EVALUATION OF THE DAILY AIR QUALITY INDEX

Evaluation Report

Appendix to final report

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A. APPENDICES

The appendices are structured as follows:

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- Appendix 6: Survey Synopsis
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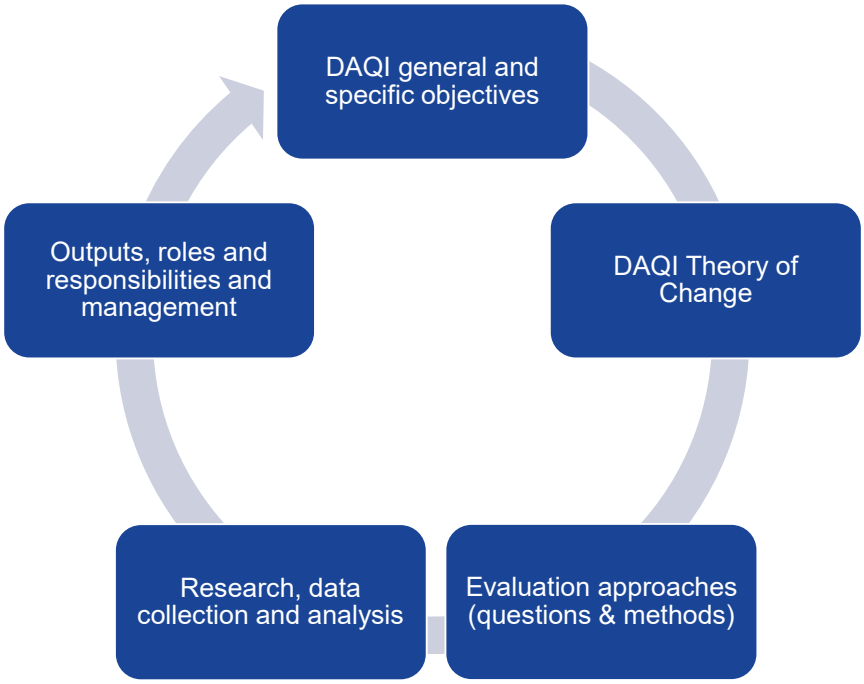
A1. Appendix 1: Evaluation Plan

In early stages of the project, an **Evaluation Plan** was developed drawing on HMT's Magenta Book[1], relevant literature and evaluation studies. The Plan was shared and agreed with Defra at early stages of the project, and subsequently implemented to perform the evaluation.

The Plan has five building blocks, which are depicted in Figure A1-1.

Figure A1-1 Building blocks of the Evaluation Plan



The rest of the Appendix provides an in-depth outline of the core building blocks, except for the DAQI general and specific objectives which are documented in Section 2 of this Report.

A1.1 INTERVENTION LOGIC AND THEORY OF CHANGE

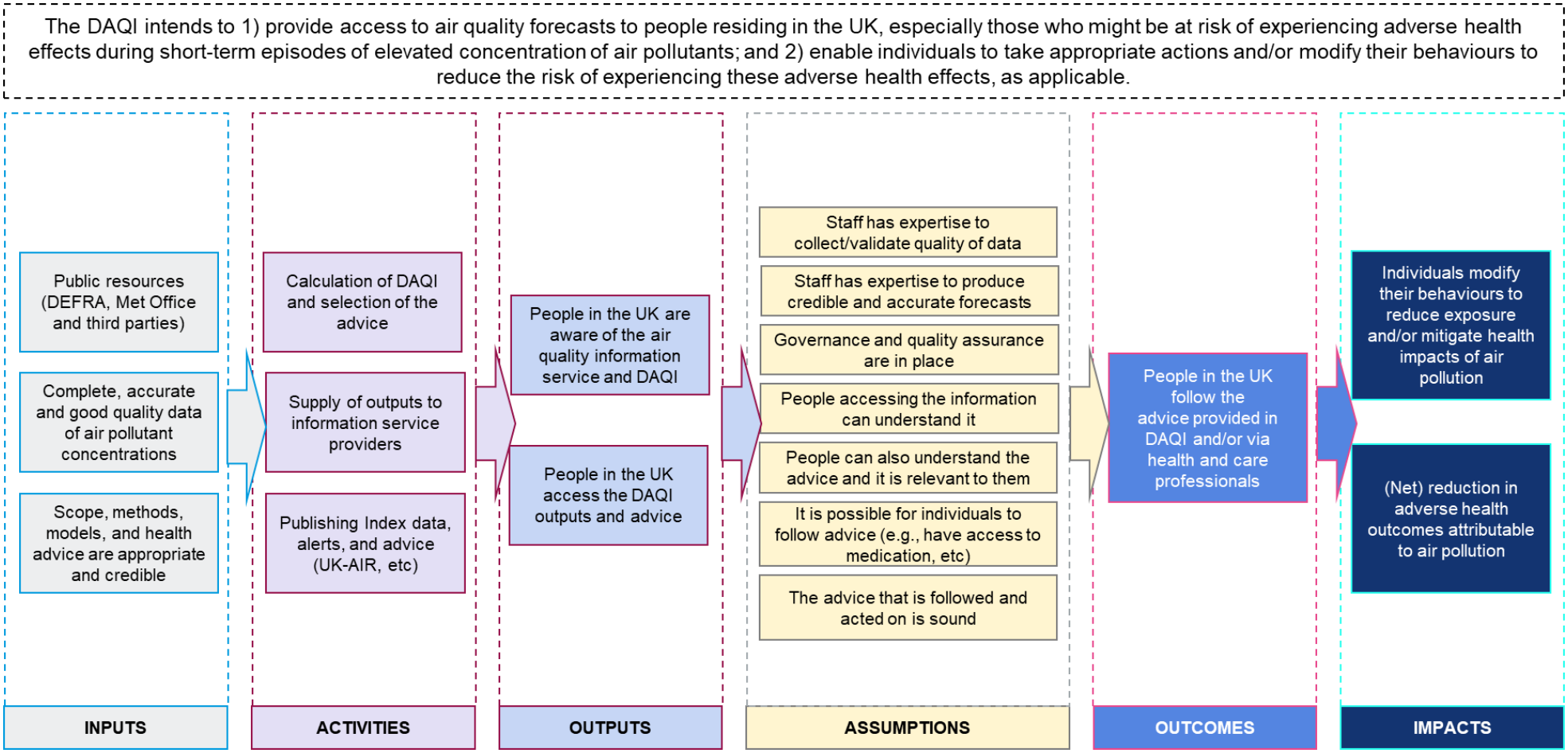
The Magenta Book sets out the stages that shall be followed to plan and execute an evaluation, starting with the scoping phase. The scoping phase seeks to develop a common understanding, in this case, of the DAQI, its objectives and evidence base; and capture this, to the extent that is possible, in a Theory of Change (TOC). The team has thus reviewed the DAQI's **intervention logic** and developed the **DAQI TOC** –the first building blocks of the Evaluation Plan. These are set out in the following sections.

A1.1.1 Revised intervention logic

Figure A1-2 sets out a revised intervention logic, which was undertaken as part of the steps to develop the DAQI's Theory of Change.

[1] HMT (2020). Magenta Book: Central Government Guidance on Evaluation. URL: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/879438/HMT_Magenta_Book.pdf

Figure A1-2 Revised intervention logic



A1.1.2 Theory of Change

The DAQI TOC sets out our **best understanding of how the DAQI might work to achieve its objectives and desired outcomes and impacts**. The TOC does this by mapping the core pathways of impact that could be associated with the DAQI. These pathways capture the key components and links between the inputs to the DAQI (e.g., public resources, air quality data, methodologies, and advice); the activities undertaken (e.g., publishing the index online); the outputs achieved (e.g., people in the UK are aware of daily levels of air pollution); the desired outcomes (e.g., the behaviour of people at risk), and impacts (e.g., mitigation of adverse, short-term health impacts attributable to air pollution). In addition, these pathways embed hypotheses or assumptions that are required for the desired outcomes and impacts to materialise but may not hold true in practice, and thus will be investigated as part of this study. Overall, the TOC will inform evaluation questions and research and evaluation methods proposed within this Plan.

The TOC has been developed by drawing on best practice[2] and following three steps as follows:

- *Step 1: In-depth review of the workings of the DAQI and targeted literature review*. The team reviewed Defra's UK Air Information Resources and the DAQI publications and associated services to understand all of the components and their objectives (see Section A4), as well as the activities that are being undertaken. The team also conducted a targeted literature review, especially considering studies that explored people's engagement with and/or access to these types of services and any links between this and behaviour change and/or health impacts.[3]
- *Step 2: Review of the intervention logic.* Based on this review and the team's expertise, the intervention logic was revised to identify the core components of the DAQI's TOC. Defra had already developed an intervention logic, and this was revised as a way to serve as a steppingstone to producing a TOC. The revised intervention logic can be found in Figure A1-2.
- *Step 4*: *Online workshop of experts.* A draft TOC was explored in an online workshop with 14 experts selected with Defra's support. This workshop sought feedback on the mapping of specific pathways of impact and gathered insights into aspects that might not be working as intended. The minutes from the TOC workshop can be found in Appendix 5.

Figure A1-3 represents the **DAQI TOC**, which underpin the design of the proposed DAQI Evaluation Plan.

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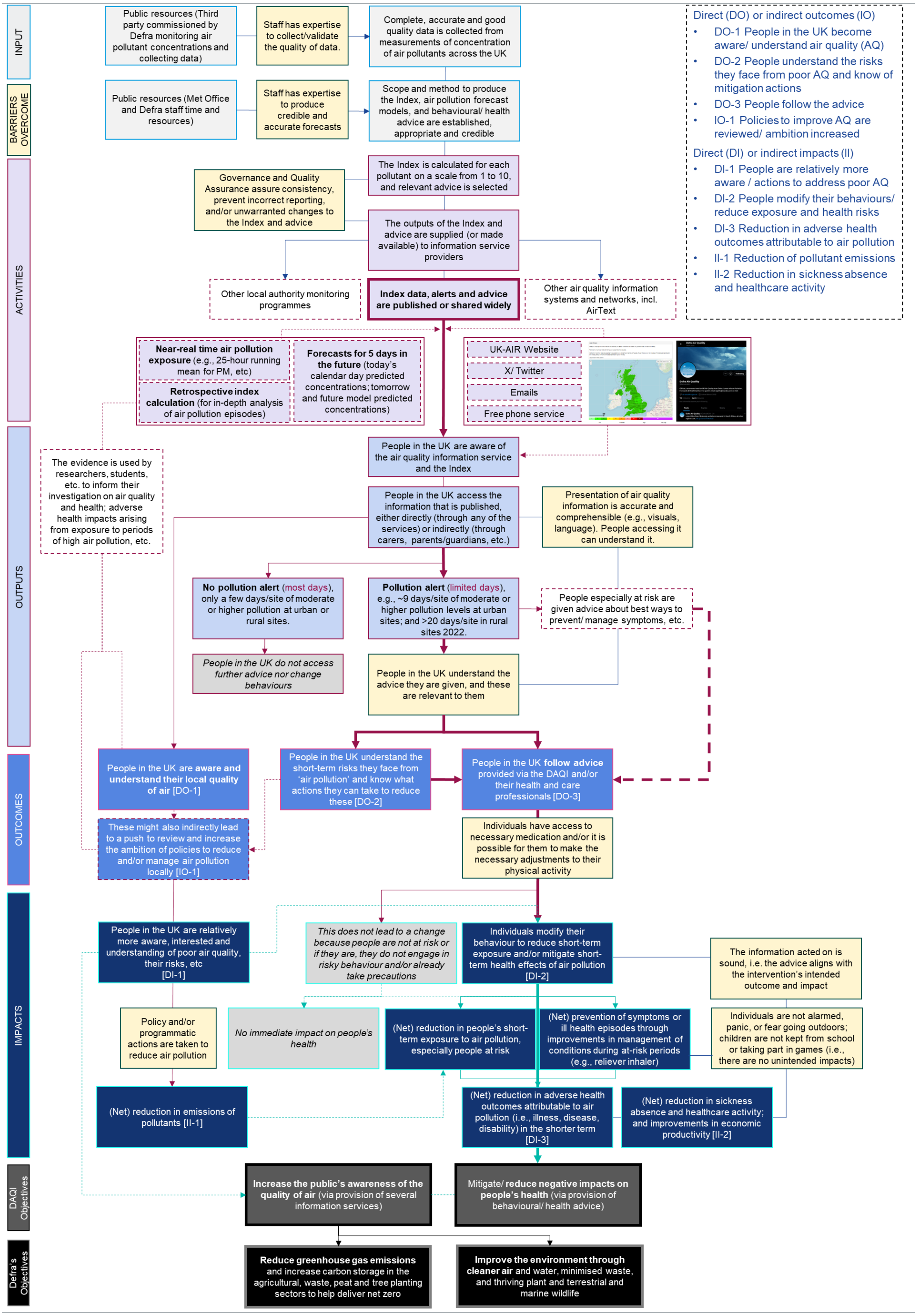
[2] HMT Magenta Book. URL: https://www.gov.uk/government/publications/the-magenta-book; and Defra Complexity Evaluation Framework. URL: https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectID=20401

[3] Studies reviewed include: Schulte, K. (2022). "'Real-time' air quality channels: A technology review of emerging environmental alert systems". Available at: https://journals.sagepub.com/doi/full/10.1177/20539517221101346; Air Quality Consultants (2020). "Air Quality and Health: Reviewing evidence and planning policy in London". Available at: https://www.london.gov.uk/sites/default/files/air_quality_health_evidence_review.pdf; Global Action Plan (2023). "Clean Air Public Insight Tracker". Available at: https://www.actionforcleanair.org.uk/capit; Northstar Air Quality (2020). "Review of international air quality indices". Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Air/review-international-air-quality-indices.pdf; D'Antoni et al. (2019). "The effect of evidence and theory-based health advice accompanying smartphone air quality alerts on adherence to preventative recommendations during poor air quality days: A randomised controlled trial". Available at: https://doi.org/10.1016/j.envint.2019.01.002; Lyons et al. (2016). "Effects of an air pollution personal alert system on health service usage in a high-risk general population: a quasi-experimental study using linked data". Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5136690/

Figure A1-3 DAQI Theory of Change



A1.2 EVALUATION APPROACH

This section sets out the research questions that will be addressed in this evaluation and the methods that will be employed to develop reasonable, evidence-based answers to these questions –the second building block to the Evaluation Plan.

A1.2.1 Evaluation questions (or CERQs)

As noted in the Report, the evaluation seeks to assess the appropriateness and effectiveness of the DAQI. To do so, six Core Evaluation Research Questions (CERQs) and Relevant Sub-Questions (RSQs) have been developed by Defra. These questions have been reviewed against the TOC and confirmed as part of this Evaluation Plan. It is thus considered that answering these questions through the research, data collection and analysis set out in Section A1.3 will allow the evaluation team to determine the extent to which the DAQI might be appropriate and effective; and will form the basis for identifying and developing recommendations to build on the DAQI's strengths and address any weaknesses.

These CERQs and RSQs have been reviewed and are presented in Table A1-1, together with a brief consideration as to how answering these questions might contribute towards the DAQI evaluation.

Table A1-1 Evaluation questions

Evaluation aims	Core Evaluation Research Questions (CERQ) grouped by theme	Relevant Sub-Questions (RSQ)	Contribution to the DAQI Evaluation
To assess appropriateness	**CERQ1:** To what extent does the modelled and measured data on which the DAQI is based, give a sufficiently, accurate and precise representation of real-world air quality conditions?	• **RSQ1.1:** To what extent does the AURN network provide sufficiently, complete and accurate measurement data to allow communication of a meaningful real time air quality index? • **RSQ1.2:** To what extent does the forecasting model on which DAQI forecasts are based provide sufficiently, precise and accurate predictions of future air quality conditions to allow individuals to meaningfully modify their behaviour? • **RSQ1.3:** To what extent does the granularity of data communicated via the DAQI (on UK-Air) allow individuals to meaningfully modify their behaviour based on their local air quality conditions?	Answering CERQ1 will allow us to: a) assess the **reliability** of the data inputs used in constructing the DAQI. Specifically, we will evaluate both the quantity and quality of these inputs. For instance, whether they constitute a reliable representation of air quality conditions and the impact of any missing data on the index. b) understand the **validity and accuracy of the methodologies** employed for forecasting and/or the accuracy of information communicated to the UK population.
	CERQ2: To what extent is the methodology by which the DAQI output (the index number and air quality band) is calculated, appropriate as a method of determining the short-term risk posed by real world conditions into an overall measure of air quality?	• **RSQ2.1:** Do the five pollutants included in the DAQI remain the most relevant pollutants to measure short-term air pollution risk in the UK setting? • **RSQ2.2:** To what extent do the breakpoints implemented in the DAQI continue to reflect the latest health evidence regarding the concentrations at which health effects may be experienced following short-term exposure to air pollution? • **RSQ2.3:** To what extent do the averaging times implemented in the DAQI reflect the latest health evidence regarding the period after which health effects may be experienced following short-term exposure to air pollution? • **RSQ2.4:** Does current understanding of the health effects of mixtures of air pollutants suggest the including mixture effects in the DAQI could have a substantial impact on health outcomes? • **RSQ2.5:** What is the health impact of treating days as discrete events for the purposes of the DAQI?	Answering CERQ2 will allow us to assess the **validity and accuracy** of: a) the methodology used for calculating the DAQI, and b) the outputs especially in terms of how well they represent the risks associated with the atmospheric conditions.

Evaluation aims	Core Evaluation Research Questions (CERQ) grouped by theme	Relevant Sub-Questions (RSQ)	Contribution to the DAQI Evaluation
To assess effectiveness	**CERQ3:** To what extent is the DAQI viewed by the people it was intended to be viewed by?	• **RSQ3.1:** Do the definitions the DAQI gives of 'at risk individuals' adequately represent the health evidence for groups at increased risk from short term periods of elevated air pollution? • **RSQ3.2:** How widely used/well recognised is the DAQI by people at increased risk from air pollution (through what channels, if at all, is this user group receiving information)? • **RSQ3.3:** How widely used/well recognised is the DAQI by the general population (through what channels, if at all, is this user group receiving information)? • **RSQ3.4:** What, if any, barriers exist that reduce or prevent access to the DAQI? • **RSQ3.5:** What, if any, facilitators have helped to broaden access to the DAQI?	Answering CERQ3 will allow us to assess: a) the **accessibility** of the DAQI, i.e., how easy it is to access the information; and b) the **extent to which** people actually access the DAQI and thus are aware of the DAQI and daily air pollution levels, especially for people at risk.
	CERQ4: To what extent is the DAQI understood by its users in the way it was intended to be understood?	• **RSQ4.1:** To what extent do DAQI users' understanding of what the DAQI is communicating align with the message it is designed to communicate? • **RSQ4.2:** To what extent does the way data is visualised in the DAQI contribute to, or limit [at risk/general population] users? • **RSQ4.3:** To what extent does the language used in the DAQI contribute to, or limit [at risk/general population] users understanding the DAQI correctly? • **RSQ4.4:** To what extent do DAQI users understand the advice associated with different DAQI readings? • **RSQ4.5:** What, if any, barriers exist that have hindered users from correctly interpreting the DAQI? • **RSQ4.6:** What, if any, facilitators have supported users' understanding of the DAQI?	Answering CERQ4 will allow us to assess: a) how **understandable** (or clear) the DAQI and associated recommendations and advice are; and b) the **extent to which** people actually understand the DAQI and associated recommendations and advice provided.
	CERQ5: To what extent do the people who use the DAQI enact the advice it provides?	• **RSQ5.1:** To what extent do at risk users change their behaviour based on a [moderate/high/very high] DAQI reading? • **RSQ5.2:** To what extent do general population users change their behaviour based on a [high/very high] DAQI reading? • **RSQ5.3:** What if any barriers exist (in terms of capability, opportunity or motivation) that prevent users from enacting DAQI – advice?	Answering CERQ5 will allow us to assess the **extent to which people actually follow the recommendations and/or advice** and might thus modify their behaviours when applicable.

Evaluation aims	Core Evaluation Research Questions (CERQ) grouped by theme	Relevant Sub-Questions (RSQ)	Contribution to the DAQI Evaluation
		• **RSQ5.4:** What if any facilitators exist that have helped users to enacting DAQI advice? • **RSQ5.5:** In what way, if any, does alert frequency impact adherence to advice?	
	CERQ6: To what extent does advice the DAQI provides align with the intervention's intended outcome (to reduce severity of symptoms exacerbated by short term air pollution spikes) and impact (to reduce adverse health impacts)?	• **RSQ6.1:** To what extent does the health literature support the assumption that reducing strenuous outdoor physical activity at [moderate/high] levels of air pollution is likely to reduce the severity of symptoms in 'at risk' groups? • **RSQ6.2:** To what extent can reducing strenuous outdoor physical activity at [moderate/high] levels of air pollution be considered to have a net positive health for at risk individuals? • **RSQ6.3:** To what extent does the health literature support the assumption that reducing strenuous physical activity at [very high] levels of air pollution is likely to reduce the severity of symptoms in at risk groups? • **RSQ6.4:** To what extent can reducing strenuous physical activity at [very high] levels of air pollution be considered to have a net positive health impact for at risk individuals? • **RSQ6.5:** To what extent does the health literature support the assumption that reducing physical exertion at [very high] levels of air pollution is likely to reduce the severity of symptoms (short term health effects) in the general population? • **RSQ6.6:** To what extent can reducing physical exertion at [very high] levels of air pollution be considered to have a net positive health impact for members of the general population? • **RSQ6.7:** To what extent does the health literature support the assumption that increased use of reliever inhaler at [high/very high] levels of air pollution is likely to reduce the severity of symptoms in at risk groups (specifically asthmatics)? • **RSQ6.8:** To what extent can increased use of reliever inhaler at [high/very high] levels of air pollution be considered to have a net positive health impact for at risk individuals? • **RSQ6.9:** Are there any known or likely unintended consequences arising from the current health advice?	Answering CERQ6 will allow us to assess the **extent to which the recommendations and advice offered by the DAQI can, if enacted: a) mitigate** the severity of symptoms exacerbated by short-term air pollution spikes, and **b) materialise in a reduction** of adverse health effects attributable to 'high levels' of air pollution.

These detailed high-level CERQs and RSQs are also valuable to determine the information that is necessary to evaluate the DAQI, which is considered in Section A1.3.

A1.2.2 Evaluation methods

A **qualitative, process evaluation** approach will be employed to assess the appropriateness of the DAQI. Secondary and primary research will be conducted to gather evidence against the evaluation questions to develop insights and/or conclusions into the extent to which the DAQI is a source of information on air quality and advice, especially for the individuals at risk, that is:

- Reliable
- Methodologically and/or technically valid and accurate
- Accessible
- Understandable

A **mixed-methods evaluation approach** will be employed to assess the effectiveness of the DAQI. It is proposed that a **theory-based, contribution analysis framework**[4,5,6] is used to examine if the DAQI has contributed to the observed outcomes (e.g., behaviour modifications) and/or potential impacts (e.g., mitigation of adverse, short-term health effects of air pollution spikes) by exploring the secondary and primary evidence that is collected against the CERQs and RSQs. Proxies for outcomes and impacts may be identified if evidence of observed outcomes and impacts does not become available. Any contribution claims will be supported by evidence that establish their validity and strength as transparently as possible.

These theory-based methods will be **complemented by quasi-experimental approaches**[7] that underpin the design of primary research and data collection methods (Section A1.3). These approaches will primarily focus on investigating the extent to which specific outputs (such as accessing the DAQI), outcomes (such as following advice) and/or impacts (such as behaviour modifications) may or not have occurred as a result of the DAQI and associated resources, at least in part. For example, by surveying people, we will seek to establish individual counterfactuals through self-reporting or scenario-based queries related to the DAQI and people's behaviours.

The proposed combination of evaluation methods will enable a practical yet credible evaluation of the causal links and pathways identified through the Theory of Change and, thus, the potential contribution(s) made by the DAQI. Overall, this means that insights and conclusions will be developed to assess the extent to which the DAQI effectively leads to the achievement of desired outcomes and impacts, such as, for example, that people:

- Access the DAQI and are aware of air pollution levels, especially those at risk

[4] Mayne, J. (2008). "Contribution Analysis: An approach to exploring cause and effect. ILAC methodological brief". Available at: https://cgspace.cgiar.org/handle/10568/70124
[5] For example, Air Quality Expert Group (2020). "Assessing the Effectiveness of Interventions on Air Quality". Available at: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2006240803_Assessing_the_effectiveness_of_Interventions_on_AQ.pdf establishes the accountability chain to consider the impact of interventions (e.g. on potential health effects) that is likely to be attributable to the intervention, associated activities, and so on.
[6] Befani, B. & Mayne, J. (2014). "Process Tracing and Contribution Analysis: A Combined Approach to Generative Causal Inference for Impact Evaluation." Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/1759-5436.12110
[7] Examples of relevant papers include, e.g., Ye (2007), which employs a differences-in-differences approach to estimate the impact of policies; Moser, G. & Bamberg, S. (2008). "The effectiveness of soft transport policy measures: A critical assessment and meta-analysis of empirical evidence". Available at: https://www.sciencedirect.com/science/article/pii/S0272494407000722 employed mixed methods to collect evidence, including surveys, A/B testing of new measures/features; and ongoing monitoring of usage data to track progress.

- Understand the levels of air pollution
- Follow the recommendations and/or modify their behaviours
- Mitigate the onset and severity of adverse health effects or symptoms attributable to short-term exposure to 'high' levels of air pollution.

In summary, the implementation of these proposed methods alongside the research proposal (Section A1.3) would enable the development of conclusions on the appropriateness and effectiveness of the DAQI. Based on the findings, the Theory of Change can also be confirmed or revised.

A1.3 RESEARCH, DATA COLLECTION AND ANALYSIS

In line with Section 4 of the HMT Magenta Book, the following sections of the Evaluation Plan:

- outline of the research and data collection methods that will be employed in this evaluation and their scope,
- review of the evidence requirements, which will determine the types of data that will be sought across methods (e.g., survey, interviews, etc), and
- present draft research findings from the rapid literature review and work that has been carried out as part of the DAQI Evaluation project.

A1.3.1 Research and data collection methods

The following **primary and secondary research methods** will be pursued for the DAQI Evaluation: 1) a **rapid literature review** (targeting international precedent of similar 'programmes', and literature and data on behavioural change projects, programmes or activities and their impact, especially on human health); 2) **semi-structured up to 16 interviews**, which may be individual, in pairs or small focus groups of air quality and health care professionals/experts; 3) **in-depth interviews with up to 25 individuals** of the 'at risk' and 'general population'; and 4) one **bespoke survey** of 'at-risk' and 'general population' (N=2,000). In addition, up to 5 cognitive interviews will be conducted to test the survey design ahead of implementation. We do not believe that observational studies or field experiments are possible within the timetable and budget.

A **rapid evidence and literature review** was undertaken, targeting both academic and grey literature. This included data from the Automatic Urban and Rural Network (AURN) and additional secondary sources (e.g., health charities, etc.). The outputs are presented in Appendix 4: Literature review findings. This review followed five steps:

- Studies and academic papers provided by Defra were reviewed and mapped against each of the CERQs and RSQs.
- A complementary 'search strategy' and criteria were developed for each of the CERQs and RSQs, seeking to address any evidentiary gaps.
- Reference software was used to store search results; review the titles and abstracts to remove any literature that does not meet our inclusion criteria. If it is not possible to tell from the title and abstract, we have read the full paper.
- Finally, an evidence gap assessment was performed and can be found in the following sections alongside the findings of the rapid literature review.

Topic guides or scripts were developed for the **semi-structured and in-depth interviews**, which offered a guide to interviewers. The scripts included: 1) structured questions that will

be asked of all experts and individuals targeted, drawing on social research techniques to elicit information necessary to answer the CERQs; and 2) themes to facilitate a more open discussion about the evidence that is available and pertaining to the evaluation requirements. At least three scripts were developed to support three target groups: 1) air quality modelling / forecasting experts, 2) air quality and health experts; 3) individuals from the at risk and general public. These topic guides can be found in Appendix 3: Data collection – Interview Topic Guides. Stakeholders were identified by drawing on the networks of Defra, UKHSA's and the consultant team.

The **bespoke survey** was designed to draw scenario-based and self-reported evidence against structured answers to delve into the participants' access, understanding and behaviours associated with the DAQI's alerts and advice (and broader aspects of the Index). The proposed survey design has been shared with Defra and reviewed and signed-off by the Survey Control Liaison Unit. The survey has been encoded by Opinion Matters, the survey provider, and underwent cognitive testing and iteration ahead of its launch. 'Appendix 2: Data collection – Survey' contains a word version of the survey as it has been encoded, which has slight structural adjustments required to deploy the agreed, stratified sampling approach effectively.

An overview of the survey's specification is set out in Table A1-2.

Table A1-2 Survey specification overview

Area	Specification
Scope	Individuals living in the England categorised by age, gender, region, socio-economic background, parenting responsibilities, and pregnancy status. Sub-populations of at-risk individuals and the digitally excluded will be specifically targeted.
Sampling	2,000 participants will complete the survey, who will be recruited by Opinion Matters, using a stratified sampling approach. That is, two random samples of at risk (N=1,000) and general populations (N=1,000) will be engaged as part of this survey.
Approach	1,900 people will be targeted through a web-based platform and answer the survey online. 5% of the target sample or 100 people of over 65-year-olds from lower income and/or educational backgrounds (as proxy for digital exclusion) will be targeted through Computer-Assisted Telephone Interviewing.
Length and duration	The survey has 34 questions, preceded by around 15 questions which cover the characteristics of the participants to confirm relevance and support with the sample stratification. The survey has been piloted and it is likely to take around 10-15 minutes, and most definitely no more than 20 minutes. The survey will be live for 10-12 days.

A review of the evidence requirements against each CERQ was also conducted to ensure that the primary and secondary research methods were employed effectively to collect the necessary evidence.

A1.3.2 Evidence requirements against each CERQ

There are evidence requirements for each of the six CERQs and 33 RSQs outlined in Section A1.2.1, which frame the evaluation and, thus, this Evaluation Plan. Table A1-3 to Table A1-5 provide, firstly, an overview of the key evidence or data requirements identified for this Evaluation Plan, which would enable us to answer the confirmed evaluation questions; and, secondly, an outline of the data collection methods that will be employed to gather the necessary evidence.

Table A1-3 Overview of core data requirements by Core Evaluation Research Questions

CERQ	Overview of data requirements
CERQ1: data inputs	Evidence and/or expert opinion regarding the validity, completeness, and accuracy of the data available, including the air pollutant monitoring data gathered by AURN; the methodology underpinning the forecasting models; and the granularity of the evidence.
CERQ2: methodology	Evidence and/or expert opinion(s) regarding the scope of pollutants monitored and the weights provided within the overall index, the thresholds employed for the alert system, the appropriateness of averaging time selected and/or treating days as discrete events, and the extent to which mixture effects are captured.
CERQ3: access (or reach)	Evidence and/or expert opinion as to the audience of the DAQI, especially the definition of at-risk people; levels of awareness of the existence of the index, use and the channels of use, as well as any enablers and/or barriers for access and use by individuals.
CERQ4: understanding	Evidence/information on people's understanding of the DAQI's publications, recommendations and advice for both at-risk people and the general public. This will include the extent to which the visualisation, language and details provided (or anything else) are enablers and/or barriers to this understanding.
CERQ5: behaviour change	Evidence/information on people's behavioural responses to episodes of 'high' levels of air pollution, any barriers for people to enact the DAQI advice, and/or how the frequency of alerts or current alert system may affect adherence to the advice given
CERQ6: soundness of advice	Evidence/information on the 1) health consequences of exercising and 2) using reliever inhalers during episodes of 'high' levels of air pollution; evidence and/or expert opinion on the impacts of the DAQI's advice on human health; and people's perceptions as to how following the DAQI's advice may affect their health.

To address these evidence needs, we will draw on the research and data collection methods listed in the previous section A1.3.1 as presented in Table A1-4.

Table A1-4 Data sources or methods to address these data requirements

Core Evaluation Research Questions (CERQ)	Monitoring data	Literature review and secondary data	16x Interviews, 1x workshop with experts	25x Interviews with individuals	Survey of 2,000 individuals (or 'users')
CERQ1: data inputs	X	X	X	X	
CERQ2: methodology	X	X	X		
CERQ3: access (or reach)		X	X	X	X
CERQ4: understanding		X	X	X	X
CERQ5: behaviour change		X	X	X	X
CERQ6: soundness of advice		X	X	X	X

A more detailed presentation of both the requirements and data sources can be found in Table A1-5.

Table A1-5 sets out a detailed outline of the project's research needs, building on Defra's own specification and further considerations.

Table A1-5 Requirements and data sources for each CERQ and RSQ

Core Evaluation Research Questions (CERQ)	Relevant Sub-Questions (RSQ)	Evidence/ data required	Sources
CERQ1: To what extent does the modelled and measured data on which the DAQI is based, give a sufficiently, accurate and precise representation of real-world air quality conditions?	**RSQ1.1:** To what extent does the AURN network provide sufficiently, complete and accurate measurement data to allow communication of a meaningful real time air quality index?	Evidence and expert opinion on the validity, completeness, and accuracy of the data available, including the air pollutant monitoring data.	AURN monitoring network; Literature review and secondary data; and Interviews and workshop with experts.
	RSQ1.2: To what extent does the forecasting model on which DAQI forecasts are based provide sufficiently, precise and accurate predictions of future air quality conditions to allow individuals to meaningfully modify their behaviour?	Evidence and expert opinion on the methodology underpinning the forecasting models; and Historic monitoring data gathered by AURN.	AURN monitoring network; Literature review and secondary data; and Interviews and workshop with experts;
	RSQ1.3: To what extent does the granularity of data communicated via the DAQI (on UK-Air) allow individuals to meaningfully modify their behaviour based on their local air quality conditions?	Evidence and expert opinion on the granularity of the evidence; and Public opinion on the data that is communicated to them.	Interviews and workshop with experts; and Interviews with individuals.
CERQ2: To what extent is the methodology by which the DAQI output (the index number and air quality band) is calculated, appropriate as a method of determining the short-term risk posed by real world conditions into an overall measure of air quality?	**RSQ2.1:** Do the five pollutants included in the DAQI remain the most relevant pollutants to measure short-term air pollution risk in the UK setting?	Evidence and/or expert opinion(s) regarding the scope of pollutants monitored and the weights provided within the overall index.	AURN monitoring network; Literature review and secondary data; and Interviews and workshop with experts.
	RSQ2.2: To what extent do the breakpoints implemented in the DAQI continue to reflect the latest health evidence regarding the concentrations at which health effects may be experienced following short-term exposure to air pollution?	Evidence and/or expert opinion(s) regarding the thresholds employed for the alert system.	As above.
	RSQ2.3: To what extent do the averaging times implemented in the DAQI reflect the latest health evidence regarding the period after which health effects may be experienced following short-term exposure to air pollution?	Evidence and/or expert opinion(s) regarding the appropriateness of averaging time selected	Literature review and secondary data; and Interviews and workshop with experts.

Core Evaluation Research Questions (CERQ)	Relevant Sub-Questions (RSQ)	Evidence/ data required	Sources
	RSQ2.4: Does current understanding of the health effects of mixtures of air pollutants suggest the including mixture effects in the DAQI could have a substantial impact on health outcomes?	Evidence and/or expert opinion(s) regarding the extent to which mixture effects are captured in the DAQI.	AURN monitoring network; Literature review and secondary data; and Interviews and workshop with experts.
	RSQ2.5: What is the health impact of treating days as discrete events for the purposes of the DAQI?	Evidence and/or expert opinion(s) regarding the potential effects on health of treating days as discrete events.	Literature review and secondary data; and Interviews and workshop with experts.
CERQ3: To what extent is the DAQI viewed by the people it was intended to be viewed by?	**RSQ3.1:** Do the definitions the DAQI gives of 'at risk individuals' adequately represent the health evidence for groups at increased risk from short term periods of elevated air pollution?	Evidence and expert opinion on the definition of at-risk people.	Literature review and secondary data; and Interviews and workshop with experts;
	RSQ3.2: How widely used/well recognised is the DAQI by people at increased risk from air pollution (through what channels, if at all, is this user group receiving information)?	Evidence on the levels of awareness of the existence of the index, use and the channels of use by at risk individuals.	Literature review and secondary data; Interviews with individuals; and Survey of 2,000 individuals.
	RSQ3.3: How widely used/well recognised is the DAQI by the general population (through what channels, if at all, is this user group receiving information)?	Evidence on the levels of awareness of the existence of the index, use and the channels of use by the general population.	As above
	RSQ3.4: What, if any, barriers exist that reduce or prevent access to the DAQI?	Evidence and expert opinion on barriers for access and use of the DAQI	Literature review and secondary data; Interviews and workshop with experts; Interviews with individuals; and Survey of 2,000 individuals.
	RSQ3.5: What, if any, facilitators have helped to broaden access to the DAQI?	Evidence and expert opinion on enablers for access and use of the DAQI	As above.
CERQ4: To what extent is the DAQI understood by its users in the way it was	**RSQ4.1:** To what extent do DAQI users' understanding of what the DAQI is communicating align with the message it is designed to communicate?	Evidence/information on people's understanding of the DAQI's publications	Literature review and secondary data; Interviews and workshop with experts; Interviews with individuals; and Survey of 2,000 individuals.

Core Evaluation Research Questions (CERQ)	Relevant Sub-Questions (RSQ)	Evidence/ data required	Sources
intended to be understood?	**RSQ4.2:** To what extent does the way data is visualised in the DAQI contribute to, or limit [at risk/general population] users?	Evidence/information on people's understanding of the DAQI's results visualization.	Literature review and secondary data; Interviews with individuals; and Survey of 2,000 individuals.
	RSQ4.3: To what extent does the language used in the DAQI contribute to, or limit [at risk/general population] users understanding the DAQI correctly?	Evidence/information on people's understanding of the language employed in the DAQI.	As above.
	RSQ4.4: To what extent do DAQI users understand the advice associated with different DAQI readings?	Evidence/information on people's understanding of the recommendations and advice for both at-risk people and the general public.	As above.
	RSQ4.5: What, if any, barriers exist that have hindered users from correctly interpreting the DAQI?	Evidence/information potential barriers to understanding the DAQI.	As above.
	RSQ4.6: What, if any, facilitators have supported users' understanding of the DAQI?	Evidence/information potential facilitators to understanding the DAQI.	As above.
CERQ5: To what extent do the people who use the DAQI enact the advice it provides?	**RSQ5.1**: To what extent do at risk users change their behaviour based on a [moderate/high/very high] DAQI reading?	Evidence/information on at risk individuals' behavioural responses to episodes of 'moderate', 'high' or 'very high' levels of air pollution.	Literature review and secondary data; Interviews with individuals; and Survey of 2,000 individuals.
	RSQ5.2: To what extent do general population users change their behaviour based on a [high/very high] DAQI reading?	Evidence/information on people's behavioural responses to episodes of 'high' levels of air pollution.	As above.
	RSQ5.3: What, if any, barriers exist (in terms of capability, opportunity, or motivation) that prevent users from enacting DAQI – advice?	Evidence/information on potential barriers to enacting DAQI advice.	As above
	RSQ5.4: What, if any, facilitators exist that have helped users to enacting DAQI advice?	Evidence/information on enablers to enacting DAQI advice.	As above.
	RSQ5.5: In what way, if any, does alert frequency impact adherence to advice?	Evidence/information on the potential effect of the frequency of alerts and current alert system on the adherence to the advice given.	Literature review and secondary data; Interviews and workshop with experts; Interviews with individuals; and Survey of 2,000 individuals.

Core Evaluation Research Questions (CERQ)	Relevant Sub-Questions (RSQ)	Evidence/ data required	Sources
CERQ6: To what extent does advice the DAQI provides align with the intervention's intended outcome (to reduce severity of symptoms exacerbated by short term air pollution spikes) and impact (to reduce adverse health impacts)?	**RSQ6.1:** To what extent does the health literature support the assumption that reducing strenuous outdoor physical activity at [moderate/high] levels of air pollution is likely to reduce the severity of symptoms in 'at risk' groups?	Evidence and expert opinion on the health consequences in at risk individuals of exercising during episodes of 'moderate' or 'high' levels of air pollution.	Literature review and secondary data; and Interviews and workshop with experts;
	RSQ6.2: To what extent can reducing strenuous outdoor physical activity at [moderate/high] levels of air pollution be considered to have a net positive health for at risk individuals?	As above.	As above.
	RSQ6.3: To what extent does the health literature support the assumption that reducing strenuous physical activity at [very high] levels of air pollution is likely to reduce the severity of symptoms in at risk groups?	As above.	As above.
	RSQ6.4: To what extent can reducing strenuous physical activity at [very high] levels of air pollution be considered to have a net positive health impact for at risk individuals?	As above.	As above.
	RSQ6.5: To what extent does the health literature support the assumption that reducing physical exertion at [very high] levels of air pollution is likely to reduce the severity of symptoms (short term health effects) in the general population?	Evidence and expert opinion on the health consequences in at risk individuals of exercising during episodes of 'high' levels of air pollution.	As above.
	RSQ6.6: To what extent can reducing physical exertion at [very high] levels of air pollution be considered to have a net positive health impact for members of the general population?	As above.	As above.
	RSQ6.7: To what extent does the health literature support the assumption that increased use of reliever inhaler at [high/very high] levels of air pollution is likely to reduce the severity of symptoms in at risk groups (specifically asthmatics)?	Evidence and expert opinion on the health consequences of using reliever inhalers during episodes of high/very high levels of air pollution.	As above.

Core Evaluation Research Questions (CERQ)	Relevant Sub-Questions (RSQ)	Evidence/ data required	Sources
	RSQ6.8: To what extent can increased use of reliever inhaler at [high/very high] levels of air pollution be considered to have a net positive health impact for at risk individuals?	As above.	As above.
	RSQ6.9: Are there any known or likely unintended consequences arising from the current health advice?	Evidence and expert opinion on the DAQI's advice on human health; and People's perception as to how following the DAQI's advice may affect their health.	Literature review and secondary data; Interviews and workshop with experts; Interviews with individuals; and Survey of 2,000 individuals.

A1.3.3 Analysis of the evidence

Descriptive analysis, significance testing and/or hypotheses testing, as well as cost-benefit analyses techniques have been employed on the qualitative and quantitative evidence collected, overlaid by monetisation techniques if required to establish the scale of impacts in line with the UK Green Book and complementary guidance[8,9].

We acknowledge the complexities associated with evaluating outcomes and impacts on behaviour change and/or improved health of individuals accessing information and advice provided by the DAQI using quasi-experimental techniques, which would be required for a quantitative impact evaluation. Firstly, multiple external factors will affect these outcomes locally and nationally and it might be difficult to estimate an unbiased impact of the DAQI, controlling for these potentially confounding factors. Secondly, issues might arise with evidence-gathering/data collection.

Furthermore, given the nationwide launch of the DAQI and the absence of neighbouring countries that have not adopted an AQIS, we face a challenge in establishing a robust control group(s) for making meaningful comparisons.

We have thus proposed a theory-driven methodology to examine the CERQs and RSQs and develop evidence-based conclusions as to the potential contribution of the DAQI, and the extent to which it is appropriate and effective, following the principles set in Section A1.2.2. This approach will be substantiated by the quantitative analysis drawing upon data collected from the surveys and/or interviews with relevant experts, at risk individuals and the general population, as well as secondary data.

A1.4 OUTPUTS, ROLES, RESPONSIBILITIES AND MANAGEMENT

This section provides an outline of the evaluation outputs, the roles and responsibilities to deliver the evaluation, the governance and quality assurance processes established, and a delivery or work plan.

A1.4.1 Reporting outputs and dissemination

The project deliverables for Defra comprise a variety of documents, facilitating ongoing feedback from Defra and its relevant stakeholders, while also aligning with Defra's strategic interest. These reporting outputs include:

- A preliminary TOC PowerPoint document, which has been submitted to Defra and workshopped, and offers the foundation to this Evaluation Plan.
- The Evaluation Plan.
- Interim evaluation findings document.
- An Evaluation Report (Draft and final).
- A slide deck with the findings obtained from the analysis, to be presented to Defra and relevant stakeholders.

[8] UK Green Book and complementary guidance. Available at: https://www.gov.uk/government/collections/the-green-book-and-accompanying-guidance-and-documents

[9] Ricardo (2023). "Air Quality damage cost update 2023 – Final Report". Available at: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2301090900_Damage_cost_update_2023_Final.pdf

All the deliverables will be submitted as drafts, allowing Defra to review them and provide feedback ideally within 1-2 weeks. The documents will then be finalised based on the comments or suggestions provided.

The findings of the evaluation will be presented to Defra and relevant stakeholders during a virtual meeting. This approach facilitates the resolution of any uncertainties pertaining to the employed methodologies or the obtained results, thereby ensuring a comprehensive understanding of the analysis by all the involved parties.

A1.4.2 Roles and responsibilities

The project draws on a wide range of stakeholders, and their collaboration is essential for the delivery of a robust evaluation report. Table A1-6 provides an outline of the roles and responsibilities of the parties involved in the project.

Table A1-6 Roles and responsibilities of the stakeholders

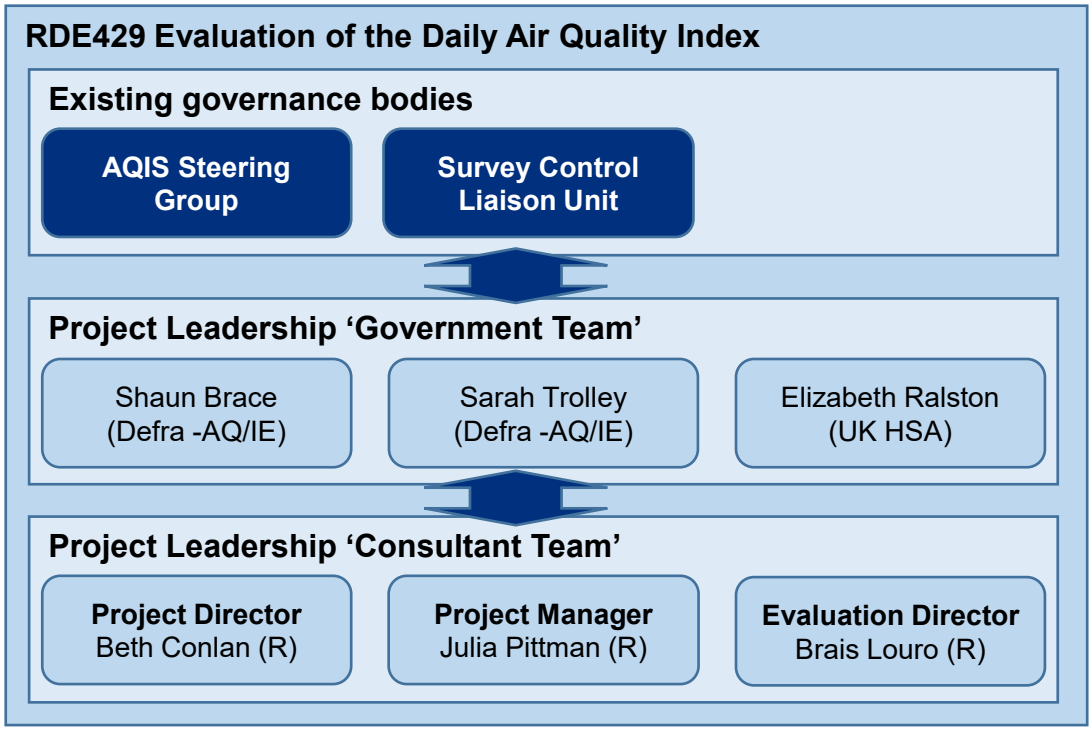
Stakeholders	Roles and responsibilities
Ricardo, MEL research and Opinion Matters (the consultant team)	The consultant team has performed a rapid literature review against the CERQs and RSQs proposed by Defra and conducted a gap analysis to identify additional evidence needs. The consultant team will perform the primary research and data collection, including through semi-structured interviews, in-depth interviews and a bespoke survey to address the gaps identified through the literature review. Ricardo will be responsible for the design of the survey and topic guides/scripts and performing interviews together with MEL research; and Opinion Matters will lead the survey implementation. The consultant team will analyse the qualitative and quantitative evidence gathered through the research (primary and secondary) to answer the evaluation questions and will evaluate the appropriateness and effectiveness of DAQI. The consultant team quality assures any interim and final finings and deliverables and shares these with Defra and its stakeholders.
Defra	Defra has established the objectives and scope of the evaluation and the evaluation questions and has shared a compilation of relevant literature with the consultant team. Defra also has a coordination role amongst other government and AQIS stakeholders interested in the project. Defra provides quality assurance directly and through internal governance structures (such as the Survey Control Liaison Unit), including by commenting on draft deliverables and providing final approval of deliverables. Defra is supported in this role by the UK Health Security Agency.
Defra's stakeholders (e.g., AQIS, MET Office, etc.)	Other stakeholders are engaged through email, interviews and workshops to provide comments, additional insights and/or evidence that would contribute to answering the evaluation questions. This includes the MET Office, COMEAP stakeholders, experts participating in the broader AQIS review, etc.

A1.4.3 Governance and quality assurance

There are three layers to the governance of the DAQI evaluation project. Firstly, the consultant team has a leadership structure that provides oversight and assurance of the work undertaken and outputs delivered. Secondly, Defra and UKHSA have identified point persons to offer another layer of oversight and assurance that the consultant team is delivering the work against the agreed specification and achieving the project's objectives. Finally, project progress as well as draft and final outputs are overseen by established groups and structures, such as the AQIS Steering Group, the Survey Control Liaison Unit

and others. Figure A1-4 illustrates the **governance** structures for the DAQI Evaluation project, for review by the Defra team.

Figure A1-4 Governance structures



The consultant team led by Ricardo operates strong quality management systems to ensure that the quality of deliverables across all our work remains consistently high. The team has an integrated ISO-certified management system covering quality, safety, health and environmental (QSHE) management across all operations (certified to ISO 9001:2015, ISO 14001:2015, ISO 45001:2018 and ISO 27001:2013).

Project Quality Assurance will be the responsibility of the Project Manager (PM) and Project Director (PD), with input from the Technical Evaluation Director. The PM will have overall responsibility for ensuring that the quality checks have been completed and organise the final quality checks and internal sign-off processes. The Technical Evaluation Director and PD will review all key deliverables to assure their quality. As a result, we guarantee the quality of all the deliverables, adhering to the UK Government Quality Assurance standards and requirements for project delivery[10].

In more detail, the reviews will check for the reliability of evidence/data, soundness of analysis, credibility of the findings, validity of the conclusions, applicability of recommendations and clarity of any output. The PM and team will adhere to Ricardo's rigorous Project Management standards, which are aligned with PRINCE2 principles; and maintain regular contact with Defra's team. Milestone, online sessions to discuss draft deliverables and seek feedback from Defra and other relevant stakeholders may also be organised.

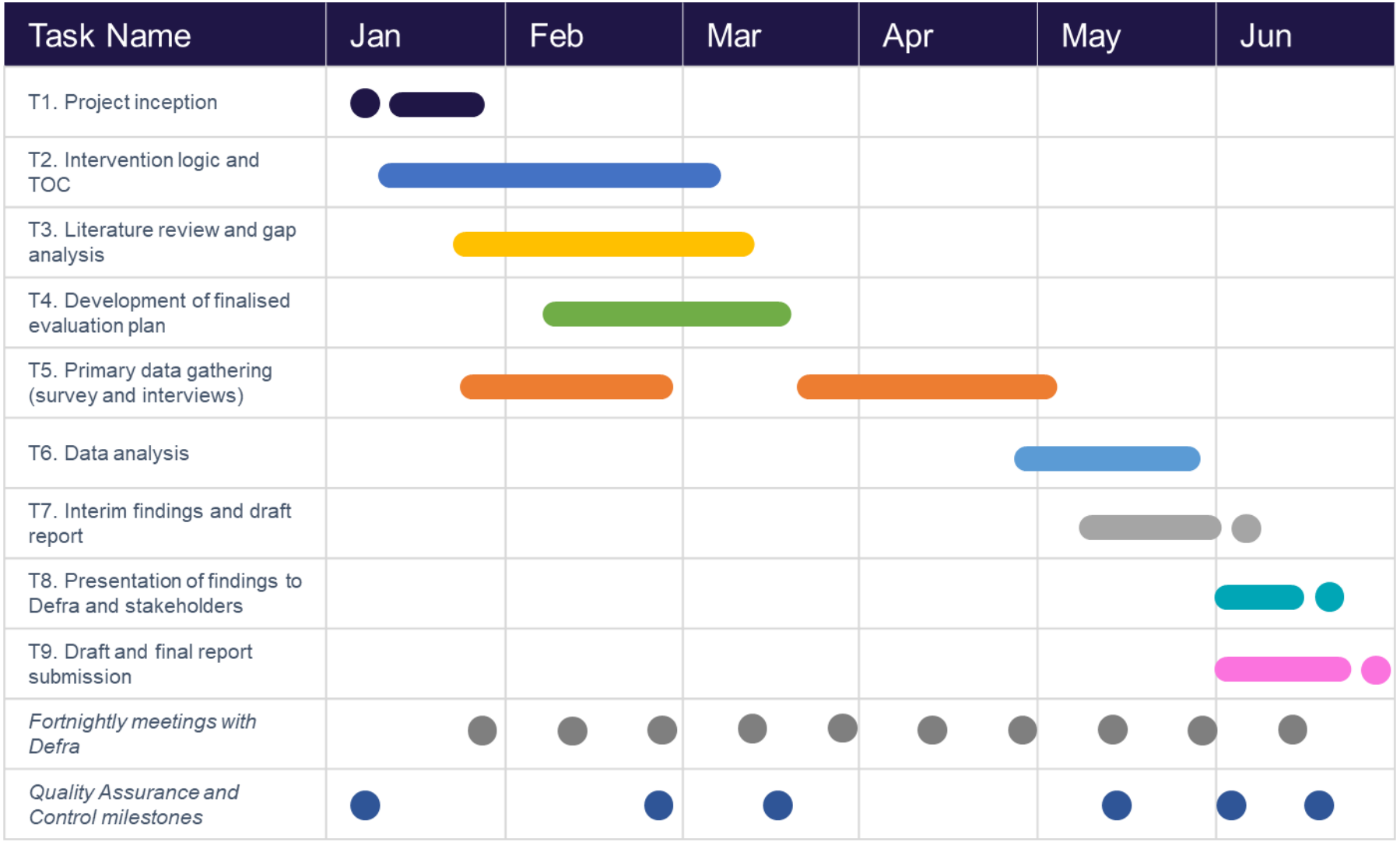
[10] UK Government (2021). Project Delivery Functional Standard. URL: https://www.gov.uk/government/publications/project-delivery-functional-standard BEIS (2018). Quality Assurance: Guidance for models. URL: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/737293/BEIS_QA_Guidance_for_Models.pdf

Defra has also identified a team of experts within the organisation and the UK Health Security Agency who allocate time and resources to review the content of the deliverables and ensure they are aligned with the scope and achieve the objectives agreed during project inception.

A1.4.4 Delivery timetable

The Evaluation Plan has been executed for delivery by the end of June, in line Defra's required timelines. Key milestone dates include the inception meeting on 10 January, the TOC workshop on 4 March, the literature review and Evaluation Plan by mid-March, the conclusion of primary data gathering by the end of April/early May, the analysis of data and provision of interim findings by end of May/early June, and the presentation of the evaluation research findings and the Final Report before the end of June. An illustrative work plan is presented in Figure A1-5.

Figure A1-5 Project timetable structured by task



A2. Appendix 2: Data collection – Survey

The design of the survey has been iterated with Defra and the Survey Control Unit for feedback and agreement. Thereafter, it has been shared with Ricardo's subcontractor for implementation. The version that is presented below is the one that has been coded into Opinion Matters' platform. It is the same as the version agreed, with some adjustments to the structure to facilitate the stratified sampling approach that has been agreed.

Survey introduction

'Text 1' on the same page as Qa

Hello!

The UK's Department for Environment, Food and Rural Affairs (Defra) has commissioned us, Ricardo plc and Opinion Matters, to conduct a survey to learn about people's access and understanding of the available air quality information, and how people may use the information to make decisions about their day-to-day activities. The findings from the survey will be used to improve Defra's air quality information services.

We would like to invite you to participate in this survey! You have been selected to complete this survey to represent the general public's understanding of the air quality information available and how you use the data. This survey should be completed by yourself based on your understanding and experiences.

The survey comprises of a questionnaire with fewer than 45 short questions and should take no more than 20 minutes or so to complete. *Please note that if you start and stop the questionnaire, leave the survey and come back, you will need to do this within three days to continue from where you left off. After that, you will need to start from the beginning again.*

The information collected will be treated as confidential and the published outputs will be aggregated and anonymised. You will not be personally identifiable in any results or reports.

A couple of these questions will ask about some of your characteristics as a person. This information is collected to analyse the experiences of different people across the UK. This information will be stored by the consultant team for a year after the project is closed and securely deleted thereafter.

Please answer the questions to the best of your ability. There are no wrong answers. And, if you have any questions, please contact us at info@opinionmatters.com.

Participation in this survey is voluntary.

Thank you in advance and know that your contribution matters!

Qa. Are you willing to continue with this survey?
Yes
No [END and show 'Text 6']

Qb. I consent to the use of any information collected for research purposes, so long as it is treated confidentially, aggregated and anonymised as described above [box].

[Show ‘Text 6’ AND end survey if box is not ticked]

Part 1: About you

Qi. Please select from the following age brackets, the one that best represents your age in years. (Select one)

16-17 [END]
18-24
25-34
35-44
45-54
55-64
65 +
Prefer not to say

Qii. Which of the following region do you reside? Please select from the following regions (listed in alphabetical order). (Select one)

East Midlands
East of England
London
North East of England
North West of England
Northern Ireland [END]
Scotland [END]
South East of England
South West of England
Wales [END]
West Midlands
Yorkshire and the Humber

Qiia. Could you also please type in the first block of letters and numbers of your postcode where you live. For example, if your postcode is SE15 XYZ, we would be looking for you to type in only SE15. [*Open text*]

Qiii. Please select one of the following that applies to you.

I am a health or social care professional (e.g., doctor, nurse, pharmacist, etc)
I am not a health or social care professional.

Qiiia. Please select one of the following that applies to you.

I work outdoors, and my work requires strenuous physical activity.
I work outdoors, and my work does not require strenuous physical activity.
I work indoors.

Qiv. Which of the following most accurately describes your household. (Tick one)

One person with no children or dependents

Lone parent with children or dependents [Show Qv]
Two or more unrelated adults with no children or dependents [Show Qv]
Two or more unrelated adults with children or dependents [Show Qv]
Couple with no children or dependents
Couple with children or dependents [Show Qv]
Multi-family household [Show Qv]
Prefer not to say

Qv. Please select one of the following options.

I have one or more dependent children [Show Qvi]
I have a caring responsibility for one or more adults [Show Qvi]
All of the above [Show Qvi]
Prefer not to say

Qvi. My child(ren) and/or adult(s) under my care have…

No chronic lung or heart conditions.
One or more chronic lung conditions (e.g., asthma, chronic obstructive pulmonary disease, bronchitis, emphysema, or another)
One or more chronic heart conditions (e.g., angina, heart failure, arrythmia, or another)
One or more chronic lung and heart conditions (e.g., asthma and heart failure or another)
Prefer not to say

Qvii. Please select from the following the statement that most accurately describes your health status.

I have no chronic lung or heart conditions.
I have one or more chronic lung conditions (e.g., asthma, chronic obstructive pulmonary disease, bronchitis, emphysema, or another)
I have one or more chronic heart conditions (e.g., angina, heart failure, arrhythmia, or another)
I have one or more chronic lung and heart conditions (e.g., asthma and heart failure)
Prefer not to say

Qviii. Have you used a medical inhaler in the last year?

Yes, I use inhalers on occasion to help with my breathing.
Yes, I use inhalers frequently to help with my breathing.
No, I have not.
Prefer not to say.

From the following characteristics, please select those which most accurately describe you.

Qix. What sex were you assigned at birth?

Male
Female

Qixa. Is the gender you identify with the same as the sex you were assigned at birth?

Yes [Skip Qixb and auto assign answer from Qix]
No

Qixb. What gender do you identify as?

Male
Female
Trans-gender
Non-binary
Other (please specify)
Don't know
Prefer not to say

[Show the following question for those selecting 'Female' at Qix AND 'Yes' at Qixa]

Qx. Which of the following applies to you?

I am not pregnant
I am pregnant
Prefer not to say

Qxi. Which of the following best describes your highest level of education?

No qualifications: no formal qualifications
Level 1-3, which includes GCSE, A level or equivalent qualifications
Level 4 or above: Higher National Certificate, Higher National Diploma, bachelor's degree, or post-graduate qualifications
Other qualifications, such as apprenticeships or other of unknown level
Prefer not to say

Qxii. Which of the following best reflects your annual household income? Note: This is household income over the last, complete calendar year (household income is the sum of all salaries, wages, profits and other forms of income before taxes or deductions)

£1 to £9, 999
£10, 000 to £14,999
£15,000 to £19,999
£20, 000 to £29,999
£30, 000 to £39,999
£40, 000 to £59, 999
£60, 000 to £69, 999
£70, 000 to £99,999
£100,000 or more
Prefer not to answer

Working Notes from the Survey Provider

The randomised stratified sampling approach will target:

- *100 digitally excluded individuals from those selecting over 65 and £1 - £29,999 at Qxii and/or 'No qualifications: no formal qualifications' or 'Level 1-3, which includes GCSE, A level or equivalent qualifications' at Qxi*
- *900 additional 'at risk' individuals from respondents:*
    - *Over 18 years old selecting 'I have one or more chronic lung conditions (e.g., asthma, chronic obstructive pulmonary disease, bronchitis, emphysema, or another)' or 'I have one or more chronic heart conditions (e.g., angina, heart failure, arrhythmia, or another)' or 'I have one or more chronic lung and heart conditions (e.g., asthma and heart failure)' at Qvii;*
    - *Over 65s;*
    - *Selecting 'I have one or more dependent children' at Qv AND 'One or more chronic lung conditions (e.g., asthma, chronic obstructive pulmonary disease, bronchitis, emphysema, or another)' or 'One or more chronic heart conditions (e.g., angina, heart failure, arrythmia, or another)' or 'One or more chronic lung and heart conditions (e.g., asthma and heart failure or another)' at Qvi*
    - *Selecting: 'I am pregnant' at Qx*
- *1,000 general population, nationally representative*

Q1. How interested are you about the quality of air in your neighbourhood? Please select the level of interest you have on the following scale of zero (no interest) to +5 (very high level of interest).

0 - No interest
1 - Very low interest
2 - Low interest
3 - Medium level interest
4 - High interest
5 - Very high interest

Q2. Are you aware of the quality of air in your neighbourhood? Please select the statement that is closest to your awareness.

I do not know what you mean by "quality of air".
I am not aware of the quality of air in my neighbourhood.
I am aware –I check it on occasion.
I am aware –I check it weekly.
I am aware –I check it daily.

Part 2: Accessing air quality information

Q3. Have you seen information that is similar to the following snapshots before? (Select all that apply)

a Visual UK AIR page
b Visual DAQI emails
c Visual UK AIR on twitter visual i
d Visual UK AIR on twitter visual ii
e Visual Air Text service
f I have not seen information as presented above until now.

Q4. How familiar, if at all, are you with the following government services?

Matrix

Rows:
Daily Air Quality Index or DAQI https://uk-air.defra.gov.uk/air-pollution/daqi
Flood alerts and warnings https://check-for-flooding.service.gov.uk/alerts-and-warnings
Heat-health alert services https://www.metoffice.gov.uk/weather/warnings-and-advice/seasonal-advice/heat-health-alert-service

Columns:
Very familiar
Somewhat familiar
Not very familiar
Not at all familiar

Q5. Do you use any of the following information services related to the Daily Air Quality Index or DAQI? (Select all that apply)

I use the free automated telephone air pollution services.
I have subscribed and received the Daily Air Pollution email bulletins.
I check the pollution forecasts online, on the UK Air Defra website.
I follow air pollution updates via the @DefraUKAir X/Twitter.
I am not aware the Daily Air Quality Index or DAQI had the mentioned information services.
I use a different source to receive information on air quality, please specify

---

[Show Q6 to those selecting:
NOT selecting '0 – No interest' at Q1;
And either 'I am aware – I check it on occasion' or 'I am aware – I check it weekly' or 'I am aware - I check it daily' at Q2
AND selecting 'I have not seen information as presented above until now' at Q3
And selecting either 'Not very familiar' or 'Not at all familiar' for 'Daily Air Quality Index or DAQI' at Q5]

Q6. You said you are interested in air quality but you have not accessed or are not familiar with the Daily Air Quality Index or DAQI. Why is that? (Select all that apply)

I follow other air quality alerts or information services. [Open text to specify]
Keeping up with air quality is not my priority.

I struggle to find the time in my day-to-day to look this up.
I struggle to find my way through the website so I have not been able to familiarise myself.
Other, please specify

[Show questions Q16 onwards (i.e., skip Q7-15) to those selecting 'I have not seen information as presented above until now' AND 'Not very familiar' or 'Not at all familiar' for all rows at Q4"]
[Show Q7 to those NOT selecting 'I have not seen information as presented above until now.' At Q3]

Q7. How frequently do you use these services? Please tick on the following table to show how frequently you use the services.

Matrix
Rows:
Free automated telephone air pollution services (0800 55 66 77).
Daily Air Pollution email bulletins
UK AIR (Air Information Resource) website (pollution forecast)
@DefraUKAir on X/Twitter
Other (such as via Local Authority websites and other services). Please specify [Opex Text]

Columns:
Every day
4-6 days a week
2-3 days a week
Once a week
Once every 2 to 3 weeks
Once a month
Once every 2 months
Once every 3 to 5 months
Once every 6 months to 11 months
Once a year
Less than once a year,
Do not use / Never
Do not know

Q8. How easy is it to access these services? (Please select one)

Not easy – for example, I struggle to find the website or X/twitter pages, I do not know how to subscribe to the email bulletins or other services, or I cannot call the free automated telephone service.

Somewhat easy – for example, I can find the website or X/twitter pages with effort but do not know/don't subscribe to the email bulletins or other services.

Easy – for example, I can find the website or X/twitter pages and have subscribed to either email bulletins or other services, or I have called or can call the free automated telephone service but have experienced some difficulties with one or more aspects.

Very easy – for example, I can find the website or X/twitter pages easily, I have subscribed or I can subscribe to the email bulletins or other services without a challenge, or have called or can call the free automated telephone service without any issues.

Q9. Have you ever accessed or read the accompanying “health messages”? These messages look like “enjoy your usual outdoor activities” or “consider reducing activity, particularly outdoors”. An example screenshot is shown below. (Please select one)

Screenshot

I have not seen these health messages before
I have seen these health messages before but not personally accessed them (for example searching for them on your mobile phone)
I have seen and accessed these health messages before
I regularly check the accompanying health messages as a reminder
Do not know

Q10. Would you identify **yourself** as someone who is ‘at risk’ of air pollution? This means your health would be particularly vulnerable to the quality of the air that you breathe.

Yes [Ask Q22, SKIP Q23]
No [Ask Q23, SKIP Q22]
Do not know [Ask Q23, SKIP Q22]

[Show Q11 to those selecting:
Lone parent with children or dependents OR;
Two or more unrelated adults with children or dependents OR;
Couple with children or dependents OR;
at Qiv]

Q11. Would you consider any ‘dependent(s)’ you care for (children and/or adult) to be ‘at risk’ of air pollution? This means that their health would be particularly vulnerable to the quality of the air that they breathe.

Yes
No
Do not know

[Show Q12 to those NOT selecting ‘Do not know’ either at Q10 or Q11]

Q12. Have you used supporting information from any of the following to reach your ‘at risk’ conclusions for yourself and dependants? *Please select the answer that most accurately represents your engagement with supporting information if any.*

No, I have not used any supporting information to reach my conclusions.
Yes, I have used the information provided on the Daily Air Quality Index or DAQI pages.
Yes, I have been told by a health and/or social care professional about the levels of risk that I or my dependents may face from poor air quality.
Yes, both of the previous apply, that is, I have been informed by health and care professionals and also used the information provided on the Daily Air Quality Index or DAQI pages.
Yes, other. Please specify

[Show Q13 to those NOT selecting 'Do not know' either at Q10 or Q11]

Q13. Are you aware that the Daily Air Quality Index or DAQI pages on the UK-AIR website has information that would help to identify whether you are at risk of air pollution?

No, I am not aware.
Yes, I am aware, but I have not read the information.
Yes, I am aware, I have read it, but I do not understand the information.
Yes, I am aware, I have read it, and understand the information.

[Show Q14 to those selecting 'I am a health or social care professional (e.g., doctor, nurse, pharmacist, etc) at Qiii]

Q14. We understand you are a health care professional. Please select from the following two statements.

I refer my patients, only or especially those who are vulnerable to air pollution, to the available air quality information services [SKIP Q15]
I do not refer any of my patients to available air quality information services

Q15. Please select one or more of the following statements as applicable. I do not refer my patients because…

I was not aware of the air quality information services available.
I was not aware that they provided any relevant health advice.
Although I am aware of these services, but do not feel confident in this domain.
In my experience, my patients do not follow up with the information or advice.
In my experience, these services do not provide evidence-based advice.
In my experience, the air quality information services that are provided do not help my patients to take action that further protects their health.
Other, please specify

Q15a. Please feel free to expand on your reasons as to why you do not refer your patients to the available air quality information services.

[Open text]

Part 3: Understanding air quality information

Q16. The Daily Air Quality Index or DAQI is an index with a value from 1-10. Consider the following example from 17 November 2023 on the UK AIR website. The evidence suggests that across most of England, and Northern Ireland, Wales and Scotland DAQI index scores between 2-3 were reported, whereas in some locations of South East England, a DAQI index score of 9 was reported. Please see the figure for a visual representation. What does this mean? (Select one)

The air was not polluted in the UK, and there is no cause for concern.
The air was not polluted in the UK, except for some locations in the South East of England. This said, it is not a cause for concern. Any person residing in any of these regions should continue their daily activities without adjustment.
The air is not polluted in the UK, except for some locations in the South East of England. This could affect people's health near those polluted locations, especially those performing activities outdoors and/or those with prior lung and heart problems.
Other, please specify
Do not know

Q17. Which of the following groups of people living in the UK might be at a **greater** health risk of air pollution (or poor air quality)? (Select all that apply)

All adults
All children
Adults with heart and/or lung problem(s)
Children with heart and/or lung problems(s)
All adults over the age of 65 years
All pregnant women (or people)
Other, please specify

Q18. Please select which of the following **visuals** is easiest to understand. Please note that these visuals are not from the same day.

Visual A
Visual B
Visual C
None of the visuals

Q18a. Please provide any insights into your previous answer as to why the image was the easiest to understand.
[Open text]

'Text 2': The following three questions are scenarios that you might have faced or will face in the future. Please answer to the best of your ability.

Q19. Scenario 1: You have received an air quality alert that indicates there is high air pollution with a DAQI score of 7-9. The following health messages were also provided:

- *Anyone experiencing discomfort such as sore eyes, cough or sore throat **should consider reducing** activity, particularly outdoors.*
- *Adults and children with lung and/or heart problems **should reduce** strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also reduce physical exertion.*

Please select your level of understanding of this advice from the options provided below.

0 – No understanding. I don't understand the action(s) I should take.
1 – Very low understanding. I have a little understanding of some of the actions I should take.
2 – Low understanding. I have some understanding of some the actions I should take.
3 – Medium understanding. I have a good understand of some of the action(s) I should take.
4 – High understanding. I have a good understanding of all actions I should take.
5 – Very high understanding. I have a complete understanding of the action(s) I should take.

Q20. Scenario 2: You have received an air quality alert that suggests a very high level of air pollution with a DAQI score of 10. The following messages were also provided:

- *Please **reduce** physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat.*
- *In particular, adults and children with lung problems, adults with heart problems, and older people, **should avoid** strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often.*

Please select your level of understanding of this advice from the options provided below.

0 – No understanding. I don't understand the action(s) I should take.
1 – Very low understanding. I have a little understanding of some of the actions I should take.
2 – Low understanding. I have some understanding of some the actions I should take.
3 – Medium understanding. I have a good understand of some of the action(s) I should take.
4 – High understanding. I have a good understanding of all actions I should take.
5 – Very high understanding. I have a complete understanding of the action(s) I should take.

Q21. Scenario 3: You have received an air quality message that suggests moderate air pollution, or a DAQI score of 4-6. The following messages were also provided:

- *Please **enjoy** your usual outdoor activities.*
- *Except adults and children with lung problems, and adults with heart problems, **who experience symptoms, should consider reducing** strenuous physical activity, particularly outdoors.*

Please select your level of understanding this advice from the options provided below.

0 – No understanding. I don't understand the action(s) I should take.
1 – Very low understanding. I have a little understanding of some of the actions I should take.
2 – Low understanding. I have some understanding of some the actions I should take.
3 – Medium understanding. I have a good understand of some of the action(s) I should take.
4 – High understanding. I have a good understanding of all actions I should take.
5 – Very high understanding. I have a complete understanding of the action(s) I should take.

Part 4: Your behaviours

'Text 3': In the following questions, we will ask you to consider three scenarios based on real examples of recent air quality alerts in the UK. Let us assume that these are occurring on the day you are completing this questionnaire.

Q22. Scenario 1: You have received an air quality alert (via online, phone, email and/or SMS). There **is high air pollution, with a DAQI score of 8.** The following message was also provided:

Adults and children with lung and/or heart problems should **reduce** strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms, such as sore eyes, cough or sore throat. People with asthma may find they need to use their reliever inhaler more often. Older people should also reduce physical exertion.

What will you do today? *Please select the one that is closest to what you would do in this situation.*

I will go about my day as I had planned (e.g., walk to work, go for a run, etc).
I will continue performing physical activity outdoors.
I will reduce any physical activity outdoors. Please specify the type of activity
I will reduce strenuous physical activity outdoors. Please specify the type of activity I will perform an alternative indoor activity Please specify the type of activity
Other, please specify

Q23. Scenario 1: You have received an air quality alert (via online, phone, email and/or SMS). There **is high air pollution, with a DAQI score of 8.** The alert is accomplished by the following health messages:

Anyone experiencing discomfort such as sore eyes, cough or sore throat should **consider reducing** activity, particularly outdoors.

What will you do today? Please select the one that is closest to what you would do in this situation.

I will go about my day as I had planned (e.g., walk to work, go for a run, etc).
I will continue performing physical activity outdoors.
I will reduce any physical activity outdoors. Please specify the type of activity
I will reduce strenuous physical activity outdoors. Please specify the type of activity
I will perform an alternative indoor activity Please specify the type of activity
Other, please specify

Q24. Scenario 1: You have received an air quality alert (via online, phone, email and/or SMS). There **is high air pollution, with a DAQI score of 8.** Will you do anything differently about scheduling and/or attending health and social care appointments?

Yes, I would delay any health and social care appointments.
Yes, please specify what you would do
No, I would carry on as usual

[Show Q25 to those selecting 'Yes, I use inhalers on occasion to help with my breathing.' Or 'Yes, I use inhalers frequently to help with my breathing.' At Qviii]

Q25. Scenario 1: You have received an air quality alert (via online, phone, email and/or SMS). There **is high air pollution, with a DAQI score of 8.**

Will you do anything differently about your medication, including inhalers, etc?

No, I will not carry my inhaler as I do not normally carry it or need it.
No, I would carry it with me as usual and/or use it if needed.
Yes, I would carry it with me especially because of poor air quality alert and just in case I need it.
Yes, I would carry it with me especially because of the poor air quality alert and use it preventatively, more frequently than usual.

[Show Q26 to those selecting either 'I have one or more dependent children' or 'I have a caring responsibility for one or more adults' or 'All of the above' at Qv]

Q26. Please consider your dependents (children and/or adults under your care) in Scenario 1: You have received an air quality alert (via online, phone, email and/or SMS). There is high air pollution, with a DAQI score of 8.

What would you advise that they do? *Please select the one that is closest to what you would do in this situation.*

That…

They go about their day as planned.
They continue performing physical activity outdoors.
They reduce any physical activity outdoors. Please specify the type of activity
They reduce strenuous physical activity outdoors. Please specify the type of activity They perform an alternative indoor activity Please specify the type of activity
Other, please specify [Open text]
Not applicable, as I would not give them any advice concerning air quality.

Q27. Scenario 2: You have received an air quality alert (via online, through phone, email and/or SMS). There is **very high air pollution, with a DAQI score of 10**. The following messages were also provided:

- Please **reduce** physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat.
- In particular, adults and children with lung problems, adults with heart problems, and older people, should **avoid** strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often.

What will you do today? Please select the one that is closest to what you would do in this situation.

I will go about my day as I had planned (e.g., walk to work, go for a run, etc).
I will continue performing physical activity outdoors.
I will reduce any physical activity outdoors. [Please add examples]
I will reduce strenuous physical activity outdoors. [Please add examples]
I will perform an alternative indoor activity [please add examples]
Other, please specify

Q28. Scenario 2: You have received an air quality alert (via online, through phone, email and/or SMS). There is very high air pollution, with a DAQI score of 10.

Will you do anything differently about scheduling and/or attending health and social care appointments?

Yes, I would delay any health and social care appointments.
Yes, please specify what you would do
No, I would carry on as usual

[Show Q29 to those selecting 'Yes, I use inhalers on occasion to help with my breathing.' Or 'Yes, I use inhalers frequently to help with my breathing.' At Qviii]

Q29. Scenario 2: You have received an air quality alert (via online, through phone, email and/or SMS). There is very high air pollution, with a DAQI score of 10.

Will you do anything differently about your medication, including inhalers, etc?

No, I will not carry my inhaler as I do not normally carry it or need it.
No, I would carry it with me as usual and/or use it if needed.
Yes, I would carry it with me especially because of poor air quality alert and just in case I need it.
Yes, I would carry it with me especially because of the poor air quality alert and use it preventatively, more frequently than usual.

[Show Q30 to those selecting either 'I have one or more dependent children' or 'I have a caring responsibility for one or more adults' or 'All of the above' at Qv]

Q30. Please consider your dependents (children and/or adults under your care) in Scenario 2: You have received an air quality alert (via online, through phone, email and/or SMS). There is very high air pollution, with a DAQI score of 10.

What would you advise that they do? Please select the one that is closest to what you would *do in this situation.*

That…

They go about their day as planned.
They continue performing physical activity outdoors.
They reduce any physical activity outdoors. [Please add examples]
They reduce strenuous physical activity outdoors. [Please add examples]
They perform an alternative indoor activity [please add examples]
Other, please specify
Not applicable, as I would not give them any advice concerning air quality.

[Show Q31, Q32 to those selecting 'Yes' at Q11]

Q31. Scenario 3: You have received an air quality message (via online, through phone, email and/or SMS). There is ***moderate air pollution, with a DAQI score of 5****. The following messages were also provided.*

Adults and children with lung problems, and adults with heart problems, who experience symptoms, should ***consider reducing*** *strenuous physical activity, particularly outdoors.*

What will you do today? *Please select the one that is closest to what you would do in this situation.*

I will go about my day as I had planned (e.g., go to work, go for a run, etc).
I will continue performing physical activity outdoors.
I will reduce any physical activity outdoors. [Please add examples]
I will reduce strenuous physical activity outdoors. [Please add examples]
I will perform an alternative indoor activity [please add examples]
Other, please specify

Q32. Scenario 3: You have received an air quality message (via online, through phone, email and/or SMS). There is moderate air pollution, with a DAQI score of 5.

Will you do anything differently about scheduling and/or attending health and social care appointments?

Yes, I would delay any health and social care appointments.
Yes, please specify what you would do
No, I would carry on as usual

[Show Q33 to those selecting either 'I have one or more dependent children' or 'I have a caring responsibility for one or more adults' or 'All of the above' at Qv AND 'Yes' at Q11]

Q33. Please consider your dependents (children and/or adults under your care) in Scenario 3: You have received an air quality message (via online, through phone, email and/or SMS). There is moderate air pollution, with a DAQI score of 5.

What would you advise that they do? Please select the one that is closest to what you would do in this situation.

That…

They go about their day as planned.
They continue performing physical activity outdoors.
They reduce any physical activity outdoors. Please specify the type of activity
They reduce strenuous physical activity outdoors. [Please specify the type of activity
They perform an alternative indoor activity Please specify the type of activity
Other, please specify
Not applicable, as I would not give them any advice concerning air quality.

[Show Q34 to those selecting either 'Yes, I use inhalers on occasion to help with my breathing.' Or 'Yes, I use inhalers frequently to help with my breathing.' At Qviii]

Q34. Please select any of the statements below that are close to your experiences with using inhalers and/or on behalf of your children and/or adult dependents as applicable. (Select all that apply)

I/we do not change the use of inhaler(s) when there is poor air quality and go about my daily activities as per usual.

I/we use inhaler(s) more frequently when air quality is poor, to help me/us breathe, and go on about my daily activities as per usual.

I/we use inhaler(s) more frequently to help me/us exercise when the air quality is poor, as I/we usually do.

I/we use inhaler(s) more frequently to prevent me/us from getting sick or symptomatic when the air quality is poor and go on about my daily activities as per usual.

I/we use inhaler(s) more frequently when the air quality is poor, but still experience symptoms which prevent me from going on about my daily activities as per usual.

Other, please specify

[Show 'Text 6' to all participants, including those selecting 'No' at Qa or not ticking box at Qb]

End

'Text 6':

Thank you, again, for your participation in this questionnaire!

Your submission will help us understand how the UK Air Information Resources are being used and will help us identify any opportunities to improve these services.

Follow this link to access the Daily Air Quality Index (DAQI) https://uk-air.defra.gov.uk/air-pollution/daqi

A3. Appendix 3: Data collection – Interview Topic Guides

Four topic guides were developed, reviewed and agreed with Defra to conduct semi-structured interviews. Thematic grids were developed to perform thematic analysis on the information gathered through the interviews across groups as follows:

- At risk and general public (20-25 interviews).
- Air quality and health experts (12-14 interviews) –of two types, closer to research and/or a health and care/ local authority setting.
- Air quality modelling/ forecasting experts (2-4 interviews).

A3.1 AT-RISK AND GENERAL PUBLIC GUIDE

Introduction

My name is XXX and I am calling from M·E·L Research / Ricardo.

We have arranged to speak to you today to talk about air quality and the Daily Air Quality Index, also known as the DAQI.

Our conversation will take around 30 to 45 minutes. Is this still a good time for you?

- IF NO, RE-BOOK APPOINTMENT.
- IF YES, CONTINUE.

I will start by providing you some brief context and a few checks, before going through a couple of interview questions.

I am an independent researcher at M·E·L Research/ Ricardo. We've been commissioned by the UK Department for the Environment, Food & Rural Affairs to evaluate the extent to which the Daily Air Quality Index is achieving its objectives and identify any improvements that could be made.

The Index seeks to inform people of the air quality in their neighbourhoods, alert of any instances when there might be health risks and provide advice and recommendations.

Thus, we are surveying and interview people like yourself to check up on the extent to which this might be happening.

To assist us with reporting and analysing the insights from our conversation, we will record the interview. No person will be identifiable in any report. Any information that you provide will be confidential and used to inform this evaluation in an anonymous way, in line with the Data Protection Act 2018 and UK GDPR. The recording and any identifiable information that is collected will be deleted within one year after the project is closed. M·E·L Research is an accredited Market Research Society, or MRS, Company Partner and we abide by the MRS Code of Conduct.

Are you happy to continue with the conversation? You are able to withdraw at any time during the interview, please let me know if you wish to stop at any point.

- IF NO, TRY TO RE-BOOK APPOINTMENT.
- IF YES, CONTINUE.

Part 1 About You

Notes for the interviewer
We will be running a pre-screening survey ahead of the interviews. If the interviewee has been pre-screened, the interviewer will get their information and this section would be simply about confirming the submission they have made.

We will start by confirming a few personal characteristics, just to make sure ask you the right set of questions.

1. Can I confirm your age please?

2. Do you have any heart and/or lung problems (or conditions)?

3. Do you have any dependents with heart and/or lung problems (or conditions)?

4. Do you consider yourself to live in a rural or urban area?

5. Would you mind providing the first block of letters of your postcode so that we understand the spread of participants?

Notes for the interviewer
At risk individuals *include people over 65, and adults and children with heart and/or lung problems (or chronic respiratory and/or cardiovascular conditions), and/or a pregnant woman.*
*The '**general population**', those not at heightened risk, include adults (18-65) without heart nor lung problems.*

6. Would you consider yourself 'at risk' of air pollution? PROBE: How did you reach this conclusion? Why do you say that?

Part 2 DAQI Awareness, access and use

Thank you!

We will now ask a few questions about your awareness and potential use of the DAQI.

7. Before today, were you aware that the Daily Air Quality Index, also known as the DAQI, existed? PROBE/clarification: Had you ever heard of the DAQI before the conversations we have had leading to this interview?
    - IF NO, please go to Part 6 "People who are unaware…"
    - IF YES, please continue.

Notes for the interviewer
There are a few ways one could access the DAQI, through the UK-AIR website, Twitter/X, email bulletins, freephone automated service.
If the interviewee shares information about how they access the DAQI, please probe further on their interactions with specific services e.g., emails or freephone or twitter or the web.

8. How do you access the DAQI information and alerts? PROBE/clarification: What methods do you use to check the DAQI? (Website, e-bulletins, Freephone service, etc)

9. Could you tell me about the DAQI services that you use primarily? FOLLOW-UP: When do you typically use them? How often do you use them? Why?

10. Do you access air quality information from any other source? FOLLOW-UP: How? What source(s)? Why?

Notes for the interviewer
Please note that if the answer is NO to the previous two questions, please skip the next questions and go to Part 6 of this guide. Otherwise continue. Please note if they use another index, you may ask about that instead and make notes for reflection thereafter.

11. How easy or difficult is it to access the DAQI information? PROBE: What makes it easy? What difficulties have you experienced in accessing the DAQI services, if any?

12. What, if anything, would make it easier for you to access and use the DAQI? PROBE: Would you be able to suggest any changes to the DAQI that would help you access it and use it?

13. How trustworthy do you consider the information on air quality provided by the DAQI? PROBE: Why do you say that?

Part 3 Understanding of the DAQI

We are happy to hear that you are aware, and access and use the DAQI services.

Notes for the interviewer
If the interviewee accesses information via another index that is similar and potentially based on the DAQI, e.g. Google Services, London Air, etc., please ask generalised versions of these questions i.e., change DAQI by Index or Air Quality Service.

14. Please tell us more of you understanding of the information you are accessing through the DAQI. PROBE: To what extent would you say you understand the DAQI information, from 1 (little understanding) to 5 (expert understanding)?

15. Please describe to me the DAQI information that you access most frequently.

16. The DAQI groups the forecasts into 1-10 score along four bands: low, moderate, high and very high. How would you describe what these scores and bands mean? PROBE: What would it mean if the DAQI forecasts 'very high' air pollution? What level of risk would you say there would be from a score of 3, for example?

17. This information is also displayed on a map of the UK with Red, Amber, Green colours indicating the risk that the levels of pollution in the air in given area may pose to you, your family and communities when exposed. How do you find this presentation? FOLLOW-UP: If relevant, what about the information provided through the email bulletins and the freephone service. How do you find these?

18. Can you tell me about any difficulties you may have experienced, if any, with understanding the DAQI information that is provided? (e.g., data, forecasts, alerts, advice, etc).

19. Can you tell me about any adjustments that could help you understand the DAQI information? PROBE: Would you change anything for how this information is presented or shared with you? Is there too much of anything? Is there anything missing? What about the visualization? Do you find the information is detailed enough for you to understand what is happening exactly where you live? Are the data updates frequent enough (daily, hourly, etc)? Why? If not, what changes would you like to see?

Part 4 Change of behaviour

Thank you for sharing with us how you understand the DAQI and related services, and ways that could make it better for you to understand the information you are presented.

Notes for the interviewer
If the interviewee accesses information via another index that is similar and potentially based on the DAQI, e.g. Google Services, London Air, etc., please ask generalised versions of these questions i.e., change DAQI by Index or Air Quality Service.

20. Now, please tell me what you do upon accessing or receiving information on your local air quality. PROBE: What information do you consider? The RAG ratings or scores of days ahead? Why is that?

21. Can you tell me more about whether you take local air quality information into account in your day-to-day decisions? PROBE: Would you change your plans upon reading the DAQI? Would you take this information into account when deciding about leaving your home? Would you adjust your plans for practicing physical activity outdoors, for example, in a park?

22. Have you ever received an alert of 'high' or 'very high' air pollution through the DAQI or other air quality information sources? If so, can you remember doing anything in response, and why?

Part 5 DAQI advice and health perceptions

Notes for the interviewer
The advice includes statements such as:
For the general public
For high alerts: Anyone experiencing discomfort such as sore eyes, cough or sore throat should consider reducing activity, particularly outdoors.
For very high alerts: Reduce physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat.
For at risk individuals
For high alerts: Adults and children with lung problems, and adults with heart problems, should reduce strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also reduce physical exertion.
For very high alerts: Adults and children with lung problems, adults with heart problems, and older people, should avoid strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often.

23. What effect do you think breathing in polluted air can have on your health? Why do you say that?

24. What health symptoms have you experienced, if any, during days with higher levels of air pollution? PROBE: Do you recall there being any differences in your wellbeing on days with higher air pollution when compared to days with lower air pollution?

Notes for the interviewer
Please skip the next two questions if the person does not access information through the DAQI at all and uses other services instead, e.g. Google Services, London Air, etc.

25. How aware are you of the DAQI's 'Recommended Actions and Health Advice'? PROBE: Have you ever read these? What can you recall if anything?

26. If so, continue; otherwise skip: What do you think about the DAQI's ''Recommended Actions and Health Advice''? PROBE: Are they easy or difficult to understand? Easy or difficult to follow? If applicable, what would make it easier to implement the advice?

27. What are your views on exercising outdoors if the air you breathe is highly polluted? PROBE: Do you recall any examples of this?

28. What medications do you use, if any, to mitigate any symptoms that you experience when there are higher levels of air pollution? And, how do these help? PROBE: Do you use any inhalers or similar? What are those? How do they help?

Part 6 People who are unaware or not accessing the DAQI

Notes for the interviewer
Please skip this whole Part 6 unless sent here from Part 2 (which would have been <Q6).

8. How interested are you in your local air quality and/or air pollution?
    - If NO/low interest, please go to 'Thank you'.
    - IF YES/some or high interest, please continue.

9. What do you know about air pollution and how it might be affecting your health? *PROBE: What effect do you think breathing in polluted air can have on your health? Why do you say that? Have you become aware of air quality risks offline or from other sources (e.g., from news, health practitioners, etc.)?*

10. Have you experienced any health symptoms that you think could be because of higher levels of air pollution? Can you tell me about these? *PROBE: for example, short of breath, cough, headaches, eye, nose or throat irritations?*

11. Could you tell me more about why you are not using air quality information services like the DAQI? *PROBE: What, if anything, is stopping? Why?*

12. What would you do if you became aware that there is high or very high air pollution in your neighbourhood? *PROBE: Would you do anything differently? Would you change your outdoor plans?*

13. Finally, would you like to receive some information on your local air quality? *PROBE: What information would you like to receive and how?*

Thank you!

That's it from us! Any questions from you?

Thank you so much for your help and contribution, which will be hugely important as we evaluate the Index and develop recommendations. We really appreciate it.

A3.2 AIR QUALITY AND HEALTH EXPERT GUIDES

There were two guides employed for two different types of experts, those with direct and/or indirect (through professionals) contact with patients (Type A) and those with a more research/policy background (Type B). The guides are similar with slight adjustments to reflect this.

A3.2.1 Type A [Air quality and health experts working in a health and care setting]

Introduction

My name is XXX and I am calling from M·E·L Research / Ricardo.

We have arranged to speak to you today to talk about air quality and the Daily Air Quality Index, also known as the DAQI.

Our conversation will take around 30 to 45 minutes. Is this still a good time for you?

- IF NO, RE-BOOK APPOINTMENT.
- IF YES, CONTINUE.

I will start by providing you some brief context and a few checks, before going through a couple of interview questions.

I am an independent researcher at M·E·L Research/ Ricardo. We've been commissioned by the UK Department for the Environment, Food & Rural Affairs to evaluate the extent to which the Daily Air Quality Index is achieving its objectives and identify any improvements that could be made.

The Index seeks to inform people of the air quality in their neighbourhoods, alert of any instances when there might be health risks and provide advice and recommendations to reduce those risks.

Thus, we are surveying and interview people like yourself to check up on the extent to which this might be happening.

To assist us with reporting and analysing the insights from our conversation, we will record the interview. You nor any other individuals will be named in any reports, nor linked to comments that you make, unless agreed otherwise. Any information that you provide will be confidential and used to inform this evaluation in an anonymous way, in line with the Data Protection Act 2018 and UK GDPR. The recording and any identifiable information that is collected will be deleted will be deleted within one year after the project is closed. M·E·L Research is an accredited Market Research Society, or MRS, Company Partner and we abide by the MRS Code of Conduct.

Are you happy to continue with the conversation?

- IF NO, TRY TO RE-BOOK APPOINTMENT.
- IF YES, CONTINUE.

Part 1 About You

Notes for the interviewer
We will have an understanding of who the interviewees will be and this will be shared with you in advance so you can be prepared to engage with the individual as effectively as possible.

Let's start with some introductions, so that we understand better your professional background and how this might interplay with air pollution as a risk factor for people's health and wellbeing.

1. Could you tell me more about your career and, specifically, your current role or roles as a health care professional? *PROBE: What type of people do you work with and in what capacity? Do you work with people who might be considered 'at risk' of air pollution? If so, in what capacity?*

Part 2 DAQI awareness, access and use

And now, let's move on to DAQI awareness, access and use.

2. What level of awareness would you say you had of the DAQI prior to agreeing to undertake this call?
    - IF None, please skip the following questions and Part 2, that is, go to Part 3.
    - IF Some, please continue.

3. How would you describe the DAQI or Index in your own words?

Notes for interviewer
The Daily Air Quality Index (DAQI) tells you about levels of air pollution and provides recommended actions and health advice. The index is numbered 1-10 and divided into four bands, low (1) to very high (10), to provide detail about air pollution levels in a simple way, similar to the sun or pollen indexes provided with weather reports.

4. Who might be especially at risk of air pollution? *PROBE: Would you think that any adult or child with lung and/or heart problems as applicable would be at risk? Any person over 65 years of age? Anyone else?*

5. How aware are you that the DAQI provides a definition of people who might be especially at health risk from short-term exposure to air pollution? *PROBE: Would you agree with their 'broad' definition of people "who are elderly, young children, and those with underlying respiratory and / or cardiovascular disease"? If not, what would you say needs to be added / what is missing from the definition?*

6. How does the DAQI support you in your role, if at all? *PROBE: Do you make use of the air pollution forecasts and alert system in any way? If so, how do you integrate them in your work? Do you use of the DAQI 'recommended actions and advice'? Are there any other air quality information sources you use? Why or why not?*

7. Do you refer any of your patients to the DAQI so they can stay informed of air pollution risks? *PROBE: Why or why not?*

8. To what extent would you say your patients are aware and/or concerned about air pollution as a health risk factor? *PROBE: What types of patients might be more concerned?*

9. To what extent do any of your patients are aware and/or use the DAQI, based on what they tell you? *PROBE: Would you say that people who perceive themselves as more at risk use it more than those who do not? Do you think that people with respiratory conditions might use it more or less than anyone else? What about those with cardiovascular conditions? What about parents of young children? What about those with dependents who might have lung or heart problems?*

10. What barriers do you and/or your patients face to access the DAQI and its services? *PROBE: What is stopping you from accessing the DAQI at present? What might stop your patients?*

11. What could be done to facilitate access to the DAQI to health care professionals who might be interested in it? *PROBE: How could health care professionals become more aware and/or access more frequently this information?*

12. What could be done to facilitate access to the DAQI to patients (or anyone else) who might be interested in it? *PROBE: Anyone or any system whereby people could be sign-posted more effectively to this information? Could health and/or social care professionals offer a way to share information? What other forums might be relevant? What about schools? Job centres? Would it be appropriate?*

Part 3 DAQI advice and behaviour change

Thank you for your responses so far. We are keen to move to exploring the 'Recommended Actions and Health Advice' that is provided by the DAQI.

13. How familiar are you with the DAQI's 'Recommended Actions and Health Advice'? *PROBE: Have you accessed the DAQI's page on the UK AIR website? Would you be able to recall any of the recommendations?*

14. Would you say that your patients are aware of this advice? PROBE: *Why or why not? If so, would you say that they draw on it to take decisions about their day-to-day, especially in high air pollution episodes? Would it be useful if they did?*

Let us explore some of this advice. In advance of this, let us also note that during our literature review, we identified limited studies covering this and thus, we ask that you share opinions based on your experience, acknowledging that this might not be fully contrasted evidence nor conclusive.

If possible, consider sharing screen of this: Daily Air Quality Index - Defra, UK ['Recommended Actions and Health Advice']. If this is possible, please go ahead and ask about the following questions in one go, by reviewing the guidance on screen.

15. For high pollution episodes, with DAQI scores of 7-9, the recommended actions and advice for 'at risk' people is as follows: "Adults and children with lung problems, and adults with heart problems, should **reduce** strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also **reduce** physical exertion." What do you think about this advice? *PROBE: Do you agree this to be reasonable? What adjustments would you make? Why?*

16. For very high pollution episodes, with DAQI scores of 10, the recommended actions and advice for 'at risk' people is as follows: "Adults and children with lung problems, adults with heart problems, and older people, should **avoid** strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often." What do you think about this advice? *PROBE: Do you agree this to be reasonable? What adjustments would you make? Why?*

17. For high or very high pollution episodes, with DAQI scores of 7 or more, the recommended actions and advice for the general population is as follows: "Anyone experiencing discomfort such as sore eyes, cough or sore throat should consider reducing OR reduce activity, particularly outdoors." What do you think about this advice? *PROBE: Do you agree this to be reasonable? What adjustments would you make? Why?*

18. One of the key recommendations is reducing (strenuous) outdoor physical activity at higher levels of air pollution, based on the assumption that this might reduce the severity of symptoms and/or provide a net health benefit to those following the advice. What are your thoughts on this? *PROBE: Can reducing physical activity be an effective way of mitigating or reducing the symptoms from exposure to high levels of air pollution? What could this mean for long-term health and wellbeing?*

19. Another recommendation is for people with asthma experiencing symptoms in episodes of elevated air pollution to use their reliever inhaler more often. What do you think about this advice? *PROBE: Would you agree with the advice? Could the increased use of reliever inhalers reduce symptoms from exposure to air pollution? Would you have any concerns about the increased use of reliever inhalers? Would this have a net positive impact on people's health and wellbeing in the shorter and longer terms?*

20. What are your thoughts on the potential unintended consequences of these recommended actions and advice? *PROBE: Could there be any unintended consequences…that would damage people's health from reducing physical activity in this context? From staying indoors? Missing health appointments? Isolating? What could those be? Would they be 'worthwhile' to reduce exposure to the high-air-pollution episodes?*

21. The DAQI is focussed on the short-term health risks of short-term exposure to episodes of elevated air pollution. What are your views about this? *PROBE: What about the long-term exposure of lower and/or moderate levels of air pollution? Is the difference understood? Could this focus on short-term episodes confuse patients? Will repeated exposure to short term high/very high air pollution events have equal long term health impacts on both 'at risk' and general population?*

22. Do you think that people accessing the DAQI's 'Recommended Actions and Health Advice' might be following it? *PROBE: In your experience, what proportion of people follow generic advice such as that provided by the DAQI? Who might be more likely to follow the advice?*

Thank you!

That's it from us! Any questions from you or comments from you?

Thank you so much for your help and contribution, which will be hugely important as we evaluate the Index and develop recommendations. We really appreciate it.

A3.2.2 Type B [Air quality and health researchers]

Introduction

My name is XXX and I am calling from M·E·L Research / Ricardo.

We have arranged to speak to you today to talk about air quality and the Daily Air Quality Index, also known as the DAQI.

Our conversation will take around 30 to 45 minutes. Is this still a good time for you?

- IF NO, RE-BOOK APPOINTMENT.
- IF YES, CONTINUE.

I will start by providing you some brief context and a few checks, before going through a couple of interview questions.

I am an independent researcher at M·E·L Research/ Ricardo. We've been commissioned by the UK Department for the Environment, Food & Rural Affairs to evaluate the extent to which the Daily Air Quality Index is achieving its objectives and identify any improvements that could be made.

The Index seeks to inform people of the air quality in their neighbourhoods, alert of any instances when there might be health risks and provide advice and recommendations to reduce those risks.

Thus, we are surveying and interview people like yourself to check up on the extent to which this might be happening.

To assist us with reporting and analysing the insights from our conversation, we will record the interview. You nor any other individuals will be named in any reports, nor linked to comments that you make, unless agreed otherwise. Any information that you provide will be confidential and used to inform this evaluation in an anonymous way, in line with the Data Protection Act 2018 and UK GDPR. The recording and any identifiable information that is collected will be deleted will be deleted within one year after the project is closed. M·E·L Research is an accredited Market Research Society, or MRS, Company Partner and we abide by the MRS Code of Conduct.

Are you happy to continue with the conversation?

- IF NO, TRY TO RE-BOOK APPOINTMENT.
- IF YES, CONTINUE.

Part 1 About You

Notes for the interviewer
We will have an understanding of who the interviewees will be and this will be shared with you in advance so you can be prepared to engage with the individual as effectively as possible.

Let's start with some introductions, so that we understand better your professional background and how this might interplay with air pollution as a risk factor for people's health and wellbeing.

1. Could you tell me more about your career and, specifically, your current role or roles as a health care professional? *PROBE: Does your work involve investigating the impacts of poor air quality on people' health? In the shorter and/or longer term?*

Part 2 DAQI awareness, access and use

And now, let's move on to DAQI awareness, access and use.

2. What level of awareness would you say you had of the DAQI prior to agreeing to undertake this call?
    - IF None, please skip the following questions and Part 2 and 3, that is, go to Part 4.
    - IF Some, please continue.

3. How would you describe the DAQI or Index in your own words?

Notes for interviewer
The Daily Air Quality Index (DAQI) tells you about levels of air pollution and provides recommended actions and health advice. The index is numbered 1-10 and divided into four bands, low (1) to very high (10), to provide detail about air pollution levels in a simple way, similar to the sun or pollen indexes provided with weather reports.

4. Who might be especially at risk of air pollution? *PROBE: Would you think that any adult or child with lung and/or heart problems as applicable would be at risk? Any person over 65 years of age? Anyone else?*

5. How aware are you that the DAQI provides a definition of people who might be especially at health risk from short-term exposure to air pollution? *PROBE: Would you agree with their 'broad' definition of people "who are elderly, young children, and those with underlying respiratory and / or cardiovascular disease"? If not, what would you say needs to be added / what is missing from the definition?*

6. How does the DAQI support you in your role, if at all? *PROBE: Do you make use of the air pollution forecasts and the alert system in any way? If so, how do you integrate them in your work? Do you use the 'recommended actions and advice'? Are there any other air quality information sources you use? Why or why not?*

Part 3 DAQI methodology

Notes for interviewer
Please note that these questions would only apply to people who appear and report being very aware of the DAQI, almost at the expert level.

We would like to explore a few detailed questions on the methodology the DAQI uses, including the types of pollutants it includes, their averaging times, and others. Are you happy to proceed with these?

- IF NO, skip to Part 4.
- IF YES, please continue.

7. At present, the DAQI is focussed on the short-term health risks of short-term exposure to elevated air pollution. What are your views about this? *PROBE: The evidence focusses on how people's health might be affected in the short-term, soon after exposure. What about the long-term exposure of lower and/or moderate levels of air pollution? Is the difference understood? Could this focus on short-term episodes confuse patients? Will repeated exposure to short term high/very high air pollution events have equal long term health impacts on both 'at risk' and general population?*

8. What are your thoughts on the pollutants currently covered by the DAQI, that is, NO_2, O_3, PM_{10}, $PM_{2.5}$, SO_2? *PROBE: What would you say are the most relevant pollutants to measure episodes of elevated high air pollution in the short-term in the UK? Are there any other pollutants that are crucial and/or should be covered? In your research, has black carbon been identified as a pollutant of concern from short-term exposures? Should this be considered?*

9. The current averaging times for pollutants are as follows: PM_{10} and $PM_{2.5}$ – 24hrs; O3 – 8hrs; NO_2 – 1hr; SO_2 – 15mins. What are your thoughts on the appropriateness of these averaging times to measure episodes of elevated high air pollution in the short-term in the UK? *PROBE: Do these reflect the latest health evidence regarding the period after which health effects may be experienced following exposure? Do you have any suggestions? Are any of these periods too long? Why or why not?*

10. The DAQI does not currently consider how mixtures of air pollutants might or might not have compounding effects on people's health upon exposure. Considering your scientific perspective on the health impacts of individuals' exposure to pollutant mixtures, what are your thoughts on this? *PROBE: Could there be a significant implication for health that is not covered by the DAQI and resulting alerts if it is not considering mixtures of pollutants? Would there be a significant difference when considering each pollutant as a single contaminant versus a mixtures approach for the DAQI? Do you think there are ways to capture pollutant mixtures in this type of Index? How could that work?*

11. At present, the DAQI treats days as discrete events. What do you think could be the potential implications of this, in terms of short-term health impacts? *PROBE: Do you think there should be more granularity in the alert system e.g. peak periods during the day? What if there are multiple, subsequent days with forecast elevated air pollution? Should the alert system take this into account? Would people's health be more affected in these instances? If so, how?*

Part 4 DAQI advice and behaviour change

Thank you for your responses so far. We are keen to move to explore the 'Recommended Actions and Health Advice' that is provided by the DAQI. Are you happy to proceed?

- IF NO, skip to Thank you.
- IF YES, please continue.

12. How familiar are you with the DAQI's 'Recommended Actions and Health Advice'? *PROBE: Have you accessed the DAQI's page on the UK AIR website? Would you be able to recall any of the recommendations?*

Let us explore some of this advice. In advance of this, let us also note that during our literature review, we identified limited studies covering this and thus, we ask that you share opinions based on your experience, acknowledging that this might not be fully contrasted evidence nor conclusive.

If possible, consider sharing screen of this: Daily Air Quality Index - Defra, UK ['Recommended Actions and Health Advice']. If this is possible, please go ahead and ask about the following questions in one go, by reviewing the guidance on screen.

13. For high pollution episodes, with DAQI scores of 7-9, the recommended actions and advice for 'at risk' people is as follows: "Adults and children with lung problems, and adults with heart problems, should reduce strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also reduce physical exertion." What do you think about this advice? *PROBE: Do you agree this to be reasonable? What adjustments would you make? Why?*

14. For very high pollution episodes, with DAQI scores of 10, the recommended actions and advice for 'at risk' people is as follows: "Adults and children with lung problems, adults with heart problems, and older people, should avoid strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often." What do you think about this advice? *PROBE: Do you agree this to be reasonable? What adjustments would you make? Why?*

15. For high or very high pollution episodes, with DAQI scores of 7 or more, the recommended actions and advice for the general population is as follows: "Anyone experiencing discomfort such as sore eyes, cough or sore throat should consider reducing OR reduce activity, particularly outdoors." What do you think about this advice? *PROBE: Do you agree this to be reasonable? What adjustments would you make? Why?*

16. One of the key recommendations is reducing (strenuous) outdoor physical activity at higher levels of air pollution, based on the assumption that this might reduce the severity of symptoms and/or provide a net health benefit to those following the advice. What are your thoughts on this? *PROBE: Can reducing physical activity be an effective way of mitigating or reducing the symptoms from exposure to high levels of air pollution? Do you think that this an effective way of reducing symptoms from elevated air pollution episodes? What could this mean for long-term health and wellbeing?*

17. Another recommendation is for people with asthma experiencing symptoms in episodes of elevated air pollution to use their reliever inhaler more often. What do you think about this advice? *PROBE: Would you agree with the advice? Could the increased use of reliever inhalers reduce symptoms from exposure to air pollution? Would you have any concerns about the increased use of reliever inhalers? Would this have a net positive impact on people's health and wellbeing in the shorter and longer terms?*

18. What are your thoughts on the potential unintended consequences of these recommended actions and advice? *PROBE: Could there be any unintended consequences…that would damage people's health from reducing physical activity in this context? From staying indoors? Missing health appointments? Isolating? What could those be? Would they be 'worthwhile' to reduce exposure to the high-air-pollution episodes?*

19. Do you think that people accessing the DAQI's 'Recommended Actions and Health Advice' might be following it? *PROBE: In your experience, what proportion of people follow generic advice such as that provided by the DAQI? Who might be more likely to follow the advice?*

Thank you!

That's it from us! Any questions from you or comments from you?

Thank you so much for your help and contribution, which will be hugely important as we evaluate the Index and develop recommendations. We really appreciate it.

A3.3 AIR QUALITY MODELLING EXPERT GUIDE

Introduction

My name is XXX and I'm an air quality consultant at Ricardo. Our call today is about the work that has been commissioned by Defra which aims to evaluate the Daily Air Quality Index to determine the extent to which the DAQI is achieving its objectives and identifying any improvements that could be made.

I have around 10 high-level questions to ask you. If you need to take a break at any time, please let me know.

For data documentation purposes, we will record the interview, but this will not be shared with Defra, and will be deleted once the meeting has been transcribed. Any information you provide will be confidential and used to inform this evaluation in an anonymous way in line with the Data Protection Act 2018 and UK GDPR. The recording and any identifiable information that is collected will be deleted soon after the project is closed.

Are you happy to continue with the conversation?

Guide aimed Met Office experts running the AQUM Model:

1. The AQUM model uses a variety of different data sources such as the global fire assimilation system data, NAEI data. Please describe some of the challenges of working with third party data providers.
Please listen to response then ask sub-questions as relevant. 1a. Do data providers conduct checks on data? For example, in 2022 there were issues with the global fire assimilation system data. 1b. If the checks are not completed by the provider, do the Met Office conduct their own checks? If not, what are the challenges involved with checking data e.g., time limitations? 1c. If there are challenges, how do you envision, they could be overcome? Could technological improvements use of AI tools, be used for data checks? 1d. How often are different data inputs updated? Is this reliant on the data provider?
2. Are any post-hoc adjustments made to the forecast model outputs? E.g., scaling factors.
3. How do you verify the DAQI model forecasts?
3a. Is this through using quarterly ratified AURN data? 3b. Do the findings lead to improvements of the model or do the quarterly reports have another purpose? 3c. Have tests been done to determine if there is any difference in forecast DAQI when using ratified and un-ratified AURN datasets in post-processing?
4. Have Met Office considered inputting additional data into the model and what effects would this have on the DAQI forecasts?
4a. Is monitoring data such as local air quality monitoring networks or sensor data used? 4b. What would be the challenges if this sort of data were to be used/what are the challenges of using this data? 4c. Any other input data e.g., satellite data?
5. In your opinion how could the DAQI forecast be improved in terms of inputs and outputs?
5a. From your experience with the AQUM model, how do you find the model's performance? What is the level of uncertainty, and how do you aim to minimise these? ***Prompt: In the reports it is stated the model does not perform as well for NO2 than ozone and PM; is this something that is looking to be improved? If so, would improving spatiotemporal resolution improve results for NO2?***

What can cause over and underestimations in DAQI?

5b. Is it possible to undertake live transfer of air quality monitoring data into the model?

5c. If not, could machine learning be used to estimate pollution levels on the forecast days to improve accuracy of DAQI?

5d. How often are improvements made currently to the model? What improvements have been considered?

5e. What would the Met Office like to change about the outputs from the forecast?

5f. Are there ways that the output could be more beneficial/useful for the end-user?

5g. Would you say the end-user is considered throughout the process of the DAQI forecasts?

5h. On the pollution forecast is the today page the live DAQI or is it the modelled DAQI?

6. What is done to mitigate the potential effects on the public e.g., vulnerable population, from underpredicting or overpredicting DAQI forecasts?

6a. What steps are taken forward to ensure DAQI are not underpredicted?

6b. In your opinion what are the potential effects on the public from underpredicting DAQI forecasts?

6c. Are model uncertainties communicated on the UK air website? Do you think they should be? Would this be beneficial to the public in your opinion?

6d. Can health advice be found easily on the air quality forecast page when the forecasts show moderate/high pollution? Can you describe where the health advice is?

6e. In your opinion, is there scope to work with other relevant stakeholders e.g., public health, improve the DAQI approach/outputs/messaging?

7. Would improvements to data granularity improve accuracy of DAQI forecast?

7a. What are the number of points on the map which are aggregated to a 11 km grid?

7b. What do these points represent, monitoring locations and/or meteorological stations?

7c. If the number of points is increased will the accuracy of the DAQI forecasts be improved?

7d. If the grid resolution is increased, will the accuracy of the DAQI forecasts be improved, including more localised pollution events?

7e. Are there any challenges associated to increasing grid resolution? Is it feasible to improve the resolution of the grid, is this something that has been considered before?

7f. How are the points aggregated to form the DAQI forecast? Is it based on regions in the country? Can you explain the process and how this effects the final forecast DAQI?

8. In your opinion does the forecast granularity/resolution meet the needs of the public?

8a. Do you feel the data granularity in terms of the forecasting time is useful for the end-user/public? Can they change their behaviours to limit exposure based on the current time-resolution of the forecasts?

Prompt: Is it feasible to change the forecast temporal resolution? Are there any challenges associated to this, has it been considered before?

8b. From your perspective, would pollutant specific forecasts be more useful to the public? 8c. What other changes in terms of granularity/resolution would be useful to the public?
9. In your opinion, how could the air pollution forecast information be communicated more clearly to the general public?
PROBE: So, this could be more information on the output page, interactive outputs?
10. If you were to make any changes to the DAQI data display what in your opinion would create the largest impact to increase public use or understanding?

Thank you!

That's it from us! Any questions from you?

Thank you so much for your help and contribution, which will be hugely important as we evaluate the Index and develop recommendations. We really appreciate it.

A4. Appendix 4: Literature review findings

This Appendix documents the literature review activities conducted in this project, structured into eight subsections, as follows:

- Methodology overview
- CERQ1 data inputs
- CERQ2 methodology
- CERQ3 access
- CERQ4 understanding
- CERQ5 change of behaviour
- CERQ6 soundness of advice
- Additional evidence relevant to this literature review

A4.1 METHODOLOGY OVERVIEW

The literature review was carried out in two steps: the first step was to review the available documentation within the invitation to tender, and the second step was to supplement this with additional documentation obtained via a targeted literature search.

Within the invitation to tender documents, Defra had outlined existing research documents which should be reviewed as part of this project. These documents were obtained from the public domain, where available, and those not publicly available were requested from Defra. The team carried out a rapid review of all documentation provided and allocated each report to the most appropriate research question; the documentation was then reviewed in more detail, and any evidence aligned to each specific sub research question was collated. The team collaborated across the research and sub-research questions, highlighting any instances where information relevant to other research questions was identified.

References from the initial set of literature were used as the starting point for the literature search for each sub-research question. The team undertook a rapid literature search based on search terms for each specific research question. The search strings were generated to target relevant literature effectively, e.g., “air quality” OR “air pollution” AND “alerts” AND “behaviour” OR “inhaler” OR “exercise”. Quick reviews of the literature after initial search results were obtained were undertaken to review whether the research question could be answered from the initial search results. Following this, an initial gap analysis was undertaken to identify specific areas where there was missing information. A further search was then undertaken to try and fill areas of missing information. Where gaps have been unable to be filled, this is summarised at the end of each sub-research question and suggestions of how to obtain the relevant information from other sources (such as the survey, and interviews) are provided.

A4.2 CERQ1 DATA INPUTS

The Automatic Urban and Rural Network (AURN) data provides accurate hourly data for NO_2, ozone, PM_{10}, $PM_{2.5}$ and SO_2. The AURN data was assessed for the years 2018 – 2023. It was found that the maximum percentage of sites with data capture below 75% during this time was:

- 12 % for nitrogen dioxide (NO_2) in 2020 (160 active monitoring sites in 2020)
- 14 % for ozone (O_3) in 2023 (95 active monitoring sites in 2023)
- 18 % for particulate matter <10 µm (PM_{10}) in 2022 (111 active monitoring sites in 2022)
- 23 % for particulate matter <2.5 µm ($PM_{2.5}$) in 2022 (101 active monitoring sites in 2022)
- 29 % for sulphur dioxide (SO_2) in 2020 (28 active monitoring sites in 2020)

The years which had the highest normalised totals of data capture below 75% were 2021 and 2022. The AURN data is input into the Air Quality Unified Model (AQUM) model and used during the post-processing stage of the model to help formulate the Daily Air Quality Index (DAQI) forecast. The performance of the model from 2018 – 2023 was assessed, and it was found that the DAQI was often underpredicted. The year with the highest percentage of poorly predicted DAQI was 2019. This did not correlate with the years with highest normalised totals of data capture below 75% indicating other AQUM model data inputs or model parameters may affect the model performance to a higher degree.

The granularity of the AURN data input into the model, in terms of temporal resolution, are in line with the averaging utilised to determine the DAQI, therefore it is unlikely that improving the temporal resolution of the data would lead to significant improvements in the DAQI forecast. It is possible that the performance of the model could be improved by adjusting spatial parameters such as the grid resolution and the number of the modelled points on the map. The use of the outputs by the public could also be enhanced by improving temporal resolution of model outputs or providing time-resolved advice based on knowledge about the circumstances causing the air pollution event.

A4.2.1?Q1:1 Monitoring Network

Research Question: ***To what extent does the AURN network provide sufficiently complete and accurate measurement data to allow communication of a meaningful real time air quality index?***

The AURN provides hourly data for NO_2, ozone, PM_{10}, $PM_{2.5}$ and SO_2. The accuracy of the data is high due to the quality assurance/quality control (QA/QC) units which ensure data produced by the AURN are robust, reliable and of high quality. As measurement data is used to fulfil the reporting requirements of the Air Quality Standards Regulations, it needs to meet the legal obligations and Daily Quality Objectives of the Regulations. The QA/QC Units interact closely with the AURN Central Management and Co-Ordination Units (CMCU) and Gas Provision contractors to ensure that these network objectives are met.[11]

The data coverage for AURN measurements each DAQI pollutant, per site and per year are presented in the Section A4.8 (Table A4-10, Table A4-11, Table A4-12, Table A4-13 and Table A4-14). Figure A4-1 and Table A4-1 condense information in the aforementioned tables, by summarising periods where data coverage is below 75%. For measurement sites in the UK, a data coverage lower limit of 75% is used to ensure the data is representative of the whole year and to ensure not too many sites are excluded.[12] Between 2018-2023:

- NO_2 had a median of 160 monitoring sites, the highest across DAQI pollutants, with a maximum of 12% of the available sites in any year being below 75% data coverage (in 2023).
- PM_{10} had a median of 93 monitoring sites, with a maximum of 18% of the available data being below 75% data coverage (in 2022).
- $PM_{2.5}$ had a median of 82 monitoring sites, with a maximum of 23% of the available sites in any year being below 75% data coverage (in 2022).
- Ozone had a median of 76 monitoring sites with a maximum of 14% of the available sites in any year being below 75% data coverage (in 2023).
- SO_2 had a median of 28 monitoring sites, the lowest across other DAQI pollutants, with a maximum of 29% of the available sites in any year being below 75% data coverage (2020).

This shows that at least 70% of the measurement sites had data coverage above 75% between 2018-2023. The number of monitoring stations for each pollutant shows that NO_2 monitoring is a key priority in terms of UK air quality. An increase in the number of monitoring stations for ozone and PM may provide more complete datasets.

The Met Office produces the DAQI forecast and uses AURN data during post-processing to adjust the AQUM model results, to improve accuracy. Ricardo sends a days' worth of AURN data to the Met Office at 06:30 on a given day. The model results are published on the following day at 01:00. The AURN data that is sent to the Met Office is provisional data.[13] Provisional data has undergone basic screening criteria to exclude clearly faulty data (this is done by Bureau Veritas). However, the data shared with the Met Office has not undergone

[11] Quality Assurance and Quality Control (QA/QC) Procedures for UK Air Quality Monitoring under the Air Quality Standards Regulations (2023) https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2309281140_All_Networks_QAQC_Document_2023.pdf
[12] Air Pollution FAQs https://uk-air.defra.gov.uk/air-pollution/faq?question=23 (Accessed 14/02/2024)
[13] Interview with Trevor Davies, Ricardo, on 05/02/2024

full quality assurance and quality control procedures, meaning the data is likely to be of lower accuracy and reliability than that required for final reporting.[14] Due to the quick turn-around of the DAQI forecast, the use of provisional data is inevitable. As a result, Ricardo also uploads quarterly ratified data on the 4th of January, April, July, and November of each year. This data can be used by the Met Office to determine if ratified AURN data improves the accuracy of the DAQI forecast.[15] An additional measure that could be introduced is for data coverage statistics to be shared when sending daily data at 06:30, so that if DAQI forecasts are inaccurate, it can quickly be determined whether incomplete AURN datasets contributed to this.

The spatial resolution of AURN sites in the UK is shown in Figure A4-1 by grey and black dots. It is clear that there are a fewer number of AURN sites in Northern England, Scotland, and Wales, compared to central and Southern England. This is a disadvantage as it prevents those living far away from AURN monitoring sites from receiving spatially representative live DAQIs. Moreover, through improving the spatial representation of monitoring sites this could improve the spatial resolution, hence accuracy, of DAQI forecasts.

[14] Northern Ireland Air, Data verification and ratification process https://www.airqualityni.co.uk/data/verification-and-ratification (Accessed 07/02/2024).

[15] Interview with Trevor Davies, Ricardo, on 05/02/2024

Table A4-1 Data coverage for ratified AURN data from 2018 – 2023. The normalised totals were calculated by dividing the number of sites with data coverage <75%, by the total number of sites per pollutant. The sum of this value for all pollutants is represented by normalised totals

	2018			2019			2020			2021			2022			2023		
	Total number of sites	DC% <75%	% of sites with DC <75%	Total number of sites	DC% <75%	% of sites with DC <75%	Total number of sites	DC% <75%	% of sites with DC <75%	Total number of sites	DC% <75%	% of sites with DC <75%	Total number of sites	DC% <75%	% of sites with DC <75%	Total number of sites	DC% <75%	% of sites with DC <75%
Nitrogen Dioxide (NO_2)	157	9	6%	160	10	6%	160	13	8%	161	19	12%	158	8	5%	160	9	6%
Ozone (O_3)	75	1	1%	76	6	8%	76	7	9%	76	10	13%	74	5	7%	95	13	14%
Particulate Matter <10 µm (PM_{10})	75	12	16%	87	12	14%	91	4	4%	94	10	11%	111	20	18%	117	9	8%
Particulate Matter <2.5 µm ($PM_{2.5}$)	79	11	14%	80	4	5%	81	5	6%	83	11	13%	101	23	23%	107	10	9%
Sulphur Dioxide (SO_2)	27	4	15%	27	5	19%	28	8	29%	28	5	18%	28	2	7%	28	1	4%
Total		**37**			**37**			**37**			**55**			**58**			**42**	
Normalised totals	0.61			0.60			0.65			0.79			0.72			0.48		

Figure A4-1 The data capture per year and per pollutant is shown in the map. Where the data capture is below 75% the data points are shown in black

It is worth noting that the AQUM models utilise other data inputs other than AURN data and continually update the model to make improvements. Table A4-2 shows the implemented improvements from 2018 – 2023 in AQUM input models. Table A4-2 shows that there was an issue with the Global Fire Assimilation System data, input into the model. This issue caused PM episodes to be incorrectly predicted in 2022. This shows that other data inputs may require regular updates/quality control checks.

Table A4-2 Model implemented improvements from 2018-2023

	Improvements
2018	• Update to NAEI 2015 NAEI emissions and EMEP 2015, improving domestic wood burning representation. • Improved diurnal cycle for ammonia emissions. This led to excessive concentrations of ammonia at night which were modified to scale the emissions reflected in measurements. • Change to chemical reaction of N_2O_5 to better reflect more realistic chemical reactions this reduced positive bias seen for $PM_{2.5}$ under episode conditions. • Introduction to additional NO_2 satellite observations • Improvement to representation of aerosol and ozone in the model radiation scheme • Improved dry deposition velocities for aerosols
2019	• Update to NAEI 2016 emissions • Update to global model that provides chemical and aerosol lateral fluxes for AQUM. Vertical level resolution improvements.
2020	• Update to NAEI 2017 emissions • Preparation and testing of emissions scenarios under COVID restrictions, with a reduced set of emissions being implemented. • Study funded to determine how traffic sites can be better modelled using statistical post-processing techniques.
2021	• Update to NAEI 2018 emissions • Scaling factors for emissions during COVID removed in July as COVID restrictions removed. • Meteorological model improvements
2022	• Update to NAEI 2019 emissions • Improved processing methods to reduce elevated pollution levels near Bristol Channel • Global Fire Assimilation System data turned off due to issues in 2022 with trials being completed to determine how to reintroduce the data for 2023

A4.2.1.1 Gaps in evidence identified by the literature review.

There were certain gaps in the evidence above which will be addressed by the interview with the Met Office:

- It is unclear from the reports how the Met Office use the ratified data to verify their DAQI model forecasts.
- It is unclear whether comparisons of model outputs using provisional and ratified data are made to determine the difference, if any, when using ratified data in the post-processing of the model.
- It is unclear whether the other input data is checked thoroughly and how often certain datasets are updated.

A4.2.2Q1:2 Forecasting Model

Research Question: ***To what extent does the forecasting model on which DAQI forecasts are based provide sufficiently precise and accurate predictions of future air quality conditions to allow individuals to meaningfully modify their behaviour?***

The DAQI forecasting model is based on weather prediction systems. This leads to considerable strengths such as operational resilience as weather forecasting models benefit from long-term investments in research and development. **The models work well at predicting regional scale and multi-day pollution events**, which is further improved when integrated with satellite observations that can represent trans-boundary sources such as Saharan dust. Other **strengths include ability to forecast development of photochemical ozone pollution associated with spring and summertime high pressure systems as well as regional scale $PM_{2.5}$ events**. The DAQI forecasting model can highlight short-term high pollution events. [16] Table A4-3 summarises the overall performance of the AQUM (Air Quality in the Unified Model). [17]

Local air quality management in the UK largely centres on reduction of NO_2 concentrations as most of the air quality management areas within the UK are declared as a result of NO_2 concentrations exceeding or being close to exceeding the UK's National Air Quality Objectives for annual mean concentrations.[18] Many measures implemented by local authorities aim to reduce NO_2 for example clean air zones, low emission zones and low traffic neighbourhoods. As a result, the public perception of air pollution in the UK, is currently shaped to a large degree by NO_2.[19] Despite this the AQUM model do not predict NO_2 as well as other pollutants such as ozone and PM, as NO_2 is a localised pollutant. The AQUM model has a coarse spatial resolution (DAQI 11 km x 11 km grid resolution), which is insufficient as it can lead to a lack of representation of the main NO_2 source locations for example the road network.[20] In terms of temporal resolution, as the forecast DAQIs are produced daily, this removes temporal variation which can further cause an underweighting in NO_2 concentrations as it is a relatively short-lived pollutant with a lifetime of a few hours. Overall, the uncertainty related to predicting NO_2 concentrations is disadvantageous considering NO_2 concentrations are clearly a priority in the UK in terms of air quality.[21]

Table A4-3 The performance of the Air Quality in the Unified Model (AQUM).

	Strengths	Limitations
General	• Model predicts start and end of episodes well	• Spatial extent of exceedances can often be inaccurate. • Underestimations of the DAQI
Ozone	• Background levels well represented.	• Highest concentrations of ozone under episode conditions may be underpredicted

[16] AQIS, *Data Stream: short summary of expert meeting on air pollution modelling on 14th June 2022*
[17] UK Air Quality Forecasting in 2022 Appendix 1 – page 27
[18] https://uk-air.defra.gov.uk/aqma/summary
[19] AQIS, *Data Stream: short summary of expert meeting on air pollution modelling on 14th June 2022*
[20] AQIS, *Data Stream: short summary of expert meeting on air pollution modelling on 14th June 2022*
[21] https://uk-air.defra.gov.uk/aqma/summary

	Strengths	Limitations
	• Responds well to high ozone during pollution episodes	
$PM_{2.5}$ and PM_{10}	• Predicts $PM_{2.5}$ and PM_{10} well	• Model overpredicts episodes when secondary inorganic aerosol is the dominant species (March/April, Sep/Oct) • Model underpredicts winter-time episodes when coarser aerosols play a greater role
NO_2	• Background levels well represented but rarely responsible for overall DAQI	• Model does not predict as well as ozone and PM; predictions significantly lower than observed especially in urban areas (caused by insufficient resolution to represent main source locations e.g., road network)
SO_2		• Unreliable predictions when high SO_2 is caused by emission control failures as the emissions inventory used in model assumes normal operating conditions.

The performance of the DAQI forecasts were evaluated using the Met Office DAQI evaluation quarterly reports from 2018 – 2023[22]. Table A4-15 in Section A4.8.2 was populated by reading the commentary in the reports and interpreting the maps for observed DAQI and forecast DAQI. Table A4-4 summarises the days of good and poor agreement of modelled DAQI compared to observed DAQI. It is worth noting that the percentages will not add up to 100%, as some pollution events could not be verified so were left blank.

The results show that the model successfully predicts spatiotemporal factors i.e., the location (76% good agreement to observed values) and onset and termination of the pollution event (80% good agreement to observed values), however the DAQI is often poorly predicted (67% pollutant DAQI poorly predicted). **Underprediction of the DAQI was commonly observed during pollution episodes in 2018 – 2023**. Where underprediction of the model occurs, this may not allow the public to modify their behaviours to reduce air pollution exposure.

Table A4-4 The DAQI forecast performance.

Year	Total Pollution Episode Days	Days of good agreement			Days of poor agreement		
		Location well-predicted	Timing/length of pollutant event well-predicted	Pollutant DAQI well predicted	Location poorly predicted	Length of pollutant event poorly predicted	Pollutant DAQI poorly predicted
2018	14	9	9	3	1	1	9

[22] DAQI quarterly evaluation reports 2018 – 2023

Year	Total Pollution Episode Days	Days of good agreement			Days of poor agreement		
		Location well-predicted	Timing/length of pollutant event well-predicted	Pollutant DAQI well predicted	Location poorly predicted	Length of pollutant event poorly predicted	Pollutant DAQI poorly predicted
2019	19	17	17	3	2	2	16
2020	32	18	24	10	10	7	22
2021	6	6	4	2	0	0	4
2022	19	16	17	7	3	2	12
2023	17	15	15	8	2	2	9
Total	107	81	86	33	18	14	72
		76%	**80%**	**31%**	**17%**	**13%**	**67%**

A4.2.2.1 Gaps in evidence identified by the literature review

- The potential effects on the public from underpredicting DAQI forecasts is not included in the reports or evidence found.
- Possible causes of underprediction of the model, could this be due to the model not predicting NO_2 well.

A4.2.3Q1:3 Data Granularity

Research Question: *To what extent does the granularity of data communicated via the DAQI (on UK-Air) allow individuals to meaningfully modify their behaviour based on their local air quality conditions?*

As mentioned previously in Section A4.2.1, the Met Office produces the DAQI forecast and uses AURN data during post-processing to adjust the model results, to improve accuracy. Ricardo sends a days' worth of AURN data to the Met Office at 06:30 on a given day. The model results are published on the following day at 01:00.[23] As live real-time transfers of AURN data into the model run are currently not possible, the AURN provides recent data from the day before to input into the model, suggesting the granularity of the data allows individuals to modify their behaviour based on their local air quality conditions. **If live real-time transfers of AURN data into the model were possible, this could increase the accuracy of the model as more recent data could be used in the post-processing adjustments**. Other data sources are input into the model such as the National Atmospheric Emissions Inventory data. To ensure the model is accurate, timely updates to emissions and other data sources are required.

The DAQI forecast is computed on 11 km x 11 km grid. If the grid's resolution were improved, the granularity of the data would increase, which could potentially improve the accuracy of the DAQI forecast[24,25]. The resolution of the AURN measurement data is in line with the methods of how the DAQI is calculated. For example, ozone DAQI is based on the 8-hour running mean, so the AURN data sent to the DAQI model includes 8-hour running mean data for every hour of the day. The resolution of nitrogen dioxide data is hourly and for particulate matter (PM_{10} and $PM_{2.5}$) the resolution consists of 24-hour running means[8 26].

A general recommendation from the AQIS group review was to improve the methods of communicating the results to the public. The temporal resolution of the outputs of the forecast could be improved through providing hourly forecasts to allow the public, especially those with health conditions, to plan their activities ahead of time with regards to high pollution episodes. Another option is to provide a more time-resolved advice-based forecast to help reduce exposure. For example, wintertime high pollution events that occur due to shallow boundary layer accumulation of NO_2 and $PM_{2.5}$ early in the morning can result in higher exposure to air pollution during that time. The later breakup of the boundary layer could lead to specific advice recommending shifting outdoor exercise to later in the day. Alternatively, when photochemical ozone builds during the day to its maximum concentration in the late afternoon, shifting exercise to the morning can prevent exposure to high levels of ozone.[27]

When providing more time-resolved forecasts the input monitoring data used in the post-processing of the model, may need to be more recent than it currently is. As live real-time transfers of AURN data into the model run are currently not possible, the AURN provides recent data from the day before to input into the model, suggesting the granularity of the

[23] Interview with Trevor Davies, Ricardo, on 05/02/2024

[24] Met Office, Air Pollution, https://www.metoffice.gov.uk/weather/guides/air-quality, (Accessed 13/02/2024)

[25] Interview with Trevor Davies, Ricardo, on 05/02/2024

[26] UK Air, Daily Air Quality Index, https://uk-air.defra.gov.uk/air-pollution/daqi, (Accessed 07/02/24)

[27] AQIS, *Data Stream: short summary of expert meeting on air pollution modelling on 14th June 2022*

data allows individuals to modify their behaviour based on their local air quality conditions. **If live real-time transfers of AURN data into the model were possible, this could increase the accuracy of the model as more recent data could be used in the post-processing adjustments**. Other potential methods that could be used are the use of machine learning tools to predict air pollutant concentrations and input this into the model. This approach may require integrating new information sources into the air pollution model such as compact sensors and new products from earth observation, to improve quality of the training dataset.[28]

A4.2.3.1 Gaps in evidence identified by the literature review

There were certain gaps in the evidence above which will be addressed by the interview with the Met Office:

- Whether it is possible for live transfers of AURN data to be incorporated into the AQUM model whilst it is running.
- To better understand whether granularity can improve DAQI forecasts more information is required such as:
  - Understanding how the modelled map assigns values to spatial points on the UK Air forecast map?
  - What do these points represent, monitoring locations and/or meteorological stations?
  - If the grid resolution is increased, will the accuracy of the DAQI forecasts be improved, including more localised pollution events?
  - How are the points aggregated to form the DAQI forecast? Is it based on regions in the country?

There are other gaps in the evidence that will be addressed by interviews with the general public:

- Do the public feel the data granularity in terms of the forecasting time is useful? Can they change their behaviours to limit exposure based on the current time-resolution of the forecasts?
- Do the public feel the spatial granularity of the forecasts meet their needs?
- What changes would they like to see in terms of data granularity? Would pollutant specific forecasts be more useful?
- How could the air pollution forecast information be communicated more clearly/usefully?

A4.3 CERQ2 METHODOLOGY

This section has considered literature including a number of review articles, and other AQIs worldwide, in order to attempt to determine the suitability of the DAQI in terms of the pollutants included, their breakpoints and averaging times, the relevance of the inclusion of pollutant mixtures and the potential impacts of treating days as discrete events. The key gaps highlighted in this literature review are mainly a lack of studies on the health impacts

[28] AQIS, *Data Stream: short summary of expert meeting on air pollution modelling on 14th June 2022*

of air pollutants, specifically short-term exposure; multiple sources noted a lack of clear enough evidence to justify major amendments and/or updates, for example, to the WHO air quality guidelines, the DAQI, or to other AQIs. This means that while **there is some evidence for making changes / improvements to the DAQI and what these improvements should be**, for example: inclusion of additional pollutants (particularly black carbon and ultra-fine particles), updating the existing breakpoints to be more stringent, considering shorter averaging times (particularly for particulate matter), including the possible effects of a mixture of pollutants, and providing health guidance on a sub-daily timescale, **there is not adequate evidence available to be able to determine the scale of the benefits of making one or more of these updates** to the DAQI.

A4.3.1Q2:1 Pollutants included

Research question: *Do the five pollutants included in the DAQI remain the most relevant pollutants to measure short-term air pollution risk in the UK setting?*

The five pollutants included in the DAQI (nitrogen dioxide (NO_2), ozone (O_3), particulate matter <2.5 µM ($PM_{2.5}$), particulate matter <10 µM (PM_{10}), and sulphur dioxide (SO_2) are in line with those included in other AQIs around the world; Priti K and Kumar (2022) note that the aforementioned criteria pollutants, plus carbon monoxide (CO) are the only pollutants included in most AQIs[29]. There is some evidence that exposure to additional pollutants such as black carbon (which the UK already monitors) and ultra-fine particles are linked to health effects and could be considered for inclusion in the DAQI.

The DAQI was last modified in 2012 when $PM_{2.5}$ was added as a DAQI pollutant and CO was removed as outdoor concentrations had dramatically reduced[30]. The Committee on the Medical Effects of Air Pollutants (COMEAP) last published a review of the DAQI in 2011[31] stating the recommendations were based on studies relating to either short-term or long-term levels of relevant pollutants. There have been no further updates from Defra or COMEAP.

Priti K and Kumar (2022) noted that **most AQIs lack the inclusion of hazardous air pollutants such as benzene, which are thought to be more harmful and carcinogenic**.[32] The Air Quality Stocktake report by the Office for Environmental Protection (OEP) makes mention to emerging pollutants, which may pose high risks to human health. Within the report, risk assessments were completed for different pollutants.[33] A scoring process was used which assessed pollutants based on their current risk, future risk, and quality of evidence. Pollutants that were deemed to be a very high or high risk include:

- Ammonia (NH_3)

[29] Priti K and Kumar (2022), *A critical evaluation of air quality index models (1960–2021),* Environ. Monit. Assess., 194: 324, https://doi.org/10.1007/s10661-022-09896-8

[30] RE: NOTIFICATION OF CHANGES TO THE AIR QUALITY INDEX, email from Dr Clare Bayley, Defra, 1st December 2011, https://uk-air.defra.gov.uk/assets/documents/Notification_of_changes_to_the_air_quality_index.pdf

[31] Review of the UK Air Quality Index, Committee on the Medical Effects of Air Pollutants (COMEAP) Standards Advisory Subgroup, 2011, https://assets.publishing.service.gov.uk/media/5a749a66e5274a44083b8003/COMEAP_review_of_the_uk_air_quality_index.pdf

[32] Priti K and Kumar (2022), *A critical evaluation of air quality index models (1960–2021),* Environ. Monit. Assess., 194: 324, https://doi.org/10.1007/s10661-022-09896-8

[33] Ricardo, Air quality stocktake report for Office for Environmental Protection (2023) https://www.theoep.org.uk/report/commissioned-research-inform-oeps-air-quality-strategy-consultation-response

Ammonia can lead to significant health impacts as it undergoes chemical reactions in the atmosphere to produce particulate matter (PM). [34]

- Benzo(k)fluoranthene (BkF)

Benzo(k)fluoranthene is a polycyclic aromatic hydrocarbon (PAH) classified for carcinogenicity Category 1B. [35] There is evidence associating exposure to airborne PAHs with adverse impacts such as reduced lung function, exacerbation of asthma, increased rates of disease and death from obstructive lung diseases, and increased risk of heart diseases.

- Bioaerosols

Bioaerosols have a wide range of human health impacts depending on the nature of the particles. An example of a toxic components in bioaerosols are endotoxins which are groups of lipopolysaccharides (LPSs) that live within the cells of gram-negative bacteria. Endotoxins can bioaccumulate within humans through inhalation of ambient air or the drinking of contaminated water, impacting the cardiovascular, respiratory and digestive systems, as well as impacting muscles and joints. Inhalation of endotoxins in the air is reported to largely impact the respiratory system.[36]

- Black/elemental carbon (BC/EC)

BC/EC is a chemical constituent of $PM_{2.5}$, that has been linked with heart disease and early death.[37]

- Brown carbon (BrC)

BrC is linked to adverse health outcomes, such as heart disease.[38]

- Chromium (Cr)

Chromium exists in different ionic states; chromium (VI) is much more toxic than chromium (III), for both acute and chronic exposures. Acute effects for chromium (VI) may occur in respiratory tract following inhalation exposure in humans. Inhalation of very high concentrations may cause shortness of breath, coughing, and wheezing. Other effects noted from acute inhalation exposure to very high concentrations of chromium (VI) include disorders of the digestive system and affects to the brain, spine or nerves. Chronic inhalation exposure to chromium (VI) in humans results in effects on the respiratory tract, with perforations and ulcerations of the septum, bronchitis, decreased lung function, pneumonia, asthma, and nasal itching and soreness reported. Epidemiological studies of workers have established that inhaled chromium is a human carcinogen, resulting in an increased risk of lung cancer. [39]

- Indeno[123-cd]pyrene (IcdP)

[34] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770715/clean-air-strategy-2019.pdf
[35] ECHA (2022) Substance Infocard - Benzo[k]fluoranthene. Available at: https://echa.europa.eu/substance-information/-/substanceinfo/100.005.379
[36] Occurrence and fate of bacterial endotoxins in the environment (air, water, wastewater) and remediation technologies: An overview - ScienceDirect
[37] Effects of Black Carbon https://www3.epa.gov/airquality/blackcarbon/effects.html#public
[38] https://doi.org/10.1080/08958370701866008
[39] https://www.epa.gov/sites/default/files/2016-09/documents/chromium-compounds.pdf

Indeno[123-cd]pyrene is a PAH that is classified by the industry for carcinogenicity Category 2, meaning it may cause cancer.[40] There is evidence associating exposure to airborne PAHs with other adverse health impacts, such as reduced lung function, exacerbation of asthma, increased rates of disease and death from obstructive lung diseases, and increased risk of heart diseases.[41]

- Nitrogen dioxide (NO_2)

Exposure to high concentrations of NO_2 in the short term can cause inflammation in the respiratory system leading to breathing difficulties and increased vulnerability to infection. This danger is increased for those who already suffer from a respiratory or heart related condition. [42] Prolonged exposure to elevated levels of NO_2 has been reported to increase the risk of several health conditions, including the development of a number of diseases related to the cardiovascular systems (such as myocardial infarction, cerebrovascular disease, heart failures). [43] [44] The WHO guideline for ambient concentrations of NO_2 are 10 μg m^{-3} annual mean and 25 μg m^{-3} 24-hour mean. [45]

- Nitrogen oxide (NO)

Nitric oxide (NO) is not considered to be hazardous to health at typical ambient conditions. However, in industrial settings where nitric acid is made or used, likelihood of exposure to nitric oxide is higher. [46] The US National Institute for Occupational Health and Safety sets the “Immediately Dangerous to Life of Health” concentration for NO as 100 ppm and sets the exposure limit at 25 ppm. [47] For context, in the UK in 2021, the maximum measured hourly mean NO concentration across all AURN monitoring NO (161 sites) was 0.6 ppm, and the average measured hourly mean NO concentration was 0.01 ppm.[48] Inhaling Nitric Oxide can irritate the nose, throat and lungs, causing coughing and shortness of breath. Repeated exposure may cause bronchitis to develop and/or shortness of breath. Repeated high exposure can cause headache, dizziness, nausea and vomiting, unconsciousness and death.[49]

- Particulate matter <2.5 ($PM_{2.5}$)

$PM_{2.5}$ can travel deeply into the human respiratory system, reaching the lungs, causing inflammation, and worsening heart and lung diseases. Exposure to $PM_{2.5}$ is linked to respiratory and cardiovascular diseases and reduced lung function. [50] [51] Recently, chronic (long-term) $PM_{2.5}$ exposure, even at low levels, was found to promote the development of diabetes, leading to insulin resistance and increased risk of mortality attributable to diabetes.

[40] ECHA (2022) Substance Infocard - Indeno[1,2,3-cd]pyrene. Available at: https://echa.europa.eu/substance-information/-/substanceinfo/100.005.359

[41] WHO (2021) Human health effects of polycyclic aromatic hydrocarbons as ambient air pollutants. Available at: https://apps.who.int/iris/bitstream/handle/10665/350636/9789289056533-eng.pdf?sequence=1&isAllowed=y

[42] Emissions of air pollutants in the UK – Nitrogen oxides (NOx) - GOV.UK (www.gov.uk)

[43] Mutual effects of fine particulate matter, nitrogen dioxide, and fireworks on cause-specific acute cardiovascular mortality: A case-crossover study in communities affected by aircraft noise - ScienceDirect

[44] Short-term Effects of Ambient Gaseous Pollutants and Particulate Matter on Daily Mortality in Shanghai, China (wiley.com)

[45] Ambient (outdoor) air pollution (who.int)

[46] Gad (2014) Encyclopedia of Toxicology (Third Edition)

[47] https://www.cdc.gov/niosh/npg/npgd0448.html

[48] 2021 AURN data for NO sourced from and analysed using R package OpenAir

[49] https://nj.gov/health/eoh/rtkweb/documents/fs/1357.pdf

[50] UK Air https://uk-air.defra.gov.uk/air-pollution/effects

[51] https://www.eea.europa.eu/themes/air/health-impacts-of-air-pollution

[52] Scientific health evidence also suggested that maternal $PM_{2.5}$ exposure during pregnancy was linked to adverse birth outcomes, including pre-term birth, lower birth weight and post-neonatal infant mortality. A number of studies have found the presence of direct-acting mutagens on $PM_{2.5}$. $PM_{2.5}$ has also been found to cause a dose-response mutagenicity, indicating mutagenic properties of the core of the particles i.e., black carbon. [3] The WHO new guideline as of September 2021, for annual average concentrations of $PM_{2.5}$ is 5 µg m^{-3}. [53] The WHO Air Quality Guidelines are based on the evidence linking concentrations of pollutants in ambient air with adverse effects on health.

- Total carbon (TC)

Public Health studies found correlations between poor health such as heart disease and cancer and high levels of carbon in the air. [54]

- Ultrafine particles (UFP)

UFP are thought to contribute to the toxicity of airborne particulate matter, but the magnitude of their contribution is currently unclear. Due to the small size of UFP, there are health concerns related to particles reaching deep into the lungs and a small fraction entering the circulatory system. Since UFP have a high surface area and capacity to absorb toxic organic compounds and hazardous metals, there are associated risks relating to oxidative stress.[55] UFP has been linked to the production of reactive oxygen species (ROS), leading to genotoxicity (toxic to DNA), neurotoxicity (affects the nervous system), heart diseases, and cancer.[56,57] Short term effects on pulmonary/systemic inflammation, heart rate variability and blood pressure are most commonly identified as being linked to UFP.[58]

Some of the pollutants included in this list are already used in the DAQI, such as **NO_2 and $PM_{2.5}$, indicating that these DAQI pollutants are still relevant**. As $PM_{2.5}$ is a mixture of substances, it will contain some of the pollutants mentioned in the list above (BC/TC, BrC, UFP, BkF and IcdP). However, it may be valuable to add data from these separate pollutant species, especially in cases where data is already being collected for the pollutant. For example, the UK currently monitors BC concentrations. Short and long-term exposure to black carbon has been linked to adverse health effects[59]. Despite this, **in the 2021 WHO report on Air Quality Guidelines, it was mentioned that the guideline development group could not formulate air quality guidance levels for BC/EC and UFP due to an absence of clear quantitative evidence on independent health effects**. Instead, guidance on these pollutants was given in the form of good practice statements, suggesting the expansion of existing air quality monitoring networks to include UFP and more BC measurements. Another recommendation for BC was to "*take measures to reduce BC/EC*

[52] The health effects of ambient PM2.5 and potential mechanisms, 10.1016/j.ecoenv.2016.01.030

[53] https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

[54] https://doi.org/10.1080/08958370701866008

[55] Kwon et al. 2020, Ultrafine particles: unique physicochemical properties relevant to health and disease, https://www.nature.com/articles/s12276-020-0405-1

[56] Moreno-Ríos et al. 2022, Sources, characteristics, toxicity, and control of ultrafine particles: An overview, https://www.sciencedirect.com/science/article/pii/S1674987121000116

[57] Downward et al. 2018, Long-Term Exposure to Ultrafine Particles and Incidence of Cardiovascular and Cerebrovascular Disease in a Prospective Study of a Dutch Cohort, https://pubmed.ncbi.nlm.nih.gov/30566375/

[58] Ohlwein et al. 2019, Health effects of ultrafine particles: a systematic literature review update of epidemiological evidence, https://pubmed.ncbi.nlm.nih.gov/30790006/

[59] Zu et al. (2023) *Short and long-term association of exposure to ambient black carbon with all-cause and cause-specific mortality: A systematic review and meta-analysis.* Environmental Pollution. Vol 324. 10.1016/j.envpol.2023.121086.

emissions from within the relevant jurisdiction and, where appropriate, develop standards (or targets) for ambient BC/EC concentrations"[60].

As well as the pollutants included in the DAQI, another consideration is the weighting of the pollutants included. **Existing AQI models consider all pollutants equally and do not assign weights to each pollutant**[61]. However, the use of weightings can sometimes be subjective, hence, any weighting developed would need to be clearly linked to relevant research papers outlining the health effects of each pollutant.

A4.3.1.1 Gaps in evidence identified by the literature review

As mentioned in the WHO 2021 report on Air Quality Guidelines, there are data gaps in the literature with regards to independent health effects of emerging pollutants such as BC and UFP.

Questions for independent health experts:

- Are the pollutants included in the DAQI the most relevant pollutants to measure short term air pollution risk in the UK?
- In your opinion should any other pollutants be included?
- Do you think further consideration should be given to the inclusion of Black Carbon?

A4.3.2 Q2:2 Breakpoints

Research question: *To what extent do the breakpoints implemented in the DAQI continue to reflect the latest health evidence regarding the concentrations at which health effects may be experienced following short-term exposure to air pollution?*

The WHO guideline levels are recommendations (expressed as a concentration of a pollutant in the air, linked to an averaging time) below which adverse health effects have not been detected in epidemiological studies. The short-term guideline levels are defined as "*a high percentile of the distribution of daily values, for example the 99th percentiles equivalent to three to four days a year exceeding this value*"[62] and so are relevant to compare the breakpoints of the DAQI. As per the most recent WHO Guidelines, **the long-term guidelines have been used to derive a short-term guideline whenever the same health effect is considered (e.g. mortality) for both long- and short-term exposures**[63]. The long-term guidelines are derived based on the lowest long-term exposures that are, with at least moderate certainty, associated with adverse health effects; if the short-term guidelines were derived based on lowest short-term exposures that are (at least moderate certainty) associated with adverse health effects, then the values obtained would be significantly lower than those determined for long-term guideline levels. The Guidelines state that, typically, the magnitude of the health effects associated with variations in long-term exposure is larger (per mass unit) than the magnitude of the health effects associated with short-term variations and as a consequence, the long-term guidelines for most health outcomes are more health

[60] WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021 https://www.who.int/publications/i/item/9789240034228

[61] Priti K and Kumar (2022), *A critical evaluation of air quality index models (1960–2021),* Environ. Monit. Assess., 194: 324, https://doi.org/10.1007/s10661-022-09896-8

[62] WHO global air quality guidelines, page ix. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021 https://www.who.int/publications/i/item/9789240034228

[63] WHO global air quality guidelines, page ix. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021 https://www.who.int/publications/i/item/9789240034228

protective than the short-term guidelines. For this reason, it is suitable to use the long-term guidelines to derive a short-term guideline in many cases. Although this is the case, **in the most recent WHO update there has been a systematic review of the evidence informing the updates to both the long- and the short-term guidelines**, and this is summarised in Annex 3 of the 2021 Guidelines.

The review of the DAQI by COMEAP in 2011 stated that the WHO air quality guidelines and interim targets were used as a starting point to review the pollutant-specific bandings, and that in most cases, the WHO values were adopted as proposed breakpoints between the bands[64]. However, since 2011, the WHO guideline values and interim targets have been updated (in 2021) to reflect advances in scientific knowledge[65], so a comparison of the current DAQI breakpoints and the current WHO values is required. In addition, we have provided a comparison to other relevant national air quality objectives, standards, and limit values, as summarised in Table A4-5.

Table A4-5 Summary and comparison of recommended long- and short-term air quality guidelines, limit values and standards for NO2, O3, PM2.5, PM10, and SO2, from the WHO, UK, EU, US, and Canada

Pollutant	Averaging Time	Concentration (µg m^{-3})				
		WHO AQG[66]	UK AQO[67]	EU AQS[68]	US NAAQS[69]	Canadian CAAQS[70]
Nitrogen dioxide (NO_2)	Annual	10	40	40	53 ppb (~100 µg m^{-3})	12 ppb (~23 µg m^{-3})
	24-hour	25	-	-	-	-
	1-hour	-	200	200	100 ppb (~188 µg m^{-3})	42 ppb (~79 µg m^{-3})
Ozone (O_3)	Peak season	60	-	-	-	-
	8-hour	100	100	120	0.07 ppm (~137 µg m^{-3})	60 ppb (~118 µg m^{-3})
Particulate matter <2.5 µM ($PM_{2.5}$)	Annual	5	20	20	9 (primary) 15 (secondary)	8.8
	24-hour	15	-	-	35	27
Particulate matter <10 µM (PM_{10})	Annual	15	40	40	-	-
	24-hour	45	50	50	150	-
Sulphur dioxide (SO_2)	Annual	-	-	-	-	4 ppb (~10 µg m^{-3})
	24-hour	40	125	125	-	-

[64] Review of the UK Air Quality Index, Committee on the Medical Effects of Air Pollutants (COMEAP) Standards Advisory Subgroup, 2011, page 23. https://assets.publishing.service.gov.uk/media/5a749a66e5274a44083b8003/COMEAP_review_of_the_uk_air_quality_index.pdf

[65] Pérez Velasco R, Jarosińska D. Update of the WHO global air quality guidelines: Systematic reviews - An introduction. Environ Int. 2022 Dec;170:107556. doi: 10.1016/j.envint.2022.107556. Epub 2022 Oct 1. PMID: 36395555; PMCID: PMC9720155.

[66] https://www.who.int/publications/i/item/9789240034228

[67] UK Air Quality Objectives update, 2023, https://uk-air.defra.gov.uk/assets/documents/Air_Quality_Objectives_Update_20230403.pdf

[68] EU air quality standards, https://environment.ec.europa.eu/topics/air/air-quality/eu-air-quality-standards_en

[69] NAAQS Table, USEPA, https://www.epa.gov/criteria-air-pollutants/naaqs-table

[70] Canada's Air, CAAQS developed by CCMA, https://ccme.ca/en/air-quality-report

Pollutant	Averaging Time	Concentration (µg m^{-3})				
		WHO AQG[66]	UK AQO[67]	EU AQS[68]	US NAAQS[69]	Canadian CAAQS[70]
	3-hour	-	-	-	0.5 ppm (secondary) (~1310 µg m^{-3})	-
	1-hour	-	350	350	75 ppb (primary) (~196 µg m^{-3})	65 ppb (~170 µg m^{-3})
	15-minute	-	266	-	-	-

As shown in Table A4-5, there is variety between the national limits and objectives, guidelines and standards from the WHO and for the UK, EU, US, and Canada, across most pollutants. Table A4-6 presents the current DAQI breakpoints. Comparing the objectives and standards with the upper limit of the DAQI's 'Low' banding:

- For NO_2, the 24-hour WHO air quality guideline is 25 µg/m^3; there is no equivalent limit for the UK, EU, US, or Canada, although they do have 1-hour standards. **The Low DAQI banding for NO_2 is up to 200 µg/m^3, considerably higher than the WHO's 24-hour guideline, but is in line with the 1-hour limit assigned by the UK and EU**. The US and Canada's 1-hour limits (provided in ppb) are equivalent to around 188 µg/m^3 and 79 µg/m^3, respectively, so are more stringent than the Low DAQI banding.
- For O_3, all the guidelines, limits and standards consider the 8-hour average; the WHO guideline and UK are 100 µg/m^3, while Canada's standard is equivalent to around 118 µg/m^3, and the EU limit value is 120 µg/m^3. The US is the highest at around 137 µg/m^3. **The DAQI Low banding extends up to 100 µg/m^3, so is in line with the more stringent standards and objectives**.
- For $PM_{2.5}$, the WHO, the US and Canada have set 24-hour guidelines and standards, at 15 µg/m^3, 35 µg/m^3, and 27 µg/m^3, respectively. The UK and EU have currently not set 24-hour standards; their annual limits are 20 µg/m^3 in both cases. T**he Low banding for the DAQI is currently up to 35 µg/m^3, which is in line with the US 24-hour standard and higher than the WHO guideline and Canadian standard** for the same averaging time.
- For PM_{10}, there are 24-hour standards from the WHO (45 µg/m^3), UK and EU (both 50 µg/m^3) and the US (150 µg/m^3) to compare to. **The Low banding for the DAQI extends up to 50 µg/m^3, so is in line with the UK and EU, and just above the WHO guideline**.
- For SO_2, there are a wide variety of averaging times and standards to compare to. **The Low banding in the DAQI is equivalent to the UK 15-minute air quality objective, 266 µg/m^3**. The UK, EU, US and Canada all also have 1-hour standards for SO_2 (350 µg/m^3, 350 µg/m^3, 196 ug/m^3 and 170 µg/m^3, respectively) and the Low banding sits above the US and Canadian standards, but far below and UK and EU standards. The WHO 24-hour guideline for SO_2 is 40 µg/m^3, considerably lower than the DAQI Low banding, and the equivalent standard for the UK and EU is 125 µg/m^3 which is also less than half of the upper limit of the Low banding.

Table A4- 6 Current DAQI breakpoints for NO2, O3, PM2.5, PM10, and SO2 (all in µg/m³)

Index	1	2	3	4	5	6	7	8	9	10
Band	Low	Low	Low	Moderate	Moderate	Moderate	High	High	High	Very High
NO_2	0-67	68-134	135-200	201-267	268-334	335-400	401-467	468-534	535-600	601 or more
O_3	0-33	34-66	67-100	101-120	121-140	141-160	161-187	188-213	214-240	241 or more
$PM_{2.5}$	0-11	12-23	24-35	36-41	42-47	48-53	54-58	59-64	65-70	71 or more
PM_{10}	0-16	17-33	34-50	51-58	59-66	67-75	76-83	84-91	92-100	101 or more
SO_2	0-88	89-177	178-266	267-354	355-443	444-532	533-710	711-887	888-1064	1064 or more

Table A4-7details the US AQI breakpoints which are broken into six categories ranging from Good to Hazardous. The pollutants included in the US AQI are the same as those in the DAQI but the concentrations are listed in ppb for some pollutants. To enable easy comparison between the bandings, the approximate converstion to µg/m³ has been provided. Comparing the US AQI breakpoints with the DAQI breakpoints, the definition of the Moderate Index 3-6 in the DAQI appears to correspond to the unhealthy for sensitive groups index in the US AQI, and the High index 7-9 in the DAQI corresponds to the Unhealthy index in the US AQI. However, considering the other bandings for each of the pollutants there are the following differences:

- Higher concentrations of NO_2 are permitted in the US AQI Unhealthy for Sensitive Groups index than the Moderate index banding in the DAQI. The range of NO_2 concentration permitted in this range in the US AQI is more than the very high (10 index) banding in the DAQI.
- The bandings for O_3 look to be of a similar range in concentrations for both the DAQI and the US AQI.
- For $PM_{2.5}$ at the lower bandings, i.e., Low and Moderate, in the DAQI these correspond with similar split in concentration bandings to the Good, Moderate, and Unhealthy for Sensitive Groups index in the US AQI. In the DAQI concentrations above 71 $\mu g/m^3$ are considered Very High (10 index) whereas the US AQI has wider bandings of between 55 and 150 $\mu g/m^3$ for unhealthy up to 500 $\mu g/m^3$ for Hazardous.
- The PM_{10} bandings do not align very well between the two air quality indices apart from the Good index the US AQI aligns to Low bandings (1-3) in the DAQI. Concentrations in the Moderate US AQI are permitted up to 154 $\mu g/m^3$ which is above what is permitted in the DAQI Very High (10 Index).
- The concentration bandings for SO_2 largely align between the DAQI and the US AQI.

Overall these comparisons indicate that the DAQI is similar to the US AQI or more stringent for all pollutants for most bandings.

Table A4-7 Current breakpoints for the US AQI[71]

Index	Good	Moderate	Unhealthy for Sensitive Groups	Unhealthy	Very Unhealthy	Hazardous
Index values	**Up to 50**	**51-100**	**101-150**	**151-200**	**201-300**	**301-500**
NO_2 (ppb, 1hr)	0-53 (~ 0-100 µg/m³)	54-100 (~102- 188 µg/m³)	101-360 (~190 – 677 µg/m³)	361-649 (~ 679 - 1220 µg/m³)	650-1249 (~ 1222- 2348 µg/m³)	1250-2049 (~ 2350 - 3852 µg/m³)
O_3 (ppm, 8hr)	0-0.054 (~ 0-10.6 µg/m³)	0.055-0.070 (~ 10.8 – 13.7 µg/m³)	0.071-0.085 (~ 13.9 – 16.7 µg/m³)	0.086-0.105 (~ 16.9 – 20.6 µg/m³)	0.106-0.200 (~ 20.8 – 39.2 µg/m³)	-
$PM_{2.5}$ (µg/m³, 24hr)	0-12.0	12.1-35.4	35.5-55.4	55.5-150.4	150.5-250.4	250.5-500.4
PM_{10} (µg/m³, 24hr)	0-54	55-154	155-254	255-354	355-424	425-604
SO_2 (ppb, 1hr)	0-35 (~ 0 - 92 µg/m³)	36-75 (~ 96 - 199 µg/m³)	76-185 (~ 202 - 492 µg/m³)	186-304 (~ 495 - 809 µg/m³)	305-604 (24hr) (~ 811 - 1607 µg/m³)	605-1004 (24hr) (~ 1609 - 2671 µg/m³)

The Canadian air quality health index (AQHI) equation is constructed as the sum of excess daily mortality risks associated with NO_2, O_3, and $PM_{2.5}$, adjusted to a 0-10 scale[72],[73]. The categories were originally defined according to the relative frequency of the numeric AQHI scale across 12 Canadian cities in a time-series study. Each unit increase in AQHI is equivalent to a roughly 1% increase in daily mortality[74]. Ozone was most frequently reported as the primary contributor to the AQHI for rural towns (such as Grand Bend) and for cities that were dominated by transboundary air pollution (such as Kingston), followed by NO_2. Particulate matter ($PM_{2.5}$), was only found to be the primary contributor to the AQHI in a few cities, such as Sarnia and Brantford. It should be noted that when the AQHI was rated as very high health risk the historic hourly mean concentration of ozone is lower but the NO_2 mean is much higher (see Table A4-8).

[71] Table 5: Breakpoints for the AQI, Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI), EPA 454/B-18-007, September 2018, https://www.airnow.gov/sites/default/files/2020-05/aqi-technical-assistance-document-sept2018.pdf

[72] Review of Air Quality Index and Air Quality Health Index, Ontario Agency for Health Protection and Promotion (Public Health Ontario), Chen H, Copes R., January 2013, https://www.publichealthontario.ca/-/media/documents/A/2013/air-quality-health-index.pdf

[73] A New Multipollutant, No-Threshold Air Quality Health IndexBased on Short-Term Associations Observed in Daily Time-Series Analyses, Stieb et. al., J. Air & Waste Manage. Assoc.58:435–450, DOI:10.3155/1047-3289.58.3.435. https://www.tandfonline.com/doi/epdf/10.3155/1047-3289.58.3.435?needAccess=true

[74] Review of Air Quality Index and Air Quality Health Index, Ontario Agency for Health Protection and Promotion (Public Health Ontario), Chen H, Copes R., January 2013, page 21.

Table A4- 8 Distributions of historical mean hourly concentrations of air pollutants in Ontario, 2003-2010, by AQHI category[75]

AQHI	Mean hourly concentration of air pollutant			
	Low (up to 3)	Moderate (4-6)	High (7-10)	Very High (over 10)
NO_2 (ppb)	10 (~ 19 μg/m^3)	21 (~40 μg/m^3)	30 (~ 56 μg/m^3)	96 (~ 180 μg/m^3)
O_3 (ppb)	25 (~ 49 μg/m^3)	34 (~ 67 μg/m^3)	53 (~ 104 μg/m^3)	5 (~ 9.8 μg/m^3)
$PM_{2.5}$ (μg/m^3)	5	16	38	45

The update to the WHO Global Air Quality Guidelines in 2021 was informed by the best available scientific evidence obtained from various research papers published up to September 2018. The process of synthesising evidence included systematic reviews, risk of bias for individual studies, and using a Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach to determining the overall certainty of bodies of evidence[76].

This systematic review and meta-analysis of short term exposure to PM_{10}, $PM_{2.5}$, NO_2 and O_3 and all cause and cause specific mortality[77] found evidence of:

- **A positive association between short-term exposure to PM_{10}, $PM_{2.5}$, NO_2 (24-hour average) and O_3 and all-cause mortality.**
- A positive association between PM_{10}, $PM_{2.5}$ and cardiovascular, respiratory, and cerebrovascular mortality.
- **NO_2 (1-hour max.) has shown a positive but nonsignificant association with all-cause mortality**.
- In general, **linear concentration response functions were found for PM_{10} and $PM_{2.5}$ associated with all-cause and cause-specific mortality**.
- In contrast, some articles found a **non-linear behaviour for NO_2 (24-hour average), with a potential threshold at 37.6 μg/m^3 average daily concentration**.
- For **O_3**, a number of articles also found a non-linear behaviour, with **potential thresholds in the range of 60–100 μg/m^3** .
- **The linear behaviour of some of the associations is consistent with the idea of a negative effect of pollutants even at low or background ambient concentrations, as was previously observed for $PM_{2.5}$, PM_{10}, and NO_2**.

[75] Table 6 (B), Review of Air Quality Index and Air Quality Health Index, Ontario Agency for Health Protection and Promotion (Public Health Ontario), Chen H, Copes R., January 2013, page 53.

[76] Velasco and Jarosińska (2022), Update of the WHO global air quality guidelines: Systematic reviews – An introduction, Environ Int., doi: 10.1016/j.envint.2022.107556.

[77] Short-term exposure to particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3) and all-cause and cause-specific mortality: Systematic review and *meta*-analysis, Environ Int., doi 10.1016/j.envint.2020.105876

This apparent absence of a safe level of air pollution below which health detrimental effects are negligible has deep implications for the development of ambient concentration limits in air quality guidelines, as even small reductions in air pollution levels might have a considerable impact in preventing mortality.

The systematic review and meta-analysis of short-term exposure to sulphur dioxide and all cause and respiratory mortality[78] found evidence of:

- A **10 µg/m^3 increase in the average 24-hour concentrations of SO_2 was associated with a higher risk of all-cause mortality in the short-term**.
- Positive associations between SO_2 (24-hour average) and respiratory mortality, and SO_2 (1-hour max.) and respiratory mortality.
- The association was positive but nonsignificant for SO_2 (1-hour max.) and all-cause mortality.
- Signs of heterogeneity for SO_2 (24-hour average) – respiratory mortality and SO_2 (1-hour max.) – all-cause mortality, and funnel plot asymmetry for SO_2 (24-hour average) – all-cause mortality. **The certainty of evidence was high in two combinations, i.e. SO_2 (24-hour average) – all-cause mortality and SO_2 (1-hour max.) – respiratory mortality**, moderate in one combination, i.e. SO_2 (24-hour average) – respiratory mortality, and low in the remaining one combination.

The evidence indicates that short-term exposure to SO_2 does carry a higher risk of mortality and therefore SO_2 remains a pollutant of importance in the DAQI.

The evidence collected to inform the 2021 WHO air quality guidelines covered an extensive review of the health literature available. The DAQI bandings should be updated to reflect this latest evidence.

A4.3.2.1 Gaps in evidence identified by the literature review.

There are a number of articles which have looked at mortality but there is **little evidence about morbidity or increased visits for accident and emergency departments for pollutant related incidents**. This is an area which may require more research to fill this evidence gap.

A4.3.3Q2:3: Averaging time

Research question: ***To what extent do the averaging times implemented in the DAQI reflect the latest health evidence regarding the period after which health effects may be experienced following short-term exposure to air pollution?***

As explained by COMEAP in their review of the DAQI (2011), the averaging times in the current index incorporate recommendations by the Expert Panel on Air Quality Standards (EPAQS) and the WHO and reflect two aspects of the evidence on health effects of air pollutants: **the timescale of exposure over which adverse health effects might be caused, and the averaging times used in the studies available**[79]. In their 2011 review, COMEAP stated that their review of the health evidence did not suggest that the averaging

[78] Short-term exposure to sulphur dioxide (SO_2) and all-cause and respiratory mortality: A systematic review and meta-analysis, Environ Int., doi 10.1016/j.envint.2021.106434

[79] Review of the UK Air Quality Index, Committee on the Medical Effects of Air Pollutants (COMEAP) Standards Advisory Subgroup, 2011, page 16

times for the pollutants included in the DAQI required revision. The averaging times and their rationale are summarised in Table A4-9. For SO_2 and NO_2, the averaging times are already very short, and in the case of SO_2, as short as is practicable. However, the averaging times for PM (24 hours) and O_3 (8 hours) are longer and have been investigated further in this literature review.

Table A4-9 Averaging times for index pollutants as recommended by EPAQS (note that carbon monoxide has not been included as it is no longer included in the DAQI, and the averaging time for PM2.5 is also 24hrs)

Pollutant	Averaging period	Rationale
Particulate matter (PM_{10})	24-hour mean	Evidence indicates that **acute health effects occur after pollution episodes lasting at least 24 hours**, therefore the averaging period should be 24 hours.
Sulphur dioxide (SO_2)	15-minute mean	Since the **effects of sulphur dioxide may occur very rapidly**, a short averaging period is desirable. Very short **periods of 1 minute are impracticable**, therefore a 15-minute averaging period is a sensible compromise between desirability and practicability.
Ozone (O_3)	Running 8-hour mean	A **running 8-hour average most closely represents the exposures likely to be harmful to human health**, as effects occur from exposure over several hours.
Nitrogen dioxide (NO_2)	1-hour mean	Since the **effects on health in experimental studies on people with asthma were detectable within an hour of exposure commencing**, an hourly averaging period is appropriate.

The DAQI was updated in 2012 to introduce 'trigger values' for moderate pollution and above, enabling the prediction of episodes of elevated pollution especially for PM and O_3, which have longer averaging times than NO_2 and SO_2[80]. The **trigger values were included because, using averaging times of 24 hours for particulate matter and 8 hours for ozone, it is not possible to provide the public information about unexpected pollution episodes until it is well established**. As there has not been a review of the DAQI since that of COMEAP in 2011, it is unknown whether the introduction of trigger values for the DAQI has been successful in providing better indication of upcoming pollution episodes.

In the US, like in the UK, the averaging time is also 24 hours for the national ambient air quality standards (NAAQS) for PM_{10} and $PM_{2.5}$[81]. The USEPA published the '*Integrated Science Assessment (ISA) for Particulate Matter*' in 2019 to provide a comprehensive evaluation and synthesis of policy-relevant science aimed at characterizing exposures to ambient PM, and health and welfare effects associated with these exposures, to be used as

[80] RE: NOTIFICATION OF CHANGES TO THE AIR QUALITY INDEX, email from Dr Clare Bayley, Defra, 1st December 2011, https://uk-air.defra.gov.uk/assets/documents/Notification_of_changes_to_the_air_quality_index.pdf

[81] Integrated Science Assessment for Particulate Matter, USEPA, December 2019, https://assessments.epa.gov/isa/document/&deid=347534

the evidence base for the review of the NAAQS for PM. According to the ISA, to date, **very few studies have examined associations with sub-daily averaging times for $PM_{2.5}$ concentrations** (e.g., 1-hour max), although **some evidence indicates associations between emergency department visits and 1-hour max $PM_{2.5}$ concentrations**[82]. The evaluation of recent epidemiologic studies focusing on respiratory- and cardiovascular-related emergency department visits and hospital admissions, cardiovascular effects, and mortality examined associations between sub-daily exposure metrics and the 24-hour average exposure metric, **did not indicate that sub-daily averaging periods for $PM_{2.5}$ are more closely associated with health effects than the 24-hour average**[83].

On the other hand, a review paper by Priti K and Kumar[84] (2022) raises that t**he 24-hour averaging time can cause temporal lags between rising concentrations at monitoring stations and rising DAQI readings**. Temporal lags such as this **delay health advisories for dangerous pollution incidents**. Priti K and Kumar suggested that AQI models should be developed considering the averaging time concentration for both hourly/daily and annually, to provide comprehensive information of low and high exposure levels[85].

Similarly, the ISA for ozone and related photochemical oxidants[86] (2020) carried out an extensive review of the literature examining the relationship between short-term concentrations of ozone in ambient air and health effects; they note that these studies primarily rely on a 1-hour max, 8-hour max, or 24-hour averaging times (with 8-hour daily max being the most common), and that epidemiologic time-series and panel studies evaluated **do not provide any evidence to indicate that any one averaging time is more consistently or strongly associated with respiratory-related health effects**.

A4.3.3.1 Gaps in evidence identified by the literature review

There is a lack of local-oriented epidemiological studies that establish health effects of the pollutants monitored[87]. In particular, **very few studies have examined associations with sub-daily averaging times for $PM_{2.5}$ concentrations**[88]. It is therefore difficult to determine, especially for PM, whether the existing averaging times in the DAQI are appropriate and in line with the latest health evidence regarding the period after which health effects may be experienced following short-term exposure to air pollution.

As the averaging times for SO_2 and NO_2 are already very short, but remain practicable, the literature review has focused on the latest available evidence for PM and O_3. The interviews with health experts should focus on validating the literature review findings for PM and O_3,

[82] Integrated Science Assessment for Particulate Matter, USEPA, December 2019, SECTION 5.1: Short-Term PM2.5 Exposure and Respiratory Effects, 5-128

[83] Integrated Science Assessment for Particulate Matter, USEPA, December 2019, SECTION 1.5: Policy-Relevant Considerations, 1-46

[84] Priti K and Kumar (2022), *A critical evaluation of air quality index models (1960–2021),* Environ. Monit. Assess., 194: 324, https://doi.org/10.1007/s10661-022-09896-8

[85] Priti K and Kumar (2022), *A critical evaluation of air quality index models (1960–2021),* Environ. Monit. Assess., 194: 324, https://doi.org/10.1007/s10661-022-09896-8

[86] Integrated Science Assessment for Ozone and Related Photochemical Oxidants, USEPA, April 2020, IS-30, https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=348522#:~:text=The%20Ozone%20ISA%2C%20in%20conjunction,protects%20public%20health%20and%20welfare.

[87] Priti K and Kumar (2022), *A critical evaluation of air quality index models (1960–2021),* Environ. Monit. Assess., 194: 324, https://doi.org/10.1007/s10661-022-09896-8

[88] Integrated Science Assessment for Particulate Matter, USEPA, December 2019, SECTION 5.1: Short-Term PM2.5 Exposure and Respiratory Effects, 5-128

as well as investigating whether there is any new evidence to suggest that the averaging times for SO_2 and NO_2 do not need to be as short as they currently are.

A4.3.4Q2:4 Pollutant mixtures

Research question: *Does current understanding of the health effects of mixtures of air pollutants suggest the including mixture effects in the DAQI could have a substantial impact on health outcomes?*

The current method for assigning an overall air quality index within the DAQI is to take the highest pollutant index. As mentioned in the COMEAP review of the DAQI in 2011, there is no provision within the index to take into account the possible effects of a mixture of pollutants[89], and this is still the case at present day. During the 2011 review, COMEAP identified that the literature available at the time provided **little evidence for the synergistic effects of air pollutants on humans, and in addition, that the existing multi-pollutant models were not sufficiently informative to enable a weighting of pollutants in an index using multiple pollutants**[90]. As such, this literature review has focused on new developments in this space, since COMEAP's review of 2011.

The WHO air quality guidelines were updated in 2021 and the current guidelines still do not include recommendations about pollutant mixtures or the combined effects of pollutant exposures. However, the WHO has acknowledged this as a key limitation of the guidelines, as **pollutant mixtures represent the reality of human exposure to air pollution in everyday life**. The WHO's justification for providing guidelines for individual pollutants only is that "***the main body of evidence on air quality and health still focuses on the impact of single markers of ambient air pollution on the risk of adverse health outcomes***"[91] and recommends three mechanisms of health effects that should be studied:

- The biological mechanisms explaining epidemiological associations with all-cause and respiratory mortality of (mixtures represented by) nitrogen dioxide and ozone, especially at low concentration levels;
- The mechanisms of effects of (mixtures represented by) nitrogen dioxide and ozone on the cardiovascular system; and
- the effects of mixtures containing particles of different sizes as wells as gaseous pollutants to understand the underlying pathophysiology due to surface interactions between pollutants and molecular or cellular structures (e.g. proteins, lipids, DNA and RNA)[92].

'A review of current air quality indexes and improvements under the multi-contaminant air pollution exposure'[93] (Tan et al., 2021) highlights three key limitations of single-contaminant-oriented AQIs (such as the DAQI): the methods do not consider the combined effects of

[89] Review of the UK Air Quality Index, Committee on the Medical Effects of Air Pollutants (COMEAP) Standards Advisory Subgroup, 2011, page 20.

[90] Review of the UK Air Quality Index, Committee on the Medical Effects of Air Pollutants (COMEAP) Standards Advisory Subgroup, 2011, page 20.

[91] WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021, page xx.

[92] WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021, page 222.

[93] Tan et. al. (2021), A review of current air quality indexes and improvements under the multi-contaminant air pollution exposure, Journal of Environmental Management, 279 (2021), 111681, https://doi.org/10.1016/j.jenvman.2020.111681

exposure to multiple pollutants, not all health impacts are suitably reflected and characterised, and the uniformity and comparability of such indices are difficult to maintain because the pollutant types and standards are continuously updated[94]. In contrast, aggregate-type AQIs attempt to reflect the cumulative effect of multiple air pollutants, although these also come with their limitations. The paper reviewed a number of single-contaminant-oriented and aggregate-type AQIs; **national multi-contaminant aggregate AQIs, developed by Canada, South Korea, and Hong Kong[95], have been correlated with different health outcomes and been proven to be better related to human health**[96], considering examples such as 'significant associations' between the index and asthma-related hospitalisations and asthma-related visits to the emergency department, and associations between the index and emergency department visits for acute ischaemic stroke (all studies from Ontario, Canada). The results of the studies indicated that **health-based AQIs could be a valid communication tool for air pollution morbidity and mortality effects and may provide more efficient and helpful air quality information or advice to the public**.

Tan et al. subsequently proposed the General Air Quality Health Index (GAQHI) as a '*pollutant-aggregated, local health-based AQI paradigm to help build a more accurate, consistent and comparable international AQI system*'[97]. The authors state that **the GAQHI could, in the future, provide a way of comparing or integrating AQIs worldwide considering multi-contaminant air pollution**. The proposed index follows the basic principles of the Canadian AQHI and additionally adapts to local air pollution conditions and health effects by making use of local epidemiological research[98]. The GAQHI was verified by applying it in Beijing (from 2013 to 2015), and then Beijing, Shanghai, and Shenzhen (from 2013 to 2019), and comparing to current AQIs. **In Beijing, on more than 80% of the days, two or more pollutants exceeded the WHO air quality guidelines, indicating that multi-contaminant conditions are typical for the city.** Daily concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3 and CO were used for the GAQHI calculation, and exposure-response coefficients were obtained via a systematic review of the health effects of the short-term exposure of the Chinese population to those air pollutants[99]. The GAQHI provided a higher sensitivity and greater accuracy under the condition of multiple contaminants than the conventional AQI, and the GAQHI performed much better than the conventional AQI especially at low and moderate air pollution levels, where the conventional AQI greatly underestimated the health risks. Tan et al. acknowledge that further adaptation of the GAQHI is required (for example, performing it with different pollutants, pollutant levels, and different cities), but this study strongly indicates that **aggregate-type AQIs are required to**

[94] Tan et. al. (2021), A review of current air quality indexes and improvements under the multi-contaminant air pollution exposure, Journal of Environmental Management, 279 (2021), 111681, page 2.

[95] Tonya et. al. (2019), An evaluation of the air quality health index program on respiratory diseases in Hong Kong: An interrupted time series analysis, Atmospheric Environment, 211 (2019), 151-158, https://doi.org/10.1016/j.atmosenv.2019.05.013

[96] Tan et. al. (2021), A review of current air quality indexes and improvements under the multi-contaminant air pollution exposure, Journal of Environmental Management, 279 (2021), 111681, page 5.

[97] Tan et. al. (2021), A review of current air quality indexes and improvements under the multi-contaminant air pollution exposure, Journal of Environmental Management, 279 (2021), 111681, page 8.

[98] Tan et. al. (2021), A review of current air quality indexes and improvements under the multi-contaminant air pollution exposure, Journal of Environmental Management, 279 (2021), 111681, page 6.

[99] Tan et. al. (2021), A review of current air quality indexes and improvements under the multi-contaminant air pollution exposure, Journal of Environmental Management, 279 (2021), 111681, page 7.

reflect the relationship between multi-contaminant exposure and health impacts, especially at low and moderate levels of air pollution.

'A critical evaluation of air quality index models (1960-2021)' by Priti K and Kumar (2022)[100] is in agreement with the above: it highlights that single-pollutant models underestimate the real condition of air quality as the aggregated effect of multi-pollutant is neglected, and because the type and concentration of pollutants vary by location, a hybrid model is recommended. Priti K and Kumar suggest a Local Multi-Pollutant Air Quality Health Index along the lines of the GAQHI; relevant **considerations regarding air pollutant mixtures include collection of meta datasets (such as health data) and local epidemiological studies, and incorporating the synergistic and antagonistic effects of different pollutants**.

A4.3.4.1 Gaps in evidence identified by the literature review

While there is acknowledgement in the literature that **multi-contaminant exposure is representative of daily life, and that determining the health effects of exposure to mixtures of pollutants is important, this remains a gap in the literature**. Tan et al. pose that the main driver is that "*the blanket control of health damage is inadequate and the combined effect of multiple contaminants is usually overshadowed by the severe impacts of primary contaminants*"[101]. There is also the consideration that the complexity of air pollutants (including different PM components) and associated health effects at the same concentrations differ among regions and nations worldwide, and even cities within the same country. **Further research is required to determine the potential impact on health outcomes attributed to mixture effects**, but there is evidence that single-contaminant AQIs (such as the DAQI) under-estimate the health impacts of real-world exposure to air pollution.

A4.3.5Q2:5 Discrete days

Research question: *What is the health impact of treating days as discrete events for the purposes of the DAQI?*

This literature review has focused on the evidence regarding lag time between exposure to air pollution and health effects. In summary, for most pollutants, there is at least some evidence of an immediate (0-1 days lag) effect of pollutant exposure on health. This means that, by treating days as discrete events, opportunities to provide more detailed health advice regarding air pollutant exposure are being lost, and this could contribute to health impacts.

The Integrated Science Assessment (ISA) for particulate matter reviewed a number of recent epidemiologic studies investigating whether there is evidence of an immediate (lag 0−1 days), delayed (lag 2−5 days), or prolonged (lag 0−5 days) effect of PM on health, with a focus on respiratory- and cardiovascular-related visits to the emergency department, as well as mortality[102]. These studies provided **evidence of associations in the range of 0−5 days for respiratory effects**, and evidence of an **immediate effect for cardiovascular**

[100] Priti K and Kumar (2022), *A critical evaluation of air quality index models (1960–2021),* Environ. Monit. Assess., 194: 324, https://doi.org/10.1007/s10661-022-09896-8

[101] Tan et. al. (2021), A review of current air quality indexes and improvements under the multi-contaminant air pollution exposure, Journal of Environmental Management, 279 (2021), 111681, page 2.

[102] Integrated Science Assessment for Particulate Matter, USEPA, December 2019, ES-18

effects and mortality (0−1 days) with some **initial evidence of associations occurring over longer exposure durations (0−4 days)**. This suggests that there could be a potential negative health impact in terms of cardiovascular effects by treating days as discrete events, but the impact of this on respiratory events is unlikely to be significant.

Similarly, the ISA for ozone and related photochemical oxidants[103] carried out an evaluation of the lag structure of associations between short-term ozone exposure and health effects. The epidemiologic studies reviewed tended to examine associations between short-term exposure and health effects over a series of single-day lags, multiday lags, or by selecting lags *a priori*[104]. **Respiratory effects** (respiratory-related hospital admissions and emergency department visits) **had the strongest associations occurring within a few days of exposure (0 to 3 days)**, and **the effects of exposure on subclinical respiratory endpoints, including lung function, respiratory symptoms, and markers of airway inflammation, occurred at lags of 0 to 1 days**. These findings were consistent with evidence from controlled human exposure and experimental animal studies that observed **respiratory effects occurring relatively soon after ozone exposures**, and suggests that there could potentially be a negative health impact by treating days as discrete events, as health effects may occur on a shorter timeframe than this.

The ISA for oxides of nitrogen[105] (2016) is currently undergoing an update. The existing ISA concluded that **no specific NO_2 averaging time, duration, or age of exposure is more strongly associated with asthma attacks or asthma development[106]**. The ISA also investigated lag structures, and found that experimental studies provide biological plausibility for the **asthma-related effects observed in epidemiologic studies in association with 2- or 5-hour exposures, same-day NO_2 exposures, as well as exposures averaged over multiple days[107]**. This suggests that there could potentially be a negative health impact by treating days as discrete events, as **health effects from NO_2 exposure occur on a shorter timeframe** than this.

Finally, the ISA for sulphur oxides[108] (2017) reviewed the limited number of available epidemiologic studies examining lag structures, which reported **associations within the first few days of exposure**. They also state that evidence from controlled human exposure studies of respiratory effects after exposures of 5−10 minutes indicates a rapid onset of SO_2-related effects[109], indicating that there could likely be negative health impacts by treating days as discrete events, as health **effects from SO_2 exposure occur on a much shorter timeframe** than this.

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[103] Integrated Science Assessment for Ozone and Related Photochemical Oxidants, USEPA, April 2020, https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=348522#:~:text=The%20Ozone%20ISA%2C%20in%20conjunction,protects%20public%20health%20and%20welfare.

[104] Integrated Science Assessment for Ozone and Related Photochemical Oxidants, USEPA, April 2020, IS-30

[105] Integrated Science Assessment for Oxides of Nitrogen – Health Criteria, USEPA, January 2016, https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=310879#:~:text=The%20ISA%20is%20one%20of,notice%20of%20proposed%20rulemaking%20(ANPRM)

[106] Integrated Science Assessment for Oxides of Nitrogen – Health Criteria, USEPA, January 2016, lxxxvii

[107] Integrated Science Assessment for Oxides of Nitrogen – Health Criteria, USEPA, January 2016, 1-40

[108] Integrated Science Assessment for Sulfur Oxides – Health Criteria, USEPA, December 2017, https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=338596#:~:text=The%20SOx%20ISA%20reviews,%2C%20epidemiologic%2C%20and%20toxicological%20studies.

[109] Integrated Science Assessment for Sulfur Oxides – Health Criteria, USEPA, December 2017, page 1

One of the broad areas for improvement identified in the AQIS Review team's meeting on air pollution modelling[110] was **using the ability of operational air pollution models that generate data on the daily evolution of pollution, to provide more nuanced advice to the public** about how air pollution concentrations are expected to / are evolving throughout the day, and how to tailor their behaviour accordingly to minimise exposure. Two examples given were the daily evolution of photochemical ozone pollution, which typically builds during the day to a maximum concentration in the late afternoon, and shallow boundary layer accumulation of NO_2 and $PM_{2.5}$ in wintertime high pollution events, where concentrations early in the morning tend to be highest. In both cases, **treating a day as a discrete event could mean losing an opportunity to provide more appropriate guidance on air pollutant exposure**, and the data is available to be able to provide this analysis.

A4.3.5.1 Gaps in evidence identified by the literature review

The literature review was able to summarise the information available on lag time between pollutant exposure and health effects for PM, O_3, NO_2 and SO_2, using the US ISAs for those pollutants. However, some of these ISAs (for example NO_2 and SO_2) are now somewhat out of date and more up-to-date epidemiological studies are likely to be available. These studies also do not explicitly help to answer the question regarding the treatment of days as discrete events, so the interviews with health experts should focus on validating the literature review findings for PM and O_3, as well as investigating whether there is any new evidence to suggest that the lag times for SO_2 and NO_2 are any different, and gathering opinion on the health impact of treating days as discrete events, particularly from a health messaging point of view.

A4.4 CERQ3 ACCESS

The literature relating to air quality monitoring and reporting is varied in terms of availability and coverage. Beginning with the definition of 'at risk', while there is some consensus between Defra and organisations such as UKHSA/OHID and WHO, the latter tend to go further with their definition, including those who are pregnant. **There is a limited amount of work covering use and awareness of the DAQI**. Where there is evidence available, this is **often limited in scope and not broadly explanatory**, for example, a survey by Asthma + Lung UK that suggests 62% of individuals with lung disease are not aware of DAQI, this however, is difficult to extrapolate beyond the sub-section of those considered at risk.

Much of the available literature is more than five years old, with many studies from 2016. This suggests a need for further research to be undertaken as our understanding of air pollution changes. Despite not being very recent, the available literature covers barriers to accessing AQIs in some depth (although this is not DAQI specific). Another gap in the literature is in relation to facilitators, there are no definitive studies describing the facilitators to access of DAQI, rather facilitators are mentioned in passing as part of other studies. Having reviewed a broad range of literature relating to DAQI access, it has become apparent that **there are significant gaps in the literature in relation to usage by those considered to be at risk, with little evidence definitively answering whether at risk populations are aware of and accessing the DAQI**.

[110] AQIS Review, Data Stream: short summary of expert meeting on air pollution modelling on 14th June 2022

A4.4.1Q3:1 At risk - definition

Research question: Do the definitions the DAQI gives of 'at risk individuals' adequately represent the health evidence for groups at increased risk from short term periods of elevated air pollution?

DAQI defines at risk individuals as those who are elderly, young children and those with underlying respiratory and / or cardiovascular disease[111]. This largely aligns with the definition of individuals who are considered at risk by other organisations, for example the WHO and Public Health England (which has now been replaced by the UK Health Security Agency (UKHSA[112]) and Office for Health Improvement and Disparities (OHID[113])) . However, Public Health England Guidance[114] and the WHO[115] both include pregnant women as being more sensitive to air pollution with air pollution linked to health issues such as premature babies and low birth weight. This definition of at risk populations is supported by the Royal College of Physicians (RCP)[116] who acknowledge that it is well-known that those with pre-existing respiratory and cardiac illnesses are at increased risk, in part due to the exacerbation of these conditions by air pollution[117]. The RCP, Public Health England and the WHO all support the DAQI definition of 'at risk' in that they recognise socioeconomic inequality as a risk factor for increased susceptibility to air pollution, highlighting that individuals from low-income backgrounds are more at risk from health problems relating to air pollution. This is attributed to: increased likelihood of living on busy roads or industrial areas, along with related comorbidities such as existing health problems or less access to jobs, healthy foods, quality housing and open green spaces which contribute to poorer health outcomes. These assertions are supported by a range of evidence which indicates maternal exposure to pollutants can have toxic effects on foetuses therefore impacting birth outcomes[118,119].

A study by Schulte K looked at 54 channels presenting air pollution readings, 49 of these presented an AQI alongside the data and 28 provided some messaging targeting specific groups. The most common distinction was between 'general population' and 'at risk' individuals however only 10 channels defined 'at risk'. Channels developed by Imperial Environmental Research Group (ERG) contained specific messaging towards different categories of commuters. The different approaches taken by channels presenting air quality information is likely to add to the lack of clarity around the definition of 'at risk'.[120]

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[111] UK Air DEFRA "Short-term effects of air pollution on health" https://uk-air.defra.gov.uk/air-pollution/effects?view=short-term

[112] https://www.gov.uk/government/organisations/uk-health-security-agency

[113] https://www.gov.uk/government/organisations/office-for-health-improvement-and-disparities

[114]Public Health England "Guidance Health matters: air pollution" Published November 2018 https://www.gov.uk/government/publications/health-matters-air-pollution/health-matters-air-pollution

[115] WHO: Online https://www.who.int/teams/environment-climate-change-and-health/air-quality-energy-and-health/health-impacts

[116] Royal College of Physicians. *Every breath we take: the lifelong impact of air pollution*. Report of a working party. London: RCP, 2016.

[117] Royal College of Physicians. *Every breath we take: the lifelong impact of air pollution*. Report of a working party. London: RCP, 2016. Pg 8.

[118] Shah PS, Balkhair T; Knowledge Synthesis Group on Determinants of Preterm/LBW births. Air pollution and birth outcomes: a systematic review. Environ Int. 2011 Feb;37(2):498-516. doi: 10.1016/j.envint.2010.10.009. Epub 2010 Nov 26. PMID: 21112090.

[119] Ha S, Hu H, Roussos-Ross D, Haidong K, Roth J, Xu X. The effects of air pollution on adverse birth outcomes. Environ Res. 2014 Oct;134:198-204. doi: 10.1016/j.envres.2014.08.002. Epub 2014 Aug 28. PMID: 25173052; PMCID: PMC4262551.

[120] Schulte, K. (2022). 'Real-time' air quality channels: A technology review of emerging environmental alert systems. Big Data & Society, 9(1). https://doi.org/10.1177/20539517221101346

A4.4.1.1 Gaps in evidence identified by the literature review

In general, **the literature[121] available supports the definition of 'at risk' by DAQI. However, having considered the available resources and information DAQI itself could do more to evidence how these groups are determined and defined.** This is because evidence supporting who is categorised as 'at risk' is not referenced on the DAQI website, with much found by relatively intense searching for the information, and the categories are broadly defined, without clear detail. Some individuals may come away from the information unsure of whether they are considered at risk. As such, it may assist in the uptake of DAQI if individuals were clearer upon whether they are considered at risk without having to consult their health professional. Furthermore, where there is information, this is often based upon studies published in 2014 – 2016. As such, there is scope for updated studies and definitions. Further to this, **whilst DAQI aligns with many other public health bodies in defining 'at risk', there is further scope to develop this by including those who are pregnant in their definition**, following UKHSA/OHID, WHO and RCP.

A4.4.2Q3:2 Use by at risk group

Research question: ***How widely used/well recognised is the DAQI by people at increased risk from air pollution (through what channels, if at all, is this user group receiving information)?***

As Schulte[122] highlights, **there is a lack of socio-economic data linked to the usage of AQIs** and as such it is hard to define who is using AQI information. **It is difficult to define whether those at increased risk are using AQI information from any source**. Evidence from Asthma + Lung UK, written by the CEO, and published in "The House"[123], suggests that 62% of those at increased risk from air pollution are aware of DAQI. This is a result of a survey conducted by Asthma + Lung UK of people with lung conditions and therefore, whilst providing an indication that overall awareness is limited[124], these findings are based on a limited sample. Delmas and Kohli (2023) suggest that having notifications of poor air quality may help at risk individuals take precautions, rather than leaving it up to the individual to check DAQI[125]. The literature suggests that individuals struggle to identify themselves as needing to access AQIs leading to limited use of DAQI by those it is intended to help.

Chen et al. (2018) **assessed the effectiveness of air quality alert programme in Toronto, Canada** (which, similarly to the DAQI, uses information campaigns such as web notifications and media coverage to advise the public to avoid outdoor physical activities) in reducing a range of health outcomes, in individuals residing in the city between 2003-

[121] Gehring U., Wijga A.H., Hoek G., Bellander T., Berdel D., Brüske I., Fuertes E., Gruzieva O., Heinrich J., Hoffmann B., et al. Exposure to air pollution and development of asthma and rhinoconjunctivitis throughout childhood and adolescence: A population-based birth cohort study. Lancet Respir. Med. 2015;3:933–942. doi: 10.1016/S2213-2600(15)00426-9.

[122] Schulte, K. (2022). 'Real-time' air quality channels: A technology review of emerging environmental alert systems. Big Data & Society, 9(1). https://doi.org/10.1177/20539517221101346

[123] https://www.politicshome.com/thehouse/article/air-pollution-alerts-dont-do-enough-to-protect-people-suffering-from-toxic-air
https://www.asthmaandlung.org.uk/sites/default/files/Alerting%20the%20Nation%20Report_v4.pdf

[124] Rappold AG, Hano MC, Prince S, Wei L, Huang SM, Baghdikian C, Stearns B, Gao X, Hoshiko S, Cascio WE, Diaz-Sanchez D, Hubbell B. Smoke Sense Initiative Leverages Citizen Science to Address the Growing Wildfire-Related Public Health Problem. Geohealth. 2019 Dec 10;3(12):443-457. doi: 10.1029/2019GH000199. PMID: 32159029; PMCID: PMC7038881.

[125] Delmas, M. A., & Kohli, A. (2021). Engagement With Air Quality Information: Stated Versus Revealed Preferences. Organization & Environment, 34(3), 413-434. https://doi.org/10.1177/1086026619837690

2012[126]. They used provincial health administrative databases to ascertain seven health outcomes known to be affected by short-term elevation of air pollution and applied a regression discontinuity design to assess the effectiveness of the air quality alert programme in Toronto. They found that **the air quality alert programme was related to some reductions in respiratory morbidity, but not any other health outcome examined**, and that **alert announcements reduced asthma-related emergency department visits** by 4.73 cases per 1,000,000 people per day (**in relative terms, by 25%**). They also noted a **non-significant trend towards decreased asthma-related and COPD-related admissions**. Chen et al. concluded that their findings suggest that **issuing air quality alerts alone has a limited effect on public health**.

A4.4.2.1 Gaps in evidence identified by the literature review

There is **a substantial gap in evidence relating to usage of DAQI by at risk populations**, looking at publicly available sources, there is no solid evidence quantifying use of DAQI.

Much of the information in relation to "usage" illustrates what is used to determine DAQI, rather than "usage" amongst at risk populations in the UK. The only research study available considers the effect of DAQI on behaviour[127] as part of a randomised control study. This study found that **behaviourally enhanced messages which recommended behaviour adaptions in response to air pollution were more likely to lead to long term behaviour change than present DAQI messaging**. This was supported by studies in the US showing individuals being more likely to engage with environmental monitoring programmes if there is a level of personalisation[128].

As it stands **there is a lack of evidence to conclusively determine whether at risk individuals are aware of and / or using DAQI in their daily lives and at what frequency.** At present, the evidence suggests that academics are the predominant users of DAQI in the course of studies into the impact of various world events on air quality, such as the Covid-19 Pandemic[129],[130]. There is evidence available that engagement with AQI apps is most closely predicted by user demographics, although intended engagement with the apps exceeds actual engagement, demonstrating an intent-action gap[131]. These demographic differences in engagement are attributed in part to the limited definitions of 'at risk'[132] ; with those with lung or heart conditions being more recognised as at risk, whilst socioeconomic

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[126] Hong Chen, Qiongsi Li, Jay S Kaufman, Jun Wang, Ray Copes, Yushan Su, Tarik Benmarhnia, Effect of air quality alerts on human health: a regression discontinuity analysis in Toronto, Canada, Lancet Planet Health 2018; 2: e19–26, https://www.thelancet.com/action/showPdf?pii=S2542-5196%2817%2930185-7

[127] D'Antoni, Auyeung, Walton, Fuller, Grieve, Weinman, The effect of evidence and theory-based health advice accompanying smartphone air quality alerts on adherence to preventative recommendations during poor air quality days: A randomised controlled trial, Environment International, Volume 124, 2019, Pages 216-235, ISSN 0160-4120, https://doi.org/10.1016/j.envint.2019.01.002.

[128] Rappold AG, Hano MC, Prince S, Wei L, Huang SM, Baghdikian C, Stearns B, Gao X, Hoshiko S, Cascio WE, Diaz-Sanchez D, Hubbell B. Smoke Sense Initiative Leverages Citizen Science to Address the Growing Wildfire-Related Public Health Problem. Geohealth. 2019 Dec 10;3(12):443-457. doi: 10.1029/2019GH000199. PMID: 32159029; PMCID: PMC7038881.

[129] Domínguez-Amarillo S, Fernández-Agüera J, Cesteros-García S, González-Lezcano RA. Bad Air Can Also Kill: Residential Indoor Air Quality and Pollutant Exposure Risk during the COVID-19 Crisis. *International Journal of Environmental Research and Public Health*. 2020; 17(19):7183. https://doi.org/10.3390/ijerph17197183

[130] Mohammad Ali Sahraei, Emre Kuşkapan, Muhammed Yasin Çodur,

Public transit usage and air quality index during the COVID-19 lockdown, Journal of Environmental Management, Volume 286, 2021, 112166, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2021.112166. (https://www.sciencedirect.com/science/article/pii/S0301479721002280)

[131] Delmas, M. A., & Kohli, A. (2021). Engagement With Air Quality Information: Stated Versus Revealed Preferences. Organization & Environment, 34(3), 413-434. https://doi.org/10.1177/1086026619837690

[132] Schulte, K. (2022). 'Real-time' air quality channels: A technology review of emerging environmental alert systems. Big Data & Society, 9(1). https://doi.org/10.1177/20539517221101346

conditions, race and ethnicity are not as widely acknowledged. This results in individuals not identifying as at risk and not using AQIs. This further suggests a need to expand and more broadly socialise the definition of 'at risk' to encourage greater usage of AQIs.

A4.4.3Q3:3: Use by general population

Research question: ***How widely used/well recognised is the DAQI by the general population (through what channels, if at all, is this user group receiving information)?***

Similar to the literature around the use of AQI by at risk populations, there is **little evidence to attribute usage of AQIs**, and by extension DAQI, to particular demographic groups. This is likely exacerbated, as Delmas and Kohli[133] highlighted, by the prevalence of AQI across numerous apps which makes it difficult to definitively determine their usage. In sum, there is no literature clearly defining usage of AQI and specifically DAQI by the general population.

A4.4.3.1 Gaps in evidence identified by the literature review

Whilst as previously explored it is difficult to definitely answer whether 'at risk' groups are engaging with DAQI and what proportions of people using DAQI are considered at risk, there are a number of studies examining the channels used to disseminate AQI information. However, it is worth noting that these studies are not specifically DAQI focused, with some considering the ways a number of AQI can be accessed [134]. As Schulte (2022) highlights, the majority of the existing literature is focused on the channels used for AQ monitoring as part of academic research. Nonetheless, it is valuable in providing an understanding of the channels available and usage of AQI channels more broadly.

As Delmas and Kohli[135] highlight, there are a vast array of apps available which provide information relating to air quality, however **there is limited information about who these apps are reaching and how effective the information provided is at effecting behaviour change.** As part of their study they created their own app, to examine influences upon engagement with AQ information. Whilst not specific to DAQI it can provide some information about how best to encourage uptake of DAQI. They found that individuals with existing health conditions or those who are focused upon living a healthy lifestyle and exercising frequently are more likely to engage with air quality information. They also found that information about air quality was more likely to be accessed if the participant receives an app notification. Whilst there is not comparative data relating to the DAQI, it is possible that similar patterns exist with the use of DAQI or will in the future should awareness be increased. Again, at present there are no definitive studies of the number of individuals who are aware of DAQI outside of randomised controlled trials and studies with limited participants.

Regarding channels used to access DAQI, the literature suggests that smartphone apps, online platforms[136], websites, public displays, television, radio and newspapers and Citizen

[133] Delmas, M. A., & Kohli, A. (2021). Engagement With Air Quality Information: Stated Versus Revealed Preferences. Organization & Environment, 34(3), 413-434. https://doi.org/10.1177/1086026619837690

[134] Schulte, K. (2022). 'Real-time' air quality channels: A technology review of emerging environmental alert systems. Big Data & Society, 9(1). https://doi.org/10.1177/20539517221101346

[135] Delmas, M.A., Kohli, A. Can Apps Make Air Pollution Visible? Learning About Health Impacts Through Engagement with Air Quality Information. J Bus Ethics 161, 279–302 (2020). https://doi.org/10.1007/s10551-019-04215-7

[136] F H Johnston et al 2018 Environ. Res. Lett. 13 044019 DOI 10.1088/1748-9326/aab1e6

Science[137],[138] projects all provide channels through which air quality data can be accessed. The channels provided do vary by region and country. Schulte evidences that in the UK, if DAQI exceeds the "moderate range" the relevant health messaging is displayed on digital displays at bus and tube stops in certain cities including London[139].

A4.4.4Q3:4 Barriers

Research question: ***What, if any, barriers exist that reduce or prevent access to the DAQI?***

Given that most methods to access DAQI are online, a commonly discussed **barrier is digital inequality**[140],[141],[142], along with **price of devices**, **digital skills** and **sharing of personal information**. Research has shown that digital inequality is more pronounced amongst elderly populations and low-income individuals[143],[144], both of whom are also identified as being at risk to air pollution by several sources such as the WHO. Therefore, whilst there is not a lot of evidence (with Schulte being the only example of a study highlighting barriers to using DAQI), it is feasible that the provision of AQIs online and through apps is a significant barrier to accessing the resource.

Another barrier provided by Schulte, is the expectation that **individuals self-identify as being at risk**. This **perception of risk is often based on local and situational knowledge** as well as the experience of negative health outcomes or side effects.[145],[146],[147]. This in itself provides a barrier to accessing DAQI as an individual may not consider themselves to be at risk. As previously discussed, whilst there are definitions of 'at risk' available online, the general population may not immediately seek these out if they have not experienced negative side effects that they attribute to air pollution.

A further barrier to usage of DAQI is highlighted by Asthma + Lung UK, who cite that DAQI alerts are often outdated, with the classifications of high, medium or low pollution now revised by updated research. Furthermore, alerts may be inaccurate or simply too late – arriving after the air quality event it is warning of, with individuals with lung conditions having

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[137] Rappold AG, Hano MC, Prince S, Wei L, Huang SM, Baghdikian C, Stearns B, Gao X, Hoshiko S, Cascio WE, Diaz-Sanchez D, Hubbell B. Smoke Sense Initiative Leverages Citizen Science to Address the Growing Wildfire-Related Public Health Problem. Geohealth. 2019 Dec 10;3(12):443-457. doi: 10.1029/2019GH000199. PMID: 32159029; PMCID: PMC7038881.

[138] Citizen science is defined by UCL as research involving members of the general public - https://www.ucl.ac.uk/library/open-science-research-support/open-science/citizen-science/defining-citizen-science

[139] Schulte, K. (2022). 'Real-time' air quality channels: A technology review of emerging environmental alert systems. Big Data & Society, 9(1). https://doi.org/10.1177/20539517221101346

[140]Rappold AG, Hano MC, Prince S, Wei L, Huang SM, Baghdikian C, Stearns B, Gao X, Hoshiko S, Cascio WE, Diaz-Sanchez D, Hubbell B. Smoke Sense Initiative Leverages Citizen Science to Address the Growing Wildfire-Related Public Health Problem. Geohealth. 2019 Dec 10;3(12):443-457. doi: 10.1029/2019GH000199. PMID: 32159029; PMCID: PMC7038881.

[141] DiMaggio, P., & Hargittai, E. (2001). From the 'digital divide'to 'digital inequality': Studying Internet use as penetration increases. *Princeton: Center for Arts and Cultural Policy Studies, Woodrow Wilson School, Princeton University*, *4*(1), 4-2.

[142] Bol, N., Helberger, N., & Weert, J. C. (2018). Differences in mobile health app use: a source of new digital inequalities?. *The Information Society*, *34*(3), 183-193.

[143]Blank, G., Graham, M., & Calvino, C. (2018). Local Geographies of Digital Inequality. Social Science Computer Review, 36(1), 82-102. https://doi.org/10.1177/0894439317693332

[144] Hannah Holmes, Gemma Burgess, Digital exclusion and poverty in the UK: How structural inequality shapes experiences of getting online, Digital Geography and Society, Volume 3, 2022, 100041, ISSN 2666-3783, https://doi.org/10.1016/j.diggeo.2022.100041

[145] Elliott, S. J., Cole, D. C., Krueger, P., Voorberg, N., & Wakefield, S. (1999). The power of perception: health risk attributed to air pollution in an urban industrial neighbourhood. Risk analysis, 19, 621-634.

[146] Bickerstaff K, Walker G (2001) Participatory local governance and transport planning. *Environment and Planning A* 33(3): 431–451.

[130] Gehring U., Wijga A.H., Hoek G., Bellander T., Berdel D., Brüske I., Fuertes E., Gruzieva O., Heinrich J., Hoffmann B., et al. Exposure to air pollution and development of asthma and rhinoconjunctivitis throughout childhood and adolescence: A population-based birth cohort study. Lancet Respir. Med. 2015;3:933–942. doi: 10.1016/S2213-2600(15)00426-9.

begun to experience symptoms before they receive an alert[148]. Asthma + Lung UK's report also highlights that the recommendations given by DAQI are often unreasonable and restrictive, such as suggesting individuals simply stay indoors when air pollution is high, which may lead to individuals choosing not to use the resource. In addition, the DAQI does not account for indoor concentrations, which may have a higher contribution to overall exposure compared to outdoor concentrations[149].

Overall, barriers to accessing DAQI are the most discussed component of DAQI, although some of these are extrapolated from barriers experienced with AQIs more broadly.

A4.4.4.1 Gaps in evidence identified by the literature review

Other than the conclusions made by Asthma + Lung UK[150], **there is little coverage in the literature about barriers to accessing DAQI specifically**. Focus is placed upon barriers to accessing AQI generally and using technology to access air quality information, rather than directly examining the barriers to accessing the Daily Air Quality Index from DEFRA. As such, this is the main gap in the literature, which relates to the lack of information around DAQI usage, that there is no definitive research outlining barriers to access specifically relating to DAQI.

A4.4.5Q3:5 Facilitators to access

<u>Research question:</u> *What, if any, facilitators have helped to broaden access to the DAQI?*

Finally, many of the factors which facilitate access to DAQI are mentioned in passing in the literature rather than being the sole focus of studies. Facilitators to access are detailed as: the ability to access some form of AQI across 54 channels including apps and websites that are broadly available. Furthermore, the use of smartphones and diffuse monitoring software allows for DAQI to provide information across the UK and be accessible across the country[151]. Much of this work detailing the facilitators to accessing Air Quality Information does not relate specifically to DAQI rather the means and facilitators to accessing air quality indicators more broadly.

A4.4.5.1 Gaps in evidence identified by the literature review

In general, **there is a lack of concrete evidence to indicate that there have been specific facilitators to broaden access to DAQI.** The majority of facilitators are discussed in relation to AQIs more generally and as part of broader studies rather than being a focus of academic work in their own right.

A4.5 CERQ4 UNDERSTANDING

There is notably limited research into DAQI users and their general understanding of DAQI. The most recent study in this area is Verian/AQIS' 3 wave 2023 qualitative study, however this study is not accessible online. Aside from this, the only other study that looks into the understanding of UK AQI, dates back to 2012 by DEFRA. After a thorough search

[148] https://www.asthmaandlung.org.uk/sites/default/files/Alerting%20the%20Nation%20Report_v4.pdf

[149] Ferguson L, Taylor J, Symonds P, Davies M, Dimitroulopoulou S. Analysis of inequalities in personal exposure to PM2.5: A modelling study for the Greater London school-aged population. Sci Total Environ. 2023 Dec 20;905:167056. doi: 10.1016/j.scitotenv.2023.167056. Epub 2023 Sep 16. PMID: 37717780.

[150] https://www.asthmaandlung.org.uk/sites/default/files/Alerting%20the%20Nation%20Report_v4.pdf

[151] Larkin A, Hystad P. Towards Personal Exposures: How Technology Is Changing Air Pollution and Health Research. Curr Environ Health Rep. 2017 Dec;4(4):463-471. doi: 10.1007/s40572-017-0163-y. PMID: 28983874; PMCID: PMC5677549.

of the literature, we saw that various online sources which use/present and explain the DAQI are widely available. However, the majority of recent literature on public engagement with DAQI is mainly centred on behavioural changes and adherence to health advice rather than reporting current understanding of the system. **This suggests there is an essential need for further research in this area.**

A4.5.1 Q4:1 Understanding - meaning

Research question: ***To what extent do DAQI users' understanding of what the DAQI is communicating align with the message it is designed to communicate?***

An unpublished Verian/AQIS' 3-wave qualitative study[152] has found that public understanding of air quality remained limited, supporting previous research in this area. Verian/AQIS study involves a 30-participant online panel over 7 months. Wave 1 of Verian's study specifically explored participants understanding of air quality and associated information sources using a range of online activities. These included reviewing images of communications materials, completing sort and rank tasks and filling in the blanks on an online platform (recollective). The findings from wave 1 saw that overall, the DAQI was well received and understood by participants, however air quality still remains a complex subject for people to understand so information provided needs to be 'entry level'. Participants also suggested to simplify features such as the scaling index and to provide further information around how readings are measured and what they mean, with easily accessible advice. A study by Defra back in 2012[153] also looked into participant perception and comprehension of air quality health advice provided by the UK and other countries. The study took a mixed method approach, involving an in-depth exploration of the key issues using focus groups and small group workshops as well as a quantitative online questionnaire to gather a broad spectrum of views. The study found a lack of awareness of AQI information and that again, the information provided needed to be concise and jargon free (but not vague).

A4.5.1.1 Gaps in evidence identified by the literature review

Currently, the UK Air[132] website provides a clear explanation grid on what the DAQI level bandings mean and the associated health advice messages. However, you do have to navigate through the website to find this. Other more publicly available sources show a simple traffic light system of air quality bandings; however, they do not include the same explanations and/or associated health messages. (For example, IQAir[133], Clean Air Hub UK[134]). This suggests some inconsistencies in public information available on the DAQI. Verian's upcoming study showed that understanding of air quality in general remains limited, supporting older studies, including the 2020 committees paper[135] which also discusses the **limitation in access and clarity of information available to the general public regarding air quality**. However, aside from Verian's upcoming study, recent literature in this area remains limited. There may also be space for a larger, general population type study, with most previous research being qualitative in nature.

[152] Defra (Pending publication)

[153] https://core.ac.uk/download/pdf/188253313.pdf

A4.5.2 Q4:2 Understanding - data visualisation

Research question: *To what extent do DAQI users' understanding of what the DAQI is communicating align with the message it is designed to communicate?*

Verian/AQIS' qualitative study (mentioned previously) showed that participants generally understood simple (i.e. RAG) type visuals, however, the associated information was sometimes misinterpreted. Two different approaches in communicating air pollution levels were shown to participants – a single colour (with gradients) and multicolour/traffic light approach. Though participants generally understood the single colour approach, it did bring up some uncertainty among some participants, with others misinterpreting the key altogether. However, there was no confusion with the multicoloured key. This supports D'Antoni's 2017 study which saw that participants felt having 'good quality' represented by the colour green and 'bad quality' represented by colour red was most preferred when looking at air quality indices.

A4.5.2.1 Gaps in evidence identified by the literature review

The Verian/AQIS study covered a relatively small number of participants providing feedback on the data visualisation. Information collected during the survey as part of this project will provide further feedback on the communication from the DAQI.

A4.5.3 Q4:3: Understanding - language

Research question: *To what extent does the language used in the DAQI contribute to, or limit [at risk/general population] users understanding the DAQI correctly?*

A4.5.3.1 Gaps in evidence identified by the literature review

Though some of the previous research discussed included at risk participants within the sample, sample sizes of this subgroup were too small to make generalised findings, which identifies a gap here.

A4.5.4 Q4:4 Understanding - advice

Research question: *To what extent do DAQI users understand the advice associated with different DAQI readings?*

Studies have shown that understanding the advice associated with air quality readings can be quite difficult and often open to interpretation. Both the studies Verian/AQIS' study and 2012 Defra study mentioned the need for clear, focused, relevant advice.

A4.5.4.1 Gaps in evidence identified by the literature review

Outside of the Verian/AQIS' study and 2012 Defra study, literature on this is limited.

A4.5.5 Q4:5 Barriers to understanding

Research question: *What, if any, barriers exist that have hindered users from correctly interpreting the DAQI?*

Verian/AQIS' study found that jargon-filled, detail orientated language around air quality was not well-received or accurately understood. One of Verian's key findings were that clear, easily accessible, entry-level daily air quality information was needed for audience understanding.

A4.5.5.1 Gaps in evidence identified by the literature review

Aside from Verian/AQIS' study and Defra's study in 2012, literature in this area is limited.

A4.5.6 Q4:6 Facilitators to understanding

Research question: *What, if any, facilitators have supported users' understanding of the DAQI?*

Studies have shown that the use of simple, clearly labelled imagery (i.e. RAG) helps aid understanding of air quality warnings.

A4.5.6.1 Gaps in evidence identified by the literature review

Aside from Verian/AQIS' study and Defra's study in 2012, literature in this area is limited.

A4.6 CERQ5 CHANGE OF BEHAVIOUR

D'Antoni's 2019 RCT study on comparing standard DAQI health messaging and edited health messaging and its effects on participant behaviour shows to be a cornerstone piece of recent research in this area. This research along with studies by Heydon et al (2019), McCarron et al (2020) and Verian (pending publication), confirm that **people's adherence to health advice around air quality is dependent on many factors**, and that **standard AQ alerts/readings alone are not enough to facilitate behaviour change**. Recent research discusses the need for personalised, relevant, up to date air quality data messaging as a proposed method to encourage behavioural change. There is also a notable gap in research regarding the effects (if any) on alert frequency and behaviour change, suggesting a need to investigate further. Additionally, most, if not all of recent research on air quality and behaviour change primarily focuses on the behaviour changes following associated health messaging; this research is also often based on individuals with online access to information. This shows that there is a clear gap in recent research around socio-economic factors and individual adherence as well as behaviours of those who receive air quality information/advice offline.

A4.6.1 Q5:1 Behaviour change - 'at risk' groups

Research question: *To what extent do at risk users change their behaviour based on a [moderate/high/very high] DAQI reading?*

In 2019, D'Antoni *et al.*[154] conducted a Randomised Control Trials (RCT) study around standard DAQI messaging and more 'personalised – behaviour-changing' messages to both non-risk and 'at risk' groups. In D'Antoni's study, eligible participants were directed to an online survey to identify any pre-existing health conditions. Based on their answers, participants were divided into two groups (general public and at-risk respondents). Respondents in both groups were randomised via an algorithm run by CityAir to either a control or intervention group. Participants were then asked to read the scenario of a hypothetical high pollution episode and asked to indicate their intentions to follow the health advice given (i.e. baseline adherence intentions). After completion of the first questionnaire, all participants were able to receive real-time CityAir notifications about real air pollution

[154] The effect of evidence and theory-based health advice accompanying smartphone air quality alerts on adherence to preventative recommendations during poor air quality days_ A randomised controlled trial (sciencedirectassets.com)

episodes. Whilst the control group was set to receive air quality notifications and associated health advice in the usual UK DAQI format, the intervention group was set to receive health advice in an enhanced format.

Overall, the study found that initially, there were no significant behaviour differences across the groups or messaging. However, significantly more respondents in the intervention group (i.e. those who received behaviourally enhanced messages targeting message specificity and psychosocial predictors of behaviour change) considered making permanent changes to reduce exposure to air pollution at four weeks, compared to the control group receiving the usual UK DAQI messages. This suggests that personalised information does have some influence on people's behaviour as well as having 'easy' and quicker preventative measures.

A4.6.1.1 Gaps in evidence identified by the literature review

There is an opportunity here for DAQI to review their health advice messaging, especially to at risk groups to facilitate behaviour change.

A4.6.2Q5:2 Behaviour change - general population

Research question: ***To what extent do general population users change their behaviour based on a [high/very high] DAQI reading?***

A4.6.2.1 Gaps in evidence identified by the literature review

There is no specific literature on this.

A4.6.3Q5:3: Barriers to behaviour change

Research question: ***What, if any, barriers exist (in terms of capability, opportunity or motivation) that prevent users from enacting DAQI advice?***

McCarron et al[155] (2022) recently argued that traditional approaches to air quality messaging (e.g. DAQI) have limited effectiveness in supporting behaviour changes. McCarron's study explored various health behaviour theories, arguing that these were frequently insufficient to instigate individual change. McCarron examined the health behaviour theoretical steps linking air quality data with reduced air pollution exposure and (consequently) improved public health. They argued that there is a need for expanded and extensive messaging to support change in this area, presenting a novel framework that they believe would help shape air quality interventions, and that has the potential to yield more effective and sustainable interventions to incite behavioural change.

An older, yet relevant literature review study into behaviour changes and AQI by D'Antoni *et al.*[156] concluded that there are a variety of influences that affect behaviour change. The 2017 study, systematically reviewed 2016 literature to find studies assessing intended or actual adherence to health advice accompanying air quality warning systems. The studies reviewed, were only chosen if they involved participants who were using or were aware of these warning systems. Studies investigating only protective behaviours due to subjective perception of bad air quality alone were excluded. The results were narratively synthesised

[155] Public engagement with air quality data: using health behaviour change theory to support exposure-minimising behaviours | Journal of Exposure Science & Environmental Epidemiology (nature.com)

[156] Psychosocial and demographic predictors of adherence and non-adherence to health advice accompanying air quality warning systems: a systematic review - PubMed (nih.gov)

and discussed within the COM-B theoretical framework[157]. D'antoni's review concluded that psychosocial factors often influenced changes in behaviours. These included: knowledge on where to check air quality indices, beliefs that one's symptoms were due to air pollution, perceived severity of air pollution, and receiving advice from health care professionals. The barriers to behaviour change identified within this study were: lack of understanding of the indices, being exposed to health messages that reduced both concern about air pollution and perceived susceptibility, as well as perceived lack of self-efficacy/locus of control, reliance on sensory cues and lack of time. All barriers discussed have been supported by more recent studies in this area. For example, Verian's 2023 study concluded that low knowledge, limited access and reduced flexibility and options to carry out certain advice were all barriers to implementing desired behaviours.

A4.6.3.1 Gaps in evidence identified by the literature review

A lot of recent research focuses on behaviour change following air quality messaging, with **a gap on recent research into socioeconomic factors and its affect/possible barriers to individual action. There is also a gap regarding behaviour change of those who are made aware of air quality 'threats' offline, e.g.** those who receive air quality information via health practitioners/ the news and do not rely on online access. Again, this may intersect with other socioeconomic factors.

A4.6.4Q5:4 Facilitators to behaviour change

Research question: ***What, if any, facilitators exist that have helped users to enacting DAQI advice?***

** It may be helpful to comment on the extent to which barriers/capabilities for behaviour change are relevant to the DAQI's design/implementation or to external factors*

Heydon's 2019 qualitative study[158] of parents found that when a situation is deemed to be stressful (i.e. a high AQI rating), coping actions are enacted. This study collected qualitative data from surveys and interviews from a sample of 45 parents and carers from 15 primary schools across Sheffield, England. The aim of this study was to explore the extent to which perceptions and behaviours of air pollution are altered by personal exposure information. Participants were asked to complete surveys to gauge general interest and/or concerns about air pollution before being given portable sensors. Participants were then asked to use the monitors for 2 weeks on the school run before being interviewed about their experiences, perceptions and behaviours during this time. The study found that over half of the participants altered their behaviour because of the monitoring data. Changes included attempting to find alternative routes to and from school, away from the main roads; using their car less and asking people to turn off their engines if seen idling outside school. Overall studies have suggested that if the threat of poor air quality is present and the messaging and associated health advice around air quality is deemed relevant and feasible then individuals are more likely to make changes to their behaviour.

[157] (PDF) The COM-B Theory of Change Model (V3) (researchgate.net)
[158] https://eprints.whiterose.ac.uk/157777/1/Heydon-Chakraborty2020_Article_CanPortableAirQualityMonitorsP.pdf

A4.6.4.1 Gaps in evidence identified by the literature review

A gap in literature here is that **most research is based on online access to this information** with scope to look into the behaviours of those who receive 'offline' information.

A4.6.5Q5:5 Alerts and behaviour change

Research question: ***In what way, if any, does alert frequency impact adherence to advice?***

D'Antoni et al (2017)[159] reviewed evidence concerning the psychosocial and demographic predictors of adherence and non-adherence to health advice accompanying air quality warning systems. They found that there is "frequent suboptimal adherence rates to health advice accompanying air quality alerts", and that "several psychosocial facilitators and barriers of adherence were identified." The facilitators included "knowledge on where to check air quality indices, beliefs that one's symptoms were due to air pollution, perceived severity of air pollution, and receiving advice from health care professionals"; and the barriers included "lack of understanding of the indices, being exposed to health messages that reduced both concern about air pollution and perceived susceptibility, as well as perceived lack of self-efficacy/locus of control, reliance on sensory cues and lack of time."

There is also a broader range of literature investigating how alerts or reminders might affect providers of health care services and patient drug/medication adherence, as well as what alert fatigue could mean for the target population (e.g., patients, or 'at risk' people).

Elias et al (2019)[160] investigated the use of interruptive alerts through electronic health records to improve patient care and found that alert fatigue might be linked to the interruptive and noncritical nature rather than the time burden required to engage with the fatigue itself. These findings are supported by other studies, e.g., Park et al (2022)[161].

The finding are relevant, as the DAQI services (such as the interactive map on the website and especially the email bulletin) inform users or visitors of the air quality rating, and generally, this is green. For example, three or more emails a day might be received by a bulletin subscriber and these are, as a rule, green. Thus, whilst people might be keen to understand air quality, the interruptive and noncritical nature of these notifications could lead to disengagement. In fact, this was independently raised as a potential issue in the Theory of Change workshop with a group of air quality and health experts.

Quan et al (2023)[162] researched drug allergy alert systems (DAAS), which focus on preventing drug adverse events within health care settings. The research suggests that "information overload, alert overrides by clinicians, and the development of "alert fatigue" may interfere with their usefulness".

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[159] Donatella D'Antoni, Louise Smith, Vivian Auyeung, and John Weinman (2017). Psychosocial and demographic predictors of adherence and non-adherence to health advice accompanying air quality warning systems: a systematic review. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5610416/

[160] Pierre Elias, Eric Peterson, Bob Wachter, Cary Ward, Eric Poon, and Ann Marie Navar (2019). Evaluating the Impact of Interruptive Alerts within a Health System: Use, Response Time, and Cumulative Time Burden. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6881214/

[161] Park H, Chae MK, Jeong W, Yu J, Jung W, Chang H, Cha WC (2022). Appropriateness of Alerts and Physicians' Responses With a Medication-Related Clinical Decision Support System: Retrospective Observational Study. JMIR Med Inform. URL:https://medinform.jmir.org/2022/10/e40511

[162] Quan, P.L., Sánchez-Fernández, S., Parrado Gil, L. et al. Usefulness of Drug Allergy Alert Systems: Present and Future. Curr Treat Options Allergy 10, 413–427 (2023). https://doi.org/10.1007/s40521-023-00351-8

Dai et al (2017)[163] explored the effect of interactive reminders on medication adherence through a randomised trial and found that reminders improve medication adherence, even after the mailings stop. The types of reminders they included prompted patients to predict adherence and/or commit to a level of adherence in the future, which contribute to actual adherence.

A4.6.5.1 Gaps in evidence identified by the literature review

No evidence was identified specifically linked to Air Quality Index alert frequency and how this might affect adherence to advice.

A4.7 CERQ6 SOUNDNESS OF ADVICE

In this section, owing to the overlap between many of the research questions, and the lack of available literature from which to answer them, we have grouped the sub-questions as follows:

- Questions 6.1 to 6.4 were grouped as they all aim to investigate the effects of strenuous physical activity at elevated levels of air pollution, on at risk groups. There is very little literature available on the effects of physical activity and exposure to air pollution, especially for at risk groups (i.e., not the general population / healthy individuals). The literature available observed that exercising, even in areas of elevated air pollution, had a positive health impact for some metrics (e.g., lung function); however, participants reported increased symptoms of their respective diseases.
- Questions 6.5 and 6.6 were grouped as they both cover the effects of physical exertion at very high levels of air pollution, on the general population. There is not a large amount of literature available, but the studies that do exist generally conclude that, in the long term, the benefits of exercising (even during high levels of air pollution) are likely to outweigh the negative health impacts. However, in the shorter term, exposure to high levels of air pollution during physical activity is likely to have a negative health effect.
- Questions 6.7 and 6.8 were grouped as they both investigate the effects of reliever inhaler use at very high levels of air pollution. Again, there is little literature on this, but the studies reviewed found that inhaler use tends to increase with increased levels of air pollution, and that inhaler use may reduce the severity of some asthma symptoms (such as wheezing) and improve pulmonary function.
- Question 6.9 covers unintended consequences of health advice provided regarding air pollution, and remains standalone. This was explored in the WHO expert consultation on Personal Interventions and Risk Communication on Air Pollution and the conclusion was that there is almost no information available, and that this topic should be prioritised for research.

[163] Hengchen Dai, David Mao, Kevin G. Volpp, Heather E. Pearce, Michael J. Relish, Victor F. Lawnicki, Katherine L. Milkman (2017). The effect of interactive reminders on medication adherence: A randomized trial, Preventive Medicine, Volume 103,2017, Pages 98-102, ISSN 0091-7435, https://doi.org/10.1016/j.ypmed.2017.07.019

A4.7.1 Q6:1 to Q6:4 At Risk Group – Outdoor Strenuous Physical Activity – Moderate / High (symptoms and health impacts), At Risk Group – Strenuous Activity – Very High (symptoms and health impacts)

Research question 6.1: ***To what extent does the health literature support the assumption that reducing strenuous outdoor physical activity at [moderate/high] levels of air pollution is likely to reduce the severity of symptoms in at risk groups?***

Research question 6.2: ***To what extent can reducing strenuous outdoor physical activity at [moderate/high] levels of air pollution be considered to have a net positive health impact for at risk individuals?***

Research question 6.3: ***To what extent does the health literature support the assumption that reducing strenuous physical activity at [very high] levels of air pollution is likely to reduce the severity of symptoms in at risk groups?***

Research question 6.4: ***To what extent can reducing strenuous physical activity at [very high] levels of air pollution be considered to have a net positive health impact for at risk individuals?***

The literature relevant to answer these four research questions is very slim, owing to a "***lack of evidence on children, pregnant women, unhealthy populations and populations of low-and middle-income countries*** *(where higher exposure to air pollution and different mixtures of pollutants may occur)*", as identified by the WHO expert consultation on Personal Interventions and Risk Communication on Air Pollution[164]. An additional consideration is the wording of the research questions, specifically **"strenuous" physical activity**, as **the definition of this is different for everyone**, and is likely to be especially different between different groups of individuals that are classed as at risk. Therefore, the literature reviewed has focused on any available evidence regarding air pollution and physical activity in at risk groups.

Meta-analysis of epidemiological studies showed a significant association between air pollutants such as ozone, nitrogen oxides, acidic aerosols and particulate matter and symptoms of exacerbation of asthma including emergency visits and hospitalisations. As a result, the Global Strategy for Asthma Management and Prevention 2020 report states that individuals with asthma should aim to stay indoors in a climate-controlled environment and avoid strenuous outdoor physical activity during high pollution episodes.[165]

The review by AQIS on 'Physical Activity and exposure to air pollution'[166] was only able to find a few studies that looked at the health effects of air pollution while engaged in physical activity compared to health effects of the same air pollution with no physical activity, and almost all of these were studies on healthy people. Similarly, most of the studies they found that looked at the health effects without a control (no physical activity) group were also focused on healthy individuals. The review was able to draw out some trends, however, due to the very limited evidence base, highlighted that none of their conclusions could be

[164] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, https://iris.who.int/bitstream/handle/10665/333781/9789240000278-eng.pdf?sequence=1

[165] Global Strategy for Asthma Management 2020 GINA Full Report 2020 Front Cover ONLY (ginasthma.org)

[166] Physical Activity and exposure to air pollution, Panagi et. al., unpublished.

considered firm. The key findings from the studies that considered individuals with chronic diseases were:

- An experimental study by DeMeo et al.[167], (2004) looked at a group of older (healthy or diagnosed with either COPD, asthma, angina, heart attack, heart failure, hypertension), Boston residents (mean age: 73 years) and found that there was a **statistically significant effect of ambient $PM_{2.5}$ air pollution, decreasing oxygen saturation at rest, and post-physical activity rest, but not during physical activity**. They also found that individuals taking β-blockers had a greater pollution related decrease in oxygen saturation at rest.
- Syed et al.[168] (2021), found that **11 healthy control participants experienced greater negative effects of exposure to traffic related air pollution during physical activity, compared to former smokers** (nine with and nine without COPD).
- A number of other studies (from 2002 to 2007) cited in the review, that did not compare physical activity to no physical activity, found that **in people with chronic diseases, higher air pollution during physical activity is associated with larger negative effects on health**.

A study by Sinharay *et al.* (2018)[169], cited in the review by AQIS, analysed the effects of walking for two hours in more- and less-polluted areas of London (Oxford Street and Hyde Park, respectively), on men and women aged 60 years and older with certain types of ischaemic heart disease or COPD (in comparison to healthy individuals). The study found that **in all participants (irrespective of disease status), walking in the less polluted area led to an increase in lung function, with the opposite observed after walking in the more polluted area** (specifically, higher concentrations of PM and NO_2). Both **'at risk' groups experienced an increase in symptoms during the walk in the highly-polluted area**; individuals with ischaemic heart disease reported an increase in coughing, and individuals with COPD reported increases in cough, sputum, shortness of breath, and wheeze. The results of the health tests were mixed, depending on the measure of health impact. **Walking in the area of higher pollution was still beneficial in terms of improving lung function (increased FEV1) for both 'at risk' groups**, though less so than walking in the area of low pollution. The COPD patients experienced increased small airways resistance from walking in higher pollution, as opposed to lower pollution. **Both 'at risk' groups experienced a decrease in arterial stiffness (for up to 26 hours) when walking in the lower-pollution area, and an increase in stiffness in the higher-pollution area**. One limitation of this study (and others included in the AQIS review) is that there was not a control group of no-exercise; as the DAQI advises people to stop strenuous activity during high levels of air pollution, a comparison to a no-exercise group would be pertinent.

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[167] DeMeo, D. L., Zanobetti, A., Litonjua, A. A., Coull, B. A., Schwartz, J., and Gold, D. R.: Ambient air pollution and oxygen saturation, American Journal of Respiratory and Critical Care Medicine, 170, 2004, doi: https://dx.doi.org/10.1164/rccm.200402-244OC

[168] Syed, N., Ryu, M. H., Dhillon, S. S., Schaeffer, M. R., Ryerson, C. J., Ramsook, A. H., Leung, J., Carlsten, C., and Guenette, J. A.: Effect of diesel exhaust on exercise endurance and cardiorespiratory responses to exercise in chronic obstructive pulmonary disease and healthy controls-a randomized, placebo controlled, crossover study, American Journal of Respiratory and Critical Care Medicine, 203, 2021, doi: https://dx.doi.org/10.1164/ajrccmconference.2021.203.1_MeetingAbstracts.A1054

[169] Sinharay et. al., 2018, Respiratory and cardiovascular responses to walking down a traffic-polluted road compared with walking in a traffic-free area in participants aged 60 years and older with chronic lung or heart disease and age-matched healthy controls: a randomised, crossover study. doi: https://doi.org/10.1016/s0140-6736(17)32643-0

The review by Carlsten *et al.*[170] (2020) also cited the above study by Sinharay *et al.*, among others. A study in Korea considered adults with COPD that did or did not exercise, and found that **the negative effect of $PM_{2.5}$ on lung function was greater for adults that did not exercise, compared to those that did**. Similarly, a study in Taiwan found that, across different levels of exposure to $PM_{2.5}$, **adults who regularly exercised had lower white blood cell counts (a marker of systemic inflammation) than those who did not regularly exercise**. However, these studies were not investigating the impacts of exercising during pollution episodes, but rather the health effects of regular exercise (as well as other lifestyle factors) and then being exposed to elevated levels of air pollution. Another study[171] included in the review examined over 50,000 subjects (between age 50-65) from the Danish Diet, Cancer, and Health cohort, for a period of 16 years, and used Cox regression to associate physical activities and NO_2 levels with asthma and COPD. This study found that, while physical activity enhances the uptake of air pollutants into the lungs, and possibly increases the harmful effects of such pollutants on chronic lung disease during exercise, **increased air pollution exposure during exercise does not outweigh the benefits of physical activity on the risk of asthma or COPD**. Carlsten *et al.* go on to say that "***even patients with pre-existing cardiorespiratory disease may experience neutral or beneficial effects of physical activities outdoors, including during periods of elevated air pollution****, but may need to decrease intensity of exertion in proportion to severity of air pollution levels*".

The review by DeFlorio-Barker *et al.*[172] (2020) also included a number of the studies discussed above, and in section A4.7.2; a key limitation identified in the review was that the majority of the articles included were among healthy adults, except for three among more susceptible populations (including the study by Sinharay *et al.*). **Two of these studies suggested a synergistic interaction between air pollution exposure and physical activity** and the review concludes that "***even in low levels of air pollution, low-intensity activities (i.e., walking), may intensify the negative impacts of air pollution, particularly among those with preexisting conditions***".

The WHO expert consultation on Personal Interventions and Risk Communication on Air Pollution recommends that, "*in accordance with the precautionary principle****, populations at specific risk*** *(due to their health status or occupation)* ***should be advised about the best time and location for physical activity*** *or for work (e.g. outdoors)* ***and to reduce moderate–vigorous physical or work outdoors during air pollution episodes***"[173]. This indicates that the recommendation is not to stop physical activity altogether, but rather to ensure that at risk groups have adequate information to be able to tailor their physical activity accordingly to reduce their exposure to air pollution.

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[170] Carlsten C, Salvi S, Wong GWK, et al. Personal strategies to minimise effects of air pollution on respiratory health: advice for providers, patients and the public. Eur Respir J 2020; 55: 1902056 https://doi.org/10.1183/13993003.02056-2019

[171] Fisher, Loft, Ulrik,et al., Physical Activity, Air Pollution, and the Risk of Asthma and ChronicObstructive Pulmonary Disease, Am J Respir Crit Care Med Vol 194, Iss 7, pp 855–865, Oct 1, 2016, https://www.atsjournals.org/doi/epdf/10.1164/rccm.201510-2036OC?role=tab

[172] Stephanie DeFlorio-Barker, Danelle T. Lobdell, Susan L. Stone, Tegan Boehmer, Kristen M. Rappazzo, Acute effects of short-term exposure to air pollution while being physically active, the potential for modification: A review of the literature, Preventive Medicine, Volume 139, 2020, 106195, https://doi.org/10.1016/j.ypmed.2020.106195

[173] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, page 36.

A4.7.1.1 Gaps in evidence identified by the literature review

The WHO expert consultation on Personal Interventions and Risk Communication on Air Pollution (2020) states that there is a "***lack of evidence on children, pregnant women, unhealthy populations and populations of low-and middle-income countries*** *(where higher exposure to air pollution and different mixtures of pollutants may occur)*", so no definite recommendations can be made[174]. They also raise that **most of the evidence addresses $PM_{2.5}$ and long-term effects**, and there is **little information on the short-term effects of multiple pollutants**. The consultation also noted that **there is very little research to support the effectiveness of air pollution-related health advisories in reducing exposure to, and health risks from, air pollution**[175].

The AQIS review on 'Physical Activity and exposure to air pollution' identified **only seven studies (only one of which was not focused on healthy individuals) that looked at the health effects of air pollution while engaged in physical activity compared to health effects of the same air pollution with no physical activity**[176]. A further 17 studies (of which seven did not cover healthy individuals) looked at the health effects without a control (no physical activity) group. The review noted that **most of the studies focused on particulate matter**, with very few studies focused on NO_2 and O_3. They recommended that **future research should prioritise randomized controlled trials in real world conditions**, spanning a range of exposure levels, pollutant mixes, and physical activity levels, **and include diverse groups of participants**.

Further reviews by Carlsten *et al.*[177] (2020) and Janjua *et al.*[178] (2021) also raise a lack of evidence and study diversity in this area; Janjua *et al.* recommend that **larger, longer-term studies using high-quality and well-described methods are required**, and **participants should include people with pre-existing respiratory conditions**. In terms of reporting, they recommend that **outcomes of importance to people with respiratory conditions (for example, hospital admissions, exacerbations, and quality of life) would be useful** in addition to the types of metrics that are usually reported (such as airway inflammation, oxidative stress, or other physiological measurements).

A4.7.2 Q6:5 to Q6:6 General Population – Physical Exertion – Very High (symptoms and health impacts)

Research question 6.5: ***To what extent does the health literature support the assumption that reducing physical exertion at [very high] levels of air pollution is likely to reduce the severity of symptoms (short term health effects) in the general population?***

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[174] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, https://iris.who.int/bitstream/handle/10665/333781/9789240000278-eng.pdf?sequence=1

[175] Review of Air Quality Index and Air Quality Health Index, page 40 https://www.publichealthontario.ca/-/media/documents/A/2013/air-quality-health-index.pdf

[176] Physical Activity and exposure to air pollution, Panagi et. al., unpublished.

[177] Carlsten C, Salvi S, Wong GWK, et al. Personal strategies to minimise effects of air pollution on respiratory health: advice for providers, patients and the public. Eur Respir J 2020; 55: 1902056 https://doi.org/10.1183/13993003.02056-2019

[178] Janjua S, Powell P, Atkinson R, Stovold E, Fortescue R. Individual-level interventions to reduce personal exposure to outdoor air pollution and their effects on people with long-term respiratory conditions. Cochrane Database of Systematic Reviews 2021, Issue 8. Art. No.: CD013441. DOI: 10.1002/14651858.CD013441.pub2

Research question 6.6: ***To what extent can reducing physical exertion at [very high] levels of air pollution be considered to have a net positive health impact for members of the general population?***

The WHO expert consultation on Personal Interventions and Risk Communication on Air Pollution (2020) observed that **evidence on healthy adult populations in high-income countries supports continued promotion of regular physical activity, even if the air quality does not reach the levels recommended by WHO, as the health benefits of physical activity are maintained**[179]. For example, **in healthy adult populations, the long-term beneficial effects of regular physical activity in reducing mortality outweigh the adverse effects of air pollution at <100 µg/m^3 $PM_{2.5}$**[180]. With exposure to air pollution, the short-term beneficial effects of physical activity remain but are reduced. A review by Carlsten *et al.*[181] (2020) is in agreement with this; they considered studies that compared commuting via car, bicycle, and on foot, and concluded that "***the benefits of physical activity when actively commuting versus using motorised transport appear to outweigh the risks associated with the increased inhaled dose of air pollutants***" and also state that, even in high air pollution environments, a protective effect of physical activity with respect to mortality has been reported. However, Carlsten *et al.* also acknowledge that "***the optimal level of physical activity or threshold at which it can be protective against air pollution-related health risks is not known and likely to vary across age and health/disease status***".

The WHO expert consultation found that the literature suggests that air pollution reduces people's engagement in physical activity[182]. However, they recommended that reliable information should be provided to the general public that will enable them to **modify their behaviour on the basis of the physical levels at which they begin to experience adverse impacts, symptoms, or discomfort**, and cite Canada as an example of this[183].

The AQIS review on 'Physical Activity and exposure to air pollution' found that, when considering studies that looked at the health effects of air pollution while engaged in physical activity compared to health effects of the same air pollution with no physical activity, **physical activity has beneficial effects on pulmonary function and to attenuate a traffic-related air pollution increase in systolic blood pressure, compared to rest**[184]; in addition, the negative effects of PM were reduced with an increase in physical activity and that **physically active individuals might have a lower risk of developing cardiovascular and metabolic diseases associated with PM exposure**. On the other hand, when considering studies that looked at the health effects without a control (no physical activity) group, most of these studies suggested that **exposure to particulate matter levels during physical activity was associated with adverse health effects**, although it was unclear

[179] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, page 38.

[180] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, page 36.

[181] Carlsten C, Salvi S, Wong GWK, et al. Personal strategies to minimise effects of air pollution on respiratory health: advice for providers, patients and the public. Eur Respir J 2020; 55: 1902056 https://doi.org/10.1183/13993003.02056-2019

[182] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, page 36.

[183] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, page 23.

[184] Physical Activity and exposure to air pollution, Panagi et. al., unpublished.

whether the health effects were due to the combination of physical activity and air pollution exposure, or mainly due to air pollution exposure (as there was no control group). The review concluded **that** "***even in highly polluted environments, moderate physical activity has beneficial effects on pulmonary function in healthy individuals compared to no physical activity***".

A review article by Tainio *et al.* (2020) found a low evidence base on the impact of short-term air pollution exposure on health impact and symptoms during physical activity[185]. However, there is a suggestion that the **short-term health benefits of physical activity may be weaker or non-existent at higher levels of air pollution**. **Over a longer period of time, it is suggested that conducting physical activity in urban areas introduces benefits that outweigh negative impacts of air pollution exposure**, although the same conclusions cannot necessarily be drawn for short-term bouts of exposure to air pollution during physical activity. This review also noted that air pollution and physical activity seem to work independently on metabolic pathways to health; therefore, the markers used for health impacts in such studies may affect the results.

The review by DeFlorio-Barker *et al.*[186] (2020) also included a number of the studies discussed in section A4.7.1 and in the other reviews discussed in this section. Most of the studies included in their review were on healthy populations, and the review found **varied interactions between air pollution and exercise**. For example, **four studies showed evidence of a synergistic interaction**, such as a study that evaluated healthy adults and adults with asthma cycling with and without exposure to UFP[187]; cycling was associated with beneficial increases in certain lung function parameters, while exposure to UFP had no evidence of an association with lung function, but cycling in the presence of UFP was associated with decreased lung function, which was only significant in healthy adults. **Five studies showed evidence of antagonistic interaction**, including a study where healthy participants undertook **moderate intensity cycling in the presence of traffic-related air pollution[188], which found an association with beneficial increases in lung function** among participants, **in comparison to resting in polluted air**. However, **sixteen studies** reviewed by DeFlorio-Barker *et al.* **indicated no evidence of interaction between physical activity and air pollution exposure** and found **no difference in effect of physical activity whether study participants were exposed to clean or polluted air**. The authors noted that they generally observed **antagonistic interactions in 'high exposure' studies with moderate or high exercise intensity, and synergistic interactions in studies with 'low exposure' pollution levels and low-intensity exercise**.

A4.7.2.1 Gaps in evidence identified by the literature review

The AQIS review on 'Physical Activity and exposure to air pollution' identified **only seven studies (six of which were in healthy individuals) that looked at the health effects of air pollution while engaged in physical activity compared to health effects of the same**

[185] Air pollution, physical activity and health: A mapping review of the evidence, Tainio et. al., Environment International 147 (2021) 105954, https://doi.org/10.1016/j.envint.2020.105954

[186] Stephanie DeFlorio-Barker, Danelle T. Lobdell, Susan L. Stone, Tegan Boehmer, Kristen M. Rappazzo, Acute effects of short-term exposure to air pollution while being physically active, the potential for modification: A review of the literature, Preventive Medicine, Volume 139, 2020, 106195, https://doi.org/10.1016/j.ypmed.2020.106195

[187] Frampton MW, Utell MJ, Zareba W, et al. Effects of exposure to ultrafine carbon particles in healthy subjects and subjects with asthma. Res Rep Health Eff Inst. 2004(126):1–47; discussion 49–63.

[188] Matt F, Cole-Hunter T, Donaire-Gonzalez D, et al. Acute respiratory response to traffic-related air pollution during physical activity performance. Environ Int. 2016;97:45–55. [PubMed: 27776225]

air pollution with no physical activity[189]. A further 17 studies (10 covering healthy individuals) looked at the health effects without a control (no physical activity) group. The review noted that **most of the studies focused on particulate matter**, with very few studies focused on NO_2 and O_3. They recommended that **future research should prioritise randomized controlled trials in real world conditions**, spanning a range of exposure levels, pollutant mixes, and physical activity levels, and include diverse groups of participants.

The review by Tainio *et al.* found that there is also **very limited evidence on the air pollution and physical activity relations on potentially more sensitive population subgroups**, such as children, elderly, pregnant women, and people with pre-existing conditions[190], and highlighted the need for further research.

The WHO expert consultation recommended that **the global impact of air pollution on morbidity and mortality due to reduced physical activity should be estimated**[191].

Reviews by Carlsten *et al.*[192] and Janjua *et al.*[193] raise a **lack of evidence and study diversity** in this area and recommend that **larger, longer-term studies using high-quality and well-described methods are required**.

A4.7.3 Q6:7 to Q6:8 At Risk Group – Reliever Inhaler – High / Very High (symptoms and health impacts)

Research question 6.7: ***To what extent does the health literature support the assumption that increased use of reliever inhaler at [high/very high] levels of air pollution is likely to reduce the severity of symptoms in at risk groups (specifically asthmatics)?***

Research question 6.8: ***To what extent can increased use of reliever inhaler at [high/very high] levels of air pollution be considered to have a net positive health impact for at risk individuals?***

Studies that investigate frequency of use demonstrated the **increased use of inhalers during periods of higher ambient PM or ozone pollution**[194, 195] when symptoms are exacerbated (not taking into account physical activity level), which may suggest a relieving effect on symptoms.

Tiotiu *et al.* (2020) suggested **inhaled corticosteroids are the first-choice treatment as a controller of asthma, as they have been proven to be beneficial in decreasing adverse responses to pollutant exposures**. Moreover, the use of N95 facemasks was

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[189] Physical Activity and exposure to air pollution, Panagi et. al., unpublished.

[190] Air pollution, physical activity and health: A mapping review of the evidence, Tainio et. al., Environment International 147 (2021) 105954, https://doi.org/10.1016/j.envint.2020.105954

[191] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, page 36.

[192] Carlsten C, Salvi S, Wong GWK, et al. Personal strategies to minimise effects of air pollution on respiratory health: advice for providers, patients and the public. Eur Respir J 2020; 55: 1902056 https://doi.org/10.1183/13993003.02056-2019

[193] Janjua S, Powell P, Atkinson R, Stovold E, Fortescue R. Individual-level interventions to reduce personal exposure to outdoor air pollution and their effects on people with long-term respiratory conditions. Cochrane Database of Systematic Reviews 2021, Issue 8. Art. No.: CD013441. DOI: 10.1002/14651858.CD013441.pub2

[194] Associations between Daily Ambient Air Pollution and Pulmonary Function, Asthma Symptom Occurrence, and Quick-Relief Inhaler Use among Asthma Patients, Ścibor et. al., Int. J. Environ. Res. Public Health 2022, 19(8), 4852; https://doi.org/10.3390/ijerph19084852

[195] Geospatial-temporal analysis of the impact of ozone on asthma rescue inhaler use, Pepper et. al., Environment International 136 (2020) 105, https://doi.org/10.1016/j.envint.2019.105331

suggested during periods of high air pollution. It was also suggested that excluding outdoor activities during poor air quality could be included into asthma management plans. [196]

A study by Ścibor *et al.* (2022) investigated the short-term relationship between airborne concentrations of PM_{10} and $PM_{2.5}$ and the health outcomes important in asthma self-management and control, by studying a group of Polish adults suffering from bronchial asthma over a 14-day period[197]. Study participants completed a peak expiratory flow (PEF) measurement in the morning and evening as well as answering a set of questions regarding asthma symptoms, use of their quick-relief inhaler, and how much time was spent outdoors, where and when. The study found that **the risk of asthma quick-relief inhaler use was 5% and 6% higher by each 5 µg/m^3 increase in PM_{10} or $PM_{2.5}$, during the day of observation**, and that a similar but weaker effect was observed with the concentration of PM_{10} or $PM_{2.5}$ from the day before the observation day. However, the risk of any of the asthma symptoms and medication use was not related to the air pollution concentrations recorded two days before observation. A number of asthma symptoms were examined: cough or shortness of breath, tight chest, and wheezing (which occurs later than other symptoms, and usually as a result of poor asthma management); an association between increased concentrations of PM and symptoms such as cough or shortness of breath and tight chest, but was not observed for wheezing. However, the study noted that **when a patient exhibiting other symptoms used a quick-relief inhaler, it reduced the likelihood of wheezing**, and suggested that **medication use can mask some severe symptoms of air-pollution exposure, such as wheezing**.

Another study by Pepper *et al.* (2020) evaluated the association of short-term exposure to air pollution (focusing on $PM_{2.5}$ and O_3) with use of short-acting beta-2 agonists (SABA), an inhaled medication used to provide quick relief for asthma symptoms[198]. The study found a **significant positive association between mean 4-hour O_3 exposure and SABA inhaler use**, which indicates that **there may be evidence for reliever inhalers reducing the severity of asthma symptoms**. However, **exposure to $PM_{2.5}$ was not found to have a significant effect on SABA use** in the study, although the authors note that the average exposure to $PM_{2.5}$ in the study may have been too low to have an effect on asthma. For both O_3 and $PM_{2.5}$, the average exposure fell within the 'Good' index value of the US AQI.

One controlled study found that **the use of a salbutamol inhaler before exercising in a room with higher levels of ozone improved pulmonary function (measured using spirometry) in patients with asthma and/or exercise induced bronchitis**, compared to no inhaler usage. However, there is a suggestion that this medication increases inflammation, compared to the control. There was no difference in symptoms between medicated and control groups.[199]

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[196] Impact of Air Pollution on Asthma Outcomes, Titou et al., Int. J. Environ. Res. Public Health 2022, 17, 6212, doi:10.3390/ijerph17176212

[197] Associations between Daily Ambient Air Pollution and Pulmonary Function, Asthma Symptom Occurrence, and Quick-Relief Inhaler Use among Asthma Patients, Ścibor et. al., Int. J. Environ. Res. Public Health 2022, 19(8), 4852; https://doi.org/10.3390/ijerph19084852

[198] Geospatial-temporal analysis of the impact of ozone on asthma rescue inhaler use, Pepper et. al., Environment International 136 (2020) 105, https://doi.org/10.1016/j.envint.2019.105331

[199] Examining the Effect of Salbutamol Use in Ozone Air Pollution by People with Asthma and/or Exercise Induced Bronchoconstriction, Bennett Stothers, B.Kin., The University of British Columbia, 2020, https://open.library.ubc.ca/soa/cIRcle/collections/ubctheses/24/items/1.0416295

A4.7.3.1 Gaps in evidence identified by the literature review

From searching the literature using the search string "*Inhaler use at risk/ vulnerable population air pollution*", there is not a wide base of literature on the effect of reliever inhaler usage on respiratory symptoms caused by air pollution. Other studies that were included in review articles, such as the review by Janjua *et al.*[200], **investigated whether participants with respiratory conditions kept their inhaler with them and/or used it more frequently during periods of elevated air pollution, rather than the impact of using the inhaler**. This article noted that "*while studies have shown that **there is an association between increased inhaler use and poorer air quality in people with COPD and asthma**, presumably in response to worsening symptoms, **it is less clear whether increasing use prophylactically is beneficial***".

A4.7.4Q6:9 Unintended Consequences

Research question: *Are there any known or likely unintended consequences arising from the current health advice?*

The WHO expert consultation on Personal Interventions and Risk Communication on Air Pollution (2020) stated that "*Given the large number of people of all ages who are at risk of adverse health symptoms and their exacerbation, **provision of an API that has no unintended consequences (i.e. discouraging outdoor physical activity) is justified***"[201]. The consultation also raised that the approach of disseminating advice on avoiding air pollution at the same time as improving ambient air quality is almost entirely based on evidence from studies looking at healthy populations, where it is assumed that a reduction in exposure will provide a health benefit. However, **a strategy of avoidance will only be effective if the accessibility and implications beyond exposure reduction are considered**; for example, **unintended consequences (such as reduced activity and social interaction and more energy use) can negate or even reverse the intended benefits[202]**. One such example is emergency interventions such as school closures, which may be applied during pollution episodes as a risk management strategy, but for which the resulting reduction in exposure of populations and the health benefits of these interventions are not clear. The expert consultation recommends that the potential benefits of such measures should be quantified[203].

A4.7.4.1 Gaps in evidence identified by the literature review

There are large gaps in the literature on potential unintended consequences arising from current health advice for periods of elevated air pollution, and this is noted in existing reviews. The WHO expert consultation on Personal Interventions and Risk Communication on Air Pollution identified that there is **no quantification of the resulting reduction in exposure of populations as a result of emergency interventions** (e.g., school closures)

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[200] Janjua S, Powell P, Atkinson R, Stovold E, Fortescue R. Individual-level interventions to reduce personal exposure to outdoor air pollution and their effects on people with long-term respiratory conditions. Cochrane Database of Systematic Reviews 2021, Issue 8. Art. No.: CD013441. DOI: 10.1002/14651858.CD013441.pub2

[201] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, https://iris.who.int/bitstream/handle/10665/333781/9789240000278-eng.pdf?sequence=1

[202] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, page 31.

[203] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, page 31.

and the health benefits of these interventions[204]. They also raise that **additional studies are needed to increase the evidence for low- and middle-income countries, populations other than healthy adults, pollutants other than $PM_{2.5}$, higher levels of $PM_{2.5}$,** as well as unintended consequences of alerts about air pollution on overall physical activity[205]. In addition, the DAQI does not account for indoor concentrations, which may have a higher contribution to overall exposure compared to outdoor concentrations[206],[207].

[204] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, page 31.

[205] Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, World Health Organization, 2020, page 36.

[206] Ferguson L, Taylor J, Symonds P, Davies M, Dimitroulopoulou S. Analysis of inequalities in personal exposure to PM2.5: A modelling study for the Greater London school-aged population. Sci Total Environ. 2023 Dec 20;905:167056. doi: 10.1016/j.scitotenv.2023.167056. Epub 2023 Sep 16. PMID: 37717780.

[207] Cowell et. al., Particulate matter in a lockdown home: evaluation, calibration, results and health risk from an IoT enabled low-cost sensor network for residential air quality monitoring, : Environ. Sci.: Atmos., 2023, 3, 65, DOI: 10.1039/d2ea00124a

A4.8 ADDITIONAL, RELEVANT EVIDENCE

This section contains additional evidence related to the findings pertaining to CERQ1 RSQ 1 and 2.

A4.8.1 CERQ1:1

The data coverage for each DAQI pollutant, at each monitoring site, per year can be found in Table A4-10, Table A4-11, Table A4-12, Table A4-13 and Table A4-14.

Table A4-40 Data coverage for NO2 measurements at 167 AURN sites from 2018 to 2023. NA indicates no measurement data was collected.

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
ABD	Aberdeen	57.15736	-2.09428	Urban Background	99%	97%	94%	69%	NA	NA
ABD7	Aberdeen Union Street Roadside	57.14456	-2.10647	Urban Traffic	99%	99%	98%	98%	99%	100%
ABD8	Aberdeen Wellington Road	57.13389	-2.0942	Urban Traffic	99%	99%	99%	100%	100%	69%
AGRN	Birmingham Acocks Green	52.43717	-1.83	Urban Background	97%	99%	56%	69%	NA	NA
AH	Aston Hill	52.50385	-3.03418	Rural Background	97%	79%	98%	88%	97%	98%
ARM6	Armagh Roadside	54.35373	-6.65456	Urban Traffic	94%	96%	96%	99%	99%	99%
BAAR	Ballymena Antrim Road	54.85149	-6.27496	Urban Traffic	96%	94%	89%	97%	91%	97%
BALM	Ballymena Ballykeel	54.8616	-6.25087	Urban Background	98%	96%	99%	98%	91%	94%
BAR3	Barnsley Gawber	53.56292	-1.51044	Urban Background	99%	86%	97%	89%	95%	96%
BATH	Bath Roadside	51.39113	-2.35416	Urban Traffic	99%	43%	NA	NA	NA	NA
BBRD	Birkenhead Borough Road	53.38862	-3.02494	Urban Traffic	100%	100%	98%	91%	91%	91%
BDMA	Bradford Mayo Avenue	53.77125	-1.75977	Urban Traffic	97%	96%	81%	97%	91%	99%
BDMP	Borehamwood Meadow Park	51.66233	-0.27	Urban Background	98%	97%	93%	75%	97%	98%
BEL1	Belfast Stockman's Lane	54.57259	-5.97494	Urban Traffic	97%	99%	97%	99%	99%	99%
BEL2	Belfast Centre	54.59965	-5.92883	Urban Background	95%	51%	68%	91%	84%	89%
BEX	London Bexley	51.46603	0.184806	Suburban Background	99%	99%	97%	96%	96%	99%
BIL	Billingham	54.60537	-1.27504	Urban Industrial	97%	100%	100%	99%	99%	99%
BIRR	Birmingham A4540 Roadside	52.47615	-1.87498	Urban Traffic	99%	87%	83%	99%	99%	100%
BLAR	Blackburn Accrington Road	53.74776	-2.45268	Urban Traffic	97%	92%	95%	96%	91%	100%
BLC2	Blackpool Marton	53.80489	-3.00718	Urban Background	93%	93%	99%	99%	99%	100%
BOLD	Oldbury Birmingham Road	52.50244	-2.0035	Urban Traffic	35%	86%	98%	97%	100%	97%
BORN	Bournemouth	50.73957	-1.82674	Urban Background	96%	99%	99%	85%	89%	97%
BOTR	Burton-on-Trent Horninglow	52.82105	-1.63572	Urban Background	91%	98%	99%	98%	76%	100%
BR11	Bristol Temple Way	51.45797	-2.58398	Urban Traffic	98%	100%	100%	98%	97%	95%
BRS8	Bristol St Paul's	51.46284	-2.58448	Urban Background	84%	85%	96%	98%	96%	99%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
BRT3	Brighton Preston Park	50.84084	-0.14757	Urban Background	99%	97%	99%	99%	99%	99%
BURW	Bury Whitefield Roadside	53.55903	-2.29377	Urban Traffic	99%	96%	98%	99%	92%	100%
BUSH	Bush Estate	55.86228	-3.20578	Rural Background	99%	95%	96%	98%	100%	100%
CA1	Camden Kerbside	51.54421	-0.17527	Urban Traffic	96%	99%	93%	70%	79%	99%
CAE6	Hafod-yr-ynys Roadside	51.68058	-3.13351	Urban Traffic	98%	99%	99%	99%	99%	68%
CAM	Cambridge Roadside	52.20237	0.124456	Urban Traffic	98%	87%	84%	99%	75%	96%
CANK	Cannock A5190 Roadside	52.6873	-1.98082	Urban Traffic	74%	99%	93%	96%	99%	98%
CANT	Canterbury	51.27399	1.098061	Urban Background	97%	99%	98%	98%	87%	86%
CARD	Cardiff Centre	51.48178	-3.17625	Urban Background	71%	63%	84%	93%	88%	95%
CARL	Carlisle Roadside	54.89483	-2.94531	Urban Traffic	95%	96%	99%	46%	NA	NA
CHAT	Chatham Roadside	51.37426	0.54797	Urban Traffic	99%	99%	98%	99%	99%	99%
CHBO	Chilbolton Observatory	51.14962	-1.43823	Rural Background	99%	87%	99%	99%	96%	61%
CHBR	Christchurch Barrack Road	50.73545	-1.78089	Urban Traffic	88%	98%	96%	99%	88%	100%
CHLG	Chesterfield Loundsley Green	53.24413	-1.45495	Urban Background	92%	94%	96%	71%	98%	95%
CHP	Chepstow A48	51.63809	-2.67873	Urban Traffic	95%	95%	99%	99%	98%	96%
CHS7	Chesterfield Roadside	53.23175	-1.45693	Urban Traffic	92%	99%	95%	95%	98%	91%
CLL2	London Bloomsbury	51.52229	-0.12589	Urban Background	99%	98%	78%	98%	87%	99%
CNPR	Cardiff Newport Road	51.49096	-3.15231	Urban Traffic	74%	99%	99%	99%	97%	100%
COAL	Coventry Allesley	52.41163	-1.56019	Urban Background	97%	99%	98%	96%	99%	97%
COBR	Coventry Binley Road	52.40771	-1.49008	Urban Traffic	99%	99%	99%	99%	99%	100%
CW	Shaw Crompton Way	53.57923	-2.09384	Urban Traffic	95%	94%	98%	97%	100%	93%
CWMB	Cwmbran	51.6538	-3.00695	Urban Background	99%	99%	60%	NA	NA	NA
DCC1	Dundee Mains Loan	56.47543	-2.95986	Urban Background	91%	96%	97%	99%	53%	99%
DCST	Doncaster A630 Cleveland Street	53.51838	-1.13806	Urban Traffic	99%	98%	98%	99%	93%	99%
DERR	Derry Rosemount	55.00282	-7.33118	Urban Background	98%	98%	99%	99%	99%	85%
DESA	Derby St Alkmund's Way	52.92298	-1.46951	Urban Traffic	100%	98%	97%	89%	98%	100%
DUMB	Dumbarton Roadside	55.9432	-4.55973	Urban Traffic	96%	97%	100%	97%	100%	94%
DUMF	Dumfries	55.07003	-3.61423	Urban Traffic	99%	99%	98%	98%	96%	98%
DYAG	Dewsbury Ashworth Grove	NA	NA	NA	31%	19%	NA	92%	98%	NA
EAGL	Stockton-on-Tees Eaglescliffe	54.51667	-1.35855	Urban Traffic	98%	99%	99%	98%	99%	97%
EB	Eastbourne	50.80578	0.271611	Urban Background	55%	91%	51%	91%	81%	58%
ECCL	Salford Eccles	53.48481	-2.33414	Urban Background	99%	97%	100%	100%	98%	100%
ED3	Edinburgh St Leonards	55.94559	-3.18219	Urban Background	97%	95%	88%	62%	98%	98%
EDNS	Edinburgh Nicolson Street	55.94476	-3.18399	Urban Traffic	100%	99%	74%	50%	100%	96%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
ESK	Eskdalemuir	55.31531	-3.20611	Rural Background	97%	97%	85%	41%	3%	39%
EX	Exeter Roadside	50.72508	-3.53247	Urban Traffic	97%	91%	99%	99%	97%	80%
FW	Fort William	56.82266	-5.1011	Suburban Background	99%	99%	99%	96%	98%	93%
GGWR	Glasgow Great Western Road	55.87204	-4.27094	Urban Traffic	99%	91%	98%	99%	96%	99%
GHSR	Glasgow High Street	55.86094	-4.23821	Urban Traffic	98%	97%	99%	98%	95%	99%
GKA8	Greenock A8 Roadside	55.94408	-4.73442	Urban Traffic	100%	99%	98%	56%	79%	100%
GLA4	Glasgow Kerbside	55.85894	-4.25912	Urban Traffic	99%	98%	99%	98%	99%	84%
GLAZ	Glazebury	53.46008	-2.47206	Rural Background	78%	97%	98%	99%	89%	96%
GLKP	Glasgow Townhead	55.86578	-4.24363	Urban Background	99%	99%	99%	99%	99%	100%
GRA2	Grangemouth Moray	56.01314	-3.71083	Urban Industrial	94%	91%	76%	89%	99%	96%
GRAN	Grangemouth	56.01032	-3.7044	Urban Industrial	94%	88%	98%	53%	92%	88%
HG1	Haringey Roadside	51.5993	-0.06822	Urban Traffic	100%	95%	98%	96%	100%	86%
HG4	London Haringey Priory Park South	51.58413	-0.12525	Urban Background	99%	99%	100%	91%	99%	96%
HIL	London Hillingdon	51.49633	-0.46086	Urban Background	93%	91%	98%	100%	100%	99%
HM	High Muffles	54.3345	-0.80882	Rural Background	95%	99%	47%	99%	98%	97%
HONI	Honiton	50.79229	-3.1967	Urban Background	98%	100%	96%	98%	93%	70%
HOPE	Stanford-le-Hope Roadside	51.51817	0.439548	Urban Traffic	99%	99%	99%	99%	97%	96%
HORE	Horley	51.16587	-0.16773	Suburban Industrial	87%	99%	99%	95%	92%	90%
HORS	London Westminster	51.49467	-0.13193	Urban Background	97%	77%	100%	97%	88%	99%
HRL	London Harlington	51.48879	-0.44161	Urban Industrial	92%	99%	99%	99%	100%	100%
HSAW	Hartlepool St Abbs Walk	54.68324	-1.20384	Urban Background	99%	99%	99%	99%	99%	99%
HUL2	Hull Freetown	53.74878	-0.34122	Urban Background	99%	99%	99%	99%	99%	94%
HULR	Hull Holderness Road	53.75901	-0.30568	Urban Traffic	99%	100%	99%	99%	98%	79%
IMGM	Immingham Woodlands Avenue	53.61924	-0.21332	Urban Background	66%	95%	95%	99%	93%	94%
INV2	Inverness	57.48131	-4.24145	Urban Traffic	99%	99%	93%	93%	95%	99%
KC1	London N. Kensington	51.52105	-0.21349	Urban Background	99%	99%	99%	99%	98%	99%
LB	Ladybower	53.40337	-1.75201	Rural Background	92%	94%	90%	99%	98%	99%
LEAM	Leamington Spa	52.28881	-1.53312	Urban Background	92%	96%	99%	94%	90%	99%
LEAR	Leamington Spa Rugby Road	52.29488	-1.54291	Urban Traffic	99%	97%	96%	99%	77%	93%
LECU	Leicester University	52.6199	-1.12718	Urban Background	99%	99%	98%	87%	99%	99%
LED6	Leeds Headingley Kerbside	53.81997	-1.57636	Urban Traffic	99%	99%	99%	76%	94%	92%
LEED	Leeds Centre	53.80378	-1.54647	Urban Background	98%	99%	97%	96%	98%	96%
LEIR	Leicester A594 Roadside	52.63874	-1.12427	Urban Traffic	99%	98%	99%	94%	96%	96%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
LEOM	Leominster	52.22159	-2.73684	Suburban Background	99%	99%	99%	94%	99%	96%
LH	Lullington Heath	50.7937	0.18125	Rural Background	99%	98%	11%	19%	96%	98%
LIN3	Lincoln Canwick Road	53.22143	-0.5342	Urban Traffic	100%	100%	97%	92%	95%	91%
LON6	London Eltham	51.45258	0.070766	Suburban Background	96%	97%	94%	90%	58%	33%
LUTR	Luton A505 Roadside	51.89229	-0.46211	Urban Traffic	99%	97%	97%	99%	98%	99%
LVP	Liverpool Speke	53.34633	-2.84433	Urban Industrial	99%	99%	64%	29%	99%	96%
MACK	Charlton Mackrell	51.05625	-2.68345	Rural Background	99%	98%	97%	99%	99%	98%
MAHG	Manchester Sharston	53.37172	-2.23892	Suburban Industrial	98%	99%	99%	99%	99%	98%
MAN3	Manchester Piccadilly	53.48152	-2.23788	Urban Background	99%	99%	99%	96%	99%	99%
MID	Middlesbrough	54.5693	-1.22087	Urban Background	98%	98%	97%	99%	99%	99%
MKTH	Market Harborough	52.55444	-0.77222	Rural Background	95%	23%	NA	NA	NA	NA
MY1	London Marylebone Road	51.52253	-0.15461	Urban Traffic	98%	95%	97%	94%	99%	95%
NCA3	Newcastle Cradlewell Roadside	54.98641	-1.59536	Urban Traffic	99%	96%	99%	99%	97%	99%
NEWC	Newcastle Centre	54.97825	-1.61053	Urban Background	88%	98%	99%	99%	99%	99%
NO12	Norwich Lakenfields	52.61482	1.302686	Urban Background	99%	99%	94%	88%	99%	82%
NOTT	Nottingham Centre	52.95473	-1.14645	Urban Background	97%	98%	99%	95%	99%	90%
NPT3	Newport	51.6012	-2.97728	Urban Background	43%	98%	98%	99%	70%	100%
NTN4	Northampton Spring Park	52.27226	-0.91661	Urban Background	99%	75%	99%	91%	97%	99%
NWBV	Nottingham Western Boulevard	52.96938	-1.18885	Urban Traffic	94%	100%	99%	99%	99%	99%
OSY	St Osyth	51.77787	1.04901	Rural Background	98%	97%	95%	94%	86%	99%
OX	Oxford Centre Roadside	51.75175	-1.25746	Urban Traffic	95%	97%	100%	100%	100%	91%
OX8	Oxford St Ebbes	51.74481	-1.26028	Urban Background	98%	97%	100%	100%	100%	100%
PEEB	Peebles	55.65747	-3.19653	Urban Background	87%	99%	99%	81%	99%	99%
PEMB	Narberth	51.78262	-4.69237	Rural Background	99%	97%	99%	98%	97%	95%
PLYM	Plymouth Centre	50.37167	-4.14236	Urban Background	99%	99%	99%	99%	99%	99%
PLYR	Plymouth Tavistock Road	50.41106	-4.13029	Urban Traffic	85%	83%	98%	97%	95%	79%
PMTH	Portsmouth	50.82881	-1.06858	Urban Background	99%	100%	15%	65%	99%	99%
POAR	Portsmouth Anglesea Road	50.79834	-1.09556	Urban Traffic	97%	99%	99%	99%	99%	99%
PRES	Preston	53.76559	-2.68035	Urban Background	99%	99%	91%	94%	88%	99%
PT4	Port Talbot Margam	51.58395	-3.77082	Urban Industrial	98%	95%	96%	99%	98%	95%
REA1	Reading New Town	51.45309	-0.94407	Urban Background	99%	58%	98%	91%	53%	93%
REA5	Reading London Road	51.4549	-0.94038	Urban Traffic	97%	96%	91%	99%	96%	100%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
ROCH	Rochester Stoke	51.45617	0.634889	Rural Background	95%	95%	99%	96%	98%	97%
SA33	Southampton A33	50.92027	-1.46348	Urban Traffic	99%	97%	99%	99%	99%	97%
SCN2	Scunthorpe Town	53.58634	-0.63681	Urban Industrial	98%	97%	96%	99%	98%	95%
SDY	Sandy Roadside	52.13242	-0.30031	Urban Traffic	98%	97%	99%	71%	98%	98%
SEND	Southend-on-Sea	51.54417	0.678331	Urban Background	76%	99%	99%	79%	99%	99%
SHBR	Sheffield Barnsley Road	53.40495	-1.45582	Urban Traffic	97%	82%	87%	87%	94%	97%
SHDG	Sheffield Devonshire Green	53.37862	-1.4781	Urban Background	99%	80%	99%	32%	99%	100%
SHE	Sheffield Tinsley	53.41058	-1.39614	Urban Background	97%	96%	98%	99%	69%	99%
SHLW	St Helens Linkway	53.45183	-2.74213	Urban Traffic	98%	84%	99%	98%	100%	99%
SK5	Southwark A2 Old Kent Road	51.4805	-0.05955	Urban Traffic	85%	98%	68%	97%	98%	98%
SOTR	Stockton-on-Tees A1305 Roadside	54.56582	-1.3159	Urban Traffic	99%	98%	99%	97%	98%	99%
SOUT	Southampton Centre	50.90817	-1.39576	Urban Background	95%	99%	79%	80%	99%	99%
STKR	Stoke-on-Trent A50 Roadside	52.98044	-2.1119	Urban Traffic	98%	99%	91%	99%	98%	99%
STOK	Stoke-on-Trent Centre	53.02821	-2.17513	Urban Background	98%	99%	99%	99%	98%	98%
STOR	Storrington Roadside	50.91693	-0.44955	Urban Traffic	99%	96%	94%	97%	70%	90%
SUN2	Sunderland Silksworth	54.88361	-1.40688	Urban Background	95%	98%	71%	13%	91%	98%
SUNR	Sunderland Wessington Way	54.91839	-1.40839	Urban Traffic	85%	89%	96%	98%	87%	99%
SWA1	Swansea Roadside	51.6327	-3.94737	Urban Traffic	99%	99%	94%	98%	93%	99%
SWHO	Swindon Walcot	51.55806	-1.76568	Urban Background	97%	99%	98%	99%	99%	98%
TDHD	Telford Hollinswood	52.67347	-2.43669	Urban Background	95%	99%	98%	99%	99%	99%
TH2	Tower Hamlets Roadside	51.52253	-0.04216	Urban Traffic	96%	100%	100%	99%	99%	99%
THUR	Thurrock	51.47707	0.317969	Urban Background	97%	99%	99%	98%	99%	99%
TRAN	Wirral Tranmere	53.37287	-3.02272	Urban Background	99%	99%	84%	91%	97%	93%
WAL4	Walsall Woodlands	52.60564	-2.03037	Urban Background	100%	99%	99%	99%	99%	98%
WAR	Warrington	53.38923	-2.61559	Urban Background	92%	88%	100%	98%	31%	87%
WFEN	Wicken Fen	52.2985	0.290917	Rural Background	98%	94%	98%	97%	97%	98%
WIG5	Wigan Centre	53.54914	-2.63814	Urban Background	98%	97%	100%	100%	97%	100%
WREX	Wrexham	53.04228	-3.00283	Urban Traffic	89%	80%	99%	99%	99%	95%
WSMR	Widnes Milton Road	53.36539	-2.73168	Urban Traffic	17%	83%	99%	98%	94%	99%
WTHG	Worthing A27 Roadside	50.83295	-0.37992	Urban Traffic	95%	97%	99%	98%	95%	85%
YK10	York Bootham	53.96751	-1.08651	Urban Background	98%	99%	61%	91%	99%	99%
YK11	York Fishergate	53.95189	-1.07586	Urban Traffic	96%	98%	98%	99%	99%	99%
YW	Yarner Wood	50.5976	-3.71651	Rural Background	98%	98%	96%	90%	94%	96%
BHA4	Bath A4 Roadside	51.39092	-2.35503	Urban Traffic	NA	19%	98%	99%	96%	82%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
COPP	Crewe Coppenhall	53.11594	-2.45349	Urban Background	NA	21%	96%	98%	100%	99%
WBKP	West Bromwich Kenrick Park	52.50834	-1.98607	Urban Background	NA	75%	96%	99%	93%	97%
BMLD	Birmingham Ladywood	52.48135	-1.91824	Urban Background	NA	NA	98%	97%	93%	98%
CWMC	Cwmbran Crownbridge	51.65382	-3.00637	Urban Background	NA	NA	25%	99%	99%	94%
DYAG	Dewsbury Ashworth Grange	53.6931	-1.63711	Urban Background	NA	NA	89%	NA	NA	97%
ABD9	Aberdeen Erroll Park	57.1574	-2.09477	Urban Background	NA	NA	NA	25%	99%	99%
CARM	Carlisle Morton A595	54.88582	-2.96496	Urban Traffic	NA	NA	NA	20%	95%	99%
CAEB	Hafod-yr-ynys Hill Roadside	51.68049	-3.13433	Urban Traffic	NA	NA	NA	NA	NA	25%
TOFT	Toft Newton	53.37413	-0.44979	Rural Background	NA	NA	NA	NA	NA	25%

Table A4-5 Data coverage for PM2.5 measurements at 111 AURN sites from 2018 to 2023. NA indicates no measurement data was collected.

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
ABD	Aberdeen	57.15736	-2.09428	Urban Background	98%	94%	100%	69%	NA	NA
ACTH	Auchencorth Moss	55.79216	-3.2429	Rural Background	92%	100%	100%	100%	100%	100%
AGRN	Birmingham Acocks Green	52.43717	-1.83	Urban Background	98%	97%	99%	69%	NA	NA
BEL2	Belfast Centre	54.59965	-5.92883	Urban Background	94%	88%	100%	99%	96%	100%
BEX	London Bexley	51.46603	0.184806	Suburban Background	99%	82%	89%	100%	99%	100%
BIRR	Birmingham A4540 Roadside	52.47615	-1.87498	Urban Traffic	94%	99%	99%	99%	99%	100%
BLC2	Blackpool Marton	53.80489	-3.00718	Urban Background	84%	85%	99%	100%	100%	100%
BMLD	Birmingham Ladywood	52.48135	-1.91824	Urban Background	36%	93%	100%	100%	100%	97%
BORN	Bournemouth	50.73957	-1.82674	Urban Background	96%	96%	94%	95%	96%	94%
BPLE	Barnstaple A39	51.07479	-4.04192	Urban Traffic	91%	95%	94%	83%	49%	88%
BRS8	Bristol St Paul's	51.46284	-2.58448	Urban Background	80%	86%	94%	96%	95%	77%
CA1	Camden Kerbside	51.54421	-0.17527	Urban Traffic	88%	98%	98%	64%	73%	96%
CARD	Cardiff Centre	51.48178	-3.17625	Urban Background	88%	64%	87%	95%	97%	55%
CARL	Carlisle Roadside	54.89483	-2.94531	Urban Traffic	91%	94%	97%	45%	NA	NA
CHAT	Chatham Roadside	51.37426	0.54797	Urban Traffic	96%	90%	90%	95%	97%	97%
CHBO	Chilbolton Observatory	51.14962	-1.43823	Rural Background	90%	100%	97%	99%	99%	85%
CHBR	Christchurch Barrack Road	50.73545	-1.78089	Urban Traffic	97%	95%	71%	95%	93%	96%
CHLG	Chesterfield Loundsley Green	53.24413	-1.45495	Urban Background	95%	88%	100%	100%	100%	100%
CHP	Chepstow A48	51.63809	-2.67873	Urban Traffic	93%	97%	87%	95%	97%	96%
CHS7	Chesterfield Roadside	53.23175	-1.45693	Urban Traffic	96%	98%	100%	100%	100%	99%
CLL2	London Bloomsbury	51.52229	-0.12589	Urban Background	92%	98%	88%	36%	60%	97%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
COAL	Coventry Allesley	52.41163	-1.56019	Urban Background	94%	94%	100%	98%	99%	100%
DERR	Derry Rosemount	55.00282	-7.33118	Urban Background	96%	83%	97%	96%	95%	94%
EAGL	Stockton-on-Tees Eaglescliffe	54.51667	-1.35855	Urban Traffic	96%	94%	93%	90%	96%	81%
EB	Eastbourne	50.80578	0.271611	Urban Background	98%	99%	98%	100%	97%	62%
ECCL	Salford Eccles	53.48481	-2.33414	Urban Background	83%	100%	100%	100%	100%	100%
ED3	Edinburgh St Leonards	55.94559	-3.18219	Urban Background	93%	93%	99%	99%	99%	100%
GHSR	Glasgow High Street	55.86094	-4.23821	Urban Traffic	98%	100%	99%	100%	100%	100%
GKA8	Greenock A8 Roadside	55.94408	-4.73442	Urban Traffic	100%	100%	100%	100%	94%	100%
GLKP	Glasgow Townhead	55.86578	-4.24363	Urban Background	94%	99%	99%	99%	99%	99%
GRAN	Grangemouth	56.01032	-3.7044	Urban Industrial	92%	97%	94%	94%	83%	98%
HOPE	Stanford-le-Hope Roadside	51.51817	0.439548	Urban Traffic	98%	91%	97%	89%	88%	90%
HORS	London Westminster	51.49467	-0.13193	Urban Background	73%	92%	95%	81%	82%	96%
HRL	London Harlington	51.48879	-0.44161	Urban Industrial	97%	97%	99%	99%	99%	100%
HUL2	Hull Freetown	53.74878	-0.34122	Urban Background	98%	95%	98%	99%	100%	100%
INV2	Inverness	57.48131	-4.24145	Urban Traffic	44%	88%	96%	100%	99%	98%
KC1	London N. Kensington	51.52105	-0.21349	Urban Background	100%	100%	100%	100%	98%	100%
LEAM	Leamington Spa	52.28881	-1.53312	Urban Background	94%	97%	100%	98%	100%	100%
LEAR	Leamington Spa Rugby Road	52.29488	-1.54291	Urban Traffic	74%	92%	99%	100%	100%	99%
LECU	Leicester University	52.6199	-1.12718	Urban Background	98%	97%	99%	99%	100%	99%
LED6	Leeds Headingley Kerbside	53.81997	-1.57636	Urban Traffic	97%	92%	93%	98%	96%	85%
LEED	Leeds Centre	53.80378	-1.54647	Urban Background	94%	95%	97%	99%	99%	100%
LN	Lough Navar	54.43951	-7.90033	Rural Background	40%	98%	100%	97%	99%	100%
LON6	London Eltham	51.45258	0.070766	Suburban Background	83%	97%	96%	90%	62%	47%
LVP	Liverpool Speke	53.34633	-2.84433	Urban Industrial	97%	95%	64%	24%	65%	96%
MAN3	Manchester Piccadilly	53.48152	-2.23788	Urban Background	95%	92%	96%	99%	98%	98%
MID	Middlesbrough	54.5693	-1.22087	Urban Background	93%	96%	89%	94%	94%	83%
MY1	London Marylebone Road	51.52253	-0.15461	Urban Traffic	90%	91%	79%	86%	85%	94%
NEWC	Newcastle Centre	54.97825	-1.61053	Urban Background	92%	94%	93%	97%	97%	93%
NO12	Norwich Lakenfields	52.61482	1.302686	Urban Background	89%	97%	99%	97%	97%	95%
NOTT	Nottingham Centre	52.95473	-1.14645	Urban Background	95%	97%	99%	99%	99%	100%
NPT3	Newport	51.6012	-2.97728	Urban Background	57%	100%	96%	100%	99%	100%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
NTN4	Northampton Spring Park	52.27226	-0.91661	Urban Background	97%	98%	97%	97%	97%	90%
OX8	Oxford St Ebbes	51.74481	-1.26028	Urban Background	96%	96%	100%	100%	100%	100%
PEMB	Narberth	51.78262	-4.69237	Rural Background	56%	75%	98%	99%	100%	100%
PLYM	Plymouth Centre	50.37167	-4.14236	Urban Background	92%	95%	92%	97%	99%	100%
PMTH	Portsmouth	50.82881	-1.06858	Urban Background	56%	93%	15%	63%	82%	100%
PRES	Preston	53.76559	-2.68035	Urban Background	96%	97%	99%	99%	100%	100%
PT4	Port Talbot Margam	51.58395	-3.77082	Urban Industrial	93%	92%	88%	95%	96%	95%
REA1	Reading New Town	51.45309	-0.94407	Urban Background	93%	38%	93%	94%	96%	90%
ROCH	Rochester Stoke	51.45617	0.634889	Rural Background	97%	100%	100%	99%	96%	98%
SASH	Saltash Callington Road	50.41146	-4.22768	Urban Traffic	96%	96%	91%	97%	97%	93%
SDY	Sandy Roadside	52.13242	-0.30031	Urban Traffic	62%	88%	74%	70%	87%	90%
SEND	Southend-on-Sea	51.54417	0.678331	Urban Background	72%	98%	100%	99%	99%	99%
SHBR	Sheffield Barnsley Road	53.40495	-1.45582	Urban Traffic	94%	92%	97%	83%	94%	97%
SHDG	Sheffield Devonshire Green	53.37862	-1.4781	Urban Background	91%	97%	100%	100%	98%	99%
SOTR	Stockton-on-Tees A1305 Roadside	54.56582	-1.3159	Urban Traffic	95%	95%	91%	87%	94%	90%
SOUT	Southampton Centre	50.90817	-1.39576	Urban Background	87%	97%	99%	99%	100%	100%
STOK	Stoke-on-Trent Centre	53.02821	-2.17513	Urban Background	92%	97%	97%	99%	100%	100%
SUN2	Sunderland Silksworth	54.88361	-1.40688	Urban Background	90%	85%	100%	99%	99%	95%
SWA1	Swansea Roadside	51.6327	-3.94737	Urban Traffic	92%	94%	86%	87%	83%	88%
TED2	London Teddington Bushy Park	51.42529	-0.34561	Urban Background	96%	93%	96%	99%	97%	75%
TRAN	Wirral Tranmere	53.37287	-3.02272	Urban Background	94%	97%	99%	100%	98%	100%
WAR	Warrington	53.38923	-2.61559	Urban Background	90%	68%	95%	96%	95%	94%
WIG5	Wigan Centre	53.54914	-2.63814	Urban Background	78%	96%	100%	100%	100%	100%
WREX	Wrexham	53.04228	-3.00283	Urban Traffic	15%	80%	100%	100%	97%	100%
WTHG	Worthing A27 Roadside	50.83295	-0.37992	Urban Traffic	75%	97%	98%	97%	93%	48%
YK10	York Bootham	53.96751	-1.08651	Urban Background	96%	95%	93%	88%	98%	98%
YK11	York Fishergate	53.95189	-1.07586	Urban Traffic	93%	68%	96%	94%	96%	97%
HP1	London Honor Oak Park	51.44967	-0.03742	Urban Background	NA	100%	100%	97%	99%	100%
BRT3	Brighton Preston Park	50.84084	-0.14757	Urban Background	NA	NA	41%	64%	94%	63%
ABD9	Aberdeen Erroll Park	57.1574	-2.09477	Urban Background	NA	NA	NA	25%	100%	96%
CARM	Carlisle Morton A595	54.88582	-2.96496	Urban Traffic	NA	NA	NA	22%	97%	95%
BDMP	Borehamwood Meadow Park	51.66233	-0.27	Urban Background	NA	NA	NA	NA	78%	98%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
BOTR	Burton-on-Trent Horninglow	52.82105	-1.63572	Urban Background	NA	NA	NA	NA	50%	99%
CANT	Canterbury	51.27399	1.098061	Urban Background	NA	NA	NA	NA	58%	96%
COPP	Crewe Coppenhall	53.11594	-2.45349	Urban Background	NA	NA	NA	NA	49%	99%
DYAG	Dewsbury Ashworth Grove	NA	NA	NA	NA	NA	NA	NA	50%	NA
GLAZ	Glazebury	53.46008	-2.47206	Rural Background	NA	NA	NA	NA	58%	99%
HIL	London Hillingdon	51.49633	-0.46086	Urban Background	NA	NA	NA	NA	65%	97%
HM	High Muffles	54.3345	-0.80882	Rural Background	NA	NA	NA	NA	59%	100%
HONI	Honiton	50.79229	-3.1967	Urban Background	NA	NA	NA	NA	76%	99%
HSAW	Hartlepool St Abbs Walk	54.68324	-1.20384	Urban Background	NA	NA	NA	NA	63%	99%
IMGM	Immingham Woodlands Avenue	53.61924	-0.21332	Urban Background	NA	NA	NA	NA	63%	100%
LH	Lullington Heath	50.7937	0.18125	Rural Background	NA	NA	NA	NA	58%	100%
MACK	Charlton Mackrell	51.05625	-2.68345	Rural Background	NA	NA	NA	NA	55%	99%
OSY	St Osyth	51.77787	1.04901	Rural Background	NA	NA	NA	NA	75%	100%
SHE	Sheffield Tinsley	53.41058	-1.39614	Urban Background	NA	NA	NA	NA	64%	99%
SWHO	Swindon Walcot	51.55806	-1.76568	Urban Background	NA	NA	NA	NA	56%	100%
TDHD	Telford Hollinswood	52.67347	-2.43669	Urban Background	NA	NA	NA	NA	49%	99%
THUR	Thurrock	51.47707	0.317969	Urban Background	NA	NA	NA	NA	8%	93%
WEYB	Weybourne	52.95049	1.122017	Rural Background	NA	NA	NA	NA	3%	87%
WFEN	Wicken Fen	52.2985	0.290917	Rural Background	NA	NA	NA	NA	56%	100%
YW	Yarner Wood	50.5976	-3.71651	Rural Background	NA	NA	NA	NA	46%	99%
BAR3	Barnsley Gawber	53.56292	-1.51044	Urban Background	NA	NA	NA	NA	NA	73%
BLAP	Blackburn Audley Park	53.74673	-2.46787	Urban Background	NA	NA	NA	NA	NA	33%
DESB	Derby Stockbrook Park	52.91606	-1.49217	Urban Background	NA	NA	NA	NA	NA	10%
DYAG	Dewsbury Ashworth Grange	53.6931	-1.63711	Urban Background	NA	NA	NA	NA	NA	100%
MKCC	Milton Keynes Civic Centre	52.04408	-0.76101	Urban Background	NA	NA	NA	NA	NA	76%
TALL	Tallington	52.65631	-0.381	Rural Background	NA	NA	NA	NA	NA	4%
TOFT	Toft Newton	53.37413	-0.44979	Rural Background	NA	NA	NA	NA	NA	25%

Table A4-6 Data coverage for PM10 measurements at 121 AURN sites from 2018 to 2023. NA indicates no measurement data was collected.

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
ABD	Aberdeen	57.15736	-2.09428	Urban Background	96%	93%	100%	69%	NA	NA
ACTH	Auchencorth Moss	55.79216	-3.2429	Rural Background	95%	100%	100%	100%	100%	100%
ARM6	Armagh Roadside	54.35373	-6.65456	Urban Traffic	95%	87%	95%	94%	96%	93%
BEL1	Belfast Stockman's Lane	54.57259	-5.97494	Urban Traffic	95%	94%	98%	97%	98%	87%
BEL2	Belfast Centre	54.59965	-5.92883	Urban Background	85%	88%	100%	99%	96%	100%
BIRR	Birmingham A4540 Roadside	52.47615	-1.87498	Urban Traffic	93%	99%	99%	99%	99%	100%
BMLD	Birmingham Ladywood	52.48135	-1.91824	Urban Background	25%	92%	100%	100%	100%	97%
BPLE	Barnstaple A39	51.07479	-4.04192	Urban Traffic	62%	95%	93%	82%	46%	92%
BR11	Bristol Temple Way	51.45797	-2.58398	Urban Traffic	94%	94%	96%	95%	77%	95%
BRS8	Bristol St Paul's	51.46284	-2.58448	Urban Background	80%	86%	96%	97%	94%	97%
BURW	Bury Whitefield Roadside	53.55903	-2.29377	Urban Traffic	94%	96%	94%	97%	96%	96%
CA1	Camden Kerbside	51.54421	-0.17527	Urban Traffic	97%	96%	97%	62%	72%	97%
CARD	Cardiff Centre	51.48178	-3.17625	Urban Background	89%	68%	89%	97%	96%	94%
CARL	Carlisle Roadside	54.89483	-2.94531	Urban Traffic	91%	95%	93%	45%	NA	NA
CHAT	Chatham Roadside	51.37426	0.54797	Urban Traffic	96%	97%	96%	97%	97%	97%
CHBO	Chilbolton Observatory	51.14962	-1.43823	Rural Background	93%	100%	97%	99%	99%	85%
CHLG	Chesterfield Loundsley Green	53.24413	-1.45495	Urban Background	95%	97%	100%	100%	100%	100%
CHP	Chepstow A48	51.63809	-2.67873	Urban Traffic	93%	95%	96%	96%	92%	97%
CHS7	Chesterfield Roadside	53.23175	-1.45693	Urban Traffic	82%	94%	100%	100%	100%	99%
CLL2	London Bloomsbury	51.52229	-0.12589	Urban Background	88%	92%	91%	96%	96%	97%
CNPR	Cardiff Newport Road	51.49096	-3.15231	Urban Traffic	66%	96%	95%	96%	96%	97%
COBR	Coventry Binley Road	52.40771	-1.49008	Urban Traffic	94%	98%	97%	97%	97%	97%
DERR	Derry Rosemount	55.00282	-7.33118	Urban Background	95%	77%	97%	96%	97%	73%
EA8	Ealing Horn Lane	51.51895	-0.26562	Urban Traffic	99%	82%	90%	90%	93%	95%
EAGL	Stockton-on-Tees Eaglescliffe	54.51667	-1.35855	Urban Traffic	89%	95%	94%	95%	96%	92%
ECCL	Salford Eccles	53.48481	-2.33414	Urban Background	86%	100%	100%	100%	100%	100%
ED3	Edinburgh St Leonards	55.94559	-3.18219	Urban Background	93%	91%	99%	99%	99%	100%
GHSR	Glasgow High Street	55.86094	-4.23821	Urban Traffic	97%	100%	99%	100%	100%	100%
GKA8	Greenock A8 Roadside	55.94408	-4.73442	Urban Traffic	100%	100%	100%	100%	94%	100%
GLKP	Glasgow Townhead	55.86578	-4.24363	Urban Background	96%	99%	99%	99%	99%	99%
GRAN	Grangemouth	56.01032	-3.7044	Urban Industrial	90%	94%	97%	85%	96%	97%
HOPE	Stanford-le-Hope Roadside	51.51817	0.439548	Urban Traffic	81%	96%	82%	86%	93%	92%
HRL	London Harlington	51.48879	-0.44161	Urban Industrial	97%	97%	99%	99%	99%	100%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
HULR	Hull Holderness Road	53.75901	-0.30568	Urban Traffic	95%	94%	94%	88%	95%	93%
INV2	Inverness	57.48131	-4.24145	Urban Traffic	44%	89%	96%	100%	99%	98%
KC1	London N. Kensington	51.52105	-0.21349	Urban Background	100%	100%	100%	100%	98%	100%
LEAM	Leamington Spa	52.28881	-1.53312	Urban Background	95%	97%	100%	98%	100%	100%
LEAR	Leamington Spa Rugby Road	52.29488	-1.54291	Urban Traffic	64%	94%	99%	100%	100%	99%
LED6	Leeds Headingley Kerbside	53.81997	-1.57636	Urban Traffic	96%	95%	96%	96%	96%	44%
LEED	Leeds Centre	53.80378	-1.54647	Urban Background	97%	89%	97%	99%	99%	100%
LEIR	Leicester A594 Roadside	52.63874	-1.12427	Urban Traffic	94%	98%	96%	95%	97%	96%
LN	Lough Navar	54.43951	-7.90033	Rural Background	92%	98%	100%	97%	99%	100%
LVP	Liverpool Speke	53.34633	-2.84433	Urban Industrial	93%	94%	66%	23%	93%	97%
MID	Middlesbrough	54.5693	-1.22087	Urban Background	94%	97%	94%	95%	96%	95%
MY1	London Marylebone Road	51.52253	-0.15461	Urban Traffic	97%	96%	75%	76%	95%	94%
NCA3	Newcastle Cradlewell Roadside	54.98641	-1.59536	Urban Traffic	83%	77%	93%	94%	93%	95%
NEWC	Newcastle Centre	54.97825	-1.61053	Urban Background	93%	95%	95%	97%	97%	97%
NO12	Norwich Lakenfields	52.61482	1.302686	Urban Background	86%	90%	99%	97%	97%	95%
NOTT	Nottingham Centre	52.95473	-1.14645	Urban Background	95%	97%	99%	99%	99%	100%
NPT3	Newport	51.6012	-2.97728	Urban Background	57%	100%	96%	100%	99%	100%
NWBV	Nottingham Western Boulevard	52.96938	-1.18885	Urban Traffic	93%	98%	98%	97%	97%	94%
OX8	Oxford St Ebbes	51.74481	-1.26028	Urban Background	97%	97%	100%	100%	100%	100%
PEMB	Narberth	51.78262	-4.69237	Rural Background	98%	75%	98%	99%	100%	100%
PLYM	Plymouth Centre	50.37167	-4.14236	Urban Background	96%	96%	97%	97%	99%	100%
PMTH	Portsmouth	50.82881	-1.06858	Urban Background	64%	99%	15%	63%	82%	100%
POAR	Portsmouth Anglesea Road	50.79834	-1.09556	Urban Traffic	97%	95%	92%	94%	96%	98%
PT4	Port Talbot Margam	51.58395	-3.77082	Urban Industrial	96%	95%	95%	92%	94%	93%
REA1	Reading New Town	51.45309	-0.94407	Urban Background	78%	53%	95%	96%	94%	91%
REA5	Reading London Road	51.4549	-0.94038	Urban Traffic	93%	93%	94%	97%	98%	95%
ROCH	Rochester Stoke	51.45617	0.634889	Rural Background	98%	100%	100%	99%	96%	98%
SA33	Southampton A33	50.92027	-1.46348	Urban Traffic	72%	90%	90%	93%	91%	97%
SASH	Saltash Callington Road	50.41146	-4.22768	Urban Traffic	88%	95%	89%	98%	96%	96%
SCN2	Scunthorpe Town	53.58634	-0.63681	Urban Industrial	96%	90%	92%	96%	79%	89%
SDY	Sandy Roadside	52.13242	-0.30031	Urban Traffic	64%	91%	81%	69%	88%	96%
SHDG	Sheffield Devonshire Green	53.37862	-1.4781	Urban Background	97%	97%	100%	100%	98%	99%
SHLW	St Helens Linkway	53.45183	-2.74213	Urban Traffic	92%	79%	96%	97%	94%	92%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
SK5	Southwark A2 Old Kent Road	51.4805	-0.05955	Urban Traffic	81%	90%	75%	96%	95%	91%
SOUT	Southampton Centre	50.90817	-1.39576	Urban Background	73%	97%	99%	99%	100%	100%
STKR	Stoke-on-Trent A50 Roadside	52.98044	-2.1119	Urban Traffic	95%	96%	96%	97%	95%	97%
SWA1	Swansea Roadside	51.6327	-3.94737	Urban Traffic	96%	94%	96%	83%	91%	96%
THUR	Thurrock	51.47707	0.317969	Urban Background	94%	98%	94%	88%	90%	93%
WAR	Warrington	53.38923	-2.61559	Urban Background	70%	94%	96%	97%	96%	94%
WREX	Wrexham	53.04228	-3.00283	Urban Traffic	16%	80%	100%	100%	97%	100%
YK10	York Bootham	53.96751	-1.08651	Urban Background	96%	95%	95%	89%	98%	96%
YK11	York Fishergate	53.95189	-1.07586	Urban Traffic	92%	96%	97%	95%	98%	97%
AGRN	Birmingham Acocks Green	52.43717	-1.83	Urban Background	NA	63%	99%	69%	NA	NA
BLC2	Blackpool Marton	53.80489	-3.00718	Urban Background	NA	47%	99%	100%	100%	100%
COAL	Coventry Allesley	52.41163	-1.56019	Urban Background	NA	59%	100%	98%	99%	100%
EB	Eastbourne	50.80578	0.271611	Urban Background	NA	95%	98%	100%	97%	62%
HP1	London Honor Oak Park	51.44967	-0.03742	Urban Background	NA	100%	100%	97%	99%	100%
HUL2	Hull Freetown	53.74878	-0.34122	Urban Background	NA	30%	98%	99%	100%	100%
PRES	Preston	53.76559	-2.68035	Urban Background	NA	52%	99%	99%	100%	100%
SEND	Southend-on-Sea	51.54417	0.678331	Urban Background	NA	27%	100%	99%	99%	99%
STOK	Stoke-on-Trent Centre	53.02821	-2.17513	Urban Background	NA	66%	97%	99%	100%	100%
SUN2	Sunderland Silksworth	54.88361	-1.40688	Urban Background	NA	26%	100%	99%	99%	95%
TRAN	Wirral Tranmere	53.37287	-3.02272	Urban Background	NA	37%	99%	100%	98%	100%
WIG5	Wigan Centre	53.54914	-2.63814	Urban Background	NA	53%	100%	100%	100%	100%
BEX	London Bexley	51.46603	0.184806	Suburban Background	NA	NA	25%	100%	99%	100%
LECU	Leicester University	52.6199	-1.12718	Urban Background	NA	NA	97%	99%	100%	99%
MAN3	Manchester Piccadilly	53.48152	-2.23788	Urban Background	NA	NA	96%	99%	98%	98%
TED2	London Teddington Bushy Park	51.42529	-0.34561	Urban Background	NA	NA	96%	99%	97%	75%
ABD9	Aberdeen Erroll Park	57.1574	-2.09477	Urban Background	NA	NA	NA	25%	100%	96%
CARM	Carlisle Morton A595	54.88582	-2.96496	Urban Traffic	NA	NA	NA	23%	94%	95%
LON6	London Eltham	51.45258	0.070766	Suburban Background	NA	NA	NA	75%	62%	47%
BDMP	Borehamwood Meadow Park	51.66233	-0.27	Urban Background	NA	NA	NA	NA	78%	98%
BOTR	Burton-on-Trent Horninglow	52.82105	-1.63572	Urban Background	NA	NA	NA	NA	49%	99%
CANT	Canterbury	51.27399	1.098061	Urban Background	NA	NA	NA	NA	58%	96%
COPP	Crewe Coppenhall	53.11594	-2.45349	Urban Background	NA	NA	NA	NA	49%	99%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
DYAG	Dewsbury Ashworth Grove	NA	NA	NA	NA	NA	NA	NA	50%	NA
GLAZ	Glazebury	53.46008	-2.47206	Rural Background	NA	NA	NA	NA	58%	99%
HIL	London Hillingdon	51.49633	-0.46086	Urban Background	NA	NA	NA	NA	65%	97%
HM	High Muffles	54.3345	-0.80882	Rural Background	NA	NA	NA	NA	59%	100%
HONI	Honiton	50.79229	-3.1967	Urban Background	NA	NA	NA	NA	76%	99%
HSAW	Hartlepool St Abbs Walk	54.68324	-1.20384	Urban Background	NA	NA	NA	NA	63%	99%
IMGM	Immingham Woodlands Avenue	53.61924	-0.21332	Urban Background	NA	NA	NA	NA	63%	100%
LH	Lullington Heath	50.7937	0.18125	Rural Background	NA	NA	NA	NA	58%	100%
MACK	Charlton Mackrell	51.05625	-2.68345	Rural Background	NA	NA	NA	NA	55%	99%
OSY	St Osyth	51.77787	1.04901	Rural Background	NA	NA	NA	NA	75%	100%
SHE	Sheffield Tinsley	53.41058	-1.39614	Urban Background	NA	NA	NA	NA	64%	99%
SWHO	Swindon Walcot	51.55806	-1.76568	Urban Background	NA	NA	NA	NA	56%	100%
TDHD	Telford Hollinswood	52.67347	-2.43669	Urban Background	NA	NA	NA	NA	49%	99%
WEYB	Weybourne	52.95049	1.122017	Rural Background	NA	NA	NA	NA	3%	87%
WFEN	Wicken Fen	52.2985	0.290917	Rural Background	NA	NA	NA	NA	56%	100%
YW	Yarner Wood	50.5976	-3.71651	Rural Background	NA	NA	NA	NA	46%	99%
BAR3	Barnsley Gawber	53.56292	-1.51044	Urban Background	NA	NA	NA	NA	NA	73%
BLAP	Blackburn Audley Park	53.74673	-2.46787	Urban Background	NA	NA	NA	NA	NA	33%
DESB	Derby Stockbrook Park	52.91606	-1.49217	Urban Background	NA	NA	NA	NA	NA	10%
DYAG	Dewsbury Ashworth Grange	53.6931	-1.63711	Urban Background	NA	NA	NA	NA	NA	100%
MKCC	Milton Keynes Civic Centre	52.04408	-0.76101	Urban Background	NA	NA	NA	NA	NA	76%
TALL	Tallington	52.65631	-0.381	Rural Background	NA	NA	NA	NA	NA	4%
TOFT	Toft Newton	53.37413	-0.44979	Rural Background	NA	NA	NA	NA	NA	25%

Table A4-7 Data coverage for SO2 measurements at 28 AURN sites from 2018 to 2023. NA indicates no measurement data was collected.

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
BALM	Ballymena Ballykeel	54.8616	-6.25087	Urban Background	72%	39%	39%	90%	90%	88%
BAR3	Barnsley Gawber	53.56292	-1.51044	Urban Background	99%	87%	96%	98%	99%	95%
BEL2	Belfast Centre	54.59965	-5.92883	Urban Background	97%	73%	87%	93%	97%	98%
CARD	Cardiff Centre	51.48178	-3.17625	Urban Background	71%	65%	89%	88%	89%	71%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
CHBO	Chilbolton Observatory	51.14962	-1.43823	Rural Background	98%	96%	92%	98%	90%	97%
CLL2	London Bloomsbury	51.52229	-0.12589	Urban Background	78%	79%	73%	82%	94%	92%
DERR	Derry Rosemount	55.00282	-7.33118	Urban Background	97%	96%	96%	96%	84%	91%
ED3	Edinburgh St Leonards	55.94559	-3.18219	Urban Background	93%	80%	71%	91%	94%	98%
GRAN	Grangemouth	56.01032	-3.7044	Urban Industrial	96%	92%	96%	51%	90%	93%
HUL2	Hull Freetown	53.74878	-0.34122	Urban Background	75%	95%	94%	94%	94%	98%
KC1	London N. Kensington	51.52105	-0.21349	Urban Background	96%	93%	91%	69%	86%	87%
LB	Ladybower	53.40337	-1.75201	Rural Background	91%	58%	77%	79%	99%	98%
LEED	Leeds Centre	53.80378	-1.54647	Urban Background	98%	99%	97%	99%	99%	94%
LH	Lullington Heath	50.7937	0.18125	Rural Background	99%	81%	86%	50%	71%	83%
LVP	Liverpool Speke	53.34633	-2.84433	Urban Industrial	76%	87%	60%	29%	94%	99%
MAN3	Manchester Piccadilly	53.48152	-2.23788	Urban Background	97%	89%	98%	81%	97%	98%
MID	Middlesbrough	54.5693	-1.22087	Urban Background	98%	94%	98%	82%	95%	98%
MY1	London Marylebone Road	51.52253	-0.15461	Urban Traffic	92%	98%	96%	95%	99%	97%
NOTT	Nottingham Centre	52.95473	-1.14645	Urban Background	95%	77%	57%	82%	82%	94%
PEMB	Narberth	51.78262	-4.69237	Rural Background	84%	80%	70%	95%	90%	96%
PT4	Port Talbot Margam	51.58395	-3.77082	Urban Industrial	99%	99%	97%	99%	98%	97%
ROCH	Rochester Stoke	51.45617	0.634889	Rural Background	95%	95%	55%	82%	83%	81%
SCN2	Scunthorpe Town	53.58634	-0.63681	Urban Industrial	99%	98%	87%	90%	95%	96%
SOUT	Southampton Centre	50.90817	-1.39576	Urban Background	90%	99%	94%	89%	97%	97%
THUR	Thurrock	51.47707	0.317969	Urban Background	96%	97%	97%	96%	98%	82%
WFEN	Wicken Fen	52.2985	0.290917	Rural Background	92%	76%	99%	97%	71%	93%
WREX	Wrexham	53.04228	-3.00283	Urban Traffic	0%	59%	54%	74%	98%	98%
BMLD	Birmingham Ladywood	52.48135	-1.91824	Urban Background	NA	NA	97%	86%	90%	79%

Table A4-8 Data coverage for O3 measurements at 99 AURN sites from 2018 to 2023. NA indicates no measurement data was collected.

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
ABD	Aberdeen	57.15736	-2.09428	Urban Background	99%	88%	61%	68%	NA	NA
ACTH	Auchencorth Moss	55.79216	-3.2429	Rural Background	99%	100 %	99%	96%	94%	99%
AGRN	Birmingham Acocks Green	52.43717	-1.83	Urban Background	99%	98%	59%	69%	NA	NA
AH	Aston Hill	52.50385	-3.03418	Rural Background	97%	87%	99%	93%	79%	79%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
BAR3	Barnsley Gawber	53.56292	-1.51044	Urban Background	99%	99%	86%	98%	99%	77%
BEL2	Belfast Centre	54.59965	-5.92883	Urban Background	99%	83%	78%	99%	90%	99%
BIRR	Birmingham A4540 Roadside	52.47615	-1.87498	Urban Traffic	97%	96%	99%	98%	99%	97%
BLC2	Blackpool Marton	53.80489	-3.00718	Urban Background	95%	95%	99%	99%	98%	100 %
BORN	Bournemouth	50.73957	-1.82674	Urban Background	98%	99%	78%	95%	99%	97%
BRS8	Bristol St Paul's	51.46284	-2.58448	Urban Background	84%	90%	96%	97%	97%	91%
BRT3	Brighton Preston Park	50.84084	-0.14757	Urban Background	99%	99%	96%	97%	77%	95%
BUSH	Bush Estate	55.86228	-3.20578	Rural Background	99%	79%	99%	98%	100 %	100 %
CANT	Canterbury	51.27399	1.098061	Urban Background	94%	99%	98%	99%	99%	95%
CARD	Cardiff Centre	51.48178	-3.17625	Urban Background	99%	72%	95%	99%	94%	99%
CHBO	Chilbolton Observatory	51.14962	-1.43823	Rural Background	99%	97%	99%	98%	98%	99%
CLL2	London Bloomsbury	51.52229	-0.12589	Urban Background	98%	98%	95%	99%	95%	96%
COAL	Coventry Allesley	52.41163	-1.56019	Urban Background	99%	99%	99%	99%	99%	99%
CWMB	Cwmbran	51.6538	-3.00695	Urban Background	99%	100 %	60%	NA	NA	NA
DERR	Derry Rosemount	55.00282	-7.33118	Urban Background	97%	97%	94%	98%	99%	99%
ED3	Edinburgh St Leonards	55.94559	-3.18219	Urban Background	98%	98%	98%	98%	46%	99%
ESK	Eskdalemuir	55.31531	-3.20611	Rural Background	95%	85%	79%	24%	3%	97%
EX	Exeter Roadside	50.72508	-3.53247	Urban Traffic	97%	99%	98%	98%	77%	64%
FW	Fort William	56.82266	-5.1011	Suburban Background	99%	99%	99%	92%	100 %	100 %
GLAZ	Glazebury	53.46008	-2.47206	Rural Background	79%	96%	90%	94%	99%	93%
GLKP	Glasgow Townhead	55.86578	-4.24363	Urban Background	99%	99%	99%	97%	99%	98%
HG4	London Haringey Priory Park South	51.58413	-0.12525	Urban Background	95%	95%	92%	93%	74%	84%
HIL	London Hillingdon	51.49633	-0.46086	Urban Background	98%	99%	99%	99%	85%	100 %
HM	High Muffles	54.3345	-0.80882	Rural Background	96%	98%	53%	94%	99%	99%
HRL	London Harlington	51.48879	-0.44161	Urban Industrial	97%	98%	98%	97%	98%	100 %
HUL2	Hull Freetown	53.74878	-0.34122	Urban Background	99%	99%	99%	99%	99%	99%
KC1	London N. Kensington	51.52105	-0.21349	Urban Background	98%	96%	86%	98%	98%	95%
LB	Ladybower	53.40337	-1.75201	Rural Background	79%	96%	97%	99%	79%	99%
LEAM	Leamington Spa	52.28881	-1.53312	Urban Background	100 %	87%	95%	94%	99%	99%
LECU	Leicester University	52.6199	-1.12718	Urban Background	99%	99%	99%	99%	99%	99%
LEED	Leeds Centre	53.80378	-1.54647	Urban Background	98%	99%	97%	98%	99%	97%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
LEOM	Leominster	52.22159	-2.73684	Suburban Background	99%	99%	100 %	100 %	95%	99%
LERW	Lerwick	60.13922	-1.18532	Rural Background	85%	99%	97%	40%	85%	89%
LH	Lullington Heath	50.7937	0.18125	Rural Background	99%	98%	97%	90%	99%	99%
LN	Lough Navar	54.43951	-7.90033	Rural Background	99%	98%	100 %	100 %	96%	100 %
LON6	London Eltham	51.45258	0.070766	Suburban Background	100 %	100 %	76%	44%	57%	39%
LVP	Liverpool Speke	53.34633	-2.84433	Urban Industrial	99%	99%	65%	29%	99%	99%
MACK	Charlton Mackrell	51.05625	-2.68345	Rural Background	0%	37%	94%	94%	97%	96%
MAHG	Manchester Sharston	53.37172	-2.23892	Suburban Industrial	98%	99%	99%	99%	99%	97%
MAN3	Manchester Piccadilly	53.48152	-2.23788	Urban Background	99%	99%	99%	99%	99%	99%
MH	Mace Head	53.32644	-9.90392	Rural Background	99%	99%	100 %	100 %	100 %	99%
MID	Middlesbrough	54.5693	-1.22087	Urban Background	97%	99%	99%	99%	99%	86%
MKTH	Market Harborough	52.55444	-0.77222	Rural Background	99%	23%	NA	NA	NA	NA
MY1	London Marylebone Road	51.52253	-0.15461	Urban Traffic	99%	98%	92%	93%	99%	95%
NEWC	Newcastle Centre	54.97825	-1.61053	Urban Background	96%	98%	99%	99%	99%	99%
NO12	Norwich Lakenfields	52.61482	1.302686	Urban Background	99%	99%	100 %	97%	99%	89%
NOTT	Nottingham Centre	52.95473	-1.14645	Urban Background	98%	99%	99%	99%	91%	99%
NTN4	Northampton Spring Park	52.27226	-0.91661	Urban Background	99%	100 %	100 %	93%	95%	99%
OSY	St Osyth	51.77787	1.04901	Rural Background	99%	99%	100 %	100 %	96%	97%
PEEB	Peebles	55.65747	-3.19653	Urban Background	94%	99%	99%	99%	99%	99%
PEMB	Narberth	51.78262	-4.69237	Rural Background	99%	99%	99%	98%	99%	94%
PLYM	Plymouth Centre	50.37167	-4.14236	Urban Background	98%	99%	99%	99%	97%	99%
PMTH	Portsmouth	50.82881	-1.06858	Urban Background	99%	97%	15%	66%	99%	99%
PRES	Preston	53.76559	-2.68035	Urban Background	99%	99%	97%	99%	99%	100 %
PT4	Port Talbot Margam	51.58395	-3.77082	Urban Industrial	99%	99%	97%	99%	97%	96%
REA1	Reading New Town	51.45309	-0.94407	Urban Background	99%	62%	99%	65%	99%	99%
ROCH	Rochester Stoke	51.45617	0.634889	Rural Background	99%	99%	96%	99%	99%	96%
SEND	Southend-on-Sea	51.54417	0.678331	Urban Background	98%	99%	99%	98%	99%	99%
SHDG	Sheffield Devonshire Green	53.37862	-1.4781	Urban Background	99%	81%	95%	99%	99%	99%
SIB	Sibton	52.2944	1.463497	Rural Background	99%	100 %	100 %	96%	100 %	99%
SOUT	Southampton Centre	50.90817	-1.39576	Urban Background	95%	99%	98%	99%	99%	99%
STOK	Stoke-on-Trent Centre	53.02821	-2.17513	Urban Background	98%	99%	99%	99%	99%	100 %

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
SUN2	Sunderland Silksworth	54.88361	-1.40688	Urban Background	86%	97%	99%	13%	92%	99%
SV	Strathvaich	57.73446	-4.77658	Rural Background	100 %	96%	99%	90%	99%	89%
THUR	Thurrock	51.47707	0.317969	Urban Background	96%	43%	97%	95%	97%	97%
TRAN	Wirral Tranmere	53.37287	-3.02272	Urban Background	94%	99%	99%	99%	99%	100 %
WAL4	Walsall Woodlands	52.60564	-2.03037	Urban Background	100 %	97%	99%	99%	99%	92%
WEYB	Weybourne	52.95049	1.122017	Rural Background	100 %	95%	99%	100 %	100 %	95%
WFEN	Wicken Fen	52.2985	0.290917	Rural Background	99%	97%	100 %	99%	99%	94%
WIG5	Wigan Centre	53.54914	-2.63814	Urban Background	99%	99%	100 %	99%	91%	98%
YW	Yarner Wood	50.5976	-3.71651	Rural Background	97%	96%	96%	99%	91%	99%
BMLD	Birmingham Ladywood	52.48135	-1.91824	Urban Background	NA	19%	98%	98%	98%	98%
CWMC	Cwmbran Crownbridge	51.65382	-3.00637	Urban Background	NA	NA	25%	99%	70%	92%
ABD9	Aberdeen Erroll Park	57.1574	-2.09477	Urban Background	NA	NA	NA	25%	95%	100 %
BLAP	Blackburn Audley Park	53.74673	-2.46787	Urban Background	NA	NA	NA	NA	NA	32%
BOTR	Burton-on-Trent Horninglow	52.82105	-1.63572	Urban Background	NA	NA	NA	NA	NA	85%
CHLG	Chesterfield Loundsley Green	53.24413	-1.45495	Urban Background	NA	NA	NA	NA	NA	88%
COPP	Crewe Coppenhall	53.11594	-2.45349	Urban Background	NA	NA	NA	NA	NA	93%
DESB	Derby Stockbrook Park	52.91606	-1.49217	Urban Background	NA	NA	NA	NA	NA	10%
DYAG	Dewsbury Ashworth Grange	53.6931	-1.63711	Urban Background	NA	NA	NA	NA	NA	84%
EB	Eastbourne	50.80578	0.271611	Urban Background	NA	NA	NA	NA	NA	8%
ECCL	Salford Eccles	53.48481	-2.33414	Urban Background	NA	NA	NA	NA	NA	84%
HONI	Honiton	50.79229	-3.1967	Urban Background	NA	NA	NA	NA	NA	67%
HORS	London Westminster	51.49467	-0.13193	Urban Background	NA	NA	NA	NA	NA	88%
HSAW	Hartlepool St Abbs Walk	54.68324	-1.20384	Urban Background	NA	NA	NA	NA	NA	81%
IMGM	Immingham Woodlands Avenue	53.61924	-0.21332	Urban Background	NA	NA	NA	NA	NA	89%
MKCC	Milton Keynes Civic Centre	52.04408	-0.76101	Urban Background	NA	NA	NA	NA	NA	34%
OX8	Oxford St Ebbes	51.74481	-1.26028	Urban Background	NA	NA	NA	NA	NA	73%
SHE	Sheffield Tinsley	53.41058	-1.39614	Urban Background	NA	NA	NA	NA	NA	86%
SWHO	Swindon Walcot	51.55806	-1.76568	Urban Background	NA	NA	NA	NA	NA	66%
TALL	Tallington	52.65631	-0.381	Rural Background	NA	NA	NA	NA	NA	4%
TDHD	Telford Hollinswood	52.67347	-2.43669	Urban Background	NA	NA	NA	NA	NA	85%
TOFT	Toft Newton	53.37413	-0.44979	Rural Background	NA	NA	NA	NA	NA	25%

Code	Site	Latitude	Longitude	Site Type	2018	2019	2020	2021	2022	2023
WBKP	West Bromwich Kenrick Park	52.50834	-1.98607	Urban Background	NA	NA	NA	NA	NA	74%
YK10	York Bootham	53.96751	-1.08651	Urban Background	NA	NA	NA	NA	NA	60%

A4.8.2 CERQ1:2

Table A4-9 Summary of DAQI performance through assessment of DAQI Evaluation Quarterly reports from 2018 – 2023.

Year	Pollution Period	Number of days	Agreement between modelled and observed DAQI						Comments
			Instances of good agreement			Instances of poor agreement			
			Location well-predicted	Timing/length of pollutant event well-predicted	Pollutant DAQI well predicted	Location poorly predicted	Length of pollutant event poorly predicted	Pollutant DAQI poorly predicted	
2018	1st - 7th July	7	7	7	2			5	• $PM_{2.5}$ DAQI underpredicted on 1st July (observed DAQI 7 reported 6) but spatiotemporal factors well predicted
2018	21st, 26th-27th July	3	1	1	1			2	• Ozone DAQI underpredicted on 26th - 27th July (observed DAQI 7 reported 6) but spatiotemporal factors well predicted
2018	5th November	1	1	1				1	• $PM_{2.5}$ DAQI underpredicted on bonfire night but spatiotemporal factors well predicted despite no related emissions input into the model
2018	22nd - 23rd November	2							• High $PM_{2.5}$ predicted, could not be verified issues with large point source data and timely updates
2018	27th December	1				1	1	1	• Falsely predicted pollution event only one single observed moderate DAQI at Southend for $PM_{2.5}$
2019	16th - 23rd April	8	8	8	2			6	• $PM_{2.5}$ elevated (16th - 18th April), high forecast DAQI for Welsh borders could not be confirmed by AURN measurements and high forecast DAQI of 7 forecast around Southampton, when observed was 6 • Ozone elevated (19th - 21st April) highest DAQI forecast as 6 compared to 7 observed.

Year	Pollution Period	Number of days	Agreement between modelled and observed DAQI						Comments
			Instances of good agreement			Instances of poor agreement			
			Location well-predicted	Timing/length of pollutant event well-predicted	Pollutant DAQI well predicted	Location poorly predicted	Length of pollutant event poorly predicted	Pollutant DAQI poorly predicted	
									• Ozone elevated 22nd April moderate forecast and observed
2019	23rd - 26th July	4	4	4				4	• Spatiotemporal factors well predicted • Underpredicted DAQI for ozone as forecast DAQI was 6 when observed was up to 8
2019	24th -28th August	5	5	5	1			4	• Spatiotemporal factors well predicted • Underpredicted DAQI for $PM_{2.5}$
2019	1st - 2nd December	2				2	2	2	• Falsely predicted pollution event
2020	20th January	1				1	1	1	• Falsely predicted pollution event
2020	9th - 13th April	5	5	4	1		1	4	• Spatiotemporal factors well predicted • DAQI over and under predicted $PM_{2.5}$
2020	14th - 16th April	3	1	3	1	2		2	• Temporal factors well predicted • DAQI overpredicted in south of England for ozone
2020	7th - 10th May	4	4	4	4				• Spatiotemporal factors well predicted • Magnitude of DAQI elevations well predicted for ozone
2020	24th - 26th June	3	3	3	1			2	• High ozone levels across England, Wales and Scotland were predicted well in terms of spatiotemporally. • The DAQI was underpredicted on 2 days.
2020	31st July	1				1	1	1	• High ozone levels across England and Wales DAQI levels 8; model did not predict the event

Year	Pollution Period	Number of days	Agreement between modelled and observed DAQI						Comments
			Instances of good agreement			Instances of poor agreement			
			Location well-predicted	Timing/length of pollutant event well-predicted	Pollutant DAQI well predicted	Location poorly predicted	Length of pollutant event poorly predicted	Pollutant DAQI poorly predicted	
2020	7th - 14th August	8	5	8	2	3		6	• The length of ozone pollution episode was well predicted • The DAQI was underpredicted for most of the episode. Where DAQI was correct, it was over a smaller area than observed.
2020	14th - 15th September	2		2		2		2	• Onset and length of ozone pollution episode well predicted • DAQI overpredicted and in wrong location
2020	5th - 9th November	5			1	1	4	4	• The onset of the pollution episode was poorly predicted • The DAQI was underpredicted • The location was poorly predicted, but DAQI matched observed (7th Nov)
2021	1st - 2nd June	2	2					2	• The location of the ozone episode was well predicted • The DAQI was underpredicted
2021	5th - 8th September	4	4	4	2			2	• The timing and location of the ozone episode were well predicted • The DAQI was underpredicted (7th and 8th Sep)
2022	17th - 21st July	5	4	5		1		5	• Onset/timing of event well predicted • Underpredicted ozone levels (17th - 19th) • Ozone overpredicted (20th - 21st) • Location well predicted except on 20th
2022	9th - 19th August	11	11	11	6			5	• Cessation and location well predicted • Ozone underpredicted

Year	Pollution Period	Number of days	Agreement between modelled and observed DAQI						Comments
			Instances of good agreement			Instances of poor agreement			
			Location well-predicted	Timing/length of pollutant event well-predicted	Pollutant DAQI well predicted	Location poorly predicted	Length of pollutant event poorly predicted	Pollutant DAQI poorly predicted	
									(12th Aug) • High levels of PM wrongly forecast included in DAQI due to Global Fire Assimilation System data
2022	15th - 17th December	3	1	1	1	2	2	2	• Model predictions matched observed DAQI for $PM_{2.5}$ on (15 and 16th Dec) in Manchester. • Moderate DAQI for Bristol not seen by model instead shown for London (16th Dec) • Moderate DAQI over Plymouth and Reading (17th Dec)
2023	21st - 24th January	4	2	2	2	2	2	2	• Spatial distribution well predicted (22nd Jan) • Model predicted high levels of pollution across Northern England which were not observed (23rd Jan) • Low moderate levels forecast in London despite remaining high (23rd) • Model predicted moderate levels well in south Wales (24th)
2023	7th - 19th June	13	13	13	6			7	• The model performed well with the timing of the event and spatial distribution being well predicted. • Highest peaks of ozone underestimated as only moderate

A5. Appendix 5: TOC Workshop synopsis

A range of experts in air quality, especially when concerning the Air Information Resources such as the Daily Air Quality Index (DAQI) were identified by the Department for Environment, Food & Rural Affairs (Defra) and Ricardo Plc 'DAQI evaluation' project team to participate in a workshop to review the DAQI's Theory of Change (TOC).

Invitations and materials were sent well in advance, including a draft DAQI's TOC. The online meeting was held on Monday 4 March, at 10:00-12:00h.

The session had three objectives, to: 1) provide an overview of the TOC; 2) gather feedback, evidence and suggestions; and 3) to inform of the 'DAQI evaluation' study and next steps.

To achieve this, the session was structured into five main parts or agenda items. The first part set out the context and purpose of the session; followed by an overview of the DAQI TOC (Section A5.1). The third part comprised a quick opinion poll of questions associated with the DAQI and a brief discussion (Section A5.2), followed by three deep dives into specific 'impact pathways' or 'impact chains' (Section A5.3). These sessions were facilitated by specific queries which encourage debate amongst the attendees. A final slot allowed attendees to provide any additional feedback or comments they were keen to provide (Section A5.4).

Minutes of the session are provided in the following sections.

A5.1 SESSION OVERVIEW AND THE DRAFT DAQI TOC

Ricardo presented an overview of the 'DAQI evaluation' project being undertaken and the purpose of the workshop.

Question: Is there another piece of work looking at how the DAQI is formulated for example its construction etc?

Answer: This project is looking at six key research questions with a number of sub-research questions, CERQ1 and CERQ 2 detailed below focus on the DAQI modelled inputs.

- CERQ 1 - To what extent does the modelled and measured data on which the DAQI is based, give a sufficiently accurate and precise representation of real-world air quality conditions?
- CERQ 2 - To what extent is the methodology by which the DAQI output (the index number and air quality band) is calculated, appropriate as a method of determining the short-term risk posed by real world conditions into an overall measure of air quality?

To answer these questions, the project team is conducting a rapid literature review and will undertake follow-up interviews with data providers to address any gaps in knowledge.

Attendees made the point that there are different pieces of work undertaken by Air Quality Information System (AQIS) Review, including those which look at different aspects of the DAQI, how it's formulated, how it's communicated, how the public engage with it and/or act upon it. These are not independent aspects, and very much interrelated. If the DAQI changes from its current form the way the public interact with the DAQI is also likely to change.

Ricardo presented an overview of the draft ToC and the interactions and interdependencies that the project team have identified in their review of the DAQI, its workings and intentions and the evidence so far. The following feedback from the stakeholders was received:

- The left-hand side of the TOC includes actions that could be taken as a result of DAQI and increased awareness. Attendees considered that it is not necessarily clear now whether policy or programmatic actions are linked to the DAQI and increased awareness. For example, in Paris, it appears that policy actions are taken as a result of data published on a similar index, such as restricting car use. This could be worth exploring in the context of the DAQI.

Action: Ricardo to consider this feedback and review, if applicable, the boxes as the project evolves.

- The Global action plan[208] has evidenced that a large chunk of population don't link air pollution with health. Moreover, it is not clear that the general public understand that the DAQI is about short-term exposure and effects of air pollution, rather than the longer-term impacts that air pollution might have on people's health. *The Ricardo project team is undertaking a survey targeting 2,000 people, which seeks to investigate whether the general population understand the messaging from the DAQI, among other aspects. Moreover, the team confirmed that the DAQI indeed focusses, by design, on the effects of acute exposures and not so much on the longer-term impacts.*
- Spatial variation is of concern for stakeholders and whether this would be taken into account during this project. *The Ricardo team is undertaking a survey that will target audiences across England and requests their postcodes of residence. If there are sufficient responses, the team will undertake analysis and include spatial insights into the DAQI evaluation outputs.*
- A rapid review has been undertaken to inform the DAQI, which looked at epidemiological studies and air quality. There was some but insufficient evidence pertaining to diabetics, asthmatics by specific subtypes of asthma and people from different age groups. Overall, the study found that the information from the epidemiological studies was insufficient to develop robust conclusions and thus inform health guidance such as the DAQI's, mainly because the limited statistical power of the studies meant that detecting association between air pollution and short-term illness or adverse health outcomes was not always possible.

Action: Ricardo to follow up and include studies as part of their rapid literature review.

- The framing of the DAQI was discussed further. Attendees considered that it would be important that the framing of acute, short-term versus long-term risks is taken into account and made clear. Moreover, it was considered that the public would benefit from better understanding of air pollution and the links with health both in the shorter and longer term. Thus, it was suggested that public awareness campaigns could be beneficial, and any campaign should stress both short-term risks but also clarify that, given the work of global action plan for example, there are long term risks to health in in most areas of the UK on most days of the year just from background concentrations of air pollutants.

[208] https://www.globalactionplan.org.uk/

A5.2 OPINION POLL

We asked the attendees to join a quick opinion poll to get an understanding of what the perceptions of group were when concerning specific aspects of the DAQI and the TOC. The results presented in Figure A5-1 to Figure A5-6 are based on the attendee's perceptions acknowledging that they are not based on fact, but their knowledge of working in specific, but not all, aspects of the air quality field and their personal experiences.

Figure A5-1 Do you think the DAQI is widely known among UK residents?

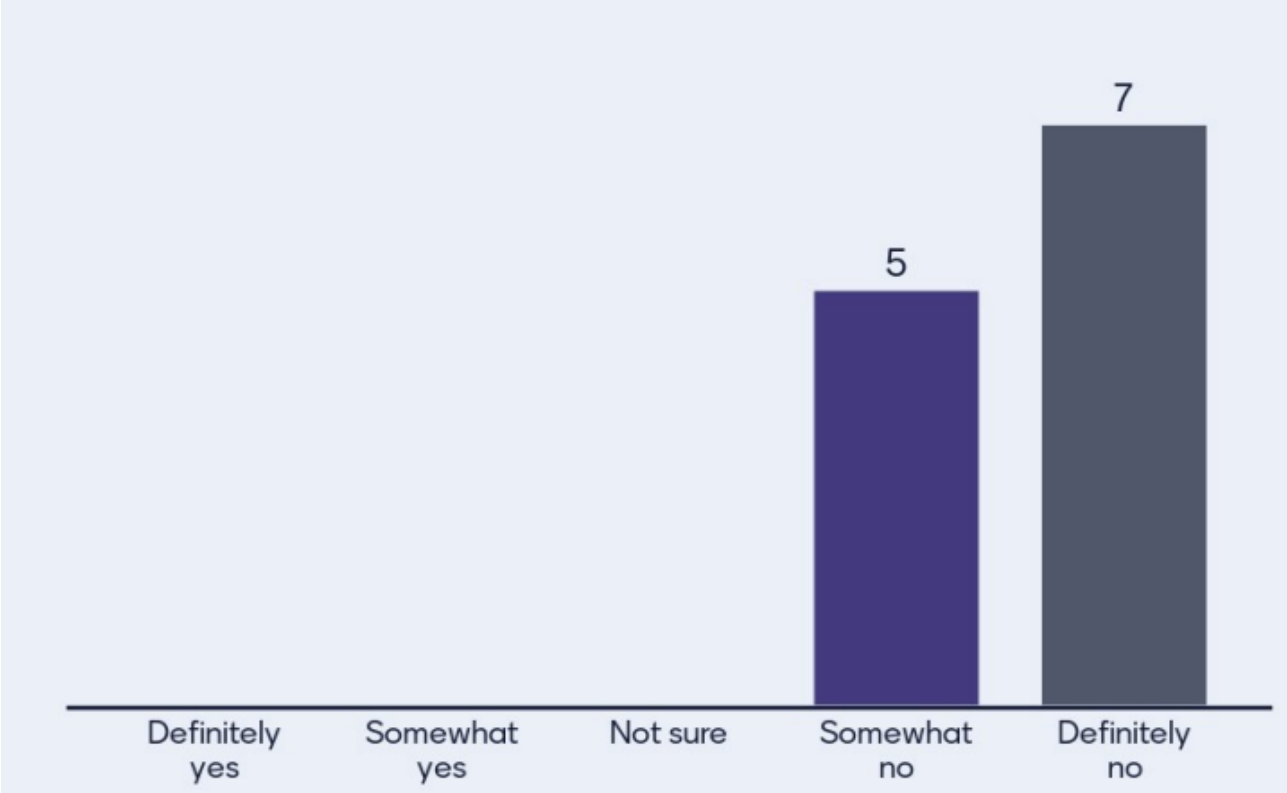


Figure A5-2 What % of the UK public would you say access the DAQI in a given month?

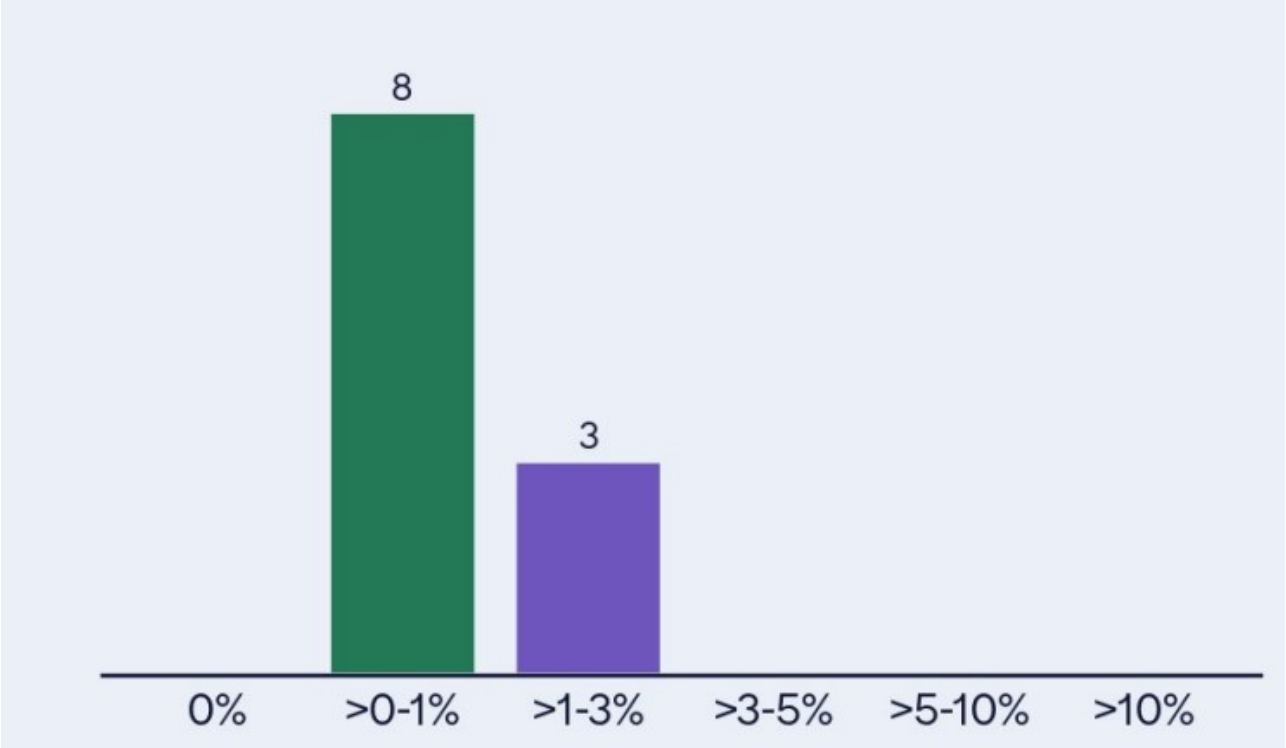


Figure A5-3 Do you think that the presentation of the DAQI/ AQ information is accurate?

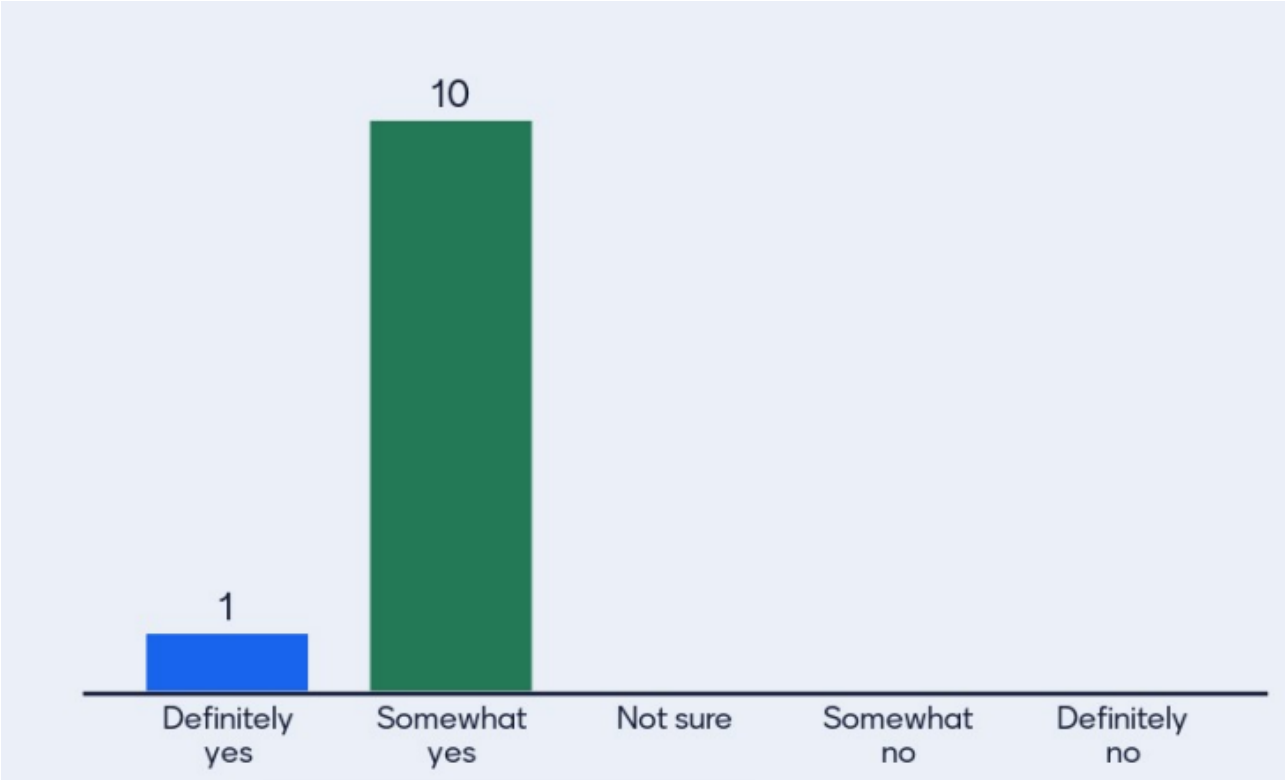


Figure A5-4 Do you think that the presentation of the DAQI/ AQ information is understood?

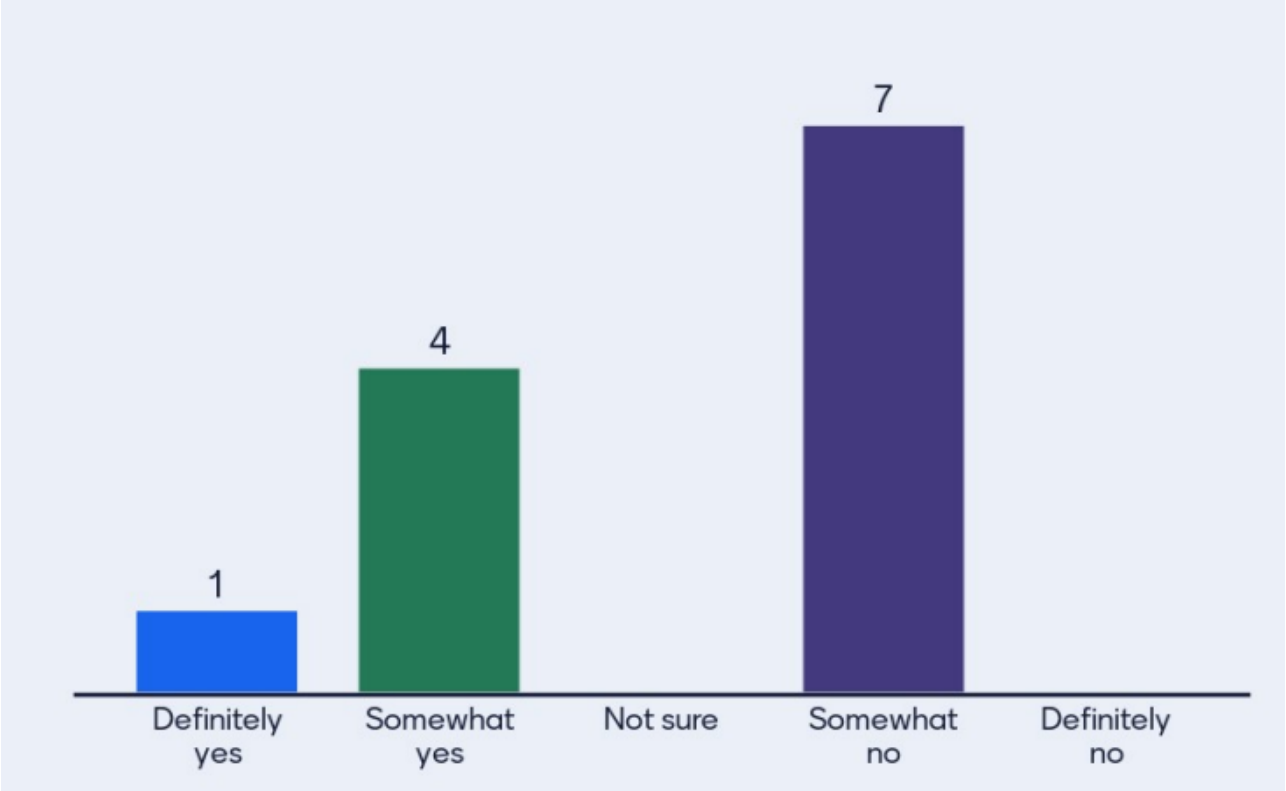


Figure A5-5 Do you think that following the advice provided by the DAQI could result in behaviour change?

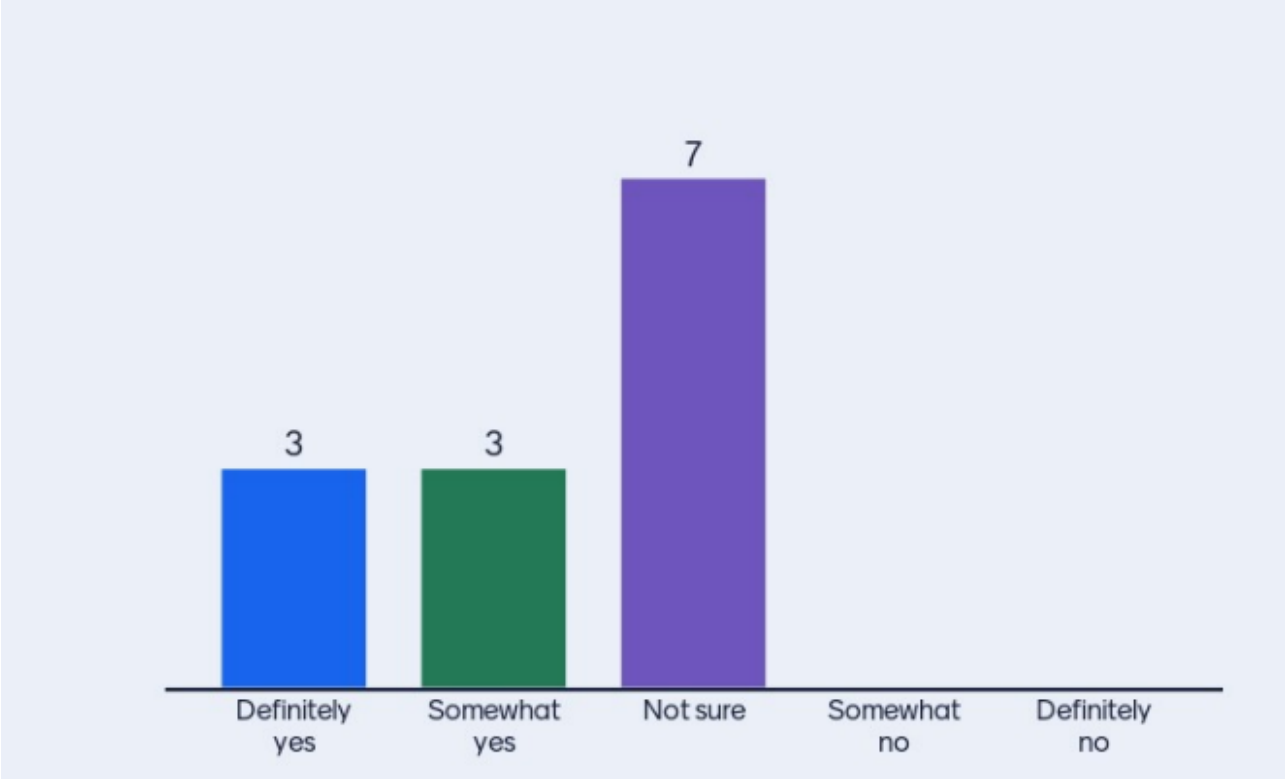
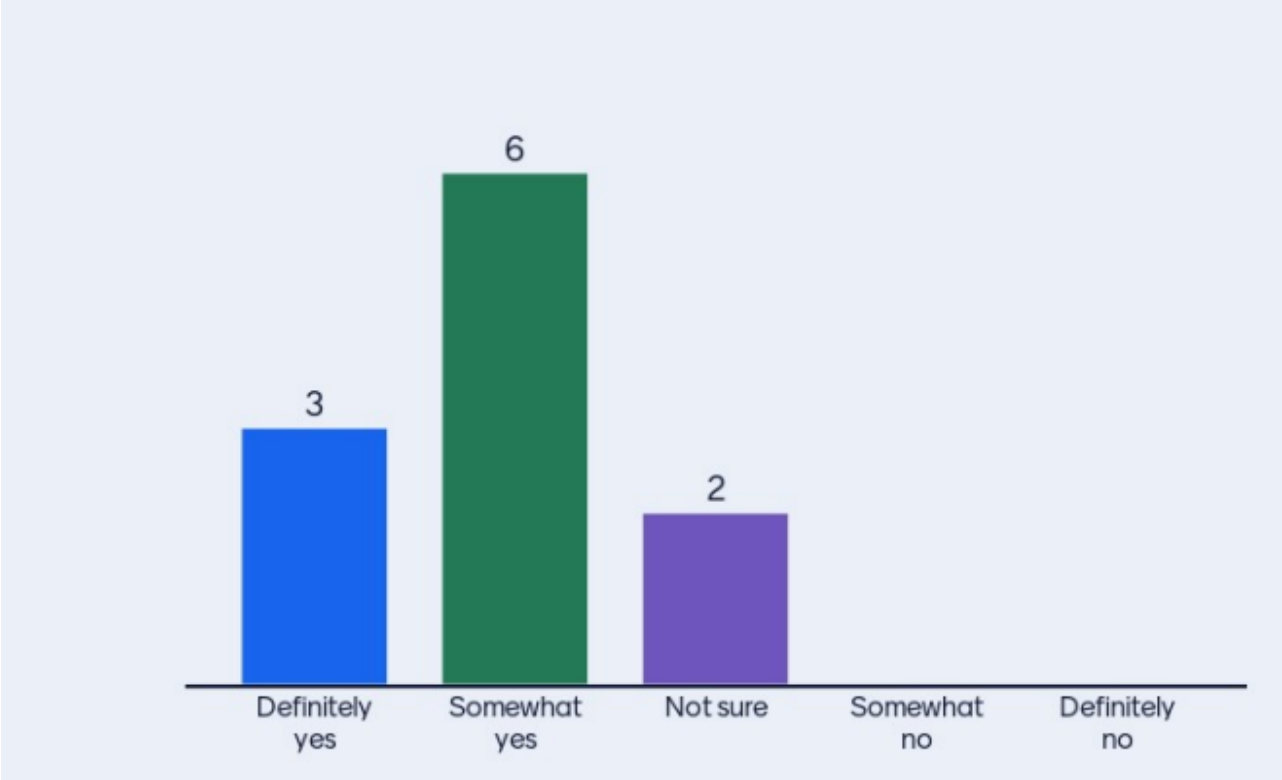


Figure A5-6 Do you think that following the DAQI advice could lead to reductions in adverse health impacts?



Overall, stakeholders attending the workshop appeared to be largely aligned in their opinion that the DAQI:

- Is not well known amongst UK residents
- Is accessed by a small proportion, likely >0-1%, of the UK population in a given month
- Accurately presents air quality information
- Might influence behaviour change, albeit attendees were predominantly unsure
- Might lead to reductions in adverse health impacts in the shorter term

However, they were in disagreement about the extent to which the DAQI information is understood. Five respondents reported 'definitely yes' (1) or 'somewhat yes' (4), against seven which reported 'somewhat no'.

The attendees raised that they answered the polling questions based on their perceptions primarily and expressed their lack of expertise across some of the areas. They considered that some of these questions should be asked of the general public. *The Ricardo team confirmed that, indeed, a survey undertaken by the general public, which will seek to answer some of these and other questions pertaining to their level of engagement and understanding of the information presented and other aspects in relation to their use of the DAQI. This survey will complement the rapid literature review and a number of deep-dive interviews with different sector groups that will also be conducted.*

A5.3 DEEP DIVES

Three specific impact pathways pertaining to behaviour change, the reduction in adverse health outcomes and DAQI awareness were selected for a deep dive and discussion with the attendees. The discussions are summarised in the following subsections.

A5.3.1 Deep dive – Behaviour change

The Ricardo team presented the core TOC pathway leading to 'behaviour change'. Questions that were asked of participants to respond to included:

- Q1. Do you know/think that those who access the DAQI understand the information they receive?
- Q2. Do you know/think that the people who receive pollution alert from DAQI follow the advice provided?
- Q3. Do you know/think that following the DAQI 'advice' leads to any modifications in behaviour?

Attendees shared their opinions across these and other dimensions, which are summarised below. We have grouped the discussions under key themes.

Overall, the attendees felt that the general population might understand the DAQI and associated information somewhat, and only very few people might completely understand and use all of the information that is being shared with the public.
The main concern shared was that the public might believe they are not at risk of poor air quality due to the fact that short-term episodes of 'high levels' of air pollution occur infrequently. This, however, does not mean the people are not at risk from continued exposure over the longer term.

Understanding of the DAQI

- The DAQI tries to roll through a single index across multiple pollutants, and all of those vary. There are some sophisticated concepts that people need to understand within the DAQI construct so that people can interpret down to their own personal level and then also respond to accordingly.
- Some attendees considered that the DAQI's understanding could be linked to educational backgrounds. For example, it was hypothesised that individuals who suffer with acute respiratory problems from a highly educated background and are aware of the DAQI might respond more robustly and effectively, whereas those that are less fortunate in their educational backgrounds might struggle with some of the concepts.
- More specifically, based on some studies conducted, it appears that people do not understand that the air quality index only alerts them of the kind of levels of air pollution that might cause immediate short-term health effects. People might not be aware that if the DAQI offers a 'green rating', this does not mean that the concentration of air pollutants is not high and, in fact, continued exposure to existing, background air pollution levels could be a risk to long-term health.
- Overall, it was considered that not many UK residents are likely to understand the air quality index. There are only a few days per year when the air quality index shows moderate values. The vast majority of the days are showing index bands between

one and two, and that doesn't change much. This is good because we are not seeing many occurrences of poor air quality but the system is not showing variability, people don't see much change for the majority of the year. It is difficult for people to link this with what they perceive as poor air pollution during their daily commutes.

DAQI communication and alerts

Overall, it was considered that the DAQI showed limited variations or no change repeatedly (i.e. green ratings). Even if accurate, this approach to communicating about air pollution could cause fatigue and result in lower levels of engagement than desired.

- There also was a discussion on the presentation of the information and the extent to which these might affect people's receptiveness and fatigue. It was considered that people could become fatigued from seeing emails that are constantly green-rated, and only very seldomly that they turn to higher alert colour. Regarding this, it was clarified that, for susceptible groups, alerts are only sent when moderate or high levels are reached, so people don't get all the green ones. However, any subscriber to emails and/or the X/twitter page will get periodic updates, mostly green. In some studies, the feedback from people was that if they get too many alerts telling them to change their behaviour, they are unlikely to respond as they get fatigued. This can lead to people unsubscribing or reducing engagement with the channels of information. People want to understand when they are really at risk. It will be important to consider both aspects of fatigue when making recommendations. Finally, work done by Kirsty Smallbone and colleagues that have over the years looked at how people respond or how people feel to having air quality alerts. There was some evidence that patients felt empowered to have the knowledge and they could then make their decisions in an informed way. It was uncertain whether there was any evidence on how people changed their behaviour.
- In addition, attendees considered that we should try and avoid conflicting messages around guidelines and evidence for health risks as there are multiple platforms people receive information about air quality. It is important that the messaging is clear as people may receive a "green" notification from the DAQI but then from another media source see that the pollution outside their home is "High or harmful to health. It's obviously very important that that awareness is built into the public conscience as well as particular targeted messaging for risk groups associated with short term episodes."

The evidence of both long-term and short-term health effects attributable to air pollution has increased since the DAQI was last updated. For example, the WHO guidelines were updated in 2021. There was some discussion about this, and the extent to which the short-term 'targets' were set based on health evidence and/or to fit with long-term targets that are based new epidemiological evidence associated with long-term exposures to air pollution. Overall, any new thresholds or targets defining the DAQI should be updated in line with the latest available evidence.

Evidence underpinning the DAQI

- Moreover, one attendee considered that much of the original colour-coding and the numbers on the DAQI came from epidemiological studies at the time, in 2011, with some input from chamber studies, but the knowledge base has increased so much since then. The shape of the dose response curve will have changed very substantially. So, the current system reports good air quality when the air quality isn't good at all. The current DAQI is inadequately granular. If the DAQI goes forward taking account of new evidence and different sort of categorisation then people may take more notice of it.
- However, another attendee pointed out that a lot of the more recent information on the new concentration response functions is more to do with long-term exposure and long-term effects of air pollution. This evidence would not necessarily affect the DAQI as the index is looking at short-term exposure and effects. Overall, thus, there were some doubts as to how much the evidence base on short term exposures has changed since 2011.
- This was discussed further by deep diving into WHO guidelines. On the one hand, an attendee noted that the WHO guidelines released in 2021 recommend lower thresholds than previous guidelines. The question is whether the air quality index should be updated to reflect the new guidelines. If we don't introduce an element of the WHO 2021 recommended guidelines and continue to stick to the legal values it may lead to confusion for members of the public who use the DAQI.
- On the other hand, attendees pointed out that the WHO air quality guidelines were used as a starting point for the index used in the current DAQI, but those 2005 air quality guidelines are based on health effects of short-term exposures. The current WHO air quality guidelines have taken quite a different approach. The new long term (annual) air quality guidelines have been updated based on updated health evidence, however the new short-term guidelines such as the daily average limits have been set by selecting a value that would likely allow the country to achieve the annual long-term guideline rather than on new short-term health evidence becoming available. So, the latest short-term guidelines are actually based on epidemiological evidence pertaining to longer term exposures rather than the effects of short-term exposure to air pollution. There is potential for confusion if different values are used in the DAQI. However, if the DAQI is focussed on addressing the effects of short-term exposure and thus it is not clear that the new WHO guidelines are the best place to start for an update of the underpinning evidence of the DAQI as designed.

Other considerations when setting new 'targets'

Other diseases which can be attributable to air pollution should be considered when setting new 'targets' and/or revising the DAQI methodology.

- Further, it was felt that the DAQI should consider a wider population of diseases rather than just asthma, such as rhinitis, eye problems, coronary and arrythmia problems, which we now know a lot more about. It should be considered that we have a unified threshold for each unified response curve. Over the last 15 years, there are other acute effects like admission to coronary care units, cardiac arrhythmia, acute effects that should be considered.

Unintended consequences of the DAQI

Unintended consequence of the DAQI included people who received alerts potentially staying at home and not exercising, going to medical appointments or altering a route which then caused them to be exposed to something different (i.e. pollen) which may cause them harm.

- Another point on the DAQI design was made. If we move away from alerts that are based on atmospheric air concentrations to other indicators such as individual personal exposure, there is a risk that this could advise people to reduce exercise, which may have other unintended consequences.
- From interactions with respiratory consultants at University Hospitals Birmingham there's some concern about negative or unintended consequences of alert systems. For example, patients essentially not coming out of their homes to attend appointments or even not using the bus because they think they are better protected in a vehicle for example, on those days. It is important to consider those that are potentially negative such as social isolation. These will be captured in the TOC and considered as part of the evaluation to the extent possible.
- Another example of unintended consequences. An example was highlighted about people changing their behaviour due to receiving an alert. People may change their travel route and be exposed to something else instead of higher levels of air pollution, such as higher concentrations of pollen, which could also be harmful to their health and/or existing conditions.

  Action: Ricardo will consider further the framing of short-term versus long-term exposure and impacts, as well as people's understanding of these two dimensions.

A5.3.2 Deep dive – Reduction in adverse health outcomes

Ricardo presented the pathway around reduction in adverse health effects. Questions that were asked of participants to respond to included:

Q4. Do you know/think that the advice shared on UK-AIR is sound?

Q5. Do you know/think that the behavioural modifications can lead to reductions in adverse health outcomes?

Attendees shared their opinions, which are summarised below. These discussions have been grouped into the following themes.

Increasing the use of the DAQI

An update to the DAQI website alone is unlikely to increase numbers of people accessing and following advice of the DAQI. Involving other actors such as GPs, hospitals, schools and influencers to help the general public access and understand the information might increase use. However, some quality controls might be needed to prevent misinformation.

- An attendee suggested that the UK Air Information Resource or a future platform along the same lines might work for disseminating general information, but it will not make a huge difference unless it is backed up by targeted campaigns aimed at the vulnerable members of the population. One would need GP's, hospitals, schools,

local influencers to take the information and liaise with the people who need it, help them to understand it, help them to sign up to the service, etc. A couple of projects the attendee was involved in, they looked at COPD patients and their patient pathway. Local GP went through the forms to enable patients to subscribe to alerts and, in those cases, it really made a difference to their understanding of health outcomes and how they can change their behaviour to improve their health. However, unless you have that direct, interaction and local influence or targeted influence, it could be very difficult for information that is primarily on the UK AIR website to make a real difference to the people who need it.

Action: Ricardo will consider whether this identifies evidence and/or questions that could lead to adjustments to the TOC chain and for the research undertaken to evaluate the DAQI around complementary actions that might be necessary to increase the likelihood that that the intended impacts are achieved.

- If the future of the DAQI relies on a cascade approach out to drive that behavioural change, it will be important to know that there's no misinformation or misinterpretation being disseminated. GPs are well regulated but social influencers and other less well governed bodies may put a spin on the information provided which may not be correct.

The DAQI advice on inhaler use might not be in line with the latest health advice, so revisions to the guidance provided might need to be considered.

Advice on inhaler use

- The advice around increased use of the reliever inhaler is not thought of as good clinical management of asthma anymore. The advice should be updated and linked to personal asthma management plans, daily use of preventer inhaler and, in the worst case if they're not managing the symptoms during an air pollution incident, then as a last resort, people should use the blue inhaler. This point has been raised by respiratory professionals during some focus group work, i.e., the health advice offered by the DAQI is not up to date anymore.

More granular information both in terms of where and when air pollution is likely to be highest could allow people to modify their behaviour perhaps more effectively.

Granularity of data

- More granular information both in terms of where and when air pollution is likely to be highest could allow people to modify their behaviour perhaps more effectively, even if it's just in terms of timing or taking a different route. At one stage, the old pollution forecasts used to include information such as “high AQ particularly around busy roads in urban centres” or “moderate, but some high patches, likely alongside busy roads” or “in rural areas air pollution likely to be the highest in the evening”. This would give people more focused information which would help people to reduce their exposures without necessarily meaning that they had to not take their exercise or not do what it

was that they meant to do that day. This might remove some of the unintentional health consequences of for example, people not taking physical activity when in the long run taking physical activity is good for you.

A5.3.3 Deep dive – Awareness of the DAQI

Ricardo presented the pathway around the awareness of the DAQI. Questions that were asked of participants to respond to included:

Q6. Do you know/think that people in the UK are aware of the UK AIR services and the DAQI? How many?

Q7. Do you know/think that people, especially at risk, access air quality information either directly or indirectly? Any estimates of the scale of this?

Q8. Do you know/think that the current presentation of the DAQI is accurate and comprehensible?

Attendees shared their opinions, which are summarised below.

Levels of awareness

The general public's awareness of air quality information was believed to be poor. Some attendees felt that there was a general lack of knowledge and understanding across the whole field of air quality which needs to be addressed.

- Awareness is generally poor of air quality information and where it's available, for example when the workshop attendee speaks to members of the public and professionals who work elsewhere, they tell him, why isn't air pollution information on the BBC website along with the weather, which is where people would expect to find it? The air pollution data is there but no one knows or accesses it. It may be because it is too far down the screen. The mechanism is there to disseminate the information through a trusted service provider, but still people do not know nor access the information.
- Another considered that the main problem is with the level of the public's knowledge across the whole field of air quality. People seem to have a better understanding of water quality and swimming and link to viruses and bacteria and how that affects their lives. The message about the adverse health effects and poor air quality does not seem to have effectively reached the general public. There is a need for a public awareness campaign to raise the profile of air quality and health. The knowledge of the general public and other stakeholders is too low to be able to make use of the detailed information the DAQI provides. We would need an engagement campaign to increase the general public's awareness about air quality.

Some attendees felt that some Local Authorities have been more proactive in engaging with the general public than others. This may have led to some areas having a higher engagement or understanding of air quality problems.

Geo-spatial differences

- To what extent will this research project be able to explore whether there are geographical differences in the levels of public understanding? There is a perception that some local authorities have been more proactive than others in communicating, and it would be really interesting to see whether it is noticeable within the results of the survey. The project team suggested that this will depend on how many people participate in the research across different geographical areas.
- An idea for the DAQI Evaluation project would be to go through the local air quality management and action planning process to see whether there is a statistic that can be pulled out from consultations and actual responses concerning engagement, so this information can be contrasted with the evidence identified by geography through the survey and interviews.
- An attendee reported to have launched an air quality website in September in partnership with the other districts in Oxfordshire and one of the tools on the website is a pollution alert system. The most up to date figures of how many people have subscribed to the alert system so far is 50. So out of a population of approximately 162,000 people who live in Oxford, this is very low engagement. The system does not appear to be working. The vast majority of complaints from members of the public relate with the fact that they don't see any substantial changes from day to day on the advice, and so some of them even questioned whether the system was broken because it doesn't change anything for their lives.

There are different indices which use different scales and could cause confusion, particularly if Europe update their air quality index and the UK did not follow the same approach. However, different apps in the UK already exist and they are likely to use different approaches.

Different data sources potentially causing confusion

- In the European context, the air quality index used to follow the same methodology across all the Member States. There are signs that the European Union is considering strengthening the limit values and including a daily average for NO_2. Now that the UK is not in the European Union, if the EU decides to change the methodology of calculating their air quality indexes, how will that work with the UK DAQI and would this lead to two different systems? This might add to the element of complexity and how difficult it might be to explain to people how we have systems working in a different way from Europe.
- The different apps that are available in the UK might also be using completely different indices and data, including using the USEPA index or some other type of world index. That is, data being presented in different ways is already happening within the UK.
- Moreover, the levels of summertime ozone in the UK compared to levels of summertime ozone in Italy, would be completely different and if you had one index and/or approach that is applied across both countries, we would be in a situation

where levels which were flagged as being unusually high in the UK could be commonplace in southern Italy.

A5.4 AOB, FEEDBACK AND NEXT STEPS

Additional feedback was provided by attendees, which is summarised below.

- The granularity of the inputs of the DAQI is very much geared towards compliance measurements at the moment, and there are now other methodologies with varying uncertainties that have now been more widely adopted as measurement techniques. Will this be considered further as part of this study?

  Response: Yes, one of Defra's research questions specifically asks us to look into data granularity so this is an area of consideration.

- When considering people with occupations where they are working outside frequently and, therefore, may not be able to follow all health advice available, it might be interesting to ask the Health and Safety executives whether they provide advice and/or any advice to this effect is followed. It would be interesting to know whether they give any advice at the moment and whether they give air quality any consideration. It was acknowledged that the DAQI is a public health website rather than occupational health tool.
- It will be important that any future changes to the DAQI are undertaken in a logical order. Any changes to the input data and index formulation to address the shortcomings identified in the workshop (and beyond) should be undertaken first. Some of those changes could be so fundamental that any discussion of how we then communicate the outputs should come after that, as this will influence the data that is publicly available and how people can interact with the data. If we change the data in order to provide guidance to minimise exposure, for example providing information about what times of day air pollution may be worse, this could fundamentally change how the DAQI is published and/or communicated to the public.
- Through discussions with Local Authorities across England, it is evident that there is a big difference in awareness of air pollution in different geographies and probably Devolved Administrations. If Local governments alerted to the public that there was an issue with air quality then public engagement would be higher. Local Authorities should be part of the discussions within this project as they are the ones dealing with the local air quality issues and have the ability to raise awareness of the DAQI.

The Ricardo Plc team thanked the attendees for their engagement and contributions and gave them a heads up that they may be contacted for follow-ups, including through potential deep dive interviews.

A6. Appendix 6: Survey synopsis

This Appendix provides a summary of outputs from a survey of England based residents conducted as part of this evaluation. It provides a summary of the survey strategy and analysis methodology, and a summary of key findings.

A6.1 OVERVIEW

The survey comprised 34 core questions, preceded by up to 15 questions capturing the characteristics of the participants, which supports the sample's stratification and the logic of the questionnaire. The core questions were designed to draw scenario-based and self-reported evidence against structured answers that would delve into the participants' access (CERQ3), understanding (CERQ4), and behaviours associated with the DAQI's publications and the recommended actions and advice (CERQs 5 and 6). This has also been detailed in Section A1.2.2 of Evaluation Plan.

In more detail, the following high-level CERQ (evaluation questions) were targeted through the survey:

- CERQ3: To what extent is the DAQI viewed by the people it was intended to be viewed by?
- CERQ4: To what extent is the DAQI understood by its users in the way it was intended to be understood?
- CERQ5: To what extent do the people who use the DAQI enact the advice it provides?
- CERQ6: To what extent does advice the DAQI provides align with the intervention's intended outcome (to reduce severity of symptoms exacerbated by short term air pollution spikes) and impact (to reduce adverse health impacts)?

The survey was developed by the consultant team (Ricardo and Opinion Matters), reviewed and signed-off by Defra and the Survey Control Liaison Unit and encoded by Opinion Matters. Ricardo and Opinion Matters conducted five cognitive tests prior to the official launch of the survey.

The online web-based survey and Computer-Assisted Telephone Interviewing (CATI) were launched on 3 April 2024. The online survey closed on 12 April 2024 and CATI ended 30 April 2024. Three specific samples were targeted: i) digitally excluded people (over 65-year-olds from lower income and/or education backgrounds) through CATI, and ii) at-risk people, and iii) everyone else (i.e., the general population) through an online, web-based survey.

In total, 2,008 individuals completed the survey, generating three random groups of 100 individuals from the 'digitally excluded' group, 907 individuals from the 'at risk' group, and 1,001 individuals from the 'general population' group. Table A6-1 summarises the number of participants to the survey, by participant group; see also Section A6.2.

Table A6-1 Number of survey participants by group

Participant group	Number of participants
Digitally excluded population	100
At risk population	907

Participant group	Number of participants
General population (i.e., everyone else)	1,001
All participants	**2,008**

These activities were carried out in line with the Section 4 of the HMT Magenta Book. Ricardo, MEL Research and Opinion Matters follow industry standards, including the Market Research Society (MRS) Code of Conduct. Data has been stored and handled using the highest standards and established protocols, in line with General Data Protection Regulation.

In more detail, the 'general population' sample sought to target national representation by key strata, using the Office of National Statistics (ONS) 2022 mid-year population estimates, and controlled for demographic characteristics such as age, gender and region. The randomised sample stratification approach is regularly tested by Opinion Matters and has been shown to lead to representative outputs well within a reasonable margin of error (<5%) for this sample size.

In addition, actions were taken to limit cognitive or other biases to the extent possible as part of the primary research undertaken in this study. Any potential for bias was carefully removed from questions through compliance checks following the MRS code of conduct, ensuring that best practice is followed. Stringent data quality checks were performed on the outputs during the survey completion period to make sure attention is paid and invalid respondents are removed.

However, no research is impervious to bias and influence. Biases are a common challenge in research and cannot be completely eradicated against in general population surveys. They are a byproduct of public opinion and are impacted by cultural norms, and agreement or acquiescence bias, whereby people are more likely to misremember a similar event as what they are being asked about. As an illustration, it has been observed that people are prone to being overly positive in their responses, and so are more confident giving a positive answer.

These research dynamics and risks were considered in depth as part of the review and analysis of the survey outputs, especially concerning evidence of awareness, access and/or use of the DAQI air quality information services. Ahead of survey completion, the literature review and research undertaken to develop the Theory of Change had resulted in an emerging conclusion (or hypothesis) that a very small proportion of the population were expected to say 'Yes' to questions regarding access to the DAQI air quality information services. However, it was identified as part of the interviews and further research that there are a large number of air quality information services provided by third-party organisations such as local government, private organisations, etc., which people appear to have accessed and/or come into contact in the UK, without necessarily understanding these might be separate from the DAQI (especially given that the DAQI is often referred to as a source or completely source of information in these third-party services). In combination with some potential overstatement from respondents based on the aforementioned biases, this has resulted in a larger proportion of respondents than expected to have responded positively to questions about their awareness, access and/or use the DAQI or similar services. The research findings and interpretations are explored in more depth in Section A6.3 and A7.4.

Following survey closure, the raw data was downloaded by Opinion Matters and organised so that it could be analysed effectively and meaningful outputs could be produced. The responses were also categorised based on characteristics such as gender identity, age, region, education, occupation (e.g., whether the respondent is a health care professional or not, works outdoors or indoors), household income, type of household, dependents, personal and dependents' health status (including medical inhaler use and pregnancy status).

This synopsis reports the responses of participants overall and by respondent type (digitally excluded, at risk and general populations). Moreover, survey responses were reviewed and analysed using Ricardo's statistical expertise and tools (Microsoft Excel and Stata) to identify any additional insights through statistical analysis as useful. The responses to open text questions were also reviewed and/or analysed, also split by respondent type.

The outputs of the survey and any analysis are presented in the following sections within this Appendix.

A6.2 SURVEY PARTICIPANTS

The survey sample comprised a total of 2,008 participants belonging to digitally excluded, at risk and 'general population' groups. Additional characteristics of the survey participants were also collected so that the sample and responses could be further stratified and analysed meaningfully, including but not only through the comparisons of answers across population sub-groups.

The characteristics of the survey participants can be summarised as follows:

- **Age**: The median age of the sample was around 45, which is close albeit slightly higher than the median age in England (under 41 years old)[209]. This is partly because the survey only targeted adults of or over the age of 18 and targeted 100 'digitally excluded people' from a population of people over 65 years old.
- **Gender identity**: The overall sample comprised 57% females, 43% males and 1% non-binary individuals. The proportion of females in the England based population is 51%, and thus lower[210]. This is partly driven by the 'at risk' and 'digitally excluded' subgroups, whilst the 'general population' subgroup is closer and more representative of the national stratification. For example, the 'at risk' group targeted women of a childbearing age so that a subsample of pregnant women could be attained. The result: around 2/5 of all adult female participants said they were pregnant, partly driven by the 'at risk' sub-sample.
- **Region**: Participants were primarily located in relatively urban areas like Greater London (~17%), South East of England (~15%) and North West of England (~13%), which was comparable to the regional distribution observed in the England based population (~15% in London, ~16% in the South East and ~13% in the North West[211]).
- **Education level**: Around 90% of survey participants in the overall sample and the at risk and 'general population' groups had at least a Level 1 educational qualification whereas around 54% of the 'digitally excluded' group had no qualifications. The

[209] ONS. Population estimates for the UK, England, Wales, Scotland, and Northern Ireland: mid-2022. URL: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland

[210] Ibid.

[211] Ibid.

proportion of individuals with at least a Level 1 qualification in England was much lower, at ~51%[212], which is partly a result of the survey excluding people aged under 18 to whom the qualification levels would not apply.

- **Employment**: A quarter of the participants were health or social care professionals, which is slightly higher than the observed 14% of people employed in human health and social work activities in England[213]. The majority of participants also worked indoors, but the 'at risk' group were less likely to work indoors than the 'general population' and 'digitally excluded' group. In addition, of those who worked outdoors, a higher proportion of participants in the 'at risk' group said their work requires strenuous activity.
- **Household income**: The median household income for the overall sample was around £35,000. The median household disposable income in the UK was £32,300 in 2022[214], which is slightly lower but comparable. The 'digitally excluded' group was observed to be relatively lower income than the other groups, as targeted.
- **Household type:** More than 2/5 of participants belonged to households with children or dependents. The majority of participants with children or dependents said they had at least one dependent child or adult for whom they had caring responsibility. These are similar proportions to families with children (~60%) and/or dependent children in England (over 30%)[215]. Participants from the 'at risk' group were more likely to come from a household with children or dependents and also to have children or dependents requiring care.
- **Health status:** More than half the participants reported having at least one chronic lung or heart conditions, especially lung conditions. This is higher than one might expect from population evidence and is completely driven by sample targeting (around half of the overall sample targeted people who might have lung and/or heart conditions). Available evidence suggests that cardiovascular diseases (a general term for conditions affecting the heart or blood vessels) affect around seven million people (~10%) in the UK[216] and respiratory diseases affect 20% of people in England[217]. In addition, more than half of the participants with children or dependents said that their dependents had one or more lung or heart conditions, especially lung conditions. Participants from the 'at risk' group were more likely to exhibit these conditions or have dependents with these conditions.
- **Medical inhaler use:** Half of the survey participants reported that they used medical inhalers, with participants in the 'at risk' group being much more likely to use inhalers than those in other groups. In the UK, around 5.4 million people (~8%) are using

[212] ONS. Education, England and Wales: Census 2021. URL: https://www.ons.gov.uk/peoplepopulationandcommunity/educationandchildcare/bulletins/educationenglandandwales/census2021
[213] ONS. Industry and occupation, England and Wales: Census 2021. URL: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/bulletins/industryandoccupationenglandandwales/census2021
[214] ONS. Average household income, UK: financial year ending 2022. URL: https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/bulletins/householddisposableincomeandinequality/financialyearending2022
[215] ONS. Families in England and Wales: Census 2021. URL: https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/articles/familiesinenglandandwales/census2021
[216] NHS. Living well, ageing well and tackling premature mortality - Cardiovascular disease (CVD). URL: https://www.england.nhs.uk/ourwork/clinical-policy/cvd/
[217] NHS. Living well, ageing well and tackling premature mortality - Respiratory disease. URL: https://www.england.nhs.uk/ourwork/clinical-policy/respiratory-disease/

treatments for asthma[218] (including medical inhalers), which is much lower than the sample figure - a result of the sample targeting.

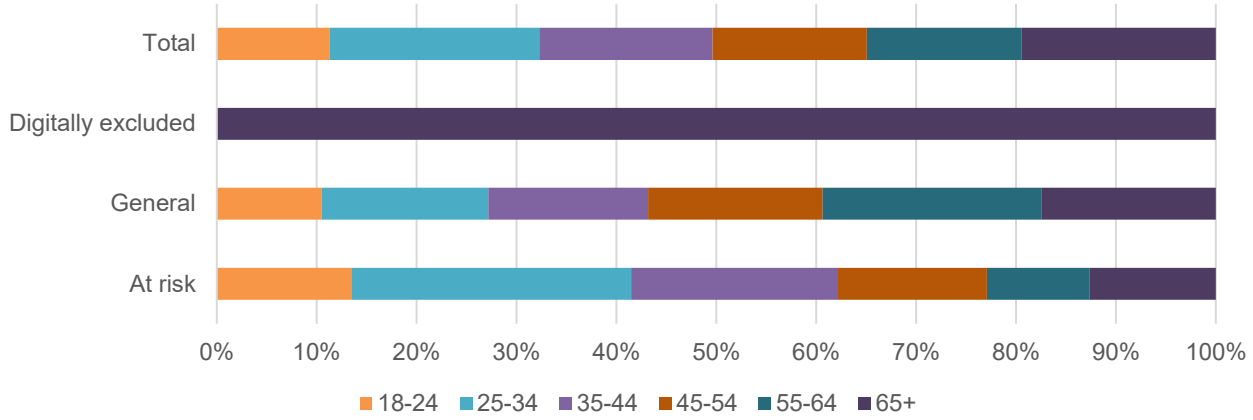
- **Risk perception:** Around 85% of participants who considered themselves to be at risk of air pollution were found to be correct based on the DAQI's definition i.e., their health was particularly vulnerable to the quality of the air that they breathe.

These characteristics are explored in detail below.

Individual characteristics

The median age of the sample is around 45. The 'at risk' group was relatively younger than the other groups. The 'digitally excluded' group targeted people aged 65 and over. An overview of the age distribution of the overall sample and sample groups is presented in Figure A6-1.

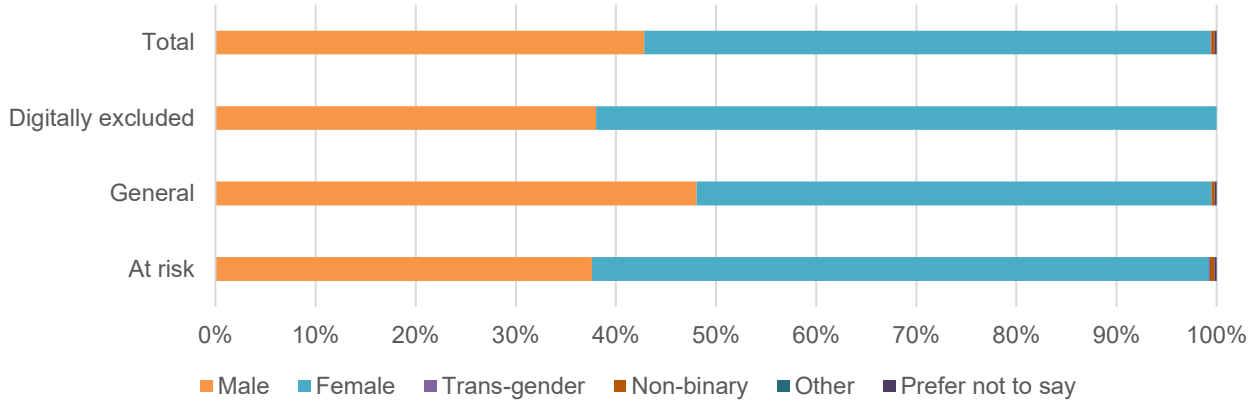
Figure A6-1 Age distribution of the survey participants (% of respondents for the overall sample and each group; n=2,008 for total, n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



The majority of the survey participants (N=2,008) were females (~57%), followed by males (~43%) and the remaining 1% comprised of individuals were non-binary, transgender or preferred not to say. Roughly similar trends were observed for the general, at risk and 'digitally excluded' groups, with the 'general population' group having a slightly higher proportion of males than the others. An overview of the gender distribution of the overall sample and the groups and is presented in Figure A6-2.

[218] NICE. Asthma: diagnosis, monitoring and chronic asthma management. URL: https://www.nice.org.uk/guidance/ng80/informationforpublic

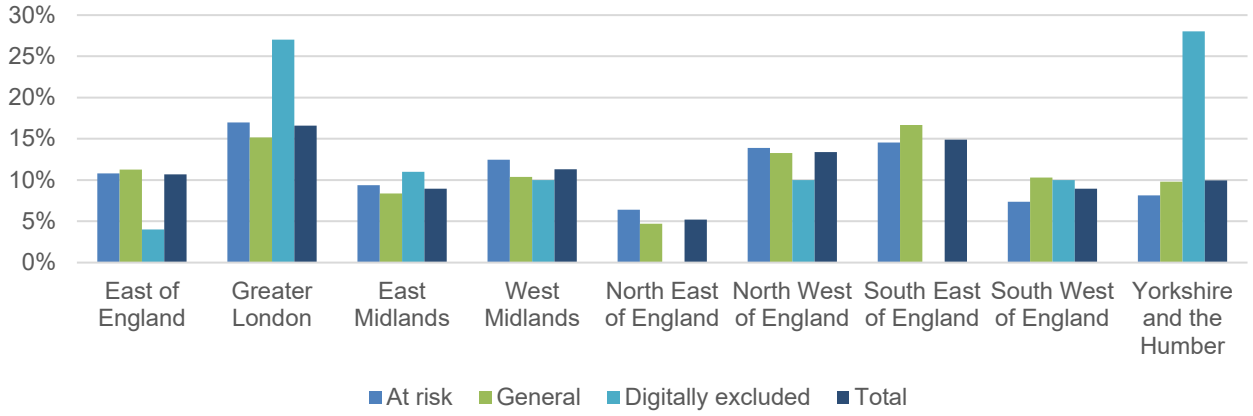
Figure A6-2 Gender distribution of the survey participants (% of respondents for the overall sample and each group; N=2,008 for total, n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



Around 41% of participants in the overall sample (n=1,129) reported that they were pregnant. **Participants in the 'at risk' group were more likely to be pregnant** (~80%; n=554) compared to those in the general (~4%; n=513) group, and potentially faced a higher health risk from exposure to air pollution. As expected, none of the participants from the 'digitally excluded' group were pregnant.

The survey participants (N=2,008) were primarily located in relatively urban areas like Greater London (~17%), South East of England (~15%) and North West of England (~13%). Fairly similar regional distributions were observed for the general and 'at risk' groups of participants. The sample for the 'digitally excluded' group (n=100) is relatively small, and thus geographical representation is more limited. An overview of the regional distribution of the overall sample and the groups is presented in Figure A6-3.

Figure A6-3 Regional distribution of the survey participants (% of respondents for the overall sample and each group; N=2,008 for total, n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)

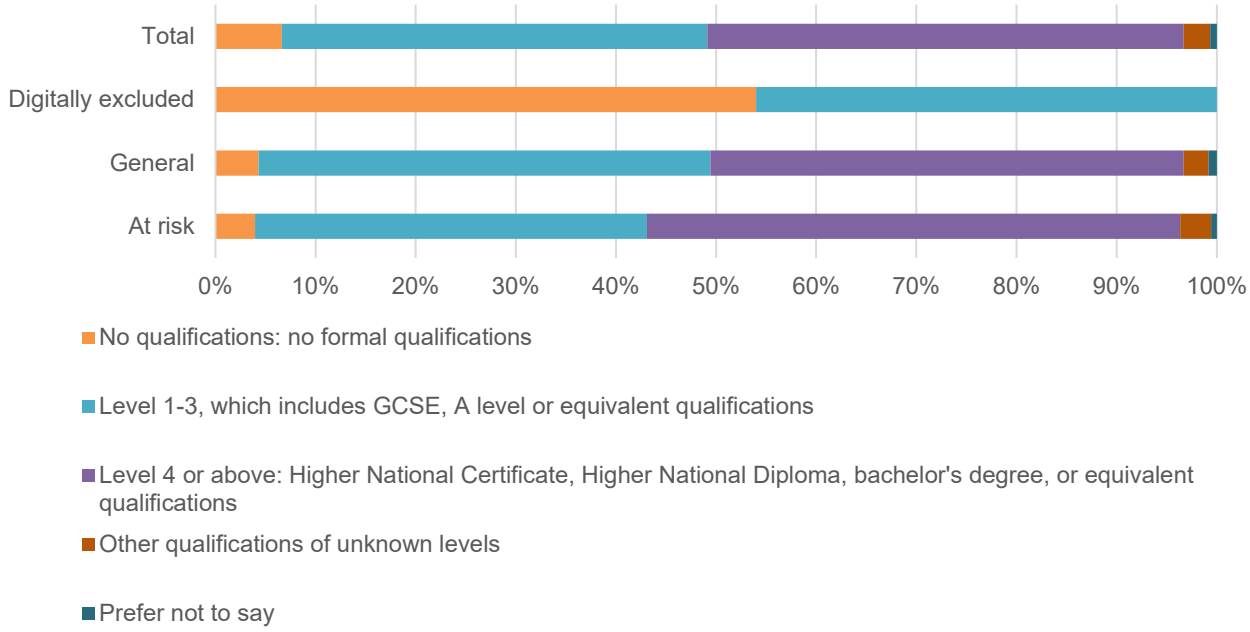


The majority of participants demonstrated a high education level, as around 48% (N=2,008) had a qualification of Level 4 or above and around 42% had a qualification of Level 1-3.[219] There were minor differences between the general and 'at risk' groups, with

[219] Level 1-3 includes GCSE, A level or equivalent qualifications. Level 4 or above includes Higher National Certificate, Higher National Diploma, bachelor's degree, or equivalent qualifications.

the former showing a slightly higher proportion of Level 1-3 qualifications whereas the latter showed a slightly higher proportion of Level 4 or above qualifications. Due to sample targeting, the majority of the 'digitally excluded' group (~54%; n=100) had no formal qualifications. An overview of the education level of the overall sample and the groups and is presented in Figure A6-4.

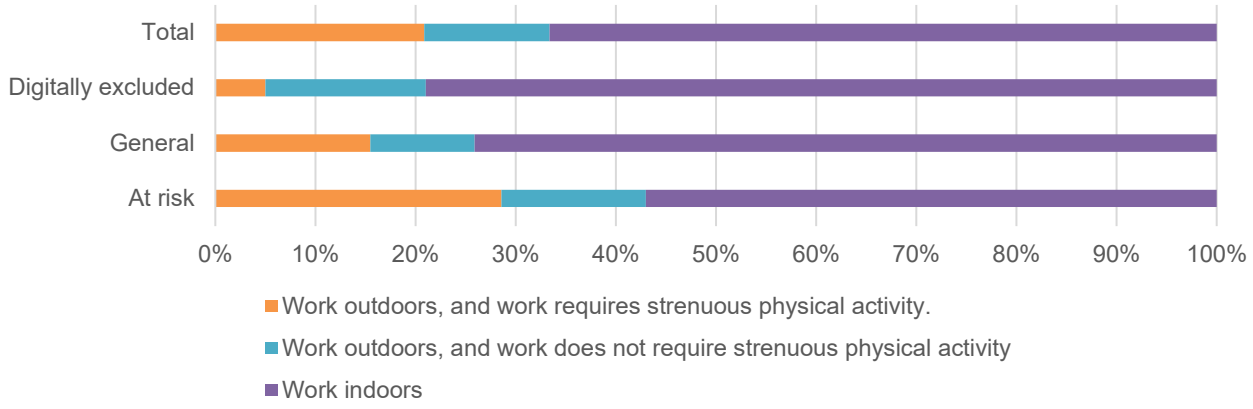
Figure A6-4 Education level of the survey participants (% of respondents for the overall sample and each group; N=2,008 for total, n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



In terms of employment, **around 25% of the survey participants (N=2,008) were health or social care professionals**. The 'at risk' group (n=907) had a higher proportion (~32%) of health and social care professionals than the 'general population' group (~19%; n=1,001) or the 'digitally excluded' group (0%; n=100).

The majority of participants (~67%; N=2,008) also worked indoors, with slightly higher figures for the general and 'digitally excluded' group than the 'at risk' group. Of those who worked outdoors, a higher proportion of participants in the 'at risk' group said their work requires strenuous activity (~29%; n=907) compared to the other groups, which would imply a greater degree of air quality risk faced by them. These responses for the overall sample and the groups are depicted in Figure A6-5, by response statement.

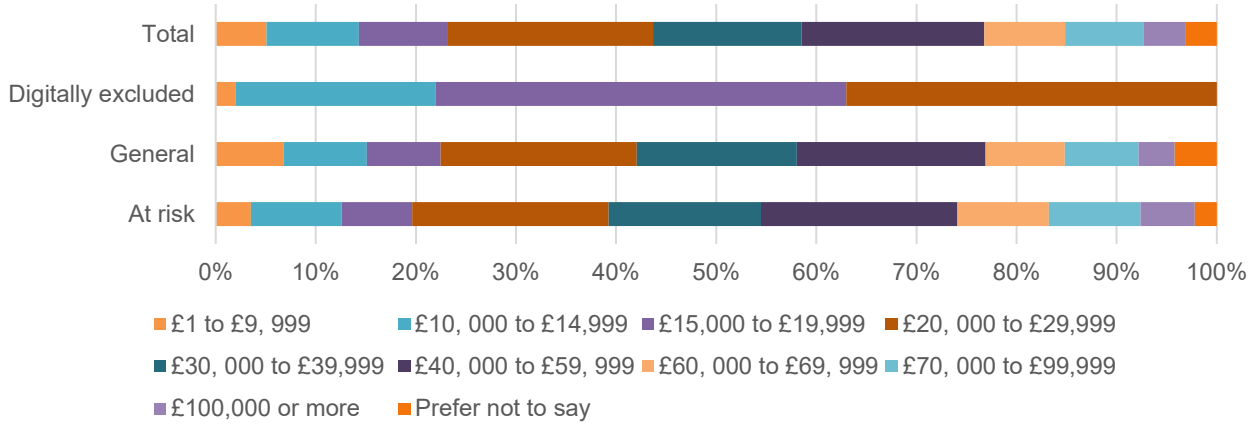
Figure A6-5 Do survey participants work outdoors or indoors? (% of respondents for the overall sample and each group; N=2,008 for total, n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



Household characteristics

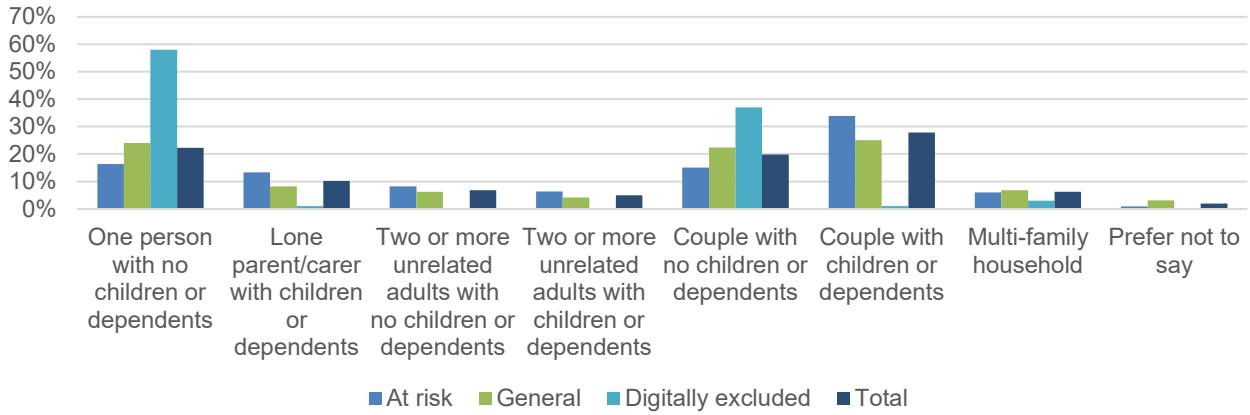
The median household income for the sample is around £35,000. Around 54% of participants from the at risk (n=907) and general (n=1,001) groups reported household incomes between £20,000 and £69,999. In comparison, the 'digitally excluded' group was relatively lower income, which is inherent to the sample targeting –only around 34% of the 'digitally excluded' group (n=100) said they had household incomes in that range. An overview of the household income of the overall sample and the groups and is presented in Figure A6-6.

Figure A6-6 Household income of survey participants (% of respondents for the overall sample and each group; N=2,008 for total, n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



In terms of household type, **around 43% of the participants (N=2,008) belonged to households with children or dependents**. Participants from the 'at risk' group were more likely to come from a household with children or dependents (~54%; n=907) compared to participants form the general (~37%; n=1,001) or digitally excluded (~2%; n=100) groups, again due to sample targeting. An overview of the type of households for the overall sample and the groups is presented in Figure A6-7.

Figure A6-7 Household type of survey participants (% of respondents for the overall sample and each group; N=2,008 for total, n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)

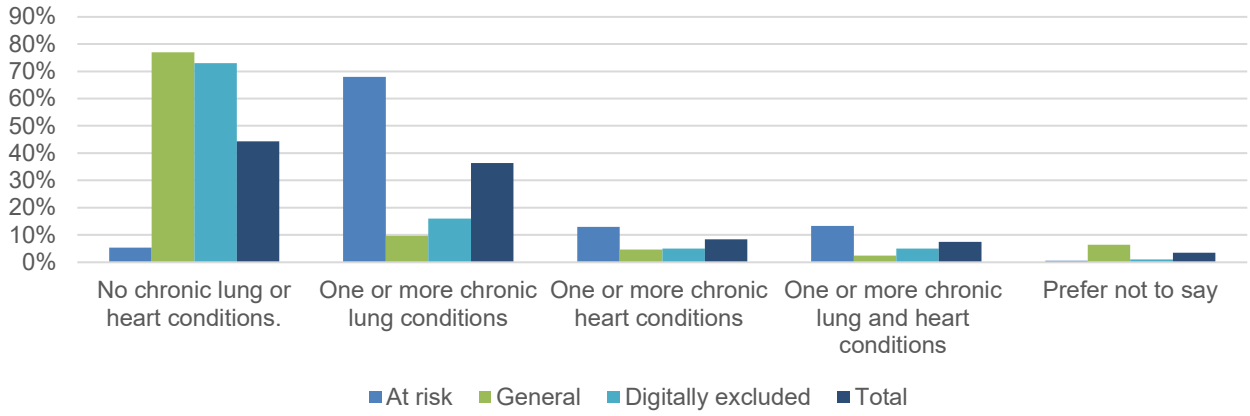


Of the participants with children or dependents (n=1,117), around 65% said they had at least one dependent child or adult for whom they had caring responsibility. Participants in the 'at risk' group were more likely to have children or dependents requiring care (~73%; n=398) than participants in the general (~57%; n=477) and 'digitally excluded' groups (~40%; n=5).

Health status

In terms of their personal health status, **more than half the participants (~52%; N=2,008) said they had at least one chronic lung or heart conditions, particularly lung conditions**. Participants from the 'at risk' group were more likely to have one or more heart or lung condition (~94%; n=907) compared to the general (~17%; n=1,001) and digitally excluded (~26%; n=100) groups, again due to sample targeting. The responses for personal health status for the overall sample and groups are presented in Figure A6-8, by statement.

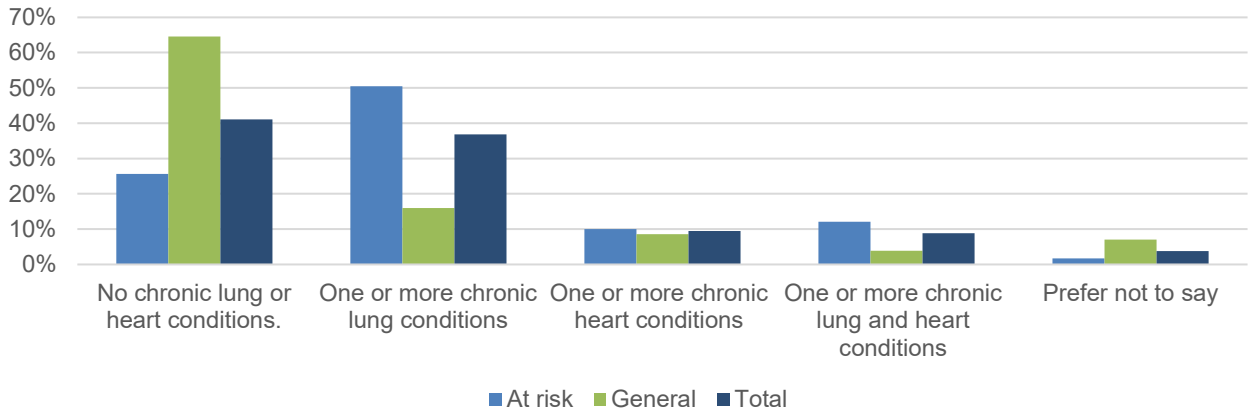
Figure A6-8 Health status of survey participants (% of respondents for the overall sample and each group; N=2,008 for total, n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



Similarly, considering dependents' health status, **around 55% of participants with children or dependents said that their dependents had one or more lung or heart conditions, especially lung conditions**. **Participants from the 'at risk' group were more likely to have dependents with lung or heart conditions** (~73%; n=398) compared to

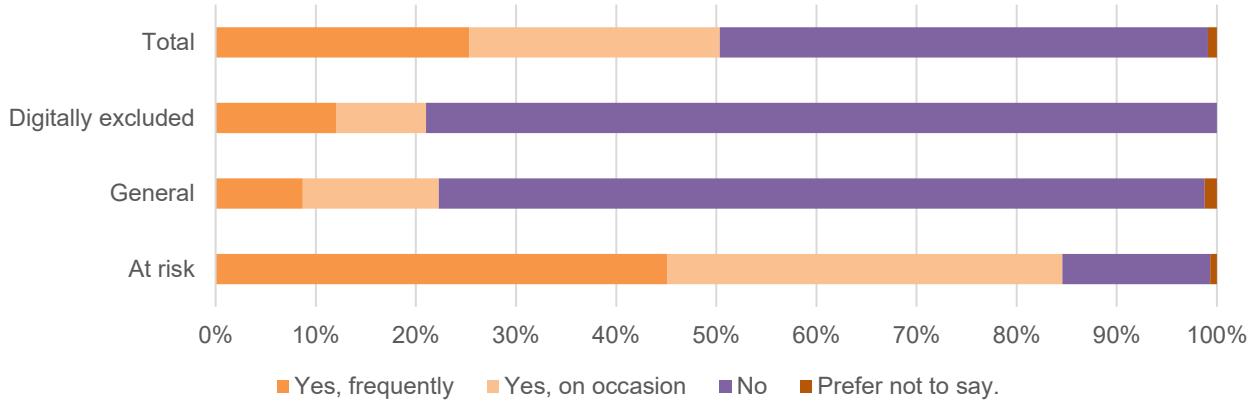
those from the general (~28%; n=257). The responses for dependents' health status for the overall sample and groups are presented in Figure A6-9, by statement.

Figure A6-9 Health status of children and dependents of survey participants (% of respondents for the overall sample and each group; n=657 for total, n=398 for at risk, n=257 for general)



Half of the survey participants (N=2,008) also reported that they used medical inhalers. Looking at sample groups, around 85% of participants from the 'at risk' group (n=907) used medical inhalers whereas just over 20% of participants in the general (n=1,001) and digitally excluded (n=100) groups used medical inhalers. This is presented in Figure A6-10 for the overall sample and groups, by response statement.

Figure A6-10 Medical inhaler usage of survey participants (% of respondents for the overall sample and each group; N=2,008 for total, n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



Around 47% of survey participants who were familiar with the DAQI information services and visuals (n=1,538) perceived themselves to be at risk of air pollution. Of these participants who perceived themselves to be at risk (n=717), around 85% were found to actually be at risk according to the DAQI definition i.e., their health was particularly vulnerable to the quality of the air that they breathe.

Participants from the at risk and 'digitally excluded' groups were more likely perceive risk when they were actually at risk of air pollution, as compared to the general population. Around 67% of participants in the 'at risk' group (n=777) who were familiar with the DAQI information services and visuals perceived themselves to be at risk from air

pollution, of whom, around 98% (n=526) were found to actually be at risk. In contrast, in the 'general population' group, only around 25% (n=709) of respondents considered themselves to be at risk from air pollution, of whom 47% (n=178) were actually at risk. In the group of digitally excluded participants (n=52), 25% of respondents considered themselves to be at risk, of whom around 77% (n=13) were currently at risk from air pollution.

A6.3 CERQ3 ACCESS

CERQ3: To what extent is the DAQI viewed by the people it was intended to be viewed by?

Over a third of the survey participants and over half of those in the at risk group recognise and use Defra's DAQI or similar air quality services built on the DAQI (e.g., map/navigation applications, weather applications, news outlets, etc).

Participants were asked about their interest and awareness of the air quality in their neighbourhood as well as the accessibility of air quality information from the DAQI services. The responses to the survey suggest:

- **Most respondents have some interest in their neighbourhood's air quality,** with around 18% of respondents reporting low interest, 34% medium and 42% high or very high interest. Participants in the 'at risk' group (N=907) are more likely to have high or very high levels of interest (~53%) when compared to those in the general population (~37%) and digitally excluded (~7%) groups.
- **Under 40% of all respondents were aware of the air quality in their neighbourhood**, which is of similar scale of the proportion of respondents with high or very high interest in air quality. Respondents in the 'at risk' group (N=907) were more likely to be aware (~51%) when compared to the general population (~30%, N=1,001) or the digitally excluded (6%, N=100) groups.
- **Respondents demonstrated a good understanding and perception of the risk faced from exposure to air pollution**. More than 70% of participants perceived there to be greater risks for adults and children with heart and/or lung conditions, and a high number of respondents also selecting adults over the age of 65 (57%), pregnant women (52%), all children (42%) and/or all adults (29%). When exploring their perception of own personal risk:
    - Survey participants who considered themselves at risk (N=717) were mostly right, with more than 85% aligning with the definition of risk provided by the DAQI (adults and children with lung and/or heart conditions).
    - Survey participants who considered themselves not at risk (N=821) were right more often than not, with more than 65% identifying not at risk in line with the DAQI.

  Over 40% of respondents (N=1,519) used information from the UK AIR website or health and/or social care professionals to reach their conclusions about being at risk of air pollution.
- **Around 45% of the survey participants have encountered the DAQI or similar air pollution information services**, having previously seen snapshots similar to the UK AIR website, email bulletins, X/Twitter page and/or Air Text service. People in the 'at risk' group, people who perceive themselves to be at risk and/or people who are

at risk from air pollution according to DAQI definition were more likely to have seen any of this information previously. When considering their level of familiarity, in comparison to other government services, a slightly lower 37% of participants suggested they were somewhat or very familiar with the DAQI, which was lower than the heat-health alert services (54%) and flood alerts and warnings (65%). Respondents in the 'digitally excluded' group had not seen any of the DAQI services before (82%) and very few were familiar (2%). Again, people who perceive themselves to be at risk and/or that are at risk according to DAQI definition were more likely to be familiar with the DAQI than those who did not.

- **Around 37% of the survey participants engage with at least one of the DAQI services (or 'DAQI users')**, checking pollution forecasts online on the UK AIR Defra website (18.5%), following the @DefraUKAir X/Twitter page (12%) using the free automated telephone air pollution services (11.7%) and/or subscribing and receiving the Daily Air pollution email bulletins (9.1%). Respondents in the 'at risk' group and/or who perceive themselves to be at risk and/or who are actually at risk from air pollution are more likely to engage with one or more of these services.
- **On average, more than 70% of the 'DAQI users' who use at least one air quality information service (N=805) engaged with their service of choice at least once a week.** Respondents in the 'at risk' group were more likely to engage more frequently than others.
- **Over 70% of respondents (N=1,538) had not seen or seen but not accessed the DAQI's 'Recommended Actions and Health Advice'**. A quarter of respondents have seen and accessed or check regulatory these recommended actions and advice. People in the 'at risk' group and/or those who perceive themselves to be at risk from air pollution and/or are at risk according to DAQI definition are more likely to access and/or check regulatory the advice provided by the DAQI.
- The **leading barriers for participants who were interested in air quality but had not accessed nor were familiar with the DAQI (N=97) were a struggle to: 1) find time (>30% of respondents) and/or 2) their way through the DAQI website (~20% of respondents).** Around 20% of respondents suggested that accessing the DAQI was not their priority, and under 10% noted that they follow other air quality alerts or information services.

These findings are explored in more detail in the following subsections.

A6.3.1 Interest and awareness of air quality in the neighbourhood

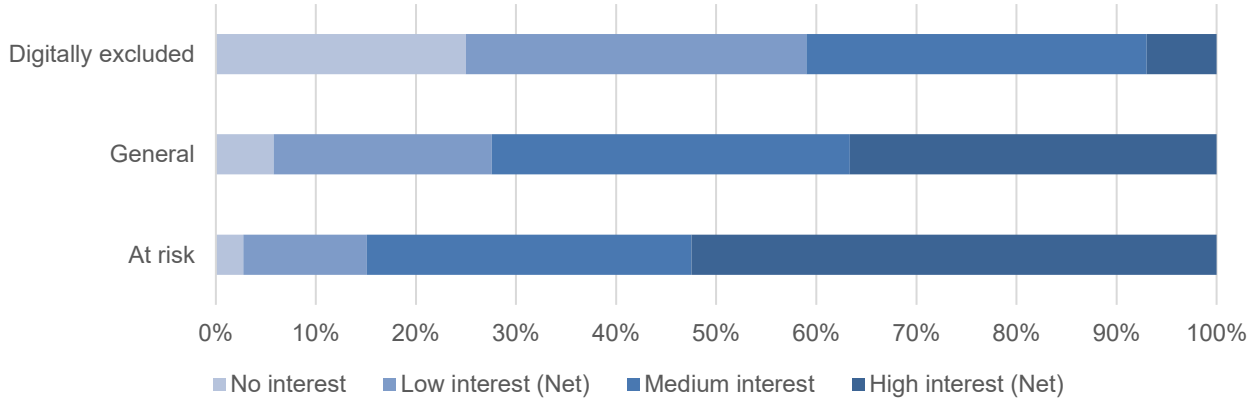
Most respondents (N=2,008) have some interest in their neighbourhood's air quality, with around 18% of respondents reporting low interest, 34% medium and 42% high or very high (Q1). More than 50% of the respondents in the 'at risk' group (n=907) had high or very high interest in the quality of air in their neighbourhood. Of the respondents in the 'digitally excluded' group (n=100), more than 30% said that they had no interest in the air quality in their neighbourhood.

On average, respondents showed a medium level of interest in quality of air in their neighbourhood, with participants in the 'at risk' group showing a relatively higher level of interest than participants in the general population and 'digitally excluded' groups. When asked to rate their level of interest on a scale of 0 (no interest) to 5 (very high level of

interest), the mean scores for the at risk, general and 'digitally excluded' groups were 3.5, 3.0 and 1.8 respectively.

Figure A6-11 presents the percentage of respondents with no, low, medium and high levels of interest for each group of participants.

Figure A6-11 Interest in the neighbourhood air quality (% of respondents for each group; n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



In addition, there are significant differences in the level of interest in air quality depending on the characteristics of the survey respondents. A summary of the findings is set out below.

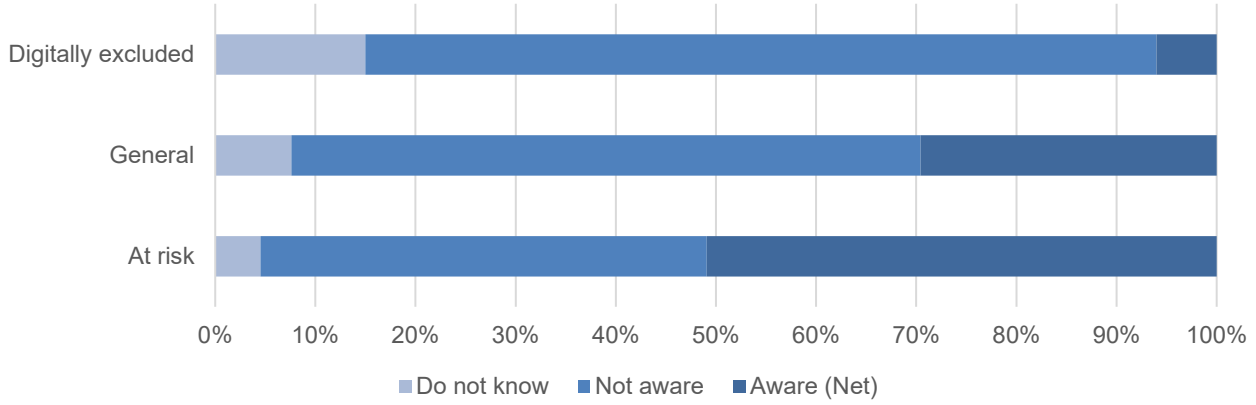
People of the following types appeared to be **more interested in air quality than average**, including people who are aged 25-44 years; reside in urban areas; suffer from one or more lung and/or heart condition and/or use medical inhalers; attained qualifications at the Level 4 or above; work in a health or social care setting and/or outdoors; live in households with dependents especially if these suffer one or more chronic lung and/or heart condition; and/or have higher levels of income (above £40,000/household).

Other types of people were **less interested in air quality than average**, such as those who are younger (under 25) or older people (over 65), and have no lung and/or heart conditions nor use medical inhalers; have no or lower level 1-3 qualifications, reside in rural areas, work in indoor settings except for the health and care sector, live in households without dependents especially if these do not have any lung and/or heart condition; and/or have lower levels of income (under £40,000/household).

Under 40% of all respondents (N=2,008) were aware of the air quality in their neighbourhood and checked it at least on one occasion, which is of similar scale of the proportion of respondents with high or very high interest in air quality (Q2). Respondents in the 'at risk' group (n=907) were more likely to be aware (51%) when compared to the general population (30%, n=1,001) or the digitally excluded (6%, n=100) groups.

Figure A6-12 presents the percentage of respondents with different levels of awareness of air quality in their neighbourhood, by group.

Figure A6-12 Awareness of the neighbourhood air quality (% of respondents for each group; n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



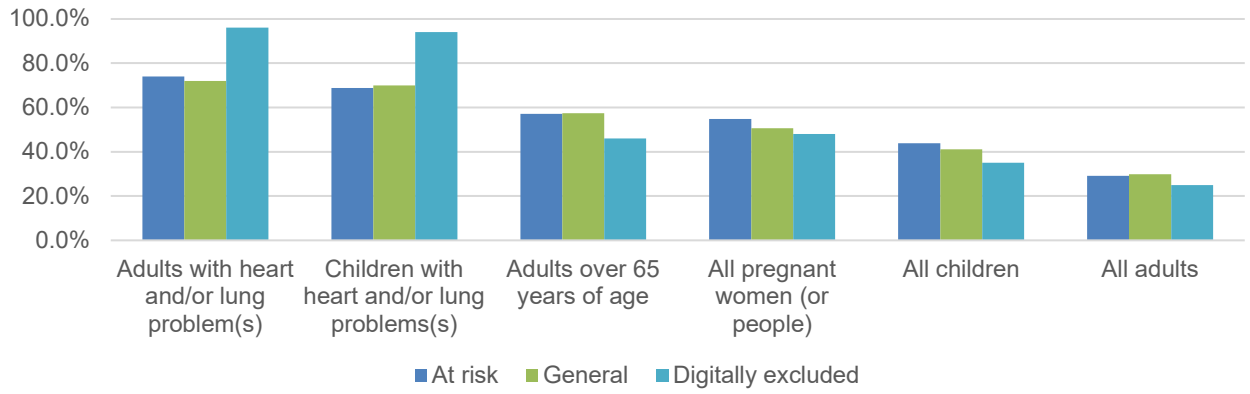
People of the following types appeared to be **more aware of air quality than average** (more than a 10 percentage-point or 'pp' difference), including people who are aged under 34; reside in Greater London; suffer from one or more lung and/or heart condition and/or use medical inhalers; pregnant women; work in a health or social care setting and/or outdoors; and/or live in households with dependents with one or more chronic lung and/or heart condition.

Other types of people were **less aware of air quality than average** (more than a 10pp difference), such as those who are aged over 55; reside in rural areas, and/or do not have any lung and/or heart conditions nor use medical inhalers; have no or lower level 1-3 qualifications; work in indoor settings except for the health and care sector; live in households with dependents without any lung and/or heart condition; and/or have lower levels of income (under £40,000/household).

A6.3.2 Understanding and perception of risk from elevated air quality (RSQ3.1)

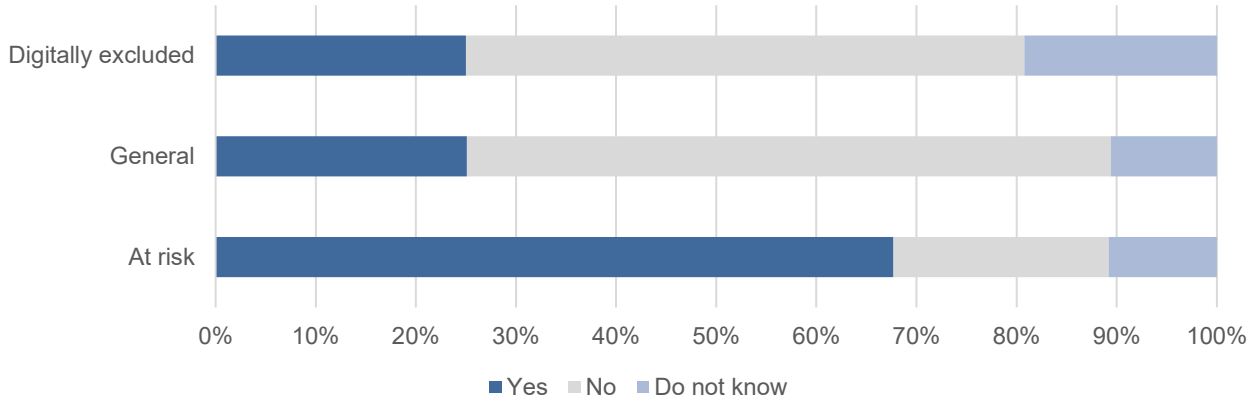
Individuals demonstrated a good understanding and perception of the risk faced from exposure to air pollution (Q17)**.** More than 70% of participants perceived there to be greater risks for adults and children with heart and/or lung conditions, and a high number of respondents also selecting adults over the age of 65 (57%), pregnant women (52%), all children (42%) and/or all adults (29%). This is summarised in Figure A6-13.

Figure A6-13 Which groups of people living in the UK might be at a greater risk of air pollution? (% of respondents for each group; n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



Participants who were familiar with the DAQI services[220] were asked if they would identify themselves as someone who is at risk of air pollution i.e., their health would be particularly vulnerable to the quality of the air that they breathe (Q10). Around 70% the respondents in the at risk sample group (n=777) identified themselves to be at risk of air pollution, whereas only around 25% in the general population and 'digitally excluded' groups (n=709 and n=52 respectively) identified themselves at risk of air pollution. Figure A6-14 summarises these responses.

Figure A6-14 Perception of being at risk of air pollution (% of respondents for each group; n=777 for at risk, n=709 for general, n=52 for digitally excluded)



Survey participants who perceived themselves at risk (n=717) were mostly right when considering their own personal risk, with more than 85% aligning with the definition of risk provided by the DAQI (adults and children with lung and/or heart conditions). Survey participants who considered themselves not at risk (n=821) were right more often than not, with more than 65% identifying not at risk in line with the DAQI.

People of the following types were **more likely to consider themselves to be at risk** (more than 10 pp difference), including people who are aged 25-44 years; suffer from one or more lung and/or heart condition and/or use medical inhalers; work in a health or social

[220] This question was asked to participants who were familiar with at least one of the DAQI services (UK AIR page, DAQI emails, UK AIR on X/Twitter or the Air Text service) and had seen visuals of them.

care setting and/or outdoors; live in households with dependents who suffer one or more chronic lung and/or heart condition.

In addition, people who reported interest in air quality and are more aware of the air quality in their neighbourhood are more likely to consider themselves to be at risk than others.

Other types of people were **less likely to consider themselves to be at risk** (more than 10 pp difference) such as those who are aged over 55; without lung and/or heart conditions and/or do not use medical inhalers; work in in indoor environments except in the health and care sector, and those who live in households with dependents without any lung and/or heart condition.

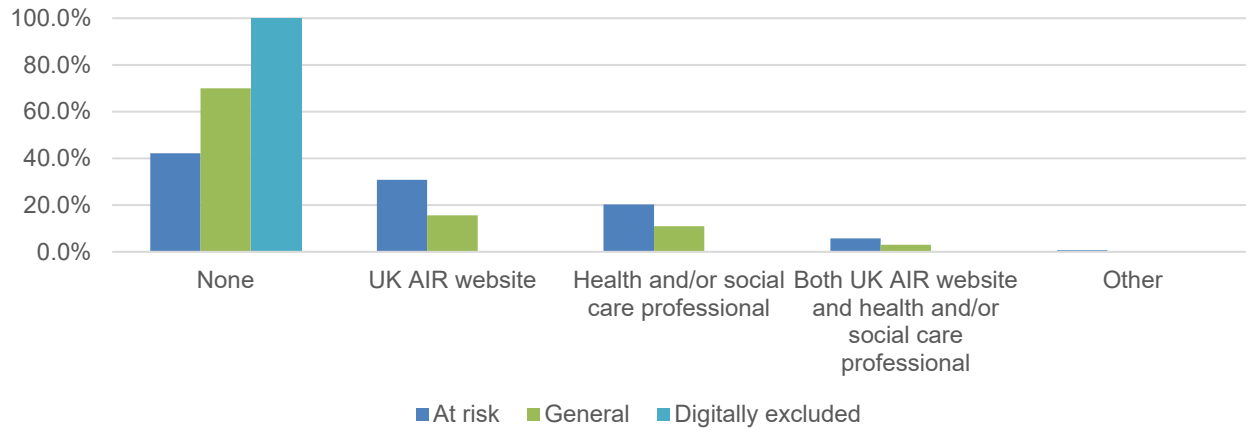
Similarly, participants with children or dependents were asked if they considered any dependent(s) they cared for (children and/or adult) to also be at risk of air pollution (Q11). Respondents who considered their dependents at risk (n=368) were mostly correct in their perception, with 77% aligning with the DAQI's risk definition. Respondents who consider that their respondents were not at risk (n=342) were correct more often than not, with 60% aligning with the DAQI's risk definition.

People who are more concerned about air quality and/or more aware of air quality in their neighbourhoods are more likely than others to consider their dependents to be at risk. Nevertheless, people with no/very low/low interest in air quality were more likely to correctly identify their dependents as being at risk from air pollution, (i.e. have one or more chronic heart and/or lung conditions), than those with high/very high interest in air quality.

Only ~40% of respondents (n=1,519) used information from DAQI services (such as the UK AIR website) or health and/or social care professionals to reach their conclusions about being at risk of air pollution (Q12). Around 60% of respondents in the 'at risk' group (n=764) said that they did use information from at least one of these sources to reach their conclusions. In comparison, only 30% of 'general population' group (n=703) and none of the digitally excluded respondents (n=52) used this information to reach their conclusions. Other sources of information included news stories on TV, medication (including oxygen and inhaler usage), Met Office website, weather apps and web searches.

People who perceived themselves at risk of air pollution were (2-2.5 times) more likely to use information from DAQI services to reach their conclusions about being, or not, at risk when compared to others. This is also case for people who are actually at risk, based on the DAQI's definition, as well as the sample of people in the 'at risk' group when compared to others. These differences are statistically significant and can be observed in Figure A6-15 by sample groups.

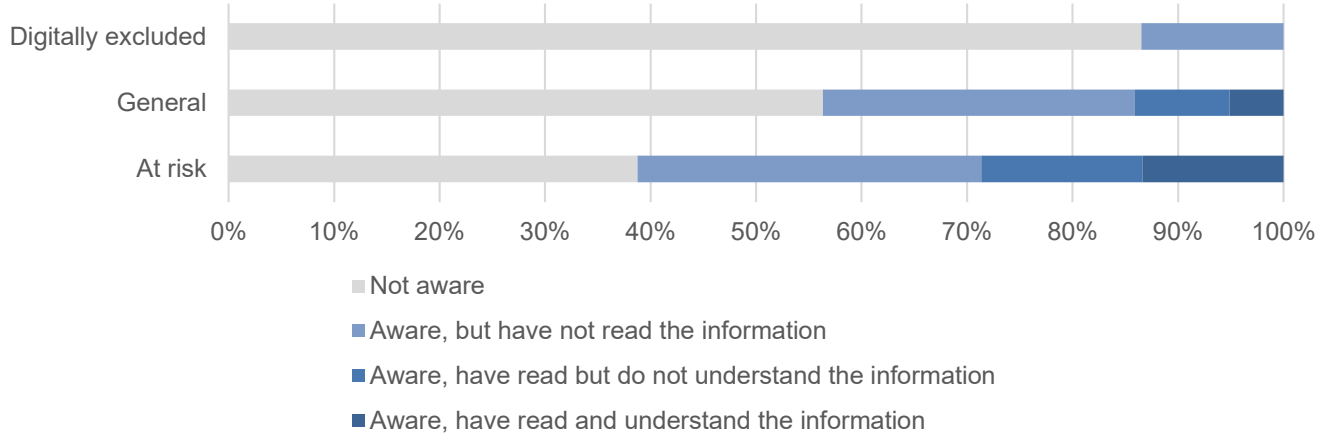
Figure A6-15 Use of DAQI information to determine risk of air pollution (% of respondents for each group; n=764 for at risk, n=703 for general, n=52 for digitally excluded)



Around 50% of participants (n=1,519) said they were aware that the DAQI pages on the UK-AIR website has information that would help to identify whether they are at risk of air pollution, albeit generally they do not access or understand the information (Q13). Around 60% of the respondents from the 'at risk' group (n=764) were aware of this, compared to around 45% of respondents from the 'general population' group (n=703) and around 15% of respondents from the 'digitally excluded' group (n=52). However, only ~10% of the respondents (n=1,519) said they are aware, have read and understand this information. (~13% of respondents from the 'at risk' group and ~5% of respondents from the 'general population' group).

People who perceived themselves to be at risk from air pollution were (1.5-2 times) more aware that the DAQI had information to help them identify whether they were at risk or not, compared to others. This is also case for people who are actually at risk, based on the DAQI's definition, as well as the sample of people in the 'at risk' group when compared to others. These differences are statistically significant and can be observed in Figure A6-16.

Figure A6-16 Awareness and use of information to determine risk of air pollution (% of respondents for each group; n=764 for at risk, n=703 for general, n=52 for digitally excluded)



A6.3.3 Awareness and use of the DAQI (RSQ3.2 and RSQ3.3)

There is a medium level of awareness and access of the DAQI in England, with people at risk being (1.5-2 times) more likely to be aware and use the DAQI services.

Around 45% of survey participants (N=2,008) have encountered or seen information similar to snapshots of the UK Air Defra website, DAQI Daily Air Pollution email bulletins, @DefraUKAir on X/Twitter or the Air Text service (Q3). Respondents from the 'at risk' group exhibited the most awareness of the 'DAQI visuals', with ~60% of them having seen at least one of these visuals (n=907), compared to corresponding figures of ~35% and ~20% for the general (n=1,001) and digitally excluded (n=100) groups.

People who perceived themselves to be at risk from air pollution were (1-1.5 times) more likely to have accessed the DAQI (seen any of the images presented in this question) than those who did not perceive themselves to be at risk. This is also the case for people who are actually at risk, based on the DAQI's definition, as well as the sample of people in the 'at risk' group when compared to others. These differences are statistically significant.

People who are more interested in air quality appeared also more likely to have accessed the DAQI, that is, the likelihood of having accessed the DAQI increases as interest in air quality increases. More specifically, about 30% of people with no/low interest in air quality have accessed the DAQI, while about 50% of people with medium/high interest in air quality have accessed it. This difference is statistically significant.

In addition, there are significant differences in the level of access to the DAQI depending on the characteristics of the respondents. A summary of the findings is presented below.

People of the following types were also **more likely than average to access the DAQI** (more than 10 pp difference), including people aged under 45; who reside in Greater London; suffer from one or more lung and/or heart condition; attained qualifications at the Level 4 or above; work in a health or social care setting and/or outdoors; and/or live in households with dependents especially if these suffer one or more chronic lung and/or heart condition; pregnant women; and/or have very high levels of income (above £100,000/household).

Other types of people were **less likely than average to access the DAQI** (more than 10 pp difference), such as those aged over 45, who reside in rural areas; have no lung and/or heart conditions; have no or other qualifications of unknown levels; reside in rural areas, work in indoor settings except for the health and care sector; live in households without dependents especially if these do not have any lung and/or heart condition; and/or have lower levels of income (under £10,000/household).

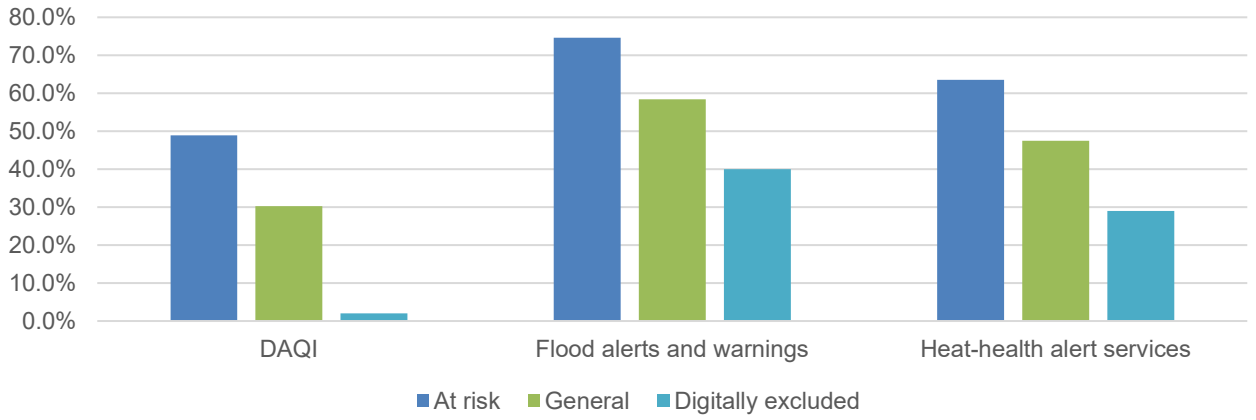
A slightly lower 37% of the survey participants report being somewhat or very familiar with the DAQI (Q4). **Overall, respondents also reported being less familiar with the DAQI as compared to the other government services.** Respondents in the 'at risk' group exhibited the most familiarity with government services like the DAQI, flood alerts and warnings and heat-health alert services followed by the general and 'digitally excluded' groups.

People who perceived themselves to be at risk from air pollution were (1.5-2 times) more likely to be familiar with the DAQI than those who did not perceive themselves to be at risk. This is also case for people who are actually at risk, based on the DAQI's definition, as well as the sample of people in the 'at risk' group when compared to others. These differences are statistically significant.

Familiarity with the DAQI increases with interest in air quality. In this respect, more than 41% of people with a medium/high interest in air quality are familiar with the DAQI, whereas this percentage drops to 22% for people with no/low interest in air quality. This difference is also statistically significant.

Figure A6-17 depicts the percentage of respondents who said they were familiar with these government services.

Figure A6-17 Familiarity with the DAQI, flood alerts and warnings and heat-health alert services (% of respondents for each group; n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



People of the following types were also **more likely than average to be familiar with the DAQI (more than 10pp difference)**, including people aged under 45; who reside in Greater London; suffer from one or more lung and/or heart condition and/or use medical inhalers; work in a health or social care setting and/or outdoors; live in households with dependents with one or more chronic lung and/or heart condition; pregnant women; and/or have higher levels of income (above £70,000/household).

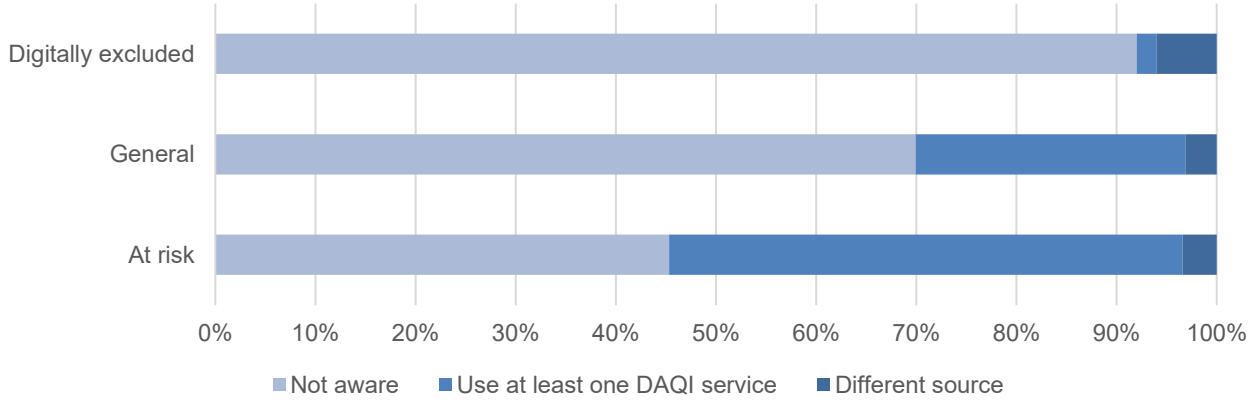
Other types of people were **less familiar with the DAQI than average (more than 10pp difference)**, such as those aged over 55; who have no lung and/or heart conditions nor use medical inhalers; have no other qualifications of unknown levels; work in indoor settings except for the health and care sector, live in households without dependents without have any lung and/or heart condition; non-pregnant women; and/or have lower levels of income (under £10,000/household).

37% of survey respondents said they use at least one of the DAQI services (UK-AIR website, X/Twitter page, email bulletins, telephone, etc) currently (Q5). People who perceive themselves at risk of air pollution are (1.5-2 times) more likely to use at least one of the DAQI services, when compared to those not perceiving themselves at risk. This is also case for people who are actually at risk, based on the DAQI's definition, as well as the sample of people in the 'at risk' group when compared to others. These differences are statistically significant and can also be observed by the results presented in Figure A6-18 by sample groups.

In addition, the likelihood of having used at least one of the DAQI services increases with interest in air quality, i.e., 25% of people with no/low interest in air quality have used at least

one of the DAQI services, while almost 45% of people with a medium/high interest in air quality have used at least one of them. The difference is also statistically significant.

Figure A6-18 Use of DAQI information services (% of respondents for each group; n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)

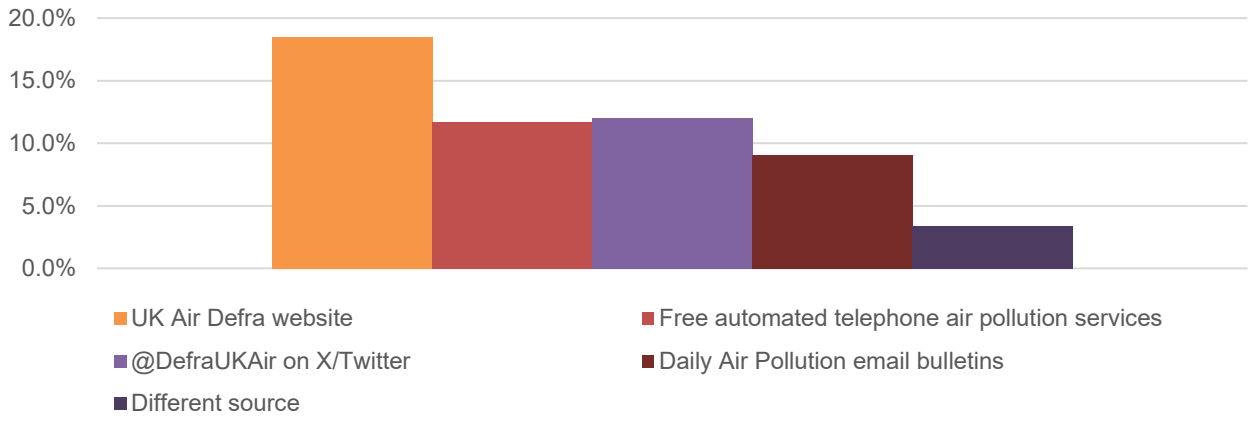


People of the following types were also **more likely to have used at least one of the DAQI services (more than 10pp difference)**, including people aged under 44; who reside in Greater London; suffer from one or more lung and/or heart condition and/or use medical inhalers; attained qualifications at the Level 4 or above; work in a health or social care setting and/or outdoors; live in households with dependents that require care and/or suffer one or more chronic lung and/or heart condition; pregnant women; and/or have higher levels of income (above £70,000/household).

Other types of people were **less likely to have used any of the DAQI services (more than 10pp difference)**, such as those aged over 55; who have no lung and/or heart conditions nor use medical inhalers; reside in South East of England, work in indoor settings except for the health and care sector, live in households with dependents who do not require care and/or do not have any lung and/or heart condition; non-pregnant women; and/or have lower levels of income (under £10,000/household).

The UK Air Defra website and @DefraUKAir X/Twitter account were observed to be the most popular, accessed by around 20% and 12% of the respondents (N=2,008) respectively, as presented in Figure A6-19. Respondents also noted accessing alternative sources of air quality information, such as news reports, weather applications, search engines, the Met Office website and personal air quality sensors.

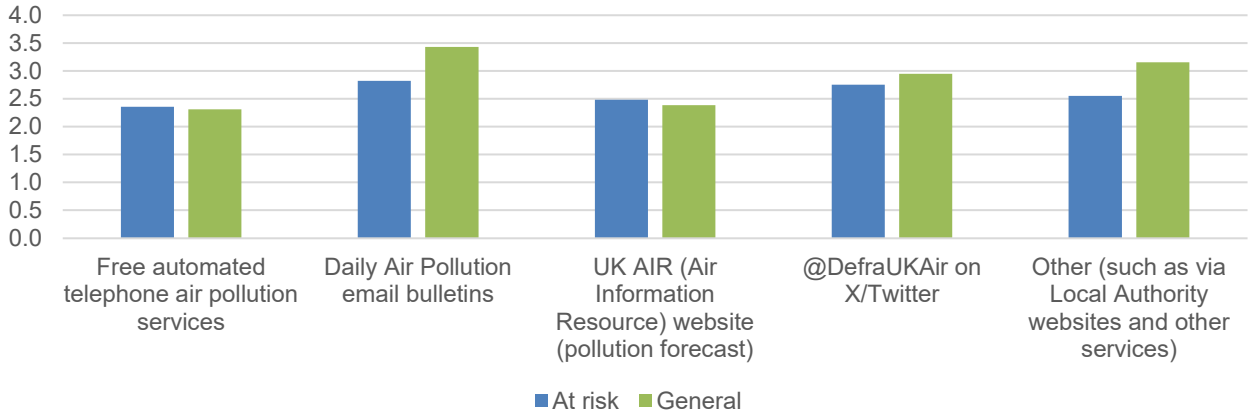
Figure A6-19 Which DAQI information services do you use? (% of respondents in overall sample; N=2,008)



More than 70% of the DAQI 'users' who were aware of the DAQI, had seen the 'DAQI visuals' and used at least one of the DAQI information services said that they engaged with their service of choice at least once a week (Q7). Around 15% of the respondents accessed the various services daily and around 55% of the respondents accessed these services at least once a week but not every day. On average, respondents from the 'at risk' group accessed the free automated telephone air pollution services and UK AIR website more times per week than those from the general population group. In contrast, respondents from the general population group, on average, accessed the daily air pollution bulletins, X/Twitter page and other sources (such as local authority websites) more times per year than at-risk respondents.

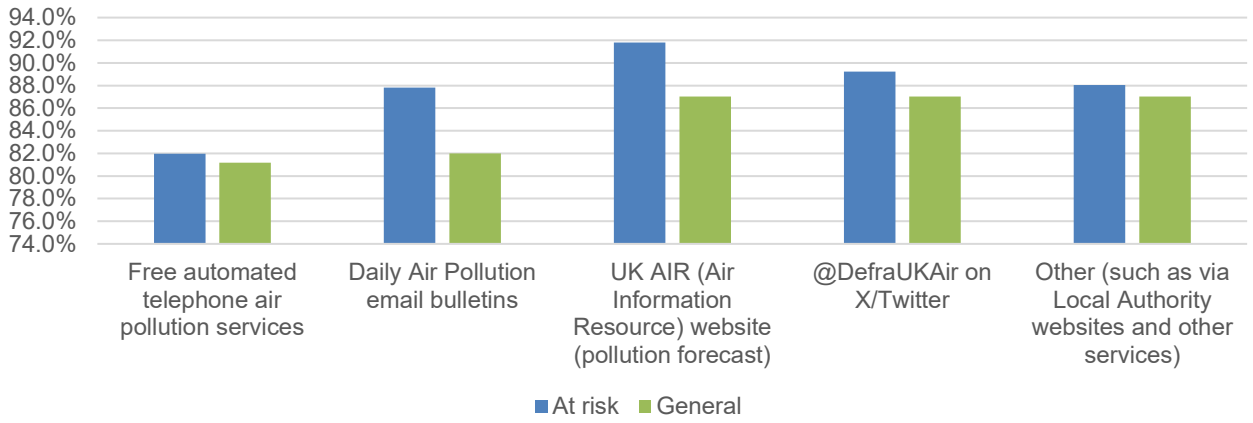
Overall, the most accessed DAQI services were the daily air pollution email bulletins followed by the @DefraUKAir X/Twitter account. People who perceived themselves to be at risk from air pollution were (1-1.5 times) more likely to access the daily air pollution bulletins and X/Twitter account than those who did not perceive themselves to be at risk. This difference is statistically significant. Figure A6-20 presents the frequency of accessing these information services for each group of respondents.

Figure A6-20 Frequency of accessing DAQI information services (average number of times per week for each group of respondents who are familiar with each information service) [221]



The majority of people who had seen information similar to the 'DAQI visuals' and were familiar with at least one of the DAQI information services (>75%; n=673) found the DAQI information services easy to access (Q8), with the UK AIR website and @DefraUKAir X/Twitter being the easiest to use for respondents from the general (>85%; N=239) and at risk (~90%; n=427) groups. The findings are presented in Figure A6-21.

Figure A6-21 Is it easy to access the DAQI information services[222] ? (% of respondents for each group; n=427 for at risk, n=239 for general)



When pooling the evidence by risk perception, people who did not perceive themselves at risk from air pollution were (1-1.5 times) more likely to find the Defra twitter account easier to access than those who perceived themselves at risk from air pollution. On the other hand, 'at risk' people were (1-1.5 times) more likely to find the daily air pollution email bulletins easier to access than the rest. In both cases, the differences are statistically significant.

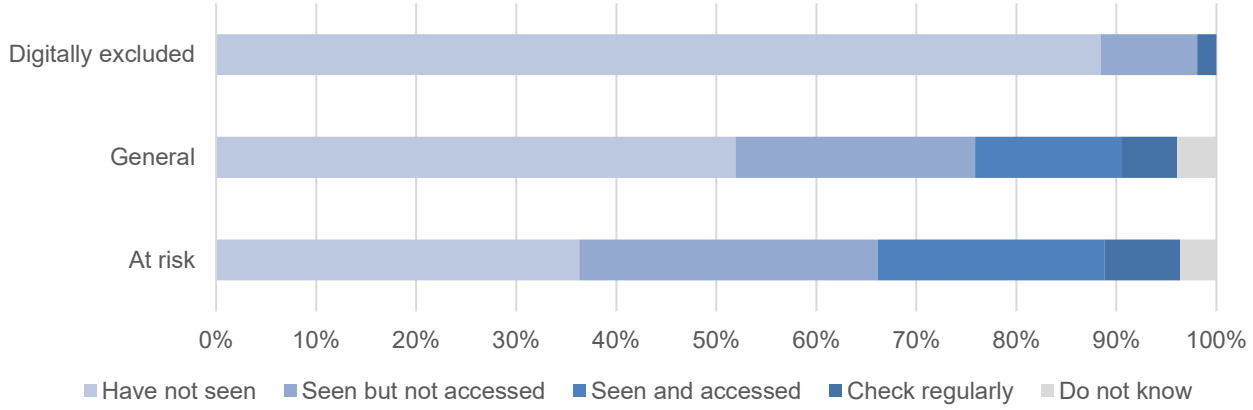
Finally, there is notably less awareness and access of the DAQI's 'Recommended Actions and Health Advice', with over 70% of respondents who had seen the 'DAQI visuals' and were familiar with the DAQI information services (n=1,538) reporting that they have not seen or have seen but not accessed these recommendations and

[221] Sample sizes: Free automated telephone air pollution services (N=115 for at risk, N=86 for general); Daily Air Pollution email bulletins (N=113 for at risk, N=55 for general); UK AIR website (N=218 for at risk, N=109 for general); @DefraUKAir on X/Twitter (N=159 for at risk, N=61 for general); Other (N=14 for at risk, N=15 for general)

[222] This refers to the respondents that found it 'Somewhat easy (can find/do not know how to use)', 'Easy (can find/use with difficulties)' or 'Very easy (can find/use with ease)' to use the information service.

advice (Q9)**.** People in the 'at risk' group appear, again, more likely to access and/or check regularly the advice provided by the DAQI. These findings are presented in Figure A6-22.

Figure A6-22 Accessing accompanying health messages (% of respondents for each group; n=777 for at risk, n=709 for general, n=52 for digitally excluded)



People who perceived themselves at risk from air pollution were (1.5-2 times) more likely than others to have accessed DAQI health messages at least once. This is also case for people who are actually at risk, based on the DAQI's definition, as well as the sample of people in the 'at risk' group when compared to others. These differences are statistically significant.

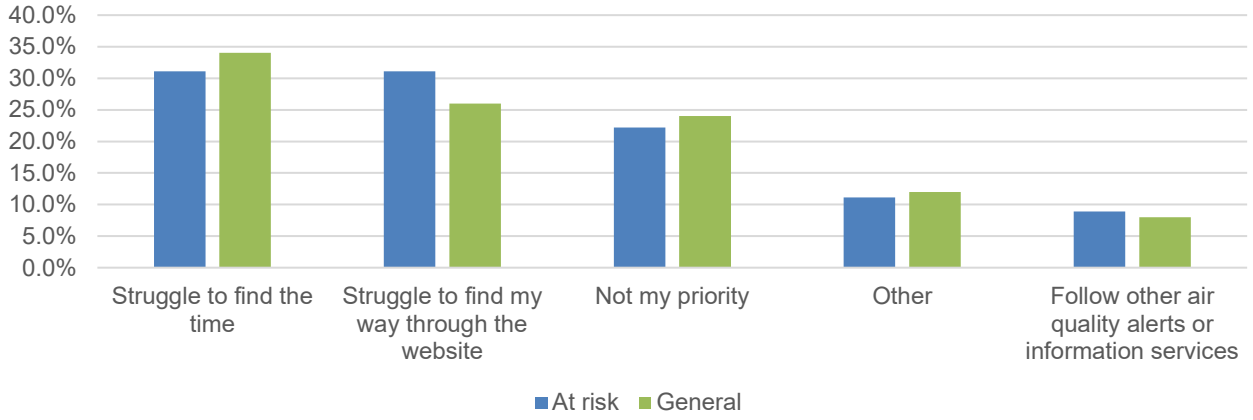
People of the following types were **more likely than average to have seen and accessed the accompanying health messages at least once** (more than 10 pp difference), including people aged under 35; and/or have very high levels of income.

Other types of people were **less likely to have accessed to the accompanying health messages** (more than 10 pp difference), such as those aged over 65; and/or have lower levels of income.

A6.3.4 Barriers to accessing the DAQI (RSQ3.4)

The most common barriers for people to access the DAQI appear to be: 1) a lack of awareness (see the previous section); 2) finding time, and/or 3) finding their way to/through the UK AIR website pages (Q6). Survey participants who were interested in air quality but had not accessed nor were familiar with the DAQI (n=97) said they struggled to: a) find time (>30% of respondents) and/or b) their way through the DAQI website (~20% of respondents). Around 20% of respondents suggested that accessing the DAQI was not their priority, and under 10% noted that they follow other air quality alerts or information services. Another barrier appears to be the lack of awareness of the health risks posed by episodes of 'high levels' of air pollution. Other reasons for not accessing the DAQI included being unable to use technology as well as the use of alternate sources like the weather reports on TV, web searches and weather applications. These findings are presented in Figure A6-23.

Figure A6-23 Barriers to accessing DAQI for those interested in air quality (% of respondents for each group; n=45 for at risk, n=50 for general)



People of the following types appeared to **find it harder than average to find the time and/or find their way through the website** (more than 10 pp difference), including people who are aged 25-34 years and 45-54; work outdoors; live in households with dependents requiring care; pregnant women; and/or have high levels of income.

Other types of people **found it easier than average to find the time and/or their way through the website** (more than 10 pp difference), such as those aged over 55; work in indoor settings; live in households with dependents who do not require care; and/or have lower levels of income.

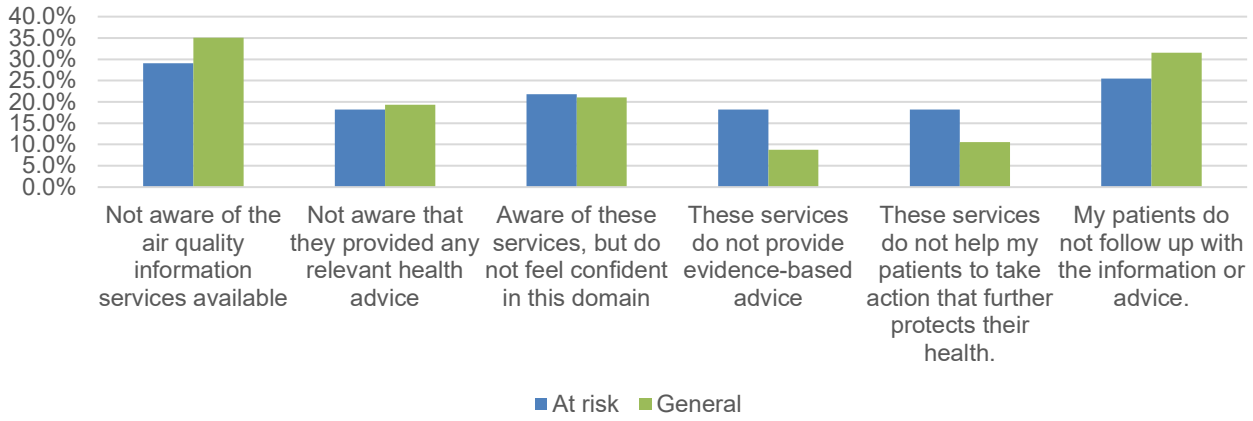
To further investigate the barriers to accessing the DAQI, the survey asked health care professionals from each group of participants about recommending the DAQI information services to their patients.

Around 75% of health care professionals said that they referred their patients to the available air quality information services, especially those who are vulnerable to air pollution (Q14).

Health care professionals who perceived themselves and/or their dependents at risk from air pollution were (1.5-2 times) more likely than others to recommend the DAQI information services to their patients. This is also case for health care professionals who are and/or have dependents actually at risk, based on the DAQI's definition. All these differences are statistically significant.

Those who did not refer their patients, ~25%, suggested that this might be because: **they were not aware of the air quality information services (over 30%) and/or that their patients would not follow-up with this information (over 25%)** (Q15). Moreover, health care professionals also felt that some of their patients had problems unrelated to air pollution or disabilities that prevented them from understanding and following the advice. Some professionals also expressed their concern that the advice could have unintended consequences for people with mild symptoms. These responses are presented in Figure A6-24.

Figure A6-24 Reasons for not referring DAQI information services to patients (% of respondents who are health care professionals for each group; n=55 for at risk, n=57 for general)



A6.3.5 Facilitators of accessing the DAQI (RSQ3.5)

Facilitators of access were not explored directly; however, analysis of the survey outputs suggests that the following could be worth exploring:

- **Interest in air quality:** Overall, people with a medium/high interest in air quality have accessed to the DAQI to a greater extent than those with no/low interest.
- **Risk perception:** Respondents who did not perceive themselves at risk from air pollution, despite their personal health status, were less likely to have accessed the DAQI than those who perceived themselves to be at risk. This indicates that risk perception could be an important facilitator of access to DAQI.
- **Education and household income:** Respondents with higher levels of education and/or income are more likely to have accessed to the DAQI than others, suggesting that these variables may be linked with greater access.
- **Third-party air quality information services:** The responses suggest that many participants access air quality information using third-party air quality information services like navigation/map and weather applications, news outlets/reports, the Met Office website, search engines, etc., which draw upon DAQI information. These could be an important facilitator of access to the DAQI.

A6.4 CERQ4 UNDERSTANDING

CERQ4: To what extent is the DAQI understood by its users in the way it was intended to be understood?

Based on the survey responses, DAQI users appear to be more likely than not to understand the DAQI in the way it was intended to be understood. The majority of participants were able to correctly understand the DAQI information and visuals, with participants from the 'at risk' group showing a slightly higher level of understanding.

Participants were asked about their level of understanding of the information, visuals and messaging provided by the DAQI information services. The responses to the survey suggest:

- **More than half of all survey respondents were able to correctly understand and interpret the message that the DAQI was designed to communicate, with at-risk respondents showing a slightly higher degree of understanding compared to general and at-risk respondents**. Around 60% of at-risk respondents (N=907), ~50% of general (N=1,001) and ~50% of digitally excluded (N=100) respondents were able to correctly interpret an example visualisation and language of the DAQI.
- **Survey respondents demonstrated medium levels of understanding of the 'Recommended Actions and Health Advice'**, with an average score of 3 or more out of 5. Respondents in the at risk and 'digitally excluded' groups reporting slightly higher levels of understanding when compared to the general population. Respondents in the 'at risk' group reported fewer times 'no' or 'low' understanding of the health advice (~19%, n=907), compared to respondents in the digitally excluded (22%; nN=100) and general (~23%; n=1,001) groups.
- **Around half of all respondents found it easier to understand 'DAQI visuals' with clear geographical boundaries and Red-Amber-Green or similar colour-coding**. Visuals with less clear or uncoloured geographical boundaries were not preferred.
- **Colour coding and labelling of air quality visuals along with clear geographical boundaries, based on aggregated regional-level air quality ratings, were observed to be the major facilitators of understanding DAQI visual information, along with education and household income.**

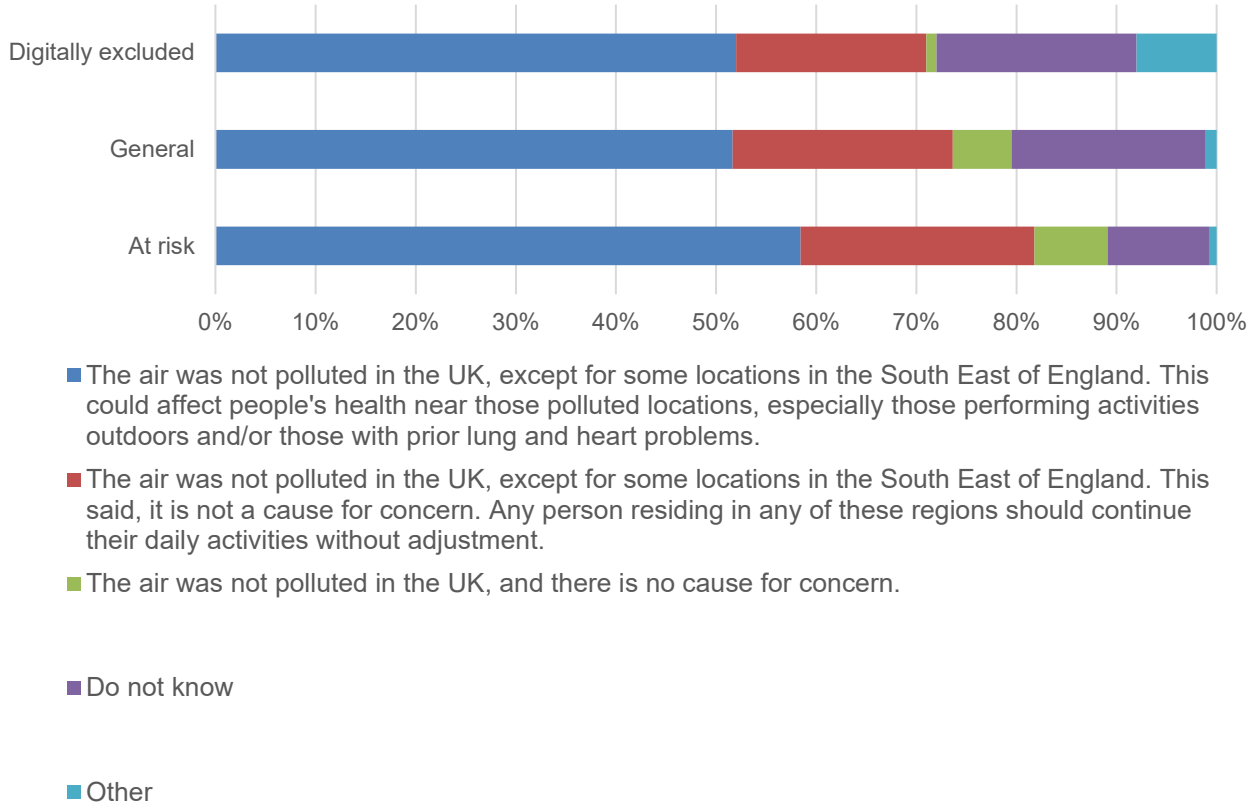
These findings are explored in more detail in the following subsections.

A6.4.1 Understanding of the DAQI in line with intention (RSQ4.1 and RSQ4.2)

More than half of all respondents (N=2,008) were able to correctly understand and interpret the message it was designed to communicate, with at-risk respondents showing a slightly higher degree of understanding compared to general and at-risk respondents (Q16). Around 60% of at-risk respondents (n=907) and 50% of general (n=1,001) and digitally excluded (n=100) respondents were able to correctly interpret an example visualisation and language of the DAQI. An additional ~20% of survey respondents (N=2,008) understood what the DAQI messaging is reporting in terms of air pollution levels, but interpreted incorrectly that high ratings are not a cause for concern. Only 10% of at-risk respondents (n=907) said they did not know what the example visualisation and language meant, compared to 20% of general (n=1,001) and digitally excluded (n=100) respondents.

Figure A6-25 presents the percentage of participants from each group corresponding to different interpretations of the following question: "*Consider the following example from 17 November 2023 on the UK AIR website. The evidence suggests that across most of England, and Northern Ireland, Wales and Scotland DAQI index scores between 2-3 were reported, whereas in some locations of South East England, a DAQI index score of 9 was reported… What does this mean?*"

Figure A6-25 Interpretation of DAQI messaging: *"The evidence suggests that across most of England, and Northern Ireland, Wales and Scotland DAQI index scores between 2-3 were reported, whereas in some locations of South East England, a DAQI index score of 9 was reported."* (% of respondents for each group; n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



People who work indoors appeared to be **more likely than average to answer this question correctly than average** (almost 10 pp difference).

People who work outdoors were **less likely to answer this question correctly** (almost 10 pp difference).

A6.4.2 Understanding of the advice associated with DAQI readings (RSQ4.4)

Despite having low awareness of the 'Recommended Actions and Health Advice', when asked to consider the advice (for the first time for many of them), survey respondents reported medium levels of understanding, with an average score of 3 or more out of 5 (where 0 means no understanding and 5 very high understanding). Respondents in the at risk and 'digitally excluded' groups reported slightly higher levels of understanding when compared to the general population.

Evidence was collected on the level of understanding of air quality alerts and accompanying health messages (see Figure A6-26) across three scenarios by asking respondents to rate their level of understanding:

- *Scenario 1: You have received an air quality alert that indicates there is high air pollution with a DAQI score of 7-9* (Q19).
- *Scenario 2: You have received an air quality alert that suggests a very high level of air pollution with a DAQI score of 10* (Q20).
- *Scenario 3: You have received an air quality message that suggests moderate air pollution, or a DAQI score of 4-6* (Q21).

Figure A6-26 Accompanying health messages presented to survey participants

Air Pollution Banding	Value	Accompanying health messages for at-risk individuals*	Accompanying health messages for the general population
Low	1-3	**Enjoy** your usual outdoor activities.	**Enjoy** your usual outdoor activities.
Moderate	4-6	Adults and children with lung problems, and adults with heart problems, **who experience symptoms**, should **consider reducing** strenuous physical activity, particularly outdoors.	**Enjoy** your usual outdoor activities.
High	7-9	Adults and children with lung problems, and adults with heart problems, should **reduce** strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also **reduce** physical exertion.	Anyone experiencing discomfort such as sore eyes, cough or sore throat should **consider reducing** activity, particularly outdoors.
Very High	10	Adults and children with lung problems, adults with heart problems, and older people, should **avoid** strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often.	**Reduce** physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat.

All respondents demonstrated medium-to-high levels of understanding of the provided health advice, with mean scores between 3.3-3.5 for each group across scenarios. Respondents from the general population reported a slightly lower understanding of the advice compared to at risk and digitally excluded respondents. These small differences between sample groups were not statistically significant.

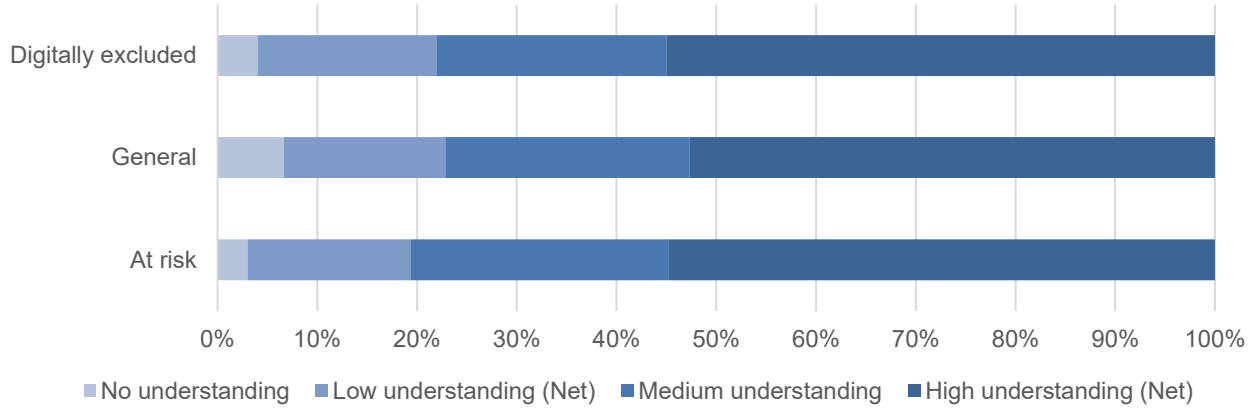
People of the following types showed a **higher level of understanding of the provided health advice than average** (more than 10 pp difference), including people who attained qualifications at the Level 4 or above; and/or very high levels of income.

Other types of people showed a **lower level of understanding of the provided advice** (more than 10 pp difference), such as those who have no or other qualifications of unknown levels.

The level of understanding does not appear to differ notably based on the level of air pollution that is notified. Respondents reported similar levels of understanding of the advice across the three scenarios i.e., very high, high and moderate air pollution levels.

The levels of understanding do not appear to differ notably across the 'at risk', 'general population' and 'digitally excluded' groups. Respondents in the 'at risk' group did show the lowest percentage of no or low understanding of the health advice across groups. On average across the three scenarios, around 19% of at-risk respondents (n=907) said they had either no, very low or low understanding of the advice, compared to corresponding figures of 23% and 22% for the general (n=1,001) and digitally excluded (n=100) respondents respectively. These results are presented in Figure A6-27.

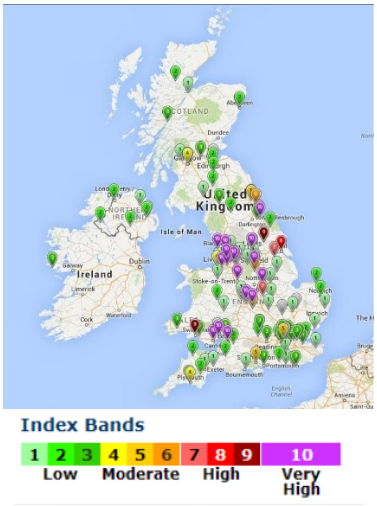
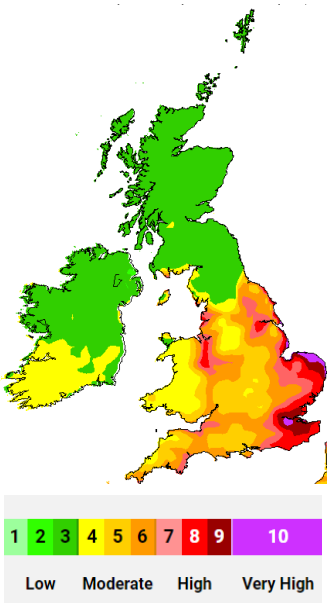
Figure A6-27 Level of understanding of health messages (average % of respondents for each group across three scenarios; N=2,008)



A6.4.3 Contribution of the visualisation to the users' understanding of DAQI (RSQ4.2)

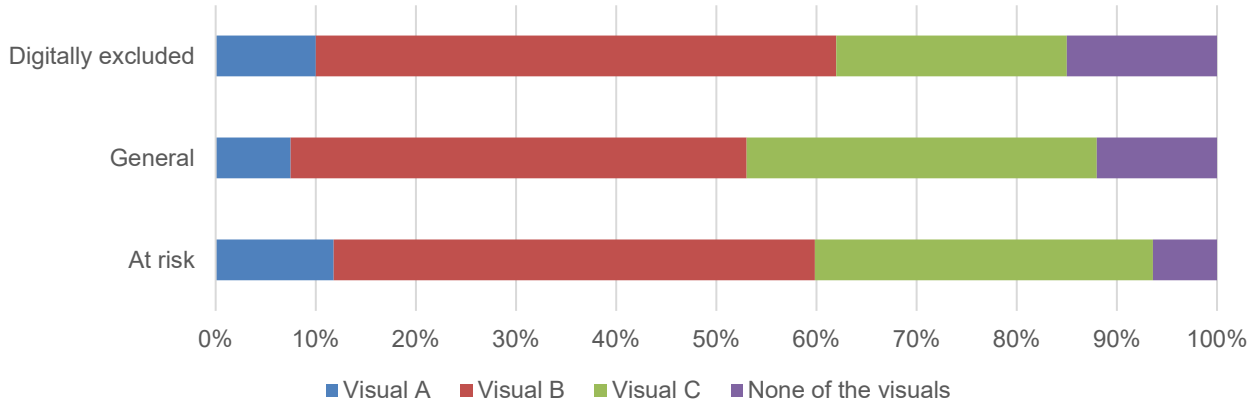
To evaluate how DAQI visualisation affected users' understanding, survey participants were asked to select which of the DAQI visuals they found easiest to understand (Q18) (see Figure A6-28).

Figure A6-28 Choice of DAQI visual representations presented to survey participants

Visual A	Visual B	Visual C
		

Respondents from all groups found Visual B to be the easiest to understand, followed by Visual C and Visual A in decreasing order of ease of understanding. While the majority of respondents found at least one of the visuals easy to understand, around 5% of respondents in the 'at risk' group (N=907), 10% of respondents in the 'general population' group (N=1,001) and 15% of respondents in the 'digitally excluded' group said they did not find any of the visuals easy to understand. These results are presented in Figure A6-29.

Figure A6-29 Which of the visuals do you find easiest to interpret? (% of respondents for each group; n=907 for at risk, n=1,001 for general, n=100 for digitally excluded)



Respondents noted that colour coding (Red-Amber-Green ratings) and area boundaries in Visual B made the visuals easier to understand, especially for those living near regional borders. Most respondents also preferred the aggregated single-colour ratings for areas in Visual B compared to the colour gradients in Visual C as they were easier to understand at

a glance, although some respondents did note a preference for the ability to identify air quality in their precise location provided by Visual C.

A6.4.4 Barriers and facilitators of understanding (RSQ4.2, RSQ4.5 and RSQ4.6)

Although barriers to the understanding of the DAQI were not explored directly by the survey, the responses suggest the following factors:

- **Colour blind or partially sighted individuals found colour coded visuals with no labels difficult to interpret.**

Based on the evidence collected from the survey, the key **facilitators** of understanding of the DAQI are:

- **Colour coding**: The majority of respondents noted a preference for colour coding of visuals and found the index band key and scale easy to follow.
- **Aggregated outlook**: For the majority of respondents, despite being less precise, block colour coding based on aggregated air quality ratings for an area enabled them to interpret the visuals quickly at a glance and avoid any errors in understanding.
- **Clear definition of area boundaries**: Most respondents found clearly defined boundaries to be visually appealing and easier to understand, especially those that lived near regional boundary areas.
- **Labels**: Labelling of visuals with air quality ratings could be considered to complement the colour coded maps and enhance the accessibility of the DAQI visuals.
- **Education and household income:** People with a level 4 qualification or above, or from high income households (closely related to education), tend to understand DAQI and its advice better than others, proving that education is an important facilitator of understanding.

A6.5 CERQ5 CHANGE OF BEHAVIOUR

CERQ5: To what extent do the people who use the DAQI enact the advice it provides?

Based on the survey responses, people generally appear responsive to air quality notifications and willing to enact the recommended actions and/or advice provided by the DAQI. At present, only a few people are aware and check the 'recommended actions and/or advice' regularly (~6%), and around half of these might respond with changes to their daily activities in the event of moderate, high or very high air pollution notifications.

Participants were asked if they would adjust their outdoor activity and inhaler usage in response to 'very high', 'high' or 'moderate' air quality readings from the DAQI information services. The responses to the survey suggest:

- **Around half of the survey participants (N=2,008) might adjust their daily activities, such as reducing activity outdoors and/or replacing it with activities indoors, in scenarios of 'very high' or 'high' air pollution.** These participants are likely to make more pronounced adjustments in 'very high' when compared to 'high' pollution days, such as replacing activities outdoors for others indoors. Moreover,

people who perceive themselves as being more at risk are slightly more likely to make adjustments to their daily activities, however, the difference is not large.

- **There are groups of people who would be responsive and make adjustments to their behaviour even in the event of 'moderate' air pollution notifications**. This was explored for people caring for children and/or dependents with perceived risk (n=368). Around 30% of this subgroup might still make adjustments to their daily activities in a 'moderate' air pollution day.
- **Around 40% of the survey respondents with dependents (n=657), children and/or adults requiring care, would also advise their dependents to adjust their daily activities,** either by reducing their physical activity outdoors and/or performing alternative activities indoors; 45% would advise their dependents to go about their day as planned; and 10% would not give their dependents advice regarding air quality.
- **Around 70% of survey participants who use/have inhalers (n=1,011) report that they might adjust their inhaler usage during periods of 'very high' and 'high' air pollution**, including carrying it with them especially due to poor air quality in case they need it and/or using it preventatively more frequently than usual.
- People's misunderstanding of DAQI readings and, of course, lack of access to DAQI and the 'Recommended Actions and Health Advice' are potential barriers to behaviour modification.

These findings are explored in more detail in the following subsections.

A6.5.1 Change of behaviour based on DAQI readings (RSQ5.1 and RSQ5.2)

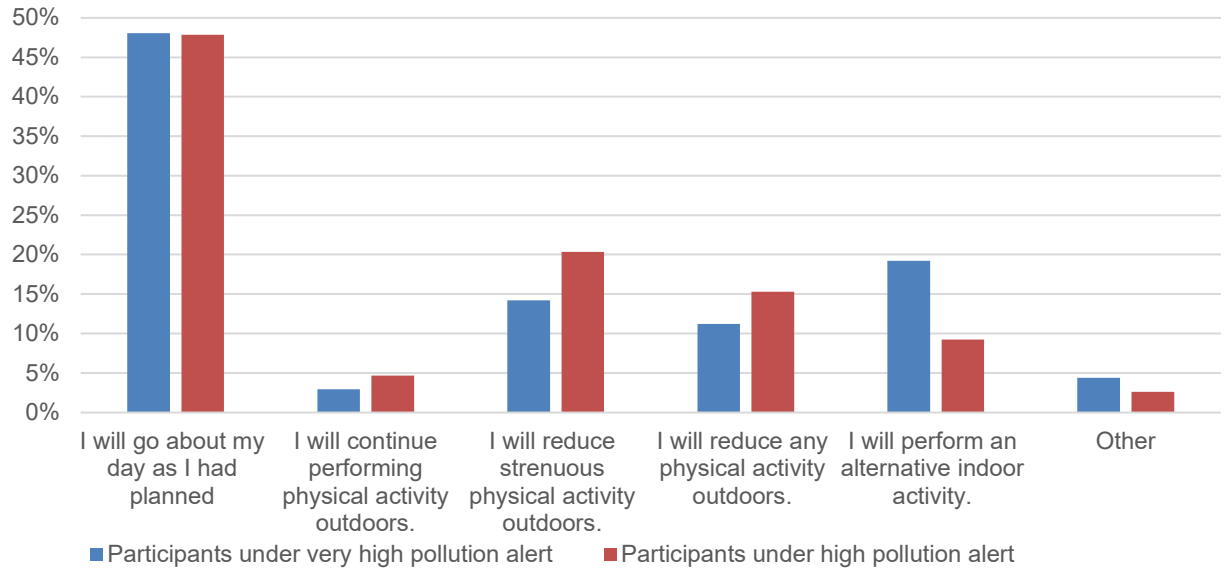
A6.5.1.1 Own behaviour

Around half of the survey participants (N=2,008) might adjust their daily activities, such as reducing activity outdoors and/or replacing it with activities indoors, in scenarios of 'very high' or 'high' air pollution, either by reducing physical activity outdoors and/or performing alternative indoor activities (Q22, Q23, Q27).

For those people willing to make adjustments, people are notably more likely to perform alternative activities indoors when alerted of 'very high' air pollution or DAQI score of 10 when compared to 'high' air pollution or a DAQI score of 8 (~20% against ~10% of survey participants respectively). This suggests that people who are responsive to the alerts and information are likely to make adjustments or more pronounced changes with higher levels of risk suggested by the alerts.

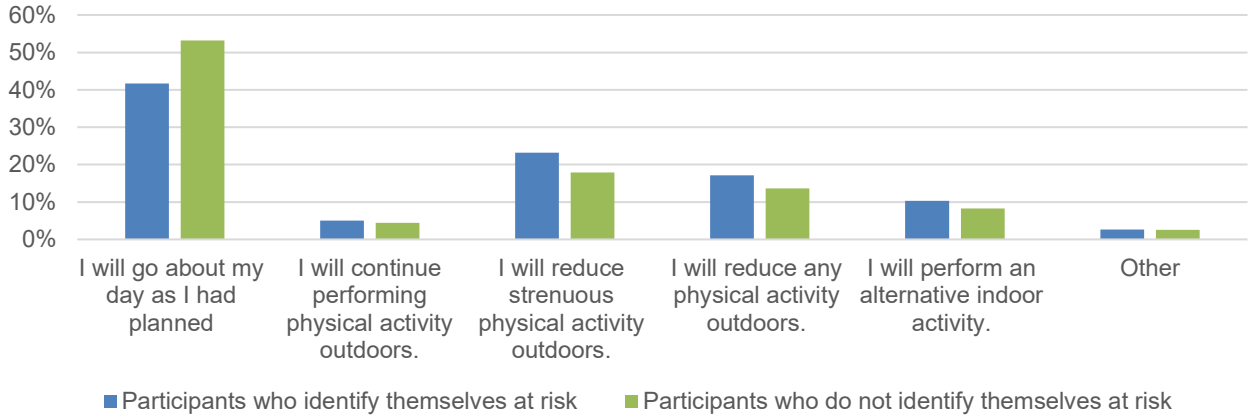
Figure A6-30 presents the comparison of responses from participants between 'very high' and 'high' air pollution scenarios.

Figure A6-30 Participant responses to a scenario of receiving a 'very high' or 'high' air pollution alert (% of respondents N=2,008 or n=1,538 respectively)



Moreover, people perceiving themselves at risk were (1-1.5 times) more likely to make adjustments to their daily activities, when compared to those not perceiving themselves at risk (51% when compared to 40% of these groups, respectively) (Q22, Q23). That is, it is more likely that people who identify themselves at risk would make some adjustments to their day (20-30% more of a chance they would reduce their activity outdoors). This is presented in Figure A6-31.

Figure A6-31 Participant responses to a scenario of receiving a 'high' air pollution alert, depending on their risk perception (% of respondents with a risk perception, n=1,538)



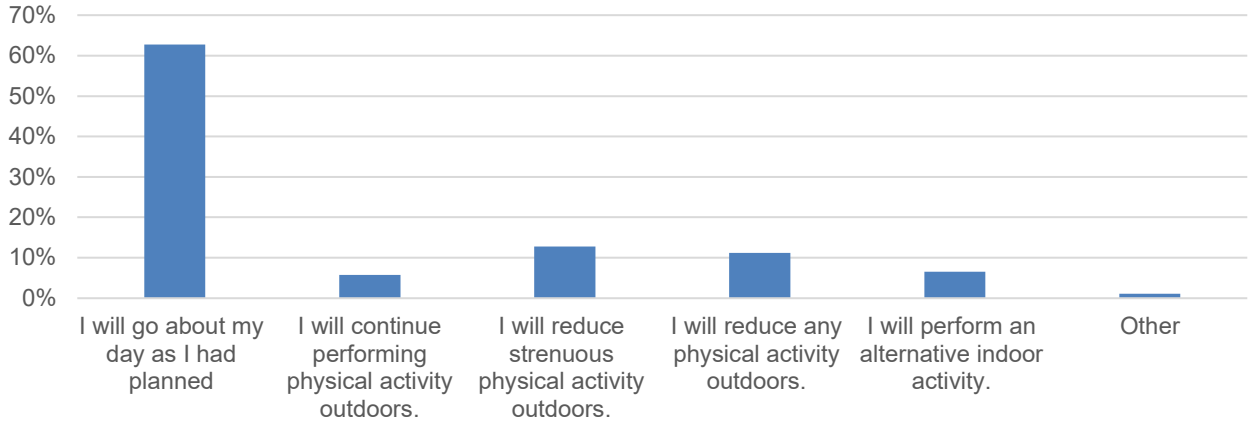
Some participants reported they would take another type of indoor activity, such as housework or indoor exercise (cycling, gym, swimming), or more leisurely physical activities like resting, reading, watching television or playing board games or online games. Please note that small percentage of participants said they would increase their inhaler use in response to these alerts.

There are groups of people who would be responsive and make adjustments to their behaviour even in the event of 'moderate' air pollution notifications or a DAQI score of 5. This was explored for people caring for children and/or dependents with perceived risk.

Around 30% of people who would perceive any dependent they care for to be at risk (N=368) might still make adjustments to their daily activities in a 'moderate' air pollution day (Q31)**.** The rest, that is 70% of the respondents (adults who would consider their dependents to be at risk of air pollution) suggested they might continue with the day as planned and/or perform physical activity outdoors in the event of a 'moderate' air pollution notification. Some respondents also said they would reduce strenuous outdoor physical activity like running and sports and substitute with walking or light jogging instead.

The participant responses in a scenario of 'moderate' air pollution are also presented in Figure A6-32.

Figure A6-32 Participant responses to a scenario of receiving a 'moderate' air pollution notification only if they would consider dependents under their care to be at risk (% of respondents with dependents at risk as perceived, n=368)



A6.5.1.2 Behavioural advice to dependents

It was observed that around 40% of the survey respondents with dependents requiring care (n=657) would advise their dependents to make adjustments to their daily activities, either by reducing physical activity outdoors and/or performing alternative indoor activities (Q26, Q30). Again, this is a relatively similar scale to the advice people give to themselves when faced with similar risks.

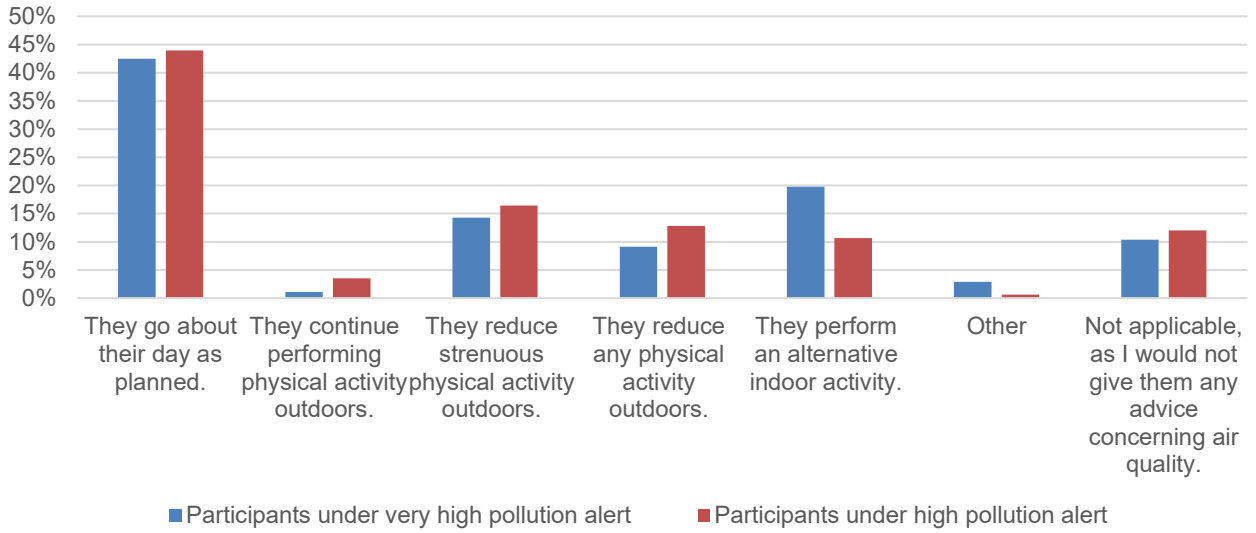
Moreover, these survey respondents who would advise their dependents to make adjustments about their daily activities are **more likely to suggest that they perform activities indoors when notified of 'very high' air pollution or a DAQI score of 10 when compared to 'high' air pollution or a DAQI score of 8** (~20% versus ~10% of the survey participants respectively). This again suggests that people who are responsive to the notifications of elevated air pollution are more likely to suggest that they and/or their dependents make more pronounced adjustments to their daily activities when facing higher pollution risks.

Around 45% of survey respondents with dependents (n=657), children and/or adults requiring care, also report they might advise their dependents to go about their day as planned or continue performing physical activity outdoors irrespective of receiving 'high' or 'very high' air pollution alerts. That is, it appears that more broadly, people with dependents might not be as sensitive to relatively elevated levels of air pollution concerning others as it is when considering their own actions.

Finally, around 10% of the respondents (n=657) also noted that they would not give their dependents any advice regarding air quality.

Figure A6-33 presents the comparison of responses from respondents between 'very high' and 'high' air pollution scenarios.

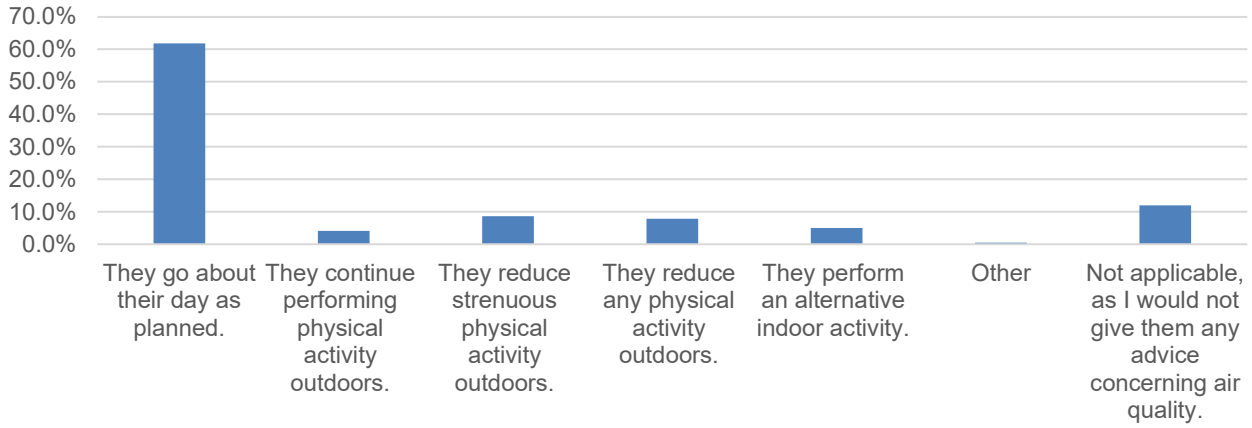
Figure A6-33 Participant advice to their dependents in a scenario of receiving a 'very high' or 'high' air pollution alert (% of respondents n=657)



To explore the sensitivity of adults with dependents to the air quality levels, participants with dependents under their care who they perceive to be at risk of air pollution were asked about the advice they would provide their dependents in case of a moderate air pollution alert with a DAQI score of 5 (Q33).

There appears to be some sensitivity to the level of air quality for respondents with dependents they care for who they perceived to be at risk (n=599), as they appear to be more likely to advise their dependents to continue with the day as planned and/or perform physical activity outdoors (>65%) in the event of a 'moderate' air pollution notification, compared to the case for 'high' and 'very high' air pollution alerts above. Around 20% of respondents might still advise their dependents to make adjustments to their daily activities in a 'moderate' air pollution day, which aligns with the suggestion that there are groups of people who are responsive to any level of alert, including 'moderate', 'high' and 'very high'. Finally, around 12% of respondents would not give their dependents any advice in response to air quality alerts. The participant advice to dependents in a scenario of 'moderate' air pollution are also presented in Figure A6-34, by statement.

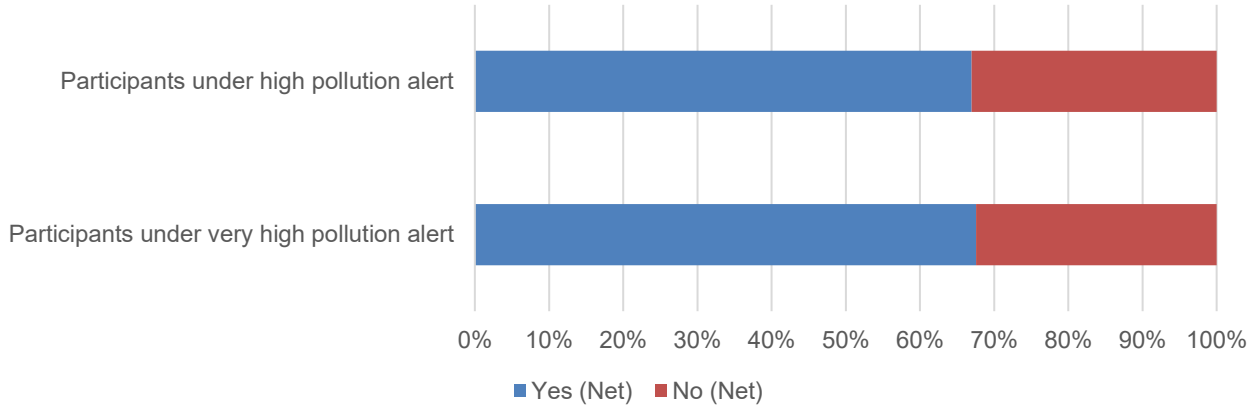
Figure A6-34 Participant advice to their dependents in a scenario of receiving a 'moderate' air pollution notification only if they have dependents under their care who they consider to be at risk (% of respondents with dependents at risk as perceived, n=599)



A6.5.1.3 Medication behaviour

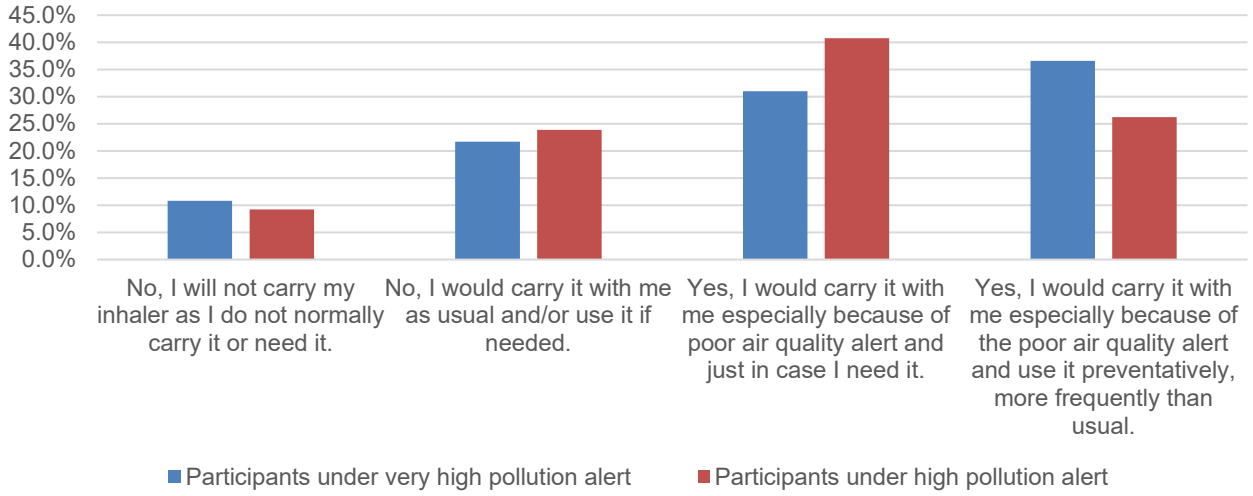
Around 70% of survey participants who use/have inhalers (n=1,011) report that they might adjust their behaviour during periods of 'very high' and 'high' air pollution, including carrying it with them especially due to poor air quality in case they need it and/or using it preventatively more frequently than usual (Q25, Q29)**.** Around 30% of the participants who used inhalers said that they would not change their behaviour in response to a 'high' or 'very high' air pollution alert and would carry on as normal by either not carrying their inhaler or carrying and using it as needed. These results are presented in Figure A6-35.

Figure A6-35 Participant response to changing their medication (including inhaler use) under 'high' and 'very high' air pollution (% of respondents who use inhalers, n=1,011)



Survey participants (n=1,011) appear more likely to use their inhaler preventatively and more frequently than usual under a 'very high' pollution alert (~37%) compared to a high air pollution alert (~27%). In case of a 'high' pollution alert, participants were more likely to carry their inhaler and use it on a need basis (~41%), compared to a 'very high' pollution alert (31%). Figure A6-36 presents the comparison of responses from respondents between 'very high' and 'high' air pollution scenarios.

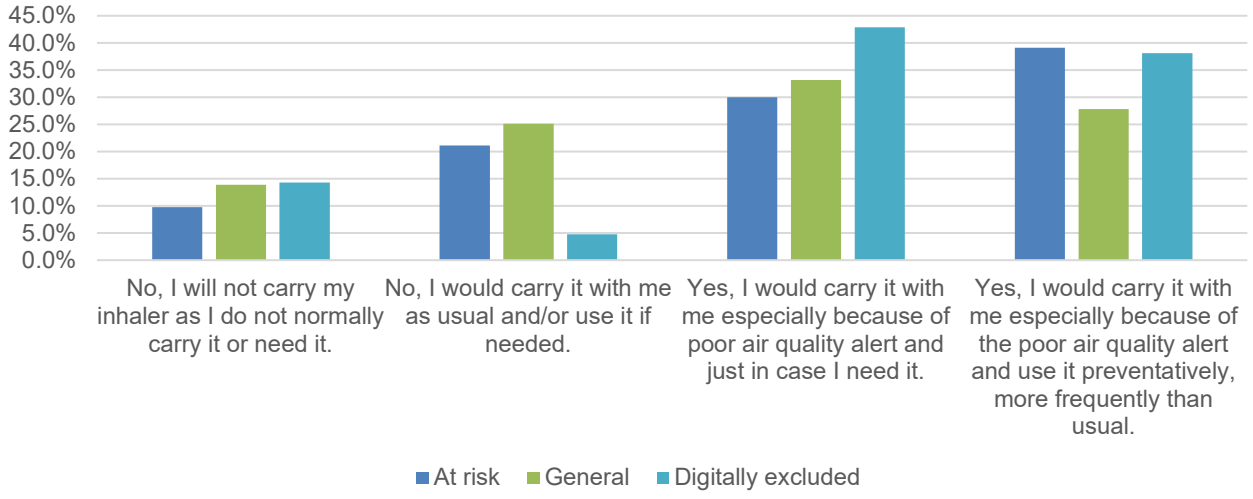
Figure A6-36 Participant response to adjusting their medication including inhaler under 'high' and 'very high' air pollution (% of respondents who use inhalers, n=1,011)



The response across the 'very high' and 'high alert' scenarios are explored in more detail below across the at risk, general and 'digitally excluded' groups.

Participants from the 'digitally excluded' group were the most likely to change their behaviour in response to a 'very high' air quality notification (N=21; ~80%), followed by the at risk (n=767; ~70%) and general (n=223; ~60%) groups (Q29). Of those who changed their behaviour in response to the alert, participants from the 'at risk' group were the most likely to carry their inhaler and using it preventatively more frequently than usual (N=767; ~40%). These results are presented by specific statement in Figure A6-37.

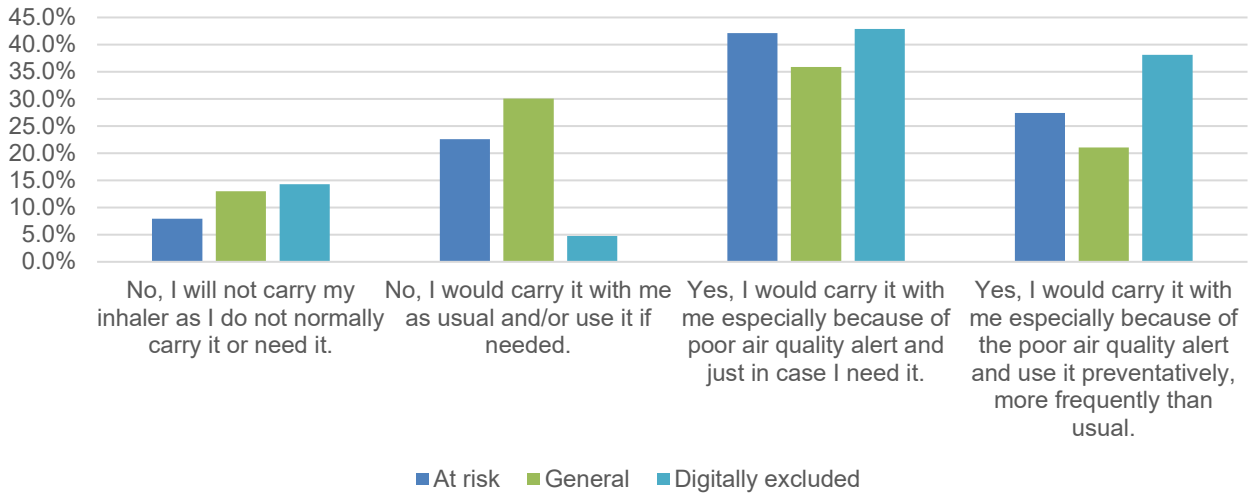
Figure A6-297 Participant response to adjusting their medication including inhaler under 'very high' air pollution (% of respondents who use inhalers, n=767 for at risk, n=223 for general, n=21 for digitally excluded)



Similar responses were received under the 'high' air quality notification (Q25)**.** Participants from the 'digitally excluded' group were the most likely to change their behaviour in response (N=21; ~80%), followed by the at risk (N=767; ~70%) and general (N=223; ~60%) groups. However, **participants were more likely to change their behaviour by carrying their inhaler just in case they need it under the 'high' air pollution alert as**

compared to the 'very high' air quality alert. Figure A6-38 presents the responses from participants under 'high' pollution alert by specific statement.

Figure A6-38 Participant response to adjusting their medication including inhaler under 'high' air pollution (% of respondents who use inhalers, n=767 for at risk, n=223 for general, n=21 for digitally excluded)



A6.5.2 Barriers to enacting DAQI advice (RSQ5.3)

Barriers to enacting DAQI advice have been primarily delved into through the interviews. The survey highlights that a key practical barrier to modifying behaviour upon a DAQI notification of air pollution episodes include the lack of awareness and access to the DAQI's 'Recommended Actions and Health Advice'. That is, even if people were notified of air pollution episodes, they might not know what to do about it.

A6.6 CERQ6 SOUNDNESS OF ADVICE

CERQ6: To what extent does advice the DAQI provides align with the intervention's intended outcome (to reduce severity of symptoms exacerbated by short term air pollution spikes) and impact (to reduce adverse health impacts)?

Survey responses suggest that the advice provided by the DAQI does not appear to be completely aligned with the intervention's intended outcomes and impacts.

The responses to the survey suggest:

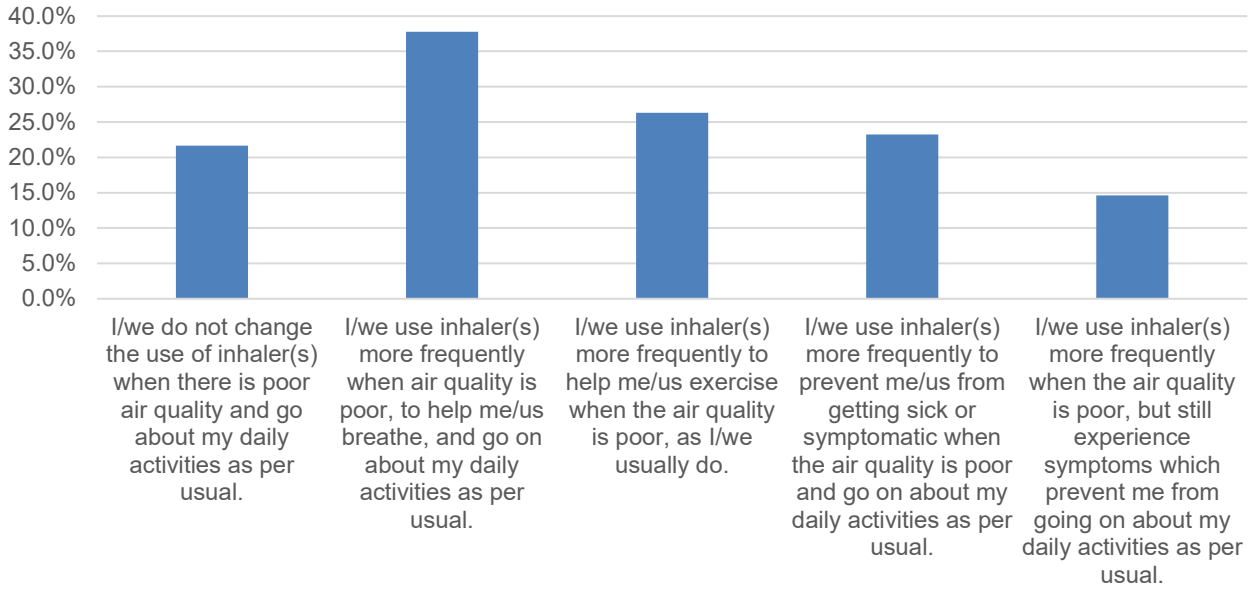
- **Generally, medical inhaler users are willing to make adjustments, increasing their frequency of use, to go about their daily activities when air quality is poor, which is perceived to be helpful** (e.g., preventing sickness, symptoms, etc). In a relatively lower number of cases, even increasing the frequency of inhaler use does not suffice.
- **Around half of the survey participants might delay health and social care appointments during episodes of poor air quality,** which could have knock-on implications on their overall health and wellbeing. Some other unintended consequences were highlighted in the survey responses, such as avoiding indoor physical activity.

These findings are explored in more detail in the following subsections.

A6.6.1 Health impact of increased use of inhaler(s) during episodes of high levels of air pollution (RSQ6.8)

Of the 1,011 who use medical inhalers frequently and/or on occasion, around 20% suggest they do not change their use when the air quality is poor and go about their daily activities as per usual (Q34)**. The rest or around 80%, however, said they would make changes to how frequently they use inhaler(s) with different perceived impacts.** The majority of people who make a more frequent use of inhaler(s) when the air quality is poor, manage to go on about their daily activities. In detail, 40% of users indicate that more frequent inhaler use help them breathe; 25% indicate that more frequent inhaler use help them exercise; and 20% indicate that more frequent inhaler use prevents them from getting sick and/or symptomatic. A smaller proportion of 15% of inhaler users, however, report that despite using inhaler(s) more frequently when air quality is poor, they still experience symptoms, which prevent them from going on about their daily activities as per usual. This is presented in Figure A6-39.

Figure A6-39 Personal experiences of using inhalers and/or on behalf of dependents during episodes of poor air quality (% of respondents who use inhalers across sample groups n=1,011)



People who perceive themselves at risk of air pollution are (1-1.5 times) more likely to change their use of inhalers when the air quality is poor than those who do not consider themselves at risk. This difference is statistically significant.

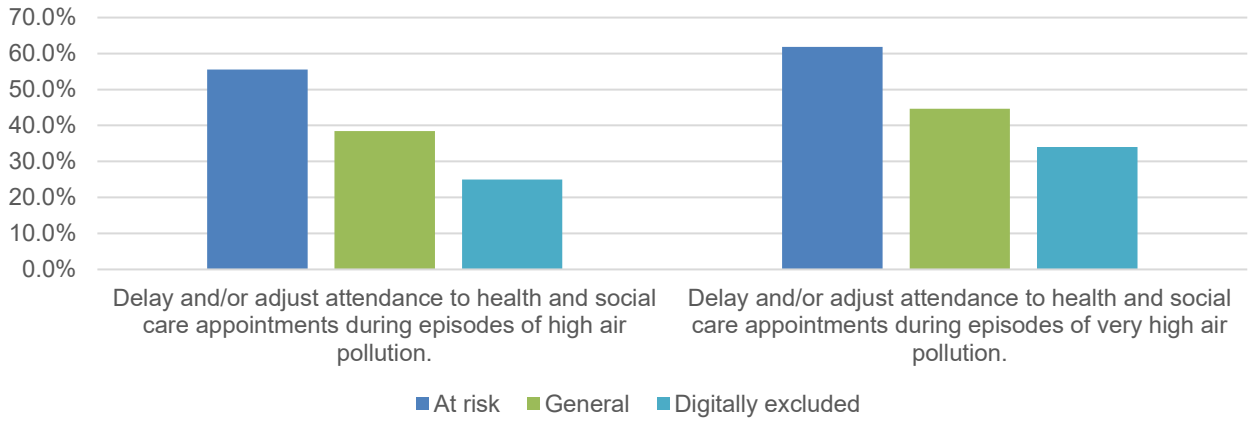
People with high levels of income appeared to be more likely to change their use of inhalers than average when the air quality is poor than the average (more than 10pp difference). On the other hand, people with lower levels of income were less likely to change their use of inhalers than average (more than 10pp difference).

A6.6.2 Unintended consequences arising from the current health advice (RSQ6.9)

The survey also considered whether people's behavioural adjustments during episodes of poor air quality could also result **in unintended consequences: Overall, around half of all survey participants reported they might delay health and social care appointments during episodes of poor air quality, which could have knock-on implications on their overall health and wellbeing**. During scenarios of 'high' (Q24) or 'very high' air pollution (Q28), participants in the 'at risk' group would be more likely to report delaying their appointments than those in the general population or 'digitally excluded' groups. Furthermore, participants are also slightly more likely to report adjusting and/or delaying their appointments in episodes of very high when compared to high air pollution.

Overall, people who perceived themselves to be at risk from air pollution were (1.5-2 times) more likely to delay their health and social care appointments during episodes of poor air quality than those who did not perceive themselves to be at risk. This is also case for people who are actually at risk based on the DAQI's definition, as well as the sample of people in the 'at risk' group when compared to others. These differences are statistically significant and can be observed in Figure A6-40.

Figure A6-40 Delay and/or adjust scheduling and/or attendance to health and social care appointments by sample group (% of all respondents N=2,008, split into at risk n=907, general n=1,001, and digitally excluded n=100)



In addition, participants noted they would reduce physical exercise and outdoor activity without any indication of substituting these with some form of indoor physical activity.

While many participants said they would consult with their doctor on whether they should attend or attend their appointment only if they are unable to reschedule, there were several who said they would still attend their appointment but would make sure to be more vigilant, take adequate precautions before going out (e.g., carry medication, wear face masks, drive instead of walking to appointments), allow extra time for travel so they are not rushed, and use their inhalers preventatively or more frequently.

Furthermore, **over half or 57% of the participants with dependents who they perceive to be at risk of air pollution (n=368) were also likely to delay appointments even in episodes of 'moderate' air pollution** (Q32). This suggests that at least for certain groups of the population, there being air pollution may be sufficient to result in action and the level (moderate, high, very high, etc) may not be the biggest driving force to adjusting behaviour or at least not in notably different ways.

A7. Appendix 7: Interview synopsis

This Appendix summarises the outputs from the interviews of 35 individuals and experts conducted as part of this evaluation, including interviews of 21 people residing in England and 14 air quality modelling and/or air quality and health (both researchers and health and care professionals).

A7.1 OVERVIEW

Interviews were conducted with air quality modelling experts, air quality and health experts, and the general public (some of whom were considered to be at greater health risk from air pollution). The aim of these interviews was to supplement the findings of the literature review and/or support the information gathered within the survey, addressing information gaps where necessary and exploring, in more depth, the core evaluation questions.

Topic guides were developed by the consultant team (Ricardo and Opinion Matters) for the semi-structured and in-depth interviews, offering a guide to interviewers. The scripts included: 1) structured questions that will be asked of all experts and individuals targeted, drawing on social research techniques to elicit information necessary to answer the CERQs and RSQs (evaluation questions); and 2) themes to facilitate a more open discussion about the evidence that is available and pertaining to the evaluation requirements. These topic guides were reviewed and signed-off by Defra.

The CERQs and RSQs were explored through interviews with one or more interviewee groups in depth, comprising:

- **Air quality modelling / forecasting experts**, to address the gaps identified in the literature review for **CERQ 1 and 2**, which focus on the data inputs and methodology of the DAQI.
- **Air quality and health experts**, to address gaps identified in the literature review for **CERQ 2, 3 and 6**, which focus on the methodology of and access to the DAQI, and the soundness of the 'Recommended Actions and Health Advice' provided by the DAQI.
- 'at risk' **and general public**, to explore in more depth people's awareness, access, understanding and use of the DAQI or similar services, as well as any actions they might or might not take as a result of the recommendations and advice provided (**CERQ 3, 4 and 5**).

The approach for recruiting and engaging interviewees varied by group:

- For **air quality modelling / forecasting experts**, the two main organisations targeted were the Met Office and Ricardo, as these organisations both work on the data and models underpinning the DAQI forecasts. Given the detailed technical requirements from these interviews, questions were shared in advance to the team's point of contact at the Met Office. Two main interviews were undertaken by consultants with expertise in air quality, as they have an existing understanding of the topic area and the content to be discussed.
- For **air quality and health experts**, two groups were targeted comprising experts working in a health and care setting, directly or indirectly linked to patients (categorised as 'Air Quality / Health Care Type A'), and leading UK-based researchers in the area (categorised as 'Air Quality / Health Care Type B'). These

professionals were sent a high-level brief in advance of the interview, highlighting the areas to be covered during the conversation. The interviews were primarily undertaken by project team from Ricardo and MEL Research.

  - For 'Type A' (those working with patients directly or indirectly), General Practitioners (GPs), Consultants, Nurses, Directors of / Consultants in Public Health, Statutory Health Advisers and other health and care practitioners were identified through Ricardo, Defra and UKHSA professional networks and contacted, including but not only members of the London Air Quality and Health Programme Office, the London Asthma Leadership and Innovation Group, and other relevant groups.
  - For 'Type B' (those with research as their primary focus), professors and researchers leading work on air quality and health in UK universities and/or research organisations were identified through Ricardo and Defra's networks and desk-based research, and subsequently contacted.

- For the **'at risk' and general public**, volunteer interviewees were recruited by the consultant team using social media (e.g., LinkedIn, Facebook, etc.) and available online communication platforms (e.g., MS Teams communities, etc.). Recruitment was undertaken in three steps:
  - A request for volunteers was launched, focussing on people who do not work and/or are not experts in air quality policy and/or its implementation. The following criteria were used to recruit people who can offer relevant insights within the scope and context of this project: 1) The people must reside in England (in line with the approach taken for the survey); 2) they must have some interest in local air quality (otherwise, they would not be offering helpful input to this project); 3) they must be willing to offer 30-45 minutes of their time for free.
  - A short screening questionnaire was issued to all individuals expressing interest, so to collect information on 1) age, 2) their perception of the health risk they might face from air pollution exposure, 3) their awareness of air quality and the DAQI, and 4) contact details and availability for interview. The screening was used to confirm whether these volunteers were available and sufficiently diverse to provide useful insights that would complement the online survey of 2,000 individuals.
  - Once the screening was completed, interviews were scheduled as soon as possible to keep the momentum. Very brief information about the interview was shared beforehand. The interviews were undertaken by project team members from Ricardo and MEL Research.

In total, **35 interviews were conducted between 22nd April and 16th May 2024**, in a short timetable that would ensure overall project timetable could be met. Table A7-1 summarises the number of interviews undertaken, by participant group.

Table A7-1 Interviews undertaken

Interview type	Interview number
At risk and general public	21
Air quality forecasting / modelling experts	2

Interview type	Interview number
Air quality and health experts working with patients directly or indirectly (Type A)	6
Air quality and health researchers (Type B)	6
Total	**35**

These activities were carried out in line with HMT Magenta Book. Data has been stored and handled using the highest standards and established protocols, in line with General Data Protection Regulation.

Interviewees summarised the outputs of the interviews into thematic grids for each interviewee group (i.e., air quality modelling experts, air quality and health care experts and researchers, and the at risk and general public). These thematic grids were developed to conduct thematic analysis on the information gathered through the interviews in line with standard and social research best practices.

The outputs of the interviews and thematic analyses are presented in the following sections within this Appendix, structured by CERQ and RSQ.

A7.2 CERQ1 DATA INPUTS

CERQ1: To what extent does the modelled and measured data on which the DAQI is based, give a sufficiently accurate and precise representation of real-world air quality conditions?

The interview evidence infers that the modelled and measured data on which the DAQI is based gives an accurate and precise representation of real-world air quality conditions at a UK regional level, albeit there are some concerns on the spatial representativeness of the measurement data for real-time DAQI, the use of provisional data in the model, and how the modelled data is presented, which would benefit from further investigation.

Data input dimensions for the DAQI were investigated in depth during the interviews with air quality modelling experts; the findings are summarised below and further detailed in the following subsections.

The interviews with air quality modelling experts highlighted that the **AURN data** used to formulate the real-time DAQI has considerable strengths in terms of representing real-world air quality conditions through good data coverage and number of monitoring sites, both of which are legally compliant. The quality of the data is to a high standard, as the AURN data undergoes vigorous QA/QC, but the data used for both real-time and forecast data is provisional, rather than ratified. This means that not all QA/QC checks have been completed. The extent to which this affects the accuracy of the real-time and forecast DAQI has not been possible to assess.

The **DAQI forecasts** are representative of real-world air quality conditions on a regional scale. However, this has inherent uncertainty caused by model parameters and inputs. This is not uncommon, as most models have uncertainties associated with their results, which can lead to occasional under or over-predictions. In the case of the DAQI, the UK AIR website communicates forecast model inaccuracies to the 'DAQI users' when these are identified but cannot be corrected in time.

The DAQI forecasts may not be representative of real-world air quality conditions on a local scale, as the values supplied on the DAQI forecast postcode tool are interpolated from the model results. As the model's spatial resolution is coarse and focuses on regional modelling, this could affect the accuracy and precision of the outputs at a local scale. However, the extent to which this is true is uncertain, as it has not been possible to assess the validity of the interpolation.

The **granularity of the DAQI** forecasts were considered. In particular, the air quality modelling experts considered that the temporal resolution may not be sufficient for users to adapt their behaviours effectively. However, the extent to which additional granularity is useful depends on how the 'DAQI users' engage with the DAQI.

Finally, **interviewees provided a wide set of recommendations** for consideration, which are reported in the following subsections.

A7.2.1 RSQ1:1 Determination of the completeness and accuracy of the AURN datasets used for the DAQI real-time index and forecasts.

The data coverage, number of sites, spatial representativeness of sites and QA/QC processes were investigated to determine the completeness and accuracy of the AURN datasets used for the real-time DAQI and forecast DAQI.

Air quality experts stated that:

- At present the data coverage of the AURN as whole, data meets the current data capture target which is set by legislation. The AURN measurement data has an annual data capture target of 90 % which in practice is treated as 85 %, as it allows 5% for planned maintenance such as servicing and auditing.
- The AURN data is used for compliance reporting, hence is subject to vigorous QA/QC processes meaning the data quality is to a high standard. However, it has been noted that provisional data is used for the real-time DAQI and forecast DAQI thus not all QA/QC checks would have been completed.
- The number of AURN sites meets the legal requirements as per the Air Quality Standards Regulations (based on Air Quality directive), which sets requirements for the number of monitoring stations for each zone and agglomeration. This number of sites per area is dependent on the typical levels of air pollution in comparison to upper and lower assessment thresholds set in legislation. Another consideration is population. It is worth noting that the AURN is currently going through a phase of expansion for $PM_{2.5}$ and ozone monitoring, with just under 100 new monitoring sites going in for $PM_{2.5}$ in England. This is driven by the fine particulate matter targets for England, which is why the sites are only in England. The Devolved Administrations (Scotland, Wales and NI) will make their own decisions about future increases in their own monitoring.

Interviewees suggested the following recommendations:

- As provisional data is used instead of ratified data, there is potential for artificial intelligence tools to complete data checks on the Met Office's behalf. It is worth noting that such checks would require finding outlier data and currently it is difficult to use machine learning models to identify outlier data due to the training datasets used.
- Improvements could be made to the methodology of real-time index. The real-time index reports a DAQI. As DAQI require 24-hours' worth of data the real-time index

uses data from the previous day to make up the 24-hour period. This approach can cause confusion to the general public. The real-time index should instead offer bands such as low, moderate, high and very high band based on the real-time measurements rather than back calculating a DAQI index.

A7.2.2 RSQ1.2: Determination of the levels of accuracy and precision of air quality forecasts and whether these levels allow individuals to meaningfully modify their behaviour.

The accuracy and precision of the air quality forecasts were determined through understanding the overall model performance, inclusive of model parameters and data inputs, and what procedures are in place when the forecast DAQI is inaccurate.

Air quality experts stated that the forecast model's performance works well for regional events, as the model captures regional pollutants such as ozone and PM rather than localised pollutants such as NOx. Whilst concentrations of ozone and PM may be impacted by local sources, they are predominantly transported from elsewhere. NOx tends to be underpredicted in urban areas and overpredicted in rural areas due to the model's grid which is coarse (11 x 11 km grid), therefore the spatial resolution is insufficient for localised pollutants such as NOx. This can lead to a lack of representation of the main NOx source locations, for example, the road network. One air quality expert noted that whilst this may occasionally cause underpredictions in the DAQI, the spatial resolution is sufficient considering the model has a daily resolution; it is uncommon for NOx to be the cause higher DAQI values. Moreover, as the DAQI provides a daily forecast, this leads to the removal of temporal variation, which leads to an underweighting in short-lived pollutants such as NOx, introducing further uncertainty to the forecasted DAQI. To mitigate misinformation the Met Office are able to add text on the UK Air website when the forecasting model under or over predicts the DAQI, if the forecast map itself could not be updated in time.

The air quality expert noted that the forecasting model currently does not use any additional data such as air quality sensor data, satellite data or local air quality monitoring data. It was stated that any data used in the model would need to undergo a high level of quality assurance before being input to the model. The Met Office currently use third-party data for the forecast model such as UK and Europe emissions data and Global Fire Assimilation data. The Met Office relies on third party data providers to check data. It is worth noting that the Met Office are currently trialling the use of satellite data through development work with universities. Challenges associated to the use of satellite data include understanding the QA/QC processes the providers use and training of staff.

Keeping the model up to date with the latest technology is extremely important for accuracy. The Met Office currently update the meteorological modelling system twice a year with improvements to the pollution side of the model at a similar frequency or somewhat less depending on the significance of the value to be had, when incorporating the change.

Interviewees suggested the following recommendations:

- Sharing forecast uncertainties through use of predictive language such as 'possible moderate pollution' or a sentence stating there is uncertainty linked to the forecast DAQI, to communicate the level of uncertainty associated to the air pollution forecasts. Reports on the model process, validation and uncertainties should be fully transparent to the public and easily accessible for those who would like to obtain more information.

- Development work to produce more spatiotemporally resolved forecasts, considering most AQMAs are declared due to NO_2 concentrations being close to or exceeding the UK's National Air Quality Objectives for annual mean concentrations. Increasing the spatial resolution to around 10 m x 10 m would help improve the ability to predict NOx concentrations.
- Increasing temporal resolution of the forecast so the public may have sufficient warning in advance to change their behaviour, especially considering individuals live more flexible lifestyles post-COVID-19. Live transfer of AURN data to the model could be useful when producing more frequent forecasts, however, it does not currently significantly benefit the prediction of the DAQI.
- Improving the messaging alongside the DAQI could be useful for example it is well known that ozone is a dominant pollutant in the summer and air quality experts are aware of the pollutants time profile; high concentrations are experienced during the late afternoon and evening.
- Machine Learning Models (MLM) could be used to improve the forecasting ability. Such potential improvements could include the incorporation of a site-specific forecast at monitoring stations to run parallel with the model forecast and/or presenting the worst-case DAQI from both regional and local projected forecast for the zone/area. Met Office have done some tests with a trial system and found MLM works poorly for secondary pollutants but well for primary pollutants such as NO_2. Other work is being done at Ricardo where initial studies have been conducted to determine the feasibility of running site-specific forecasts to 3 days in the future for ozone and $PM_{2.5}$ using available monitoring data using random forest methods. The initial findings showed good performance for ozone but less so for $PM_{2.5}$ due to complex nature of sources. When using such models, a consideration is ensuring erroneous data is not used within the training model therefore the training model should be updated with ratified data when it becomes available.

A7.2.3 RSQ1.3: Understanding the extent to which individuals can meaningfully modify their behaviour based on the granularity of the communicated DAQI.

The spatial and temporal resolution, and pollution speciation of the forecasting model were assessed to determine whether the granularity of the communicated DAQI allowed individuals to meaningfully modify their behaviour.

The DAQI forecasts may not be representative of real-world air quality conditions on a local scale, as the values supplied on the DAQI forecast postcode tool are interpolated from the model results. As the model's spatial resolution is coarse and focuses on regional modelling, this could affect the accuracy and precision of the outputs at a local scale. The extent to which this is true is uncertain as it has not been possible to assess the validity of the interpolation.

The DAQI forecast tool currently includes a postcode checker where users can input their postcode checker and see forecast levels in their areas. The forecast DAQIs on this map are interpolated from the model results. The outputs from this feature may have a high level of uncertainty as the model's resolution is too coarse to provide local scale forecast DAQIs.

Air quality experts conveyed the limitations in the temporal resolution of the DAQI. Daily forecasts were thought to limit the ability to adjust behaviours in accordance with air quality

levels. One air quality expert noted the daily forecasts and the real-time DAQIs were sufficient for helping modify behaviours, but it is unknown if the public interact with the DAQI data in this way.

Air quality experts did not believe that increasing the DAQI's granularity through pollution speciation would be useful to the public, as it could make the information/messaging difficult to understand. Moreover, it was mentioned that pollutants in the air come as mixtures with similar health risks, therefore there may not be much benefit in distinguishing between pollutants. Contrastingly, the general population and at risk individuals felt that showing which pollutant caused moderate and high DAQIs would be useful information, as well as information on air pollution hotspots. One participant stated more granular information would be useful.

Interviewees suggested the following recommendations:

- Health care B experts suggested increasing the grid resolution as current research programmes use 1 km x 1 km grids for forecasts.
- Two air quality experts felt improving the resolution of the grid may not be useful, as it would not have a net benefit to our understanding of air quality, as it is well known that air pollution is higher closer to sources e.g., busy roads. Instead, it was recommended that accompanying information could detail pollution hotspots, periods/hours that are likely to have the highest concentration, as this would remove unintended health consequences of people not exercising due to moderate or high pollution episodes.

A7.3 CERQ2 METHODOLOGY

CERQ2: To what extent is the methodology by which the DAQI output (the index number and air quality band) is calculated, appropriate as a method of determining the short-term risk posed by real world conditions into an overall measure of air quality?

Overall, the methodology by which the DAQI output is calculated is appropriate as a method for highlighting short-term risks posed by real world conditions. Due to a lack of new evidence on short-term exposure, it is not necessary to update most methodological aspects of the DAQI (for example: the pollutants included, their breakpoints and averaging times, and the exclusion of pollutant mixture effects). However, there were some disagreements about whether the latest evidence on long-term exposure to air pollution should be used to inform and update the DAQI methodology.

Key aspects of the DAQI's methodology were examined with air quality modelling experts, as well as other air quality and health researchers. This included the pollutants currently included in the DAQI, their breakpoints and averaging times, as well as the potential for pollutant mixtures to affect health. The DAQI's treatment of days as discrete events was also discussed. The findings are presented below and elaborated upon in the subsequent sub-sections.

The general consensus from the interviews with health care B experts was that **the pollutants currently used in the DAQI are still the most relevant**. There were some suggestions about the potential to include other pollutants in the future, and the possible removal of SO_2 as a DAQI pollutant.

Air quality experts from the Theory of Change workshop believed that the DAQI breakpoints did not need updating, due to a lack of new evidence on health risks associated to short-term exposure to air pollution. There was **disagreement about whether the breakpoints of the DAQI should be updated using new research on the health risks associated to long-term exposure**, as the DAQI focuses on health risks from short-term exposure.

Whilst the majority of air quality and health researchers agreed that **the pollutant averaging times used by the DAQI reflect the latest health evidence**, some experts expressed **concerns about whether the averaging times were too coarse to capture the typical rise and fall of pollutants throughout the day**.

Expert interviewees were **unable to determine whether the current understanding of health risks of air pollutant mixtures would have a substantial impact on health outcomes if included into the DAQI**. This was mainly due to a need for more evidence on the health risks of pollutant mixtures. Two health care experts discussed methodologies used in research papers; however, the findings were not discussed.

Expert interviewees mentioned that **treating pollution episodes as discrete events for the purpose of the DAQI means the health risks are likely to be underestimated**. Despite this, it was stated that the DAQI does not necessarily need to present pollution episodes as non-discrete days, as it focuses on health risks of short-term pollution episodes.

A7.3.1 RSQ2.1: Determining if the DAQI includes the most relevant pollutants for assessing short-term air pollution risks in the UK.

Interviews with air quality and health experts suggested that the pollutants covered by the DAQI are still relevant as they are the pollutants that have the largest evidence base in terms of associated health risks. One expert stated that the inclusion of SO_2 may no longer be relevant from a health perspective.

There was some discussion on whether new pollutants could be incorporated in the DAQI. There was a particular focus on black carbon, as it is currently measured within the UK through the Black Carbon Network. Some health care B experts thought that using black carbon as a DAQI pollutant could be potentially useful due to its links to climate change and health effects. Other health care specialists suggested that the DAQI would be currently triggered by NO_2 and $PM_{2.5}$ if black carbon levels were high, so there might not be a benefit in including the pollutant.

Interviewees suggested that other pollutants could be incorporated into the DAQI in the future, once there is sufficient monitoring, such as very small particles via particle number, or volatile organic compounds (VOCs).

A7.3.2 RSQ2.2: Understanding the extent to which the DAQI breakpoints reflect the latest health evidence on short-term exposure to air pollution.

No interview questions answered this research question; however, findings from the Theory of Change workshop helped to formulate an answer. Some air quality experts at the Theory of Change workshop felt the DAQI breakpoints reflected the latest health advice, whilst other air quality experts disagreed.

Air quality experts agreed that the evidence base on short-term exposure to air pollution had not changed much since 2011, hence, the methodology remains up to date. The recent evidence has a larger focus on long-term exposures and health effects of air pollution, and there was discussion on whether this should be used to update the DAQI breakpoints.

Air quality experts stated that the current DAQI breakpoints did not reflect the updated WHO Air Quality Guidelines 2021. There were disagreements about whether the DAQI should reflect these changes to the WHO guidelines. Some experts felt that aligning the DAQI with the new WHO guidelines would be clearer to the public, as the new WHO guidelines reflect up to date evidence on exposure effects. However, other air quality experts in the workshop stated that the updated WHO air quality guidelines denote new long-term (annual) air quality guidelines, with average daily limits being set to a value that would allow the country to achieve the annual long-term guidelines, rather than based on new evidence on short-term exposure effects. Whilst this is true, basing the DAQI on long-term guidelines may be more health protective than using short-term guidelines.

A7.3.3 RSQ2.3: Understanding the extent to which the averaging times implemented in the DAQI reflect the latest health evidence with regards to short-term exposure to air pollution.

The majority of air quality and health expert interviewees agreed that the averaging times used by the DAQI were in line with the latest health evidence with regards to short-term exposure to air pollution, as they align with the WHO averaging times. Two other interviewees expressed that the averaging times may be insufficient to capture pollution episodes.

Three air quality and health experts stated that the averaging times used for the DAQI were appropriate. Another expert agreed with the averaging times for most pollutants except NO_2, as NO_2 is a kerbside pollutant linked to vehicle exhaust emissions, hence the current averaging times do not capture the rapid changes in concentrations that occur. One health care B expert fully disagreed, stating that the averaging times were insufficient to capture the typical rise and fall of pollutants throughout the day.

An additional expert recommended using rolling averages in the DAQI to better capture short-term exposure to pollution episodes.

A7.3.4 RSQ2.4: Determining whether the inclusion of air pollutant mixtures in the DAQI would have a substantial impact on health outcomes.

Interviewees were not able to determine whether the health risks of air pollutant mixtures would have a substantial impact on health outcomes if included in the DAQI; however, there was agreement that the current evidence base is not substantial enough to allow for the inclusion of pollutant mixtures into the DAQI in a robust manner.

The interviewees did not provide a direct answer to this research question. It was, however, mentioned by air quality and health experts that there is currently not enough information or evidence on the health impacts of pollutant mixtures to understand how different pollutants interact with one another, and what potential risks this has on human health. The current lack of evidence means it is difficult to incorporate any changes into the DAQI methodology confidently and transparently. Some research papers were discussed, which have looked at the varying health risks in different pollutant mixtures. However, concerns were expressed about the difficulty in incorporating this into the DAQI, as well as the public's understanding of pollutant mixtures.

One health care B expert recommended a potential method to improve the DAQI's response to pollutant mixtures, based on a recent paper. This method uses artificial intelligence to

develop an algorithm that enables two or three pollutants to be assessed with a refinement of the index.

A7.3.5 RSQ2.5: Assessing the health impact of treating days as discrete events for the purposes of the DAQI.

By treating days as discrete events in the DAQI, the health risks of short-term pollution are likely to be underestimated due to the cumulative impacts. The literature provides a large amount of evidence stating that the effects of being exposed to pollution can last up to several days (lag effects). As pollutants can linger in the atmosphere, people may still be at risk a few days after the alert is triggered.

Air quality and health researchers expressed that the DAQI does not necessarily need to present days as non-discrete, as the DAQI's purpose is to look at the health risks from short-term exposure. Moreover, changes to this may confuse the general public (specifically, messaging changes). Nevertheless, it was agreed that the public should be made aware of multiple days of elevated pollution as the health risks remain, especially for at risk individuals, after the event. This could be achieved through health advice or pollution alerts.

Interviewees suggested the following recommendations:

- Development of another tool to be used in addition to the DAQI, which would look at long-term background concentrations of air pollutants to help describe health risks of air pollution as non-discrete days.
- Improve DAQI messaging through text that accompanies the forecast, about multiple and subsequent forecasted pollution episodes. The messaging could cover emissions and exposure, as well a clinical message for the public which could be issued before and after the event.
- To better understand and communicate conditions that may exacerbate acute health effects caused by air pollution, the Met Office could work with health organisations to determine which climatic variables, such as temperature and humidity, exacerbate reactions to air pollution for groups with different health conditions. For example, asthma patients react to air pollutants more on days with high humidity and high pollution, compared to days of low humidity and high pollution.

A7.4 CERQ3 ACCESS

CERQ3: To what extent is the DAQI viewed by the people it was intended to be viewed by?

The DAQI was recognised by interviewees, especially those who perceived themselves at risk. The majority of interviewees accessed the DAQI data indirectly through third-party services (e.g., other websites, map phone applications, weather applications, etc). Interviewees appeared to use these air quality information services infrequently.

At risk and general public interviewees were asked about their awareness of the DAQI, if and how they use the DAQI and/or similar services and the extent to which they use the information to modify their behaviours. Air quality and health experts were asked about the adequacy of the Defra definition of being 'at risk' of air pollution. The findings are summarised below and elaborated in the following subsections.

- **Air quality and health experts interviewed broadly agreed with the definition of people 'at risk' of elevated air pollution in the short-term**. However, experts considered that it would be worth investigating whether pregnant women and infants in the womb should be included within the DAQI's definition and noted that everyone is at risk from longer-term exposure.
- **The DAQI was recognised by the interviewees**, including those who perceive themselves to be at risk of air pollution and those who did not.
- **Interviewees reported accessing air quality information primarily through third-party air quality services** (e.g., map/navigation and weather digital applications, news outlets, etc), **and did so infrequently.**
- **Air quality and health experts working with patients directly or indirectly appeared familiar with the DAQI. However, generally, they did not use the DAQI directly within their role**, although again, a number did appear to use secondary services indirectly linked to the DAQI, such as local sites, internal resources developed based on the DAQI, etc. Some experts stated they would refer clients and businesses to the DAQI to stay informed of air pollution risks.
- **Interviewees shared their thoughts on a range of barriers** they experience to access and/or use the DAQI, including a lack of awareness and training or understanding of the information, lack of time/prioritisation, and/or relatively 'difficult' access (e.g., not linked to commonly used applications, etc).
- **The majority of interviewees accessed the DAQI information primarily via secondary services that they used frequently or were easy to access, such as map/navigation or weather applications.** This suggested that linking the DAQI to commonly used and relevant digital applications could help facilitate awareness, access and use of the DAQI.

A7.4.1 RSQ3.1: Determining whether the Defra definition of 'at risk individuals' adequately represents the health evidence for groups at increased risk from short-term exposure effects of elevated air pollution.

Air quality and health experts broadly agreed with the Defra definition of those at greater risk of symptoms defined as "adults and children with heart or lung problems". Interviewees mentioned that people with specific respiratory and cardiovascular conditions were indeed more likely to be at risk of experiencing symptoms during episodes of elevated air pollution. This group could include people who are fragile to respiratory irritants (asthmatics, oxygen users, people with chronic obstructive pulmonary disease, etc) and people who suffered strokes, heart attacks and/or have lung cancer, among others.

Interviewees suggested that it would be **worth exploring the available evidence linking exposure to episodes of elevated levels of air pollution** and adverse health outcomes for mothers and their children during pregnancy, such as prematurity, etc. At least one interviewee also mentioned that it would be worth exploring the risks faced by people living with dementia and autoimmune conditions.

Interviewees also mentioned other **individual characteristics** that might be relevant for targeting people who might be most likely at risk of experiencing symptoms during episodes of elevated air pollution, such as working conditions, ethnicity, level of deprivation and others.

One expert suggested that an evidence review to refine the definitions would be necessary and stated “the DAQI is now behind science and the view of ‘at risk’ is much too narrow”. Many of the experts interviewed also agreed that, whilst the ‘at risk individuals’ as defined by the DAQI might be most at risk to experiencing symptoms during short-term episodes of elevated air pollution, **all individuals irrespective of age might be at risk of adverse health outcomes from long-term exposure to air pollution and this risk might change throughout a person’s lifetime**.

A7.4.2 RSQ3.2: Determining how widely used/well recognised the DAQI is by people at increased risk from air pollution, and what channels, if at all, this user group is receiving information.

The DAQI was recognised by the interviewees who perceived themselves at risk, who primarily accessed the information through third-party services of air quality information rather than the official DAQI services. Out of the 17 interviewees who perceived themselves to be at risk to air pollution, 14 interviewees were aware of the DAQI services, and 5 interviewees used the official DAQI services. The other interviewees who perceived themselves at risk accessed air pollution information from third-party sources such as weather apps (Met Office and third-party), news outlets, map/navigation applications, the pollen index, and others.

Interviewees used the DAQI and alternative air quality information services infrequently, with one at risk interviewee mentioning they only use the service when they feel symptoms of air pollution or hear of an air pollution event on the news. For example, one interviewee noted: *"Every now and again it [the DAQI website] catches my eye, if I had to put a number on it [about frequency of use] maybe once a month, but realistically I should probably be checking it more often."*

Air quality and health experts believed that their patients were generally unaware of the DAQI. Generally, they believed that if patients were to be accessing air quality information, it would likely be through third-party sources and local air quality websites (e.g., local authority sites, etc). These experts also believed that individuals with chronic diseases and especially at risk of experiencing symptoms from elevated episodes of air pollution may be more aware and conscious of their health, and hence potentially more likely to look at the DAQI or other air quality information services to keep informed. Some experts also suggested that people with a higher proportion of discretionary time, educated and/or wealthier might be more aware.

Air quality and health experts working with patients directly or indirectly noted that they do not use the DAQI directly in their role (i.e., the DAQI does not support them in their role directly), even if they do refer to the DAQI or alternative, third-party air quality information sources for their own personal use. Some experts did highlight that the evidence underpinning the DAQI is employed by health and care teams in providing services and/or developing policy and programmes, especially for those working in local authority settings. Three experts had accessed the DAQI’s page, and two had not. Only one expert was able to recall some of the recommendations. Whilst some experts would refer clients and businesses to look at the DAQI to stay informed of air pollution risks, others said they would not.

A7.4.3 RSQ3.3: Determining how widely used/well recognised the DAQI is by the general population (through what channels, if at all, this user group is receiving information).

The DAQI is used/recognised by interviewees who did not perceive themselves at risk, and they appear to access air quality information primarily through third-party sources rather than the official DAQI services. One interviewee was using the official DAQI services, and another two interviewees were using third-party sources of air quality information such as weather apps, map/navigation apps and online news outlets. One interviewee was not accessing the DAQI through official nor third-party sources.

In addition, the interviewee use of the official DAQI services and alternative air quality services was infrequent.

Air quality and health experts considered that the level of awareness of 'patients' or the 'general public' was generally low, albeit some would be likely to be more aware than others. For instance, some experts highlighted the role of schoolchildren, who might be more likely to be aware of air pollution due to school programmes, as well as their parents. Experts considered that other adults are less likely to be aware, except potentially for adults with higher levels of educational attainment, higher income and older in age, those that have more discretionary time, and/or might be more conscious of health and the environment.

A7.4.4 RSQ3.4: Identifying barriers that may reduce or prevent access to the DAQI.

A couple of interviewees from the **at risk and general public** who used the DAQI and related services found the information relatively easy to access and use. Generally, however, interviewees from the at risk and general public did highlight a range of barriers to accessing the DAQI, including:

- Lack of knowledge and/or understanding of the topic of air quality
- Lack of public awareness of the DAQI
- Lack of time and/or priority allocated to keeping up to date with air quality information. For example, one interviewee noted: *"It's one of those things where I am like "oh I should look at it" but just never get round to it. There's a lot of things to keep abreast of."*
- Lack of 'worry' (which could be linked to giving low priority to the issue) given that at least half of the interviewees who did not use the DAQI could not recall experiencing any symptoms from air pollution.
- Not easy to access regularly as it could be easily found on search engines and/or linked to other more commonly used digital applications, such as weather or map/navigation applications. For example, one interviewee noted that: *"If I knew that you could just Google it and look, almost like checking the weather I guess, then I would probably have a look."*
- Vague recommendations and advice make it difficult for individuals to know what to do when notified of elevated air pollution levels by the DAQI services.

Air quality and health experts considered that the access and use of the DAQI services by health and care professionals was easy, but that access barriers existed for them and their patients, which could include:

- Lack of awareness of the DAQI services, especially those that are non-digital or for people who might not have access to digital services such as the freephone service.
- Lack of knowledge and understanding on air quality information and related services, due partly to limited training, which prevents professionals from using the information and/or referring patients to information sources.
- Lack of training and/or resources on how to use the DAQI data and what to do with it, especially during episodes of elevated air pollution.
- Lack of clear and consistent advice on what people should do when there is elevated levels of air pollution.
- Ineffective communication, including a lack of information in the mainstream media and awareness to the official sites, proliferation of third-party sources, which might or not be trustworthy.
- Mistrust of the information and/or the underpinning methodology. For example, one interviewee considered that there was *"not enough readily accessible information to determine trustworthiness"*. Another mentioned that *"more detail on the methodology, calculations and components that produce overall air quality index"* would make it easier to trust the DAQI information.

A7.4.5 RSQ3.5: Identifying any facilitators that have helped to broaden access to the DAQI.

Actions to address the aforementioned barriers identified above could help to broaden access. For example, **improving external and target communication about air quality information and the risks, for example, through health and care settings, increasing education directly and/or through health and care professionals, and/or integrating the information into commonly used and trusted digital applications (e.g., map/navigation services and/or weather applications, etc) could address multiple barriers.**

At present, interviewees reported accessing air quality information through third-party services. For example, one interviewee stated that they use the Met Office app to look at air quality forecasting as they are already using the app for weather updates. Another interviewee, who accessed the DAQI, suggested that an app or a widget for the computer would facilitate DAQI access. Other interviewees who had accessed the DAQI service suggested that the DAQI being linked to an already-established weather app would help with access. One noted: *"I think if it was…intrinsically linked… to the weather apps that everyone uses on a daily basis and something like the Met Office … I think would be really useful."*

A couple of interviewees also suggested that the DAQI and other, third-party air quality information services would be accessed and used more if the methodology behind what they are viewing were more accessible, such pollutant levels, location boundaries, and reasoning behind the scoring.

A7.5 CERQ4 UNDERSTANDING

CERQ4: To what extent is the DAQI understood by its users in the way it was intended to be understood?

Interviewees from the general public found the presentation and data visualisation of DAQI information intuitive and easy to understand. Only a few interviewees were aware and accessed the 'Recommended Actions and Health Advice' and their understanding was more limited. Interviewees' understanding of the definition of at risk and the reasoning and methodology underpinning the DAQI was generally low.

Interviewees were asked about their understanding of DAQI. The findings are summarised below and elaborated in the following subsections.

In general, interviewees who used the DAQI understood the ratings or scoring, banding, and data visualisation. There were doubts surrounding the methodology and reasoning underpinning the DAQI, although people have different preferences regarding how much information they would like available to them. Those who accessed third-party air quality information services tended to have a lower self-perceived understanding of the DAQI than those who had directly accessed the DAQI. The primary third-party services accessed were the Met Office and navigation/map applications, which generally have a more visual presentation of air quality information, only showing either the banding or Red, Amber, Green ratings on a map, as well as the scoring, with minimal text. However, when interviewees were asked to describe the daily air quality information and their understanding was rated by the interviewer, there was minimal difference between direct DAQI users and third-party service users.

Interviewees from the general public do not always perceive risk from air pollution in the way it is defined by the DAQI. The majority of interviewees considered themselves at risk; however, they did so due to the proximity of their residence to a point of pollution (such as a main road or large city). This may demonstrate a lack of understanding of the purpose of the DAQI being aimed at short-term effects of episodes of especially elevated air pollution, particularly for those with respiratory and cardiovascular health conditions. This could be due to the complexity of shorter versus longer term risks, which experts also raised as an issue that could lead to confusion and misunderstanding.

The data visualisation in the DAQI had positive feedback, with interviewees generally valuing its simplicity and usefulness. A common theme was the intuitiveness of the Red, Amber, Green colour coding, with it being a primary facilitator to understanding. However, its accessibility to people with colour blindness was found to be an issue, with one interviewee (with colour blindness) being unable to distinguish between the colour graduations.

Interviewees did not provide a lot of insights into the understanding (or lack thereof) of the **language used in the DAQI. The limited information gathered suggested that the language may be overcomplicated.**

Interviewees did not appear to understand well the 'Recommended Actions and Health Advice' provided by the DAQI. Although interviewees using the DAQI directly reported that they found the advice easy to understand, comments made in response to interview questions suggested otherwise. The lack of clear answers surrounding the extent to which the DAQI advice is understood may suggest a lack of confidence related to the

health advice. However, very limited information was gathered as only a couple of interviewees were even aware of the health advice.

The **barriers and facilitators to understanding the DAQI** were not universal and sometimes contrary, for example, the degree of simplicity being a barrier to some and a facilitator to others. Whilst some users wanted more information to understand the air quality forecasting information, others found it too complicated or valued simplicity. A solution could be to continue to prioritise a simple main interface with the data visualisation and health advice, potentially integrated in commonly used digital applications, which can be effectively signposted and/or linked to resources and methodological notes for those who are interested.

A7.5.1 RSQ4.1: Determining the extent to which DAQI users' understanding of what the DAQI is communicating, aligns with the message it is designed to communicate.

There were two DAQI user groups whose understanding of the DAQI was investigated as part of the interview process. The health care A and B user group had a good understanding of the DAQI and its presentation. They correctly identified that the DAQI focuses on the short-term impacts of air pollution.

The second user group comprised the general population (including those at risk). Overall, there was a mixed understanding of the DAQI, with some elements being more strongly understood than others. For example, the scoring, banding, "Red, Amber, Green" system and map, and how these related to levels of air pollution, were well understood. However, understanding became more vague when related to the methodology that underpinned this, with some interviewees expressing an interest in understanding more whilst others expressing that it is sufficient ("*I've never felt that I need to understand it in more detail - just what's good and what's bad, that is as much as I need to know"*). Similarly, the link between the DAQI scoring systems and the health advice was less well understood, in regard to how the pollutants link to the health advice and why the health advice is banded it is. That being said, the vast majority of air quality information service users understood that there is a negative impact on health associated with air pollution and similarly the majority of users considered themselves to be at risk of air pollution (*"It is widely accepted and well understood that poor air quality does have an impact on your health."*).

There was a difference in self-reported understanding between DAQI users and third-party service users such as Google Maps or weather apps. DAQI users tended to rate their own understanding higher (*"I Wouldn't say I'm an expert… but it's pretty straightforward."*) whilst third-party service users were less confident in their own understanding (*"I know roughly what it's trying to gauge, levels of different air pollutants, particulates..."*). Nevertheless, when interviewees were asked to describe the DAQI scores and air pollution banding and how they are connected, their responses were rated with a high level of understanding by the interviewer regardless of which service had been used.

Although not directly investigated, the idea that the DAQI is targeted at limiting the impacts of short-term air pollution, as opposed to long-term impacts of air pollution, did not appear to be well understood. The majority of interviewees identified themselves as at risk, whereas only 3 of the 15 users of the DAQI and other air quality services were at risk as per the evidence. Reasons given for self-perception as at risk primarily related to the proximity of where interviewees live to a main road or a source of pollution, or living in a large city such as London. Of those that were at risk, one did not identify their health condition as the reason

that they were at risk and gave a location-based response. The majority of air quality service users considered air pollution to have a negative impact on human health, with a particular impact on the lungs. Some mentioned they had heard of this through the news, social media, or that it was generally known. Therefore, the terminology of 'at risk' in the DAQI could be adjusted so that it clearly distinguishes between the general risk to all people and the specific risks to those with a health condition.

A7.5.2 RSQ4.2: Determining the extent to which the way data is visualised in the DAQI contributes to, or limits, [at risk/general population] users.

Across the general population of DAQI users and third-party service users, the majority of interviewees understood the data visualisation, in terms of its scoring, banding and colour coding. Key words used to describe the data visualisation were *"useful"* and *"simple"*. In particular, the "Red, Amber, Green" system was well interpreted. Several interviewees commented on the intuitive nature of the "Red, Amber, Green" system ("*I think visually it's really simple, we typically know that red means bad and green is like a good thing, that's the kind of mentality we have in us anyway"*). That being said, one user of the Met Office air pollution forecast, which only displays air quality information using the DAQI banding system from Low – Very High, commented that this presentation was too broad which impeded their understanding. Although this was only one user, it suggests that the combination of the scoring, the banding and the map together help to visualise the DAQI information.

It is important to highlight that one interviewee was colourblind and therefore the colour coded map was not accessible to them. They are not able to distinguish the graduation of colour across the bands on the map. To make the map accessible to those with colour blindness, they suggested having the DAQI numbered scoring system overlaid on the map.

A7.5.3 RSQ4.3: Determining the extent to which the language used in the DAQI contributes to, or limits, [at risk/general population] users understanding the DAQI correctly.

Whilst there were no specific questions put to general population interviewees about the language used in the DAQI, interviewees' general understanding of the written parts of the DAQI can be used to help answer this RSQ. The DAQI health advice is the primary written-language based component of the DAQI. There were only three direct DAQI users (as opposed to third party services) who were aware of the health advice, so the sample size is small, however, when asked directly if the DAQI advice is easy to understand, all three agreed that it is. This suggests the language used is appropriate to facilitate understanding of the health advice for those that have read it. However, as discussed in section 13.5.4, at other points in the interview process some of these same interviewees cited issues with the health advice and messaging. Therefore, the answers to this question may not be reliable.

As mentioned in section 13.5.1, the use of the term 'at risk' in the health advice may cause a degree of misunderstanding, as the majority of daily air quality information users perceived themselves to be at risk for reasons other than having a health condition. The majority of these were not at risk as per the DAQI definition. An alternate term to identify those specifically at risk due to a health condition may be more appropriate.

On the DAQI in general, one user mentioned that the terms used can be overcomplicated and felt that less jargon could be used: *"Sometimes the glossary of terms is confusing, for example the explanation of the term may include words that I cannot understand, which again needs further explanation"*.

A7.5.4 RSQ4.4: Determining the extent to which DAQI users understand the advice associated with different DAQI readings.

Health care experts shared their opinions on the way that health advice is communicated in the DAQI. The majority of the health care experts did not think that their patients were aware of the DAQI advice. The sample size of DAQI users in the general population interviews was too small to draw conclusions on this assertion. There was individual feedback on the health advice provided by the expert interviewees. One health care professional felt that some of the wording in the health advice needed to be amended, for example “Reliever inhaler should be used more frequently” should be adjusted to “Reliever inhaler may need to be used more frequently”. One health care expert was concerned that the DAQI was misleading, as green might be assumed to be low air pollution and therefore no health risk, however, in terms of risk to health it means low risk of acute impacts on people’s health. Another expert suggested that individuals may not be able to take action to avoid exposure unless it is a localised event. Experts suggested the following improvements to strengthen the advice:

- Improve wording.
- Simplify advice: “Put on a mask, up medication, and/or think about travel options”.
- Avoid discouraging exercise as exercise is almost always good.
- Do not encourage individuals to exercise elsewhere if there is no evidence to suggest the air quality is better in these alternative locations/settings.
- Allow clinical groups to advise on best available evidence in terms of actions that may be most effective at mitigating short-term exposure.
- Consider the use of masks in high pollution episodes if these would be readily available to the public and the evidence supports this.
- Medical intervention use of preventative inhaler and carrying relieve inhaler but being aware that using this could lead to side effects so might not be the best advice and may need to take other actions.
- Provide general advice instead of advice per banding.
- Avoid suggesting that indoor air quality is better when there is not enough evidence to suggest this.

Approximately two thirds of the interviewees from the general public (6 out of 9) were aware of the ‘DAQI or similar’ advice; however, only three had accessed the DAQI directly. The other three were third-party air quality information service users (e.g., Map/Navigation applications and the Met Office application). Therefore, the advice that they had viewed cannot be verified. Therefore, this analysis will focus on the three DAQI users that were aware of the health advice. One of these interviewees caveated that they use the DAQI for work related activities, and therefore they may be more familiar with the advice compared to the rest of the general population.

All three DAQI users had read the health advice and when asked directly, stated they found it easy to understand. However, in a previous question about their understanding of the DAQI, one of these interviewees previously scored their own understanding of the DAQI as a one out of five and cited the advice being hard to understand and follow as the reason.

Similarly, when asked on improvements that could be made to the DAQI in general, one interviewee mentioned improving the health messaging. It is worth noting that the interviewees were only able to answer based on their own perception of their understanding of the health advice, which may not reflect their true understanding.

When the interviewees were asked if they would change anything about the health advice, one interviewee stated that they would like to know what exactly to do in response to the DAQI readings other than "don't go outdoors". This is an oversimplification of DAQI advice, however, it demonstrates a desire for advice that the interviewee considers more feasible to integrate into their life. This interviewee was at risk and did perceive themselves to be at risk. The other two interviewees did not have any opinions on changes that could be made to the advice, though one suggested that doctors could be more involved in raising awareness of the DAQI.

A7.5.5 RSQ4.5: Determining what, if any, barriers exist that have hindered users from correctly interpreting the DAQI.

There were varying barriers identified amongst the general population. What may be a barrier for one person may be a facilitator for others. For example, several interviewees that had accessed air quality information via a third-party service mentioned that the methodology behind the air quality data was not clear or explicit enough. One Met Office user stated that the bandings alone (Low - Very High) were too broad. Others mentioned that they would like to view a more detailed methodology, such as the choice of pollutants, break points, and why these are linked to health. It is worth mentioning that on both the Google Maps and Met Office applications, a more detailed methodology is available if the user follows links to the appropriate page (Met Office application links to the uk-air website). On the other hand, one interviewee that used AccuWeather (which does not use DAQI as its data source) said that they would like the information presented to be more simply (*"For people like me, simplicity is really important."*). Similarly, one DAQI user found the information that accompanies the DAQI confusing (*"… if I need to read a table, that can be confusing because the information can be similar and confusing…").* As mentioned in section 13.5.3, one DAQI user felt that the language could be more tailored to a lay audience and found the professional terms used confusing. Therefore, the DAQI may need to be tailored to accommodate the variety of its potential users.

One further barrier identified was the inaccessibility of the "Red, Amber, Green" system to those with colour blindness. One interviewee, who is colourblind, stated they could not distinguish the graduations between different colours on the map. They suggested that the map could include the DAQI scores as an overlay to the colours.

A7.5.6 RSQ4.6: Determining what, if any, facilitators exist that have enabled users to correctly interpret the DAQI.

There were not many facilitators identified, although in reflection of what is discussed in section 13.5.5, what was a barrier for some was a facilitator for others. For example, some interviewees also mentioned clarity and brevity of the DAQI and its visualisation as a facilitator to its understanding, whilst others either found it too complicated or wanted a deeper understanding of its methodology.

One universal facilitator to understanding was the data visualisation. Overall, the "Red, Amber, Green" system was identified as helpful and intuitive. The colours were regarded as

easy to understand: *"… the daily index was really useful because it was very obvious… everyone can understand green, amber, red."*.

Although few current facilitators were identified in the interview process, there were several potential adjustments or areas to investigate that could facilitate understanding if developed. For example, one interviewee stated that there needs to be better signposting of the health advice. They stated that the DAQI information should be on one page with links to direct users to additional information if they are interested.

Touching upon what is discussed in 13.5.1 and 13.5.3, the majority of interviewees did not interpret the meaning of 'at risk' to be as it is defined by the DAQI, and instead self-identified as being at risk due to their proximity to high or abundant pollution sources. Although the DAQI does have a webpage dedicated to explaining the "short-term effects of air pollution on health", and the definition of 'at risk' is integrated into the health advice by specifying "adults and children with lung problems, and adults with heart problems", this may be in conflict with people's preconceived understanding of being at risk from the long-term health impacts of air pollution. Using a term other than "at risk individuals", such as "individuals with a health condition" may help to ensure that the DAQI is being understood as it is intended. The majority of interviewees were not familiar with the health advice which indicates the importance of the terms 'at risk' and 'general population' being understood when the DAQI is being used on a surface-level basis. Being specifically targeted by the terminology of the DAQI may encourage those who are at risk as per the DAQI definition to further investigate the health advice.

During the interviews, there were mixed preferences for the level of complexity of DAQI information. Whilst some interviewees valued simplicity, others stated that they do not feel that they understand the DAQI because they do not understand the methodology behind it. This suggests that a facilitator for all interviewees' understanding could be adjusting how the DAQI website is arranged. In alignment with the feedback from the interviews, the primary page of the DAQI could feature all information that is essential to understanding what the current daily air quality is and what the reader should do in reaction: the colour-coded map; the scoring system; the banding; and the health advice. This would accommodate those who solely want to see what the day's air pollution score and related advice is, without having their understanding impacted by additional information. A secondary DAQI webpage could be set up that is clearly signposted from the primary page that presents: how daily air quality is monitored; which pollutants are included; how the daily score is determined; the scale of locality; and the reasoning behind the health advice. Alternatively, this information could be indexed on the secondary page. This would facilitate the understanding of those who need to contextualise the DAQI forecast in order to better understand it. To ensure that both pages are understood by as many users as possible, layman language should be used.

A7.6 CERQ5 CHANGE OF BEHAVIOUR

CERQ5: To what extent do the people who use the DAQI enact the advice it provides?

Interviewees appear willing to change their behaviour in response to a DAQI rating in principle, however, they cannot recall having done it in the past. In part, this is because the majority of interviewees could not remember having ever encountered a high or very high DAQI rating. Based on the responses from a small number of individuals who are actually at risk (based on the DAQI's definition), the most likely behavioural modification would be to carry relevant medication to relieve symptoms of elevated air pollution.

Generally, interviewees who perceived themselves at risk reported that they would not change their behaviour based on DAQI information. A smaller number of interviewees, who were actually at risk based on the DAQI's definition, reported they would change their behaviour based on DAQI ratings, especially by carrying medication to alleviate any symptoms of elevated air pollution.

Interviewees from the general public, who were not at a special risk, reported they would not change their behaviour in response to air quality readings. However, some said that they would in certain hypothetical situations, such as a significant local air pollution event or seeing a high reading on the DAQI.

The majority of the interviewees had not seen a high or very high air pollution alert before, which may explain their historic lack of behavioural modification. Several interviewees purported they would reconsider actions such as exercising outdoors if they were to see a high reading. That being said, there is a difference between the desire to change one's behaviour and the ability or commitment to carry it out. This is indirectly evidenced by the observed divergence between people who are interested in air quality information and report would change their behaviour if they knew air pollution was especially high, and the relatively lower number of these people who actually access and use air quality information services such as the DAQI.

The primary barriers to behaviour modifications were the perception of the DAQI being less relevant to them as an individual, or the ability to prioritise the DAQI. Specific facilitators were not identified directly during the interviews, however, addressing the barriers identified could indeed facilitate behavioural change.

A7.6.1 RSQ5.1: Determining the extent to which at risk users change their behaviour based on a [moderate/high/very high] DAQI reading.

The air quality/health care experts did not give specific answers related to at risk individuals, however, their thoughts on the general population enacting DAQI advice is discussed in the following section A7.6.2

In the general population interviews, there were only three individuals who are at risk as per the definition of the DAQI (out of 21 interviewed in total). Therefore, the sample size is relatively small. Two of these at risk individuals stated that they adjust their behaviour based on air quality information. Of these, one asthmatic user of the DAQI stated that they use the service as a guide for whether they need to carry their inhaler with them. The other user, who used a third-party service, will consider air quality information when making plans, by modifying their outdoor behaviours, avoiding asthma triggers and carrying medication.

Overall, whilst the small sample size makes it difficult to draw solid conclusions, the interviews suggest that some at risk users do use the DAQI or third-party services to help them make decisions about their behaviour.

It is also pertinent to consider the general population that perceive themselves to be at risk but are not at risk as per the definition of the DAQI. The primary reason for self-reporting as at risk was due to living in proximity to main roads, emission sources, or in a large city such as London. Of this subsection of the general population interviewees, the majority stated that they would not change their behaviour. Therefore, there was not a link found in the interviews between self-perceived risk and a change of behaviour in response to air quality information.

A7.6.2 RSQ5.2: Determining the extent to which general population users change their behaviour based on a [high/very high] DAQI reading.

The air quality/health care experts did not agree on whether people accessing the DAQI's 'Recommended Actions and Health Advice' might be following it, with a roughly equal split. While some experts thought that if people are aware of the information source and actively look at it, they are likely to follow the advice, others said that from evidence they had seen, advice typically needs to be more tailored to the group it's targeting in order to be useful. The experts were not really able to give a proportion of people that might follow generic advice such as that provided by the DAQI, but raised factors that may make people more or less likely to follow the advice. For example, people who are more educated and have more agency are more likely to have more opportunity and more motivation to change their behaviour, whereas those with less agency (such as children) may not be able to access or follow the advice. These were factors that were not brought up in the general population interviews, but several interviewees did touch upon their priorities lying elsewhere.

Amongst the general population, the majority stated that they do not currently change their daily behaviour dependant on local air quality information, although some caveated this that they might in certain situations. For example, one stated that they had never seen a high pollution alert but would maybe reconsider undertaking outdoor activity if they lived in a large city such as London. Similarly, another mentioned they would change their behaviour if they knew of a significant air pollution event happening locally, such as a fire, but it is unlikely they would be informed of this via the DAQI or another air quality service. Others stated that they may change their outdoor exercise plans if a particular area had high pollution, although they would not stay indoors completely.

One Met Office user found the daily air quality information too vague and considers the air outside to be the same as the air inside and therefore said "*It is unlikely to affect my general day-to-day activities"*.

One interviewee who said that they do change their behaviour in response the air quality information gave the explanation that they use it to determine whether to wear suncream or a sunhat. This may suggest a misunderstanding of the purpose of the DAQI. This interviewee was not aware of the DAQI advice and therefore likely does not know the advised behavioural response to higher levels of air pollution risk.

When asked whether they had ever seen a high or very high air pollution alert, the majority of the general population interviewees said that they had not. Overall, the interviews suggest that whilst currently there are no behavioural changes made in response to DAQI readings, if air pollution alerts were more severe, the general population may respond. However, there

is not enough evidence to suggest the general population would follow through with changing their behaviour in response to high DAQI readings.

Of the general population that had directly accessed the DAQI (four in total), two were aware of the health advice related to the DAQI. Although both had previously mentioned that they perceive themselves as at risk for location-based reasons, only one responded that they would change their behaviour based off DAQI information. The other stated that they wouldn't as they do not have any health conditions. Neither have experienced strong symptoms related to air pollution, which may factor into their behaviour.

It is worth mentioning general population interviewees who had not accessed the DAQI or third-party air quality service. The majority stated that if they were aware of high air pollution locally, they would change their behaviour. The one interviewee that stated they would not, said that they would in the future when they have children. This suggests there is an underlying desire to do something about the risk of air pollution.

A7.6.3 RSQ5.3: Determining what, if any, barriers exist (in terms of capability, opportunity or motivation) that prevent users from enacting DAQI advice.

There were barriers identified in terms of what interviewees were willing or able to do. For example, several interviewees noted that although they wouldn't stop going outside completely, they would be willing to make changes to their outdoor exercise routines, such as exercising in a location with lower air pollution or waiting until the air quality improved. If the health advice is interpreted as being instructed to stay indoors, as suggested by some responses, this would seem unfeasible to many due to other commitments in their daily routine (*"It is unlikely to affect my general day-to-day activities"*).

On a similar note, one interviewee mentioned they do not check the app daily, which could imply that air quality information and reacting to air pollution is not a priority. This is supported by interviewees who do not use daily air quality information and have not accessed the DAQI. The idea that people have many competing and conflicting concerns and therefore need to prioritise those that are personally important or possible, was expressed amongst several of these interviewees ("*Its one of those things where I am like oh I should look at it but just never get round to it. There's a lot of things to keep abreast of.").*

Another barrier identified to behavioural change was the feeling that the DAQI is not relevant to them, as they do not have a health condition or do regular outdoor exercise (*"Personally, I don't have asthma or anything, and I'm not a runner… I'd still go on like a walk in, sort of a high medium because … I don't have any preexisting conditions… but I do let my friends and family, who do, who have bad asthma and are like frequent runners.").* Similarly, one Met Office application user felt that the air inside is the same as the air outside, implying that they don't think changing their behaviour will make a difference to health outcome. Similarly, an interviewee stated that the benefits of exercise outweigh the harms of pollution. On the other hand, the vast majority of the general population interviewees considered that breathing in polluted air has an impact on their health and that they were at risk from air pollution. It should be noted that only 3/12 of all interviewees had seen an alert for high pollution, which may have an influence on whether they believe they would act in response to a high alert. The health advice for the general population only suggests behavioural change at a high level of pollution.

One third-party service user (Met Office) stated that the air quality information presented was too vague and therefore they did not know what to do in reaction to the rating. The

information on the Met Office app displays only the DAQI banding from Low to Very High, without any text. It does, however, link externally to the UK-Air website. Therefore, if an individual exclusively uses a third-party service that does not clearly and explicitly present accompanying information, they may not know what to do in reaction to a daily air quality forecast.

Health care professionals provided some insight on potential barriers to acting on DAQI advice. It was stated that people who are more educated and have more agency are more likely to have more opportunity and more motivation to change their behaviour, whereas those with less agency (such as children) may not be able to access or follow the advice.

A7.6.4 RSQ5.4: Determining what, if any, facilitators exist that have helped users to enacting DAQI advice.

Overall, there were no particular facilitators to behaviour change currently in the DAQI that were identified in the interview. Potential facilitators could be viewed as removing the barriers identified in section 13.6.3.

A7.6.5 RSQ5.5: Determining in what way, if any, alert frequency impacts adherence to advice.

The frequency of DAQI alerts was not covered in the interview questions. 3/12 interviewees had received a high pollution alert and of these, only one had done something in response. There is not enough data to draw conclusions about the relationship between frequency of alerts and behaviour change from the interviews.

A7.7 CERQ6 SOUNDNESS OF ADVICE

CERQ6: To what extent does advice the DAQI provides align with the intervention's intended outcome (to reduce severity of symptoms exacerbated by short-term air pollution spikes) and impact (to reduce adverse health impacts)?

The expert interviews suggested that the 'Recommended Actions and Health Advice' provided by the DAQI might not be completely aligned with the intervention's intended outcomes and impacts. Key concerns raised included current DAQI messaging not being in line with the most up to date NHS guidance on asthma management, as well as the potential unintended consequences of discouraging physical activity. Moreover, while the current 'Recommended Actions and Health Advice' provided by the DAQI could reduce the severity of symptoms exacerbated by short-term air pollution spikes, these actions may not reduce adverse health impacts in the longer term and could even be harmful to overall health and wellbeing.

The DAQI's 'Recommended Actions and Health Advice' were reviewed with air quality and health experts. The advice and messaging regarding physical exertion, particularly outdoors, as well as use of a reliever inhaler by asthmatics, was examined in more detail. The interviewees were also asked to consider the potential unintended consequences arising from the 'Recommended Actions and Health Advice'. The findings are summarised below and elaborated in the following subsections.

Air quality and health experts generally agreed that **reducing strenuous outdoor physical activity during higher levels of air pollution could alleviate the severity of any**

immediate symptoms, especially for people considered at risk. However, this was strongly caveated with:

- concerns regarding the current messaging which has the potential to discourage physical activity and could have negative impacts on the overall health of the population.
- the potential for the unintended consequence, for example, substituting outdoor activity with activity in indoor spaces which also suffer from air that is polluted at a similar level (given the lack of air conditioning/filtering in indoors spaces across the UK).

It cannot be concluded from the interviews that reducing strenuous outdoor physical activity at moderate, high, or very high levels of air pollution could be considered to result in a net positive health impact for at risk individuals. **The experts had concerns that the DAQI's 'Recommended Actions and Health Advice' could discourage physical activity, which could have a negative impact on overall health and wellbeing in the longer term**. Similar concerns were raised for the general population, albeit they considered it less likely that reducing physical exertion would have a net positive health impact on people who might not be at risk than otherwise.

The **air quality and health experts generally agreed with the use of blue 'reliever' inhalers when needed during elevated air pollution episodes could reduce asthmatic symptoms. However, experts also raised concerns that this messaging may not be consistent with latest NHS advice**, which is centred around asthma management plans. Expert input was not conclusive as to whether increased use of a blue 'reliever' inhaler at high or very high levels of air pollution could result in a net positive health impact for asthmatics, albeit it is possible.

Air quality and health experts agreed **the current 'Recommended Actions and Health Advice' could result in unintended consequences**. Key themes included potentially:

- alarming individuals and causing them to stay indoors and reduce levels of exertion/physical activity, which might not reduce their exposure to elevated levels of air pollution (if there is no air conditioning/filtering in the indoor spaces) and/or have negative knock-on effects on their physical and/or mental health and wellbeing especially in the longer term; and
- Increasing the use of reliever inhalers could increase their reliance / dependence, and overuse can lead to, e.g., muscle pain or weakness, headaches, and dizziness.

Some experts also suggested there could be unintended consequences arising from the DAQI's focus on the short-term health effects of short-term pollution episodes, and provided some suggestions as to how this could be managed.

Finally, **air quality and health experts also provided recommendations as to how the current 'Recommended Actions and Health Advice' could be improved**, especially to address their concerns regarding physical activity, asthma management, and the potential unintended consequences.

A7.7.1 RSQ6.1, 6.3: Determining the extent to which the health literature supports the assumption that reducing strenuous outdoor physical activity at moderate, high, or very high levels of air pollution is likely to reduce the severity of symptoms in at risk groups.

The air quality and health experts generally agreed that reducing strenuous outdoor physical activity during higher levels of pollution likely reduces severity of symptoms in at risk groups; however, this was caveated with concerns regarding the current messaging which has the potential to discourage physical activity and could have negative impacts on overall health. The experts also had multiple suggestions on how to improve the DAQI messaging for at risk individuals.

One expert, who thought reducing outdoor physical activity is an effective way of reducing symptoms, clarified that this advice needs to be explained clearly to patients as you would not want individuals to stop exercise because it greatly benefits general health. In addition, there is the potential for an unintended consequence, for example, substituting an outdoor activity with activity in an indoor space with air that is polluted at a similar level to outside (given the lack of air conditioning/filtering in indoors spaces across the UK), which would offer no health benefit and likely have a worse impact on health than exercising outside. Another expert stated that there is currently not enough evidence to justify advising individuals to reduce or avoid exercise.

A key message raised in the interviews was that the consequences of reducing physical activity (outside) will be different for each person, and this difference could be quite extreme when comparing a very healthy young person with an older person with a chronic disease (and would also vary between those categorised as at risk). The longer-term benefits of regular physical activity were mentioned, albeit acknowledging there are large uncertainties in exactly how beneficial this is due to lack of evidence. It was also brought up that there are many factors being studied that can affect symptoms, in addition to air pollution and physical exercise, reiterating that there is much uncertainty (and variation between individuals) in how these different factors influence symptoms.

There were a number of suggestions from the experts on how to improve the current messaging provided by the DAQI for at risk individuals during high and very high pollution episodes, with regards to physical activity:

- Experts thought the advice for a very high air pollution episode should focus on limiting the time spent outside as much as possible (rather than limiting physical activity specifically) and providing guidance on what to do if people are unavoidably exposed to these levels of air pollution.
- Similarly, one expert suggested that it should be made clearer on the DAQI webpage that any exposure to air pollution is harmful.
- The experts suggested clarifying the definitions of “physical activity” and “strenuous” and/or providing examples; they raised that the term “strenuous” was ambiguous or subjective and therefore suggested more clear wording or definition, aligned with those used by the NHS, such as “moderate” and “vigorous”.
- Another suggestion was to include a recommendation to monitor any symptoms for a period of time after the pollution event (for example, up to one week).

- Experts also raised that the advice on reliever inhalers should be expanded upon in terms of asthma management plans and beyond undertaking / limiting physical activity.

A7.7.2 RSQ6.2, 6.4: Determining the extent to which reducing strenuous outdoor physical activity at moderate, high, or very high levels of air pollution can be considered to have a net positive health impact for at risk individuals.

It was not possible to conclude from the expert interviews whether reducing strenuous outdoor physical activity at moderate, high, or very high levels of air pollution can result in a net positive health impact for at risk individuals. All experts had concerns about the current DAQI messaging discouraging physical activity, and the impact that this could have on long-term health.

The experts across both groups agreed that physical activity is extremely important for long-term health, and the current messaging could lead to reducing physical activity levels in the population (implying this would not have a net positive impact on health). One health care A expert stated that there is currently not enough evidence to justify advising individuals to reduce or avoid exercise. However, it was acknowledged that there would likely be a large difference in the consequences of reducing physical activity (outside) when comparing a very healthy young person with an older person with a chronic disease (and this would also vary between those categorised as at risk).

The same recommendations provided by the experts in Section A7.7.1 regarding DAQI advice wording for high and very high pollution episodes, with respect to physical activity, apply.

A7.7.3 RSQ6.5: Determining the extent to which the health literature supports the assumption that reducing physical exertion at very high levels of air pollution is likely to reduce the severity of symptoms (short-term health effects) in the general population.

The experts generally agreed that reducing strenuous outdoor physical activity during higher levels of pollution likely reduces severity of symptoms for the general population; however, this was heavily caveated with concerns regarding the current messaging, which has the potential to discourage physical activity and could have negative impacts on overall health. The experts also had suggestions on how to improve the DAQI messaging for the general public.

A recurring theme was that the current wording of the advice had the potential to discourage people from partaking in physical activity, which could have a negative impact on the general health of the population. As raised for the discussion on at risk individuals, another key point was that the consequences of reducing physical activity (outside) will be different for each person, and this difference could be quite extreme when comparing a very healthy young person with an older person with a chronic disease. It is likely that the benefits of continuing to undertake physical exercise would be greater for someone in the general population compared to someone classed as at risk. In addition, and again as raised in Section A7.7.1, there is the potential for an unintended consequence, for example, when substituting an outdoor activity with activity in an indoor space with air that is polluted at a similar level to outside (given the lack of air conditioning/filtering in indoors spaces across the UK), which would offer no health benefit and likely have a worse impact on health than exercising outside.

It was acknowledged by the interviewees that, although there are long-term benefits of regular physical activity, there are large uncertainties in exactly how beneficial this is (especially when undertaken at high levels of air pollution). It was also raised that there are many factors being studied that can affect symptoms in addition to air pollution and physical exercise, reiterating that there is much uncertainty (and variation between individuals) in how these different factors influence symptoms.

Another theme in the advice for the general population was that the wording, in particular for a very high pollution episode, is not currently strong or serious enough. Experts raised concerns about this advice focusing on activity or physical exertion, rather than exposure to air pollution.

There were a number of suggestions from the experts on how to improve the current messaging provided by the DAQI for the general population during high and very high pollution episodes, with regards to physical activity:

- Experts thought the advice for a very high air pollution episode should focus on limiting the time spent outside as much as possible (rather than limiting physical activity specifically) and providing guidance on what to do if people are unavoidably exposed to these levels of air pollution. They suggested providing links or references to more detailed advice such as from the NHS or advise consulting your GP if symptoms become a re-occurring issue (as this could lead to development of other lung conditions).
- One expert suggested that it should be made clearer on the DAQI webpage that any exposure to air pollution is harmful, and another suggested that for the general population, the advice for the low banding should acknowledge the impact of long-term concentrations of air pollution on health.
- The experts suggested clarifying the definitions of “physical activity” and “strenuous” and/or providing examples; they raised that the term “strenuous” was ambiguous or subjective and therefore suggested more clear wording or definition, aligned with those used by the NHS, such as “moderate” and “vigorous”.
- Another suggestion was to include a recommendation to monitor any symptoms for a period of time after the pollution event (for example, up to one week).

A7.7.4 RSQ6.6: Determining the extent to which reducing physical exertion at very high levels of air pollution can be considered to have a net positive health impact for members of the general population.

It was not possible to conclude from the expert interviews whether reducing strenuous outdoor physical activity at moderate, high, or very high levels of air pollution can result in a net positive health impact for the general population, as there is not enough evidence and the answer varied between individuals. However, all experts had concerns about the current DAQI messaging discouraging physical activity and the impact that this could have on long-term health. It is less likely that reducing physical exertion would have a net positive health impact on the general population than for the at risk population, where reducing exposure might have a greater positive impact on health.

One expert stated that there is currently not enough evidence to justify advising individuals to reduce or avoid exercise. The experts across both groups agreed that physical activity is extremely important for long-term health, and the current messaging could lead to reducing

physical activity levels in the population, which could have a net negative impact on health. It was also raised that there would likely be a large difference in the consequences of reducing physical activity (outside) when comparing, for example, a very healthy young person with an older person with a chronic disease.

The same recommendations provided by the experts in Section A7.7.3 regarding DAQI advice wording for high and very high pollution episodes, with respect to physical activity, apply.

A7.7.5 RSQ6.7: Determining the extent to which the health literature supports the assumption that increased use of a reliever inhaler at high, or very high levels of air pollution is likely to reduce the severity of symptoms in at risk groups (specifically asthmatics).

The experts generally agreed with the use of reliever inhalers during elevated air pollution episodes to alleviate symptoms. However, the experts also raised that this messaging is inconsistent with current NHS advice, which is centred around asthma management plans.

Several experts agreed with the use of the reliever inhaler during elevated pollution episodes, whilst they were also concerned that the current wording of the guidance misses the opportunity to encourage asthma patients to follow their asthma management plans. One expert was unsure about the advice to increase use of the reliever inhaler, believing it may be better for those with asthma to stay indoors during elevated pollution episodes if possible.

The key recommendation from experts was that the DAQI advice for asthmatics should be reframed in terms of asthma management plans, which asthma patients should have (but not all do at present). More generic advice would be to remind patients to continue following their asthma plans, use their preventative inhaler, carry their reliever inhaler, and arrange a review after every exacerbation.

A7.7.6 RSQ6.8: Determining the extent to which increased use of a reliever inhaler at high, or very high levels of air pollution be considered to have a net positive health impact for at risk individuals.

It was not possible to conclude from expert interviews whether increased use of a reliever inhaler at high, or very high levels of air pollution can be considered to have a net positive health impact for at risk individuals (specifically, asthmatics) as there was not enough evidence available and the answers varied between individuals. However, while health care experts generally agreed with increased use of the reliever inhaler during elevated pollution episodes, there were concerns that the DAQI messaging is not up to date with current NHS advice on asthma management, and therefore could result in a net negative impact on health.

Several health care experts agreed with the use of the reliever inhaler during elevated pollution episodes, although this was combined with concern that the current wording of the guidance misses the opportunity to encourage asthma patients to manage their condition effectively under normal conditions (i.e., via asthma management plans as per the most up to date NHS guidance).

The main concerns raised by experts regarding increased use of reliever inhalers were increasing reliance / dependence on the reliever inhaler, and overuse, which can lead to muscle pain or weakness, headaches, dizziness, etc. Overuse of the reliever inhaler could

also mean the asthma is not well controlled. As a result of this, we conclude that health care A experts thought the current DAQI advice regarding reliever inhalers would not necessarily have a net positive health impact on people's health and wellbeing.

Experts were not able to say whether the recommendation for people experiencing symptoms during episodes of elevated pollution to use their reliever inhaler more would likely have a net positive impact on people's health. However, the same concerns regarding deviation from asthma management plans, and potential consequences of over-use of the reliever inhaler, were raised.

Again, the key recommendation from the experts was that the DAQI advice for asthmatics should be reframed in terms of following an asthma management plan. It was recommended that clinicians ensure the management plan covers both normal conditions and high pollution episodes.

A7.7.7 RSQ6.9: Identifying any known or likely unintended consequences arising from the current health advice.

Experts generally agreed there are likely unintended consequences arising from the current DAQI's 'Recommended Actions and Health Advice'. Key themes raised were alarming individuals, causing them to stay indoors and reduce levels of exertion/physical activity, which may have knock-on effects as outlined below. The experts also felt there could be unintended consequences arising from the DAQI's focus on the short-term health effects of short-term pollution episodes.

Unintended consequences from alarming individuals and causing them to stay indoors and reduce levels of exertion/physical activity, could include: the health impacts of increased exposure to indoor air pollution, the health impacts of decreasing physical activity/exercise, social isolation, loss of work opportunities, missed school days, issues with mental health, missing health appointments, and impacts on families. Interviewees also raised that the advice could actually encourage the use of cars, which would then worsen air pollution. It was generally agreed or implied that, for most people, the potential unintended consequences of the advice were unlikely to be 'worthwhile' to reduce exposure to high air pollution episodes.

A key recommendation from the experts was to provide additional context and advice alongside the recommended actions, to avoid discouraging people from doing things that are hugely beneficial to their health (such as going outside, undertaking physical activity, attending school, and attending health appointments) and to avoid marginalising the most vulnerable people in society.

Experts also considered that there could be unintended consequences from the DAQI's focus on short-term health risks of short-term exposure to elevated air pollution. While the experts generally agreed that the DAQI's focus on short-term health risks of short-term exposure to elevated air pollution is appropriate for its purpose as is currently, they considered that by focusing on short-term exposure/health risks, this might confuse and/or lead to misunderstandings about people's risks from longer-term exposure, even though it is arguably the larger risk. Some experts felt that focus on symptoms that might be experienced during elevated air pollution episodes could mislead the public (e.g., through the 'Low' banding being green) and confuse patients.

However, this is a complicated 'tension'. For example, one expert stated that focusing on short-term health risks from air pollution was a targeted approach and could work well, as

long as the purpose of this was clear. Whilst another expert felt that the DAQI should not focus on short-term exposure anymore, as the evidence has moved on since its creation, and one went so far as to say that the DAQI is no longer “fit for purpose”.

Experts provided some suggestions on how the DAQI could recognise the long-term effects of air pollution whilst maintaining its original purpose:

- One expert suggested having two separate tools: one focusing on short-term effects and one that focuses on long-term effects, through either local authorities or other institutions who could understand the trends.
- Some of the experts thought the DAQI should be retained as a tool to help people manage short-term health risks of short-term exposure to air pollution, but that long-term exposure also needs to be addressed somewhere in the DAQI, and potentially also as a separate tool or index.
- Another expert suggested that the public may also need to be informed of the lag effects of air pollution exposure, in that effects may not be apparent until 3-4 days after the event.

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