AIR QUALITY STOCKTAKE

Technical report

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NON-TECHNICAL SUMMARY

The purpose of this project was to support the Office for Environmental Protection (OEP) in gaining a comprehensive understanding of air pollution issues in England and Northern Ireland. This included identifying the drivers of air pollution and the pressures it causes on environmental and human health, as well as barriers that may prevent progress in reducing air pollution. The project will provide the OEP with the information they need to make informed decisions.

There were a number of project components broken up into different tasks:

- A comprehensive stocktake of current and emerging air quality issues.
- A risk assessment of the impacts from each air pollutant both on the natural environment and to public health.
- A synthesis of delivery mechanisms available to reduce air pollutants posing the greatest risk.
- A register of recommendations to government and commitments made by government for improving air quality in England and Northern Ireland.

Stocktake of air pollutants

108 pollutants were reviewed as part of the air quality stocktake, 18 of which are considered to be emerging pollutants due to new evidence or recent developments in chemicals production and use. The focus of this review was on pollutants that are not currently being regulated, or which could be regulated more stringently, due either to their increasing presence in the environment or their increasing impact on human health or the natural environment. Pollutants were systematically reviewed and categorised into Tier 1, Tier 2 and Excluded Pollutants (Tier 3) (Table 1).

Table 1: Categorisation of Tier 1, Tier 2 and Excluded (Tier 3) pollutants for review.

Tier 1	Tier 2 (not meeting Tier 1 criteria)	Tier 3 - Excluded (Not meeting Tier 1 and 2 criteria.
Pollutants included in the Clean Air Strategy 2019	Pollutants with Environmental Assessment Levels (Old EAL derivation method from EH40/2001 OEL)	Pollutants listed in Montreal Protocol (already dealt with)
Pollutants included in Air Quality Standards Regulation 2010 or Air Quality Standards (NI) 2010	Pollutants listed in Annex I of the Environmental Quality Standards Directive (EQSD; Directive 2008/105/EC amended by Directive 2013/39/EU	Persistent Organic Pollutants (due to green classification in NCC and already dealt with in National Implementation plan for the Stockholm convention on Persistent Organic Pollutants)
Pollutants included in National Emissions Ceilings Regulation 2018	Emerging pollutants classified on a case-by-case basis, through expert judgement	Identified as compliant with the Air Quality Standards Regulation limit values since 2008
Emerging pollutants classified on a case-by-case basis, through expert judgement		Emerging pollutants classified on a case-by-case basis, through expert judgement

Pollutants categorised into Tier 1 and 2 were investigated further, and factsheets were created for each pollutant (see Appendix 1).

Risk assessments

Risk assessments were carried out for each pollutant taken forward for further investigation. A scoring process was developed which assessed pollutants based on the following elements:

- Current risk: based on a combination current concentrations and emissions against standard limit values, and level of pollutant hazard
- Future risk (where projections were available)
- Quality of evidence

Risk assessments are provided in Appendix 2. Table 2 summarises the findings of the Risk Assessment, presenting the current risk, potential future risk, quality of evidence and overall risk rating on a four point colour scale for each pollutant.

Table 2: Summary of Risk Assessment findings

Air Pollutant	Current risk	Potential future risk	Quality of the evidence	Overall risk rating
Key	Low Moderate High Very high	Improvement No change Deterioration Significant deterioration	Very good Good Moderate Poor	Low Moderate High Very high
Tier 1 Pollutants				
Ammonia (NH_3)				
Arsenic				
Benzo[a]pyrene				
Black carbon				
Cadmium (Cd)				
Nickel (Ni)				
Nitrogen Dioxide (NO_2)				
NMVOCs				
Ozone (O_3)				
$PM_{2.5}$				
Ultrafine Particles (UFP)				
Tier 2 Pollutants				
1,3-butadiene				
Benzo(G,H,I)Perylene				
Benzo(K)Fluoranthene				
Beryllium				
Bioaerosols				
Brown carbon				
Chlorine				
Chromium				
Copper				
Dioxins				
Hydrogen Fluoride (HF)				
Formaldehyde				
Hydrogen cyanide				

Hydrogen Chloride				
Indeno[123-cd]pyrene				
Manganese				
Micro- and nano- plastics				
Nitric Oxide (NO)				
Nitrogen trifluoride				
Organic carbon				
Per-Polyfluorinated compounds (PFC)				
PM_{10}				
Selenium				
Sulphur Dioxide (SO_2)				
Sulphur Hexafluoride (SF_6)				
Toluene				
Total carbon				
Vanadium				
Xylene				

Two pollutants were assessed to be of very high risk overall: $PM_{2.5}$ and Ultrafine particles. $PM_{2.5}$ refers to particulate matter in the air with diameter less than 2.5 micrometres. Ultrafine particles (UFP) are defined as particles with one dimension less than 100 nanometers (or 0.1 micrometers (μm)), and comprise a minor component of $PM_{2.5}$ and PM_{10}.For reference on the scale of $PM_{2.5}$ and UFP, the width of a human hair is at least 50,000 nanometers (nm) (50 micrometers (μm)) thick[1]. Both $PM_{2.5}$ and UFP are comprised of a wide variety of chemical compounds and materials, including dust, dirt, smoke and liquid droplets, and therefore consists of a wide variety of chemical compounds and materials.

13 pollutants were classified as high risk: ammonia (NH_3), black/elemental carbon, benzo(k)fluoranthene, bioaerosols, brown carbon, chromium, indeno[123-cd]pyrene, nitric oxide (NO), nitrogen dioxide (NO_2) and total carbon. 11 were classified as medium risk, and 13 were classified as low risk.

Assessment of delivery mechanisms

Measures that could be used to mitigate pollution risks were investigated for the following pollutants:

1. Pollutants ranked as very high or high risk in the risk assessments
2. The five key pollutants in Defra's Clean Air Strategy
3. Pollutants which are non-compliant with the Air Quality Standards Regulations from Defra's most recent "Air pollution in the UK 2021" report.
4. Pollutants with a 'deterioration'/'significant deterioration' in the 'potential future risk' category of the risk assessments – $PM_{2.5}$ and bioaerosols.

Delivery mechanisms were identified for the following eight source sectors:

- Road Transport
- Aviation, Railways and National Navigation (non-road transport)
- Public electricity and heat production
- Combustion in manufacturing industries and construction

[1] https://www.bbc.com/news/science-environment-37276219.amp

- Commercial/Institutional and residential combustion
- Industrial processes
- Waste Treatment and Disposal
- Agriculture

The impact or scale of improvement for each measure was assessed across different pollutants, based on the evidence collated in the literature and data search. It was found that the majority of delivery mechanisms benefited multiple pollutants. The only measure found to likely improve all pollutants including ammonia, benzo[a]pyrene or dioxins concentrations to a measurable extent was the Road Transport delivery mechanism *"Improve vehicle fleet with sustainable and low emission vehicles*". Other measures scoring high across multiple pollutants included measures to reduce emissions from combustion, emissions abatement and policy and regulations for industrial processes, fuel switching, and Aviation, Railways and National Navigation infrastructure improvements.

Delivery mechanisms have been assessed for reliability/certainty of success, speed of deployment and cost. The measures scoring the highest in terms of deliverability across these criteria are:

- OEP3 - Land use planning and vehicle restriction (Road Transport)
- OEP6 - Replacement of energy supply (Public electricity and heat production)
- OEP7 - Improve building fabric for efficient energy use (Public electricity and heat production)
- OEP9 - Replacement of energy supply (combustion in manufacturing industries and construction)
- OEP18 - Improve building fabric for efficient energy use (Commercial/Institutional and residential combustion)

Delivery mechanisms were also assessed for co-benefits and trade-offs with other pollutants, other environmental trade-offs and risks to delivery. This identified a few trade-offs and risks to be managed and monitored in implementing delivery mechanisms:

1. Reduction of NO_2 emissions can lead to increased ground level O_3 concentrations in the short term, due to atmospheric reactions between NO, NO_2 and O_3. Research suggests that this can be managed through effective VOC control in combination with NOx mitigation.
2. Trade-offs with greenhouse gas emissions when air pollutants are reduced by delivery mechanisms which result in increased GHG emissions, or when delivery mechanisms for reducing GHG emissions result in increased emissions or concentrations of air pollutants.
3. The cost of new technology limiting the speed and scale of uptake of delivery mechanisms.

It was found that delivery mechanisms which require a change through regulations and legislative actions result in less risk in implementing mitigation measures.

Government commitments/recommendations?

As a standalone task during this project we collated government recommendations/commitments a summary of which are provided in Section 4 and full details are found in annex 3.

Evidence Gaps /Recommendations for future work?

We assessed evidence gaps and recommend that work should be carried out to address the following items in the future:

1. Further research into the composition, behaviours, measurement techniques and (if necessary) control/reduction measures for emerging very high and high risk pollutants: ultrafine particles, brown carbon, total carbon and Bioaerosols.
2. Increased monitoring and improved monitoring techniques of the following very high and high-risk pollutants: $PM_{2.5}$, ultrafine particles, black carbon and ammonia.
3. A review of standards and targets for all air pollutants to accompany the new UK $PM_{2.5}$ objectives.

4. Investigation of delivery mechanisms for reducing emissions and concentrations of ultrafine particles, and research to better understand the effectiveness of delivery mechanisms for reducing PM_{10} and $PM_{2.5}$ on PM constituents: ultrafine particles, total carbon black carbon, brown carbon and bioaerosols.
5. Investigation of delivery mechanisms to reduce emissions from emerging and ongoing sources such as brake and tyre wear.
6. Investigation of delivery mechanisms to reduce indoor air pollution.
7. Implementation of delivery mechanisms should be coordinated to ensure an integrated approach is adopted to take advantage of co-benefits and avoid trade-offs. Delivery mechanisms to reduce nitrogen oxides (NOx) emissions should be implemented alongside mechanisms to reduce NMVOCs and other precursor pollutants of ozone (O_3), to ensure a trade-off increase in O_3 is prevented in the short term.

1. INTRODUCTION

The Office for Environmental Protection (OEP) has the mission to protect and improve the environment by holding government and other public authorities to account. The OEP corporate plan sets out commitments to:

- Evaluate evidence of the drivers and pressures on air quality in England and Northern Ireland.
- Respond to the UK government on any updates to their air quality strategies, and any other changes to environmental laws intended to promote governments' ambitions to improve air quality.
- Respond to any draft ammonia strategy prepared by DAERA.

Recent developments in air quality policy include new air quality targets for $PM_{2.5}$[2] and other legislative changes introduced in the Environment Act (2021). Forthcoming publications are expected such as an update to the Draft UK National Air Pollution Control Programme[3] to further set out the approach to improving air quality in the UK, and a Clean Air Strategy for Northern Ireland[4].

To support OEP's commitments and activities, Ricardo Energy and Environment were contracted to support the OEP in developing an independent view of air pollution challenges in England and Northern Ireland, including understanding the drivers of air pollution and the pressures it causes on environmental and human health, and barriers to improvements, in line with the vision of Government's 25 Year Environment Plan and current Environmental Improvement Plan.

Atmospheric pollution is made up of a complex cocktail of chemicals that vary substantially in their spatial distribution and residence time. In addition, while current policy and mitigation measures take effect, the levels of such chemicals will vary over time. Such policy may be directly targeting these pollutants, others may be indirect and have co-benefits or unintended consequences on air pollutants, e.g. policy targeting climate change may have a positive or negative impact on air quality. As scientific understanding progresses new emerging pollutants may come to light. Consequently, this review aims to take stock of the current evidence on the most impactful current and emerging pollutants, carry out an assessment of their risk to human health and the environment and undertake a comprehensive assessment of available mitigation measures. This stocktake will also review the commitments by government to reduce air pollutant levels and recommendations by others to government to do so.

This report summarises the task methodologies, the findings of the pollutant risk assessments, the catalogue of commitments and recommendations, and the synthesis of delivery mechanisms to reduce air pollutants. Pollutant factsheets, pollutant risk assessments, the full catalogue of commitments and recommendations, the full delivery mechanism review table and the marginal abatement cost curves accompany this report as separate Appendices.

Appendix 1: Pollutant factsheets

Appendix 2: Pollutant risk assessments

Appendix 3: Delivery mechanisms for pollutant mitigation spreadsheet

Appendix 4: Catalogue of air pollution recommendations and commitments.

Appendix 5: Marginal abatement cost curves

[2] https://questions-statements.parliament.uk/written-statements/detail/2022-12-16/hlws449

[3] https://consult.defra.gov.uk/napcp/consultation-on-the-draft-national-air-pollution-c/supporting_documents/Draft%20NAPCP%20for%20consultation.pdf

[4] https://www.daera-ni.gov.uk/clean_air_strategy_discussion_document

2. METHODOLOGY

The project tasks were as follows:

- **Task 1: Project Inception**
  - Project Inception meeting.
- **Task 2: Air Quality Stocktake; a comprehensive summary of air pollution**
  - Development of a pollutant longlist
  - Classification of pollutants into 1st Tier, 2nd Tier, and those excluded from further assessment within this project.
  - Development of a pollutant factsheet template, determining what information should be included.
  - Identification of key literature and sources using expert knowledge of relevant sources of information.
  - Search of key literature to populate the pollutant factsheets.
- **Task 3: Air Pollution Risk Assessment**
  - Development of a risk assessment methodology and template, including development of assessment criteria and scoring categories.
  - Conducting qualitative risk assessments on the long list of pollutants based on information collated in the pollution factsheets, expert knowledge, and further literature search if needed.
- **Task 4: Delivery Mechanism review**
  - Identification of mechanisms which deliver reductions of pollutants, grouping by pollutant source sectors.
  - Presentation of source apportionment of pollutants from each source sector, where possible.
  - Quantification of potential scale and speed of deployment, reliability and certainty of success, cost at a national and individual scale, and risks to success for each mechanism.
  - Identification of synergies and trade-offs across the sectors and pollutants for each mechanism.
- **Task 5: Catalogue of Recommendations and Commitments**
  - Literature review and search of publications which include government commitments related to air quality as well as recommendations from scrutiny bodies.
  - Review of relevant reports and documents to identify commitments and recommendations which may have a direct and strong indirect impact to air quality.
- **Task 6: Reporting and presentation.**
  - Preparation of this technical report.

2.1 SEARCH STRATEGY (LEADING INTO TASKS 2, 3 AND 4)

This search strategy outlines how information was sourced to inform the air quality stocktake, pollutant factsheets, pollutant risk assessments, and the delivery mechanism review (Tasks 2, 3 and 4). The methodologies of Tasks 2, 3, 4 and 5 are expanded on further in sections 2.2 – 2.5.

2.1.1 Data streams

The data, evidence and literature search targeted the following sources in the following priority order:

1. Air quality database/portal sources
   - UK-Air[5] – including the automatic and non-automatic monitoring networks and supporting reports.

[5] https://uk-air.defra.gov.uk/

This portal is managed by Ricardo and includes the following networks:

i. Automatic Urban and Rural Network;
ii. Automatic Hydrocarbon Network;
iii. UK Eutrophying and Acidifying Network;
iv. Heavy Metal Network;
v. Black carbon Network;
vi. Polycyclic Aromatic Hydrocarbon (PAH) Network;
vii. Toxic Organic Micro Pollutants (TOMPS) Network; and
viii. UK Urban NO_2 Network.

- .gov websites- includes COMEAP, AQEG
- The National Atmospheric Emissions Inventory (NAEI)[6] – the UK's air pollutant emissions inventory and supporting reports.
- The UK Pollutant Release and Transfer Register (PRTR)[7]
- The UK Greenhouse Gas Emissions Inventory (GHGEI)
- AQUILA (European National Air Quality Reference Laboratories Network)
- EMEP (European Monitoring and Evaluation Programme),
- ACTRIS (Aerosols, Clouds and Trace gases Research InfraStructure),
- WMO-GAW (World Meteorological Organization-Global Atmosphere Watch)
- USEPA (United States Environmental Protection Agency
- WHO

2. Government and public body websites: list of relevant public bodies including government departments, audit committees, previous national focus groups on air quality to include devolved administrations and government agencies e.g. Defra, Environment Agency, JNCC, Natural England (a list is found in section 2.5.1).
3. International treaties and agreements
   - National Emissions Ceiling Directive
   - The Stockholm Convention on Persistent Organic Pollutants[8]
   - The Montreal Protocol[9]
4. UK-focused Research Institutes
   - NERC Clean air champions
   - Met Office research programmes
5. Academic literature
   - Google Scholar
   - ScienceDirect
   - ResearchGate
   - Web of Science.

2.1.2 Search terms

Search terms used to identify key relevant documents to inform pollutant factsheets and risk assessments are summarised in Table 3. These terms were used flexibly during the literature search and combined strategically in order to find documents and data efficiently.

[6] https://naei.beis.gov.uk/overview/ap-overview
[7] https://prtr.defra.gov.uk/pollutant-list
[8] http://chm.pops.int/TheConvention/ThePOPs/ListingofPOPs/tabid/2509/Default.aspx
[9] https://treaties.un.org/doc/publication/unts/volume%201522/volume-1522-i-26369-english.pdf

Table 3: Search terms used to find data, legislation, and research papers regarding each pollutant.

Generic terms			
Atmosphere	Air quality England	Air pollutants effect on environment	Brake dust emissions
Air pollution	Air Quality Northern Ireland	Air pollutants effect on ecosystems	Tailpipe emissions
Air Quality	Pollutant releases	Air pollutants effect on habitats	Traffic Emissions
Emerging pollutants	Industrial air pollutants	Tyre emission	Air pollution UK
Climate change	Burning pollutant releases	Non- exhaust emissions	Air pollution effect on species
Air pollution and public health	Accidental air pollutant releases	Agricultural emissions	Air pollution effect on biodiversity
Risks of air pollutants	Source air pollution	Air quality effect on agriculture	Domestic cleaning emissions
Air pollution England	Vehicle emission composition	Air quality effect on water	Soft furnishing emissions
Air Pollution Northern Ireland	Biomass pollutant	Waste emissions	Stove emissions
Air Pollutant trends	Woodsmoke emissions	Air pollutants from waste	Exhaust emissions
'air pollutant' human health risks	Combustion pollutant emissions	Waste incineration emissions	Brake pad emissions
Emerging pollutants			
Elemental carbon (EC)	Organic carbon (OC)	Total carbon (TC)	Black carbon (BC)
NitroPAHs (nPAH)	Levoglucosan	Brown carbon (BrC)	Ultrafine particles (UFP)
Bioaerosols	Acrylonitrile	Chloroform	Dichloromethane (DCM)
Ethylene Oxides	1-4-Dioxane	Trichloroethylene	Micro- and nano- plastics
2,2',4,4',5-Pentabromodiphenyl ether (BDE-99)	Short-chained chlorinated paraffins (SCCP)	Perfluorooctanesulfonic acid (PFOS)	
Gases			
Ammonia (NH_3)	Carbon monoxide (CO)	Chlorine (Cl)	Inorganic compounds
Fluorine and inorganic compounds (HF)	Hydrogen cyanide (HCN)	Ozone (O_3)	
Heavy Metals			
Arsenic (As)	Beryllium (Be)	Cadmium (Cd)	Cobalt (Co)
Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)
Manganese (Mn)	Mercury (Hg)	Nickel (Ni)	Platinum (Pt)
Selenium (Se)	Tin (Sn)	Vanadium (V)	Zinc (Zn)
Greenhouse gases			
Carbon dioxide (CO_2)	Hydrofluorocarbons (HFC)	Methane (CH_4)	Perfluorocarbon (PFC)
Sulphur hexafluoride (SF_6)	Nitrogen trifluoride (NF3)	Nitrous oxide (N_2O)	
Ozone depleting substances			
Carbon tetrachloride (CCl_4)	Chlorofluorocarbons (CFC)	Halons	Hydrochlorofluorocarbons (HCFCs)
Methyl Bromide (CH_3BR)	Methyl chloroform	$C_2H_3Cl_3$	
Non methane volatile organic compounds			
1,3 Butadiene	Benzene (C_6H_6)	Non-methane volatile organic compounds (NMVOCs)	Formaldehyde
Toluene	Xylene	Propane	Butane
Poly aromatic Hydrocarbons (PAH)			

Naphthalene	Acenaphthylene	Acenaphthene	Fluorene
Phenanthrene	Anthracene	Pyrene	Fluoranthene
Benzo (a)anthracene	Chrysene	Benzo (b)fluoranthene	Benzo (k)fluoranthene
Benzo[a]pyrene (B[a]P)	Indeno[123-cd]pyrene	Dibenz[ah]anthracene	Benzo(g,h,i)perylene
Nitro-PAHs	Oxy-PAHs	Me-PAHs (methylated)	Alkyl-PAHs (alkylated)
Particulate matter			
$PM_{2.5}$	PM_{10}	Dust	Fine particulate matter
Ultrafine particulate matter	Coarse particles	Primary fine particles	Secondary fine particles
Particle pollution	Suspended particulate matter	Black carbon	Soot
Suspended dust	Settling dust	Heavy dust	Total suspended particulates (TSP)
Elemental carbon	Coarse fraction	Resuspended road dust	Diesel emission particulates
Ambient aerosol			
Acid gases			
Hydrogen chloride (HCl)	Hydrogen Fluoride (HF)	Nitric acid (NO)	Nitrogen dioxide (NO_2)
Sulphur dioxide (SO_2)	Sulphur trioxide (SO_3)		
Persistent organic pollutants			
Dieldrin	Dioxins and furans polychlorinated-p-dioxins (PCDDs)	polychlorinated-p-dioxins (PCDDs)	Polychlorinated dibenzofurans (PCDFs)
Endrin	Linane- Hexachloro-cyclohexane	(HCH)	Polychlorinated biphenyls (PCBs)
Endosulfan	Tetrabromodiphenyl ether	Perfluorooctane sulfonic acid	DDT
Chlordane	Hexachlorobenzene (HCB)	Chlordecone	Aldrin
Pentachlorobenzene	Mirex	Toxaphene	Hexabromobiphenyl
Hexabromo-cyclododecane (HBCD)	Polychlorinated naphthalene	Hexachlorobutadiene	Alkanes C10 – C13, chloro(short-chain chlorinated parrafins)

2.1.3 Inclusion/exclusion criteria

The inclusion/exclusion criteria included:

- Indoor air pollutants are excluded, unless the source cannot be disentangled from outdoor pollutants e.g., $PM_{2.5}$ from stoves or NMVOCs from domestic cleaning products.
- Language – we only reviewed documents written in English.

2.2 AIR QUALITY STOCKTAKE METHODOLOGY (TASK 2)

2.2.1 Longlist of pollutants

2.2.1.1 Summary of the longlist

Informed by the literature, data and evidence review (as summarised in Section 2.1), a longlist of air quality pollutants was developed. The longlist comprises 108 “current” and “emerging” air pollutants. 90 current pollutants were identified as substances which have been the subject of monitoring, research and/or regulation for a long period of time, due to their potential or known effects on health or the environment. Additionally, 18 emerging pollutants were identified. These are substances which have recently come to the attention of the scientific and regulatory community, due to emerging scientific understanding or the recent introduction of the chemicals themselves or precursors by manufacturers.

Of the 90 "current" pollutants in the longlist, 66 pollutants are included in the Natural Capital Committee's (NCC) report[10] as potential substances that are acting as a pressure on air quality or atmospheric processes. These substances are also regarded to have the greatest impact and pose the greatest risks to the environment and human health. They are categorised into the following nine groups:

1. Particulate matter (PM)
2. Polycyclic aromatic hydrocarbons (PAHs)
3. Greenhouse gases (GHG)
4. Acid gases
5. Ozone depleting substances (ODS)
6. Non-methane volatile organic compounds (NMVOCs)
7. Heavy metals
8. Persistent organic pollutants (POPs)
9. Other gases

The remaining 24 pollutants were identified by considering groups of pollutants which are not extensively represented in the NCC shortlist, and comprise:

- Volatile organic compounds (formaldehyde, toluene, xylene, propane, butane)
- Polycyclic aromatic hydrocarbon derivatives which have been identified as emerging issues[11] (Oxy-PAHs, Methyl-PAHs, Alkyl-PAHs)

The 18 emerging pollutants were identified in the strategic literature and data search, informed by the combined experience of the OEP and Ricardo teams working in the fields of air quality technical and policy research, and broader environmental policy.

2.2.1.2 Longlist categorisation

For the purposes of this project, the focus is on those pollutants that potentially should be more stringently regulated or begin to be regulated, due either to their increasing presence in the environment or their increasing impact on human health or the natural environment. To assist in this, all pollutants on the longlist were categorised into three tiers of importance:

- Tier 1 pollutants of the highest priority;
- Tier 2 pollutants may potentially be important but less likely to be of concern;
- Tier 3 pollutants excluded from further investigation as part of this project.

In our assessment we have taken the NCC report findings into account under a systematic review of each of the "current" pollutants individually, and classified them following the categorisation matrix in Table 4. The matrix was developed based on existing regulations or environmental assessment levels. Expert judgement, based on the evidence in the above-mentioned databases, has been used to assign the categories, taking account of whether the groups of pollutants are of continuing concern or are showing continuing decline in concentrations. However, our priority is not only concerning whether emissions are reducing but also whether they are reaching safe limits for human health and the natural environment.

"Emerging" pollutants were categorised into Tier 1, 2 and 3 on a case-by-case basis using expert judgement and evidence found in the literature review.

Table 4: Categorisation process to classify "current" pollutants into Tier 1, Tier 2 and Excluded (Tier 3).

	Classification question	Yes	No
1	Is the pollutant included in the Clean Air Strategy 2019	Tier 1 pollutant	Go to next question

[10] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/933803/ncc-final-response-25yr-env-plan.pdf

[11] Andersson JT, Achten C. "Time to Say Goodbye to the 16 EPA PAHs? Toward an Up-to-Date Use of PACs for Environmental Purposes." Polycycl Aromat Compd. 2015 Mar 15;35(2-4):330-354

	Classification question	Yes	No
2	Is the pollutant included in Air Quality Standards Regulation 2010 or Air Quality Standards (NI) 2010	Tier 1 pollutant	Go to next question
3	Is pollutant in National Emissions Ceilings Regulation 2018	Tier 1 pollutant	Go to next question
4	Does Pollutant have an Environmental Assessment Level (Old EAL derivation method from EH40/2001 OEL)	Tier 2 pollutant	Go to next question
5	Does the pollutant have an Environmental Assessment Level (EPAQS Halogen and Hydrogen Halides (2006))	Tier 2 pollutant	Go to next question
6	Is the pollutant listed in Montreal Protocol?	Tier 3 (exclude from study)- pollutants are already dealt with	Go to next question
7	Is the pollutant listed in Annex I of the Environmental Quality Standards Directive (EQSD; Directive 2008/105/EC amended by Directive 2013/39/EU	Tier 2 pollutant	Go to next question
8	Is the pollutant a POP?	Tier 3 (exclude from study) due to green classification in NCC and already dealt with in National Implementation plan for the Stockholm Convention on Persistent Organic Pollutants	Go to next question
9	Has the pollutant been identified as compliant with the Air Quality Standards Regulation limit values since 2008[12]?	Tier 3 (exclude from the study) as pollutants have been compliant for nearly 15 years with limit values in the Air Quality Standard Regulations which transpose EU Directives 2008/50/EC and 2004/107/EC, designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole.	Review classification

Following the classification of the longlist, 10 pollutants were classified as Tier 1, 24 categorised as Tier 2, and 56 pollutants were categorised as Tier 3 and excluded from the shortlist. Amongst the excluded pollutants include persistent organic pollutants (POPs) which are listed in the Stockholm Convention, and ozone depleting pollutants listed in Montreal Protocol. These were excluded from further investigation as pollutants listed in the Montreal Protocol have been reduced and have existing controls in place in the form of binding, time targeted and measurable commitments. The POP's have been dealt with through the Stockholm Convention and the use of all pesticides and industrial chemicals listed in the convention has been banned in the UK for many years. The pollutants in these categories are very unlikely to require further intervention as concentrations have already been successfully reduced through existing controls and therefore were not considered further within this project.

[12] https://uk-air.defra.gov.uk/library/annualreport/assets/documents/annualreport/air_pollution_uk_2021_Compliance_Assessment_Summary_Issue1.pdf

The longlist of current and emerging pollutants are presented in Table 5 and Table 6 respectively, alongside the classified Tier for each pollutant, and the evidence and reasoning for the classification.

Table 5: Classification of current pollutants (according to the process set out in Table 4).

Name	Tier (1st, 2nd, excluded)	Evidence	Additional reasoning
Gases			
Ammonia (NH_3)	1st Tier	Included in the Clean Air Strategy 2019, included in the national emissions ceilings regulation 2018	
Carbon monoxide (CO)	Excluded	Included in the Air quality Standards regulation 2010	Has been in compliance with Air Quality Standards Regulation since 2008
Chlorine (Cl) and Inorganic compounds	2nd Tier	1-Hour mean 290 EPAQS Halogen and Hydrogen Halides (2006)	
Fluorine and inorganic compounds (HF)	2nd Tier	1-Hour mean 160 EPAQS Halogen and Hydrogen Halides (2006) monthly mean 16 EPAQS Addendum to Halogen and Hydrogen Halides (2009)	
Hydrogen cyanide (HCN)	2nd Tier	1 hour mean 220 Old EAL derivation method from EH40/2001 OEL	
Ozone (O_3)	1st Tier	Included in Air Quality Standards 2010	
Heavy Metals			
Arsenic (As)	1st Tier	Included in Air Quality Standards 2010	
Beryllium (Be)	2nd Tier	0.002 EPAQS Metals and Metalloids (2009)	
Cadmium (Cd)	1st Tier	Included in Air Quality Standards 2010	
Cobalt (Co)	Excluded	Not found in any of the searched regulations	Limited range of sources[13]; no air quality guideline specified by Environment Agency[14]
Chromium (Cr)	2nd Tier	1 hour mean 150, annual mean 5 Old EAL derivation method from EH40/2001 OEL	
Copper (Cu)	2nd Tier	1 hour mean 200, annual mean 10 Old EAL derivation method from EH40/2001 OEL	
Iron (Fe)	Excluded	Not found in any of the searched regulations	Extremely common and widely used metal; non-toxic at levels generally observed in the environment.
Lead (Pb)	Excluded	Included in Air Quality Standards 2010	Historical pollutant associated with leaded fuels. Can be excluded from further evaluation

[13] https://www2.bgs.ac.uk/mineralsuk/download/cmp/cobalt.pdf
[14] https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit

Name	Tier (1st, 2nd, excluded)	Evidence	Additional reasoning
Manganese (Mn)	2nd Tier	1 hour mean 1500, annual mean 0.15 Old EAL derivation method from EH40/2001 OEL	Retained due to low annual mean guideline
Mercury (Hg)	Excluded	1 hour mean 7.5, annual mean 0.25 Old EAL derivation method from EH40/2001 OEL	Main sources are coal mining- only 2 coal fields in NI
Nickel (Ni)	1st Tier	Included in Air Quality Standards 2010	
Platinum (Pt)	Excluded	Not found in any of the searched regulations	Limited range of sources; no air quality guideline specified by Environment Agency[15]
Selenium (Se)	2nd Tier	1 hour mean 30, annual mean 1 Old EAL derivation method from EH40/2001 OEL	
Tin (Sn)	Excluded	Not found in any of the searched regulations	No air quality guideline specified by Environment Agency[16]
Vanadium (V)	2nd Tier	WHO AQ guideline for Europe- Increased use for Electric vehicles and found possibly in NI	
Zinc (Zn)	Excluded	Zinc Oxide 1 hour mean 1000, annual mean 50 Old EAL derivation method from EH40/2001 OEL	Extremely common and widely used metal; low toxicity
Greenhouse gases			
Carbon dioxide (CO_2)	Excluded	Included in Air Quality Strategy 2010	Exclude as widely studied and considered elsewhere; low toxicity
Hydrofluorocarbons (HFC)	Excluded	HFC added to the Montreal protocol	Exclude as widely studied and considered elsewhere; low toxicity
Methane (CH4)	Excluded	Included in Air Quality Strategy 2010	Exclude as widely studied and considered elsewhere; low toxicity
Perfluorocarbon (PFC)	2nd Tier	Not found in any of the searched regulations	There are reported links to health effects.[17]
Sulphur hexafluoride (SF_6)	2nd Tier	1 hour mean 759,000, annual mean 60,700 Old EAL derivation method from EH40/2001 OEL	
Nitrogen trifluoride (NF_3)	2nd Tier	Not found in any of the searched regulations	There are reported health effects so was included as Tier 2 pollutant[18].
Nitrous oxide (N_2O)	Excluded	Included in Air Quality Strategy 2010	Exclude as widely studied and considered elsewhere; low toxicity at environmental exposures
Ozone depleting substances			
Carbon tetrachloride (CCl_4)	Excluded	Montreal protocol	Exclude as already effectively controlled under Montreal Protocol; low toxicity

[15] https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit
[16] https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit
[17] https://www.atsdr.cdc.gov/sites/pease/documents/perflourinated_chemicals_508.pdf
[18] https://www.cdc.gov/niosh/npg/npgd0455.html

Name	Tier (1st, 2nd, excluded)	Evidence	Additional reasoning
Chlorofluorocarbons (CFC)	Excluded	Montreal protocol	Exclude as already effectively controlled under Montreal Protocol
Halons	Excluded	Montreal protocol	Exclude as already effectively controlled under Montreal Protocol
Hydrochlorofluorocarbons (HCFCs)	Excluded	Montreal protocol	Exclude as already effectively controlled under Montreal Protocol
Methyl Bromide (CH_3Br)	Excluded	Montreal protocol	Exclude as already effectively controlled under Montreal Protocol
Methyl chloroform ($C_2H_3Cl_3$)	Excluded	Montreal protocol	Exclude as already effectively controlled under Montreal Protocol
Non methane volatile organic compounds			
1,3 Butadiene	2nd Tier	Included in Air Quality Strategy 2007	Extensively studied and found to be low risk throughout the UK. As no absolutely safe levels can be specified in ambient air, this pollutant was included as a Tier 2 pollutant to check if further research was needed..
Benzene (C_6H_6)	Excluded	Included in Air Quality Standards 2010	Has been in compliance with Air Quality Standards Regulation since 2008
Non-methane volatile organic compounds (NMVOCs)	1st Tier	Included in Clean Air Strategy 2019 and included in the national emissions ceilings regulation 2018	
Formaldehyde*	2nd Tier	30 minute mean hour mean 200, annual mean 5 Old EAL derivation method from EH40/2001 OEL	
Toluene*	2nd Tier	1 hour mean 8,000, annual mean 1,910 Old EAL derivation method from EH40/2001 OEL	
Xylene*	2nd Tier	1 hour mean 66,200, annual mean 4,410 Old EAL derivation method from EH40/2001 OEL	
Propane*	Excluded	Not found in any of the searched regulations	Exclude because non-toxic; no air quality guideline specified by Environment Agency[19]
Butane*	Excluded	1 hour mean 181,000, annual mean 14,500 Old EAL derivation method from EH40/2001 OEL	Exclude because of low toxicity
Poly aromatic Hydrocarbons (PAH)			
Acenaphthene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis
Acenaphthylene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those

[19] https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit

Name	Tier (1st, 2nd, excluded)	Evidence	Additional reasoning
			identified for PAHs included in the analysis
Anthracene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis
Benzo (a)anthracene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis
Benzo[a]pyrene (B[a]P)	1st Tier	Included in Air Quality Standards 2010	
Benzo (b)fluoranthene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis
Benzo(g,h,i)perylene	2nd Tier	Annex I of the Environmental Quality Standards Directive (EQSD; Directive 2008/105/EC amended by Directive 2013/39/EU EA consult	
Benzo (k)fluoranthene	2nd Tier	Annex I of the Environmental Quality Standards Directive (EQSD; Directive 2008/105/EC amended by Directive 2013/39/EU EA consult	
Chrysene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis
Dibenz[ah] anthracene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis
Fluoranthene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis
Fluorene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis
Indeno[123-cd]pyrene	2nd Tier	Annex I of the Environmental Quality Standards Directive (EQSD; Directive 2008/105/EC amended by Directive 2013/39/EU EA consult	
Naphthalene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis
Phenanthrene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis
Pyrene	Excluded	Not found in any of the searched regulations	No new sources or risks over and above those identified for PAHs included in the analysis

Name	Tier (1st, 2nd, excluded)	Evidence	Additional reasoning
Oxy-PAHs*	Excluded	Not found in any of the searched regulations	Little information available; may add to overall toxicity of PAHs, but no new issues expected over and above those identified for PAHs included in the analysis
Me-PAHs (methylated) *	Excluded	Not found in any of the searched regulations	Little information available; may add to overall toxicity of PAHs, but no new issues expected over and above those identified for PAHs included in the analysis
Alkyl-PAHs (alkylated) *	Excluded	Not found in any of the searched regulations	Little information available; may add to overall toxicity of PAHs, but no new issues expected over and above those identified for PAHs included in the analysis
Particulate matter			
$PM_{2.5}$	1st Tier	Included in Clean Air Strategy 2019 and Air Quality Standards 2010	
PM_{10}	2nd Tier	Included in Air Quality Standards 2010	Sources similar to $PM_{2.5}$. $PM_{2.5}$ accounts for the majority of adverse impacts associated with fine particulate matter
Acid gases			
Hydrogen chloride (HCl)	2nd Tier	1-Hour mean 750 EPAQS Halogen and Hydrogen Halides (2006)	
Hydrogen Fluoride (HF)	2nd Tier	1-Hour mean 160 EPAQS Halogen and Hydrogen Halides (2006) monthly mean 16 EPAQS Addendum to Halogen and Hydrogen Halides (2009)	
Nitric oxide (NO)	2nd Tier	1 hour mean 1,000, annual mean 52 Old EAL derivation method from EH40/2001 OEL	Include jointly with nitrogen dioxide
Nitrogen dioxide (NO_2)	1st Tier	Included in Clean Air Strategy 2019 and Air Quality Standards 2010	
Sulphur dioxide (SO_2)	2nd Tier	Included in Clean Air Strategy 2019 and Air Quality Standards 2010	Extensively studied and no significant areas of exceedance in England or NI
Persistent organic pollutants			
Dieldrin	Excluded	Included in National Implementation Plan – Annex A (P)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Dioxins and furans polychlorinated-p-dioxins(PCDDs) polychlorinated-p-dioxins(PCDDs)	1st Tier	Included in National Implementation Plan – Annex C (U)	

Name	Tier (1st, 2nd, excluded)	Evidence	Additional reasoning
Polychlorinated dibenzofurans (PCDFs)			
Endrin	Excluded	Included in National Implementation Plan – Annex A (P)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
α,ß,γ Hexachloro-cyclohexane (HCH)	Excluded	Included in National Implementation Plan – Annex A (P)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Dioxin-like Polychlorinated biphenyls (PCBs)	Excluded	Included in National Implementation Plan – Annex A and C (I, U)	Airborne exposure pathways not likely to be significant. Systems in place to manage small residual reservoir of PCBs used as dielectric fluid in electrical equipment.
Endosulfan*	Excluded	Included in National Implementation Plan – Annex A (P)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Tetrabromodiphenyl ether*	Excluded	Included in National Implementation Plan – Annex A (I)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Perfluorooctane sulfonic acid*	Excluded	Included in National Implementation Plan – Annex B (I, P)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
DDT*	Excluded	Included in National Implementation Plan – Annex B (P)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Chlordane*	Excluded	Included in National Implementation Plan – Annex A (P)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Hexachlorobenzene (HCB) *	Excluded	Included in National Implementation Plan – Annex A and C (P, I)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Chlordecone*	Excluded	Included in National Implementation Plan – Annex A (P)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Aldrin*	Excluded	Included in National Implementation Plan – Annex A (P)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Pentachlorobenzene*	Excluded	Included in National Implementation Plan – Annex A and C (P, I, U)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Mirex*	Excluded	Included in National Implementation Plan – Annex A (P)	Airborne exposure pathways not likely to be significant. Usage severely restricted in the UK

Name	Tier (1st, 2nd, excluded)	Evidence	Additional reasoning
Toxaphene*	Excluded	Included in National Implementation Plan – Annex A (P)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Hexabromobiphenyl*	Excluded	Included in National Implementation Plan – Annex A (I)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Hexabromo-cyclododecane (HBCD) *	Excluded	Included in National Implementation Plan – Annex A (I)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Polychlorinated naphthalene*	Excluded	Included in National Implementation Plan – Annex A and C (I, U)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Hexachlorobutadiene*	Excluded	Included in National Implementation Plan – Annex A and C (P, I)	Airborne exposure pathways not likely to be significant. Usage banned in the UK
Alkanes C10 – C13, chloro(short-chain chlorinated paraffins)*	Excluded	Included in National Implementation Plan – Annex A (I)	Airborne exposure pathways not likely to be significant. Usage banned in the UK

*Note *: not included in the Natural Capital Committee's (NCC) report[20]*
National Implementation Plan nomenclature
Annex A = Elimination; Annex B: = Restriction; Annex C = Unintentionally produced
Category (in brackets): P: Pesticide; I: Industrial chemical; U: Unintentionally produced

Table 6: Classification of emerging pollutants (on a case-by-case basis, based on gathered evidence and expert judgement).

Emerging Pollutants	Priority	Evidence
Elemental carbon (EC)	2nd Tier	Air quality impacts addressed via consideration of $PM_{2.5}$.
Organic carbon (OC)	2nd Tier	Air quality impacts addressed via consideration of $PM_{2.5}$.
Total carbon (TC)	2nd Tier	Air quality impacts addressed via consideration of $PM_{2.5}$.
Black carbon (BC)	1st Tier	Interactions with climate change
NitroPAHs (nPAH)	Excluded	Existing knowledge is rudimentary, and nitro-PAHs have substantially lower concentrations than their parent PAHs.[21]
Levoglucosan	Excluded	Component of bioaerosols
Brown carbon (BrC)	2nd Tier	Air quality Impacts addressed via consideration of $PM_{2.5}$ and black carbon.
Ultrafine particles (UFP)	1st Tier	Emerging evidence base[22], UFP may contribute to the toxicity of particulate matter but the magnitude of contribution is unclear, they may also be harmful to health but the available evidence is limited so should be included
Bioaerosols	2nd Tier	Established evidence base but limited range of sources and impacts; overlap with $PM_{2.5}$ assessment

[20] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/933803/ncc-final-response-25yr-env-plan.pdf
[21] https://aaqr.org/articles/aaqr-22-04-ir-0164
[22] https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1807261113_180703_UFP_Report_FINAL_for_publication.pdf

Acrylonitrile	Excluded	Not aware of evidence for significant new impacts – can be kept under review
Chloroform	Excluded	Not aware of evidence for significant new impacts – can be kept under review
Dichloromethane (DCM)	Excluded	Not aware of evidence for significant new impacts – can be kept under review
Ethylene Oxides	Excluded	Not aware of evidence for significant new impacts – can be kept under review
1-4-Dioxane	Excluded	Not aware of evidence for significant new impacts – can be kept under review
Trichloroethylene	Excluded	Not aware of evidence for significant new impacts – can be kept under review
Micro- and nano- plastics	2nd Tier	Component of $PM_{2.5}$
2,2',4,4',5-Pentabromodiphenyl ether (BDE-99)	Excluded	Included in POPs National Implementation Plan – Annex A; impacts therefore under control and expected to decline
Short-chained chlorinated paraffins (SCCP)	Excluded	Included in POPs National Implementation Plan – Annex A; impacts therefore under control and expected to decline

2.2.2 Short list of pollutants and pollutant factsheets

2.2.2.1 Summary of the shortlist

Following classification of the longlisted current and emerging pollutants, a shortlist of 10 Tier 1 pollutants and 24 Tier 2 pollutants was produced for further assessment. Tier 1 and Tier 2 pollutants are summarised in Table 7.

Table 7: List of Tier 1 and Tier 2 pollutants, with pollutant description and key sources.

Pollutant names	Description	Key Sources
1st Tier pollutants		
Ammonia (NH_3)	A colourless, strong-smelling gas, which can react in the atmosphere to produce particulate matter.	Agriculture, use of nitrogen-based fertilisers and from livestock farming, particularly cattle.
Arsenic (As)	Arsenic is mainly found in minerals, which is highly toxic in its inorganic form. Inorganic arsenic is naturally occurring, found in water, air and soil, and widely distributed in the Earth's crust, while organic arsenic is found in fish. Human activities further distribute arsenic in the environment.	Open burning of treated wood, iron and steel production.
Benzo[a]pyrene (B[a]P)	B[a]P, is a PAH, which comprise a large group of compounds consisting of hydrocarbons containing two or more benzene rings fused together or to other hydrocarbon rings. They can occur naturally or are formed during incomplete combustion.	Fuel combustion, largely domestic.
Black carbon (BC) (also known as elemental carbon (EC)	A type of particulate matter composed mostly of carbon formed through incomplete combustion processes. It is defined by the way the presence of carbon is measured - an optical measurement of the extent of light absorption by samples.	Fuel combustion activities, biomass combustion, particularly industrial, industrial off-road mobile machinery, municipal waste incineration.
Cadmium (Cd)	A silvery-blue malleable metal, naturally occurring in zine ores in the Earth's crust. Cadmium is a by-product of zinc refining.	Combustion in the manufacturing industry and production processes.

Pollutant names	Description	Key Sources
Nickel (Ni)	A metal that is hard and resists corrosion at high temperatures, making it useful for producing alloys such as stainless steel. Occurs naturally in the environment, through minerals.	Combustion of petroleum coke, solid smokeless fuels containing petroleum coke, and heavy fuel oil, mainly by the residential sector but also by industry.
Nitrogen dioxide (NO_2)	A gaseous compound that can have secondary impacts in its decomposed form (NO). NO_2 and NO can quickly interchange between forms at high temperatures and are referred to collectively as NOx.	Road and other transport (rail, shipping and mobile machinery). Power stations and other energy generation and other industrial sites.
Non-methane volatile organic compounds (NMVOCs)	A broad class of organic chemicals that can sometimes be directly harmful, but more generally act as precursors to the formation of ozone and particulate matter (PM).	Solvent and other product use, agriculture/waste/accidental fires, production processes, extraction and distribution of fossil fuels.
Ozone (O_3)	Generally not emitted directly to the atmosphere but formed in the atmosphere due to interactions between oxides of nitrogen (NOx), volatile organic compounds (VOC), and solar radiation.	Global emissions of methane, NOx and VOC (from energy waste and agriculture sectors).
$PM_{2.5}$	$PM_{2.5}$ refers to particles less than 2.5 micrometres (μm) in diameter. It consists of both primary components, which are emitted directly into the atmosphere, and secondary components, which are formed within the atmosphere as a result of chemical reactions.	Combustion (industry/commercial/residential), production processes and road transport.
Ultrafine particles	Ultrafine particles (UFP) are defined as particles with one dimension less than 100 nanometres. They are therefore the smallest group of particles in the atmosphere and comprise a minor component of $PM_{2.5}$ and PM_{10}. It is typical for >90% of the number of particles in the air to be UFP, but as they have very little mass, the contribution of UFP to the mass of particles in the air is very small.	Industrial, commercial and residential combustion, production processes, and road transport.
2nd Tier Pollutants		

Pollutant names	Description	Key Sources
1,3 Butadiene	A chemical made from the processing of petroleum; 1,3 butadiene is a non-methane volatile organic compound (NMVOCs).	Vehicle exhaust emissions, incomplete combustion of biomass, cigarette smoke.
Benzo(g,h,i)perylene	Benzo(g,h,i)perylene is a PAH, which comprise a large group of compounds consisting of hydrocarbons containing two or more benzene rings fused together or to other hydrocarbon rings. They can occur naturally, but are also formed during incomplete combustion.	Fuel combustion, largely domestic.
Benzo(k)fluoranthene	Benzo(k)fluoranthene is a PAH, which comprise a large group of compounds consisting of hydrocarbons containing two or more benzene rings fused together or to other hydrocarbon rings. They occur naturally or are formed during incomplete combustion.	Fuel combustion, largely domestic.
Beryllium (Be)	An important industrial metal because of its unusual material properties: it is lighter than aluminium and six times stronger than steel. Beryllium compounds can be found in mineral rocks, soil, coal and volcanic dust.	Refineries, road traffic, domestic combustion, power stations and waste incinerators.
Bioaerosols	Although no formal definition exists, Bioaerosols are generally accepted as particles within the 0.1 – 100 micrometre (µm) range that originate from plant and animal life, including pollen and pathogens.	Agricultural and waste management activities.
Brown carbon	Organic compounds that are essentially non-volatile and the light that passes through is reddish orange, or brown. Unlike black carbon, brown carbon can be semi-volatile, and it can either consist of primary material, often from the same combustion sources producing black carbon, or it can be produced via atmospheric chemistry as secondary brown carbon.	Primary emissions from combustion activities, often from the same as black carbon.

Pollutant names	Description	Key Sources
Chlorine (Cl) and Inorganic compounds	A reactive gas with a characteristic odour similar to bleach. Part of the group of chemicals called 'halogens'. Also present in inorganic chloride compounds normally present in particulate matter.	Accidental releases during manufacture and use as an industrial chemical and as a water disinfectant.
Chromium (Cr)	Chromium exists in two main forms chromium (III) and chromium (VI) and occurs naturally in the Earth's crust, predominately as, chromium (III), form. It is ubiquitous in air, water, soil and biological materials.	Manufacturing, combustion of coal and oil, cement works and waste incineration.
Copper (Cu)	A metallic element found naturally in rocks, water, soils, and air. It is an essential nutrient to plants, animals, and humans, and is found in many foods.	Lubricants for road engine vehicles, and vehicle brake pad wear.
Dioxins and furans	A family of chemicals with a shared molecular structure of aromatic carbons bonded with oxygen and chlorine atoms. 30 have been identified as particularly hazardous to humans and the natural environment and were listed as a Persistent Organic Pollutant (POP).	Open burning of waste, accidental fires and bonfire night, residential combustion emissions, industrial combustion.
Fluorine and inorganic compounds (HF)	Elemental fluorine is extremely reactive with only small amounts found in nature. HF (Hydrogen Fluoride) is a highly reactive fluorine compound used for industrial purposes, and gaseous HF combines readily with water to form hydrofluoric acid.	Fuel combustion, mineral products.
Formaldehyde	An organic compound and the simplest, smallest member of the aldehyde group of organic chemicals. It is a widely used chemical. It is a main precursor to many other chemical compounds, especially polymers.	Industrial processes, household products, agriculture, domestic burning and transport (NMVOCs as a whole).
Hydrogen cyanide (HCN)	A chemical compound and highly toxic acid historically used as a poison and a chemical weapon. It is also naturally present in plants.	Used in manufacturing of chemicals and released as a by-product when burning nitrogen-containing compounds.

Pollutant names	Description	Key Sources
Hydrogen chloride (HCl)	At room temperature a colourless to slightly yellow, corrosive, non-flammable gas that is heavier than air and produces a strong irritating odour. When hydrogen chloride gas comes in contact with water vapour in the air, it produces white fumes of hydrochloric acid.	Combustion of coal and solid fuels, other industrial combustion, and burning of biomass and waste for heat and power.
Indeno[123-cd]pyrene	Indeno[123-cd]pyrene is a PAH, which comprise a large group of compounds consisting of hydrocarbons containing two or more benzene rings fused together or to other hydrocarbon rings. They occur naturally or are formed during incomplete combustion.	Combustion of coal and oil and vehicle exhaust.
Manganese	An abundant elemental metal that does not exist naturally in its pure form, but rather is found as a component in many minerals. It is also an essential nutrient, and a certain level of intake is necessary for good health.	Used in fertiliser, fungicide and livestock feed.
Micro- and nano- plastics	Micro-plastics are solid plastic particles typically less than 5 mm in size, nano-plastics range from 1 to 100 nm. Both are composed of mixtures of polymers and functional additives.	Degradation of plastic waste, plastic production, vehicle tyre wear.
Nitric oxide (NO)	Nitric oxide (NO) is a colourless, non-combustible gas, consisting of one nitrogen and one oxygen atom. It represents the dominant portion of nitrogen oxides (NOx) and can react with other gases to form NO_2.	Road and other transport (rail, shipping and mobile machinery), particularly diesel emissions. power stations and other energy generation and other industrial sites.
Nitrogen trifluoride (NF_3)	Nitrogen trifluoride (NF_3) is a compound comprising of one nitrogen atom attached to three fluorine atoms and is widely used in the electronics industry as an etching agent.	Semiconductor industry and manufacturing.
Organic carbon (OC)	Organic carbon (OC) is a term that includes brown carbon and is defined as all carbonaceous components in PM apart from black carbon (or elemental carbon). It includes primary carbon released from sources directly, and secondary formed through atmospheric reactions.	The sources of different components of OC are extremely variable. See sources of B[a]P and NMVOCs.

Pollutant names	Description	Key Sources
Perfluorocarbon (PFC)	Per- and polyfluorinated compounds (PFCs) are substances that contain compounds comprising of a carbon and fluorine (CF) bonded structure. The CF bonds are chemically, biologically and thermally stable, and result in desirable properties for products designed for long-term use. Some sub-groups of PFCs have been listed as Persistent Organic Pollutants (POPs).	Chemical industry, and other production manufacture and use.
PM_{10}	PM_{10} refers to particles less than 10 micrometres (μm) in diameter. It consists of both primary components, which are emitted directly into the atmosphere, and secondary components, which are formed within the atmosphere as a result of chemical reactions.	Production processes, combustion in industry/commercial and residential, agriculture/waste and road transport.
Selenium (Se)	A naturally occurring substance that is toxic at high concentrations but is also a nutritionally essential element.	Combustion of coal and petroleum fuels, refining and smelting of metals, waste incinerators.
Sulphur dioxide (SO_2)	A colourless gas with a strong odour. It can also contribute to the build-up of particulate matter.	Fossil fuel combustion, industrial processes, transport, volcanic eruptions.
Sulphur hexafluoride (SF_6)	Sulphur hexafluoride (SF_6) is a chemical compound comprising of one sulphur atom bonded to six fluorine atoms.	Metal production, and other product manufacture and use.
Toluene	Toluene is an aromatic hydrocarbon, and a NMVOC.	Solvent production and gasoline evaporation.
Total carbon (TC)	Total carbon is a term that refers to all carbonaceous components within Particulate Matter (PM), that is, the sum of black carbon/elemental carbon, brown carbon and organic carbon.	See sources of black carbon, B[a]P and NMVOCs.

Pollutant names	Description	Key Sources
Vanadium (V)	A bright white ductile metal belonging to the transition metals. Found in many different minerals and can become adsorbed to particulate matter.	Industrial sources, especially oil refineries and power plants using vanadium-rich fuel.
Xylene	Xylene is an aromatic hydrocarbon, and a NMVOC	Solvent production and gasoline evaporation.

2.2.2.2 Pollutant factsheets

Informed by the literature and data search (summarised in Section 2.1), factsheets were compiled for each shortlisted pollutant, starting with the Tier 1 pollutants, followed by Tier 2, The formats and content covered in the factsheets was agreed in discussion with OEP.

Factsheets for each pollutant can be found in Appendix 1. They cover the following content:

- Description of pollutant and impacts to human health and the natural environment.
- Summary of compliance and current level of action.
- Relevant legislation, standards, benchmarking against other relevant standards, and assessment methods.
- Sources, including any notable changes in sources over time.
- Summary of relevant plans and strategies
- Descriptions of urban versus rural trends, relationships with other pollutants, effect on ozone and photochemical smog, and climate interactions.

2.3 AIR POLLUTION RISK ASSESSMENT METHODOLOGY (TASK 3)

To assess the level of risk that air pollutants pose to public health and the environment various parameters were considered:

1. Current levels of concentrations compared to legislative standards
2. The level of harm attributed to individual pollutants as exposure to some pollutants are more harmful than others
3. The potential future risk posed by pollutant levels i.e. are concentrations declining or increasing?
4. How strong is the evidence to support the risk assessment, which is particularly important for emerging pollutants where there may be evidence gaps and further research needs.

These parameters were assessed for each pollutant against criteria presented in five tables.

Evidence used to score each pollutant was obtained from the literature and data search (summarised in Section 2.1).

2.3.1 Scoring for current risk

A score is given with regards to the “Ambient concentrations compared to air quality standards” in each risk assessment. Scoring was informed by the data on current pollutant concentrations or emissions and relevant limits and standards. This evidence is summarised in the risk scoring table. The scoring categories were as follows:

Low	**Moderate**	**High**	**Very high**	**No evidence of concentration**
Below limit value	1-5% above	5-10% above	>10% above	

A score was also given with regards to the “Hazard of pollutant on human health and environment” in each risk assessment. Scoring was informed by the evidence and information as collated in the Air Quality Stocktake factsheets from table rows “**Impact on human health**” and “**Impact on nature conservation**”, and this evidence was summarised in the table for each pollutant. In relation to “harmful” and “dangerous to health” score categories, it was recognised that some pollutants may be very harmful but exposure in concentrations that are likely to cause harm is unlikely. The evidence provided in the table highlighted where this was the case, but pollutants were categorised in this table on the basis of the magnitude of impact rather than the likelihood of occurrence.

The scoring categories for hazard on health and environment were as follows:

Minimal or none	**Harmful** Exposure could cause health problems	**Dangerous to health** Exposure may cause acute health problems	**Very Dangerous to health** Could cause long term health problems or death if exposed to for long periods	**No evidence of health impacts of pollutant**

2.3.2 Scoring for potential future risk

A score was given with regards to potential future risk in each risk assessment. The score was determined using projections data for future concentrations or emissions of pollutants, where available.

Evidence and supporting information were also provided in the future risk score table for each pollutant. Where evidence was available for future projections scoring was based on this and comparison to NECD commitments. For a large number of pollutants only historical emission trends were available, these trends with knowledge on likely future changes in emission sources were combined to provide expert judgement on likely potential future risks.

The score categories for potential future risk were as follows:

Improvement Decrease by more than 10%	**No Change** Remain the same (+/- 10%)	**Deterioration** Increase 10-20%	**Significant Deterioration** Increase by greater than >20%

2.3.3 Scoring for quality of evidence

A score was given to describe the quality of evidence in each risk assessment. If the quality of different pieces of evidence was determined to be of varying quality each main piece of evidence was categorised separately (e.g. Black carbon has a quantitative forecast for emission estimates, and extensive evidence of health effects in peer reviewed literature, which is “very good evidence”, but was also rated “moderate” in terms of the quality of evidence of measurements data, as there are only 14 monitoring sites in the UK).

Where the information was long standing and available on government or agency websites this was classified as good, and very good where the evidence base included a quantitative emissions or concentrations forecast, measured pollutant data, and evidence from peer reviewed publications.

A score of “Poor” was applicable for evidence from unpublished reports or very little evidence. The overall score for quality of evidence was entered directly into the summary table (Section 2.3.4).

The score categories for quality of evidence were as follows:

Very good Quantitative forecast used to support UK government report/ measured data or peer reviewed publication	**Good** International agency/independent NGO report/ indirect evidence	**Moderate** Professional opinion supported by limited evidence	**Poor** Opinion/ speculation/ Unpublished report or provenance unclear	**No score, but: “Quality of Evidence” 0** No environmental standard or no guideline

In some cases multiple scores, were given for quality of evidence. This approach was considered suitable because of the breadth covered in this category. A pollutant might have very good evidence regarding the health and environmental impacts of a pollutant, but limited information on current concentration and emission levels due to a lack of monitoring.

In the cases where two scores where given, it was still necessary to determine an overall score for quality of evidence in the summary score (discussed in Section 2.3.4 below). These cases were dealt with in three ways:

1. Evidence for criteria under multiple scores was considered imbalanced – criteria which merited one score outweighed the other score, based on expert judgement of the importance of the criteria. The score which represented the more important criteria was taken as the overall score for quality of evidence. For example, NO_2 was "poor" on one point – that the extent of health impacts are uncertain due to it being difficult to distinguish between effects of NO_2 and PM_{10}. But NO_2 was "very good" in terms of quality evidence for monitoring, emissions estimates and projections data, and other aspects of evidence of health impacts. NO_2 was judged overall as "very good" for quality of evidence as the evidence for monitoring, emissions and other aspects of health evidence outweighed the poor evidence in just one aspect of evidence of health impacts.
2. Evidence for criteria under multiple scores was considered balanced, and a median score could be taken, i.e. balanced criteria for "very good" and "moderate" would result in an overall "good" score, or balanced criteria for "good" and "poor" would result in an overall "moderate" score. For example, the evidence for monitoring and emissions estimates of NMVOCs was "very good", but research on health impacts was "moderate". These areas were considered to be of equal importance, so a score of "good" was given for overall quality of evidence.
3. A combination of 1 and 2. For example, brown carbon scored "very good" for evidence relating to monitoring and emissions estimates of PAHs - a key component of brown carbon, but "poor" for evidence relating to understanding of the pollutant's constituents. The poor understanding of the pollutant's constituents was judged to be more important than the monitoring and emissions estimates of one of its constituents. But the poor evidence was not considered by expert judgement to be so much more significant than the very good evidence than an overall "poor" score was considered suitable. The overall score for quality of evidence was judged to be "moderate" - leaning more towards poor than very good, due to the greater importance of the poor evidence.

2.3.4 Summary of scoring "Overall evidence" tables

Summary tables were created from the evidence collected in the sub-tables described above and are presented at the start of each pollutant risk assessment. A risk assessment moderation exercise was carried out by two independent assessors to review all risk categories applied to each pollutant. This moderation determined that the relative assessments were applicable and the overall quality of the risk assessment was appropriate. The current risk rating is generated from combined risk of "Ambient concentrations compared to air quality standards " and "Hazard of pollutant on human health and environment ". The overall risk rating is based on expert judgement based on the evidence collected and is not based on all three columns, current risk, potential future risk and quality of evidence, having an equal rating.

Air Pollutant	Current risk	Potential future risk	Quality of the evidence	Overall risk rating
Key	Low Moderate High Very high	Improvement No change Deterioration Significant deterioration	Very good Good Moderate Poor	Low Moderate High Very high

2.4 DELIVERY MECHANISM REVIEW METHODOLOGY (TASK 4)

2.4.1 Identification of delivery mechanisms and source sectors.

This section of the project focused on the following pollutants:

1. Pollutants ranked as 'very high' or 'high' for overall risk in the risk assessments (ammonia (NH_3), nitrogen dioxide (NO_2), black/elemental carbon, $PM_{2.5}$, ultrafine particles, bioaerosols, chromium VI,

benzo(G,H,I)perylene, Benzo(K)Fluoranthene, brown carbon, Indeno[123-cd]pyrene, nitric oxide (NO), total carbon)

2. Defra's five key pollutants in the Clean Air Strategy (nitrogen dioxide (NO_2), sulphur dioxide (SO_2), NMVOCs, $PM_{2.5}$, ammonia (NH_3))
3. Pollutants which are non-compliant with the Air Quality Standards Regulations from Defra's most recent "Air pollution in the UK 2021" report – nitrogen dioxide (NO_2), ozone (O_3), nickle (Ni) and B[a]P.
4. Pollutants with a 'deterioration'/'significant deterioration' in the 'potential future risk' category of the risk assessments – $PM_{2.5}$ and bioaerosols.

2.4.2 Source apportionment

Information regarding source apportionment of the above pollutants in the UK was collated as part of the literature and data search (summarised in Section 2.1). Source apportionment was presented quantitatively for NO_2, NH_3, PM_{10}, $PM_{2.5}$, SO_2, VOC, benzo[a]pyrene and dioxins, sourced from the NAEI. The source apportionment for some of the pollutants (chromium VI, benzo(G,H,I)perylene, benzo(K)fluoranthene, brown carbon, total carbon, black carbon, bioaerosols, Indeno[123-cd]pyrene, NO) are not available from the NAEI. Nevertheless, as they are sub-components of other pollutants, a qualitative assessment of their potential improvement was carried out based on expert judgement and information on the pollutant matrix (typically $PM_{2.5}$).

2.4.3 Delivery mechanisms

Delivery mechanisms for reducing emissions of pollutants were also collated as part of the literature and data search (summarised in Section 2.1). Defra's Air Quality Emissions Scenario Modelling Tool (SMT) was a key resource, which provided a comprehensive list of mitigation measures. The SMT is a web-based tool designed to allow policy makers and air quality modellers to investigate the likely impacts of different policy scenarios on emissions of NH_3, NOx, $PM_{2.5}$, SO_2, VOCs and greenhouse gases. In creating the SMT tool, a comprehensive review was carried out to identify all potentially relevant/quantifiable options for mitigation of the relevant pollutants. The tool includes a suitable range of measures for all source sectors, with the exception of agriculture. Measures relating to the agriculture sector have therefore been taken from other sources.

The delivery mechanisms were developed by categorising similar measures within a source sector into a delivery mechanism, based on how they deliver air quality improvements. For example, the delivery mechanism OEP 1 includes the group of measures to "Improve vehicle fleet with sustainable and low emission vehicles" within the "Road Transport" source sector and this includes measures such as

- Road to zero - replace vehicles with sustainable transport i.e., PHEV, FHEV, electric, alternative fuels
- Scrappage scheme for LGVs
- Implementing Euro 6 or VI emissions standard for vehicles
- Use of sealed wet brake retrofit (buses)
- Adoption of low PM tyre
- Application of Diesel Particulate Filter.

The source sectors considered above have been established, following the European Environment Agency Air Pollutant Emissions Inventory Guidebook[23].

2.4.4 Assessment of delivery mechanisms or measures

Research was undertaken to determine the effectiveness of measures within the delivery mechanism to improve specific pollutants. This research revealed a PHE[24,25] study which had been undertaken to determine

[23] https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

[24] Public Health England, 2019, Annexe 8: Evaluating interventions
https://app.box.com/s/kt5m8gugipky7lif3xyskjjwf3o5s1m6/file/415286781138

[25] Public Health England, 2019, Principal interventions for LAs: improving air quality and public health
Public Health England, 2019, Review of interventions to improve air quality
Public Health England, 2019, A4.1 REA3- Vehicles (IOM report)
Public Health England, 2019, A5.1 REA4 - Agriculture (IOM Report)

the potential scale of improvement (of pollutants), the reliability and certainty of deployment success, and the potential speed of deployment/effect for a range of measures using the criteria set out in Table 8.

Table 8: Assessment criteria of air quality improvement measures

Aspect	Low	Medium	High
Scale of air quality improvement associated with measure – "Potential scale of improvements"	Limited effectiveness - Evidence is available to show the measure will have a limited improvement in air quality	Potentially effective - Evidence and/or PHE opinion shows the measure has potential improvement in air quality	Fully effective - Evidence and/or PHE opinion shows the measure has a significant improvement in air quality
Deployment success – "Reliability and certainty of success"	Limited feasibility - Evidence and/or PHE opinion shows the intervention has limited feasibility with respect to implementation	Potentially feasible - Evidence and/or PHE opinion shows the intervention is potentially feasible to implement	Fully feasible - Evidence and/or PHE opinion shows the intervention will be feasible to implement
Deployment term – "Potential speed of deployment/effect"	Long (years+) - Evidence suggests that the intervention will take years or longer to have full effect	Medium (months/years) - Evidence and/or PHE opinion shows the intervention will take months/years to have full effect	Immediate to short-term - Evidence and/or PHE opinion shows the intervention will have an immediate effect, or an effect in the short-term

Most of the measures identified in the PHE study have been considered within the delivery mechanisms OEP1 to OEP24. These measures have also been categorised for their potential scale of improvement (of pollutants), the reliability and certainty of deployment success, and the potential speed of deployment/effect.

Using this information, the potential scale of improvement for each delivery mechanism has been identified based on the average 'scale of improvement' of each measure within the delivery mechanism. Similarly, the 'reliability and certainty of deployment success' for each delivery mechanism has been established based on the average 'reliability and certainty of deployment success' of each measure with the delivery mechanism. Lastly, the 'potential speed of deployment/effect' for each delivery mechanism has been established based on the average 'potential speed of deployment/effect' of each measure with the delivery mechanism. The full details are provided in Appendix 4.

In addition, the cost of implementing each delivery mechanism group has been assessed using professional judgement and information from the research documents. Where evidence remains sparse on these sectors or delivery mechanisms, this has been highlighted as unknown. It assumes that a measure that can be supported by public funding is more likely to be deployed (due to more resources) as opposed to private funding who would have limited funding.

Using the above information, the potential scale of improvement (of pollutants), the reliability and certainty of deployment success, and the potential speed of deployment/effect and cost of the delivery mechanisms have been simplified within this report using the following criteria in Table 9. In addition, a score of 1 - 3 was determined for each mitigation measure for their 'potential scale of improvement (of pollutants)', 'the reliability and certainty of deployment success', and 'the potential speed of deployment/effect' and cost. It should be noted that the criteria are similar to that by PHE except that a new category, (0 = no improvement or unknown) has been added. A score of 0 was given if the mitigation measure was not expected to have any improvement effect on a pollutant or where the 'reliability and certainty of deployment success', 'the potential speed of

Public Health England, 2019, A2.1 REA1 - Industry (Wood REPORT and Peer review)
Public Health England, 2019, A6.1 REA5 - Behaviour (IOM REPORT)
Public Health England, 2019, A3.1 REA2 - Planning (IOM REPORT)

deployment/effect' and 'cost' was unknown. The scoring in Table 9 has been used to also estimate the delivery assurance assessment.

Table 9: Scoring key for delivery assurance assessment

Aspect	Score			
Scale of improvement	0 = no improvement	1 = low improvement	2 = medium improvement	3 = high improvement
Reliability /certainty	0 = Unknown	**1 = Limited feasibility**	**2 = Potentially feasible**	**3 = Fully Feasible**
Speed of deployment	0 = Unknown	**1 = Long-term**	**2 = Medium-term**	**3 = Short-term**
Cost	0 = Unknown	**1 = Private only**	**2 = Public and private**	**3 = Public only**
Overall Deliverability		**Low (sum score 1-3)**	**Medium (sum score 4-6)**	**High (sum score 7-9)**

The delivery assurance assessment focused on the following aspects:

1. Reliability/certainty of successful implementation
2. Speed of deployment
3. Cost

A total score for overall deliverability was based on the total score of the three aspects as such where the maximum score of 9 was achieved would mean that the potential for delivery is "High".

2.5 CATALOGUE OF RECOMMENDATIONS AND COMMITMENTS METHODOLOGY (TASK 5)

The purpose of this task was to undertake a comprehensive literature review of government commitments and scrutiny body recommendations on tackling air pollution.

2.5.1 Literature search

Strategic searches were conducted for known relevant strategies, policies and other publications through expert knowledge as part of the literature, evidence and data search (summarised in Section 2.1). Publications for England and Northern Ireland have been the focus of our research, however in some instances, particularly UK-wide commitments, the focus has been on all nations. Publications from 2018 were focused on, with the exception of some cases, when documents remain current and have not been superseded, the most recent version has been included (e.g., The UK Air Quality Strategy, 2007). Additional searches for relevant publications and web pages were carried out from the following websites:

- UK government
- NI government
- Defra
- DAERA
- Environment Agency
- Natural England
- Joint Nature Conservation Committee (JNCC)
- The Air Quality Expert Group (AQEG)
- The Committee on the Medical Effects of Air Pollutants (COMEAP)

- National Audit Office
- Public Accounts Committee
- Climate Change Committee
- Environment Audit Committee
- All-Party Parliamentary Group on Air Pollution
- Courts and Tribunals Judiciary
- Client Earth
- Friends of the Earth

Additional searches were made via search boxes on the above listed websites, and by reviewing lists of publications on websites, using the following keywords as search terms:

"air quality", "emission", "emissions", "pollution", "environment", "climate change", "greenhouse"

Documents with measures or policies related to Greenhouse Gas Emissions (GHG) were also included in this review given the interlink between air pollution and climate change.

The catalogue of documents was managed using the open-source literature review software Zotero. The documents were compiled and categorised using the Zotero desktop app, which was also used to generate citations and bibliography through Microsoft Word.

2.5.2 Screening and review

Publications were then screened to establish whether they contained commitments and recommendations which impact air quality or GHGs, or elements that would indirectly impact air quality and/or climate change. Wider policies such as the Industrial Strategy which contain elements that would impact air quality and/or climate change indirectly have also been included.

The screened-in documents and publications were reviewed in detail, and commitments and recommendations from government bodies, agencies, and external scrutiny bodies were extracted as text quotes. Short summaries were written or extracted from publications to accompany the extracted commitments and recommendations.

Once the literature review was complete, a high-level analysis was carried out to establish key themes within government commitments and recommendations.

The commitments and recommendations have been organised by publication body (government, local authority, and scrutiny body) and date of publication overall. Government commitments are further categorised by six themes:

- Concentration reductions
- Emissions reductions
- Ecological protection
- Health protection
- Public communication
- Monitoring, review and assessment

Seven themes have also been drawn out from the review of scrutiny body recommendations:

- The delivery mechanism and timetable for better air quality
- Stronger linkages between air quality and public health protection
- Development on a framework to reduce nitrogen emission for habitat protection/restoration
- Clarity on the linkages between air quality and climate change policy
- Evidence of the impact of indoor air quality
- Improving public access to air quality information

- Clarity and transparency of how government undertake monitoring and evaluation of their policy commitments

Where recommendations and commitments directly related to specific policies or legislation, these relationships have been highlighted.

3. RISK ASSESSMENT OF POLLUTANTS

Current and emerging pollutants were assessed for current risk, potential future risk, and quality of evidence following the methodology outlined in Section 2.3. An overall risk rating was produced based on the assessment of the combined risk for each pollutant. The following Section 3.1 provides a summary of the pollutants categorised as very high risk, high risk, medium risk and low risk pollutants. For the very high risk and high risk pollutants the overall risk summary table has been included which provides more detail on the risks for each pollutants and reasoning for the classification. For the medium and low risk pollutants a list of the pollutants that fall into each of the categories has been provided and further detail of the classification can be found in the full risk assessments.

3.1 RISK ASSESSMENT SUMMARY

3.1.1 Very high risk pollutants

Two pollutants were classified as very high risk: $PM_{2.5}$ and ultrafine particles. Both of these pollutants were categorised as Tier 1: pollutants of the highest priority for the reasons set out in the risk assessment summaries in Table 10.

Table 10: Risk assessment summaries for very high-risk pollutants.

Air Pollutant	Current risk	Potential future risk	Quality of the evidence	Overall risk rating
$PM_{2.5}$ *Particulate matter (PM) is a term for particles found in the air including dust, dirt, smoke and liquid droplets, and therefore consists of a wide variety of chemical compounds and materials. $PM_{2.5}$ refers to particles with diameter less than 2.5 micrometres (μm).*	**VERY HIGH** A new concentration target of 10 µg/m^3 was proposed by DEFRA as well as a population exposure reduction target of 35% reduction in the population exposure metric compared to a 2018 baseline, and both to be met by 2040. The new concentration target is not currently met within the UK.	**DETERIORATION** The UK has emission reduction commitments (ERCs) for $PM_{2.5}$ under the 2018 NECR and the CLRTAP Gothenburg Protocol The ECR for 2020-2029 has been met (as assessed for 2025). The 2030 target for $PM_{2.5}$ is at risk of not being met. Emission trends are not sufficiently declining and the target of 65.66 kt is likely to be exceeded by 14.31 kt.	**VERY GOOD** There is a good evidence base for $PM_{2.5,}$ supported by a monitoring network and emission projections.	**VERY HIGH** The $PM_{2.5}$ emission and concentration trend are relatively stable from 2011 to 2020. However, with the expected exceedance of the ECR 2030 target and introduction of new stringent concentration targets, $PM_{2.5}$ emissions and concentrations will need to decrease at a faster pace to meet the new targets. Health effects of $PM_{2.5}$ are known to be dangerous and exposure to concentrations that may exceed new limit values will be more widespread than the current levels.
Ultrafine Particles (UFP) *Ultrafine particles (UFP) are defined as particles with one dimension less than 100 nanometres. They are therefore the smallest group of particles in the atmosphere and comprise a minor component of $PM_{2.5}$ and PM_{10}. It is typical for >90% of the number of particles in the air to be UFP, but as they have very little mass, the contribution of UFP to the mass of particles in the air is very small.*[26]	**VERY HIGH** Potentially hazardous substance to humans and the natural environment. There is large uncertainty because of data gaps.	**NO CHANGE** Emissions from industrial combustion, transport and agricultural waste have decreased since the 1990s. Unlikely to worsen significantly, following declining historical trend in emissions. Overall there is limited evidence to determine what future changes might be. However, there is potential future risk from emerging PM sources such as tyre and brake pads in electric vehicles. Policies and actions to control ambient PM will not always control ultrafine particles.	**GOOD** The UK Particle Counting Network measures UFP at three sites. Emission estimates are available from the NAEI, though not projections. Evidence for health effects of UFP is relatively scarce.	**VERY HIGH** Likely to be of high risk in areas of high exposure (roadside and industrial sites). Linked to levels of particulate matter (PM_{10} and $PM_{2.5}$)

[26] AQEG Ultrafine Particles in the UK, 2018, https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1807261113_180703_UFP_Report_FINAL_for_publication.pdf

$PM_{2.5}$ was classed as very high for current risk because the health effects of $PM_{2.5}$ are known to be dangerous. The number of attributable deaths to anthropogenic $PM_{2.5}$ was calculated by the Committee On the Medical Effects of Air Pollutants (COMEAP) to be 26,799 in England and Wales and 502 in Northern Ireland, during 2008[27]. The burden of total survival (life-years lost) in 2008, was 315,000 for England and Wales, and 6000 for Northern Ireland.[28] A new annual mean $PM_{2.5}$ concentration target of 10 µg/m^3 has been committed to by the UK government, as well as a population exposure reduction target of 35% reduction in the population exposure metric compared to a 2018 baseline, with both to be met by 2040. With the introduction of these new targets, emissions and concentrations will need to decrease at a faster pace to meet the new targets. The new WHO guideline for annual average concentrations of $PM_{2.5}$ is even more ambitious, at 5 µg/m^3. The UK is projected to meet its NECD target for 2025, but to exceed the 2030 target.[29]

Ultrafine particles were classed as very high for current risk because there are health concerns about UFP reaching deep into the lungs and a small fraction entering the circulatory system. UFP has been linked to serious and fatal health outcomes[30,31]. They are believed to contribute to the toxicity of airborne particulate matter, but the magnitude of their contribution is currently unclear. There is large uncertainty about the current level of risk. For example, UFP is only monitored at three sites in the UK[32, 33]. There are no standards for UFP, and policies and actions to control ambient PM will not always control UFP. Emissions are unlikely to worsen substantially, but there is potential future risk from sources such as tyre and brake wear in electric vehicles. Overall there is limited evidence to determine future risk.

3.1.2 High risk pollutants

11 pollutants were classified as high-risk. Three of these were categorised as Tier 1: pollutants of the highest priority. These are ammonia (NH_3), black/elemental carbon and nitrogen dioxide (NO_2). Eight were categorised as Tier 2 pollutants: may potentially be important but less likely to be of concern. These were benzo(G,H,I)perylene, benzo(k)fluoranthene, bioaerosols, brown carbon, chromium, indeno[123-cd]pyrene, nitric oxide (NO) and total carbon. Risk assessments summaries are presented in Ammonia was classed as high risk because concentrations are high in agricultural areas, it has adverse impacts on nature conservation sites, and it is a precursor to the very high risk pollutant $PM_{2.5}$. Nitrogen dioxide is classed as high risk because it is of high concern for human health and environment, and whilst concentrations are well monitored, decreasing, and subject to controls, evidence from the WHO indicates much lower standards are required to better protect human health. NO is classed as high risk as it is a precursor to NO_2, and also has a role in producing acid rain, photochemical smog and Greenhouse Gas N_2O.

Similarly to other high risk pollutants, Chromium VI is classed so because of its risk to human health and the natural environment. The metals monitoring network indicates high levels of exceedance of the Environment Agency EAL for air for Chromium close to industrial areas, urban centres and busy roads.

Finally, PAHs Benzo(G,H,I)Perylene, Benzo(k)fluoranthene and Indeno[123-cd]pyrene were classed as high risk due to their risk for to the natural environment, with Benzo(k)fluoranthene also posing an additional risk to human health. The environmental risk of these three PAHs is more significant than that of Benzo[a]Pyrene, which has therefore been scored as a medium risk pollutant.

[27] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/304641/COMEAP_mortality_effects_of_long_term_exposure.pdf

[28] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/304641/COMEAP_mortality_effects_of_long_term_exposure.pdf

[29] https://naei.beis.gov.uk/reports/reports?report_id=1085

[30] https://www.sciencedirect.com/science/article/pii/S1674987121000116

[31] https://pubmed.ncbi.nlm.nih.gov/30566375/

[32] https://uk-air.defra.gov.uk/data/particle-data

[33] https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1807261113_180703_UFP_Report_FINAL_for_publication.pdf

Table 11Ammonia was classed as high risk because concentrations are high in agricultural areas, it has adverse impacts on nature conservation sites, and it is a precursor to the very high risk pollutant $PM_{2.5}$. Nitrogen dioxide is classed as high risk because it is of high concern for human health and environment, and whilst concentrations are well monitored, decreasing, and subject to controls, evidence from the WHO indicates much lower standards are required to better protect human health. NO is classed as high risk as it is a precursor to NO_2, and also has a role in producing acid rain, photochemical smog and Greenhouse Gas N_2O.

Similarly to other high risk pollutants, Chromium VI is classed so because of its risk to human health and the natural environment. The metals monitoring network indicates high levels of exceedance of the Environment Agency EAL for air for Chromium close to industrial areas, urban centres and busy roads.

Finally, PAHs Benzo(G,H,I)Perylene, Benzo(k)fluoranthene and Indeno[123-cd]pyrene were classed as high risk due to their risk for to the natural environment, with Benzo(k)fluoranthene also posing an additional risk to human health. The environmental risk of these three PAHs is more significant than that of Benzo[a]Pyrene, which has therefore been scored as a medium risk pollutant.

Table 11.

Of the 11 high risk pollutants, three are emerging pollutants: bioaerosols, brown carbon, and total carbon (brown carbon and black/elemental carbon are constituents of total carbon). A key factor in the high risk score of these emerging pollutants are the information gaps. For example, there is no monitoring or standards for these pollutants, which all form constituents of particulate matter. Evidence suggests bioaerosols, brown carbon and total carbon all pose a risk to human health. For bioaerosols there is uncertainty regarding their composition, behaviour and the extent of the risk. Similarly for brown carbon, more evidence and research is required, which would lead to improved monitoring and measurements.

Black carbon is a more well-researched and well-monitored constituent of total carbon – hence being viewed as a current and not emerging pollutant. Similarly to brown carbon, it is associated with adverse health effects, and no specific guideline values are in place.

Ammonia was classed as high risk because concentrations are high in agricultural areas, it has adverse impacts on nature conservation sites, and it is a precursor to the very high risk pollutant $PM_{2.5}$. Nitrogen dioxide is classed as high risk because it is of high concern for human health and environment, and whilst concentrations are well monitored, decreasing, and subject to controls, evidence from the WHO indicates much lower standards are required to better protect human health. NO is classed as high risk as it is a precursor to NO_2, and also has a role in producing acid rain, photochemical smog and Greenhouse Gas N_2O.

Similarly to other high risk pollutants, Chromium VI is classed so because of its risk to human health and the natural environment. The metals monitoring network indicates high levels of exceedance of the Environment Agency EAL for air for Chromium close to industrial areas, urban centres and busy roads.

Finally, PAHs Benzo(G,H,I)Perylene, Benzo(k)fluoranthene and Indeno[123-cd]pyrene were classed as high risk due to their risk for to the natural environment, with Benzo(k)fluoranthene also posing an additional risk to human health. The environmental risk of these three PAHs is more significant than that of Benzo[a]Pyrene, which has therefore been scored as a medium risk pollutant.

Table 11: Risk Assessment summaries for high risk pollutants.

Air Pollutant	Current risk	Potential future risk	Quality of the evidence	Overall risk rating
		Tier 1		
Ammonia (NH_3) *A colourless, strong-smelling gas, which can react in the atmosphere to produce particulate matter. Key sources from agriculture: use of nitrogen-based fertilisers and from livestock farming, particularly cattle.*	**HIGH** Ammonia is a precursor to $PM_{2.5}$ and therefore concentrations need to be restricted to protect human health from the effects of increased particulates. In addition. ammonia is also exceeding limits for protecting ecosystems.	**NO CHANGE** For 2020, the National Emissions Ceilings Directive (NECR) and the Convention on Long-Range Transboundary Air Pollution (CLRTAP) ceiling for ammonia was 257.6 thousand tonnes, set as a reduction of 8 per cent from 2005 levels. Annual total emissions of ammonia in 2020 were 259.2 thousand tonnes. Therefore, the UK has only achieved a 7 per cent reduction in emissions of ammonia since 2005, and has exceeded the emission ceilings for ammonia in 2020 by 1.6 thousand tonnes. Agriculture will remain the main source and an estimated NH_3 emission reduction of 19% is projected for the agriculture sector between 1990 and 2030, and just a 1% reduction between 2005 to 2030., Since emissions of NH_3 were at similar levels in both 2005 and 2020, further reductions would be required to meet the 2020 – 2029 and 2030 emission reduction commitments .	**GOOD** Monitoring network well established with good coverage in England and NI. Impact on ecosystem well researched. Emission estimates are of good quality but there are some reports of under reporting from agriculture sector.	**HIGH** NH_3 is not of significant concern for the public health on its own but it is a precursor for $PM_{2.5}$ which is of high concern for human health. $PM_{2.5}$ concentrations for all UK zones are compliant with current limit values. However, a new annual average concentration target of 10 $\mu g/m^3$ at each monitoring station was proposed by DEFRA. In addition a population exposure reduction target of 35% reduction in the population exposure metric compared to a 2018 baseline, and both to be met by 2040. The new concentration target is not currently met within the UK. Secondary $PM_{2.5}$ is a significant component (60%) of $PM_{2.5}$ and therefore NH_3 must be tackled if $PM_{2.5}$ is to be lowered for the protection of human health. NH_3 levels are high in agricultural areas of England in particular. The Clean Air Strategy 2019 does set out some plans to reduce NH_3 emissions particularly tackling the largest source (farming).
Black Carbon *A type of particulate matter composed mostly of carbon formed through incomplete combustion processes. It defined by the way presence of carbon is measured - an optical measurement of the extent of light absorption by samples. Also known as elemental carbon.*	**VERY HIGH** There are no AQ standard limit vales for black carbon. The health effects are difficult to distinguish from $PM_{2.5}$ as a whole. However, associations have been observed between daily variations in black carbon concentrations and short-term and long-term changes in health. BC also can also effect the health of ecosystems. There is large uncertainty because of data gaps.	**NO CHANGE** Emission projections for black carbon remain stable to 2030.	**MODERATE** There is good evidence on health effects of black carbon. Black carbon is monitored in the UK, however only across 14 sites. There are no air quality guideline values for BC.	**HIGH** Spatial representativeness of black carbon monitoring in the UK needs to improve, especially as we transition into new carbon neutral fuels e.g., biomass combustion. Given black carbon is associated with severe health effects, mortality and effects on climate, the pollutant is of concern, however emission projections remain stable.

Air Pollutant	Current risk	Potential future risk	Quality of the evidence	Overall risk rating
Nitrogen Dioxide (NO_2) *A gaseous compound that can have secondary impacts in its decomposed form (NO). NO_2 and NO can quickly interchange between forms at high temperatures and are referred to collectively as NOx. Key sources: Road and other transport (rail, shipping and mobile machinery). power stations and other energy generation and other industrial sites.*	**HIGH** The UK has been compliant with EU regulatory standard for exposure to nitrogen dioxide as a hourly mean in all 43 of its zones. The UK remains non-compliant with the EU regulatory standard for exposure to nitrogen dioxide as an annual mean in 10 of its zones. The UK has been compliant with the EU regulatory critical level of NOx release set for the protection of vegetation. The WHO recommend that current annual limits for NO_2 are reduced therefore this pollutant could exceed new limit values at more locations in England and NI.	**NO CHANGE** The NAEI projections suggest that the target value will be missed by 63.87 kilotonnes which is approximately 4% over the 2030 target level of emission reduction relative to a 2005 baseline.	**VERY GOOD** Monitoring network well established with good coverage in England and NI. Health effects well researched but some uncertainty ratio of health impacts by NO_2 and PM. Emission estimates are based on good quality evidence.	**HIGH** Pollutant already being well monitored and has controls in place to keep levels decreasing. Recent evidence from the WHO indicates much lower standards are required to better protect human health. Proposal for the revision of the Air Quality Directive in Europe have reduced the NO_2 standard. Consequently, this pollutant remains of concern for our health and environment.
Tier 2				
Bioaerosols *Although no formal definition exists, Bioaerosols are generally accepted as particles within the 0.1 – 100 micrometres (µm) range that originate from plant and animal life, including pollen and pathogens. Key sources are agriculture and waste management activities.*	**HIGH** Bioaerosols represent a risk to human health, but the extent of this risk is not systematically documented or managed	**DETERIORATION** It is likely that sources of bioaerosols will increase in the future. Regulation is in place to manage sources of bioaerosols.	**POOR** There is currently no system in place to robustly monitor the concentrations, and compositions, of bioaerosols in ambient air in the UK. There is poor understanding as to how bioaerosols in ambient air are currently impacting public health.	**HIGH** It is well understood that bioaerosols can have an adverse impact on public health. There is currently poor understanding of the composition and behaviour of bioaerosols in ambient air. Levels may increase in the future.

Air Pollutant	Current risk	Potential future risk	Quality of the evidence	Overall risk rating
Chromium *Chromium exists in two main forms Chromium (III) and Chromium (VI) and occurs naturally in the Earth's crust, predominately as, Chromium (III) form. Key sources are manufacturing, combustion of coal and oil, cement works and waste incineration.*	**VERY HIGH** Chromium VI is of significant concern for spatial exceedance. Of concern for natural environment. There are significant health effects from exposure to Chromium.	**NO CHANGE** Potential emissions from domestic and industrial sources have been reducing. This performance is expected to be maintained. Existing controls are to remain in place.	**VERY GOOD** Routinely measured at UK Heavy Metal Network sites. NAEI emission data provides evidence on key sources. Good evidence on hazard to health.	**HIGH** Chromium VI pollutant of significant concern especially around industrial centres. Health effects are judged as high when people are exposed. There are controls in place to keep residual levels decreasing. The metals network indicates high levels of exceedance.
Benzo(G,H,I)Perylene *A Polycyclic Aromatic Hydrocarbon (PAH). PAHs comprise a large group of compounds consisting of hydrocarbons . Key source is fuel combustion (largely domestic).*	**HIGH** Benzo(g,h,i)perylene is of very high concern to the environment as it has high aquatic toxicity and is persistent. It is not classified for human health hazards so is not currently of high concern for human health.	**NO CHANGE** Historical data on benzo(g,h,i)perylene emissions in the UK suggest that annual emissions will stay relatively stable.	**GOOD** There is a high quality of evidence as there is and established network of monitoring sites measuring airborne benzo(g,h,i)perylene levels in the UK. The human health and environmental effects of benzo(g,h,i)perylene exposure have also been well studied.	**HIGH** High overall risk to natural ecosystems with emissions expected to remain fairly stable.
Benzo(K)Fluoranthene *A Polycyclic Aromatic Hydrocarbon (PAH). PAHs comprise a large group of compounds consisting of hydrocarbons . Key source is fuel combustion (largely domestic).*	**HIGH** Benzo(k)fluoranthene is of very high concern to the environment as it has high aquatic toxicity and is persistent. It is also of high concern to human health as it is classified as a potential carcinogen.	**NO CHANGE** Historical data on benzo(k)fluoranthene emissions in the UK suggest that annual emissions will stay relatively stable.	**GOOD** There is a high quality of evidence as there is an established network of monitoring sites measuring airborne benzo(k)fluoranthene levels in the UK. The human health and environmental effects of benzo(k)fluoranthene exposure have also been well studied.	**HIGH** High overall risk to human health natural ecosystems with emissions expected to remain fairly stable.

Air Pollutant	Current risk	Potential future risk	Quality of the evidence	Overall risk rating
Brown carbon *Organic compounds that are essentially non-volatile and the light that passes through is reddish orange, or brown. Unlike black carbon, brown carbon can be semi-volatile, and it can either consist of primary material, often from the same combustion sources producing black carbon, or it can be produced via atmospheric chemistry as secondary brown carbon.*	**MODERATE** There are no AQ standard limit vales for brown carbon although some components of brown carbon such as PAHs are monitored, and no sites exceeded the regulatory Assessment Threshold of 1 ng/m^3 for B[a]P concentrations (TC components) no sites exceeded the regulatory Assessment Threshold of 1 ng/m^3 for B[a]P.	**NO CHANGE** There are no emission projections for brown carbon or its chemical constituents	**MODERATE** PAHs, in particular B[a]P, chemical constituents of brown carbon, are monitored within the UK and included in the National Atmospheric Emissions Inventory however more research is required, to understand/ identify the chemical constituents of brown carbon and their health and environmental effects.	**HIGH** More evidence/research is required for brown carbon, considering its detrimental impact on health and environment. With more evidence/research, improved monitoring and measurements will follow.
Indeno[123-cd]pyrene *A Polycyclic Aromatic Hydrocarbon (PAH). PAHs comprise a large group of compounds consisting of hydrocarbons . Key source is fuel combustion (largely domestic).*	**HIGH** Indeno[123-cd]pyrene is of high concern to the environment as it has high aquatic toxicity and is persistent. It is not classified for human health hazards so is not currently of high concern for human health.	**NO CHANGE** Historical data on indeno[123-cd]pyrene emissions in the UK suggest that annual emissions will stay relatively stable.	**GOOD** There is a high quality of evidence as there is an established network of monitoring sites measuring airborne indeno[123-cd]pyrene levels in the UK. The human health and environmental effects of indeno[123-cd]pyrene exposure have also been well studied.	**HIGH** High overall risk to natural ecosystems with emissions expected to remain fairly stable.
Nitric Oxide (NO) Nitric oxide (NO) is a colourless, non-combustible gas, consisting of one nitrogen and one oxygen atom. It represents the dominant portion of nitrogen oxides (NOx) and can react with other gases to form NO2.	**MDOERATE** No national standards for NO concentrations only for NO_2. There is a decreasing trend in NOx concentrations between 2013 and 2019. Nitric oxide (NO) is not considered to be hazardous to health at typical ambient conditions. NOx (NO and NO_2) interacts with water, oxygen and other chemicals in the atmosphere to form acid rain.	**NO CHANGE** Whilst emissions of NOx are currently compliant NECR and CLRTP ceilings, it is forecast that the UK is expected to not meet the 2030 NECD objective for NOx. The NAEI projections suggest that the target value will be missed by 63.87 kilotonnes which is approximately 4% over the target level of NOx emission reduction.	**GOOD** Large well established monitoring network of NO, with good coverage in England and NI. - Well established modelling and projections for NOx, but not NO specifically. - Health effects research fairly well researched, though difficult to find - overall research into health effects of NOx is largely dominated by NO2, and similarly for environmental impacts. - High quality emissions data/ emission projections available for NOx, though not for NO specifically.	**HIGH** NO is of concern due to the risk it poses to the environment and to human health in terms of its role in producing NO_2, acid rain, photochemical smog and Nitrous Oxide (N_2O). NO is being well monitored and is modelled and forecast as part of NOx emissions. Emissions and concentration of NOx are decreasing but are forecast to miss the NECD emission reduction target in 2030.

Air Pollutant	Current risk	Potential future risk	Quality of the evidence	Overall risk rating
Total carbon *Total carbon is a term that refers to all carbonaceous components within Particulate Matter (PM), that is, the sum of black carbon/elemental carbon, brown carbon and organic carbon.*	**HIGH** There are no Air Quality standards for total carbon. Emissions limits for NMVOCs (TC component) were met in 2020. For B[a]P concentrations (TC components) no sites exceeded the regulatory Assessment Threshold of 1 ng/m^3 for B[a]P. Health effects of BC are related to the component of PM2.5 it makes up. Health effects of PM2.5 are very dangerous.	**NO CHANGE** Latest projections suggest that the UK is on track to meet the 2030 Emission Reduction Commitments (ERC) for NMVOCs, and BC projections decreased in 2040 compared to 2025.	**GOOD** The different components of total carbon (black carbon, PAHs, NMVOCs) are monitored within England and Northern Ireland. The National Atmospheric Emissions Inventory also provides emission estimates and/or projections for these components.	**HIGH** As total carbon comprises of a wide range of carbonaceous components, national strategies, legislation and regulation, focus on components of total carbon which pose health and environmental risks such as black carbon, PAHs and NMVOCs.

3.1.3 Medium risk pollutants

The 12 pollutants assessed as medium risk were as follows (emerging pollutants indicated with *):

- Benzo[a]pyrene
- Dioxins
- Micro- and nano-plastics*[a]
- Nickel
- Ozone
- Formaldehyde
- Hydrogen Fluoride (HF)
- Nitrogen trifluoride
- Organic carbon
- Per-Polyfluorinated compounds
- Sulphur hexafluoride
- PM_{10}

Common themes among reasoning for “medium-risk” scoring included:

- Pollutant well monitored and compliant but at risk of increases in the future.
- Risk likely low based on evidence available, but evidence is limited.
- Available evidence suggests current measures are sufficient for protection of human health.
- Potentially harmful exposure in limited areas or from specific sources, but robust mitigation measures in place and further mitigation being worked on at government level for the industry sources.

  Whilst PM_{10} has previously been of concern for the UK, national compliance assessment for PM_{10} indicates no exceedances against Air Quality Regulations 2010 limit values, supported by both monitoring and modelling. Whilst this is also true for $PM_{2.5}$ against current limit values, the new targets which will be introduced for $PM_{2.5}$ are not currently met. PM_{10} concentrations have decreased at UK urban background and roadside sites. The emission inventories for PM_{10} have remained relatively stable since 2008. National strategies, legislation and regulation now focus on $PM_{2.5}$ rather than PM_{10} - therefore the overall risk associated to PM_{10} is medium.

[a] Although micro and nano plastics been assessed as medium risk, there are gaps in evidence relating to the current monitoring in place and the health effects from micro and nano plastics in the atmosphere. There is more evidence of the effects of micro and nano plastics in waterways, however there is also emerging evidence of microplastics in the atmosphere. These pollutants may be of future concern and may warrant further research.[34]

3.1.4 Low risk pollutants

The 15 pollutants assessed as low risk were as follows:

- Arsenic
- Cadmium
- NMVOCs
- Copper
- 1,3-butadiene
- Beryllium
- Chlorine
- Hydrogen cyanide
- Hydrogen Chloride

[34] https://www.sciencedirect.com/science/article/pii/S0160412019330351?via%3Dihub

- Manganese
- Selenium
- Sulphur dioxide
- Toluene
- Vanadium
- Xylene

Common themes among reasoning for "low-risk" scoring included:

- Monitoring targets/standards being achieved, and in many cases concentrations and emissions are well below targets/standards.
- Potentially very hazardous substances only harmful at extremely high levels of exposure, unlikely to ever occur.
- Strong pollutant controls in place to keep levels low.
- Of low concern for spatial exceedance, human health and/or natural environment.

A few pollutants which have previously been of concern for the UK, and prominent in air quality legislation, have been scored as "low-risk" in this assessment, for example Arsenic, Cadmium and NMVOCs.

For both Cadmium and Arsenic, exposure risk is low, despite these being potentially very hazardous pollutants. Measurements carried out across the UK Heavy Metal Network, supported by national compliance modelling shows long-term compliance.

4. AIR POLLUTION COMMITMENTS AND RECOMMENDATIONS

A comprehensive literature review of national and local government commitments and scrutiny body recommendations on tackling air pollution produced a Catalogue which can be found in Appendix 3. The review largely focused on policies, strategies, plans and reports which were published after 2015, with a few exceptions of key documents which haven't been revised since they were published prior to 2015.

Within the Catalogue, the commitments and recommendations have been organised by publication body (government, local authority, and scrutiny body) and date of publication overall. Government commitments are further categorised by theme e.g., concentration reductions, emissions reductions, ecological protection, etc. Key themes have also been drawn out from the review of scrutiny body recommendations e.g., the delivery mechanism and timetable for better air quality, stronger linkages between air quality and public health protection etc. Where recommendations and commitments directly related to specific policies or legislation, these relationships have been highlighted.

4.1 UK GOVERNMENT COMMITMENTS

The UK air quality management framework is formed from a mixture of national and international legislation and supporting policy. Useful recent documents providing a summary of this framework include the Air Pollution in the UK 2021 report[35] and Air pollution in Northern Ireland 2021[36] annual reports (the latest in a long series of such reports), along with the UK Government Air Quality Provisional Common Framework 2022[37], all of which have been key sources of information for summaries of the strategies, plans and other legislation assessed in this review.

The main components of UK air quality policy commit the Government to meeting the requirements of standards and regulations concerning the concentrations of pollutants in ambient air, the total emissions of pollutants and the emissions of pollutants from specific sources. These key components are:

- The UK Air Quality Strategy 2007 (Volume 1 and Volume 2)
- Clean Air Strategy 2019 (for the UK)

[35] https://uk-air.defra.gov.uk/library/annualreport/viewonline?year=2021_issue_1#report_pdf
[36] https://www.daera-ni.gov.uk/publications/air-pollution-northern-ireland-2021
[37] https://www.gov.uk/government/publications/air-quality-provisional-common-framework

- 25 Year Environment Plan (2018) and the current Environmental Improvement Plan (2023)
- Environment Act 2021
- Air Quality Plan for Nitrogen Dioxide (NO_2) in the UK (2017)
- Clean Air Zone Framework (2022)
- National Air Pollution Control Programme (2023)

Strategies and plans pending publication were summarised but not reviewed in detail due to not being available or being available in draft form but not formally adopted. These were all Northern Ireland strategies, and included:

- Environmental Strategy for Northern Ireland (2021)
- Clean Air Strategy for Northern Ireland
- Northern Ireland Ammonia Strategy (2022)
- Northern Ireland Green Growth Strategy (2021)

In terms of the wider legislation review, and commitments relating directly or indirectly to air quality, key strategies included:

- Industrial Strategy: Building a Britain Fit for the Future (2017)
- Industrial Strategy – The story so far (2018)
- Industrial Strategy: Automotive Sector Deal (2018)
- Construction Sector Deal (2018)
- Aerospace Sector Deal (2018)
- The Industrial Strategy: The Grand Challenges (2021)
- The Government's 'Build Back Better: Our Plan for Growth' (2021)
- Off-shore wind: Sector Deal (2019)
- Aviation 2050 — the Future of UK Aviation (2018)
- Flightpath to the Future: A Strategic Framework for the Aviation Sector (2022)
- Maritime 2050 (2019)
- The Clean Growth Strategy (2017)
- Industrial decarbonisation Strategy (2021)
- Transport Decarbonisation Plan (2021)
- Net Zero Strategy: Build Back Greener (2021)
- Heat and Buildings Strategy (2021)
- Biomass Policy Statement: A Strategic View on the Role of Sustainable Biomass for Net Zero (2021)

The Government commitments largely fall into the following six categories:

1. Concentration reductions
2. Emissions reductions
3. Ecological protection
4. Health protection
5. Public communication
6. Monitoring, review and assessment.

There is some level of overlap across these themes, for example, concentration and emission commitments relating to pollutants have direct implications on ecological and health protection, and the communication, monitoring, review and assessment commitments often relate to specific measures to protect ecology and health. When commitments fell across multiple categories it was assessed on a case by case basis and most relevant category was chosen for the overall focus of the measure.

4.1.1 Concentration reductions

Government commitments in relation to concentration reduction, range from specific numeric objectives and standards for concentrations of pollutants in the atmosphere, such as those set out in the UK Air Quality Strategy, to more general commitments to actions and measures which are intended to reduce pollutant concentrations.

In the air quality plan for nitrogen dioxide (NO_2) in the UK, there are commitments to provide local authorities with funding in order to achieve concentration reductions, and within the Clean Air Strategy, the Environment Act 2021 and the Clean Air Zone framework, there are commitments and provisions to provide local authorities with powers to enable action at a local level. Further information is provided regarding commitments at a local level in Section 4.2. The Northern Ireland Executive Draft Programme for Government 2016- 2021 commits to increase sustainable transport through a number of actions to improve air pollutant concentrations.

Following a 2022 consultation[38] to introduce new environmental targets under the Environment Act 2021, the Government published new legally binding environment targets on the 16th December 2022[39, 40]. These include long term targets for air quality, notably on $PM_{2.5}$ concentrations, which should be met by 2040. The Environmental Improvement Plan published 31st January 2023 sets out the Governments plans to deliver these long term targets and sets out further interim targets for $PM_{2.5}$ concentrations to be met by January 2028.

In terms of wider legislation, there are fewer commitments specifically relating to concentration reductions. The draft Northern Ireland Environment Strategy (2021) has been under consultation and approved by the Environment Minister but as the time of producing this report, has not yet approved by an Executive so is not yet published in it's final draft. Within this strategy there are commitments to publish NI's first Clean Air Strategy and develop new SMART targets and actions, continue funding improvements to local air quality and fewer pollutants released by home heating systems.

4.1.2 Emissions reductions

Commitments include specific numeric objectives and targets for concentrations of pollutants in the atmosphere, such as those set out in the Clean Air Strategy 2019, and both specific and general commitments to actions and measures which are intended to reduce pollutant emissions.

The National Air Quality Strategy, the 25 Year Environment Plan and the Clean Air Strategy contain a large number of commitments regarding the investigation and review of measures with the potential to achieve emissions reductions, including incentives for uptake of low emission vehicles. The 2023 Environmental Improvement Plan reinforces the 25 Year Environment Plan including targets on emissions reductions and plans to deliver these targets.

The plans and strategies sometimes include some more specific quantified measures setting out committed funds against measures to reduce emissions. The Air Quality Plan for Nitrogen Dioxide (2017) in particular contains a considerable number of quantified commitments to reduce emissions largely from the transport sector, and to a lesser extent industrial and domestic heating sectors. Emphasis on commitments which reduce emissions from the transport sector is seen across the National Air Quality Strategy, the 25 Year Environment Plan and the Clean Air Strategy also.

In terms of the wider legislation there are a number of commitments to reduce emissions within the industrial strategy through providing funding for the most energy intensive sectors to cut their energy use and reduce carbon emissions and commitments to developing cleaner energy across power heating and transport sectors. Within the aviation strategy there are commitments to reduce and off-set CO_2 emissions and a requirement for all major airports to develop air quality plans to manage emissions. There are aspirations to develop technology to realise zero emissions flights across the UK within the decade. The Clean Maritime Plan sets out the governments vision to transition to a zero emission shipping future. The Environment strategy for Northern Ireland commits to address ammonia emissions through the Ammonia Strategy and the Northern Ireland Green Growth Strategy sets out plans to meet sector specific greenhouse gas emission targets.

[38] https://www.gov.uk/government/consultations/environment-act-2021-environmental-targets
[39] https://www.gov.uk/government/news/new-legally-binding-environment-targets-set-out
[40] https://questions-statements.parliament.uk/written-statements/detail/2022-12-16/hlws449

4.1.3 Ecological protection

There are specific commitments relating to ecological protection in the UK Air Quality Strategy, The Air Quality Plan for Nitrogen Dioxide (2017) and the 25 Year Environment Plan. The Environment Strategy for Northern Ireland and the Northern Ireland Green Growth Strategy also include commitments to ecological protection.

There are not as many specific commitments relating to ecological protection, however it is worth noting that there are a number of concentration and emission reduction commitments in the National Air Quality Strategy and the Clear Air Strategy which focus on pollutants which pose a threat to habitats – e.g. targets for the reduction of ammonia, nitrogen oxides, and nitrogen deposition in the Clean Air Strategy, and commitments to actions to reduce emissions of these pollutants.

There are also commitments regarding the monitoring of impacts of air pollution on habitats in the 25 Year Environmental Plan and the Clean Air Strategy, and the Clean Air Strategy also includes a commitment to monitor the impacts of air pollution on natural habitats, with annual reporting.

4.1.4 Health protection

Almost every plan and strategy reviewed highlights the importance of air quality as a human health issue. However, there are not many commitments which specifically relate to health protection. The 25 Year Environment Plan includes a specific commitment to establish a cross government alliance to develop the "Natural Environment for Health and Wellbeing Programme", and the Clean Air Strategy includes a commitment to equip health professionals, local authorities and directors of public health, with regard to air quality and health. The Net Zero Strategy outlines the need to consider health impacts of any shift in technology particularly to biomass and hydrogen combustion.

Cross-over with other themes mean that further plans and strategies contain commitments which link to health protection, including concentration and emission reduction targets concerning pollutants which pose a risk to human health. For example, the commitment to set new targets and objectives for reducing $PM_{2.5}$ exposure and concentrations, as set out in the Clean Air Strategy and the Environment Act 2021, now reflected in the legally binding targets set within the 2023 Environmental Improvement Plan.

Commitments to measures which encourage active transport (walking and cycling) will deliver health benefits directly in addition to indirect health benefits via improvements to air quality. Such commitments are included in the UK Air Quality Strategy, the Air Quality Plan for Nitrogen Dioxide (NO_2), the 25 Year Environment Plan, the 2023 Environmental Improvement Plan, and the ten point plan for a green industrial revolution. The Clean Air Strategy and the draft Environment Strategy for Northern Ireland contain commitments relating to increasing public awareness of the health effects of poor air quality and of specific pollutants.

Many of the plans and strategies reviewed acknowledged inequalities of impacts of air quality, but did not contain specific commitments regarding this.

4.1.5 Public communication

Commitments made by the government which relate to public communication, include informing the public of air quality and pollutant impacts, undertaking stakeholder engagement to develop and implement schemes and guidance, and improving the accessibility of information about air quality.

In particular, the Clean Air Strategy contains a number of commitments about improving the accessibility of air quality information, including bringing together local and national monitoring to a single accessible portal, developing an air quality messaging system, and working with media outlets to improve public access to the air quality forecast.

4.1.6 Monitoring, review and assessment

Government commitments include monitoring air quality concentrations and reviewing progress against objectives, standards and targets; commitments to further develop the evidence base for air quality in the UK and conduct research into specific pollutants and measures to reduce emissions and improve concentrations.

The majority of policies and plans also contain commitments regarding the monitoring and evaluation of implementing the plans and strategies themselves.

4.2 LOCAL AUTHORITY COMMITMENTS THROUGH AIR QUALITY ACTION PLANS AND AIR QUALITY STRATEGIES

The Environment Act 1995[41] requires local authorities to **review the air quality in their respective areas** and **assess whether the air quality standards are being met.** The Environment Act 2021[42] amends the Environment Act 1995 to strengthen the Local Air Quality Management framework to enable greater local action on air pollution. In the case of Northern Ireland, District Councils are required to carry out an air quality review in their districts under the Environment (Northern Ireland) Order 2002[43]. The system by which local authorities are required to assess air quality in their area is known as Local Air Quality Management (LAQM).

The air quality objectives applicable to LAQM are set out separately to the national level in the following regulations:

- Air Quality (England) Regulations 2000 as amended by the Air Quality (England) (Amendment) Regulations 2002[44], for England.
- Air quality Regulations (Northern Ireland) 2003[45] as amended, for Northern Ireland.

Air Quality Action Plans (AQAPs) are required of certain local authorities as set out in the Environment Act (as amended):

- Where air quality standards or objectives are not being achieved or are not likely within the relevant period to be achieved, local authorities should designate an air quality management area (AQMA) and prepare an air quality action plan (AQAP).
- An AQAP is a written plan which must:
    - set out how the local authority will exercise its functions in order to secure that air quality standards and objectives are achieved in the area, and maintained after they have been achieved.
    - Set out particular measures the local authority will take to secure the achievement and maintenance of air quality standards and objectives, and specify a date by which it will be carried out.

Local authorities are required to notify relevant air quality partners, combined authorities and county councils of the intention to prepare an action plan, and these bodies must provide the local authorities with proposals for particular measures they will take to contribute towards the achievement and maintenance of air quality standards.

The exact number of published AQAPs currently live in the UK is unknown. The best available proxy data is the number of active AQMAs, as summarised in

Table 12. However, it is important to note than a local authority may have multiple AQMAs all addressed within one AQAP, and not every local authority with an AQMA will have a published and up to date AQAP.

Some recent AQAP examples can be found here (for Birmingham City Council), here (for Belfast City Council)

Table 12 - Number of active AQMAs (29 Nov 2022)

	England	Northern Ireland
Particulate matter PM_{10}	48	3
Nitrogen dioxide NO_2	522	17
Sulphur dioxide SO_2	6	0
Benzene C_6H_6	0	0

[41] https://www.legislation.gov.uk/ukpga/1995/25
[42] https://www.legislation.gov.uk/ukpga/2021/30
[43] https://www.daera-ni.gov.uk/articles/air-pollution-northern-ireland
[44] https://www.legislation.gov.uk/uksi/2002/3043/made
[45] https://www.legislation.gov.uk/nisr/2003/342/contents/made

4.3 Scrutiny bodies technical and policy recommendations

Scrutiny bodies periodically publish recommendations to Government on air quality matters. These include those closely linked to government such as the National Audit Office or Government Committees such as the All Party Parliamentary Group (APPG) on Air Pollution and the Environment, Food and Rural Affairs (EFRA) Committee. Other lobby groups such as ClientEarth have regularly provided recommendations to Government particularly in relation to public consultations from Government on proposed policy. Below further information is provided on recommendations made in recent years by key scrutiny bodies.

Recommendations to government tend to focus around seven themes as follows:

1. The delivery mechanism and timetable for better air quality
2. Stronger linkages between air quality and public health protection
3. Development on a framework to reduce nitrogen emission for habitat protection/restoration
4. Clarity on the linkages between air quality and climate change policy
5. Evidence of the impact of indoor air quality
6. Improving public access to air quality information
7. Clarity and transparency of how government undertake monitoring and evaluation of their policy commitments

4.3.1 The delivery mechanism and timetable for better air quality

Effectiveness and priority of mitigation measures

In general, it is acknowledged that on a national scale, ambient pollution levels are declining, and indications are that this will continue into the future. However, the speed at which this is predicted to occur depends on society's and government's desire to implement measures that are known to reduce emissions. There is general consensus on the types of mitigation measures that are available to government to improve air quality with recommendations from CMO, APPG and EFRA in recent reports. While these mitigation measures are all technically feasible, there are calls on government to prioritise these to achieve compliance with statutory targets as soon as possible. For example, the Government's 2017 NO_2 Plan to reduce roadside concentrations has resulted in Clean Air Zones being implemented in Bath, Birmingham, Plymouth, Bradford and Bristol but some of these have just recently been launched. Plans for improving NO_2 in some areas are still in development e.g. Greater Manchester, and progress is much slower than expected.

In addition to action being placed on Local Authorities in the Government's NO_2 Plan, National Highways were tasked with improving air quality across the Strategic Road Network. However, since 2015 National Highways, despite research and pilots, have concluded there are no viable measures to improve air quality on 17 out of 30 road links identified as hotspots. The NAO have recommended that clarity is published on the criteria to judge the viability of measures to increase transparency. Indeed, the NAO report that in January 2022, the Transport Select Committee recommended that government "assess the potential effect of a road pricing mechanism based on telematic technology on changing drivers' behaviour and delivering its wider policies" including air quality.

Update to the National Air Pollution Control Programme

Further recommendations focus on the requirement to meet the national emission reduction commitments set out in the 2018 national emissions ceilings regulations with concern being raised that the UK is not on track to meet all of these by the 2030 target date. The Government consulted on an update to the National Air Pollution Control Programme which closed in September 2022. The National Air Pollution Control Programme was published in February 2023[46]. Key measures were assessed related to domestic combustion, agriculture to reduce ammonia emissions, industry and the quantification of the co-benefits to air quality from decarbonisation of road transport and net zero policies on the power, industry and residential sectors.

[46] https://www.gov.uk/government/publications/air-quality-revised-uk-national-air-pollution-control-programme

4.3.2 Stronger linkages between air quality and public health protection

During 2022 the Government consulted on its commitment to develop longer term targets for air quality, notably on $PM_{2.5}$, leading to the publication of new legally binding environment targets on the 16th December 2022. The new targets for $PM_{2.5}$ include long term targets which should be met by 2040. The Environmental Improvement Plan published 31st January 2023 sets out the Governments plans to deliver these long term targets and sets out further interim targets for $PM_{2.5}$ concentrations to be met by January 2028. Further detail on the delivery plan to ensure such targets can be met across the country have been recommended most recently by the NAO. While it is acknowledged that $PM_{2.5}$ is a key pollutant being attributed to increased mortality and morbidity outcomes, there is a lack of information on Government's ambitions for other major pollutants and emerging pollutants. The World Health Organisation set new, more stringent guidelines for other pollutants in September 2021, and subsequently the European Commission is consulting (December 2022) on a proposed revision to European limit values which would be stricter for many pollutants in addition to $PM_{2.5}$. It is also noted that the European choice of attainment date is 2030 rather than a decade later for England.

Other recommendations around public health focus on more being done to address health inequalities and the role for the health sector should be strengthened. This was recommended by DEFRA in 2018, and within the Coroner's report on the death of nine year old Ella Kissi-Debrah in 2021 and again in 2022 by the CMO. In particular, the training of health professionals on the health effects of air pollution and how to minimise these was recommended.

4.3.3 Development on a framework to reduce nitrogen emission for habitat protection/restoration

It should be noted that many recommendations by scrutiny bodies focus on the protection of public health. JNCC, an advisor to Government on ecological matters, commissioned several independent reports as part of their Nitrogen Futures project which aims to enhance the protection of sensitive habitats to excess nitrogen deposition. Recommendations from these reports focus on the need to work with stakeholders to develop a clear nitrogen emission reduction framework for identifying priority actions in each locale.

4.3.4 Clarity on the linkages between air quality and climate change policy

The importance of understanding co-benefits of the policy commitments from air quality and decarbonisation/climate change has long been acknowledged. This has focussed on the early identification of unintended consequences of policy on other areas stemming from the increase in diesel cars to lower CO_2 emissions over 15 years ago which resulted in higher NOx emissions. While the impacts of decarbonisation of road transport and net zero policies on industry, power and the residential sectors have been included in the quantification of emission reduction for air pollutants in the Government's draft NAPCP, there remains recommendations from scrutiny bodies to do more in this area. For example, in the CMO report (December, 2022)[47] further calls for the electrification of the rail sector were made, which would be most beneficial in terms of public health protection in enclosed areas such as train stations where exposure is high.

4.3.5 Evidence of the impact of indoor air quality

It is generally acknowledged that our understanding of indoor air quality is in its infancy and further research into this area is commencing. For decades Government action has been on ambient outdoor pollution levels, driven by regulations. Occupational exposure to high pollutant levels has been controlled and enforced under relevant health and safety legislation which has left indoor air quality in homes and other public spaces largely unregulated. It has been recommended by PHE [now UKHSA] and CMO that the role of infrastructure planning should be strengthened in the area of air quality . Planners should encourage the lowering of pollutant concentrations especially where exposure is high. Building design is also important, and while ventilation is a crucial consideration to meet energy efficiency targets, the impact on air quality and respiratory infections should also be considered as a potential trade off.

More evidence is being published on volatile organic compounds emissions from products regularly used within residential homes. The importance of emissions from wood burning in the residential sector for air quality within homes is also being recognised. Further research for both these sources and more generally on indoor air quality has been recommended to improve overall understanding.

[47] https://www.gov.uk/government/publications/chief-medical-officers-annual-report-2022-air-pollution

4.3.6 Improving public access to air quality information

A key theme from scrutiny bodies is the need for improved access to public information on air quality. This was a prominent recommendation from the Coroner's report "Prevention of Future Deaths"[48] in 2021 and within the NAO report on air quality in 2022[49]. It has also been a key shortcoming identified by the European Commission in their evaluation of the implementation of the Ambient Air Quality Directive 2008. While it is acknowledged that evidence and data on air quality is published daily, and a daily air pollution is forecast and published by Defra, the format of this information is not easy to understand and be fully accessible to the general public.

4.3.7 Clarity and transparency of how Government undertake monitoring and evaluation of their policy commitments

While it takes time to develop and implement policy, recommendations are often made for Government to more regularly publish delivery plans including timetables, and monitoring and evaluation outcomes. These should include cost of policy and value for money information. Appropriate milestones and setting of interim targets should make it clear to the public if Government are on track to deliver better air quality.

It was recommended that progress reports on air quality should be published by Government every six months to enable transparency, oversight and scrutiny.

5. DELIVERY MECHANISMS AND SOURCE SECTORS

The assessment of delivery mechanisms by source sector has focused on the following air pollutants:

1. Pollutants ranked as very high or high risk in the risk assessments (NH_3, NO_2, black/elemental carbon, $PM_{2.5}$, ultrafine particles, bioaerosols, chromium VI, benzo(g,h,i)perylene, benzo(k)fluoranthene, brown carbon, indeno[123-cd]pyrene, nitric oxide (NO), total carbon)
2. Defra's five key pollutants in the Clean Air Strategy (NO_2, SO_2, NMVOCs, $PM_{2.5}$, NH_3)
3. Pollutants which are non-compliant with the Air Quality Standards Regulations from Defra's most recent "Air pollution in the UK 2021" report – NO_2, Ni and B[a]P excluding O_3
4. Pollutants with a 'deterioration'/'significant deterioration' in the 'potential future risk' category of the risk assessments – $PM_{2.5}$ and bioaerosols.

5.1 SOURCE SECTORS

Source apportionment for NO_2, NH_3, PM_{10}, $PM_{2.5}$, SO_2, VOC, benzo[a]pyrene and dioxins, sourced from the NAEI are provided in Table 13. The source apportionment for the remaining pollutants (chromium VI, benzo(G,H,I)perylene, benzo(K)fluoranthene, brown carbon, total carbon, black/elemental carbon, bioaerosols, indeno[123-cd]pyrene, NO), were not available from the NAEI and as such the sources have been categorised as major or minor source based on the source apportionment for the other pollutants, collated evidence from the literature and data search, and expert judgement. These are provided in Table 14.

Table 13 shows that the highest contribution of NO_2 is from the transport sector followed closely by the energy and industrial combustion sectors. The highest contribution of ammonia is from the agriculture sector while the highest contribution of PM_{10} and VOC is from the industrial process and solvent sector. The highest contributions of $PM_{2.5}$ and SO_2 are from energy and industrial combustion sectors. BaP highest sector contribution is from the residential, commercial and public sector while dioxins highest sector contribution is from waste.

Table 14 shows that for the pollutants which are subcomponents of PM_{10} (i.e., black/elemental carbon, ultrafine particles, bioaerosols, chromium VI, brown carbon, total carbon, nickel), their major sources vary across all source sectors. For pollutants that are subcomponent of BaP (i.e. benzo[a] pyrene (B[a]P) (applicable to benzo(G,H,I) perylene, benzo(K)fluoranthene, indeno[123-cd]pyrene), their major sources are energy and industrial combustion, residential, commercial and public sector combustion and waste.

[48] https://www.judiciary.uk/prevention-of-future-death-reports/ella-kissi-debrah/
[49] https://www.nao.org.uk/reports/tackling-local-breaches-of-air-quality/

Table 13: Source apportionment for pollutants in England 2020, NAEI (%).

	% Pollutant contributions for 2020							
Sector	**Nitrogen Dioxide (NO2)**	**Ammonia (NH3)**	**Particulate Matter (PM10)**	**Particulate Matter (PM2.5)**	**Sulfur Dioxide (SO2)**	**Volatile Organic Compound (VOC)**	**Benzo[a]pyrene (B[a]P)**	**Dioxins**
Transport	**45.3**	**1.8**	**14.7**	**16.8**	**4.3**	**5.1**	**3.8**	**4.1**
Energy and industrial combustion	**36.6**	**0**	**18**	**30.3**	**56.8**	**11.9**	**9.2**	**20.2**
Residential, commercial and public sector combustion	11.8		15.9	27.5	30.1	4.3	77.6	27.2
Industrial process and solvent process		1.4	34.7	13.5	7.5	60.7	2.7	8
Waste		3.4	1.1	1.8			6.4	40.1
Agriculture	0.3	83.6	10.6	3.1		15.9		
Other	6	9.8	5	7	1.3	2.1	0.3	0.3
	100	**100**	**100**	**100**	**100**	**100**	**100**	**99.9**
Included elsewhere, as emissions insignficant								

Table 14: Major and minor sources for other pollutants without NAEI source apportionment

Sector	**Black carbon**	**Ultrafine particles**	**Bioaerosols**	**Chromium VI**	**Benzo(G,H,I) Perylene**	**Benzo(K) Fluoranthene**	**Elemental carbon**	**Brown Carbon**	**Indeno[123-cd]pyrene**	**Nitric Oxide (NO)**	**Total Carbon**	**Nickel**
Transport	Major source	Major source		Minor source	Minor source	Minor source	Minor source	Minor source	Minor source	Major source	Minor source	Minor source
Energy and industrial combustion	Minor source	Major source	Minor source	Major source	Major source	Major source	Minor source	Minor source	Major source	Major source	Major source	Major source
Residential, commercial and public sector combustion	Major source				Major source	Major source	Major source	Major source	Major source	Major source	Major source	Minor source
Industrial process and solvent process		Major source										Major source
Waste	Major source		Major source	Major source	Major source	Major source	Minor source	Minor source	Minor source	Minor source	Minor source	
Agriculture		Minor source	Major source		Minor source	Minor source			Major source	Minor source		

5.2 SUMMARY OF DELIVERY MECHANISMS BY SECTOR

Table 15 provides a summary of the delivery mechanisms available to reduce pollution. For each main source sector a number of combined delivery mechanisms have been listed and the scale of the impact of each delivery mechanism will have on the different pollutants is provided. The table highlights which delivery mechanisms will have the greatest impact on pollutants in each sector.

Table 15 shows that there are some measures that can make a high improvement across a number of pollutants. For example, delivery mechanism "*OEP1 - Improve vehicle fleet with sustainable and low emission vehicles*" would make substantial improvements to NOx, PM_{10} and $PM_{2.5}$ concentrations. This is the only transport measure likely to improve ammonia, benzo[a]pyrene or dioxins concentrations to a measurable extent. Delivery mechanism "*OEP 11- Improved fuel and emissions standards*" would result in a substantial improvement in NO_2 and SO_2 emissions and a medium improvement on PM_{10} and $PM_{2.5}$ in the aviation, railways and national navigation source sector. There are a number of delivery mechanism expected to reduce emissions for all pollutants apart from ammonia, including "*OEP12/13-infrastructure improvement*", *OEP8 and OEP15 – "Reduce emissions from combustion"*, "*OEP16 - Fuel switch", "OEP19 - Adopting abatement systems"*, and "*OEP20 - Policy and regulations".*

Most policies do not yet address UFP. This is due to a lack of knowledge/understanding of UFP, and/or the absence of policy drivers for improving UFP. While there is a lack of evidence, the measures which result in benefits for $PM_{2.5}$ would in most cases also be expected to improve UFP.

The full table review of delivery mechanisms can be found in Appendix 4.

Table 15: Summary of delivery mechanisms available to reduce pollution. Scoring as follows: 0 = no improvement; 1 = low improvement; 2 = medium improvement; 3 = high improvement.

Source sector	Delivery mechanisms available	Impact or scale of improvement of measure on pollutants							
		NO_2*	NH_3	PM_{10}**	$PM_{2.5}$**	SO_2	VOC	B[a]P***	Dioxins
Road Transport	OEP1 - Improve vehicle fleet with sustainable and low emission vehicles	3	1	3	3	1	2	1	1
	OEP2 - Compliance checks	1	0	1	1	1	1	0	0
	OEP3 - Land use planning and vehicle restriction	2	0	2	2	1	1	0	0
	OEP4 - Business and behaviour change	2	0	2	2	0	0	0	0
Aviation, Railways and National Navigation	OEP11 - Improved fuel and emissions standards	3	0	2	2	3	0	0	0
	OEP12/13 - Infrastructure improvement	2	0	3	3	1	1	1	1
	OEP14 - Policy and regulations	2	0	1	1	3	0	0	0
Public electricity and heat production	OEP5 - Reduce emissions from combustion	3	0	3	3	3	0	1	1
	OEP6 - Replacement of energy supply	2	1	2	2	0	0	1	1
	OEP7 - Improve building fabric for efficient energy use	2	0	2	2	1	0	0	0
Petroleum refining, manufacture of solid fuels and combustion in manufacturing industries and	OEP8 - Reduce emissions from combustion	3	0	3	3	3	3	1	1
	OEP9 - Replacement of energy supply	2	0	2	2	1	1	0	0

Source sector	Delivery mechanisms available	Impact or scale of improvement of measure on pollutants							
		NO_2*	NH_3	PM_{10}**	$PM_{2.5}$**	SO_2	VOC	B[a]P***	Dioxins
construction; and fugitive emissions from energy production	OEP10 - Modification of processes with fugitive emissions	0	0	0	0	0	3	0	0
Commercial/Institutional and residential combustion	OEP15 - Reduce emissions from combustion	3	0	3	3	3	3	1	1
	OEP16 - Fuel switch	2	0	3	3	1	1	1	2
	OEP17 - Regulations	1	0	2	2	1	1	0	0
	OEP18 - Improve building fabric for efficient energy use	2	0	2	2	1	0	0	0
Industrial processes	OEP19 - Adopting abatement systems	3	0	3	3	3	3	1	1
	OEP20 - Policy and regulations	3	0	2	2	3	1	1	1
	OEP21 - Use of improved products	0	0	0	0	0	3	0	0
Waste Treatment and Disposal	OEP22 - Reduce biodegradable waste	0	3	1	1	0	0	0	0
	OEP23 - Improve waste processes	2	3	1	1	0	0	0	0
Agriculture	OEP24 - Adopt new farming practices	0	3	1	1	0	0	0	0

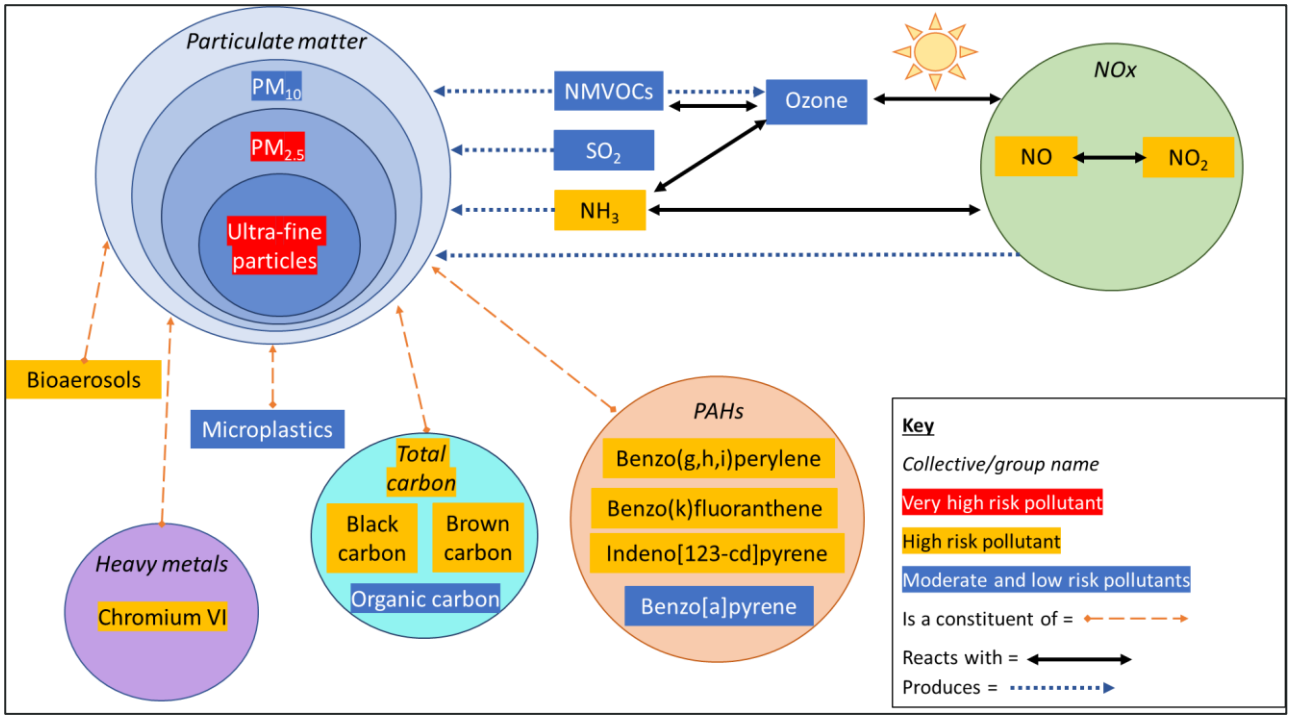
*Also applicable to nitric oxide
** Also applicable to black/elemental carbon, ultrafine particles, bioaerosols, chromium VI, brown carbon, total carbon, nickel
*** Also applicable to benzo[g,h,i]perylene, benzo[k]fluoranthene, indeno[123-cd]pyrene

5.3 SYNERGIES AND TRADE-OFFS BETWEEN HIGH AND VERY HIGH RISK POLLUTANTS

Table 15 demonstrates that the majority of delivery mechanisms have benefits across multiple pollutants. Some measures have co-benefits across pollutants due to shared sources.

Additionally, delivery mechanisms will have co-benefits due to the relationships and synergies between pollutants. Figure 1 presents key relationships between the pollutants, with a focus on the very high and high risk pollutants.

Figure 1: Schematic of key relationships between pollutants included in Task 4



Many of the pollutants under consideration in this study are constituents of particulate matter. Measures which reduce PM, including PM_{10}, $PM_{2.5}$ and ultra-fine particles, would typically be expected to have co-benefits for bioaerosols, chromium VI, black carbon, brown carbon, total carbon, and/or PAHs.

Similarly, as both NO and NO_2 are constituents of NOx, measures aimed at NOx as a group will benefit both NO and NO_2.

Measures which reduce NH_3, NOx, SO_2 and NMVOCs will have co-benefits for particulate matter (PM_{10} and $PM_{2.5}$), as these precursor pollutants produce secondary particulate matter pollution.

NO, NO_2, NH_3 and O_3 key interactions are as follows.

- NO_2 and NO can quickly interchange between forms at high temperatures.
- Atmospheric NH_3 reacts with NOx (NO and NO_2) emissions to produce ammonium (NH_4) aerosol (fine particulate matter).
- O_3 reacts with NH_3 to form ammonium nitrate (NH_4NO_3) aerosol (particulate matter).
- O_3 oxidises NO to convert it to NO_2 and can oxidise NO_2 to form NO_3.

At ground level, reactions between NO, NO_2 and O_3 are driven by sunlight and heat. Typically, higher levels of NO_2 are associated with lower levels of O_3 and vice versa. In day and summertime NOx is a major precursor of O_3. In the presence of solar radiation, NO_2 reacts with other chemical compounds in the troposphere (lower atmosphere) to form NO and O, which reacts with O_2 to produce O_3. Other pollutants including carbon monoxide, methane and NMVOCs have the same effect on O_3. Conversely, O_3 also reacts with NO to produce NO_2 and O_2 (NOx titration). At night and wintertime NO is a scavenger of O_3 through NOx titration. Due to these formation and scavenging processes, levels of ozone and NOx are in constant daily flux. The reduction

of emissions of NOx is likely to lead to increased exposure to concentrations of ground level O_3. This is because reduced concentrations of NOx result in a reduction of titration of O_3 by NO.

This trade-off was demonstrated in air quality monitoring data during the Covid19 pandemic. Data analysed from 246 ambient monitoring stations across Europe between February and July 2020, showed that at the maximum point of restriction on mobility, NO_2 concentrations reduced by 34% at roadside locations and 32% at urban background locations, whilst O_3 was 30% and 21% higher in the same respective environments[50].

This study highlights that VOC concentrations did not change during the lockdown period, and suggests based on the relationship between VOCs and O_3 (VOCs playing a significant role in O_3 formation), that enhanced control of VOC emissions will be critical to avoiding higher O_3 as NOx emissions are reduced[51].

Other studies support this conclusion. For example, it has been found that O_3 increases in major cities in China where measures are in place to reduce NOx without effective VOC control[52]. Other studies which investigated the increase in O_3 during the Covid-19 lockdown drew similar conclusions, that holistic combined management of NOx with VOCs should prevent this trade-off effect where O_3 increases as NOx decreases[53,54].

Close monitoring of O_3 is needed whilst implementing mechanisms to reduce NO and NO_2, to ensure that concentrations don't rise to problematic levels.

A summary of synergies and trade-offs in relation to implementing mitigation measures is provided in Table 16.

Table 16: Summary of synergies and trade-offs of delivery mechanisms

Measures impacting pollutant	Will have a positive impact on pollutant(s)
NO_2	NO
PM_{10}	Black carbon, ultrafine particles, bioaerosols, chromium VI, elemental carbon, brown carbon, total carbon, nickel
$PM_{2.5}$	
Benzo[a] pyrene (B[a]P)	Benzo(G,H,I) perylene, benzo(K) fluoranthene, indeno[123-cd]pyrene)
NO_2, NO, NH_3, NMVOCs, SO_2	PM_{10}, $PM_{2.5}$
Measures impacting pollutant	**May have an adverse impact on pollutant(s)**
NO_2 and NO, VOC	O_3

5.4 OTHER ENVIRONMENTAL TRADE-OFFS

When considering delivery mechanisms for reducing air pollutants, there are sometimes trade-offs to consider with other environmental benefits. The main trade-off being with greenhouse gases (GHGs) when air pollutants are reduced by delivery mechanisms which result in increased GHG emissions, or when delivery mechanisms for reducing GHG emissions result in increased emissions or concentrations of air pollutants.

The Net Zero Strategy 2021[55] offers the opportunity to reduce air pollution as climate change and air pollution have many of the same sources. However, some policies and proposals such as hydrogen combustion in a

[50] Grange et al. (2021) COVID-19 lockdowns highlight a risk of increasing ozone pollution in European urban areas. *Atmos. Chem. Phys.*, 21, 4169–4185. Accessed online: https://acp.copernicus.org/articles/21/4169/2021/ (31/01/2023)

[51] Grange et al. (2021) COVID-19 lockdowns highlight a risk of increasing ozone pollution in European urban areas. *Atmos. Chem. Phys.*, 21, 4169–4185. Accessed online: https://acp.copernicus.org/articles/21/4169/2021/ (31/01/2023)

[52] Ren, J. and Xie, S. (2022) Diagnosing ozone-NOx-VOC sensitivity and revealing causes of ozone increases in China based on 2013-2021 satellite retrievals, Accessed online: https://acp.copernicus.org/preprints/acp-2022-347/acp-2022-347.pdf (31/01/2023)

[53] Fenech, S. et al. (2021) COVID-19-Related Changes in NO2 and O3 Concentrations and Associated Health Effects in Malta, Front. Sustain. Cities, 28 January 2021 Sec. Health and Cities Volume 3. Accessed online: https://www.frontiersin.org/articles/10.3389/frsc.2021.631280/full (08/02/2023)

[54] Brancher, M. (2021) Increased ozone pollution alongside reduced nitrogen dioxide concentrations during Vienna's first COVID-19 lockdown: Significance for air quality management. *Environmental Pollution*, volume 284, 117153.

[55] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

domestic or industrial setting, anaerobic digestion and biomass combustion may increase NO_2, NH_3 and fine particulate matter respectively.

Additional schemes with environmental benefits, such as reducing GHGs, also have trade-offs with air pollutants. The Boiler Upgrade Scheme (previously named the Clean Heat Grant), the successor policy to the Domestic RHI was launched in 2022 and will provide financial support for the installation of heat pumps and in limited circumstance biomass boilers in domestic and small non-domestic properties in England and Wales. Defra is currently undertaking a research study to develop emission factors for domestic solid fuels, including wood, in order to better understand air pollutant emissions from domestic combustion.

5.5 RISKS TO DELIVERY

In collating the delivery mechanisms for each of the sectors a number of risks to delivery were identified, these ranged from the cost of new technology to lack of engagement with new technologies from different sectors. The risks to delivery are outlined in Appendix 4. A summary of main risks to delivery is provided in Table 17 below.

The main risks to the delivery mechanisms often include cost either to householders or the authority implementing a new scheme or technology. If regulations or legislative actions require a change there will be less risk to the implementation of the measures. The delivery mechanisms often require a behaviour change or increase in uptake of new technology.

Table 17: Summary of delivery risks

Source sector	Delivery mechanisms group	Risks to delivery
Road Transport	OEP1 - Improve vehicle fleet with sustainable and low emission vehicles	- The high cost of replacing existing fuel based vehicles with low emission electric vehicles. There is a risk of limited or slow uptake associated with the high cost. - The fact that retrofitting would only be applicable to heavy duty vehicles. - Adoption of scrappage schemes are perceived as expensive and have the potential to break state aid rules as supporting the motor industry and are cost-effective only in the short term
	OEP3 - Land use planning and vehicle restriction	- Planning and consultation delays. Risks relating to vehicle restriction zones, e.g. low emission or clean air zones: - The possibility of emissions increase at the boundary of the restriction zone, although limited evidence of this in relation to London.
	OEP4 - Business and behaviour change	Risks related to modal shift to active and/or public transport: - The need for regular and consistent communication and education of the public on the benefits is needed to support behaviour change and acceptance. - Cost - as modal shift to alternative modes would also need to be more affordable to influence public uptake. There is a risk of low uptake if costs remain high and unaffordable. - Infrastructure - barriers to implementation of active modes include limited dedicated cycle lanes, road safety and adverse weather conditions. Risks related to anti-idling enforcement: - No alternative cooling system in current freight refrigeration units, so as to enforce anti-idling as the engine needs to run for temperature control although a novel regenerative auxiliary power system could be available in the near future.
Aviation, Railways and National Navigation	OEP11 - Improved fuel and emissions standards	Risks relating to adoption of abatement retrofit to diesel train engines: - Cost of abatement retrofit to diesel trains to electric is prohibitive. Risks relating to adoption of alternative fuels in aviation (synthetic paraffinic kerosene or Liquid Hydrogen (LH2)) and maritime (LNG fuel) industries: - Liquid hydrogen (LH2) is currently at the research and conceptual level for the aviation industry and its viability will be known in due course. - High costs of retrofitting maritime vehicles with LNG may be prohibitive alongside the current lack of infrastructure to support its use.
	OEP12/13 - Infrastructure improvement	Risks relating to electrification of railway and bimodal (electric-diesel) trains: - Cost is main barrier to electrification of the railway - Currently, all 1,030 bi-mode trains operating in the UK have diesel generators as their on-board power source. Drawbacks include less power when in diesel mode, increased weight, increased complexity and maintenance and less favourable environmental performance.
	OEP14 - Policy and regulations	No direct evidence on the risks to success from research on these measures

Source sector	Delivery mechanisms group	Risks to delivery
Public electricity and heat production	OEP5 - Reduce emissions from combustion	Risks relating to combustion modification/abatement options: - The willingness of operators to adopt additional abatement technology may be low, especially where operator already meets their permit limits, unless upgrades are mandatory or at an affordable cost - A risk of Carbon Capture and Storage, which is that although CCS reduces CO_2 significantly, there is the potential for all the other pollutants to increase slightly
	OEP6 - Replacement of energy supply	- There is a risk of limited or slow uptake due to high cost. Although investments are being made to allow for affordable heat pumps, Photovoltaic and other renewable energy supply, this may not be sufficient enough to support individuals or businesses in making this change.
	OEP7 - Improve building fabric for efficient energy use	- There is a risk of limited or slow uptake due to high cost. Although investments are being made to allow for improved building performance for new buildings, this may not be sufficient to help with old buildings retrofit.
Petroleum refining, manufacture of solid fuels and combustion in manufacturing industries and construction; and fugitive emissions from energy production	OEP8 - Reduce emissions from combustion	- The willingness of operators to adopt additional abatement technology may be low, especially where operator already meets their permit limits, unless upgrades are mandatory or at an affordable cost
	OEP9 - Replacement of energy supply	- There is a risk of limited or slow uptake due to high cost. Although investments are being made to allow for affordable heat pumps, photovoltaic systems and other renewable energy supply, this may not be sufficient enough to support individuals or businesses in making this change.
	OEP10 - Modification of processes with fugitive emissions	No direct evidence on the risks to success from research on these measures.
Commercial/ Institutional and residential combustion	OEP15 - Reduce emissions from combustion	- The willingness of operators to adopt additional abatement technology may be low, especially where operator already meets their permit limits, unless upgrades are mandatory or at an affordable cost
	OEP16 - Fuel switch	- Willingness of households to take-up technology may be low where initial cost is high. It is possible that current high energy costs may make take-up attractive.
	OEP17 – Regulations	Risks relating to banning pre-packaged traditional house coal for domestic burning: - Consultation of proposed regulations found that respondents were concerned that on an energy density basis, burning dry wood may result in more $PM_{2.5}$ emissions relative to burning coal, based on the findings of an industry assessment.[56] This risk has been investigated in detail and Government has concluded it should proceed with the proposed phase out of coal.[57]
	OEP18 - Improve building fabric for efficient energy use	- The costs of improvements like cavity, loft and solid wall insulation creates a risk of low or slow uptake. Although investments are being made to allow for improved building performance for new buildings, this may not be sufficient to help with old buildings retrofit.

[56] https://www.legislation.gov.uk/ukia/2020/50/pdfs/ukia_20200050_en.pdfpage 8.
[57] https://www.legislation.gov.uk/ukia/2020/50/pdfs/ukia_20200050_en.pdf, page 8.

Source sector	Delivery mechanisms group	Risks to delivery
Industrial processes	OEP19 - Adopting abatement systems	- Cost of adopting a new abatement system could result in limited or slow uptake, unless required by regulation or there are grants available. - One common problem with selective catalytic reducers (SCR) is that they operate well only within narrow temperature bands. Consequently, control units are required to ensure the exhaust gas temperatures are within the range that will allow the catalytic reaction to occur.
	OEP20 - Policy and regulations	- Compliance cost and administrative or permitting cost for the competent authorities and operators could prevent or delay development and adopted of new policy or regulations.
	OEP21 - Use of improved products	- Cost of improved products such as solvent-free coating systems could result in limited or slow uptake.
Waste Treatment and Disposal	OEP22 - Reduce biodegradable waste	Risks relating to anaerobic digestion or composting of waste (as preferred options to landfill) - The main limitations on anaerobic digestion compared to composting is the higher investment costs. - Limitations in compost quality and regulatory barriers to land application.
	OEP23 – Improve waste processes	Risks relating to digestate spreading techniques to reduce ammonia emissions: - Due to the variability of the organic wastes from which digestate can be obtained and their pH changes, they can have different NH_3 to N ratio , and consequently different emissions to the atmosphere.
Agriculture	OEP24 - Adopt new farming practices	Risks relating to fertiliser application changes: - NH_3 emissions from fertilisers application is dependent on application rate, rainfall (or irrigation), temperature, and rate of crop uptake. - Understanding of emissions variation with agroclimatic conditions is limited. Data are needed to allow usage of urease inhibitors to be optimised. There has been little testing of urease inhibitors for minimisation of NH_3 emission from outdoor livestock excreta under field conditions. - In the case of urea inhibitors or urea substitution, there is limited evidence of any agronomic advantage, which is a barrier to uptake, even where N losses to air are decreased (Cancellier et al, 2016). However, this could be implemented by legislation to make urea without urease inhibitor unavailable in the UK. Risks relating to banning the use of urea: - There are risks on the economic impact such as increased costs of AN and/or reduced competition in the fertiliser market. Risks relating to covering solid manure heaps: - There is a risk of unwanted trade-offs, as NH_3 emissions saved early in the management chain can be lost at a later stage (Hou et al, 2015). Reductions in NH_3 emissions at the manure storage stage will result in increased N (TAN) content of manure and therefore in potentially larger NH_3 losses (emissions) following land spreading. - A risk to successful implementation is farmers' perceptions of benefits.

5.6 DELIVERY ASSURANCE ASSESSMENT

In this section, views on the assurance of mitigation measures, and the availability of viable delivery pathways for short-term and long-term actions are considered. This evaluation shows that measures focusing on land-use planning and energy efficiency are the most likely to be successful.

Table 18: Delivery assurance assessment of mitigation measures, used to determine overall deliverability. Total scores of 1-3 are “Low”, 4-6 are “Medium” and 7-9 are “High".

Relevant sector in Mitigation Table (Annex ###)	Delivery mechanisms group	Measure ranking			
		Reliability/ certainty	Speed of deployment	Cost	Deliverability
Road Transport	OEP1 - Improve vehicle fleet with sustainable and low emission vehicles	2	1	3	Medium
	OEP2 - Compliance checks	0	0	2	Low
	OEP3 - Land use planning and vehicle restriction	3	2	3	High
	OEP4 - Business and behaviour change	2	3	1	Medium
Aviation, Railways and National Navigation	OEP11 - Improved fuel and emissions standards	2	0	0	Low
	OEP12/13 - Infrastructure improvement	2	1	2	Medium
	OEP14 - Policy and regulations	3	0	0	Low
Public electricity and heat production	OEP5 - Reduce emissions from combustion	2	2	1	Medium
	OEP6 - Replacement of energy supply	3	2	2	High
	OEP7 - Improve building fabric for efficient energy use	3	2	2	High
Petroleum refining, manufacture of solid fuels and **combustion in manufacturing industries and construction;** and fugitive emissions from energy production	OEP8 - Reduce emissions from combustion	2	2	1	Medium
	OEP9 - Replacement of energy supply	3	2	2	High
	OEP10 - Modification of processes with fugitive emissions	2	1	0	Low
Commercial/Institutional and residential combustion	OEP15 - Reduce emissions from combustion	2	2	1	Medium
	OEP16 - Fuel switch	0	1	2	Low
	OEP17 - Regulations	2	1	1	Medium
	OEP18 - Improve building fabric for efficient energy use	3	2	2	High
Industrial processes	OEP19 - Adopting abatement systems	2	1	1	Medium
	OEP20 - Policy and regulations	2	1	2	Medium

Relevant sector in Mitigation Table (Annex ###)	Delivery mechanisms group	Measure ranking			
		Reliability/ certainty	Speed of deployment	Cost	Deliverability
	OEP21 - Use of improved products	2	1	1	Medium
Waste Treatment and Disposal	OEP22 - Reduce biodegradable waste	0	0	0	Low
	OEP23 - Improve waste processes	1	0	0	Low
Agriculture	OEP24 - Adopt new farming practices	1	2	2	Medium

5.7 AMBITION ASSESSMENT

In this section, an assessment of how England and Northern Ireland standards and targets compare with other countries and international guidelines was carried out. Comparisons could be made against EU Ambient Air Quality Directive targets (current and those proposed in 2022), the WHO international guidelines, and the USA National Ambient Air Quality Standards.

It's worth noting that the proposed revisions to the EU Ambient Air Quality Directive targets and the USA National Ambient Air Quality Standards are not yet secured.

Table 19: Comparison of air quality targets and standards for “very high risk” and “high risk” pollutants between England and NI, and the EU, the WHO and USA

Pollutants	Standard/target (units)	Comparison of standards and targets					
		England and NI	EU		USA		WHO
		Current	Current	Proposed	Current	Proposed	
Very high risk pollutants							
$PM_{2.5}$	Annual mean concentration (µg/m^3) (Year to be achieved by, if applicable)	10 (2040)	25 (2010)	10 (2030)	12	9-10	5
	24-hour mean concentration (µg/m^3) (Year to be achieved by, if applicable)	NA	NA	25* (2030)	35	NA	15
Ultrafine particles	*No standards or targets found for ambient air quality*						
High risk pollutants							
NO_2	Annual mean concentration (µg/m^3) (Year to be achieved by, if applicable)	40 (2005)	40 (2010)	20 (2030)	~99.64	NA	10
	Hourly concentration limit (µg/m^3) (Year to be achieved by, if applicable)	200 (2006)	200 (2010)	NA	~188**	NA	NA
NO	*No standards or targets found*						
Chromium VI	Annual mean concentration (µg/m^3)	0.00025	*No standards or targets found*				
Ammonia	Annual mean critical level for vegetation protection (µg/m^3)	1 or 3	*No standards or targets found*				
Benzo[k] fluoranthene	*No standards or targets found*						
Ideno[123-cd]pyrene	*No standards or targets found*						
Bioaerosols	*No standards or targets found*						
Black carbon/ Elemental carbon	*Standards exist for $PM_{2.5}$ but not for BC/EC*						
Brown carbon	*Standards exist for certain organic species such as B[a]P within brown carbon but not for brown carbon / TC as a whole.*						
Total carbon							

Green = England and NI standard/target lower, yellow = same standard, orange = England and NI standard/target higher.

*Not to be exceeded on more than 18 occasions per year ** 1-hour daily maximum limit

For the majority of very high risk and high risk pollutants, there is a lack of standards and targets globally. Only for $PM_{2.5}$ and NO_2 are there are comparable standards.

The annual mean standard for $PM_{2.5}$, has recently been updated from 20 µg/m^3 to 10 µg/m^3 in England and Northern Ireland, to be achieved by 2040[58]. This is in line with the EU proposed standard for annual mean $PM_{2.5}$, though by different deadlines (2030 is the deadline for the EU proposed standard). The 10 µg/m^3 annual mean concentration standard for England, Ireland and the EU is twice the WHO guideline annual mean limit of 5 µg/m^3 for $PM_{2.5}$. The new England and Northern Ireland standards are slightly below the USA annual mean standard for $PM_{2.5}$. It's worth noting that the recently published Environmental Improvement Plan[59] cites that the UK government will also introduce an interim target of 12 µg/m^3 for $PM_{2.5}$ to be achieved by the end of January 2028. There are 24-hour mean objectives for $PM_{2.5}$ in the proposed EU AAQD update, in the WHO guidelines and in the US standards, however a 24-hour mean or a short-term concentration standard or target for $PM_{2.5}$ is not currently in place or proposed for England and Northern Ireland.

For NO_2, England and Northern Ireland have the same current annual mean concentration standard, as the current EU standard. Recent evidence from WHO indicates that much lower standards are required to protect human health. The WHO guideline for annual mean NO_2 is 10 µg/m^3. As such, the NO_2 annual mean standard is due to be reduced by half (to 20 µg/m^3) in the updated EU Ambient Air Quality Directive. The proposed new EU standard is still twice as high as the WHO guideline, whilst the England and Northern Ireland standard is four times as high. There are no current known proposals or plans to change the NO_2 concentration targets in England and Northern Ireland. The USA annual mean standard is 53 ppb, which converts to approximately 99.64 µg/m^3, which is considerably greater than any other standard. The USA hourly mean is slightly less than that of England and Northern Ireland, and is not to be exceeded once in a year where the England and Northern Ireland (and EU) hourly objective is not to be exceeded more than 18 times per year.

The chromium VI limit is an Environmental Assessment Level (EALs) and are used by the Environment Agency to judge the acceptability of proposed emissions to air from industrial site, and therefore apply only to England and not to Northern Ireland.

Non-statutory critical levels are used in England and Northern Ireland for protection of nature conservation sites. Additionally, emissions are controlled at an international level in accordance with CLRTAP and NECR requirements.

There are no other comparable standards and targets for the very high risk and high-risk pollutants, though standards and guidelines relating to $PM_{2.5}$ and B[a]P are relevant to total carbon, black carbon and brown carbon.

[58] https://www.gov.uk/government/news/new-legally-binding-environment-targets-set-out

[59] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1133967/environmental-improvement-plan-2023.pdf

6. EVIDENCE GAP ANALYSIS

Based on the evaluations set out above, the quality of evidence for each pollutant was identified. Key knowledge gaps were identified which can be used as the basis for further prioritised research.

The overall scores for "Quality of the evidence" for each pollutant reviewed in the Risk Assessments are summarised in Table 20, categorised by score. The risk assessment summaries presented in Section 3.1 also include this information, with further detail explaining why the "Quality of evidence" score was achieved.

Table 20: Quality of evidence scores

15x "Very good" Quality of the evidence	16x "Good" Quality of the evidence score	6x "Moderate" Quality of the evidence score	2x "Poor" Quality of the evidence score
$PM_{2.5}$	Ultrafine particles	Black carbon	Micro- and Nano-plastics
Nickel	Ammonia	Hydrogen Fluoride	Bioaerosols
Nitrogen dioxide	Dioxins	Black carbon/elemental carbon	**2**
Benzo[a]pyrene	NMVOCs	Brown carbon	
Cadmium	Formaldehyde	Hydrogen cyanide	
Ozone	Per-Polyfluorinated compounds	Hydrogen chloride	
1,3-butadiene	Toluene	**6**	
Beryllium	Xylene		
Chromium	Benzo(G,H,I)Perylene		
Copper	Benzo(K)Fluoranthene		
Manganese	Indeno[123-cd]pyrene		
Vanadium	Nitric oxide		
Selenium	Nitrogen trifluoride		
PM_{10}	Organic carbon		
Sulphur dioxide	Sulphur hexafluoride		
15	Total carbon		
	16		

The majority of pollutants scoring "very good" or "good" on quality of evidence are those which are included in national monitoring networks and/or modelling compliance assessment of concentrations, and in the National Atmospheric Emissions Inventory (NAEI).It should be noted that for some pollutants there were multiple scores representing different types of evidence and therefore although the overall ratings are provided above there may be other types of evidence that were not so good for some pollutants.

6.1 EVIDENCE GAPS AND AREAS FOR PRIORITY RESEARCH

6.1.1 Evidence gaps relating to government commitments and recommendations

Some of the government strategies, policies and plans reviewed as part of Task 5 included acknowledgement of evidence gaps. Further evidence gaps were highlighted in reports by scrutiny bodies. Five key themes amongst evidence gaps and recommended areas for further research were identified:

1. A lack of information on Government's ambitions for pollutants outside of $PM_{2.5}$, and emerging pollutants
2. Indoor air pollution as a research priority. Effective ventilation for reducing indoor air pollution is a major engineering challenge which needs solving,
3. Emissions from tyres and road wear is a key research and innovation need.
4. A greater range of options for reducing air pollution emissions from heavy vehicles is needed.

5. Best practise methods should be identified for integrating measures for agricultural pollution to both air and water.

The Chief Medical Officer's 2022 annual report provided a comprehensive list of research gaps on air pollution, including:

- The role of different forms of PM at $PM_{2.5}$ sites and smaller
- Understanding of health impacts of indoor air pollution and impacts of building design, the building materials used, consumer products such as personal care products, cleaning products, paints or glues, and ventilation.
- Understanding the relative importance of peak concentrations of air pollution compared to cumulative (area-under-the-curve) exposure on different acute and chronic health conditions
- The impact of tyre wear on health.
- Tyres which minimise PM emissions whilst maintaining road safety
- Emissions from trains (especially in urban areas), underground transport, aviation and shipping need research to reduce impacts
- Emissions from refrigerated vehicles and last-mile deliveries need solutions
- Engineering solutions for indoor air quality, building heating and energy efficiency should be identified.
- Better evaluations of interventions to reduce air pollution, e.g. traffic flow interventions, green spaces, improved active transport infrastructure.

Evidence gaps relating to specific pollutants in the recommendations by scrutiny bodies are summarised in Table 21.

Table 21: Evidence gaps relating to specific pollutants flagged by scrutiny bodies

Pollutant	Recommendation	Evidence gap area	Recommended by
Dioxins	Increased monitoring of dioxins "**"**semi-continuous measurements in the incinerator smokestack, including during [other than normal operating conditions]: start-ups, shutdowns, failures, and air pollution control device fallouts"	Monitoring	National Audit Office[60]
$PM_{2.5}$	The monitoring network needs significant expansion. Establishing a binding, minimum requirement for the number of $PM_{2.5}$ monitors is critically important as this does not exist in current legislation.	Monitoring	Client Earth[61]
NH_3	Examine co-benefits of tackling local rural NH_3 sources for biodiversity protection and human health (e.g. formation of urban $PM_{2.5}$ by ammonium nitrate).	Mitigation	JNCC[62]
NH_3	Update and maintain national source attribution data. A more detailed source attribution dataset is required allowing the proportion of long-/medium-/short-range N inputs at each site for each source type.	Sources	JNCC[55]
NH_3, NO, NO_2	Address outstanding gaps to demonstrate what restoration measures can help maintain (or improve) habitat quality in situations where nitrogen deposition remains too high	Mitigation	JNCC[55]

[60] All-Party Parliamentary Group on Air Pollution. Pollution from Waste Incineration: A Synopsis of Expert Presentations on Health and Air Quality Impacts. https://appgairpollution.org/report-pollution-from-waste-incineration/ (2021).

[61] ClientEarth. Consultation on Environmental Targets – ClientEarth response. https://www.clientearth.org/latest/documents/clientearth-responds-to-uk-consultation-on-environmental-targets/ (2022).

[62] Joint Nature Conservation Committee, Natural England, Natural Resources Wales, Northern Ireland Environment Agency, & Scottish Natural Heritage. A framework for UK research and evidence needs relating to air pollution impacts on ecosystems. https://hub.jncc.gov.uk/assets/3bf07082-670c-4dc1-b059-b1dfb97069f9 (2015).

UFP	Policies and actions to control ambient $PM_{2.5}$ and PM_{10} do not always control UFPs, indicating a regulatory gap and room for improvement in this respect.	Mitigation	AQEG[63]

6.1.2 Evidence gaps relating to current pollutants.

Pollutant-specific evidence gaps identified in the literature, data and evidence search are summarised in Table 22. Evidence gaps were not found for every pollutant, which doesn't necessarily indicate that the state of evidence is perfect – the risk assessments in Annex 2 and specifically the scores for quality of evidence provide further information for the different pollutants.

Table 22: Summary of evidence gaps relating to current pollutants. X = Limited or lacking evidence.

Pollutant Name	Monitoring	Nature/ composition	Sources	Health impacts	Environmental impacts	Trade-offs
Very high risk pollutants						
$PM_{2.5}$						
Ultrafine particles (UFP)*	X		X	X		
High risk pollutants						
Ammonia (NH_3)			X			
Benzo(g,h,i)perylene						
Benzo (k)fluoranthene						
Bioaerosols*	X	X		X	X	
Black/ Elemental carbon *	X			X		
Brown carbon*	X	X		X	X	
Chromium (Cr)						
Indeno[123-cd]pyrene						
Nitrogen dioxide (NO_2)				X		
Nitric oxide (NO)				X	X	
Total Carbon*	X					
Medium risk pollutants						
Benzo[a]pyrene (B[a]P)						
Dioxins and Furans					X	
Formaldehyde	X				X	
Hydrogen chloride	X					
Micro- and nano-plastics*	X	X		X	X	
Nickel						
Organic carbon	X					
Ozone (O_3)						X
Perfluorocarbon	X				X	
PM_{10}						
Sulphur hexafluoride (SF_6)		X				
Low risk pollutants						
1,3 Butadiene						
Arsenic						
Beryllium	X					
Cadmium						
Chlorine and Inorganic compounds	X					

[63] Department for Environment Food and Rural Affairs, Scottish Government, Welsh Government & Department of the Environment in Northern Ireland. Ultrafine Particles (UFP) in the UK. https://uk-air.defra.gov.uk/library/reports.php?report_id=968 (2018).

Pollutant Name	Monitoring	Nature/ composition	Sources	Health impacts	Environmental impacts	Trade-offs
Copper						
Hydrogen Fluoride	X				X	
Manganese						
Nitrogen trifluoride (NF_3)					X	
Non-methane volatile organic compounds (NMVOCs)				X	X	X
Selenium						
Sulphur dioxide (SO_2)						
Toluene	X				X	
Vanadium						
Xylene	X					

**Emerging pollutant*

6.1.3 Evidence gaps relating to delivery mechanisms for pollutant reduction

Evidence gaps highlighted in Task 4 in relation to the effectiveness of delivery mechanisms and mitigation measures are summarised in Table 23.

Table 23: Summary of evidence gaps in relation to the effectiveness of mitigation measures

Delivery mechanisms group	Evidence gap
OEP1 - Improve vehicle fleet with sustainable and low emission vehicles	No information available from this research on the UK Government's schemes for supporting alternative fuels, scrappage, retrofitting and installation of DPFs or the enforcement of Euro 6/VI standards.
OEP2 - Compliance checks	No evidence was found that vehicle emissions tests (MOT) and roadside checks improve air quality. No direct evidence from research on the speed of deployment of these measures.
OEP4 - Business and behaviour change	There is no evidence on the effectiveness of active transport (walking and cycling), but this likely to be low, although it has health benefits.
OEP6 - Replacement of energy supply	No direct evidence was found on the scale of improvement associated with replacement of both gas and coal with renewable energy.
OEP7 - Improve building fabric for efficient energy use	The Government has announced a mission to at least halve the energy use of new buildings by 2030 through developing innovative energy and low carbon technologies driving lower cost, and high-quality construction techniques. No direct evidence was found on the scale of improvement associated with this measure. No information found concerning progress to date on commitments by the UK Government to halve the energy use of new buildings.
OEP8 - Reduce emissions from combustion	The extent of the adoption of combustion modification/ abatement options i.e., SCR, SNCR, ESP,FGD)/ low sulphur fuel/Regenerative catalytic oxidise (RCO) plants / Regenerative thermal oxidisers (RTO) plants/carbon Capture and Storage (CCS) within the existing facilities is not known and as such the certainty of success cannot be deduced.
OEP9 - Replacement of energy supply	The extent of the adoption of measures relating to homes switching from wood to gas boilers, heat pumps/ switch from oil, coal or wood to

Delivery mechanisms group	Evidence gap
	renewables/ solar water heating is not known, and as such the certainty of success cannot be deduced.
OEP11 - Improved fuel and emissions standards	No direct evidence from research on the speed of deployment of these measures
OEP12/13 - Infrastructure improvement	There is currently no evidence on emissions decrease due to the use of bimodal trains.
OEP14 - Policy and regulations	No direct evidence from research on the speed of deployment of these measures.
OEP15 - Reduce emissions from combustion	The extent of the adoption of combustion modification/ abatement options i.e., SCR, SNCR, ESP,FGD)/ low sulphur fuel/ Regenerative catalytic oxidise (RCO) plants / Regenerative thermal oxidisers (RTO) plants/carbon Capture and Storage (CCS) within the existing facilities is not known and as such the certainty of success cannot be deduced.
OEP16 - Fuel switch	The extent of the adoption of measures relating to homes switching from wood to gas boilers, heat pumps/ switch from oil, coal or wood to renewables/ solar water heating is not known, and as such the certainty of success cannot be deduced.
OEP18 - Improve building fabric for efficient energy use	The Government has announced a mission to at least halve the energy use of new buildings by 2030 through developing innovative energy and low carbon technologies driving lower cost, and high-quality construction techniques. No direct evidence was found on the scale of improvement associated with this measure. No information found concerning progress to date on commitments by the UK Government to halve the energy use of new buildings.
OEP22 - Reduce biodegradable waste	No direct evidence from research on the reliability or certainty of success of composting, incineration and anaerobic digestion of biodegradable waste which would otherwise be sent to landfill. No direct evidence from research on the speed of deployment of these measures.
OEP23 - Improve waste processes	No direct evidence from research on the speed of deployment of these measures.
OEP24 - Adopt new farming practices	Baseline data are needed on current levels of implementation to allow estimation of potential further uptake. Little evidence on speed of deployment/effect of these measures.

Additionally, there was limited evidence regarding the cost of the following groups of measures:

- OEP2 - Road transport compliance checks
- OEP3 - Road transport land use planning and vehicle restriction
- OEP4 - Road transport business and behaviour change measures
- OEP10 - Modification of processes with fugitive emissions
- OEP11 - Improved fuel and emissions standards for aviation, railways and national navigation
- OEP12 - Infrastructure improvement for aviation, railways and national navigation
- OEP13 – Policy and regulations for aviation, railways and national navigation
- OEP22 - Reduce biodegradable waste
- OEP23 - Improve waste processes

- OEP24 - Adopt new farming practices

6.2 RECOMMENDATIONS FOR FUTURE WORK

Following our evidence gap analysis, and based on our literature, evidence, and data search, we would recommend future work should address the following items:

1. Further research into the composition, behaviours, measurement techniques and (if necessary) control/reduction measures for emerging very high and high risk pollutants: ultrafine particles, brown carbon, total carbon and bioaerosols.
2. Increased monitoring and improved monitoring techniques of the following very high and high-risk pollutants: $PM_{2.5}$, ultrafine particles, black carbon, ammonia.
3. A review of standards and targets for all air pollutants to accompany the new UK $PM_{2.5}$ objectives.
4. Investigation of delivery mechanisms for reducing emissions and concentrations of Ultrafine particles, and research to better understand the effectiveness of delivery mechanisms for reducing PM_{10} and $PM_{2.5}$ on PM constituents: Ultrafine particles, Total Carbon Black carbon, Brown carbon and Bioaerosols.
5. Investigation of delivery mechanisms to reduce emissions from emerging and ongoing sources such as brake and tyre wear.
6. Investigation of delivery mechanisms to reduce indoor air pollution.
7. Implementation of delivery mechanisms should be coordinated to ensure an integrated approach is adopted to take advantage of co-benefits avoid trade-offs. Delivery mechanisms to reduce NOx emissions should be implemented alongside mechanisms to reduce NMVOCs and other precursor pollutants of O_3, to ensure a trade-off increase in O_3 is prevented.

In relation to point 3, it is important for the UK government to keep its pollutant standards and targets under review, and consider new evidence as and when it emerges, and if updates are needed. It is understood that the recent review and update of targets for $PM_{2.5}$ involved advice from AQEG and COMEAP and a call for evidence on future $PM_{2.5}$ concentrations. Development of the new targets also included evaluation of international $PM_{2.5}$ target setting. The Evidence Report produced notes that the WHO guideline for annual mean $PM_{2.5}$ was updated from 10 µg/m^3 to 5m µg/m^3 during the time of evidence gathering on the new UK targets[64].For example, the ambition assessment in Section 5.7 identified that UK annual mean objective limit for Nitrogen Dioxide is twice as high as the new NO_2 objective which will be introduced in the updated EU Ambient Air Quality Directive, and four times as high as the WHO recommended limit. It should also consider new evidence as it emerges for pollutants which do not currently have standards or targets, and consider if it would be appropriate to introduce them.

In relation to point 6., it is important to state that indoor air pollution is outside of the scope of this project, and not considered in depth. However, this was a point consistently made in recommendations by scrutiny bodies, as assessed in Task 5 of the project (Appendix 3).

[64]https://consult.defra.gov.uk/natural-environment-policy/consultation-on-environmental-targets/supporting_documents/Air%20quality%20targets%20%20Detailed%20Evidence%20report.pdf

APPENDICES LIST (PROVIDED SEPERATLEY)

The below appendices are provided as separate documents:

APPENDIX 1: POLLUTANT FACTSHEETS

APPENDIX 2: POLLUTANT RISK ASSESSMENTS

APPENDIX 3: CATALOGUE OF RECOMMENDATIONS AND COMMITMENTS

APPENDIX 4: DELIVERY MECHANISMS REVIEW TABLE

APPENDIX 5: MARGINAL ABATEMENT COSTS

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