $PM_{2.5}$, describes particles no bigger than 2.5 micrometres (about 30 times smaller than the width of a human hair). This size is particularly dangerous because such miniscule particles can penetrate human lungs with ease and the tiniest particles can even enter the bloodstream. Breathing in $PM_{2.5}$ can harm human health in many ways, even at concentrations lower than those currently measured in large parts of the UK.

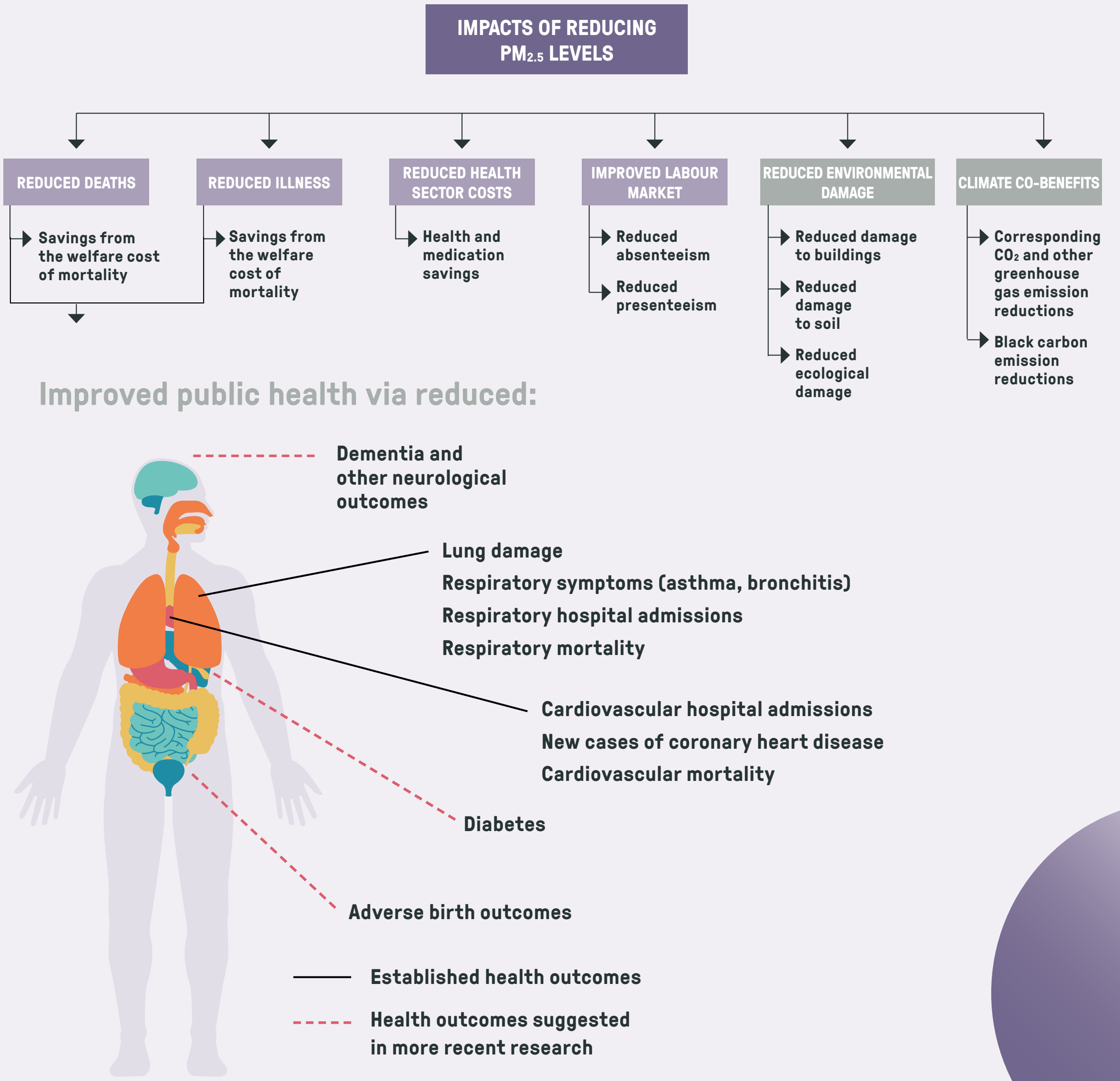
FIGURE 2: PRIMARY EMISSION SOURCES OF $PM_{2.5}$ IN THE UK AND THEIR PERCENTAGE CONTRIBUTIONS.

Source: National Atmospheric Emissions Inventory 2018; Imperial College London ERG, 2021.

[c] This is the latest available evidence.

FIGURE 3: HEALTH, ECONOMIC AND CLIMATE IMPACTS OF $PM_{2.5}$

Only economic impacts shown in purple were quantified within this study.



$PM_{2.5}$ pollution in the UK

Emissions of $PM_{2.5}$ have declined since the 1970s as a result of the gradual move away from using coal as an energy source, and stricter regulations on emissions from road transport and industry. However, since 2009, the rate of decline has generally slowed. Interestingly, recent measurements have shown that the 2020 COVID lockdown resulted in compliance with WHO-10 at all but a small number of monitoring sites in London, driven by reduced emissions during this time.

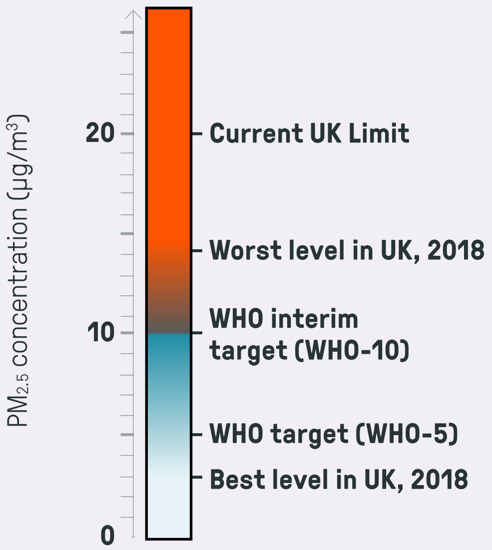
Levels of $PM_{2.5}$ in the air are influenced by fluctuations in emissions, complex atmospheric effects and stagnant weather conditions. The UK's major cities have higher levels than surrounding rural areas, because these cities have larger local emissions. For example, emissions from domestic wood burning and from diesel vehicles, plus abrasion from tyres, brakes and road surfaces for all vehicles, contribute significantly to local levels of urban $PM_{2.5}$.[6] Meanwhile, the south and east of England are more affected than the rest of the country by $PM_{2.5}$ transported from mainland Europe. Background $PM_{2.5}$ concentrations vary across the UK but with a general trend for higher concentrations in the southeast.

Current targets for $PM_{2.5}$ in the UK

The UK's current legal limit for annually averaged $PM_{2.5}$ is 20 $\mu g/m^3$,[7] coupled with a population-exposure target to reduce average urban background concentrations by 15% by 2020, compared to 2010 levels. In 2019, the Government published the Clean Air Strategy (CAS), which stated: 'We will set a new, ambitious, long-term target to reduce people's exposure to $PM_{2.5}$ ... By implementing the policies in this Strategy, we will reduce $PM_{2.5}$ concentrations across the UK, so that the number of people living in locations above the WHO guideline level of 10 $\mu g/m^3$ is reduced by 50% by 2025.' Whether this objective is met depends on the extent to which the UK Government realises the potential of the 2021 Environment Act. Adopting the WHO-10 target as a legally binding standard would make the UK only the second country in Europe (after Switzerland) to do so,[8] sending the message that it is serious about addressing harmful air pollution, and setting an ambitious example for others.

FIGURE 4: CURRENT UK AND WHO TARGETS, AND CORRESPONDING LEVELS OF $PM_{2.5}$ IN THE UK.

Source: Imperial College London ERG, 2021. Population-weighted $PM_{2.5}$ by local authority area is used for current UK levels.



World Health Organization targets for $PM_{2.5}$

For over 30 years, the World Health Organization (WHO) has issued air quality guidelines to protect public health worldwide. These guidelines are based on a rigorous, detailed evaluation of scientific evidence by global experts, which is peer-reviewed and made publicly available. This high-quality evidence base is designed to inform governments when setting national standards. An air quality guideline level is given for key pollutants – including $PM_{2.5}$ – expressed as a concentration in the air and linked to an averaging time.

In September 2021, WHO reduced the guideline level for $PM_{2.5}$ from 10 to 5 $\mu g/m^3$. However, the WHO scientists could not identify any level of $PM_{2.5}$ that was safe; rather they found a nearly linear relationship between $PM_{2.5}$ and health outcomes, meaning that any reduction in $PM_{2.5}$ would have benefits. As a result of these findings, the former WHO guideline level of 10 $\mu g/m^3$, which had originally been set in 2005, became a WHO interim target. WHO states that interim targets are intended to deliver stepwise improvements in air quality for countries and regions struggling with high air-pollution levels.

BOX 2 THE POLICIES BEHIND THE UK2030 SCENARIO

The UK2030 scenario was based on a suite of implemented and in-the-pipeline policies, directives and regulations representing Defra's business-as-usual pathway.[9]

Road transport policies were replaced by the CCC Balanced Net Zero Pathway, which seeks to achieve Net Zero by 2050. Key government policies in the scenario include:

- The Industrial Emissions Directive (IED), which seeks to prevent pollution to air, water and land by avoiding and reducing industrial emissions
- The Medium Combustion Plant Directive (MCPD), which regulates emissions from the combustion of fuels in plants that are too small to be covered by the IED
- Euro 6/VI engine standards, a set of limits for harmful exhaust emissions from new petrol or diesel vehicles
- Regulations covering burning of wood and coal

FINDINGS OF THE STUDY

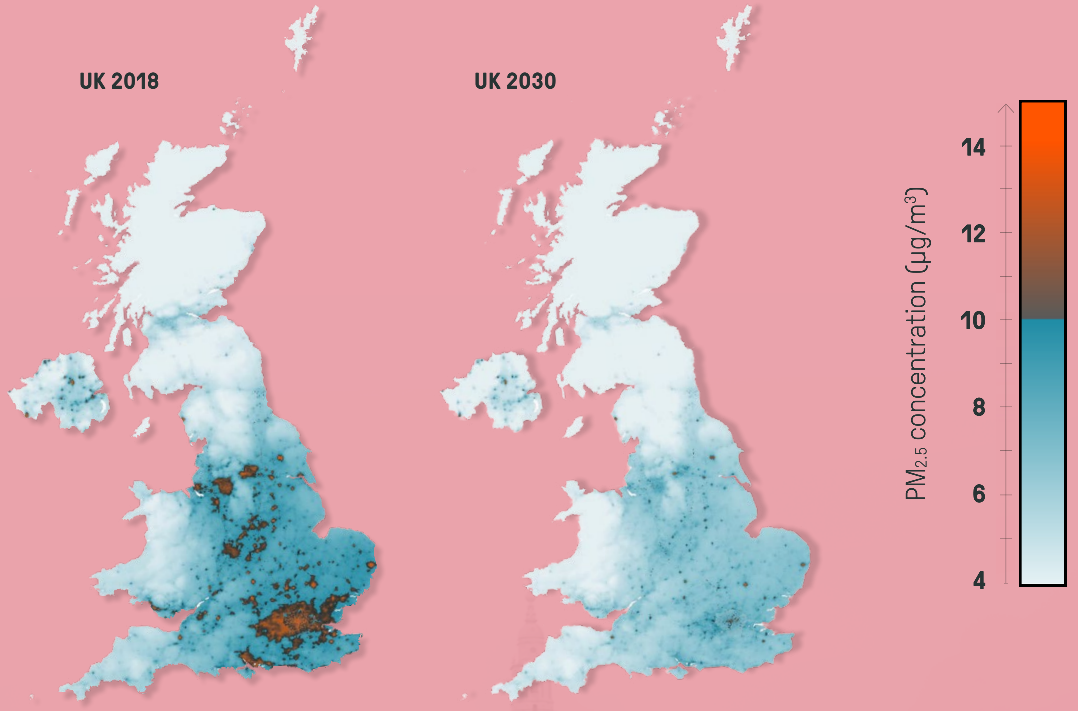
For more detail on these findings, see the technical report.

$PM_{2.5}$ concentrations and exposure in the UK in 2030

1. LARGE PARTS OF THE UK ALREADY COMPLY WITH WHO-10

The percentage of the UK with $PM_{2.5}$ concentrations that exceeded WHO-10 in 2018 was 6.4%. So, large areas of the UK already comply with WHO-10. These include wide swathes of northern and western England, Scotland, Wales and Northern Ireland. However, the modelled map also reveals that highly populated major cities, along with a number of specific locations south of a line connecting Liverpool on the west coast to Scarborough in the east, had concentrations higher than WHO-10 in 2018.

FIGURE 5: ANNUAL MEAN $PM_{2.5}$ CONCENTRATIONS ACROSS THE UK IN 2018 AND 2030, FOLLOWING THE UK 2030 AND LS1 POLICY SCENARIOS.



BOX 3 INVESTIGATING HOTSPOTS OF HIGH $PM_{2.5}$ CONCENTRATIONS

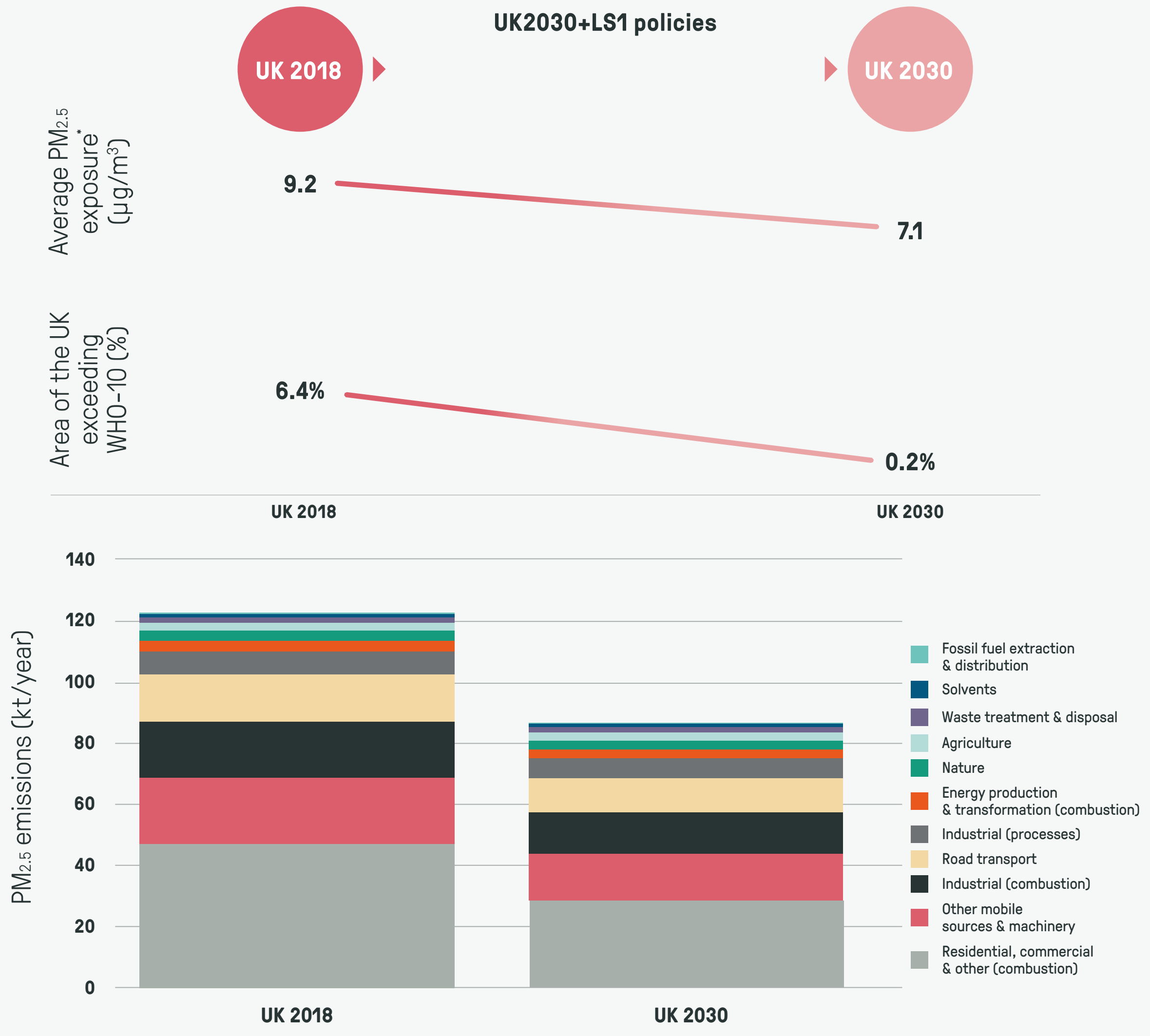
Outside major cities, isolated sites with $PM_{2.5}$ concentrations exceeding WHO-10 appear in both the 2018 and 2030 model estimates.[d] In 2018 there are 1,500 such sites; by 2030, this falls to 59. The sources of these elevated concentrations are typically industrial estates, confirmed by the National Atmospheric Emissions Inventory (NAEI) to be sources of emissions from biomass burning. In some cases, the ground-level concentrations around these sites were higher than expected in the modelling results. After investigating further, the researchers from Imperial College concluded they were likely to represent a worst-case scenario.

[d] Note, $PM_{2.5}$ concentrations within each roadway and at larger junctions were removed (a standard practice, since people do not spend much time in road-centre locations).

2. THE VAST MAJORITY OF THE UK – 99.8% – IS FORECAST TO BE COMPLIANT BY 2030 UNDER EXISTING AND ANTICIPATED POLICIES

Following the UK2030+LS1 scenario, of existing and anticipated policies, directives and regulations (see Box 2) the 6.4% figure falls to just 0.2% by 2030. The modelled concentrations for 2030, shows this widespread compliance with WHO-10 across the UK, with exceedances limited to locations close to roads in major cities, including London, and to some of the larger sources of industrial biomass burning (see Box 4).

FIGURE 6: REDUCTIONS IN EXPOSURE TO $PM_{2.5}$, EXCEEDANCES OF WHO-10 AND $PM_{2.5}$ EMISSIONS ACROSS THE UK IN 2030, FOLLOWING THE UK2030 AND LS1 POLICY SCENARIOS.



*Average exposure was estimated using population-weighted average annual mean PM2.5 concentrations aggregated at the local authority area scale'

3. WITH ADDITIONAL POWERS LONDON CAN CONSIDERABLY REDUCE AIR POLLUTION

By 2030, only London and other major cities are likely to need to take additional action to attain WHO-10. In London, the Mayor has already committed to meeting WHO-10 by 2030. Scenarios show potential pathways to reduce $PM_{2.5}$ in London.

The percentage of the Greater London Authority area with PM2.5 concentrations exceeding WHO-10 in 2018 was 82.6%. Three modelled scenarios for London (see Box 4), based on the London Environment Strategy (LES), the Major of London's roadmap for $PM_{2.5}$ and the Port of London Authority's air quality strategy, show what can be achieved by 2030 in London – and highlight locations where residual pockets of exceedance remain. These findings can potentially guide future action for London and other cities.

Following the LS1 scenario, this figure falls drastically by 2030 to just 0.6%. The results of the modelling under LS1 show annual average concentrations of $PM_{2.5}$ largely ranging from 7.5 µg/m^3 in outer London, towards 9 µg/m^3 on the boundary of the original Ultra Low Emissions Zone (ULEZ) and greater than 10 µg/m^3 within this zone. A few very small islands exceeding 10 µg/m^3 $PM_{2.5}$ concentration occur close to major roads beyond the city centre. Small pockets of exceedance also show up close to shipping piers on the River Thames in central London. Very large concentrations – greater than 40 µg/m^3 – are highlighted on the Heathrow Airport site, at the hold point for aircraft taking off, but this is off-limits to people.

The LS2 and LS3 scenarios bring the percentage of the Greater London Authority area with $PM_{2.5}$ concentrations exceeding WHO-10 as low as 0.02% – close to negligible. Under LS2, the additional reduction of emissions from wood burning and commercial cooking significantly cuts $PM_{2.5}$ concentrations within central London, where concentrations are typically 8.5-9µg/m^3 (compared with greater than 10 µg/m^3 under LS1), and around 7-8 µg/m^3 for the rest of London.

LS3 delivers relatively minor additional impacts on $PM_{2.5}$ concentrations, considerable benefits having already been realised from the policy changes of LS2. For example, LS2 achieves a 75% reduction in domestic wood burning through improved messaging on appropriate fuels and technologies for smoke-free zones, and greater powers for the Mayor to set tighter standards for wood-burning stoves sold in the capital. Any additional drop between LS2 and LS3 is therefore limited to 25%. The influence of the complete ban on domestic wood burning in London incorporated in LS3 therefore appears relatively modest. A few very small central London locations exceeding WHO-10 remain, close to major roads.

BOX 4 THE POLICIES BEHIND THE THREE LONDON 2030 SCENARIOS

LS1 This is primarily based on ambitions laid out in the London Environment Strategy, which includes emissions reductions from: road traffic; cooking; wood burning; non-road mobile machinery (NRMM); domestic and commercial gas, coal and oil combustion; railways, ships and aviation; agriculture; and small-scale waste burning. Additional policy detail on shipping was added from the Port of London Authority's emissions-reduction roadmap and air quality strategy.

LS2 This builds on LS1 with aspects from the Mayor's $PM_{2.5}$ roadmap document, bringing further reductions in cooking and domestic wood burning, a ban on burning oil and coal, and additional cuts in small-scale waste burning emissions.

LS3 This scenario builds on LS2, assuming a ban on domestic wood burning.

FIGURE 7: CHANGES TO AVERAGE EXPOSURE TO $PM_{2.5}$ AND WHO-10 EXCEEDANCES BETWEEN 2018 AND 2030 , FOLLOWING PLANNED AND ANTICIPATED POLICIES.

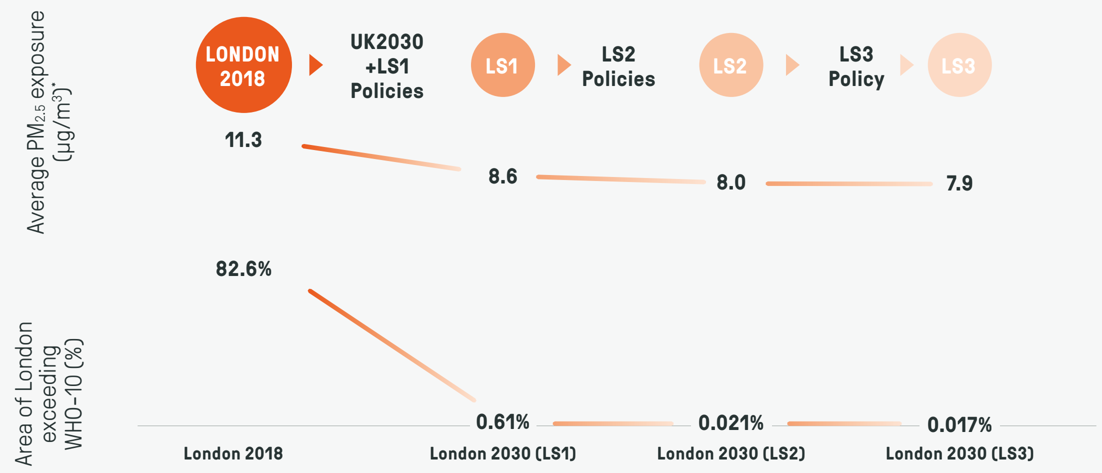


FIGURE 8: ANNUAL MEAN $PM_{2.5}$ CONCENTRATIONS IN LONDON IN 2018 AND 2030, FOLLOWING THE UK 2030, LS1 AND LS2 POLICY SCENARIOS.

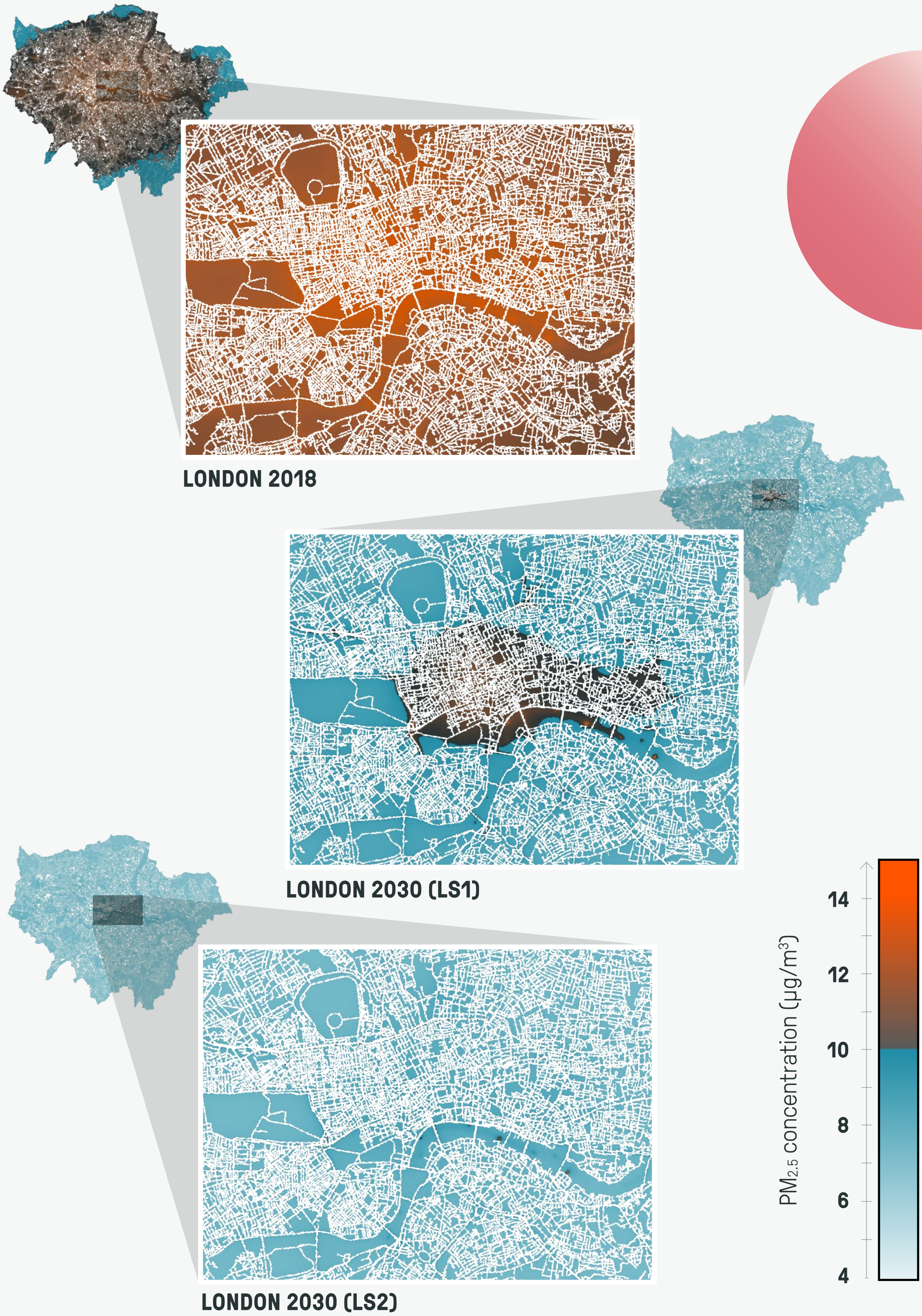
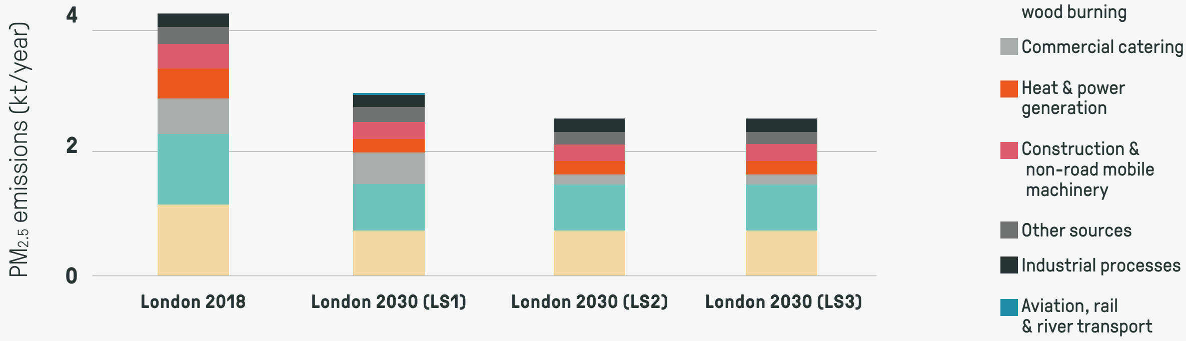


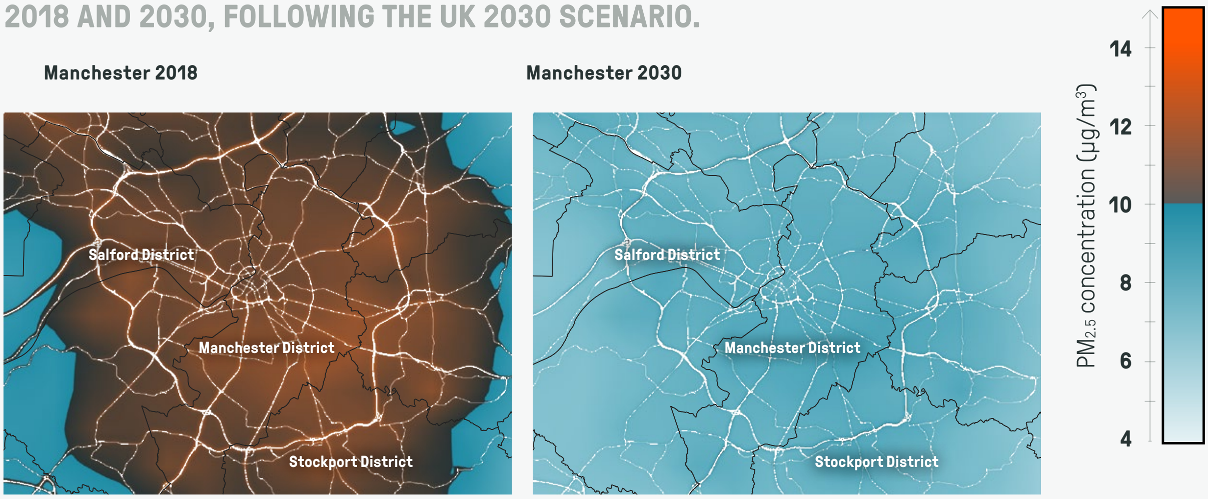
FIGURE 9: CHANGES TO $PM_{2.5}$ EMISSIONS IN LONDON BETWEEN 2018 AND 2030, FOLLOWING THE UK 2030 LS1, LS2 AND LS3 SCENARIOS.



4. OTHER CITIES WILL ALSO NEED TO TAKE TARGETED ACTION

UK cities largely reach $PM_{2.5}$ levels under the WHO-10 target, based on the UK2030+LS1 scenario. The 2030 forecast for Manchester, the UK's second largest urban agglomeration, represents the situation in many UK cities. The UK2030+LS1 scenario forecasts urban background concentrations within Manchester's M60 ring road of around 8.5 µg/m^3, with some exceedances very close to major roads.

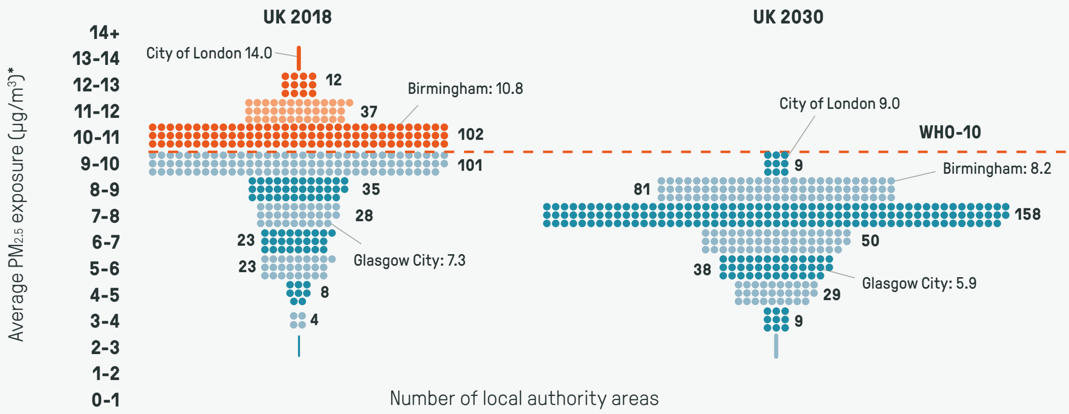
FIGURE 10: ANNUAL MEAN $PM_{2.5}$ CONCENTRATIONS IN MANCHESTER IN 2018 AND 2030, FOLLOWING THE UK 2030 SCENARIO.



5. FEWER PEOPLE WILL BE EXPOSED TO $PM_{2.5}$ BY 2030

Population-weighted average concentration (PWAC) data, calculated for all of the 382 local authorities in the UK (2019 figure), predicts that exposure to $PM_{2.5}$ between 2018 and 2030 will reduce by between 0.9 µg/m³ (Scotland) and almost 4 µg/m³ (Inner London), depending on where people live, bringing all local authorities' PWACs under WHO-10. The percentage of local authorities in the UK with population-weighted exposure levels above WHO-10 will be reduced from 41% in 2018 to <1% in 2030 (UK2030+LS1) and to 0% in 2030 (Scenario UK2030, plus each of LS2 and LS3). This analysis can be used to inform Defra's target-setting process for population exposure.

FIGURE 11: CHANGES TO THE NUMBER OF LOCAL AUTHORITY AREAS IN THE UK WITH $PM_{2.5}$ CONCENTRATIONS ABOVE WHO-10 BETWEEN 2018 AND 2030, FOLLOWING UK 2030, LS1 AND LS2 POLICY SCENARIOS.



*Average exposure was estimated using population-weighted average annual mean $PM_{2.5}$ concentrations aggregated at the local authority area scale

Health benefits

6. SIGNIFICANT HEALTH BENEFITS FROM FORECAST $PM_{2.5}$ REDUCTIONS

The air-pollution reductions produced by the policies analysed in the UK2030+LS1 and three individual London scenarios result in substantial improvements in health outcomes – from increased life expectancy to reduced incidence of coronary heart disease (CHD) and fewer respiratory symptoms.

7. DEATHS FROM ALL CAUSES FALL, AND LIFE EXPECTANCY RISES ACROSS THE UK

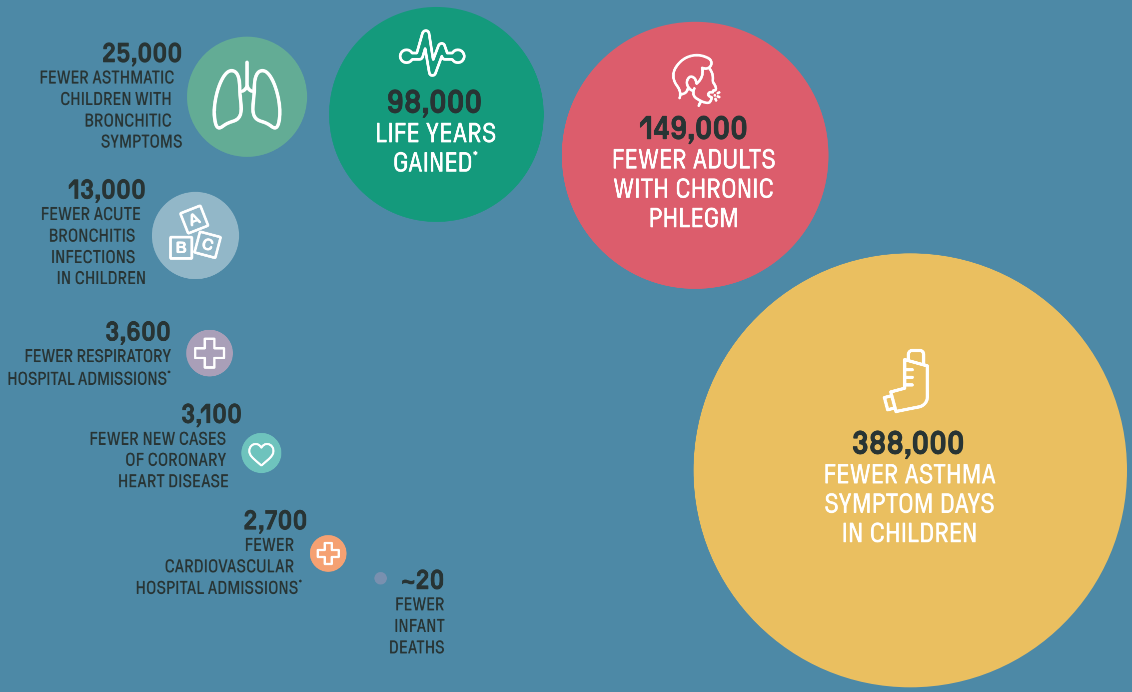
The UK2030+LS1 scenario leads to 11.5 million life years (see Box 5) saved across the UK population over the time period 2018–2134.[e] This is a 23% reduction in life years lost compared with 2018 concentrations being maintained. For context, a gain of 115,000 life years for the 745,000 people born in 2018 equates to an average gain in life expectancy of 8–9 weeks for each of those people.

BOX 5 EXPLAINING LIFE YEARS

For policies intended to be maintained over the longterm, 'life years' gained is a more useful measure than declines in numbers of deaths because it takes into account when people die. One life year is one year lived by one person. The average life expectancy for people born between 2018 and 2020, estimated by the Office for National Statistics, is 79 years for men and 83 years for women;[10] this is the equivalent of 79 and 83 life years. For all the 745,000 people born in 2018, we would anticipate there would be 590 million life years to be lived. The total number of life years lived across the population during the calculation period of 2018–2134[e] is 8 billion. Birth cohorts beyond 2030 and other age groups do not experience the change in $PM_{2.5}$ exposure for their whole lifetimes (for birth cohorts because the analysis stops in 2134, a lifetime after 2030, and for other age groups because the policy change happens part way through their lives). Adding up life years gained over all age groups in the population, and over the entire time period, gives the large total of 11.5 million life years gained.

FIGURE 12: REDUCTIONS IN HEALTH IMPACTS FROM THE AIR POLLUTION IMPROVEMENT IN THE UK UP TO 2030, FOLLOWING THE UK 2030 AND LS1 POLICY SCENARIO (CASES PER YEAR AVERAGED OVER 2018-2134).[e]

Comparison is made against a scenario where concentrations remain unchanged from UK 2018.



*Decreases in hospital admissions and gains in life years were calculated for both $PM_{2.5}$ and NO_2 and the largest result between the two pollutants taken (summing both would lead to double counting due to overlap between the pollutants). See technical report for details.

8. REDUCED POLLUTION BRINGS GAINS FOR HEART AND RESPIRATORY CONDITIONS

The study considered the impacts of lower air pollution on eight health conditions.[f] The findings on two of these health conditions – new cases of CHD and symptom days for children with asthma per year – are presented here. These clearly show that improvements can be made to both heart and respiratory conditions by reducing $PM_{2.5}$. Across the UK, for the UK2030+LS1 scenario, the number of new cases of CHD is projected to reduce by, on average, 3,100 each year (1.4%),[g] and the number of symptom days in asthmatic children by 388,000 (0.5%) annually.

9. ADDITIONAL POLICIES IN LONDON DRIVE FURTHER HEALTH BENEFITS

Under LS1, the population of the capital would gain around two million life years over a lifetime, compared with a gain of around 2.4 million life years for LS2 and around 2.5 million life years for LS3. These figures are equivalent to a 24% (LS1), 28.5% (LS2) and 29.3% (LS3) reduction in life years lost compared with 2018 concentrations being maintained. Put another way, the additional policies in London in LS2 and LS3 add 0.4 and 0.5 million life years, respectively, to the life years gained under LS1. The improvement in average life expectancy from birth in 2018 in London is around 2–2.5 months under LS1, and 2.5–3 months for LS2 and LS3.

The two disease outcomes also improve. An additional 43 new cases of CHD are avoided under LS2, compared with LS1, and asthma symptom days fall by a further 8,000 and 9,100 for LS2 and LS3, respectively, compared with LS1.

[e] The end date is 2134 because life tables (tables of deaths and population by age group over time) needed to be run for 105 years beyond 2030. This is because differences in life expectancy cannot be modelled until predicted deaths in the population have occurred.

[f] Note these calculations were less complex than those for the life-years research.

[g] Note, the study did not take into account knock-on impacts across other parts of the National Health Service

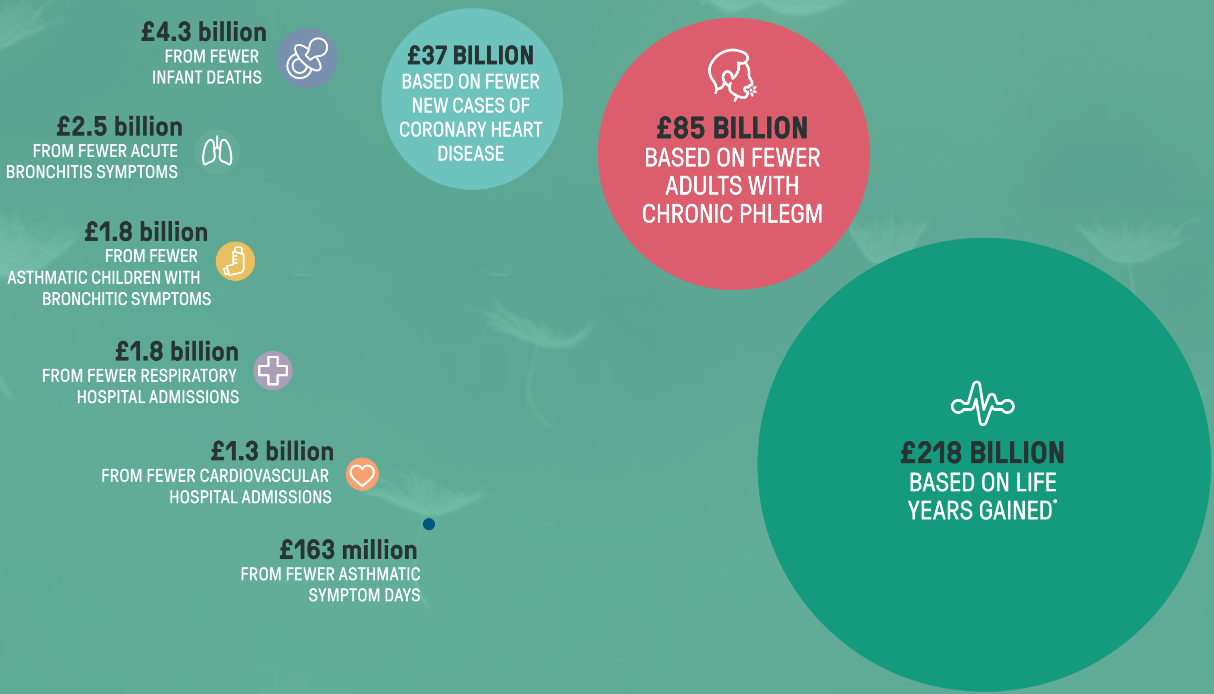
Economic benefits

10. SIGNIFICANT MONETARY VALUE TO HEALTH BENEFITS GAINED

The monetary value for the life years gained, reduced disease, lower health-sector costs and associated improved productivity from the forecast lower pollution between 2018 and 2030 – assuming the WHO-10 level is maintained from 2030 – is over £380 billion (net present value). This figure refers to benefits gained during 2018–2134, under the UK2030+LS1. It equates to policies costing up to £3.3 billion per year to 2134. From an economic perspective, air-pollution-reduction policies that cost less or the same as the economic benefits they provide can be justified. This is based on an assessment of benefits related solely to lower air pollution. It is worth noting that many government policies, particularly those related to achieving Net Zero, will reduce air pollution alongside greenhouse gases, and could potentially lower consumer bills, too.

FIGURE 13: CUMULATIVE ECONOMIC BENEFITS FROM THE REDUCED DEATH AND ILLNESS ASSOCIATED WITH AIR POLLUTION IMPROVEMENT IN THE UK UP TO 2030, FOLLOWING THE UK 2030 AND LS1 POLICY SCENARIO (CALCULATED OVER 2018-2134).

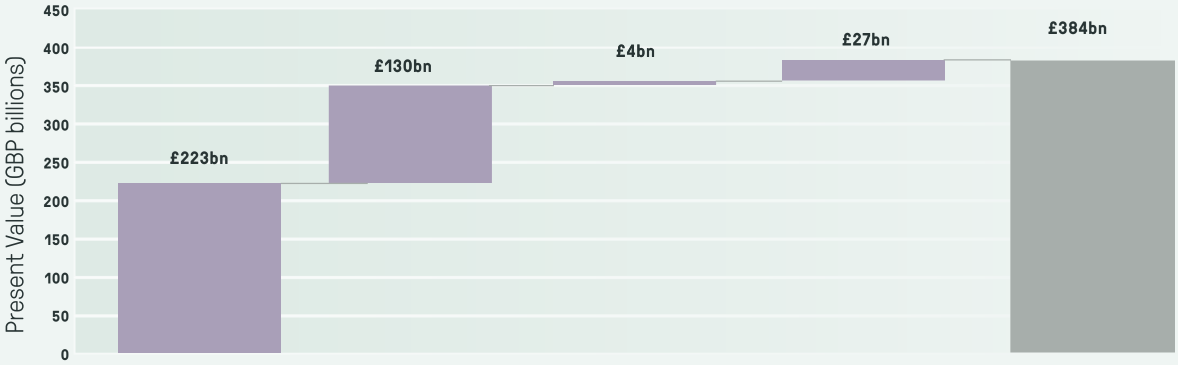
Comparison is made against a scenario where concentrations remain unchanged from UK 2018. Cumulative benefits given here whereas average cases per year given in Figure 11.



The specific pathways that deliver these economic benefits are:

- People living longer due to cleaner air
- Individuals suffering from fewer diseases or disease symptoms
- Health-sector benefits, in the form of financial savings that would otherwise have paid for primary, secondary and palliative care, and medication
- Labour-market benefits resulting from reduced absenteeism and presenteeism in the workforce

FIGURE 14: CUMULATIVE ECONOMIC BENEFITS RESULTING FROM ENHANCED AIR QUALITY , FOLLOWING UK 2030 AND LS1 SCENARIOS.



Reduced deaths

Due to each life-year saved as a result of reducing and maintaining lower levels of air pollution. The total number of life years saved up to 2134 is 8 billion.

Reduced illness

Welfare gain due to reduced onset of disease and hospitalisation. The monetisation of these benefits reflect patient willingness to pay to avoid disease and hospitalisation.

Health sector

Costs that are avoided by the health-care system due to air pollution related coronary heart disease and chronic bronchitis.

Labour market

Costs avoided because of lower absenteeism and presenteeism. Absenteeism captures workplace absences and loss of labour. Presenteeism is when people work but are less productive because of air pollution related illness.

Total benefits

Total benefits in the UK are **£384 billion** in 2018, which can be annualised to **£3.3 billion** per annum up to 2134.

11. TARGETED ACTION CAN BRING LONDON BELOW WHO-10

The London scenarios reflect the need for targeted air-pollution policies to improve air quality in London. That GLA, TfL and PLA supported the researchers from Imperial College London to define the scenarios, and the Mayor's already stated commitment to meeting WHO-10 by 2030, signify a willingness among the capital's authorities to develop specific policy solutions to address the issue. Analysis indicates that air-pollution policies specifically implemented in London lead to an additional £10.6 billion of health and productivity benefits (LS2), with the elimination of remaining pollution from wood burning resulting in further benefits of £1.5 billion (LS3). Therefore, air pollution-reduction policies that cost less or the same as these economic benefits can be justified.

A concerted effort by the London Government is anticipated to reduce $PM_{2.5}$ emissions from commercial catering, domestic wood burning, and construction. The detailed scenario assumptions are noted in the technical report.

12.THE BENEFITS OF POLICIES TO REDUCE AIR POLLUTION OUTWEIGH THE COSTS

An analysis of individual policies included in the UK2030 scenario, based on government analysis, indicates that the benefits outweigh the costs. The main policies affecting air pollution, and the associated costs and benefits, are summarised in Table 1.[11]

Table 1: Key policies for air pollution implemented by the UK Government.

SECTOR	POLICY	PRESENT VALUE (£ MILLION 2018)		BENEFIT COST RATIO
		Total benefits	Total costs	
ENERGY & INDUSTRY	Industrial emissions directive (upper and lower scenario)[h]	6,748–10,650	2,927–1,758	2.3–6.1
	Medium combustion plant directive	1,082	224	4.8
TRANSPORT	BNZP for transport*	690,558	182,500	3.8
	Euro VI standards			NA
BIOMASS	Regulations covering wood burning and coal	8,141	128	64
BUILDINGS	Building regulations 2010	45,924	23,126	2.0
	Building regulations 2013	1,669	1,245	1.3
	Technical standards for boilers (boiler plus)	1,526	1,025	1.5
	Private rented-sector energy-efficiency regulations	1,517	926	1.6
	The heat network investment project (green heat network fund)	1,179	589	2.0

*The Balanced Net Zero Pathway is justified mainly through operational savings for vehicle users over the lifetime of the asset (net present value (NPV) of £279 billion) and through the carbon savings generated from this transition (NPV of £411 billion). The policy also reduces air pollution but this benefit is not quantified by the CCC.

[h] Latest scenarios modelled by Defra in 2011/12

MAKING A STRONG CASE FOR WHO-10

This study concludes that less than 0.2% of the UK will exceed WHO-10 in 2030, provided the existing and anticipated policies outlined in the UK2030+LS1 scenario – including the electrification of the UK's vehicle fleet – are met. While hotspots of $PM_{2.5}$ pollution may remain close to major roads and industrial biomass-burning sites, these could be tackled through targeted actions facilitated, in part, by devolved powers for London and other cities. Meeting WHO-10 by 2030 could accrue over £380 billion of associated health and productivity benefits in the longterm,[i] indicating that, from an economic perspective, policies costing up to this amount (around £3.3 billion per year) would be justified. These benefits range from 11.5 million life years being gained (a 23% reduction in life years lost compared with 2018 concentrations being maintained) to 3,100 fewer new cases of coronary heart disease and 388,000 fewer reported asthma symptom days in children on average per year. For policies that are likely to have the greatest impact on air quality – regulations covering industrial emissions and domestic wood burning – the benefits are more than double the costs.

This evidence, grounded in sophisticated modelling and benefits analyses, makes a strong case for the UK Government to: set the annual average concentration target for $PM_{2.5}$ at WHO-10, to be achieved by 2030; commit to effectively implementing existing and anticipated policies outlined in the UK2030+LS1 scenario; and consider devolving powers to aid further air pollution reductions in cities. Doing so would make the UK a world leader in air quality and health, and would set the country on the path to ultimately meeting the WHO-5 guideline level.

[i] UK2030+LS1 scenario

METHODS

For more detail on the methods used, and associated uncertainties, see the technical report.

Modelling $PM_{2.5}$ concentrations across the UK

ABOUT THE MODEL

The researchers from Imperial College London used a bespoke model called CMAQ-urban for the study. This tried-and-tested model is ideal for simulating air pollutants at continental and country to city scales. It has been widely used for health research and policy applications, including work undertaken on behalf of Defra.

CMAQ-urban combines three state-of-the-art models:

- The Weather Research and Forecasting (WRF) model, a numerical weather-prediction model designed for both atmospheric research and operational forecasting uses.
- The United States Environmental Protection Agency Community Multiscale Air Quality Modeling system (CMAQ), a chemical-transport model that relies on scientific first principles to predict concentrations of airborne gases and particles. One of the world's leading chemical-transport models, it is used and developed globally by many scientists.
- The Atmospheric Dispersion Model System–Road (ADMS–Road), designed to model air pollution derived from networks of roads.
- In a 2011 review of air quality models, both CMAQ and ADMS were confirmed as suitable for further use for policy development by Defra.

ESTABLISHING THE 2018 BASELINE

The Imperial College London team modelled 2018 pollution concentrations across the UK, to provide a baseline and evaluate the model against real data. Emissions data for this baseline year came from: the European Monitoring and Evaluation Programme (EMEP – for data covering Europe); the UK National Atmospheric Emissions Inventory (NAEI – for data covering the UK), and Imperial College London (for data covering UK roads). Data from both anthropogenic and biogenic sources was used.

The European and UK data covered emissions from a diverse set of chemical species to ensure that primary emissions of $PM_{2.5}$, as well as secondary sources of $PM_{2.5}$ derived from chemical reactions in the atmosphere, would be accurately output by the model. Each set of emissions data was tailored to fit the required resolution – 50km across Europe, and between 10km and 2km across the UK.

People are often exposed to particularly high levels of $PM_{2.5}$ along road networks but the NAEI does not provide road-by-road emissions estimates across the UK. To overcome this lack of critical data, Imperial College London ERG developed a tool to generate annual emissions of traffic pollutants every 10m along 55,000 km of UK major roads. For Northern Ireland, NAEI 1km x 1km emissions were used, with a more limited dataset of roads, primarily covering Belfast.

EVALUATING THE MODEL

The model outputs for 2018 showed good agreement with concentrations of $PM_{2.5}$ measured at 135 high-quality UK fixed-site monitors that form part of the UK government's air quality monitoring network, located in a range of environments from rural to kerbside. Calculations made using other standard statistical methods also indicated good performance by the model.

It is important that predictive models such as CMAQ-urban perform consistently across different years. Although a comprehensive evaluation for other years was not conducted for this project, previous work conducted using the model in 2012 testifies to its ability to produce consistent results from similar input emissions. The model was also comprehensively evaluated during a model inter-comparison exercise by Defra; another such exercise is currently under way and should report soon. Internationally, the model was assessed as part of the Air Quality Model Evaluation International Initiative.

BOX 6 UNCERTAINTY IN THE MODELLING

There remain important uncertainties in both the emissions data and air-pollution modelling forecasts, as well as in the costs and benefits analyses. However, it is possible to state, with 95% confidence, that less than 5% of the UK will exceed WHO-10 in 2030. For LS1, it is possible to state with 95% confidence that less than 27.1% of the Greater London Authority area will exceed WHO-10 in 2030; this reduces to 4.3% for LS2. In other words, it is possible to confidently state that less than 5% of the UK will exceed WHO-10, even considering the worst-case model uncertainty - although these are areas where people live.

ACHIEVING A REALISTIC SCENARIO FOR 2030

After establishing the 2018 baseline, the emissions changes resulting from the policies underpinning the UK2030+LS1 scenario were applied to the input data for 2018 to simulate pollution concentrations in 2030. To cover European emissions affecting the UK, projections were taken from the European Union (EU)'s Second Clean Air outlook, published in 2021.

Modelling $PM_{2.5}$ concentrations across London

ABOUT THE MODEL

To assess impacts of policies on air pollution in London, the researchers from Imperial College London used the London Toolkit model. This model has been used in combination with data from the London Atmospheric Emissions Inventory (LAEI) for all of London's air quality policy developments, such as the ULEZ. For this study, data from LAEI 2016[12] and 2019[13] was used. This model has built-in functionality for calculating chemistry that makes it quicker to run than CMAQ-urban, facilitating testing of different future scenarios.

ESTABLISHING THE 2018 BASELINE

As with the UK-wide modelling, a baseline simulation was used to capture $PM_{2.5}$ concentrations in London in 2018. The London emissions data was taken from the LAEI, which includes detailed estimates of all anthropogenic emissions sources in the city. The LAEI is similar to the NAEI but also includes emissions from commercial cooking and London specific domestic wood-burning in the capital. Road-transport emissions – incorporating London-specific vehicle stock – were calculated using Imperial College's London road emissions tool.

The London Toolkit model produces concentration predictions derived from 23 individual source sectors (from commercial catering, to construction dust and accidental fires). To assess the impacts of various policy actions on different types of emissions, the source sectors were aggregated into eight major source categories:

1. Commercial catering (cooking)
2. Domestic wood burning
3. Road transport
4. Construction (dust, non-road mobile machinery, industrial non-road mobile machinery)
5. Domestic and commercial gas and other fuels (oil and coal)
6. Industry (from large facilities, such as refineries, to small services, such as petrol stations)
7. Mobile non-road transport (rail, shipping, aviation)
8. Other (including waste treatment)

EVALUATING THE MODEL

The 2018 model showed good agreement with concentrations of $PM_{2.5}$ measured at 26 high-quality UK and London Air Quality Network fixed-site monitors, located in a range of environments from suburban to kerbside. For more information, see the technical report.

DEFINING THREE POTENTIAL SCENARIOS FOR 2030

After the 2018 baseline simulation was undertaken, three further model runs were made to capture the changes in emissions from the LS1, LS2 and LS3 scenarios. After running the model for 2030 under LS1, the researchers from Imperial College London adjusted emissions in appropriate source categories to highlight the impact of LS2 (with the Mayor having additional policy powers) on $PM_{2.5}$ concentrations. This process was then repeated for LS3 in which all emissions from domestic wood burning stoves were removed, emulating the impact of a ban on these appliances.

Analysis and Uncertainty

CALCULATING THE PROPORTION OF THE UK'S POPULATION EXPOSED TO $PM_{2.5}$

Using a geographic information system, researchers from Imperial College London mapped the annual average concentration of $PM_{2.5}$ for each ward. Relating each ward's annual average concentration to the number of people living there enabled the team to derive population-weighted average $PM_{2.5}$ exposure for each LAA. This value was obtained for the 2018 baseline and the UK2030 scenario in combination with each of the three London scenarios. The values were also aggregated into country and city regions.

CALCULATING THE HEALTH BENEFITS TO THE UK OF REDUCED AIR POLLUTION

A 'life table' – containing the size of the population and numbers of deaths in each age group per year – was used to calculate the number of life-year and life-expectancy gains from the effect of reduced pollution on all-cause mortality. Calculating life years gained involved first examining the modelled pollution outputs for 2018 and calculating the number of deaths caused by that pollution based on relationships between deaths and pollution in previous research studies. The population for year two was then reduced by that number of deaths. This left the year two population smaller and younger than it would have otherwise been, due to deaths among older people. This process was repeated for the entire period from 2018 to 2134 (105 years after 2030, to account for everyone's full life cycle). A linear relationship was assumed between pollution in 2018 and 2030, with pollution remaining at the 2030 level thereafter.

The calculations for life expectancy used the same population figures but only considered people born in 2018. This subset of people was followed for a full life-time, assuming (i) no change in pollution and (ii) reduced pollution due to the UK2030+LS1 scenario. Dividing the difference in life years for (i) and (ii) by the size of the population gave the life-expectancy gain. Equivalent calculations were made for LS2 and LS3.

CALCULATING THE IMPACT OF REDUCED AIR POLLUTION ON DISEASE

Health impact assessments take the relationship between health outcomes and pollution concentrations from studies undertaken by others and apply this in a new context. In this study, the relationships were applied to the projected concentration reductions for the UK2030 scenario combined with each of the London scenarios, using the UK population, and then applying the relevant percentage decrease to the typical rates of disease in the UK.

The study considered the impacts of setting the WHO-10 target for 2030 on eight diseases. For consistency, the impacts were calculated over the years 2018 to 2134 to match the calculations for life years gained. The results for new cases of CHD and asthmatic symptom person days in asthmatic children are included in this summary document.

Coronary Heart Disease: Studies on CHD are based on cohort studies that follow a group of people over time. Comparisons are made between the levels of pollution ($PM_{2.5}$) and the number of new cases of CHD in different places to give a concentration-response relationship. For this study, the concentration-response relationship was applied to provide the average number of new cases of CHD per year over the period 2018 to 2134, taking into account population changes resulting from general trends over time, such as mortality improvements, and declines in births. The pollution levels were adjusted according to the model outputs for the UK2030 scenario (combined, in turn, with LS1, LS2 and LS3). This showed the benefits of each scenario set for the whole of the UK.

Asthmatic symptom person days in asthmatic children: Panel studies were used as the basis for the health benefit calculations. These compare instances of asthmatic symptoms recorded by children in diaries with pollution levels on particular days to give a concentration-response relationship. This relationship was used, together with data on the number of children with asthma in the UK and the proportion of those children who typically have symptoms, to derive figures for the average annual number of asthmatic symptom days under the 2018 baseline and 2030 scenario sets for PM_{10} (see Box 7).

[i] The UK has around 8,700 wards that are grouped into 382 (2019 figure) Local Authority Areas (LAA). This means there are roughly 23 wards per LAA.

BOX 7 HEALTH BENEFITS COME FROM REDUCTIONS IN SEVERAL POLLUTANTS

While this report and the study on which it is based have focused on the impacts of reducing $PM_{2.5}$, some of the policies in the UK2030+LS1 and LS2 scenarios will also reduce other pollutants, including larger-particulate PM (PM_{10}) and nitrogen dioxide (NO_2). As cuts to these pollutants can also affect health outcomes, the researchers from Imperial College London considered the potential impact of all three pollutants on diseases.

In some cases, such as when considering life years, there was evidence for effects from more than one pollutant, and results were given for the pollutant with the greatest impact (for life years this was $PM_{2.5}$). For CHD, the impact from $PM_{2.5}$ was studied, while for asthmatic symptom days in children the focus was PM_{10}. Setting the WHO-10 target will not only deliver benefits because people are exposed to less $PM_{2.5}$ but also because they breathe in less PM_{10}, NO_2 and other toxic chemicals.

UNCERTAINTIES IN THE BENEFITS ANALYSIS

In addition to uncertainties in the modelling described above, there are also uncertainties and assumptions in the benefits modelling. These are not quite as crucial to conclusions, as they are not compared against an absolute number such as WHO-10. Analyses of some aspects of uncertainties were undertaken, such as the ranges around the concentration-response functions and assumptions about whether the health effects extend to very low concentrations. The evidence linking air pollution to some health outcomes is stronger than for others.

EVALUATING THE BENEFITS FROM, AND THE POLICY COSTS OF, THE UK 2030 AND LONDON SCENARIOS

Economic valuation tools were used to monetise the health benefits – the impact of air pollution on deaths and disease. This followed approaches and assumptions in line with UK government guidance. It was not possible to attribute benefits to specific policies included in the UK2030 scenario. Therefore, the analysis drew on existing government impact assessments for key policies – particularly those covering industrial emissions and biomass burning – to show how the total value of forecast benefits (related to air pollution, climate change and energy savings) compared to costs.

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