Title: Environment Act Targets Impact Analysis: Air Quality **IA No:** N/A **RPC Reference No:** **Lead department or agency:** Department for Environment Food and Rural Affairs **Other departments or agencies:**	# Impact Assessment (IA) **Date:** 19/12/2022 **Stage:** Final **Source of intervention:** Domestic **Type of measure:** Secondary legislation **Contact for enquiries:** AQEvidence@defra.gov.uk

Summary: Intervention and Options

RPC Opinion: N/A

Cost of Preferred (or more likely) Option (in 2020 prices)			
Total Net Present Social Value (£m) **£107,935m**	**Business Net Present Value**	**Net cost to business per year**	**Business Impact Target Status** Not a regulatory provision

What is the problem under consideration? Why is government action or intervention necessary?

Air pollution poses the biggest environmental risk to public health, and fine particulate matter ($PM_{2.5}$) is the air pollutant which causes the most serious harm to health. Evidence suggests that both short-term and long-term exposure to $PM_{2.5}$ are linked with a range of negative health outcomes, including shortening the lives of susceptible individuals through stroke, cancers, respiratory and other diseases. Government intervention is necessary to reduce public exposure to this harmful pollutant and deliver associated health benefits. To deliver this, actions will be required across all levels of government and industry, and across all aspects of society. Therefore, it is appropriate for action to be taken at a central government level.

What are the policy objectives of the action or intervention and the intended effects?

The primary aim is to reduce concentrations of $PM_{2.5}$ to improve public health, in particular where they are highest and where the most people are exposed. The Environment Act requires the government to set long-term, legally binding environmental targets. The objectives of the two air quality targets, which support the delivery of the overall aim, are 1) to reduce the annual mean level of $PM_{2.5}$ in ambient air, and 2) to reduce population exposure to $PM_{2.5}$. The intended effects are to establish a new minimum standard for $PM_{2.5}$, and drive continuous improvement in levels across the country, even in areas which meet the minimum standard. The changes in concentrations and population exposure will be assessed through an expanded English network of $PM_{2.5}$ air quality monitoring stations.

What policy options have been considered, including any alternatives to regulation? Please justify preferred option (further details in Evidence Base)

This document will provide analysis on one option, in addition to the “do nothing” option where no further concentration and population exposure reduction measures are pursued (for comparison purposes only):

Option 0: “Do nothing” (Annual mean $PM_{2.5}$ concentration target = 20 µg/m^3 and 27% reduction of $PM_{2.5}$ population exposure by 2040)
Option 1: Annual mean $PM_{2.5}$ concentration target = 10 µg/m^3 by 2040 and 35% reduction of $PM_{2.5}$ population exposure by 2040

Two additional options for setting the level of each of the two targets were considered but not shortlisted as we believe that option 1 best reflects the evidence and provides an appropriate balance between health benefits across the population / vulnerable groups, and overburdensome requirements on people and society.

An alternative to targets setting is not considered as there is a legally binding commitment for government to set targets.

Is this measure likely to impact on international trade and investment?				
Are any of these organisations in scope?	**Micro**	**Small**	**Medium**	**Large**
What is the CO_2 equivalent change in greenhouse gas emissions? (Million tonnes CO_2 equivalent)		**Non-traded:**		
Will the policy be reviewed?	**If applicable, set review date:**			

I have read the Impact Assessment and I am satisfied that, given the available evidence, it represents a reasonable view of the likely costs, benefits and impact of the leading options.

Signed by the responsible SELECT SIGNATORY: Minister Trudy Harrison Date: 15/12/2022

Summary: Analysis & Evidence — Policy Option 1

FULL ECONOMIC ASSESSMENT

Price Base Year 2020	PV Base Year 2020	Time Period 2023-2040	Net Benefit (Present Value (PV)) (£m)		
			Low: **£30,620**	**High:** **£232,898**	**Best Estimate:** **£107,935**

COSTS (£m)	**Total Transition** (Constant Price) Years	**Average Annual** (excl. Transition) (Constant Price)	**Total Cost** (Present Value)
Low			
High			
Best Estimate			**£27,074**

Description and scale of key monetised costs by 'main affected groups'

The cost of reaching the targets will depend on what action is taken to meet them. There will be a cost to households, businesses, and government. The sectors that will incur costs include domestic and commercial combustion, transport, agriculture and industry. Whilst many measures are national, there are some which are applied only to urban centres, and there may be additional measures for London. Therefore, the cost may not be uniform across the country and will be significantly influenced by policy choices. No decisions on policy pathways have yet been made.

Other key non-monetised costs by 'main affected groups'

BENEFITS (£m)	**Total Transition** (Constant Price) Years	**Average Annual** (excl. Transition) (Constant Price)	**Total Benefit** (Present Value)
Low			**£57,694**
High			**£259,972**
Best Estimate			**£135,009**

Description and scale of key monetised benefits by 'main affected groups'

Most of the monetised air quality benefits are for human health, based on individuals' willingness to pay. Also monetised is the impact on ecosystems, building damage, productivity and greenhouse gas reduction. Poor air quality is a particular threat to vulnerable groups, including the elderly, the very young, and those with existing health issues, like respiratory problems. Those living in city centres, and near busy roads, often on the lowest incomes, are most exposed to dangerous levels of air pollution so these groups will receive the most benefit.

Other key non-monetised benefits by 'main affected groups'

Other impacts include reduced levels of congestion and noise pollution as well as reduced exposure to air pollution in Devolved Administrations from English emission sources.

Key assumptions/sensitivities/risks	**Discount rate (%)**	1.5

The analysis presented in this document is based on scenarios defining possible pathways to improve air quality. These scenarios have been created to inform decision making on achievability of considered levels and timelines of two $PM_{2.5}$ targets, allowing an assessment of possible key costs, benefits, risks, and opportunities of different target levels and dates. The measures included in these scenarios are not necessarily government policy. They should not be considered as expectation on how government intends to take action to meet these air quality targets, which will be for future policy decisions, with public consultations and impact assessments conducted in their own right as and when required. Other pathways to reach the targets would have different associated costs and benefits. Policy measures that are pursued to reach the target will be subject to their own IA in the future.

The analysis presented gives a sense of the challenges. Concentration reduction and lower population exposure are valued using the central air quality concentration damage costs published by Defra, with the low and high values used as sensitivities. Carbon values series are used to value impacts of the measures on greenhouse gases. As a sensitivity on the baseline, the impact on air quality of policy package for setting Carbon Budget 6 level by BEIS is tested as well as the impact of the National Emission Ceilings Regulations (NECR) 2018 that set legally binding emissions ceilings for $PM_{2.5}$ and other air pollutants.

BUSINESS ASSESSMENT (Option 1)

Direct impact on business (Equivalent Annual) £m:			**Score for Business Impact Target (qualifying provisions only) £m:**
Costs: £	**Benefits:** £	**Net:** £	N/A

Contents

Glossary

Abbreviation	Full expression / term
AMCT	Annual Mean Concentration Target
AQEG	Air Quality Expert Group
BAT	Best Available Technique
BAU	Business as Usual
BBAU	Beyond business as Usual
CAPEX	Capital Expenditure
CAS	Clean Air Strategy
CBA	Cost Benefit Analysis
COMEAP	Committee on the Medical Effects of Air Pollutants
GhG	Greenhouse gas
IED	Industrial Emissions Directive
IGCB	Inter Departmental Group on Costs and Benefits
IIR	Informative Inventory Report
kt	Kilo tonnes
LCP	Large Combustion Plant
MCP(D)	Medium Combustion Plant (Directive)
MPMD	Multi-pollutant Measures Database
NAEI	National Atmospheric Emissions Inventory
NAPCP	National Air pollution Control Programme

NECD	National Emission Ceilings Directive
NECR	National Emission Ceilings Regulations, 2018
NH_3	Ammonia
NMVOCs	(Non-methane) Volatile Organic Compounds
NOx	Nitrogen Oxides
OPEX	Operating Expenditure
PERT	Population Exposure Reduction Target
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter of less than 2.5µm
PWMC	Population weighted mean concentration
PWME	Population weighted mean exceedance
SMT	Scenario Modelling Tool
SO_2	Sulphur Dioxide
SIA	Secondary Inorganic Aerosol
UKIAM	United Kingdom Integrated Assessment Model
UNECE	United Nations Economic Commission for Europe

Executive Summary

The purpose of this Impact Assessment (IA) is to provide a summary of the economic analysis that has been undertaken in support of the proposed Environment Act air quality targets. This IA is complementary to the Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report[1] which includes further details on the approach used to define the target metrics and analysis commissioned to inform decision making regarding the setting of targets.

The Environment Act 2021[2] includes the power for England to set long-term, legally binding environmental targets. It requires the government to set two targets for air quality, one for $PM_{2.5}$ based on annual mean concentrations and an additional long-term air quality target. Setting targets will provide a strong mechanism to deliver long-term environmental outcomes. The proposed air quality targets both focus on $PM_{2.5}$ as this is the air pollutant which is most damaging to public health.

The two proposed targets are:

- Annual mean $PM_{2.5}$ concentration target – based on $PM_{2.5}$ ambient air concentration (unit: µg/m³)
- $PM_{2.5}$ population exposure reduction target (PERT) – based on $PM_{2.5}$ concentration and population data (unit: % reduction compared to a reference year)

Aside from the option of doing nothing beyond what is required by those government policies, that have been implemented or are scheduled to be implemented before October 2022 (Option 0), a preferred option (Option 1) has been selected to reflect an ambition to provide better human health outcomes, with particular attention to the most deprived population and improving our ecosystem:

Table 1: Target options

	Description	Target 1: Annual mean $PM_{2.5}$ concentration target	Target 2: $PM_{2.5}$ population exposure reduction target (PERT)
Option 0	"Do nothing" baseline	20 µg/m³	27% by 2040
Option 1	Preferred option	10 µg/m³ by 2040	35% by 2040

1 Air Quality Targets in the Environment Act - Defra, UK
2 Environment Act 2021 (legislation.gov.uk): www.legislation.gov.uk/ukpga/2021/30/contents/enacted

This IA provides the analysis of the preferred option for the dates and end points of the two air quality targets. The appraisal uses illustrative pathways demonstrating what may be required to reach the targets. This does not pre-empt specific policy choices that will be implemented in the future, and there is a high degree of uncertainty around what policies will be pursued to meet the targets and what their costs and benefits will be. Other pathways to meet the targets would have different associated costs and benefits. Policy measures that are pursued to reach the targets will be subject to their own consultation process and IA in the future.

The monetisation of measures intended to reduce concentration is provided as an illustration only, and is based on knowledge of theoretically achievable options, which are assumed to be deliverable from a technical perspective.

The tables below give a summary of the net present value of the preferred option over the 2023-2040 period. The total social cost for the appraisal period is estimated to be £27bn and the total social benefit is estimated at £135bn. Most (72%) of the benefits result from Greenhouse Gas (GhG) reductions, while the proportion of benefits resulting from air quality is 28%. The total net present value is estimated to be £108bn over the appraisal period.

Table 2: CBA Summary results, 2023-2040, discounted (£m, 2020 prices)

	Total Social Cost	Total Social Benefit	Net Present Social Value
Preferred Option (Option 1)	£27,074	£135,009	£107,935

	PM2.5 benefits	Total AQ benefits
Cumulative Benefits (2023-2040)	£31,969	£37,891

Table 3: England: Cumulative benefits from reduced damage to health, productivity, ecosystems and soiling of buildings from $PM_{2.5}$ exposure for preferred option (£m, 2020 prices)

	Preferred Option (Option 1)
Greenhouse Gas abatement ($ktCO_2e$)	540,225
Monetised Value (£m)	£97,118

Table 4: England: Cumulative (2023-2040) benefit from Greenhouse Gas (GhG) emission abatement relative to the baseline (£m, 2020 prices)

1. Introduction

The purpose of this IA is to provide a summary of the economic analysis that has been undertaken in support of the proposed Environment Act air quality targets. The analysis presented should not be interpreted as a full appraisal of the government's decision to pursue such targets, which will be for future policy decisions, with public consultations and impact assessments conducted as and when required.

The *Overarching Impact Assessment for proposed Environment Act (2021) targets* provides a high-level, descriptive, and largely qualitative analysis of all the targets under the Environment Act.

This IA is complementary to the Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report[3] which includes further details on the approach used to define the target metrics and analysis commissioned to inform decision making regarding the setting of targets.

The Environment Act requires the government to set at least two targets for air quality, one for $PM_{2.5}$ based on annual mean concentrations, and an additional long-term air quality target. The proposed air quality targets both focus on $PM_{2.5}$ as this is the air pollutant which is most damaging to public health[4].

The two considered targets are:

- Annual mean $PM_{2.5}$ concentration target – based on $PM_{2.5}$ ambient air concentration (unit: $\mu g/m^3$)
- $PM_{2.5}$ population exposure reduction target – based on $PM_{2.5}$ concentration and population data (unit: % reduction compared to a reference year)

The "**Annual mean concentration target**" establishes a minimum level of air quality to be achieved by the target year. Achievement of this target is dependent on measurements made from appropriately defined "representative monitoring". These measurements must not report concentrations greater than the concentration target by, and beyond, the achievement date. The primary compliance metric will be based on the annual mean concentrations reported at each measurement location (fixed monitoring site) and compared to the level set in the target. Appropriate criteria will define: the requirements for monitoring (numbers of monitors, location types, instrument types, instrument performance characteristics etc), the data capture objectives and matters such as analytical rounding prior to comparison to the target. Progress towards achievement of the target will be legally defined by trends in the monitoring station data on an annual basis.

[3] Air Quality Targets in the Environment Act - Defra, UK
[4] PM2.5 is the most damaging air pollutant, according to Defra (2020): Air Quality Appraisal: damage cost guidance

The second target, named “**The population exposure reduction target (PERT)**” looks to affect the average exposure across the population and ensure that this is reduced by a fixed or proportionate amount, relative to a base year. Compliance with the PERT is assessed using measurements from monitoring equipment located at sites which are representative of population exposure. This monitoring network is being expanded over the next three years to support target assessment. The calculation of the change in population exposure from 2018 to 2040 uses a statistical approach that accounts for the planned expansion of this monitoring network, ensuring that the assessment is not biased by the change in network. This involves calculating year-on year changes in exposure using a common set of monitoring sites and then summing these yearly increments to give the total change in population exposure. It is important that whilst a limit is placed on the highest level of pollution in any one location assessed (i.e., the annual mean concentration target), that action to meet the target does not simply move the pollution to other locations, potentially exposing more people and therefore creating negative health benefits. Similarly, whilst there is some guidance on what levels are suitable to protect health, there is no safe level of $PM_{2.5}$. Any exposure imposes some impact on health, and therefore this target aims to drive long term improvement beyond the annual mean concentration target and drive action where concentrations could otherwise remain static or increase up to the concentration target if they are already below. The aim of setting both targets is to reduce the public health impact and therefore the population exposure reduction target is more closely aligned to this objective, but there is general acceptance that both a target to reduce maximum levels and a target to drive population exposure will be an efficient dual target approach. Understanding how this target interacts with other air quality targets to manage impacts on ecosystems will be important to avoid any unintended consequences such as moving more polluting activities from highly populated areas and not reducing overall concentrations.

Together, these two targets aim to:

Provide equity by driving action in the locations where the highest levels of exposure occur, thereby delivering a ‘minimum’ level of air quality across the country

- We propose to do this by setting an annual mean $PM_{2.5}$ concentration target.
- This target should drive action that is most effective at reducing levels where the concentrations exceed the ‘minimum’.
- Alone, this target will not drive wider action, nor will it be the most efficient at delivering public health benefits, however it would help to protect the more vulnerable members of society living in areas with the highest exposure.

Incentivise actions that reduce levels of $PM_{2.5}$ in ways that deliver the greatest public health benefits (at all levels of government and sectors of society)

- We propose to do this by setting the PERT.

- This target should drive action that is the most beneficial in delivering public health benefits across the population wherever they live

Drive continuous improvement over the long-term, to encourage action to deliver air quality improvements beyond the 'minimum' level of air quality – addressing the fact that there is no threshold beyond which exposure to $PM_{2.5}$ does not have an impact.

- We propose to do this in part through the population exposure reduction target; alongside a defined role for local authorities in supporting delivery of these national targets.

Include consideration of health disparities with regards to air pollution; and the most appropriate way to deliver benefits for those most at risk from adverse health effects of air pollution

- An annual mean concentration target will partly address these disparities by ensuring a 'minimum' level across the country; and the PERT will benefit the whole population, including those who are most susceptible.

Form part of a comprehensive and integrated strategy to deliver cleaner air, and sit within a supporting target framework of measurement, regular review and assurance.

- We will work with other government departments and local government so that independencies with other environmental policy aims, such as Net Zero, are captured

- The Environment Act creates a new statutory cycle of monitoring, planning and reporting. Long-term targets will be supported by interim targets, which will set a five-year trajectory towards meeting the long-term targets. The Act requires Government to set interim targets in the Environmental Improvement Plan. This will ensure that there is always a shorter-term goal Government is working towards, as well as the long-term target and will allow for an ongoing assessment of whether the government is on track to meet its long-term target ambitions.

2. Problem under consideration and rationale for intervention

2.1. Impact of exposure to particulate matter on human health

Air pollution poses the biggest environmental risk to public health, and fine particulate matter is the air pollutant which causes the most significant harm to health. Particulate matter (PM) is anything in the air that is not a gas. Fine particulate matter, also known as $PM_{2.5}$, relates to particulate matter particles with a size of 2.5 microns in diameter or less (1/400th of a millimetre). It can come from natural sources such as pollen, sea spray and desert dust, as well as human-made sources such as smoke from fires, soot from vehicle exhausts, and dust from tyres and brakes.

There is strong evidence[5] which suggests that both short-term and long-term exposure to $PM_{2.5}$ are linked with a range of negative health outcomes, including shortening the lives of susceptible individuals through stroke, cancers, respiratory and other diseases. The Committee on the Medical Effects of Air Pollutants[6] (COMEAP) established that there is little evidence of a threshold of effect below which there is no harm, nor a threshold below which there are decreases in relative risk associated with long-term average concentrations of $PM_{2.5}$. It is assumed that the marginal benefit of reducing $PM_{2.5}$ is linear. These findings suggest that continuing to reduce concentrations would benefit public health. Modelled data from Public Health England[7] shows that reducing the concentration of this pollutant by 1 $\mu g/m^3$ in England in a single year can prevent around 50,000 cases of coronary heart disease, 15,000 strokes, 9,000 cases of asthma and 4,000 lung cancers by 2035.

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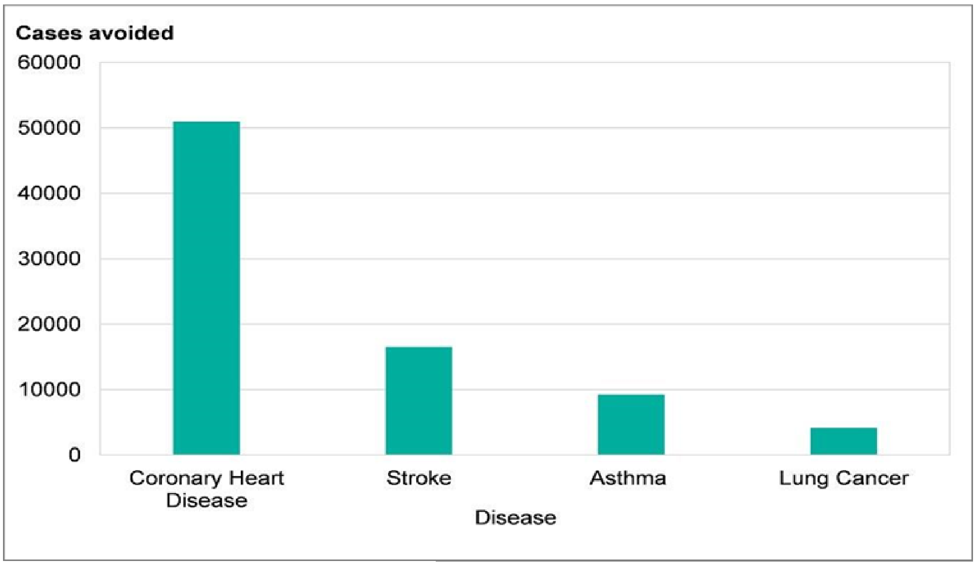
[5] Source: The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom, Committee on the Medical Effects of Air Pollutants, 2010

[6] Source: Advice note on the health evidence relevant to developing targets for fine particulate air pollution (PM2.5) under the Environment Bill, Committee on the Medical Effects of Air Pollutants, July 2021 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1002468/COMEAP_Env_Bill_PM2.5_targets_health_evidence_questions_responses.pdf

[7] Source: Estimation of costs to the NHS and social care due to the health impacts of air pollution, Public Health England, 2018 - www.gov.uk/government/publications/health-profile-for-england-2018

Figure 1: Cumulative new cases of disease avoided by 2035 for 1 µg/m³ reduction in $PM_{2.5}$, England



Source: Public Health England, 2018

2.2. Existing legislations and regulations

Until recent years, action to manage and improve air quality had been largely driven by international protocols and European (EU) legislation.

The revised United Nations Economic Commission for Europe (UNECE) Gothenburg Protocol[8] sets national emission limits (ceilings) for $PM_{2.5}$ as well as four other key pollutants (ammonia (NH_3), nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOCs), and sulphur dioxide (SO_2)). Similar ceilings were set in European law under the 2016 National Emission Ceilings Directive (2016/2284/EU), which was subsequently transposed into UK law as the National Emission Ceilings Regulations 2018[9] requiring the UK to reduce emissions for $PM_{2.5}$ by 46% in 2030 from 2005 level (see table below). There are estimated benefits of approximately £2.7 billion[10] per year from 2030 just from meeting existing emissions ceilings.

[8] UNECE Gothenburg Protocol
[9] National Emission Ceilings Regulations 2018
[10] The Clean Air Strategy estimates the costs of air pollution to society at £1.7 billion every year by 2020, rising to £5.3 billion every year from 2030, as calculated by Defra in 2018 based on the projected air pollutant emission exceedances published in March 2018. Based on updated emissions projections (NAEI 2018 projections published in March 2020), these costs were revised downwards by Defra in 2020, at £2.7 billion per year every year from 2030 (Discounted, price base year: 2020).

Table 5: National Emission Ceilings Regulations, 2018[11]

	2005 Baseline (kt)	Reduction required by 2020	Reduction required by 2030	2020 target (kt)	2030 target (kt)
NOx (Excludes agriculture)	1,699	55%	73%	764	459
SO_2	773	59%	88%	325	95
NMVOCs (Excludes agriculture)	1,060	32%	39%	731	656
$PM_{2.5}$	124	30%	46%	90	70
NH_3	279	8%	16%	255	233

The UK has also legally binding limits for concentrations of pollutants in air. The 2008 ambient air quality directive (2008/50/EC)[12] sets legally binding limits for concentrations of $PM_{2.5}$ in outdoor air as well as other major air pollutants that impact public health. The directive was made law in England through the Air Quality Standards Regulations 2010[13], setting a target value of 25 µg/m^3 for $PM_{2.5}$ on average over a calendar year. This was subsequently revised to 20 µg /m^3 through the Environment (Miscellaneous Amendments) (EU Exit) Regulations 2020.

In 2019, the government set out its Clean Air Strategy[14] (CAS) and its National Air Pollution Control Program[15] (NAPCP) for improving air quality. It establishes the ambition to "progressively cut public exposure to particulate matter pollution as suggested by the World Health Organization [by setting] a new, ambitious, long-term target to reduce people's exposure to $PM_{2.5}$." This ambition is then made clear in the Environment Act. These have driven government policies over the past years, as set out in Table 6.

[11] Data in Table 5 is based on National Atmospheric Emissions Inventory (NAEI) projections from 2018 which anticipated that 2020 targets for $PM_{2.5}$ would not be met. Updated NAEI projections (2020) were published in February 2022 and reported that the ceiling limit for $PM_{2.5}$ has been met.
[12] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF
[13] http://www.opsi.gov.uk/si/si2010/uksi_20101001_en_1
[14] http://www.gov.uk/government/publications/clean-air-strategy-2019
[15] http://www.gov.uk/government/publications/air-quality-uk-national-air-pollution-control-programme

Table 6: Examples of action taken to reduce $PM_{2.5}$ emissions and concentration

- Ready to Burn programme of actions
- Ban sales of the most polluting fuels to homes - The Air Quality (Domestic Solid Fuels Standards) (England) Regulations 2020
- Work with local authorities on Smoke Control Areas awareness and compliance
- Improve affordability for local government or provide national framework
- Support development of standards / innovation on tyre and brake wear
- Funding to support new technology to reduce emissions and incentivise adoption
- Implement Medium Combustion Plant Directive (MCPD) and generators regulations

2.3. Market failure and requirement for further government intervention

Air pollution is a classic form of market failure, as it can cause significant third-party costs through poor air quality which can impact their health. Yet the external cost is not reflected in prices, nor are third parties compensated for this. This is known as a **negative externality** – where the cost is not reflected in the price. The government intervention in this instance aims to correct the market failures to safeguard public health and increase societal welfare.

While existing regulations are driving efforts to reduce emissions of $PM_{2.5}$ until 2030 and ensuring that ambient air concentration is below 20 $\mu g/m^3$ on average, there is scope to be more ambitious and reduce further public exposure to $PM_{2.5}$.

Further reducing levels of $PM_{2.5}$ will deliver significant public health benefits as this is the most harmful pollutant to human health. To deliver these reductions, actions will need to be driven across all levels of government, many sectors, and all aspects of society. Therefore, it is appropriate for action to be taken at a central government level. A target is an appropriate means of intervention for this problem because $PM_{2.5}$ is a complex pollutant, and its chemical composition and sources are both numerous and variable, and therefore a broad range of actions are need instead of measures focused on one or two sources. Introducing legally binding targets will drive action by successive governments to improve air quality. They will allow for robust, objective scrutiny and accountability of government's progress, in addition to providing long-term certainty to businesses and society to support planning, innovation and investment.

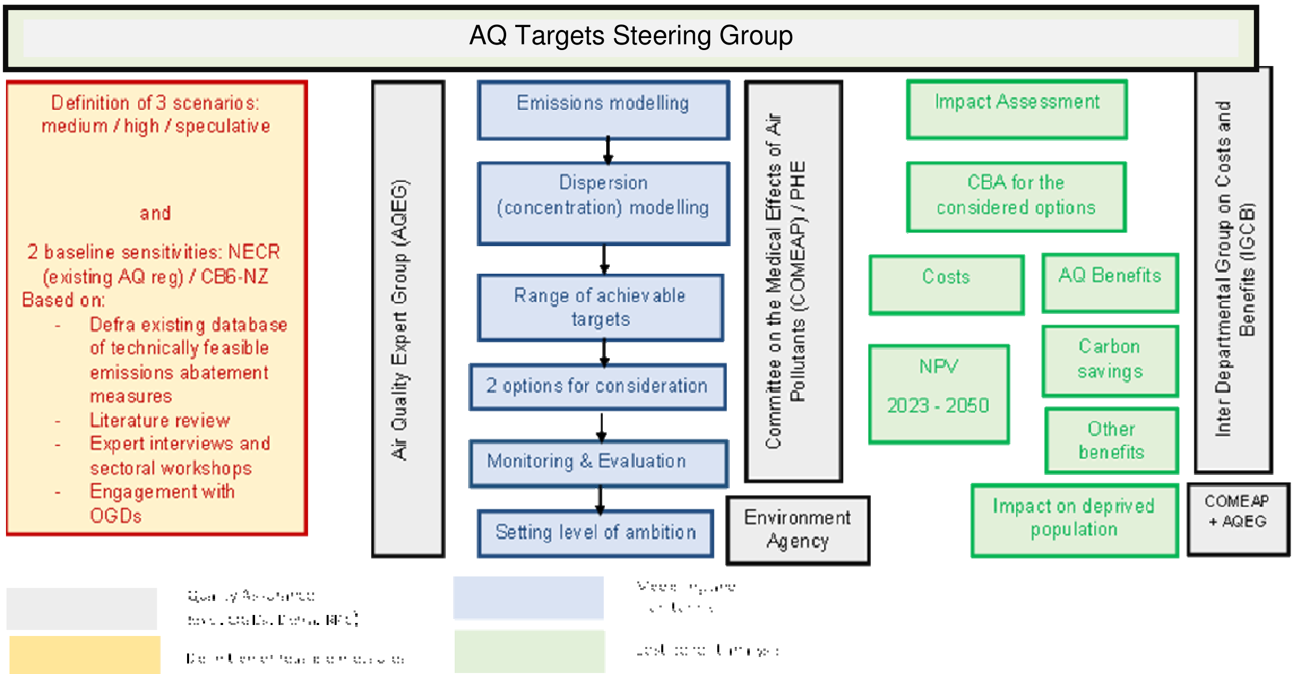
3. Rationale and evidence to justify the level of analysis used in the IA

The evidence used across the impact assessment has been gathered from a variety of sources, such as literature review, European Commission reports on air pollution, input by recognized health, air pollution scientists and sectoral experts, and databases on air pollution inventory and damage costs.

An in-depth evaluation of the factors affecting the analysis has been conducted and a thorough approach was used to set the targets and appraise the options. Many factors were considered such as the relevance of the targets to drive government action to improve air quality, the scale of ambition, the risks and overall achievability, the uncertainty around the baseline, the monitoring and evaluation, and the technical feasibility of the illustrative pathways to reach the set targets levels and end points.

Quality assurance of the process, from definition of the measures to the cost-benefit analysis, was conducted with input from the Air Quality Expert Group (AQEG), COMEAP, the Environment Agency, and the Inter Departmental Group on Costs and Benefits (IGCB).

Figure 2: Overall approach used for the analysis



The evidence used reflects the best possible evidence available at this time. This IA provides a summary of the evidence produced and is used to define the options, understand the uncertainty and risks, and evaluate costs and benefits. The Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report[16] includes a detailed description of the approach

[16] Air Quality Targets in the Environment Act - Defra, UK

used to define the target metrics, the value and timeframe, the modelling, the uncertainties, and the legal assessment method.

4. Policy objective

The primary aim is to reduce concentrations of $PM_{2.5}$ to improve public health, in particular where concentrations are highest and where the most people are exposed. The objectives of the targets, which support the delivery of the overall aim, are:

- **Objective 1**, to reduce the annual mean level of $PM_{2.5}$ in ambient air through the annual mean concentration target, establishing a new minimum standard across the country. This will focus action on reducing $PM_{2.5}$ where concentrations are highest, for example in large cities.

- **Objective 2**, reducing population exposure to $PM_{2.5}$ through the exposure target, will ensure that action is taken in a way which focuses on delivering the most significant public health benefit. This will drive continuous improvement across England as a whole, including in areas which already meet the annual mean concentration target. $PM_{2.5}$ is a regional pollutant, which means that reducing population exposure across the country will also play a role in enabling locations with elevated levels (hot spots) to meet the annual mean concentration target.

Setting and delivering these targets together will deliver greater public health benefits than either one alone. This approach has been supported by AQEG and COMEAP.

The changes in concentrations and population exposure will be assessed through the English network of $PM_{2.5}$ air quality monitoring stations. This will be expanded and enhanced to ensure that we are able to assess legal compliance against the new targets.

5. Description of options considered

The setting of the air quality targets has been supported by an evidence-based approach to ensure that the levels and end points selected are technically feasible, and socially beneficial. A review of possible measures and policies to reduce $PM_{2.5}$ concentration and population exposure was conducted through stakeholder engagement (expert interviews, workshops, etc) and a literature review. For each measure, uptake rates and timescales have been varied to apply within each of three scenarios, based on technology development, required behaviour changes, and timeframe for implementation. These have formed the basis for three policy options:

- Option 0 – Business as usual (BAU) - Do nothing - There is no cost associated with this option as it is estimated under the most reasonable 'business as usual' scenario. It is included for comparative purposes only. This option is not feasible as there is a legal commitment in the Environment Act to set a long-term air quality target and a target to reduce $PM_{2.5}$ annual mean concentration.

- Option 1 - High ambition – This scenario includes emerging technologies that are perceived as likely to be successful, and a medium degree of behaviour change. Implementation dates and uptake rates are toward the middle of estimates.

- Option 2 - Medium ambition – In this scenario only proven technology measures and limited behaviour change are employed, and the implementation dates and uptake rates are towards the lower end of estimates.

- Option 3 - Speculative ambition – In this scenario the maximum possible action is taken, all emerging technology is assumed to be successful and there is radical behaviour change. Optimistic (but still possible) implementation and uptake rates are used. This scenario represents the maximum technically feasible reduction in $PM_{2.5}$ concentrations.

After considering all the evidence, government proposes that that the annual mean concentration target is set at a level of 10µg/m^3 from a current level of 20µg/m^3, and the PERT at 35% reduction in population exposure compared to the 2018 baseline. Both are proposed to be met by 2040. We believe that these targets best reflect the evidence and provide an appropriate balance between health benefits across the population / vulnerable groups, and overburdensome requirements on people and society.

The High ambition scenario provides a trajectory that fits these targets, as described in the Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report[17]. Therefore, options 2 (Medium ambition) and 3 (Speculative ambition) were not shortlisted as the former did not provide a pathway with sufficient certainty to meet the targets, and the latter was considered not likely to be feasibly implemented as it was based on more speculative assumptions. The shortlisted options are:

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[17] Air Quality Targets in the Environment Act - Defra, UK

- **Option 0 – Business as Usual (BAU) - Do nothing** - There is no cost associated with this option as it is estimated under the most reasonable 'business as usual' scenario. It is included for comparative purposes only. This option is not feasible as there is a legal commitment in the Environment Act to set a long-term air quality target and a target to reduce $PM_{2.5}$ annual mean concentration.

- **Option 1 – High ambition (preferred option) –** Government intends to set very ambitious air quality targets that require setting policies, regulations, or incentives, possibly requiring the use of emerging technologies that are perceived as likely to be successful, and medium degree of behaviour change.

Table 7: Shortlisted air quality targets options

	Description	Target 1: Annual mean $PM_{2.5}$ concentration target	Target 2: $PM_{2.5}$ population exposure reduction target
Option 0	"Do nothing"	20 µg/m³ [18]	27% by 2040
Option 1	Preferred Option (High ambition)	10 µg/m³ by 2040	35% by 2040

[18] This level corresponds to the 2008 ambient air quality directive (2008/50/EC) legally binding limits for concentrations of $PM_{2.5}$ in outdoor air which was made law in England through the Air Quality Standards Regulations 2010, setting a target value of 25 µg/m³ for $PM_{2.5}$ on average over a calendar year. This was subsequently revised to 20 µg /m³ through the Environment (Miscellaneous Amendments) (EU Exit) Regulations 2020.

6. Summary and preferred option with description of implementation plan

The preferred option (Option 1) is to implement a target to lower legally binding limits for annual mean concentrations of $PM_{2.5}$ in ambient air in England to 10 µg/m^3 by 2040, from the existing limit of 20 µg/m^3 as set through the Environment (Miscellaneous Amendments) (EU Exit) Regulations 2020, as well as to reduce $PM_{2.5}$ population exposure by 35% by 2040.

The targets proposed will be implemented via secondary legislation, with the targets to come into force once approved by Parliament. The measures and policies to achieve these targets will the subject of separate legislation, with IAs and public consultations conducted as and when required.

7. Evidence base

The analysis presented in this document is based on scenarios defining possible pathways to improve air quality from 2023 to 2050. These scenarios have been created to inform decision making on achievability of considered levels and timelines of two $PM_{2.5}$ targets, allowing an assessment of possible key costs, benefits, risks, and opportunities of different target levels and dates.

The measures included in these scenarios should not be considered as an expectation on how government intends to take action to meet these air quality targets, which will be for future policy decisions, with public consultations and IAs conducted in their own right as and when required. The IA provides a summary of the evidence produced and used to define the options, understand uncertainty and risks, and evaluate costs and benefits. The Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report[19] published alongside the IA includes detailed reports on the modelling methodology and measures included in the scenarios.

[19] Air Quality Targets in the Environment Act - Defra, UK

8. Definition of measures and scenarios to meet targets

The capacity to meet a certain target at a certain date is highly sensitive to the assumptions made on technological progress, change in industry and consumers' behaviours, and government's ambition. For the purposes of this IA, three scenarios have been developed representing different ambitions, technology availability, and behavioural conditions. Annex 2 provides further detail on the modelling pathways used in the cost benefit analysis.

Pathway 1 – High Scenario
This scenario includes new technologies that are perceived as likely to be successful, and a medium degree of behaviour change. Implementation dates and uptake rates are toward the middle of estimates.

Pathway 2 – Medium Scenario
In this scenario only proven technology measures and limited behaviour change are employed, and the implementation dates and uptake rates are towards the lower end of estimates.

Pathway 3 – Speculative Scenario
In this scenario the maximum possible action is taken, all emerging technology is assumed to be successful and there is radical behaviour change. Optimistic (but still possible) implementation and uptake rates are used. This scenario represents the maximum technically feasible reduction in $PM_{2.5}$ concentrations.

The scenarios modelled consist of packages of technological and behavioural measures spanning across multiple sectors including but not limited to, transport, domestic and commercial combustion, agriculture, industry, and manufacturing. The measures were identified by a contractor commissioned by Defra to identify potential actions or trends that would impact on emissions of $PM_{2.5}$ or its precursor pollutants (mainly NOx and NH_3). The contractor carried out a literature review and extensive stakeholder engagement, including 8 sector workshops and over 100 interviews. Participants included sector experts, industry practitioners, and other government department analysts. Existing Defra evidence projects, such as Measures in the Multi-Pollutant Measures Database (MPMD)[20] were also considered for inclusion in each of the three scenarios. The MPMD is a spreadsheet-based database of measures which reduce emissions of air pollutants beyond the level expected to be achieved under business as usual (BAU).

The relevant measures were assigned to the three scenarios reflecting different levels of emissions reduction referred to as medium, high, and speculative. Medium contains more established technology, limited behaviour changes, and slower uptake rates. High contains

[20] https://uk-air.defra.gov.uk/library/reports?report_id=725

greater innovation and behaviour change with medium uptake rates, and speculative includes emerging technology, significant behaviour changes, and rapid uptake. Speculative represents the maximum feasible reduction based on the review findings.

The measures included in these modelling scenarios do not necessarily correspond with any government policy, and therefore, the scenarios developed should not be viewed as potential policy pathways. They are possible futures for the purposes of mapping out which targets are feasible and only provide an indication of the types of action and scale of intervention that would be needed to achieve different concentrations by different dates in the future.

Based on cost-benefit analysis (see thereafter) and ambition, and accounting for risks and uncertainties, the three considered options were defined, with Option 1 based on the high ambition pathway, and Options 2 and 3 based on the medium and speculative ambition pathways.

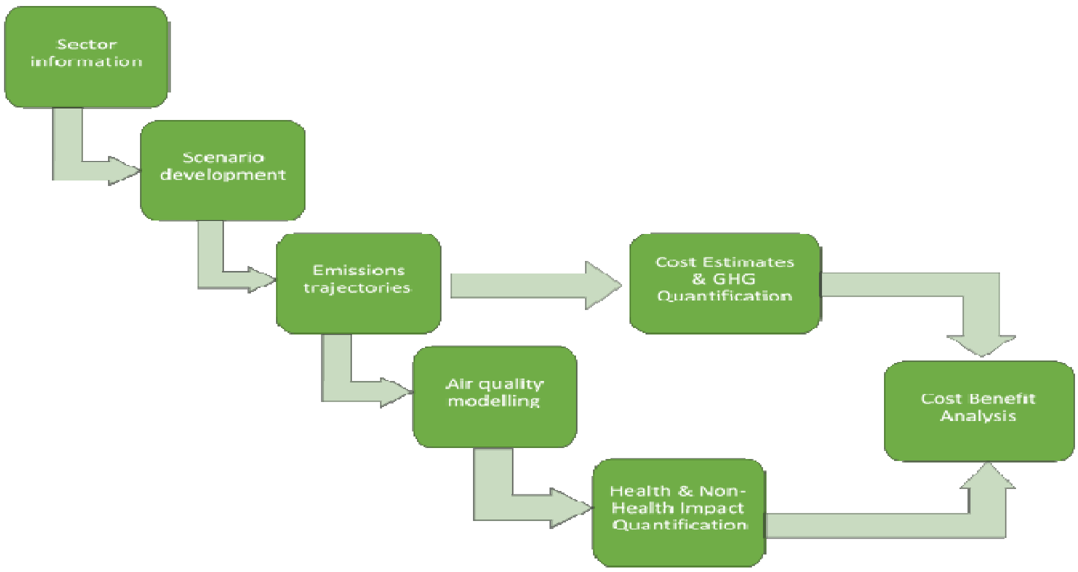
9. Modelling

Extensive modelling has been carried out to support the development of target setting by providing an indication of what $PM_{2.5}$ concentration levels could be achievable under different scenarios, and what timeframes are likely to be feasible. This modelling is the basis for assessing the monetised health and non-health impact of the cost-benefit analysis conducted for this IA and is composed of two steps:

- The first step was to assess the aggregate impact on emissions of the measures included in the modelling scenarios. This was conducted using the Scenario Modelling Tool (SMT) developed by Ricardo for Defra.
- The second step in the modelling process takes the emission outputs from the SMT and calculates the dispersion of pollutant concentrations across the UK to determine the potential health impacts. This dispersion modelling was conducted by Imperial College London for Defra using the UK Integrated Assessment Model (UKIAM).

Figure 3 below provides a flow diagram outlining how the modelling inputs and outputs interact to produce the cost-benefit analysis.

Figure 3: Modelling Flow Diagram



Emission Modelling: *Scenario Modelling Tool (SMT)*

Emissions modelling was conducted with the SMT, a powerful application for modelling emission mitigation scenarios developed for Defra in 2019-2021. It enables users to evaluate the efficacy of emission reduction strategies under a range of defined or user developed scenarios on outcomes over a variety of spatial scales and user-defined time frame. The tool has been designed, developed, and delivered by data scientists, software developers, and air quality experts. The tool has undergone rigorous user consultation and testing through a programme of user workshops and progress monitoring overseen by a user steering group. The tool's design and development benefited from a detailed quality assurance programme.

The baseline and emission abatement measures were uploaded into the SMT, enabling the three scenarios to be run for the UK based on their specific list of measures, uptakes, reduction efficiency, and starting dates, producing emission trajectories up to 2050.

In addition to emissions abatement data, the SMT provides data for each measure on costs (CAPEX, OPEX, operational life and annualised costs) as well as GhG emissions change, all parameters estimated based on literature review and expert knowledge.

Dispersion Modelling: *UK Integrated Assessment Model (UKIAM)*

The emissions modelling outputs were provided to Imperial College London, who used the UKIAM to model pollutant concentrations across the UK. The modelled concentrations for different years and scenarios provide Defra with the necessary evidence to understand which targets are viable. They also enable the benefits of the scenarios to be estimated. The costs of the scenarios are sourced from the SMT.

The UKIAM model[21] brings together projected emissions of SO_2, NO_x, NH_3, $PM_{2.5}$, and VOCs as adjusted to represent abatement measures specified, and calculates pollutant concentrations and deposition of sulphur and nitrogen across the UK. Exposure of the populations and monetised health impacts are assessed, as well as effects on protection of natural ecosystems.

For the UK, unabated emissions are taken from NAEI[22] projections, distinguishing up to 90 different point and area sources. As described in the section above, the reduction in emissions due to the abatement measures selected have been taken from the SMT.

Also represented are imported contributions from other countries and from international shipping, through the formation of secondary $PM_{2.5}$ concentrations and deposition. Shipping emissions, both domestic and international, in the seas surrounding the UK are taken from recent data, give an important but uncertain contribution. Emissions in other countries are based on data reported to the UNECE[23], and commitments under the National Emission Ceilings Directive.

The contribution of each source to concentrations and deposition is calculated by scaling and superimposing pre-calculated footprints for each source. For contributions of UK sources, concentrations of secondary inorganic aerosol, (SIA), and deposition of sulphur and nitrogen, are based on the Fine Resolution Atmospheric Multi-pollutant Exchange (FRAME)[24] model of Centre for Ecology and Hydrology (CEH). FRAME has been used to

[21] A more detailed description of the UKIAM, including on uncertainty, can be found in The UK Integrated Assessment Model for source apportionment and air pollution policy applications to $PM_{2.5}$ (imperial.ac.uk)
[22] NAEI, 2018: Air Pollutant Inventories for England, Scotland, Wales, and Northern Ireland: 1990-2018
[23] LRTAP/NECD Submission Archive - NAEI, UK (beis.gov.uk)
[24] Fine Resolution Atmospheric Multi-pollutant Exchange (FRAME)

examine the effect of reducing each pollutant from each source one at a time within a baseline scenario for 2020, with the results for changes in concentrations or deposition normalised to unit emission reductions. For concentrations of NOx/NO_2 and primary $PM_{2.5}$ where more local scale dispersion dominates, the Gaussian Primary Particulates Model (PPM) of Imperial College is used, with adjustments for urban areas such as street canyon effects for road-side concentrations. Annual average $PM_{2.5}$ concentrations are calculated on a 1x1 km grid across the UK, and deposition on a 5x5 km grid.

Other contributions which are not variable, such as natural contributions (as provided by Ricardo), and organic aerosol (calculated with the Numerical Atmospheric dispersion Modelling Environment (NAME) of the Met Office), are superimposed as an additional background. International contributions from other countries are based on source-receptor matrices calculated with the EMEP model.

The advantage of this approach, superimposing contributions derived with different models, is that the model is quick to run and also enables detailed source apportionment and sensitivity studies to specific assumptions about individual sources. The limitations include no accounting for the non-linear effects of chemical interactions between pollutants. Sensitivity studies with FRAME have indicated that such effects are small compared with other uncertainties in such modelling of future scenarios, but these can be important when large changes in emissions are made.

Health impacts have been assessed by combining pollutant concentrations on a 1x1 km grid with the population distribution and using monetised costs of health impacts per person per $\mu g//m^3$ of $PM_{2.5}$ and of NO_2 equivalent to those assumed in Defra's recently published damage costs. More information on the methodology applied for this step is available in Annex 3.

The output from UKIAM was compared to the output of an alternative model, the European Monitoring and Evaluation Program Unified Model for the UK (EMEP4UK) which is run by CEH. This comparison provides further assurance about the anticipated impact of the considered measures on air pollution and allows for the assessment of additional factors, such as weather patterns, that UKIAM does not provide. EMEP4UK was used for validation only, with the full scenario set run on UKIAM as it is quicker to run and easier for scenarios to be adjusted.

Further details on the methodology, assumptions made, strengths and limitations of the modelling is available in the Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report[25].

[25] Air Quality Targets in the Environment Act - Defra, UK

10. Summary of cost benefit analysis

This section presents the results of the cost benefit analysis for the preferred option. The modelling scenarios used contain theoretical policy choices and technological and behavioural assumptions of actions that may be required to reach the targets. However, the measures included in these scenarios should not be considered an expectation on how government intends to take action to meet these air quality targets, which will be for future policy decisions, with public consultations and impact assessments conducted as and when required. There is a high degree of uncertainty around what actual policies will be used to meet the target and what their costs and benefits will be. Therefore, alternative pathways to reach the same targets could have different associated costs and benefits.

The costs and benefits for both the annual mean concentration and population exposure targets are given in aggregate given the difficulty in disaggregating the impact of each target. Table 8 below gives a summary of the Total Social Costs and Benefits and Net Present Social Value of the preferred option for the periods 2023-2030 (for reference) and 2023-2040.

Table 8: Cost Benefit Analysis Summary results for preferred option, discounted (£m, 2020 prices)

	Total Social Cost	Total Social Benefit	Net Present Value
Cumulative (2023-2040)	£27,074	£135,009	£107,935
Cumulative (2023-2030)	£8,721	£22,518	£13,797

Figures 4 and 5 below further outline graphically the profile of costs and benefits throughout the appraisal period of the preferred option. From these two figures it is clear that while improvements in air quality only are cost beneficial, a large proportion of the total monetised benefits are derived from greenhouse gas co-benefits as opposed to improved air quality and further discussion of this is available in section 15.1.

Figure 4 shows the time profile of cumulative net present social value of the preferred option under consideration. The cumulative values presented here show a composite of avoided damages for both air quality and GhG emissions relative to baseline projections, and the value of avoided damages for air quality in isolation.

Figure 5 shows the time profile of costs and benefits of the preferred option and how the composition of monetised benefits is split between avoided air quality damages and GhG emission reductions.

Figure 4: England: Cumulative Net Present Social Value of Preferred Option (2023-2040, £m 2020 prices)

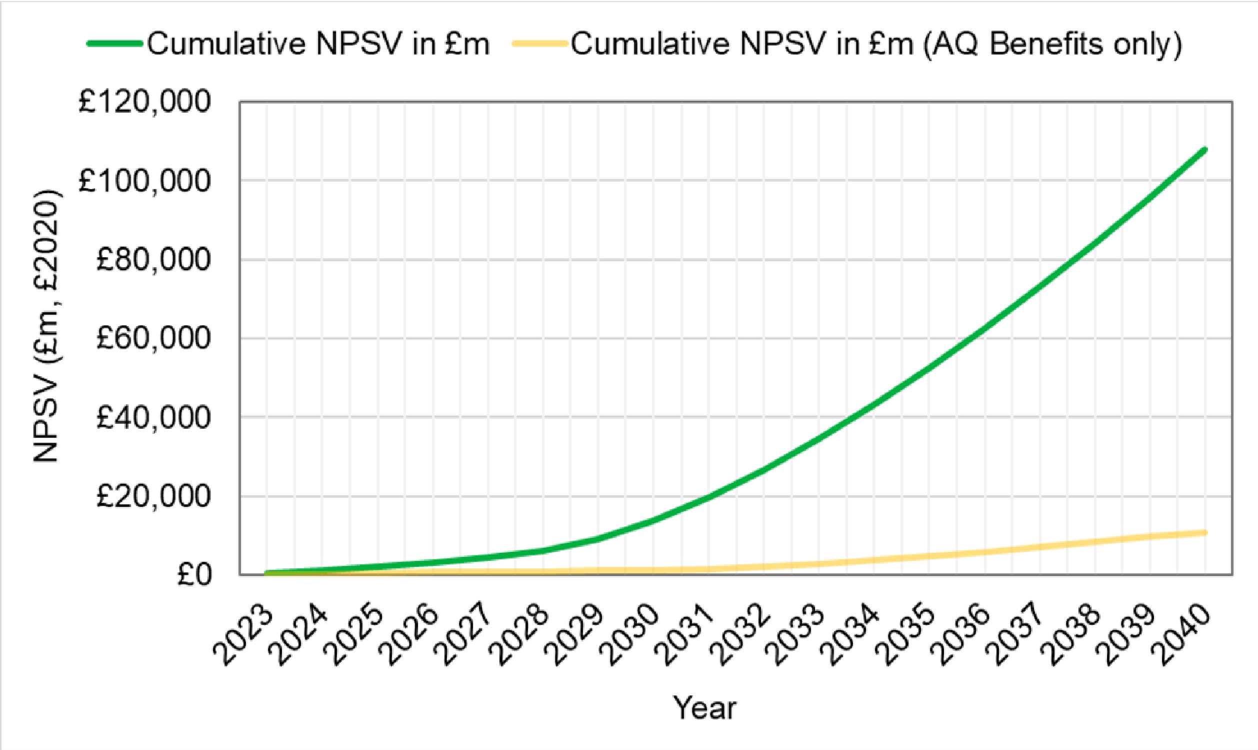
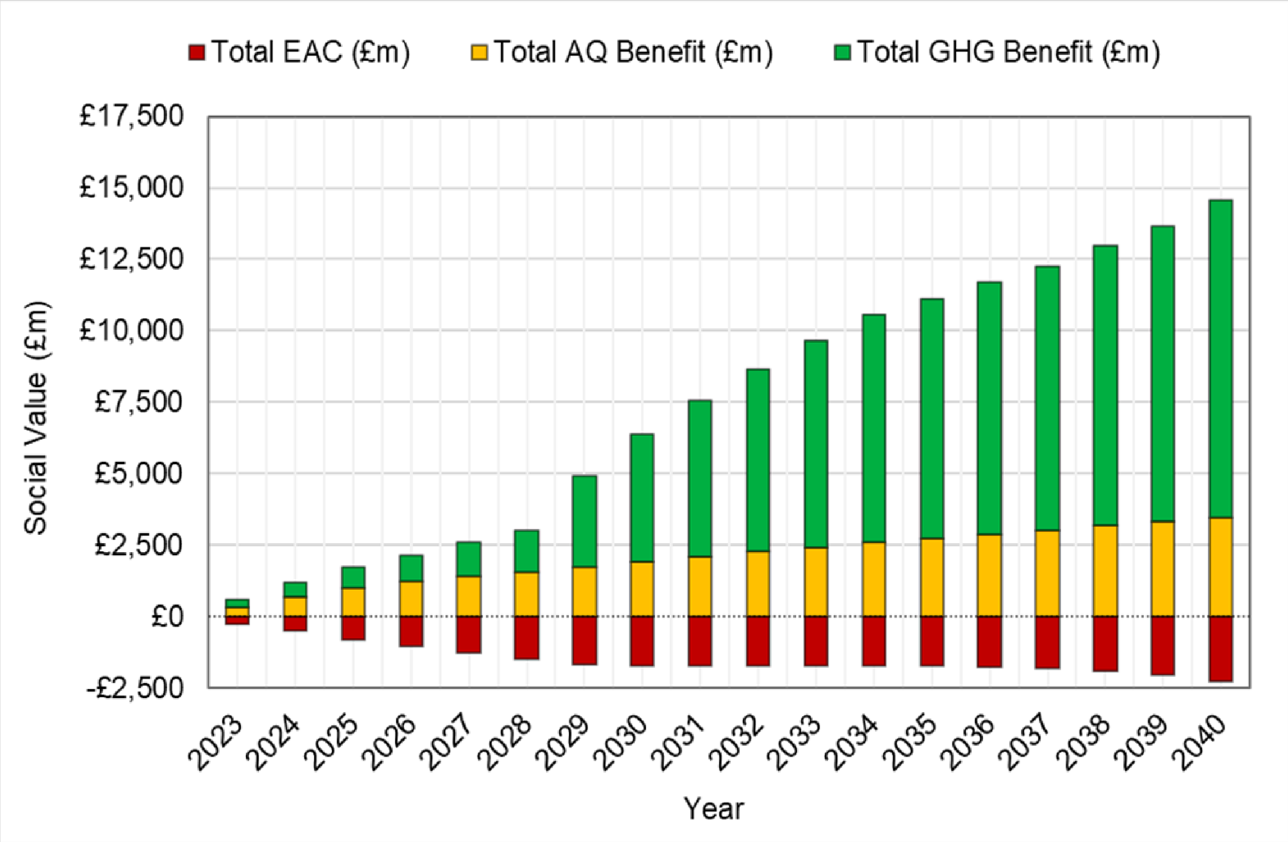


Figure 5: England: Time Profile (2023-2040) of Costs and Benefits of Preferred Option (£m, 2020 prices)



11. Methodology

This section outlines the methodology used to calculate the costs and benefits of the target options.

The appraisal period used is 2023 to 2040. As the appraisal covers a variety of measures with different lifetimes, we have chosen an appraisal period between the usual 10 years and the 60 years recommended for infrastructure as some of the cost involve new infrastructure.

The baseline is based on emissions projections as outlined in annex 1 and does not meet existing legally binding emissions ceilings by 2030 (i.e., the National Emission Ceilings Regulations, 2018). Neither does it includes measures to reach future Carbon Budgets and the Net Zero 2050 target. These are not yet committed or funded by government, yet both will impact on emissions of air pollutants, and therefore on costs to meet the $PM_{2.5}$ targets. Hence, not all costs and benefits presented in this section are additional to current government ambition or policy plans.

As the purpose of this IA is to support the decision on setting the air quality targets, the cost-benefit-analysis should not be interpreted as a full appraisal of the UK's decision to pursue such targets. Further details on the methodologies applied to calculating costs and benefits are provided in the following sub sections.

11.1. Costs

The cost appraisal is based on the additional technological, infrastructure, and energy use variation impact from the SMT model scenario runs compared to the baseline run.

Additional costs in the SMT include capital costs (on an annualised basis), operating costs, and fuel costs. Administrative and disruption costs associated with the scenarios are not included.

In this assessment, total estimated costs derived from the SMT have been increased to account for optimism bias. Optimism bias can be defined as the systematic tendency for appraisers to be over-optimistic about project parameters, including capital and operating costs. Green Book guidance[26] therefore, recommends adjusting anticipated costs upwards, and so in this assessment total estimated costs have been increased by 10%. While it is acknowledged that the effects of optimism bias may be more significant for certain projects, such as infrastructure investments, a flat rate uplift was deemed proportionate in this case due to the significant variation in the type of measures included in the modelling scenarios. The inclusion of an optimism bias adjustment is caveated by

[26] Green Book supplementary guidance: Optimism Bias (2013)

evidence from previous Defra research[27], which indicates the existence of pessimism bias when assessing costs associated with air quality legislation.

Further details on the results of costs in this impact assessment are available in section 13 and Annex 5.

11.2. Benefits

When quantifying and valuing the health impacts of air pollution, the population-weighted mean concentration (PWMC) is the primary metric of interest and will be discussed in further detail in the following sections of this Impact Assessment.

The Annual Mean Concentration Target (AMCT) establishes a minimum level of air quality to be achieved in all locations in England by the target year, in effect working as a limit value which should not be exceeded. It is important to distinguish this concept from the PWMC level as a measure of average exposure. For instance, the PWMC for England being below the target level by a certain date does not necessarily mean that the AMCT will be met if the level of exposure across the country is non-uniform. Achievability of the AMCT is discussed in more detail in the Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report[28].

The benefits of abated air pollutant emissions compared to the baseline, are monetised using the Defra concentration and emission damage costs[29]. Central values have been used with the low and high values tested as a sensitivity. This reflects uncertainty on the valuation of the impact on human health, ecosystem, productivity and building soiling. Similarly, the benefits of abated greenhouse gas emissions, compared to the baseline, are monetised using the central series of BEIS carbon values[30], with low and high values tested for sensitivity analysis.

A more detailed discussion of the methodology for calculating benefits is available in Annex 3 and results are provided in sections 14 and 15.

[27] An Evaluation of the Air Quality Strategy (2004).
[28] Air Quality Targets in the Environment Act - Defra, UK
[29] Air Quality damage cost update 2020 (defra.gov.uk)
[30] Valuation of greenhouse gas emissions: for policy appraisal and evaluation

12. Baseline - Option 0: Counterfactual

The baseline used in the analysis for comparison is the National Atmospheric Emissions Inventory (NAEI), which includes projections of activities and emissions of air pollutants up to 2030. The key sources include BEIS Energy and Emissions Projections[31] (EEP), Digest of UK Energy Statistics[32] (DUKES) dataset, as well as EU Emissions Trading System and industry statistics and survey[33].

The most recent year for the inventory available in the NAEI data used is 2018[34]. A few adjustments are made to account for new evidence and legislation brought in between 2018 and 2021, and some assumptions are made to extend it to 2040. This is a conservative projection as it includes only agreed and funded policies, but it was agreed that given the uncertainty of future policy decisions, this should be used. Further details of the assumptions used in the baseline are given in Annex 1.

The baseline shows that significant improvement is expected in the next 20 years, with average $PM_{2.5}$ concentrations declining to levels below 10µg/m^3 by 2030 in most of England, except in London and limited areas in South-East England where several hotspots remain. As noted in the section above, it is important to distinguish between average concentration levels (population weighted mean concentration), which are important for calculating impacts and benefits, as well as achieving the limit value portion of the target by ensuing all locations do not exceed the Annual Mean Concentration Target (AMCT) by the target date.

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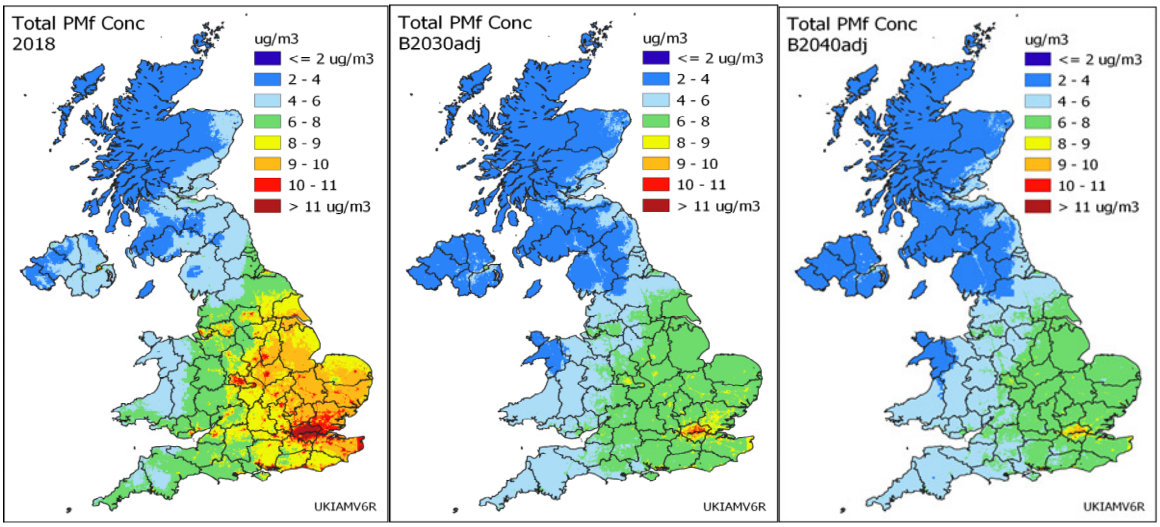
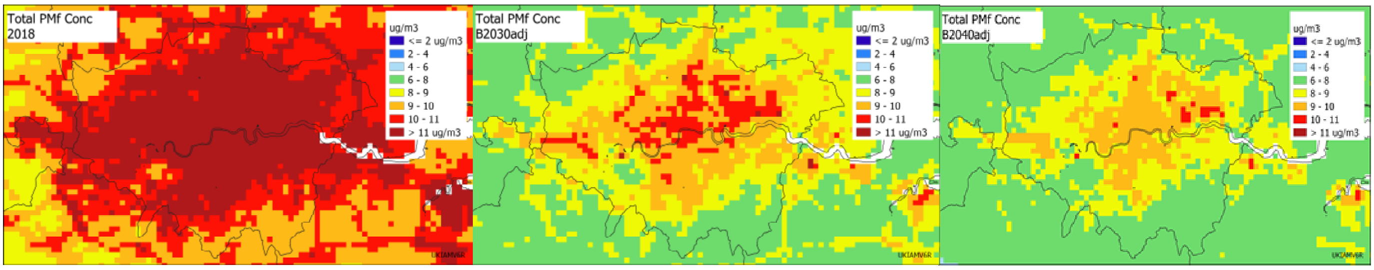
31 https://www.gov.uk/government/collections/energy-and-emissions-projections
32 https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2020
33 For more information, consult the NAEI website https://naei.beis.gov.uk/
34 NAEI 2019 and 2020 and new emissions projections were published since the modelling analysis started.

Figure 6: UK: Baseline PM2.5 concentration and projections in 2030 and 2040[35]



It is also important to note that modelling produces average concentrations for 1 km grid squares, specific locations including monitoring sites may have higher concentrations.

Figure 7: London: Baseline PM2.5 concentration and projections in 2030 and 2040[36]



Figures 6 and 7 above shows that exceedance of population exposure to $PM_{2.5}$ varies significantly based on the target level established. For instance, a target level set at 12µg/m^3 for 2018 would have required additional measures mostly only in London, while a target set at 8 µg/m^3 would have required nation-wide action.

12.1. Baseline sensitivity analysis

Two baseline sensitivities were run for comparison, one is a pathway for the UK to reach its existing legal air quality commitments (i.e., the NECR ceilings) and the other refer to meeting Carbon Budget 6 level as modelled by BEIS using UKTIMES data.

[35] Source: Imperial College of London, UKIAM run, Sep 2021
[36] Source: Imperial College of London, UKIAM run, Sep 2021

Table 9: Baseline sensitivities[37]

		Population weighted mean $PM_{2.5}$ concentration, μg/m³	Population weighted mean exposure, % change vs 2018
Baseline	2018	9.70	-
	2030	7.48	23%
	2040	7.29	25%
	2050	7.30	25%
NECR	2018	9.70	-
	2030	6.76	30%
	2040		
	2050		
CB6 (UKTM Core run)	2018	9.70	-
	2030	7.44	23%
	2040	6.66	31%
	2050	6.37	34%

The modelled outputs in Table 9 show that:

- In the NECR sensitivity scenario, successfully meeting the 2030 emission ceiling targets would lead to a significant decrease in population weighted mean $PM_{2.5}$ concentrations and a 30% reduction in population weighted mean exposure (PWME) relative to the 2018 baseline.

[37] Source: Imperial College of London, UKIAM run

- Net Zero CB6 Core sensitivity scenario achieves a less significant reduction in PWMC relative to the baseline by 2030. However, the impact of the NZ sensitivity increases post 2030 with a 31% reduction in PWME by 2040.

More information on the assumptions made, methodology, and strengths and limitations are available in Annex 1.

13. Costs

13.1. Description of the social costs

Costs are estimated for all the measures to reduce $PM_{2.5}$ concentrations that form the modelling scenarios. The cost estimates were gathered from a variety of sources including literature review, interviews, workshops with stakeholders, and existing data already obtained from previous Defra work.

For most measures there is a capital cost and operating cost (separating fuel and non-fuel cost). The capital and operating costs, along with the average lifetime of the measure and the uptake rate, are used to calculate equivalent annualised cost. This allows for a representative cost per year of the measures to be compared where lifetimes of costs differ. In some cases, the cost of measures can be negative as there is a cost saving due to reduced fuel consumption. Cost data has been adjusted where necessary to be presented as present value in 2020 prices. Total Equivalent Annualised Cost have been increased by 10% to control for the effects of optimism bias, as discussed in previous sections.

The analysis conducted for this IA is not of specific agreed government policy and some of the measures which have been costed include speculative technologies and behaviour changes. It is therefore outside the scope of this analysis to give detail on how the costs will be divided across business, government, and households. It has not been possible at this stage to provide a breakdown of the total transition (capital) and operating costs for several measures, as would be required for a full regulatory impact assessment.

Table 10 below summarises the estimated annual average and cumulative equivalent annualised cost of the preferred option.

Table 10: England: Cumulative Equivalent Annualised Cost (EAC) of Preferred Option (£m, 2020 PV)

	Preferred Option (2023-2030)	Preferred Option (2023-2040)
Annual Average (£m)	£1,090	£1,504
Cumulative (£m)	£8,721	£27,074

An indication of how the costs will be split across sectors based on the considered pathway is provided in Annex 5: Detailed costs of illustrative pathway.

14. Air quality benefits

14.1. Benefits accrued to reduction in $PM_{2.5}$ concentrations and population exposure

This section assesses response to $PM_{2.5}$ exposure only, based on the output of the UKIAM runs described earlier – overall air quality benefits are discussed in a subsequent section. The metric of exposure used for the calculation is the 'average population weighted exposure'. Modelled concentration data are combined with population data on a grid covering the whole of the UK. Averaging of concentration then takes account of variation in exposure across the country (rather than, more simply, concentration averaged over geographic area, which would significantly underestimate population exposure as the majority of people live in areas of higher concentration).

Annual average population weighted $PM_{2.5}$ concentrations for each scenario are shown below in Table 11. In the baseline, there is a significant decline expected in England, by about 23% in 2030 and 25% by 2040, compared to the level in 2018. Implementing further action would bring the population weighted mean concentration to even lower levels, as Option 1 projects a reduction by 28% in 2030 and by 35% in 2040 compared to the level in 2018.

Table 11: England: population weighted mean $PM_{2.5}$ concentration, µg/m^3; and percentage change compared to 2018

	2018	2025	2030	2040	2050
Baseline	9.70	7.99	7.48 *-22.9%*	7.29 *-24.8%*	7.30 *-24.7%*
Option 1 (High)	9.70	7.73	6.95 *-28.4%*	6.32 *-34.8%*	6.06 *-37.5%*

Quantification of economic benefit related to the reduction of the population weighted mean $PM_{2.5}$ concentration can be monetised using estimates of damage per unit exposure from Ricardo (2020). The damage costs used in this analysis are shown in Table 13 and are based on the same concentration response functions, population fractions, valuations, etc. that are used to calculate the most recently published Defra damage costs per unit pollutant emission (£/tonne)[38] and also take into account updated guidance from COMEAP on the quantified mortality risk associated with long-term exposure to $PM_{2.5}$[39]. Further, discussion of this methodology is outlined in Annex 3 and sensitivity analysis of variation in the central damage costs to reflect further guidance from COMEAP is outlined in Annex 7. The methods used to generate the damage costs are also described in a report by Ricardo (2020)[40].

The benefits are considered in terms of 'damage avoided' by reducing the concentration of $PM_{2.5}$. Benefits have been calculated using the concentration damage cost which gives a monetary value to the reduction in $PM_{2.5}$ concentration. The concentration damage cost is in £ per population weighted mean (1µg/m^3) change per person, and has a central, low and high estimate.

Table 12: England: Cumulative benefits from reduced damage to health, productivity, ecosystems and soiling of buildings from $PM_{2.5}$ exposure (£m, 2020 prices)

Cumulative Benefits (2023 – 2040)	Preferred Option (Option 1)
Low estimate	£8,755
Central estimate	£31,969
High estimate	£90,514

Table 12 shows the benefits derived from reductions in damage from $PM_{2.5}$ exposure throughout the appraisal period, which generate a large proportion of the air quality benefits. A further breakdown of the benefits associated with each pollutant and corresponding impact pathways are also included thereafter.

The central, low, and high damage cost sensitivities have differences in assumptions, such as in the critical response functions (CRFs) applied to each health pathway across the sensitivities. The CRFs link a change in exposure to a pollutant to its consequent impacts by expressing a change in a health, or non-health, outcome for a given change in pollutant concentrations. Also, some impact pathways are excluded from the central damage cost and are only recommended for inclusion in the high damage cost (such as chronic bronchitis associated). The range of the central, low, and high damage cost values are included below in Table 13. The full methodology is provided in Annex 3.

[38] https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance
[39] COMEAP (2022): Statement on quantifying mortality associated with long-term exposure to PM2.5
[40] https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2007031424_Damage_cost_update_2020_FINAL.pdf

Table 13: Damage costs for $PM_{2.5}$ and NO_2 per unit concentration (£2020 per pop. weighted mean 1 µg/m^3 change per person), by sensitivity[41]

	Low	Central	High
$PM_{2.5}$	£16.93	£62.79	£178.47
NO_2	£0.53	£7.02	£27.67

The damage cost values used have been standardised to 2020 prices (using GDP deflators) and uplifted by 2% per annum, in line with Green Book guidance. The uplift captures the higher willingness to pay of the population, and therefore value of health benefits as income (economic growth) rises.

Emissions of NOx, SO_2, and NH_3 contribute to damage costs via the secondary inorganic aerosol (SIA) contribution to ambient PM concentrations and the long and short-term exposure to PM concentration pathways. A full mapping of the different impact pathways included in each of the damage costs is described in the report by Ricardo for Defra entitled "Air Quality damage cost update 2020"[42].

The $PM_{2.5}$ concentration damage cost pathway captures most of the damage linked to primary $PM_{2.5}$ emissions, and, via quantification of the effects of secondary $PM_{2.5}$, also emissions of NOx, SO_2 and NH_3. Quantification of health damage covers most (>90%) of the total damage from these pollutants. However, part of the emissions damage costs of NOx, SO_2 and NH_3 are not included and should be added.

14.2. Other air quality benefits

The pathways not accounted for in the $PM_{2.5}$ concentration damage cost include:

- For NO_2: Respiratory hospital admission (only included under the 'high' damage cost), chronic mortality, productivity, ecosystems, asthma (in adults, small children, and older children), diabetes, lung cancer
- For SO_2: Deaths brought forwards, respiratory hospital admission, material damage, ecosystems
- For NH_3: Ecosystems
- For O_3: Deaths brought forward, respiratory hospital admission, cardiovascular hospital admission, productivity, material damage, ecosystems

[41] Sources: Ricardo (2020); EMRC (Mike Holland), 2021
[42] See https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2007031424_Damage_cost_update_2020_FINAL.pdf)

Table 14 below shows how the total air quality benefits derived from reduced damage to health, productivity, ecosystems, and soiling of buildings from are split by pollutants. Benefits associated with reductions in $PM_{2.5}$ exposure generate the largest proportion of the total air quality benefits, forming 85% of total benefits for the preferred option, with NO_2 constituting the second largest pollutant source of benefits. The negative value associated with ammonia results from lower timber and livestock production as well as reduced carbon sequestration due to lower nitrogen available. More detail on ecosystem impacts is available in section 19 of this IA and in the Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report [43]. Further detail on the valuation of ecosystem impacts is available in Jones et al. (2014)[44].

Table 14: England: Cumulative (2023-2040) air quality benefits of the preferred option from reduced damage to health, productivity, ecosystems and soiling of buildings, broken down by pollutant and sensitivity (£m, 2020 prices)

Air Pollutant	Low	Central	High
$PM_{2.5}$	£8,755	£31,969	£90,514
NO_2	£440	£6,059	£23,976
NH_3	-£67	-£159	-£199
VOC	£9	£17	£34
SO_2	£5	£6	£7
Total	£9,142	£37,891	£114,332

Figure 8 shows the estimated decline in monetised social damages attributed to the expected improvement in air quality from the preferred option, relative to the baseline. The distance between the two lines in Figure 8 is equivalent to the height of the bars in Figure 9.

[43] Air Quality Targets in the Environment Act - Defra, UK
[44] Jones, L., Mills, G. & Milne, A. 2014. Assessment of the Impacts of Air Pollution on Ecosystem Services – Gap Filling and Research Recommendations (Defra Project AQ0827)

Figure 8: England: Reduction in Social Damages linked to Air Quality improvement (2023-2040) relative to baseline (£m)

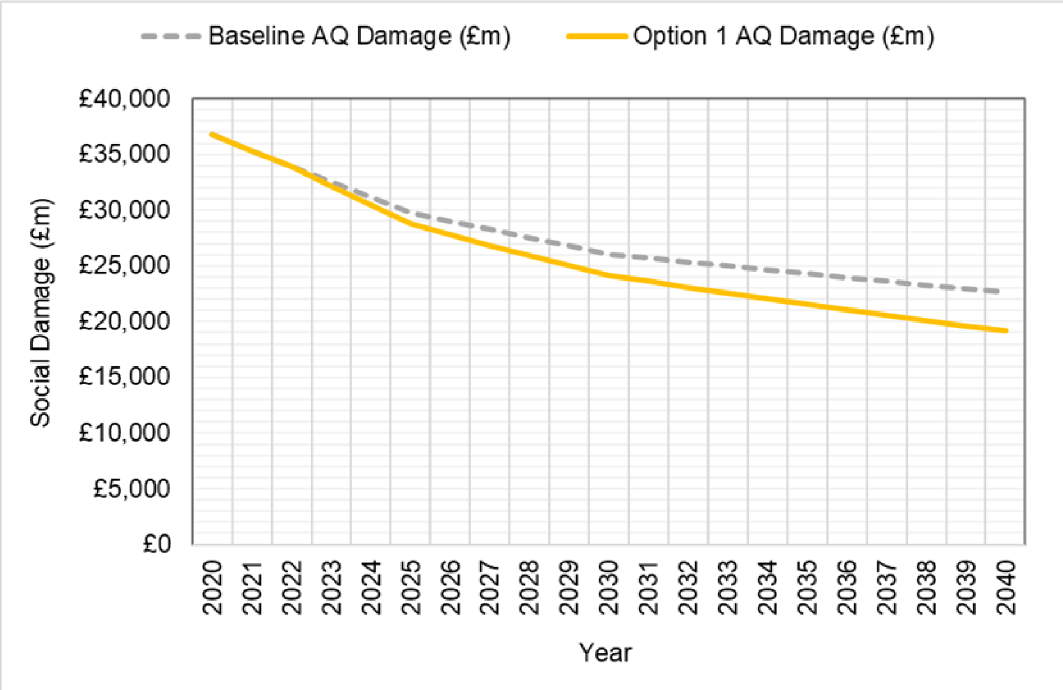


Figure 9 below illustrates how the annual monetised air quality benefits produced under the preferred option are split between $PM_{2.5}$ and other air pollutants. It is clear from this graph that $PM_{2.5}$ is the key driver of the modelled air quality benefits, however, the share of other pollutants (notably NO_2) does increase later in the appraisal period.

Figure 9: England: Annual Monetised Air Quality Benefits of the preferred option, central sensitivity

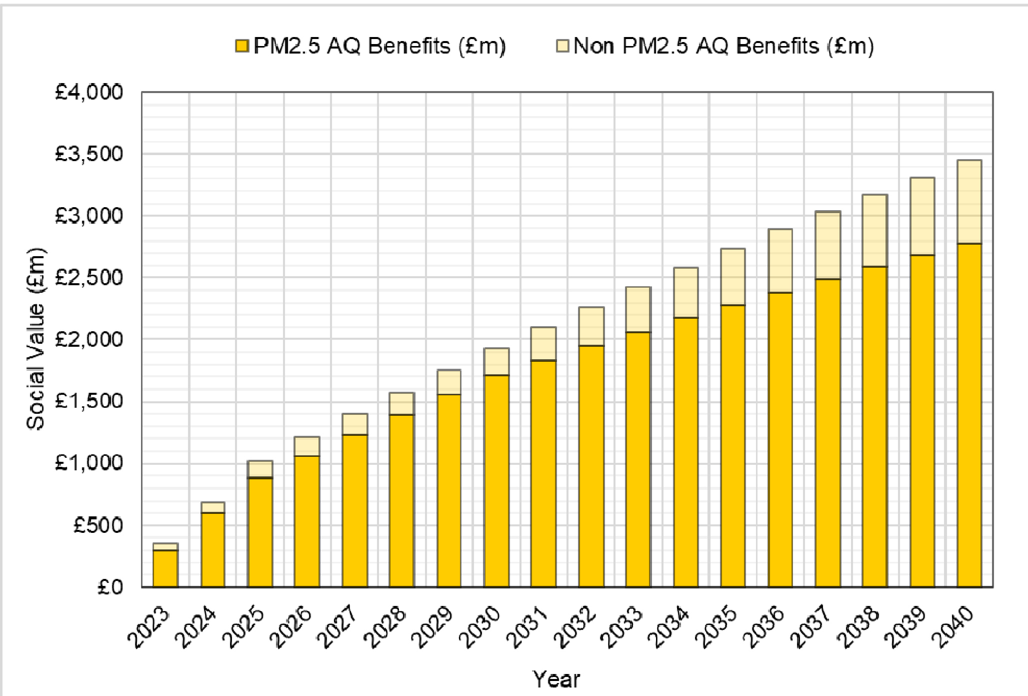


Table 15 below illustrates which health and non-health outcomes are generating the air quality benefits for the preferred option, under the central cost sensitivity cases relative to baseline projected damages.

Table 15: England: Breakdown of cumulative (2023-2040) damage costs (central sensitivity) by impact pathway for the preferred option

Pathway	Units	Quantitative Value	Monetised Benefit (£m)
Chronic mortality	Reduction in Life years lost	446,199	£17,338
Coronary heart disease	Reduction in New Cases	38,464	£7,654
Asthma (Children)	Reduction in New Cases	19,903	£8,931
Stroke	Reduction in New Cases	10,166	£2,880
Lung Cancer	Reduction in New Cases	4,135	£186
Respiratory hospital admission	Reduction in Hospital Admissions	11,352	£86
Cardiovascular hospital admission	Reduction in Hospital Admissions	8,255	£64
Productivity (£m)	Monetary Value		£710
Material Damage & Building soiling (£m)	Monetary Value		£186
Ecosystem (£m)	Monetary Value		-£141

More disaggregated data on air quality benefits are available in Annex 4: Detailed Benefits.

15. Co-benefits and trade offs

$PM_{2.5}$ has many sources and so there are many different measures used to create the modelling scenarios. While all the measures in the scenarios reduce $PM_{2.5}$ concentrations, most will also have other impacts. Some of these additional impacts will be beneficial to society (co-benefits) and some will be negative (trade-offs). The co-benefits that have been monetised for this IA are reductions in greenhouse gas emissions and reduction in other air pollutants. There will likely be other co-benefits that have not been monetised, for example reduction in noise pollution and traffic congestion.

For many of the measures, although they reduce $PM_{2.5}$ concentrations this is not the main driver of the policy and therefore the main benefit of the measure is not a reduction in $PM_{2.5}$ concentration. If the whole benefit of a measure is included, then so must the whole cost to assess the benefit cost ratio and therefore value for money of the target options. This means that a significant amount of the monetised benefit in this IA is not derived from improved air quality.

15.1. Greenhouse Gas Emission Reduction

Many of the measures that will reduce $PM_{2.5}$ are also decarbonisation measures so there is a large reduction in carbon dioxide (CO_2) emissions as well as reductions in other greenhouse gasses such as methane (CH_4), and nitrous oxide (N_2O) from the pathways. These greenhouse gas emission savings have been quantified and monetised in accordance with BEIS guidance[45], and included in cost-benefit analysis as co-benefits.

These results should be interpreted with caution in relation to similar projections of future emission scenarios, such as the sixth carbon budget (CB6). Achieving the government's Net Zero commitments will reduce emissions of several air pollutants as climate change and air pollution are strongly related and have many of the same contributing emission sources. Whilst we recognise that Net Zero will play a significant role in future air quality targets ambition, it is not clear what the impact of the commitment will be on $PM_{2.5}$ and therefore the impact of Net Zero does not form part of the baseline. As such, the monetised carbon benefits outlined in this section should not be interpreted as additional to those outlined in the sixth carbon budget IA, due to the similar nature of many of the measures modelled in both pathways. More information on Net Zero/CB6 Sensitivity is available in Annex 1.

Table 16 below presents the estimated GhG emission abatement of the preferred option and associated monetised value.

[45] BEIS 2021: Valuation of greenhouse gas emissions: for policy appraisal and evaluation

Table 16: England: Cumulative (2023-2040) Monetised Benefit of Greenhouse gas (CO_2 Eq.) emission reduction from preferred option

	Preferred Option (2023-2040)
GHG Abatement ($ktCO_2e$)	540,225
Monetised Benefit – Central Carbon Value (£m)	£97,118

15.2. Non-Monetised Costs and Benefits

For many of the measures included in this analysis, although they all reduce $PM_{2.5}$ pollution they will also have other additional impacts, some of which may be beneficial to society (co-benefits), or some may have a negative impact on society (trade-offs). The impact of the measures included in the modelled policy options on potential co-benefits and trade-offs can be assessed qualitatively against the criteria outlined in Green Book supplementary guidance[46].

For example, some of the modelled policies in relation to transport offer additional benefits such as reduced levels of congestion and noise pollution. Quantification of these additional effects, beyond stating whether they are likely to be positive or negative, has not been attempted given the uncertainty on the detail of these future scenarios.

The impacts on other devolved administrations of the United Kingdom, as a result of actions taken in England to reduce emissions and meet the targets, are not included in the cost benefit analysis but are presented in Annex 6.

[46] Dunn, H. (2012) Accounting for environmental impacts – supplementary Green Book guidance. For Defra and HM Treasury.

16. Sensitivity Analysis

There are various types of uncertainty affecting the costs and benefits associated with the scenarios. The air quality modelling results the benefits are based on are affected by uncertainty in historic and future emissions, assumptions within the model, and external factors such as climate change that could not be incorporated in the model. The measures within the scenarios are very uncertain, not just regarding whether they will take place, but in the scale of the impact on $PM_{2.5}$ and how quickly they can be implemented. The costs of the measures are also very uncertain.

Sensitivity analysis has been carried out on some types of uncertainty to understand the impact of different emissions, test assumptions within the air quality modelling and look at the impact of meteorology on concentrations. However, many uncertainties within the modelling remain unqualified.

The sensitivity analyses reported here focus specifically on the valuation of benefits of abated air pollutant emissions, compared to the baseline. Table 14 in section 14.2 shows sensitivity values for the impact of the preferred option on air quality. This range reflects uncertainty on the valuation of the impact on human health, ecosystem, productivity, and building soiling.

Sensitivity analysis has also been conducted on the abatement of GhG emissions projected for each pathway, relative to the baseline by applying the low and high carbon value series published by BEIS, with results shown in Table 17.

Table 17: England: Sensitivity Analysis: Cumulative (2023-2040) Monetised Benefit of GhG (CO_2e) savings from preferred option

	Low Sensitivity	Central Sensitivity	High Sensitivity
Monetised Benefits (£m)	£48,552	£97,118	£145,641

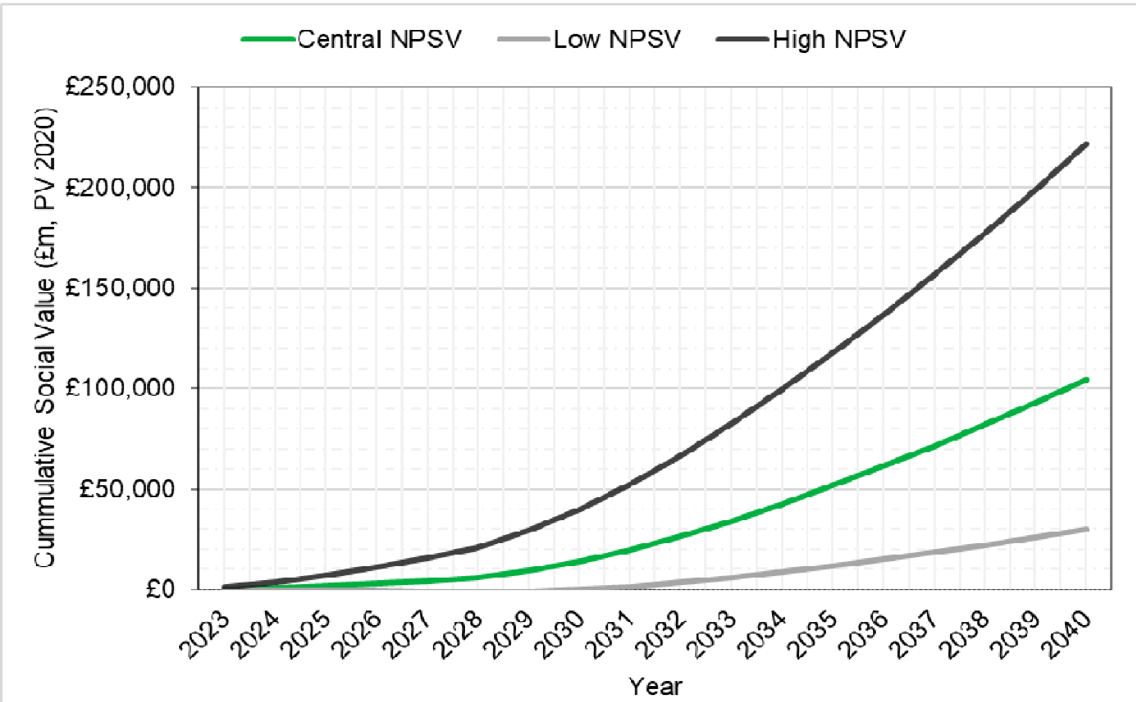
Table 18 below displays the effect of applying the range of sensitivity values for both air quality and greenhouse gas co-benefits to aggregate cost-benefit analysis indicators such as Net Present Social Value and Benefit Cost Ratio. At the lowest sensitivity included in this analysis the preferred option still achieves a benefit cost ratio of approximately 2:1, which would suggest the preferred pathway would be likely to achieve good value for money.

Table 18: England: Sensitivity Analysis: Preferred Option Cumulative (2023-2040) Cost-Benefit Analysis

	Low Sensitivity	Central Sensitivity	High Sensitivity
Monetised Benefits (£m)	£57,694	£135,009	£259,972
Equivalent Annualised Cost (£m)	£27,074	£27,074	£27,074
Net Present Social Value (£m)	£30,620	£107,935	£232,898
Benefit Cost Ratio	2.1	5.0	9.6

Figure 10 below displays the range of cumulative net present value sensitivity outcomes for the preferred option.

Figure 10: England: Cumulative Net Present Social Value of Preferred Option (2023-2040) – Sensitivity Analysis



A summary of uncertainty analysis and full details are available in Annex 4.

17. Risks and assumptions

The appraisal is for pathways that are illustrative of what may be required to reach the targets. There is a high degree of uncertainty around which policies will be used to meet the target and what their costs and benefits will be. Other pathways to reach the targets would have different associated costs and benefits.

Emissions from other countries also contribute to UK $PM_{2.5}$ concentrations so we have made assumptions reflecting this. The projections produced by the International Institute for Applied Systems Analysis (IIASA) is used in this modelling. The scenario used assumes current EU legislation is enforced by member states.

There is a risk of omission of impacts from the health analysis.

18. Impact on Deprivation

Poor air quality is a particular threat to vulnerable groups, including the elderly, the very young, and those with existing health issues such as respiratory problems. Those living in city centres and near busy roads – often on the lowest incomes – are most exposed to dangerous levels of air pollution. By combining the modelling of reduction in $PM_{2.5}$ concentration with the index of multiple deprivation (IMD), we have analysed how the target will impacts deprived areas.

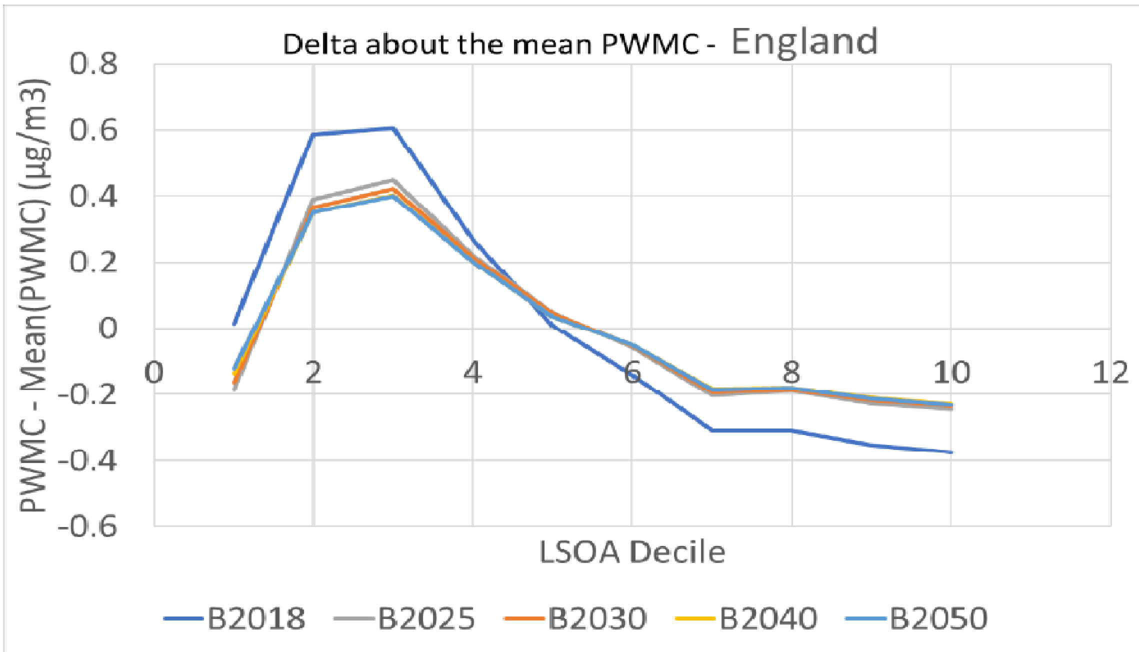
The relationship between IMD and $PM_{2.5}$ concentrations can be investigated by overlaying the map of the IMD onto the pollutant concentrations calculated by UKIAM using the 1x1km grid used for deriving population exposure and health impacts. The individual tiles of the IMD may overlap different grid-cells and have been apportioned in GIS according to the respective areas of overlap. In this way we can integrate across the map area of England to calculate the population weighted mean concentration for each decile of the IMD. These can then be plotted, as in the graphs below, ranging from the most deprived in decile 1 on the left, to the least deprived decile 10 on the right. Across England as a whole, the highest exposure does not coincide with the most deprived sector, but with the neighbouring deciles.

Here, we are interested in the disparity between the different deciles, rather than the absolute concentrations. We therefore plot the delta PWMC, calculated by subtracting the mean concentration from the PWMC for each decile. The delta plot brings out the difference between the deciles more clearly and is used for the remaining analysis.

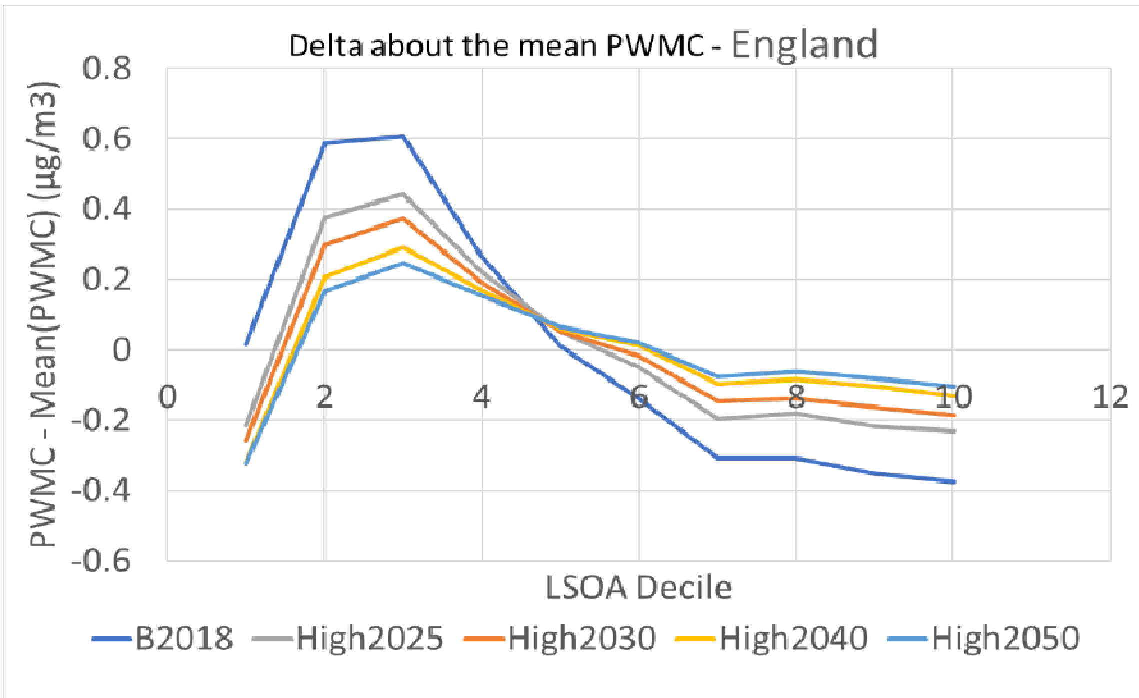
The analysis shows a progressive reduction in exposure bias, as shown in the figure below. For 2030, the improvement is limited in the high scenario, however, by 2040 a more significant improvement is seen. This may reflect the time taken for the enforcement of certain measures to translate to emission reductions. For example, NOx reduction due to the phase out of ICE vehicles is limited in 2030, however lead to a significant reduction by 2040.

Figure 11: Deprivation index and Population weighted mean concentration (PWMC): Baseline, preferred option

Baseline



Preferred Option



19. Impact on Ecosystems

In addition to its impact on human health, air pollution also damages the natural environment. This is mainly through the impact of Ammonia (NH_3), Nitrous Oxides (NO_x), Non-Methane Volatile Organic Compounds (NMVOCs), and Sulphur Dioxide (SO_2) (all $PM_{2.5}$ precursors) on ecosystem health. This can be through direct exposure to concentrations in the atmosphere or through deposition onto soils and water.

The main environmental impact is through reactive nitrogen deposition onto sensitive habitats. This results in eutrophication damaging biodiversity, and a separate assessment of this is discussed in more detailed in the Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report[47].

The impact of NH_3, NO_x, NMVOCs, and SO_2 on ecosystem services has been quantified and included in the calculation of damage costs. More information on the methodology applied is available in the Defra Impact Pathway Approach[48] guidance.

The net impact on ecosystems implied by the damage cost methodology is negative, and this is largely driven by the impact of ammonia on provisioning (timber and livestock production) and regulating (carbon sequestration) ecosystem services. However, there is a considerable degree of uncertainty underpinning this negative value because the validity of the damage cost for ammonia is disputed as the net change in emissions increases beyond a 10% threshold. This is because the relationship between emissions and deposition is non-linear and has a strong spatial context. For more detail on the valuation of these ecosystem impacts, see Jones et al. (2014)[49].

The negative ecosystem value implied by the damage cost methodology reported in this Impact Assessment contrasts with the net positive impact of the modelled target pathways on reducing damaging nitrogen disposition on sensitive habitats, as outlined in the Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report[45].

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[47] Air Quality Targets in the Environment Act - Defra, UK
[48] Defra 2021: Air quality appraisal: impact pathways approach
[49] Jones, L., Mills, G. & Milne, A. 2014. Assessment of the Impacts of Air Pollution on Ecosystem Services – Gap Filling and Research Recommendations (Defra Project AQ0827)

20. Crossover with other Environment Act targets

Due to the nature of the Environment Act targets setting process there is the potential for overlap between some of the statutory target impacts. For example, the sensible use of tree planting could in theory be included in pathways to achieve $PM_{2.5}$ concentration and population exposure targets, due to the regulating services provided by trees in air filtration. However, within the context of the air quality targets, tree planting only has a marginal impact on overall pollutant removal. The contribution to the air quality targets of increased vegetation to achieve the Terrestrial Biodiversity Targets is both location and species dependent. Therefore, the air quality benefits provided by trees will be quantified within the Terrestrial Biodiversity Targets IA and will not be accounted for within the air quality targets impact assessment.

21. Impact on small and micro business

The analysis presented is not of specific agreed government policy, and some of the measures that have been modelled include speculative technologies and behaviour changes. It is therefore outside the scope of this impact assessment to provide detail on how the cost and benefits will be divided across business, government, and households. Impacts on small and micro business will be considered at a later stage in future IAs.

22. Monitoring and Evaluation

Achievement of both targets will be demonstrated by $PM_{2.5}$ measurements made by appropriately defined "representative monitoring" at stations across England and set out in the statutory instrument. This will define the required numbers of monitors, location types, instrument types, instrument performance characteristics, and the data capture objectives. Progress towards achievement of the targets will be legally defined by assessing data and trends on an annual basis (using defined metrics). Additional monitoring stations will be added to the existing 63 $PM_{2.5}$ monitoring network sites to improve geographical/spatial coverage and to ensure reporting integrity. More information on this is available in the target assessment chapter of the Air Quality $PM_{2.5}$ Targets – Detailed Evidence Report[50].

In addition, supplementary assessment will be carried out with modelling to establish how $PM_{2.5}$ source contributions are changing, and to support appropriate action to reduce those contributions in future years. This modelling will support the assessment of public health benefits and future policy interventions.

[50] Air Quality Targets in the Environment Act - Defra, UK

Annexes

Annex 1: Baseline adjustments and baseline sensitivities

Introduction

In order to robustly assess the achievability of the targets and understand their impacts, it is important to establish a realistic counter-factual baseline projection. There is a high amount of uncertainty in assessing and projecting future change air pollution, particularly for $PM_{2.5}$ emissions due to the wide diversity of sources, the limitations of measurements and modelling, and the challenges in assessing impacts resulting from policies already introduced.

For this analysis the baseline used is the National Atmospheric Emissions Inventory (NAEI) which publishes projections of activities and emissions of air pollutants up to 2030[51], the key source is BEIS EEP[52] dataset. The most recently published NAEI data at the time of the modelling work was initiated was for the 2018 inventory. Eight adjustments to the baseline are made to account for new evidence and new legislation brought in between 2018 and 2021 and some assumptions are made to extend it out to 2050. This projection includes only agreed and funded policies.

It is acknowledged that this is a very conservative, and potentially unrealistic, future projection of $PM_{2.5}$ given existing legally binding commitments and drivers from other government departments. However, as measures to reach existing commitments are not currently agreed, and there is quite a wide scope as to what packages of measures will be pursued, these cannot be incorporated into the baseline. Therefore, to reduce uncertainty on what future policies will be pursued, this conservative approach is our baseline.

There is a risk of overestimating the costs and benefits of the $PM_{2.5}$ targets by using such a conservative baseline because actions we will include in our scenarios would have happened without the target. Running sensitivities on the baseline will give an indication of what the impacts of some of these uncertainties could have and demonstrate that these targets encourage additional action.

Therefore, two baseline sensitivities have been run for comparison, one on reaching the emissions ceilings as set in the National Emission Ceilings Regulations (NECR) 2028, and the other on accounting for meeting the Carbon Budget 6 level through implementing a range of policies as considered in the Carbon Budget 6 pathways modelling of UKTIMES data[53] (See below).

[51] https://naei.beis.gov.uk/
[52] Energy and emissions projections - GOV.UK (www.gov.uk)
[53] The Carbon Budget Order 2021 - Impact Assessment (legislation.gov.uk)

Baseline adjustments

Table A1: Baseline Adjustments

Topic: Defra BAU	Assumption descriptions	Evidence
The National Atmospheric Emissions Inventory (NAEI) publishes projections of activities and emissions of air pollutants up to 2030. Activity and emissions beyond 2030 up to 2050 were estimated to be flat for most sectors, except for road transport and domestic combustion. The 2018 NAEI published in 2020 will be used as our baseline.	This projection includes only agreed and funded policies and is a very conservative future scenario. NAEI estimates of future trends in emissions of air pollutants are based on a set of assumptions about changes in key parameters. For example, emission projections may require assumptions to be made regarding future levels of activity such as industrial production, or consumption of fuels or materials, as well as how emission factors may change over time, perhaps in response to technological changes, or the introduction of additional regulation.	The key sources are: • BEIS Energy and Emissions projections [54]. NAEI data[55] and report[56]:
Adjustments to the NAEI incorporated into the baseline. **The 2018 NAEI published in 2020 does not account for the following new evidence and new legislation brought in**	Defra new domestic wood burning activity and emission factors for wet wood	Defra conducted a survey that revealed that the domestic wood combustion activity data in the NAEI are overestimated: The NAEI wood combustion emission factor applies to seasoned wood and does not

54 https://www.gov.uk/government/collections/energy-and-emissions-projections
55 https://naei.beis.gov.uk/
56 https://uk -air.defra.gov.uk/assets/documents/reports/cat07/2003131327_GB_IIR_2020_v1.0.pdf

between recently:		correctly reflect the increased emissions from wet wood[57].
	Legislation regulating the sale of wet wood and traditional coal in England	The sales of house coal and wet wood in England was phased out in May 2021, with transition periods available[58].
	Power stations – Adjustment for new natural gas projection data	The original emission projections developed for NAEI are adjusted to reflect the more recent generation projections from BEIS (2020). An adjustment was also included to reflect the differences in gas generation between EEP2019 and the latest generation estimates from BEIS.
	Power stations Adjustments to reflect BAT conclusions for Waste Incinerations (WI)	The baseline projections have been adjusted to also account for the BAT conclusions for Waste Incinerations (WI) which will be legally binding in 2025 and 2030.
	MCPD & HNG Regulations	The NAEI does not fully account for the impact of the Medium Combustion Plant Directive (MCPD) and the

57 http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=20159&FromSearch=Y&Publisher=1&SearchText=burning&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

58 https://www.legislation.gov.uk/ukdsi/2020/9780348210194

		High NOX Generators (HNG)
	Directive 97/68/EC on emissions from non-road mobile - NRMM gas oil	To account for the revision of Directive 97/68/EC on emissions from non-road mobile machinery engines (proposed measure Introducing Stage control limits for <18kW industrial off-road machinery, setting a limit of 7.5 g/kW for NOx and 0.4 g/kW for PM).
	Euro 6 diesel adjustment	Based on data from COPERT v5.4, the emission factor for NOx from certain Euro 6 diesel cars in real world conditions is expected to be lower compared to the emission factors previously provided in COPERT v5.3 (which the NAEI projections are based upon). The total NOx emissions from Euro 6 diesel cars currently used in the MPMD projection is likely to be an overestimate, so a baseline adjustment is applied.
	Phase out of the use of Red Diesel	The NAEI does not fully account for the removal of the entitlement to the use of gas oil, otherwise known as red diesel, from April 2022 for all users except for agriculture, rail and for non-commercial heating (Finance Bill 2021)[59].

[59] https://www.gov.uk/government/publications/reform-of-red-diesel-entitlements/reform-of-red-diesel-and-other-rebated-fuels-entitlement

Baseline Sensitivities

National Emissions Ceiling Regulations, 2018

The UK's international commitments to reduce its emissions of key air pollutants are set under the Gothenburg Protocol to the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP), and the EU National Emission Ceilings Directive that was transposed into UK legislation in the National Emissions Ceiling Regulations (NECR)[60]. The regulations set targets for the total emissions of 5 key pollutants (including $PM_{2.5}$) across the UK, to be met by 2020 and 2030. Measures and policies laying out what further action will be taken to meet these legally binding commitments have not yet been committed to or funded. Therefore, the impact of reaching these targets on pollution concentration is not included in the central baseline.

The $PM_{2.5}$ targets focus on air pollution concentration in England, whereas the NECR is for total emissions in the UK. While there is a relatively strong correlation between emissions and concentrations, pollution emitted in a specific area will impact concentration in other areas. In addition, the other pollutants under NECR also contribute to $PM_{2.5}$ concentration in the country, as do emissions of such pollutants from outside the UK. However, the measures considered to address $PM_{2.5}$ emissions ceilings and $PM_{2.5}$ concentration targets are broadly the same, but there will be a greater focus on the spatial distribution (and potentially more localised measures applied) when considering meeting the concentration targets. A pathway to meet NECR commitments will not be included in the main baseline as policies on how they will be reached are yet to be agreed. The $PM_{2.5}$ target should drive further action and be more ambitious than the targets that the UK is already committed to, although the fact that action will need to be taken spatially (on top of NECR total emission reduction) is an additional requirement.

As a baseline sensitivity exercise, a scenario where the UK meets the NECR emissions ceiling requirements for all pollutants by 2030 was modelled. This showed that this scenario would result in $PM_{2.5}$ concentrations slightly lower than the high target scenario in 2030, with a PWMC of 6.8 $\mu g/m^3$ compared to 6.9 $\mu g/m^3$. The medium and high scenarios both meet the primary $PM_{2.5}$ emissions ceiling required under NECR, but as the primary aim of the scenarios was to reduce $PM_{2.5}$ concentrations, emissions reductions commitments for all other NECR commitments are not modelled to be met in all scenarios. The results of these baseline sensitivity analysis can be seen in Table A2.

[60] The National Emissions Ceiling Directive (EU) 2016/2284 ('the NECD') was transposed into UK law: the National Emission Ceilings Regulations 2018

Figure A1: NECR Baseline Sensitivity, PM2.5 concentration projections in 2030 in the UK[61]

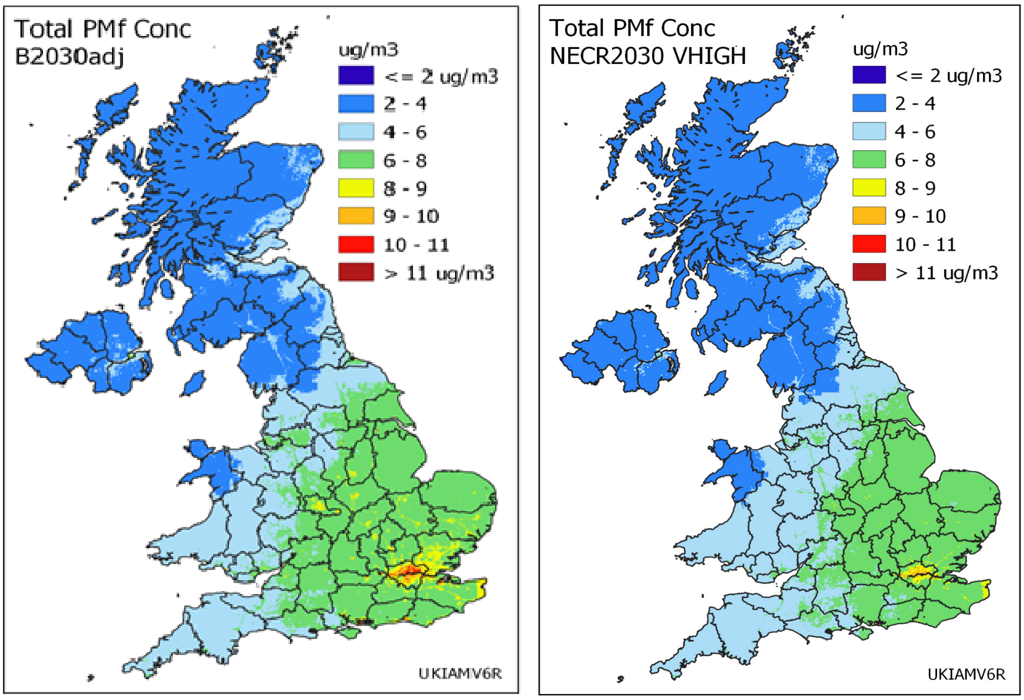
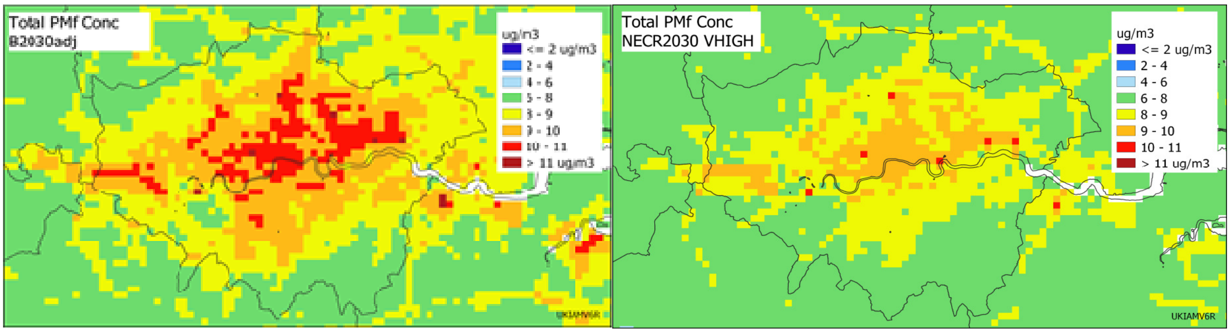


Figure A2: NECR Baseline Sensitivity, $PM_{2.5}$ concentration projections in 2030 in London[62]



Net Zero / Carbon Budget 6 (CB6)

The UK government has committed to reach Net Zero greenhouse gas emissions by 2050[63]. Climate change and air pollution have many of the same contributing emission sources (such as fuel combustion). Many of the actions taken to meet Net Zero will also have air quality benefits, for example a shift from conventionally powered vehicles to electric will reduce exhaust emissions. However, Net Zero actions will not address all $PM_{2.5}$ sources. For instance, emissions from brake, tyre and road wear may not necessarily be addressed by a shift to electric vehicles. The effect of switching from

[61] Source: Imperial College of London, UKIAM run, Sep 2021
[62] Source: Imperial College of London, UKIAM run, Sep 2021
[63] https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law

internal combustion engine vehicles to electric vehicles on non-exhaust $PM_{2.5}$ emissions is uncertain. On the one hand, this change in vehicle fleet composition may result in more non-exhaust emissions due to cheaper running costs and potentially heavier vehicles. However, on the other hand non-exhaust $PM_{2.5}$ emissions may decrease due to the impact of regenerative braking technology.

There are also some potential trade-offs to consider, such as the use of biomass, which are seen as making a positive contribution to reducing carbon emissions, but unabated, generate $PM_{2.5}$. As such whilst we recognise that Net Zero could play a significant role in future air quality targets ambition, it is not clear what the impact of the Net Zero commitment will be on $PM_{2.5}$, and therefore the impact of Net Zero cannot form part of the baseline.

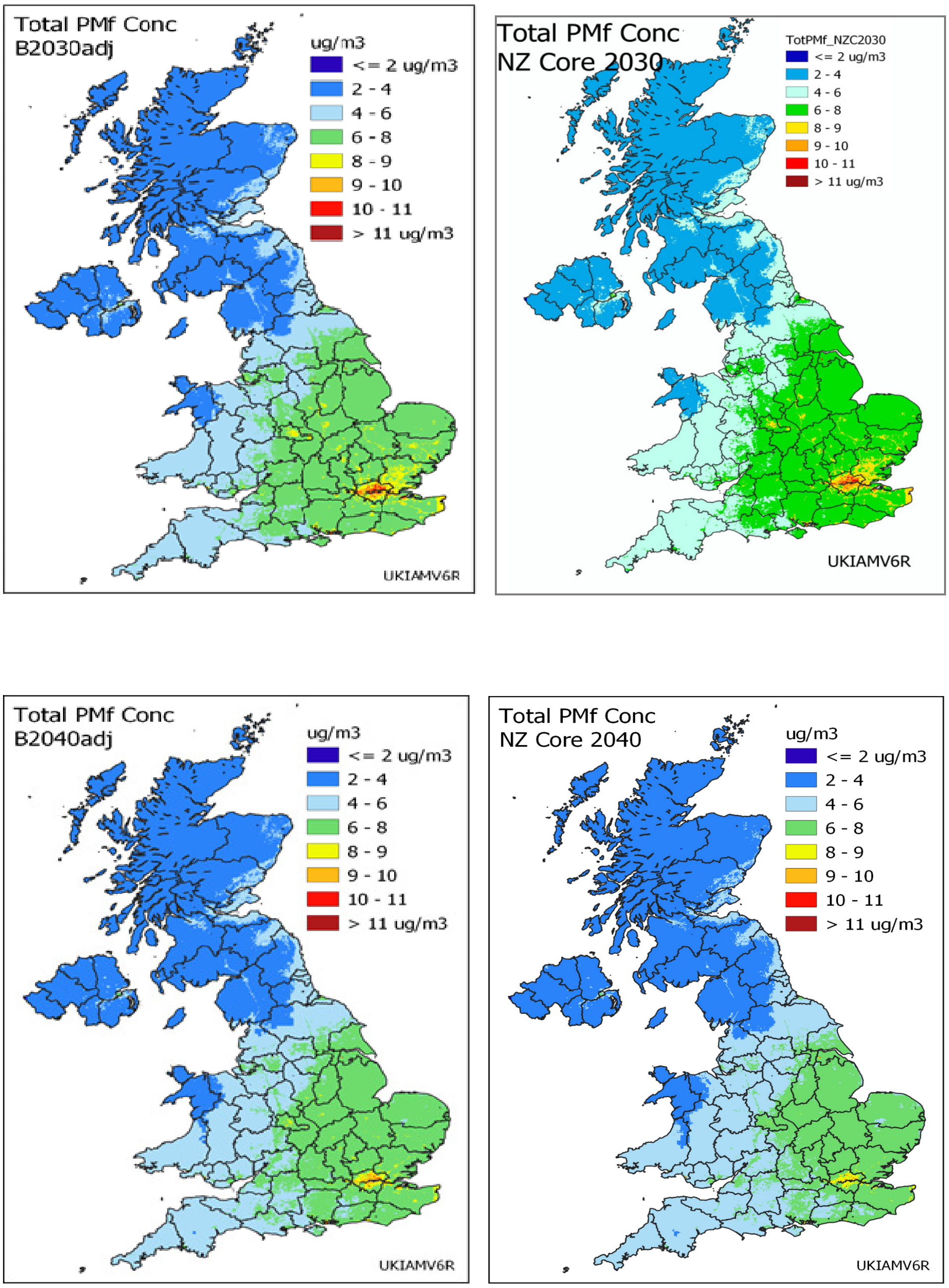
Possible Net Zero pathways have been included in a sensitivity analysis of the baseline as an indication of what the impact of Net Zero could be on achieving the $PM_{2.5}$ targets. This assessment is based on BEIS CB6/Net Zero pathways modelling of UKTIMES data[64]. As shown in Table A2 following the Net Zero pathway would result in $PM_{2.5}$ concentrations declining to 6.7 µg/m^3 in 2040 and 6.4 µg/m^3 in 2050.

Table A2: Baseline Sensitivity Analysis: England: population weighted mean $PM_{2.5}$ concentration, µg/m^3

	2018	2030	2040	2050
Baseline	9.70	7.48	7.29	7.30
Baseline (NECR)	9.70	6.76		
Baseline (Net Zero)	9.70	7.44	6.66	6.37
Option 1 (High – Preferred Option)	9.70	6.95	6.32	6.06

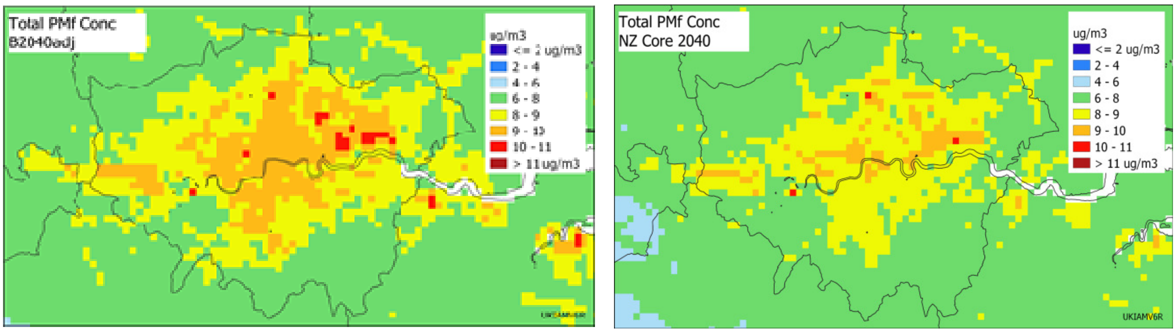
64 Impact Assessment for the sixth carbon budget (legislation.gov.uk)

Figure A3: Net Zero Baseline Sensitivity, PM2.5 concentration and projections in 2030, and 2040 in the UK[65]



65 Source: Imperial College of London, UKIAM run, Dec 2021

Figure A4: Net Zero Baseline Sensitivity: $PM_{2.5}$ concentration projections in London in 2040[66]



Annex 2: Pathways used in the cost-benefit analysis

Figure A5: Summary Target Scenarios

Target baseline	• Based on existing interventions and policies • Natural technology turnover • NAEI 2018 projections with some adjustments to account for recent legislation and updated data
Medium	• Based on measures/activity identified by the sector review • Implementation of proven technology and limited behaviour change, typical timescales and uptakes
High	• Based on measures/activity identified by the sector review • Technology considered likely to be implementable in the future by stakeholders, increased behaviour change and more rapid timescales
Speculative	• Based on measures/activity identified by the sector review • All feasible measures including emerging technology and significant behaviour change, optimistic timescales and uptakes

Figure A5 provides a summary of the target modelling scenarios used in the cost-benefit analysis for this IA.

[66] Source: Imperial College of London, UKIAM run, Dec 2021

Annex 3: Benefits Methodology

Air pollution has damaging impacts on human health, productivity, buildings and other materials, and the health of the environment. These detrimental impacts have associated economic and/or social costs (known as external costs or externalities) that are not captured in the market price of the goods or services consumed that produce the pollution. Defra has produced guidance to steer the assessment of air quality impacts and the valuation of external costs such that these can be captured in policy appraisal, based on the work of the Defra-led Interdepartmental Group on Costs and Benefits (IGCB). This guidance supplements the Green Book (HMT, 2020)[67] which provides wider guidance for impact assessment and valuation.

The following factors are accounted for in the valuation of air pollution impact:

The health impacts:

The health impact pathways are selected using advice from the Committee on the Medical Effects of Air Pollution (COMEAP) and UK Health Security Agency (UKHSA). These are impacts for which there is strong or reasonable evidence of an association with exposure to air pollutant concentrations. For some impacts there is only weak or emerging evidence of an association – where possible, these impacts are included only in the high estimates of damage costs for use in sensitivity analyses.

The environmental impacts:

Air pollutants can have a range of negative impacts on the environment and ecosystems, and for any particular policy or project there may only be specific pathways that are relevant. Four environmental impact pathways are included in the impact pathway methodology: damage caused by sulphur dioxide to buildings; damage caused by ozone to materials; soiling of buildings due to particulate matters; and ecosystem damages.

The economic impact:

Air pollution affects the economy by reducing the ability of workers to attend the workplace and produce efficiently. The effects on productivity are included through a range of morbidity and mortality pathways, and consideration is taken to avoid double counting by including the following: absenteeism and workdays lost for employees, volunteers, and carers ($PM_{2.5}$); and presenteeism and minor restricted activity days for employees ($PM_{2.5}$ and O_3).

[67] The Green Book (2020) - GOV.UK (www.gov.uk)

Air quality appraisal: impact pathways approach

The air quality benefits calculations are based on the Defra impact pathway approach (IPA) methodology[68] which is used to assess the impact of policy interventions on air quality of more than £50 million, as it is the case in this analysis. However, where air quality impacts are less than £50 million, the damage cost approach[69] which provides a set of pre-calculated values, expressed in cost per tonne (£/tonne) of emissions, can be used instead.

The calculation to quantify air quality impacts for the two targets uses the damage cost per unit of exposure approach, which identifies the impacts associated with one microgram change in exposure per person. The IPA and application of damage costs per unit exposure are equivalent methods that will give similar results. Other uncertainties, for example in the selection of effects that should be included in the analysis, will be far more significant.

The steps are as follows:

1. Emissions - Modelling the pollutant emissions data.
2. Pollutant concentrations – Using the emissions data (from the above step) and dispersion modelling to determine how pollutant concentrations are impacted by the policy.
3. Population exposure – Using the pollutant concentration estimates found in the last step and combining them with the relevant population data. This will produce a population weighted mean concentration for each pollutant.
4. Health & other impacts (internal to Damage Cost) – Identifying how the population weighted concentration changes, estimated in the previous step, will change outcomes associated with health, the environment, and the economy. Health impacts are assessed using concentration response functions (CRFs) which express changes in health outcomes per unit concentration, and applying them to their corresponding health impact pathways to derive estimates of life years lost, hospital admissions, cases of disease, etc.
5. Valuing impacts – The final stage involves calculating the damage cost per unit of exposure using the outputs from preceding steps.

The central, low, and high sensitivities of the damage cost per unit of exposure have differences in assumptions regarding the set of impacts included, and the concentration response functions (CRFs) applied to each health pathway across the sensitivities and valuations. The CRFs link a change in exposure to a pollutant to its consequent impacts by

68 More information on the Impact Pathway Approach can be accessed in Air quality appraisal: impact pathways approach - GOV.UK (www.gov.uk)

69 More information on air quality appraisal using damage costs can be accessed in Air quality appraisal: damage cost guidance - GOV.UK (www.gov.uk)

expressing a change in a health, or non-health, outcome for a given change in pollutant concentrations. Also, some impact pathways are excluded from the central damage cost and are only recommended for inclusion in the high damage cost (such as chronic bronchitis associated). The range of the central, low, and high damage cost values are included in the table below.

Table A3: Damage costs for $PM_{2.5}$ per unit concentration (£2020 per pop. weighted mean 1 µg/m^3 change per person), by sensitivity (low, central, high estimates)

	Low estimate	Central estimate	High estimate
$PM_{2.5}$	£16.93	£62.79	£178.47[70]

The damage cost values have been standardised to 2020 prices (using GDP deflators) and uplifted by 2% per annum, in line with Green Book guidance. The uplift captures the higher willingness to pay of the population, and therefore the increased value of health benefits as income (economic growth) rises.

Emissions of NOx, SO_2, and NH_3 contribute to damage costs via the secondary inorganic aerosol (SIA) contribution to ambient PM concentrations, and the long and short-term exposure to PM concentration pathways. Emissions of NOx and VOCs also affect ground level ozone concentrations, with associated impacts on health, materials, and ecosystems. A full mapping of the different impact pathways included in each of the damage costs is described in the report by Ricardo for Defra entitled "Air Quality damage cost update 2020" [71].

The methodology used to evaluate the benefits of the two $PM_{2.5}$ targets was taken for consideration, and subsequently approved by the Interdepartmental Group on Costs and Benefits (IGCB) of air quality during its December 2020 meeting. The IGCB is tasked with undertaking the formal economic analysis of air quality policy. It is responsible for approving any changes to the Defra DC/IGCB guidance. The group consists of a number of cross government stakeholders who ensure that the methodology uses the latest evidence for robustly valuing air quality impacts. Accordingly, the IPA and the damage cost per unit of exposure approach has previously received IGCB approval, prior to its publication.

[70] Sources: Ricardo; EMRC (Mike Holland)

[71] See https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2007031424_Damage_cost_update_2020_FINAL.pdf)

Annex 4: Detailed benefits

This annex provides a more detailed breakdown of the benefits presented in this impact assessment, with a focus on results of the quantified and monetised impact on air quality, split by pollutant, impact pathway and sub-region.

Table A4 below shows which health outcomes are generating the air quality benefits for the modelled scenarios, under the central cost sensitivity case. Table A5 below displays the equivalent monetised value attributed to these health pathways with the additional monetary impact on economic (productivity) and environmental (ecosystem) pathways also reported.

Table A4: Benefits by health pathway, cumulative 2023-2040 relative to baseline

Impact Pathway	Units	Option 1 (High scenario)
Chronic Mortality[1]	Life years	446,199
CHD[2]	Cases	38,464
Asthma[3]	Cases	19,903
Stroke[4]	Cases	10,166
Lung Cancer[5]	Cases	4,135
RHA[6]	Hospital admissions	11,352
CHA[7]	Hospital admissions	8,255

Notes:

1. Chronic (long-term) effects of mortality are expressed as avoided life years lost relative to baseline.
2. CHD = coronary heart disease, expressed as reduction in incidence (cases) of CHD as a long-term condition
3. Asthma (children) is expressed as reduction in incidence (cases) of asthma as a long-term condition
4. Stroke is expressed as reduction in cases of non-fatal stroke. Valuation accounts for the long-term effect of stroke on health. Fatal cases are accounted for under mortality.
5. Lung cancer is expressed as reduction in cases. Valuation accounts for the long-term effect on health.
6. RHA = respiratory hospital admissions, expressed as reduction in admissions relative to baseline.
7. CHA = cardiovascular hospital admissions, expressed as reduction in admissions relative to baseline.

Table A5: Monetised Benefits by pathway, central damage cost value, cumulative 2023-2040 (£m)

Impact Pathway	Option 1 (High scenario)
Chronic mortality	£17,338
Coronary Heart Disease	£7,654
Asthma (Children)	£8,931
Stroke	£2,880
Lung Cancer	£186
Respiratory hospital admission	£86
Cardiovascular hospital admission	£64
Productivity	£710
Building soiling & Material Damage	£186
Ecosystems	-£141

The negative value for ecosystems presented in Table A5 above is largely driven by the impact of ammonia on provisioning and regulating ecosystem services (from lower timber and livestock production as well as reduced carbon sequestration due to lower nitrogen available), more detail on these ecosystem impacts is discussed in section 19 of this IA.

The economic benefit of improved air quality of the preferred option relative to the baseline scenario has been disaggregated to English sub-region. Table A6 presents these cumulative air quality benefits by region for the periods 2023-2030 and 2023-2040. When interpreting the results in Table A6, it is important to note that there is substantial variation in baseline population weighted mean concentrations of $PM_{2.5}$ across English regions and therefore variation in the benefits accrued over the appraisal period.

Table A6: Cumulative Air Quality Benefits by region in England (£m, 2020 prices)[72]

Region	Option 1 (High scenario) (2023-2030)	Option 1 (High scenario) (2023-2040)
East Anglia	£942	£3,531
East Midlands	£769	£2,914
London	£2,562	£9,123
North East	£340	£1,194
North West	£1,225	£4,615
South East	£1,483	£6,043
South West	£660	£2,716
West Midlands	£1,018	£4,027
Yorkshire	£940	£3,697

Table A7 presents the low and high range in estimated monetised benefits derived from reductions in damage from $PM_{2.5}$ exposure for the preferred option. A further breakdown of the benefits associated with each pollutant is also included thereafter, in Table A8.

[72] There is a slight discrepancy between the total air quality benefits for all English regions, as reported in this table, and the total air quality benefit reported elsewhere in this Impact Assessment. This is due to a small difference between the underlying population data applied to benefit calculation and modelling changes in population weighted mean concentrations. The size of the difference is less than 0.1%.

Table A7: England: Cumulative benefits from reduced damage to health, productivity, ecosystems and soiling of buildings from $PM_{2.5}$ exposure (£m, 2020 prices)

Cumulative Benefits (2023-2040)	Option 1 (High scenario)
Low Estimate	£8,755
Central Estimate	£31,969
High Estimate	£90,514

Table A8 below shows how the total air quality benefits derived from reduced damage to health, productivity, ecosystems, and soiling of buildings are split by pollutants. Benefits associated with reductions in $PM_{2.5}$ exposure generate a large proportion of the total air quality benefits, forming 84% of total air quality benefits using the central sensitivity values for option 1, with NO_2 constituting the second largest pollutant source of benefits.

Table A8: England: Cumulative (2023-2040) air quality benefits broken down by pollutant and sensitivity (2020 prices, £m)

	Option 1 (High scenario)		
Pollutant	**Low**	**Central**	**High**
$PM_{2.5}$	£8,755	£31,969	£90,514
NO_2	£440	£6,059	£23,976
NH3	-£67	-£159	-£199
VOC	£9	£17	£34
SO2	£5	£6	£7
Total Air Quality Benefits	£9,142	£37,891	£114,332

Annex 5: Detailed costs of illustrative pathway

Costs are estimated for all the measures to reduce $PM_{2.5}$ concentrations that form the illustrative scenario. The cost estimates were gathered from a variety of sources including literature review, interviews, workshops with stakeholders and existing data already obtained from previous Defra work.

For most measures there is a capital cost and an operating cost (separating fuel and non-fuel cost). The capital and operating costs, along with the average operating lifetime of the measure and the uptake rate, are used to calculate equivalent annualised cost. This allows for a representative cost per year of the measures to be compared where lifetimes of costs differ. In some cases, the cost of measures can be negative as there is a cost saving due to reduced fuel consumption. Cost data has been adjusted as necessary to present values in 2020 prices and to account for optimism bias.

The analysis conducted for this IA is not of specific agreed government policy, and some of the measures which have been costed include speculative technologies and behaviour changes. It is therefore outside the scope of this analysis to give detail on how the costs will be divided across business, government, and households. It has not been possible at this stage to provide a breakdown of the total transition (capital) and operating costs for several measures.

Table A9: England: Equivalent Annualised Cost of Illustrative Measures split by sector, discounted (2020 prices, £m)

	Option 1: High Scenario	
	All Measures	Refined Measures
Sector	Cumulative (2023-2040)	Cumulative (2023-2040)
Agriculture	£1,286	£1,286
Power generation	-£343	-£343
Industry	£1,608	£1,608
Residential	£20,944	£6,050
Transport	£3,579	£3,579
Total	£27,074	£12,180

Table A9 above provides an indication of how the costs may be split across different sectors. The first column shows cost per sector for all measures included in the high modelling scenario. The second column presents the same data once the package has been filtered to remove the least cost-effective measure (as it is a high cost / relatively low air quality impact measure). This filtering of least-cost effective measures significantly lowers total scenario costs without necessarily impacting on the objective of meeting the preferred target level.

In the scenario modelled for this cost-benefit analysis, the highest costs are borne by the residential sector. However, it is important to clarify that residential sector costs should not be misinterpreted as costs borne by households as the analysis conducted is not of specific agreed government policy and disaggregating cost estimates between costs to government, households and industry is out of scope, as highlighted in Section 13.1 of this IA.

Annex 6: Impact on devolved administrations of the United Kingdom

Air pollution is a trans-boundary problem. Therefore, actions taken to reduce emissions to meet concentration targets set in England will likely have impacts on $PM_{2.5}$ concentration levels in other devolved administrations of the United Kingdom. The reduction in PWMCs of $PM_{2.5}$ in devolved administrations of the United Kingdom attributable to English sources of both primary $PM_{2.5}$ and secondary inorganic aerosols has been modelled and the monetised benefits of these projected reductions for the preferred option relative to the baseline scenario are summarised in Table A10 below.

Table A10: Cumulative monetised benefit (£m, 2020 Prices) of reduced $PM_{2.5}$ damage from English sources on devolved administrations of the United Kingdom

Devolved Administration	Cumulative spill-over benefit (£m)	
	(2023-2030)	(2023-2040)
Northern Ireland	£4	£17
Scotland	£20	£75
Wales	£64	£215
Total	**£88**	**£307**

Annex 7: Damage Cost Sensitivity Analysis

As set out in Annex 3, the impact pathways used to calculate damages associated with human health have been selected based on advice provided by the Committee on the Medical Effects of Air Pollutants (COMEAP) and UKHSA.

The central damage costs used in the cost-benefit analysis for this impact assessment is based on updated guidance from COMEAP[73]. This updated guidance from COMEAP includes recommendations for quantifying mortality associated with long-term exposure to $PM_{2.5}$, based on consideration of new scientific evidence. The recommended coefficient (concentration-response function, CRF) of RR = 1.08 per 10 µg/m^3 $PM_{2.5}$ is higher than the previous (2018) recommendation of RR = 1.06. per 10 µg/m^3.

The decision to apply these updated damage costs in the cost benefit analysis for this impact assessment was arrived at as a result of previous advice provided by COMEAP with respect to the setting of $PM_{2.5}$ targets[74].

These central damage costs are compared in this annex against additional sensitivity checks based on further subsequent updates from COMEAP[75,76].

Table A11 presents the sensitivity analysis on the damage costs per unit of exposure of $PM_{2.5}$ and NO_2 for the central sensitivity values only. Values in parenthesis show the percentage change relative to the baseline central damage cost values used in cost-benefit analysis.

Table A12 displays the impact of these sensitivity damage costs on appraisal summary indicators, such as the net present value and benefit cost ratio of the proposed target scenario.

The two sensitivity scenarios result in a 0.8% increase and a 6.5% decrease in the total monetised air quality benefits. However, the impact on net present value and benefit cost ratio is less significant since the majority of monetised benefits are derived from greenhouse gas abatement.

[73] COMEAP (2022): Statement on quantifying mortality associated with long-term exposure to PM2.5
[74] COMEAP (2021): Advice on health evidence relevant to setting PM2.5 target
[75] COMEAP (2022): Statement on update of recommendations for quantifying hospital admissions associated with short-term exposures to air pollutants (2022)
[76] COMEAP: Quantification of the effects of long-term exposure to ambient air pollution on cardiovascular morbidity – to be published

Table A11: Damage Cost Sensitivity Analysis – Central Estimates (£2020 per pop. weighted mean 1 µg/m3 change per person)

Central Damage Cost (£2020 ug/m3)	$PM_{2.5}$	NO_2
Central value used in CBA	(62.79)	(7.02)
(a) Sensitivity 1: Update for hospital admissions	63.11 (0.5%)	7.18 (2.3%)
(b) Sensitivity 2: Update for cardiovascular	57.65 (-8.2%)	7.18 (2.3%)

Table A12: Damage Cost Sensitivity Analysis – Impact on Cost Benefit Analysis (£m, £2020, Cumulative 2023-2040)

Central Damage Cost (£2020 ug/m3)	Total Air Quality Benefits	Net Present Value	Benefit Cost Ratio
Central value used in CBA	£37,891	£107,935	5.0
(a) Sensitivity 1: Update for hospital admissions	£38,193 (0.8%)	£108,237 (0.3%)	5.0
(b) Sensitivity 2: Update for cardiovascular	£35,411 (-6.5%)	£105,455 (-2.3%)	4.9