



EVALUATION OF THE DAILY AIR QUALITY INDEX

Evaluation Report

Final Report

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NON-TECHNICAL SUMMARY

According to the UK Government's 2023 Environmental Improvement Plan, air pollution "continues to be the biggest environmental risk to human health and a source of harm to the natural environment". However, there are still low levels of public awareness of air pollution levels and the effect that air pollution can have on people's health.

Defra's Daily Air Quality Index (DAQI) informs the public about the potential levels of air pollution in different parts of the UK, up to five days ahead. The air quality information services, such as the webpage, email bulletin, etc., create alerts when there are high or very high levels of air pollution and provides 'recommended action and health advice' that people can take to avoid or reduce symptoms they could experience otherwise. These information services intend to protect people's health during episodes of especially high air pollution.

Defra commissioned this study to evaluate whether the DAQI services are achieving the intended objectives and provide recommendations for how these services could be improved in the future (the 'study').

In particular, this evaluation sought to answer six main research questions, supported by a review of the existing evidence and relevant literature, as well as primary data collection comprising an online survey of over 2,000 people residing in England; 21 interviews of people from the general public (or 'potential users'); and 14 interviews of air quality, public health and healthcare experts.

The analysis of the evidence collected against the research questions suggests that the DAQI can be a reliable source of air pollution forecasts; and presents valid and accurate information. The DAQI and related services, also appear technically accessible and understandable for the general public.

However, these services are accessed directly by a very low number of people based in the UK. It appears that a larger proportion of people may directly access the information through third-party services that draw on the DAQI such as navigation applications, etc. Finally, the DAQI may have a direct or indirect influence on people's intentions to change their behaviour but the evidence supporting this was very limited, further research is suggested.

Overall, the study concludes that the DAQI services provide air quality information and recommended actions and health advice appropriately, with some areas for potential improvement. However, the DAQI services might not be effective at achieving its intended aim, that is, that people change their behaviours in ways that can reduce the health risks or symptoms they could otherwise face in days with especially high levels of air pollution.

There are ways in which the DAQI could be improved, especially to be more effective at achieving its intended objectives of protecting people's health. In summary, it is recommended that Defra and UK Health Security Agency work collaboratively with relevant stakeholders (e.g., the National Health Service (NHS), Local Government, Weather Broadcasters, Navigation System providers, etc.) to connect on, and ideally integrate, their air quality information systems; improve the communication of air quality information; and, together, facilitate the mainstreaming of air quality notifications and advice.

EXECUTIVE SUMMARY

According to the UK Government's 2023 Environmental Improvement Plan, air pollution "continues to be the biggest environmental risk to human health and a source of harm to the natural environment". **Air pollution presents a particular risk to vulnerable groups**, including the elderly, young children and individuals with cardiovascular and/or respiratory conditions.

In this context, the **Daily Air Quality Index (DAQI) provides near-real-time air quality data to inform the public about short-term fluctuations in air pollution levels**, alerting them to especially high levels of air pollution, and providing health advice; with the intention of influencing people's behaviours to alleviate any attributable acute health episodes.

Despite this, the 2021 Prevention of Future Deaths Coroner's¹ report raised "low public awareness of the sources of information about national and local pollution levels" as one of the several matters of concern about the risks and impacts of air pollution on human health.

As part of the Government's response to this report, an Air Quality Information System Review (AQIS Review) was initiated. As part of the AQIS review, the Department for the Environment, Food and Rural Affairs (Defra) has commissioned **an evaluation that aims to assess the appropriateness and effectiveness of the DAQI; and provide recommendations on improvements** to the air quality information system.

Six Core Evaluation Research Questions (CERQs) and a number of Relevant Sub-Questions (RSQs) were set by Defra and reviewed by the consultant team to structure and plan the evaluation of the DAQI in line with the UK Government's Magenta Book. Primary and secondary research was undertaken and the findings were outlined against each of these evaluation questions, coupled with theory-based methods to assess the DAQI's appropriateness and effectiveness.

Three data collection methods were employed in this study: **an evidence and literature review, an online survey of people residing in England, and interviews of people from the general public (or 'potential users') and experts.**

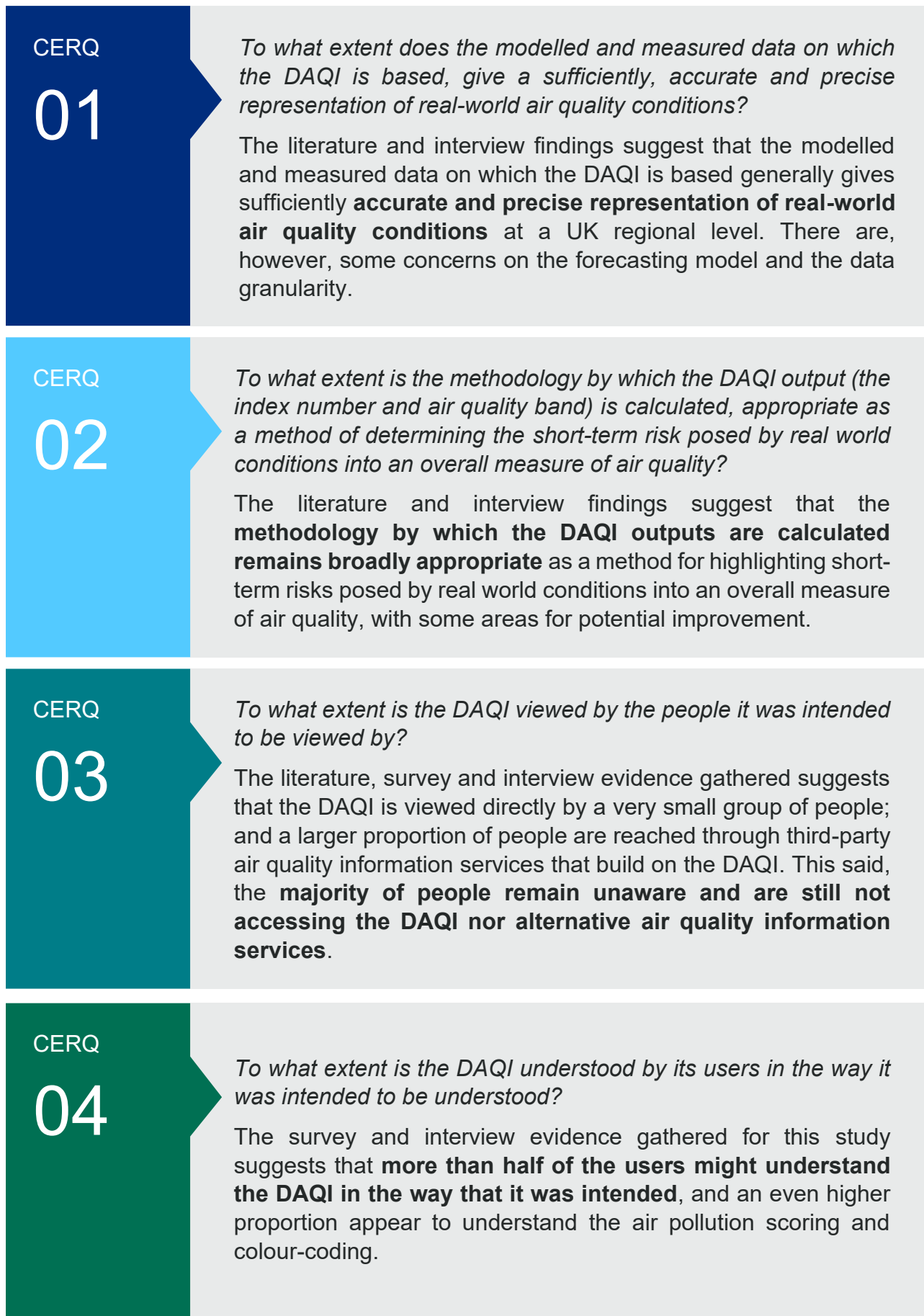
The survey engaged 2,008 individuals from three subsamples: i) a stratified random sample of 1,001 people that is intended to reflect the population of England; ii) a random sample of 907 people representative of those who might especially be at risk of air pollution; and iii) a smaller sample of 100 digitally excluded people.

35 semi-structured interviews were conducted: i) 21 England based residents were interviewed to explore, in more depth, the levels of awareness, access, understanding, use and behaviours related to the DAQI; and ii) 14 experts in air quality modelling and forecasting as well as public health and healthcare were interviewed to identify additional evidence and/or considerations that should be taken into account as part of this evaluation.

The figure below provides a **high-level overview of the research findings** against each of the evaluation questions, by CERQ.

¹ Regulation 30: Action to prevent future deaths (judiciary.uk) Available at: <https://www.judiciary.uk/wp-content/uploads/2021/04/Ella-Kissi-Debrah-2021-0113-1.pdf>

Figure i: High-level research findings against the Core Evaluation Research Questions



CERQ

05

To what extent do the people who use the DAQI enact the advice it provides?

The literature, survey and interview findings suggest that people appear responsive to air quality notifications and willing to enact the ‘Recommended Actions and Health Advice’ provided by the DAQI. However, the **extent to which people will, in fact, enact any behavioural modifications remains uncertain.**

CERQ

06

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 research undertaken suggests that **the ‘Recommended Actions and Health Advice’ provided by the DAQI are no longer fully aligned with the latest evidence and understanding** of the mitigative actions that individuals should take during episodes of elevated air pollution.

The literature, survey and interview findings were analysed and used to:

- *Assess appropriateness:* By considering the extent to which the DAQI is a source of information on air quality and advice, especially for at risk, that is: 1) reliable; 2) methodologically and/or technically valid and accurate; 3) accessible; and 4) understandable.
- *Assess effectiveness:* By evaluating the extent to which the DAQI results in the achievement of the desired outcomes and impacts, including that people, especially those at risk 1) access the DAQI and are aware of air pollution levels; 2) understand the levels of air pollution and risk; 3) follow the ‘Recommended Actions and Health Advice’ and/or modify their behaviours; and 4) mitigate adverse health effects or symptoms attributable to short-term exposure to elevated air pollution.

Based on the analysis of the available evidence and these research findings, the DAQI is considered to be generally a reliable, valid and accurate, accessible and understandable source of air quality information. Thus, it was concluded that the DAQI is broadly appropriate, with areas of potential improvement especially concerning its accessibility and understandability.

In addition, the available evidence suggested the DAQI might not, generally and by itself, result in a reduction of health risk faced by individuals nor mitigate adverse health effects from their short-term exposure to elevated air pollution. Thus, it was concluded the DAQI might not be effective at achieving its intended outcomes and impacts.

In conclusion, Defra’s Daily Air Quality Index services providing air quality information and recommended actions and health advice are appropriate, with some areas for potential improvement. However, these DAQI services appear generally ineffective at achieving behaviour modifications that could reduce the health risk faced by individuals, or at mitigating any adverse health effects people may suffer from their acute exposure to elevated air pollution.

Recommendations on improvements to the DAQI services were also identified based on evidence gathered and the evaluation’s conclusions, for consideration by Defra and the AQIS Review.

Overall, it is **recommended that Defra and UK Health Security Agency (UKHSA) work collaboratively with relevant stakeholders (e.g., the National Health Service (NHS), Local Government, Weather Broadcasters, Navigation System providers, etc) to connect on, or ideally integrate, their air quality information systems; improve the communication of air quality information; and, together, facilitate the mainstreaming of consistent air quality notifications and advice.** Thirteen detailed recommendations are outlined below at a high level.

Table i: Summary of recommendations

Improving the DAQI’s...	Recommendation
Reliability	<p>#1 Defra and/or the Met Office should improve the current spatial resolution of the forecasting model that is used to provide the DAQI notifications on a postcode level.</p> <p>#2 Defra and/or the Met Office could enhance the forecasting approach by drawing on technological advances.</p> <p>#3 Defra, in collaboration with relevant stakeholders, should update the ‘Recommended actions and health advice’, particularly advice relating to physical activity and inhaler use. Additional advice should be included so that people are encouraged to monitor symptoms for a day or more after elevated pollution episodes and reach out to healthcare professionals as needed.</p>
Methodological validity and accuracy	<p><i>No methodological updates are suggested at this time. A couple of areas that should be monitored for potential future updates were identified.</i></p>
Accessibility	<p>#4 Defra should build on existing third-party air quality information services, collaborating with their providers for an effective and assured use of the methodologies, evidence and/or information they are currently drawing from.</p> <p>#5 Defra and UKHSA should collaborate with health and care providers and/or educational facilities to integrate the use of the DAQI in their services, particularly targeting at-risk individuals.</p> <p>#6 Defra should review and potentially expand the communication channels of the DAQI, based on the latest trends and developments. For example, joining TikTok, Instagram or similar platforms or including messaging as part of weather channels or TV</p>

Improving the DAQI's...	Recommendation
	<p>weather broadcasts. Defra could also then use this expanded stakeholder and reach to promote air quality events and increase the public's awareness and knowledge about the effects of air pollution.</p> <p>#7 Defra should make minor adjustments to the visual display of the DAQI information, by including scores (1-10) in addition to the colour-coding or Purple Red Amber Green (PRAG) rating, so to improve the accessibility for people who are colourblind.</p>
<p>Understandability</p>	<p>#8 Defra should include additional text suitable for a lay person in the DAQI services, accommodating people of different ages, interest levels, education, and backgrounds, and that any messaging is as practical as possible for clarity and ease of understanding.</p>
<p>Effectiveness – behaviour modification</p>	<p>#9 Defra (and/or other providers of air quality information that Defra collaborates with) should review the visuals to limit 'green fatigue' and only issue notifications and alerts when the air pollution is 'high' or 'very high' (and potentially 'moderate') to improve people's engagement with the information and adherence to the advice.</p> <p>#10 Defra should develop and implement a communication and/or educational plan alongside the DAQI publications to: i) raise the profile of air pollution risks amongst UK residents, and ii) improve people's understanding of what elevated episodes of air pollution could mean to their health in practical terms in the short-term</p> <p>#11 Defra should also include more contextual information that can help people enact any action in addition to providing understandable and actionable 'recommended actions and health advice' for people to consider during elevated air pollution episodes.</p> <p>#12 Defra should explore actions that people with limited discretion over their time might be able to take to reduce their acute exposure to elevated air pollution.</p> <p>#13 Defra should explore approaches to issue dynamic and tailored messages to people.</p>
<p>Effectiveness – mitigation of symptoms</p>	<p><i>There were no additional recommendations that could help improve the mitigation of symptoms. Seeking to improve accessibility and understandability, as well as the design of the DAQI to enhance adherence to a set of clearer and more concrete 'Recommended Actions and Health Advice' would have positive spillover effects on the extent to which the DAQI might contribute to mitigating symptoms from the acute exposure to elevated air pollution.</i></p>

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1. CONTEXT AND INTRODUCTION TO THE PROJECT

According to the UK Government's 2023 Environmental Improvement Plan, **air pollution "continues to be the biggest environmental risk to human health and a source of harm to the natural environment"**². Air pollution presents a particular risk to vulnerable groups, including the elderly, young children and individuals with cardiovascular and/or respiratory conditions.

In this context, the **Daily Air Quality Index (DAQI) provides near-real-time air quality data** to inform the public about short-term fluctuations in air pollution levels, alerting them to especially high levels of air pollution, and providing health advice; with the intention of influencing people's behaviours to alleviate any attributable acute health episodes.

Despite this, the 2021 Prevention of Future Deaths coroner's report³ **raised "low public awareness of the sources of information about national and local pollution levels"** as one of the several matters of concern about the risks and impacts of air pollution on human health.

As part of the Government's response to this report an Air Quality Information System Review (AQIS Review) was initiated.⁴ As part of the AQIS review, the Department for the Environment, Food and Rural Affairs (Defra) has commissioned an **evaluation study that aims to assess the appropriateness and effectiveness of the DAQI; and provide recommendations on improvements to the air quality information system.**

This document is the **DAQI's Evaluation Report**, in line with the Magenta Book and Defra's project requirements. The rest of the document is structured in six main sections as follows:

- Section 2 presents the DAQI and its objectives.
- Section 3 summarises the methodology underpinning this evaluation.
- Section 4 presents the main evaluation research findings, including an overview and summary against each of the six core evaluation research questions.
- Section 5 sets out the evaluation conclusions.
- Section 6 outlines the recommendations for the future of the DAQI, and outlines limitations and opportunities for further research.

These sections comprising the main Evaluation Report are supported by primary and secondary data collection, described in-depth in a separate 'Appendix report' that contains the following:

- Appendix 1: Evaluation Plan, which presents the plan and framework developed and agreed ahead of conducting the evaluation, including the Theory of Change, the evaluation questions, selection of research and evaluation methods, etc.
- Appendix 2: Data collection – Survey, which sets out the survey as designed ahead of launch.

² HM Government (2023). "Environmental Improvement Plan 2023". Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1168372/environmental-improvement-plan-2023.pdf

³ Regulation 30: Action to prevent future deaths (judiciary.uk) Available at: <https://www.judiciary.uk/wp-content/uploads/2021/04/Ella-Kissi-Debrah-2021-0113-1.pdf>

⁴ HM Government (2021). "Inquest touching the death of Ella Adoo Kissi-Debrah: Response to Regulation 28 Report". Available at: <https://www.judiciary.uk/wp-content/uploads/2021/04/2021-0113-Response-from-Central-Government-Departments-DEFRA-DFT-and-DHSC-Redacted.pdf>

- Appendix 3: Data collection – Interview Topic Guides comprising the scripts that guided the semi-structured interviews conducted as part of this project.
- Appendix 4: Literature review findings, containing a detailed account of the findings from a review of the available secondary and grey literature.
- Appendix 5: TOC Workshop synopsis, summarising the outputs of the Theory of Change workshop undertaken as part of this project.
- Appendix 6: Survey synopsis, presenting the outputs of a survey of individuals residing in England.
- Appendix 7: Interview synopsis, synthesising the outputs of 35 interviews of individuals and experts.

2. THE DAILY AIR QUALITY INDEX

The DAQI provides information about air pollution levels and offers ‘Recommended Actions and Health Advice’. It intends to offer a **simple way for the general public to understand air quality**, especially targeting individuals who are at a particular risk of episodes of elevated levels of air pollutant concentration. The index is numbered 1-10 and divided into four bands, low (1) to very high (10), similar to the sun index⁵ or the pollen index⁶.

Defra guidance on the use of the DAQI asks people to take three steps as follows.

Step 1: Determine whether you (or your children) are likely to be at-risk of air pollution. Please note that people at greater risk of symptoms from short-term exposure of fluctuations in air pollution comprise adults and children with heart and/or lung problems.

Step 2: If you may be at-risk and are planning strenuous physical activity outdoors, check the air pollution forecast.

Step 3: Use the health messages below (see Table 2-1) corresponding to the highest forecast level of pollution as a guide.

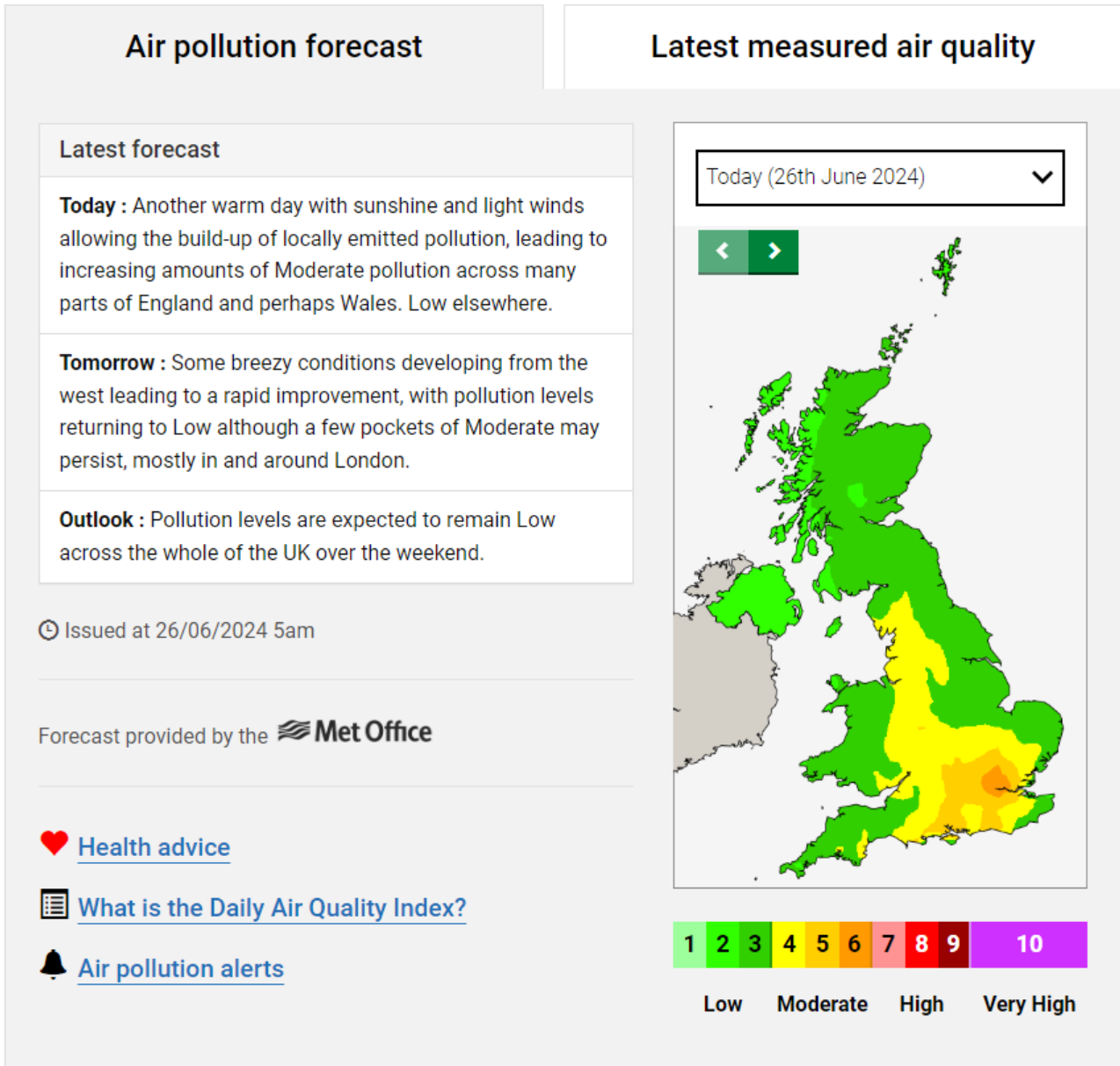
People can check the air pollution forecasts and other DAQI data in multiple ways. The UK-AIR websites home page contains the air pollution forecast map as shown in Figure 2-1

The UK-AIR website’s Pollution Forecast provides a more detailed interactive view of the UK Air Pollution Forecast for up to 5 days ahead. People can zoom in on the map to find their nearest forecast location or enter their postcode in the box lower down within the page. Once they have zoomed in, they can click on a marker (or select from the postcode search results list) to show their local 5-day pollution forecast and save it as their default location to display above the map. The Figure 2-2 provides a visual of this.

⁵ UK Defra. UV Index. Available at: <https://uk-air.defra.gov.uk/data/uv-index-graphs>

⁶ Met office. The Pollen Forecast. Available at: <https://www.metoffice.gov.uk/weather/warnings-and-advice/seasonal-advice/pollen-forecast>

Figure 2-1 UK AIR home page



Source: UK AIR

Figure 2-2 UK Air Pollution Forecast page

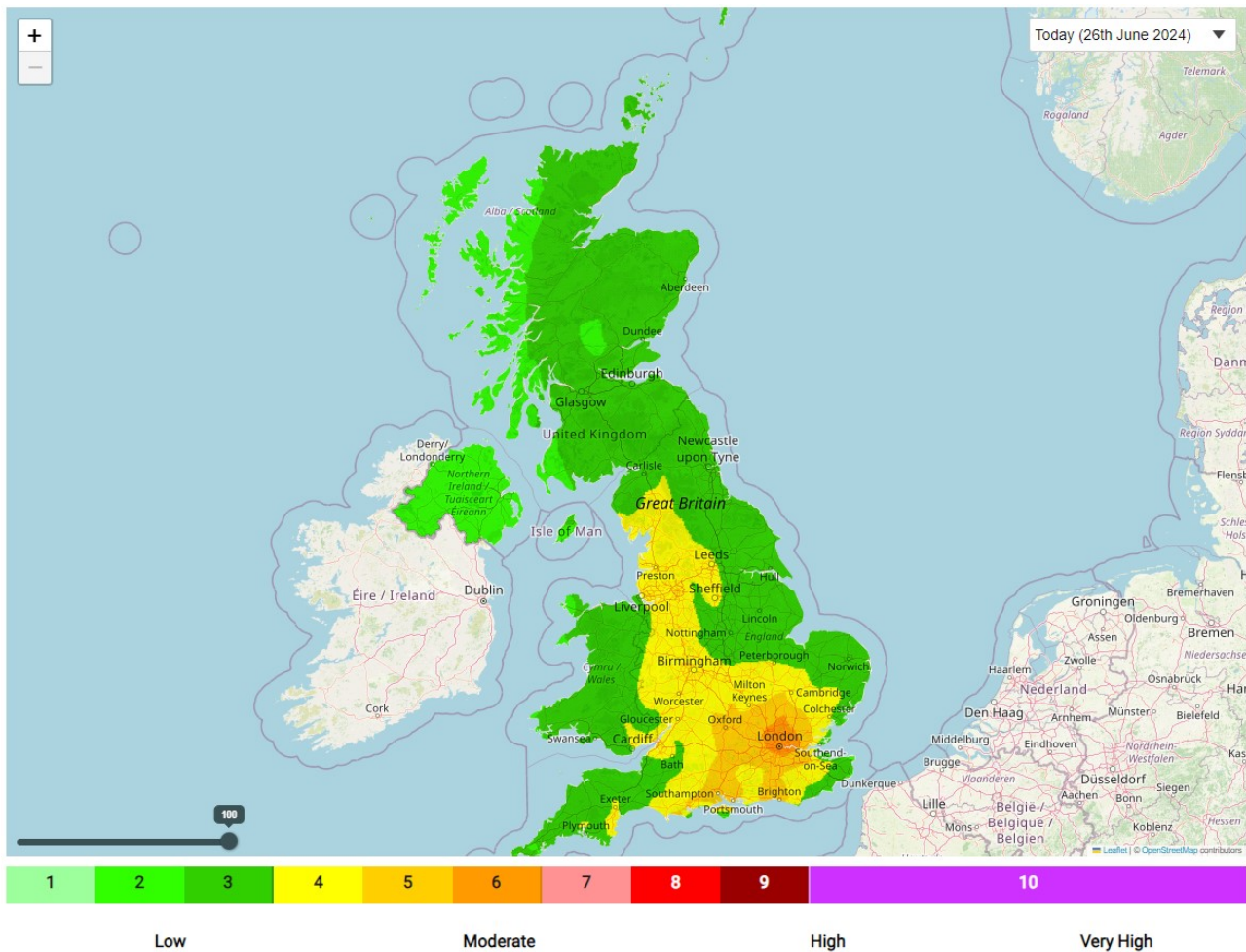
Latest Forecast

Today: Another warm day with sunshine and light winds allowing the build-up of locally emitted pollution, leading to increasing amounts of Moderate pollution across many parts of England and perhaps Wales. Low elsewhere.

Tomorrow: Some breezy conditions developing from the west leading to a rapid improvement, with pollution levels returning to Low although a few pockets of Moderate may persist, mostly in and around London.

Outlook: Pollution levels are expected to remain Low across the whole of the UK over the weekend.

Issued at 26/06/2024, 05:19:00



Source: UK AIR

People can access information through Defra’s UK AIR @defraukair X/Twitter Site; and/or subscribe and access information through the email ‘Daily Air Pollution Bulletin’.

People can also use Defra’s freephone air pollution bulletin service at 0800 556 677 to get updates on air quality in their local area. Air pollution levels and forecasts are provided and are updated every hour.

There are also other providers of air pollution information, which might build upon the DAQI/ Defra UK AIR data. These are not necessarily officially linked to the DAQI; however, they are part of the broader air quality information landscape that people based in the UK engage with.

Finally, the DAQI provides ‘Recommended Actions and Health Advice’ against four bands, as presented in Table 2-1.

Table 2-1 Recommended Actions and Health Advice⁷

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.

*Adults and children with heart or lung problems are at greater risk of symptoms. Follow your doctor's usual advice about exercising and managing your condition. It is possible that very sensitive individuals may experience health effects even on Low air pollution days. Anyone experiencing symptoms should follow the guidance provided below.

Source: UK-AIR.defra.gov.uk

⁷ UK AIR. Daily Air Quality Index page. Available at: <https://uk-air.defra.gov.uk/air-pollution/daq>

The UK AIR pages also provide additional information as to the short-term effects of air pollution on people’s health⁸. The DAQI is not designed to communicate health effects associated with longer-term exposure to air pollution, nor is it intended to suggest a “safe” threshold for exposure.

The methodology underpinning the DAQI was recommended by the Committee on Medical Effects of Air Pollutants (COMEAP)⁹. The index for a given site or geography is determined by the highest concentration of five air pollutants –nitrogen dioxide (NO₂), sulphur dioxide (SO₂), ozone (O₃), particles < 2.5µm (PM_{2.5}) and particles < 10µm (PM₁₀), based on a set of pollutant-specific bandings¹⁰. The DAQI is published for up to five days into the future, communicating to the public the extent to which there could be episodes of lower or higher air pollution in their neighbourhoods.

3. EVALUATION METHODOLOGY

The **DAQI Evaluation** commissioned by Defra aims to:

- **Assess the appropriateness and effectiveness the DAQI; and**
- **Provide recommendations on improvements to the air quality information system.**

These aims have been translated into more specific evaluation objectives, which are described in Table 3-1 below and set the direction of the evaluation.

Table 3-1 The specific evaluation objectives

General objectives	Specific objectives
To assess appropriateness	To assess the extent to which the DAQI is a source of information on air quality and advice, especially for the individuals at risk, that is: <ol style="list-style-type: none"> 1) Reliable 2) Methodologically and/or technically valid and accurate 3) Accessible 4) Understandable
To assess effectiveness	To assess the extent to which the DAQI results in the achievement of the desired outcomes and impacts, including that people: <ol style="list-style-type: none"> 1) Access the DAQI and are aware of air pollution levels, especially those at risk 2) Understand the levels of air pollution and risk 3) Follow the recommendations and/or modify their behaviours 4) Mitigate adverse health effects or symptoms attributable to acute exposure to elevated air pollution

⁸ UK AIR. The short-term effects of air pollution on health. Available at: <https://uk-air.defra.gov.uk/air-pollution/effects?view=short-term>

⁹ <https://www.gov.uk/government/groups/committee-on-the-medical-effects-of-air-pollutants-comeap>

¹⁰ Defra (2013). Update on the implementation of the Daily Air Quality Index. Information for Data Providers and Publishers. Available at: https://uk-air.defra.gov.uk/assets/documents/reports/cat14/1304251155_Update_on_Implementation_of_the_DAQI_April_2013_Final.pdf

General objectives	Specific objectives
To develop recommendations	To identify strengths and weaknesses of the DAQI alongside its baseline Theory of Change; and to develop suggestions for how to build on the strengths and address the weaknesses in a way that better support the achievement of the DAQI’s desired outcomes and impacts.

Based on this, an **Evaluation Plan** was developed drawing on His Majesty’s Treasury (HMT’s) Magenta Book¹¹, relevant literature and evaluation studies.

The plan has five building blocks, comprising:

- a) review of the DAQI’s general and specific objectives and in-depth dive into the workings of the index;
- b) the DAQI’s Theory of Change;
- c) selection of evaluation approaches, including research questions and evaluation methods;
- d) selection of research and data collection methods (e.g., workshops, interviews, surveys, etc.) and analysis; and
- e) the deliverables, roles, responsibilities and delivery timetable.

The plan was shared and agreed with Defra at early stages of the project (see Appendix 1 in a separate ‘Appendix report’), and subsequently implemented to perform this evaluation.

The evaluation is limited by a literature review of the available, published research; and the evidence gathered from an online survey or Computer-Assisted Telephone Interviewing of 2,008 England-based residents, and in-depth interviews of 21 England-based residents and 14 air quality and/or health experts. 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. Nevertheless, the primary research conducted during this study has sample limitations and challenges inherent to online surveys of this type. These are summarised in the Box 3-1 below.

Box 3-1 Primary research limitations

The ‘general population’ survey 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

¹¹ 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

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.

The sample of people and experts interviewed were more limited by time (~2-3 weeks) and budget. Air quality, public health and healthcare experts were identified through relevant programmes and academic networks by Defra and Ricardo. The project team engaged with representatives from Met Office, the London Air Quality and Health Programme Office and their networks, the London Asthma Leadership and Innovation Group, teams across Councils in England, NHS organisations, and leading air quality and health researchers across academic institutions in the UK, resulting in 14 interviews. Over 30 England-based volunteers from the general population were recruited primarily through social media, such as LinkedIn and Facebook. These volunteers were asked to participate in a very short screening questionnaire (<1 minute to complete) to better understand their background and schedule interviews from a sufficiently diverse pool of individuals, to gather insights that could complement the survey. As a result, 21 interviews of the general population were completed.

These and other limitations have been taken into consideration when triangulating all of the available evidence to develop answers to the research questions and evaluation conclusions.

Section 4 presents the research findings for each of the research (or evaluation) questions asked. The complete set of Core Evaluation Research Questions and Relevant Sub-Questions can also be found in the separate 'Appendix report'.

4. EVALUATION RESEARCH FINDINGS

This section summarises the evaluation research findings, gathered through an evidence and literature review, an online survey of people residing in England and interviews of potential users and experts.

The survey engaged 2,008 individuals from three subsamples: i) a stratified random sample of 1,001 people that is nationally representative; ii) a random sample of 907 people representative of those more likely to be at risk of air pollution; and iii) a smaller sample of 100 digitally excluded people.

35 semi-structured interviews were conducted: i) 21 England-based residents were interviewed to explore in more depth the levels of awareness, access, understanding, use and behaviours related to the DAQI; and ii) 14 experts of air quality modelling / forecasting, air pollution and health were interviewed to identify additional evidence and/or considerations that should be taken into account as part of this evaluation.

The following sections provide an overview of the research findings, and a more developed summary of the findings against each of the evaluation questions split into Core Evaluation

Research Questions (CERQs) and Relevant Sub-Questions (RSQs), which are described in the 'Appendix report'.

4.1 OVERVIEW OF RESEARCH FINDINGS

Primary and secondary research findings against each CERQ and RSQ are summarised below and further described in the following subsections. The 'Appendix Report' includes more detailed synopses of the literature review, the TOC Workshop, the survey and the interview findings.

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 literature and interview findings suggest **the modelled and measured data on which the DAQI is based generally gives sufficiently accurate and precise representation of real-world air quality conditions at a UK regional level. There are, however, some concerns on the forecasting model and the data granularity.**

- Data from Automatic Urban and Rural Network (AURN) is generally accurate and complete to allow for a meaningful 'real time' air quality index especially at the UK regional level, even though it is provisional data and not diversely distributed across UK (RSQ1.1).
- Published evidence suggests the forecasting model employed produces generally precise and accurate estimates for regional air pollution levels, except in the case of NO₂ air concentrations, which can result in an unintended underprediction of air pollution (RSQ1.2). Accuracy and precision may be insufficient at the postcode level, which is accessible to DAQI users.
- Published research suggests that increasing the granularity of the data outputs could be useful for individuals to meaningfully consider their behaviour, e.g., including estimates for specific time periods within a day instead of daily averages (RSQ1.3).

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?

The literature and interview findings suggest that **the methodology by which the DAQI outputs are calculated remains broadly appropriate as a method for highlighting short-term risks posed by real world conditions into an overall measure of air quality, with some areas for potential improvement.**

- The five pollutants included in the DAQI remain the most relevant pollutants to measure short-term air pollution risk in the UK setting (RSQ2.1).
- The breakpoints of the DAQI are aligned with other similar indices focussed on short-term impacts of elevated air pollution episodes. Some expert interviews and the latest evidence (e.g., WHO Global Air Quality guidelines) suggest there may be a case to review these breakpoints; however, it is considered there is insufficient additional evidence pertaining short-term health risks faced during elevated air pollution events to determine any adjustments to the thresholds just yet (RSQ2.2).

- The averaging times employed by the DAQI are already very short for most of the pollutants and there is no evidence that shorter averaging periods could improve the notification and alert system (RSQ2.3).
- Research suggests that the DAQI should consider the combined effects of short-term air pollutant exposures on human health; however, there is insufficient evidence to develop and introduce amendments to the DAQI at this stage (RSQ2.4).
- The DAQI is concerned with short-term exposure, therefore, it may not be appropriate to present data as non-discrete days. There is evidence that the effects of being exposed to pollution can last for several days (lag effects), therefore there is a possibility of being exposed to high pollution events over multiple days in a row may have a greater effect. A suggestion is to include accompanying messaging to highlight increased risk when there are multiple real time and forecasted pollution events (RSQ2.5).

CERQ3: To what extent is the DAQI viewed by the people it was intended to be viewed by?

The literature, survey and interview evidence gathered suggests that **the DAQI is viewed directly by a very small group of people; and a larger proportion of people are reached through third-party air quality information services that build on the DAQI.**

- Air quality and health experts interviewed broadly agreed with the definition of people 'at risk' of elevated air pollution in the short-term. However, the literature findings and the experts interviewed as part of this study also suggested that it would be worth investigating whether pregnant people and infants in the womb should be included within the DAQI's definition, which would be in line with the approaches taken by the World Health Organization (WHO), UKHSA, Office for Health Improvement and Disparities, and the Royal College of Physicians. Experts also noted that people from lower income background living in deprived areas might face greater exposure risks, and that everyone is at risk from longer-term exposure (RSQ3.1).
- The majority of the public (89% of survey participants) report in Defra's 2023 Survey on Attitudes to the Environment¹² that they have at least some concern about air quality, which is broadly aligned with findings from the survey and interviews undertaken for this study. Despite this, the available data on historical access to the digital DAQI services, such as the UK AIR website, the @DefraUKAir account on X/Twitter and the daily air pollution email bulletin, suggests that a very small number of people access the DAQI services directly. However, evidence from the survey has highlighted that 51% of the 'at-risk' participants (n=907), 27% of the 'general population' participants (n=1,001) and 2% of the 'digitally excluded' participants (n=100) access or use at least one of the DAQI information services. The interviews identified that people appear to be accessing air quality information primarily through third-party services, which have proliferated since the last DAQI update in 2010. These insights lead to two key findings (RSQ3.2-3.3):

¹² Defra, Kantar (2023). Survey on Attitudes to the Environment -Wave 2. Available at: <https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=20907>

- The majority of the population remain unaware (64%, n=1,001) and are still not accessing the DAQI nor alternative air quality information services (73%, n=1,001).
- The majority of the people who have reported accessing (or ‘viewing’) the DAQI are likely to be doing so through third-party services, which they might consider to be a part of the DAQI especially given that Defra and the DAQI are often referred and/or reported as their main source.
- The survey and interviews suggested that the most common barriers for people accessing the DAQI or similar services could be: 1) awareness of the DAQI and/or health risks posed by episodes of elevated air pollution (i.e., there are people who remain unaware); 2) a lack of time; 3) lack of priority given to air quality; and/or 4) finding their way to/through the services e.g., UK AIR website pages (RSQ3.4).
- The survey and interviews found that factors which have helped broaden access to air quality information include the proliferation of third-party services that provide that information (e.g., navigation/map and weather applications, news outlets, the Met Office website, search engines, etc., have broadened access); increased communication about and interest in air quality, and risk perception (people who perceive and/or understand their risk are more likely to have accessed air quality information services); education (people with higher levels of education appear to be more inclined to have accessed the DAQI), and/or household income (people with higher levels of income also appear more inclined to have accessed the DAQI) (RSQ3.5).

CERQ4: To what extent is the DAQI understood by its users in the way it was intended to be understood?

The survey and interview evidence gathered suggests that **more than half of the users might understand the DAQI in the way that it was intended, and a higher proportion might understand the air pollution scoring and colour-coding.**

- More than half of survey respondents and interviewees showed a ‘correct’ understanding and interpretation of the DAQI (RSQ4.1). An additional 22% of survey participants understood what the DAQI is reporting in terms of air pollution levels, but interpreted incorrectly that high ratings are not a cause for concern. A large proportion of people who perceived themselves at risk of air pollution did so correctly based on the DAQI’s definition.
- Around half of all survey respondents found it easier to understand ‘DAQI visuals’ with clear geographical boundaries and PRAG ratings. Interviewees also found the presentation and data visualisation of the DAQI information intuitive and easy to understand (RSQ4.2). Interviewees generally valued the simplicity and usefulness of the colour-coding or PRAG rating approach.
- Some attendees from the Theory of Change Workshop and one expert interviewee suggested the jargon-filled, detail-oriented language associated with the field may overcomplicate the messaging and affect understanding (RSQ4.3).
- Survey participants, even when aware of the DAQI or other air quality information services, were generally not aware of the ‘Recommended Actions and Health Advice’. However, when asked to consider these actions and advice (presented to them as it

is on the website), survey respondents reported medium levels of understanding (with an average score of 3 out of 5, in which 0 is no understanding and 5 is very high understanding). Five people who were interviewed and were aware of the 'Recommended Actions and Health Advice' stated that they found it easy to follow and understand. (RSQ4.4).

- For some, the barriers to understanding the DAQI included the complexity of the language and messaging (RSQ4.5). Others found the lack of detailed methodological information a barrier. Moreover, a discussion amongst experts during the Theory of Change workshop suggested that, by design, the DAQI was predominantly rated Green, and that Amber, Red, Purple or other ratings were unusual. This was highlighted as a possible contributor to the lack of engagement by DAQI users.
- The main enablers to understanding the DAQI include the use of simple, clearly labelled imagery, such as simple colour-coding or PRAG rating approaches (RSQ4.6). People who are colour blind would especially benefit from having the numerical DAQI scores (1-10) also presented in any visuals.

CERQ5: To what extent do the people who use the DAQI enact the advice it provides?

The literature, survey and interview findings suggest that **people appear responsive to air quality notifications and willing to enact the 'Recommended Actions and Health Advice' provided by the DAQI. However, the extent to which people will, in fact, enact any behavioural modifications remains uncertain.**

- Published research suggests that people's adherence to health advice in response to poor air quality is dependent on many factors, and standard air quality notifications alone are not enough to facilitate behaviour modifications (RSQ5.1-5.2). Interviewees could not remember having encountered a moderate, high or very high air pollution event and could not recall having modified their behaviour. Both interviewees and survey respondents reported willingness to change their behaviour if they were notified of elevated air pollution levels, especially so when they perceived themselves at risk, e.g., carrying and/or using medication accordingly. However, the survey and interview evidence does suggest that people may have a greater intention to modify behaviour compared to actually changing their behaviour upon receiving an air pollution notification.
- The main barriers to behaviour modification highlighted primarily through the interviews include a lack of: i) individual discretionary time (which is affected by employment status, type of employment, income, and other socio-economic factors); ii) awareness, access and understanding of the DAQI notifications and the 'Recommended Actions and Health Advice' (with a proportion of people who are still unaware and/or do not completely understand the DAQI nor the advice); iii) prioritisation given to air quality as a risk factor; and/or iv) prioritisation given to the use of the DAQI or similar services (RSQ5.3).
- Facilitators, which have encouraged behaviour modification so far, include the provision of location-specific, clear and practical advice to individuals based on their personal backgrounds and context, through health and care settings, schools or other formal settings (RSQ5.4).

- The extent to which alert frequency may affect adherence to advice remains unknown, although the literature suggests that unnecessary and avoidable notifications (e.g., on green ratings) could lead to alert fatigue and increased disengagement, which could reduce adherence to advice (RSQ5.5).

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 research undertaken suggests that **the 'Recommended Actions and Health Advice' provided by the DAQI are no longer fully aligned with the latest evidence and understanding of the mitigative actions that individuals should take during episodes of elevated air pollution.**

- Reducing strenuous outdoor physical activity by at-risk individuals and physical exertion by the general population during elevated episodes of air pollution could alleviate the severity of symptoms (RSQ6.1, 6.3, 6.5). However, the published evidence is limited. Moreover, other factors play a role in the health outcomes that could result from a reduction in outdoor activity. For example, replacing physical activity outdoors for indoor spaces with air that is similarly polluted.
- The available literature and expert interviews suggest that reducing outdoor physical activity performed by at risk individuals and physical exertion performed by the general population during episodes of elevated air pollution might not have an overall net positive effect on people's health (e.g., lung function, etc). Instead, continuing to conduct physical activity outdoors might be overall beneficial, even if short-term symptoms linked to air pollution arise (RSQ6.2, 6.4, 6.6). The literature and interviews also suggest that reducing physical activity would likely result in net negative health outcomes in the longer term.
- Published research that investigates the frequency of use of inhalers demonstrated that their use increased during periods of higher air pollution, suggesting at least a perception of relieving symptoms. Survey responses suggest that the majority of medical inhaler users modify their behaviour by increasing their frequency of use when air quality is poor, which they perceive 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 (RSQ6.7).
- The aforementioned published research and survey outputs (RSQ6.7) suggest that inhaler use during elevated air pollution episodes can have immediate health benefits. This is supported by additional expert interviews; however, experts noted that, while increased use of reliever (blue) inhaler during elevated air pollution episodes might reduce the severity of asthma symptoms at the time, this may or may not result in a net positive health impact on at risk individuals in the longer term (RSQ6.8). This is primarily because the negative unintended consequences of increased inhaler use (see below) may outweigh any immediate benefits.
- The literature, expert interviews and survey have provided insights into potential unintended consequences from the advice (RSQ6.9). Experts suggested that alarming individuals and causing them to stay indoors and reduce levels of physical activity might not necessarily reduce their exposure to elevated levels of air pollution and could have negative knock-on effects on their physical and mental health and

wellbeing. Around half of all survey participants also 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. Experts noted that 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. Moreover, NHS publications note that “asthma deaths are largely attributable to avoidable factors, [including an] over-reliance upon [blue] reliever inhalers and under-prescription or use of preventer medications. The use of either short or long-acting relievers in isolation has been identified as a particular risk. Poor adherence to preventer treatments from any cause, intentional or non-intentional, is associated with worse outcomes.”¹³ Experts also highlighted a list of other possible unintended consequences, such as economic losses, increased isolation and loneliness. Finally, some experts were also concerned that the DAQI’s focus on the short-term health effects during episodes of air pollution (instead of more long-term risks) could also have unintended consequences, such as a misunderstanding that ‘everything is well’ from a green rating, when in fact people face a larger, cumulative risk they might need to account for and/or consider when they go about their lives.

The rest of this section provides a **more in-depth summary of the research findings** against each of the CERQ and RSQ. The ‘Appendix Report’ provides detailed synopses of the outputs of the research from the literature review, the Theory of Change workshop, the survey, and the interviews underpinning these findings and conclusions.

4.2 CERQ1 DATA INPUTS

The literature and interview findings suggest the modelled and measured data on which the DAQI is based generally gives sufficiently accurate and precise representation of real-world air quality conditions at a UK regional level. There are, however, some concerns on the forecasting model and the data granularity (CERQ1).

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?

The **AURN** generally provides a complete and accurate dataset of hourly data for DAQI pollutants. There is a data capture target of 85 – 90 % derived from legislation and at present the AURN meets that data capture target for the network as a whole. The number of monitoring sites across the UK meets the legal requirements as per the Air Quality Standards Regulations 2010¹⁴, which specifies the number of monitoring stations based on population density¹⁵. This means that there are fewer monitoring sites in Northern England, Scotland, and Wales compared to central and Southern England. This may mean the spatial representation of AURN measurements may be insufficient for the communication of real-time DAQIs, and for post-processing/verification of AQUM/forecasting model results.

¹³ NHS England (2021). National bundle of care for children and young people with asthma. Available at: <https://www.england.nhs.uk/publication/national-bundle-of-care-for-children-and-young-people-with-asthma/>

¹⁴ The Air Quality Standards Regulations, 2010. Available at: <https://www.legislation.gov.uk/uksi/2010/1001/contents/made>

¹⁵ Defra Air quality monitoring regime assessment: compliance network status (2016-2020). Available at: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2309281136_Monitoring_Regime_Assessment_2016-2020.pdf

The data used in the forecast model is provisional which means the data has undergone basic screening criteria to exclude clearly faulty observations, but it has not undergone the complete, comprehensive quality assurance and control procedures, meaning the data is likely to be of lower accuracy and reliability than that required for final reporting.¹⁶ However, measurement data is ratified throughout the year quarterly in arrears, therefore it is not possible for the model to use ratified data due to timescales. From our analysis the completeness and accuracy of the dataset is unlikely to affect the forecast DAQI results as much as other model parameters and data inputs. However, there is scope for trials to be conducted, comparing DAQI forecasting model runs using ratified and unrated data. Methodological improvements were suggested by air quality experts for the real-time and forecast DAQI, these can be found in the recommendations.

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?

The **forecasting model** provides precise and accurate predictions of future air quality on regionally transported pollutants. Like all models, the forecasting model has a level of uncertainty involved that leads to either under or over predictions of the DAQI due to model parameters and data inputs. Where the model under or over predicts the DAQI, the commentary alongside the forecast map can highlight this, hence lowering the risks of communicating inaccurate forecasts to the public.

The public can meaningfully adjust behaviours based on the current forecast DAQI depending on how they interact with the DAQI forecast map. If looking at the forecast DAQI for a region, the DAQI will generally be accurate with regards to:

- The location of the pollution event
- The onset and termination of pollution event

However, the model can underestimate the forecast DAQI. Moreover, if the public use the tool to zoom into their postcode, the forecast DAQI may be inaccurate as the modelled forecast DAQI is interpolated to assign a DAQI for these specific areas/postcodes as the resolution of the model (11 km x 11 km) is too coarse to provide a forecast DAQI for this level of spatial detail. Important short-lived pollutants such as NO₂, are not captured well with the current spatial or temporal resolution, which could explain the underpredictions of the forecast DAQI. Improvements were suggested by air quality experts with regards to the methodologies used to formulate the forecast DAQI, the language/messaging accompanying the forecast DAQI maps and spatiotemporal resolution of the model for the forecast DAQI, these can be found in the recommendations.

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?

¹⁶ The air quality data validation and ratification process. Available at: https://uk-air.defra.gov.uk/assets/documents/Data_Validation_and_Ratification_Process_Apr_2017.pdf (Accessed 26/06/2024).

The **granularity** of the data communicated to individuals is useful as it consists of the real-time DAQI paired with daily forecasts which works well to inform individuals of any pollution episodes. However, the number of the AURN monitoring stations throughout the UK could be improved to help provide a more spatially representative real-time DAQI.

Some interview participants within the general population and at-risk group expressed that the following changes would be useful in terms of data granularity:

- Highlighting which pollutant caused moderate and high DAQIs.
- Providing information on air pollution hotspots in local areas.

The development of a more temporally resolved forecast was discussed with air quality experts who suggested that in the future it may be useful to provide a more time resolved advice based forecast, to provide users with more flexibility to modify their behaviours/planned activities. For example, wintertime high pollution events that occur due to shallow boundary layer accumulation of NO₂ 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.

4.3 CERQ2 METHODOLOGY

The literature and interview findings suggest that the methodology by which the DAQI outputs are calculated remains broadly appropriate as a method for highlighting short-term risks posed by real world conditions into an overall measure of air quality, with some areas for potential improvement.

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?

The **five pollutants included** in the DAQI are in line with those included by other AQIs worldwide.¹⁷ However, research studies indicate the emergence of additional pollutants that may pose risk to human health such as volatile organic compounds (VOCs) and black carbon (BC).¹⁸ While some of these pollutants are implicitly accounted for within PM_{2.5} measurements, it could be valuable in the future to include separate data from these pollutant species, especially in cases where data is already being collected (e.g., the UK currently monitors BC concentrations).

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?

The **breakpoints** of the DAQI are either aligned or more stringent than AQIs used in other countries. The assessment of the DAQI by COMEAP in 2011, indicated that the WHO air quality guidelines and interim targets served as an initial reference point for evaluating the pollutant-specific bandings. In most instances, the WHO values were adopted as proposed

¹⁷ Priti K and Kumar (2022), A critical evaluation of air quality index models (1960–2021), Environ. Monit. Assess., 194: 324; Available at: <https://doi.org/10.1007/s10661-022-09896-8>

¹⁸ Ricardo (2023). Air quality stocktake report for Office for Environmental Protection. Available at: <https://www.theoep.org.uk/report/commissioned-research-inform-oeps-air-quality-strategy-consultation-response>

breakpoints between the bands.¹⁹ However, the WHO global air quality guidelines (AQG) were updated in 2021 and were informed by the best available scientific evidence obtained from multiple research papers published up to September 2018 covering an extensive review of the epidemiological literature available. The WHO Short-term (24-hour average) AQGs for PM, NO₂ and O₃ were derived from the long-term AQGs. This is a different approach from that used for most of the previous (2005) short-term AQGs, which were based on a consideration of the evidence of health effects following short-term exposure to elevated air pollution. These latest guidelines state that the magnitude of 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, which means that the long-term guidelines for most health outcomes are more protective than the short-term guidelines. In many cases, it can be suitable to use long-term guidelines to derive short-term guidelines. Thus, in the future, it should be considered whether a revision of the DAQI bandings is warranted to take into account latest evidence on short-term health effects of acute 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?

The **averaging times** implemented in the DAQI are already very short for most of the pollutants, and according to COMEAP, which reviewed the DAQI in 2011, there was no new health evidence to suggest that the averaging times for the pollutants included in the DAQI needed to be revised.²⁰ The available literature on the pollutants with longer averaging times (i.e., PM and ozone) found that shorter averaging periods were not associated with different health effects than the current averaging times.

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?

The literature states that single-pollutant approaches, such as the DAQI, may underestimate the health risks associated to exposure to a **mixture of air pollutants**. There are Air Quality Indices (AQIs) that aim to reflect the cumulative effect of multiple pollutants, rather than using a single-pollutant approach like the DAQI. These aggregate-type AQIs were developed by Canada, South Korea and Hong Kong, and inform the public of periods where exposure to air pollution may be of high-risk to human health.²¹ When used in Ontario (Canada), the level of the aggregate AQIs showed associations with the level of hospitalisations.²² Despite this, air quality and health experts noted that the evidence available that focusses on health risks associated with pollutant mixtures is limited and

¹⁹ Committee on the Medical Effects of Air Pollutants (COMEAP) Standards Advisory Subgroup, 2011, Review of the UK Air Quality Index, page 23.

²⁰ Committee on the Medical Effects of Air Pollutants (COMEAP) Standards Advisory Subgroup, 2011, Review of the UK Air Quality Index, page 16.

²¹ 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, 151-158. Available at: <https://doi.org/10.1016/j.atmosenv.2019.05.013>

²² 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, 111681, page 5.

potentially insufficient to design and incorporate changes into the DAQI methodology confidently and transparently.

RSQ2.5: What is the health impact of treating days as discrete events for the purposes of the DAQI?

The DAQI is a daily air quality index tool, which treats **days as discrete events**. There is evidence that the effects of being exposed to air pollution can last up to several days (lag effects). As pollutants can linger in the atmosphere, people may still be at risk several days after the alert is triggered. Treating days as discrete events may underestimate the health risks of pollution episodes.

4.4 CERQ3 ACCESS

The literature, survey and interview evidence gathered suggests that the DAQI is viewed directly by a very small group of people; and a larger proportion of people appear to be accessing air quality information through third-party services that build on the DAQI.

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?

The DAQI’s definition of ‘at risk individuals’ as “*adults and children with heart and/or lung problems are at greater risk of symptoms*” is considered to accurately capture those at relatively higher risk from acute exposure to elevated air pollution. This definition is aligned with those used by other organisations such as the WHO and UKHSA. Survey participants were also in broad agreement, as more than 70% reported their perception that adults and children with heart and/or lung conditions might be at greater risk.

Air quality and health experts interviewed for this study generally agreed with a targeted definition of people ‘at risk’ from acute exposure to air pollution, given the DAQI’s focus on health impacts during episodes of elevated air pollution. However, many of them commented that everyone is at risk of cumulative exposure to air pollution in the longer term, and they were concerned with the potential confusion between shorter- and longer-term risk.

Some experts mentioned that it is worth exploring whether to include people with autoimmune conditions and/or with one or more specific conditions that might make them particularly vulnerable to acute exposure to elevated air pollution. Some experts also considered that it would be worth investigating whether pregnant people and infants in the womb should be included within the DAQI’s definition. Both the WHO²³ and UKHSA²⁴ consider pregnant people as being more sensitive to air pollution since air pollution is linked to health issues such as premature babies and low birth weight. These may not be short-term health risks that pregnant people face during elevated air pollution episodes; however, they may nevertheless warrant further consideration. A high number of survey respondents

²³ WHO global air quality guidelines (2021). Particulate matter (PM_{2.5} and PM₁₀), ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide.

²⁴ Public Health England (2018). Guidance Health matters: air pollution; Available at: <https://www.gov.uk/government/publications/health-matters-air-pollution/health-matters-air-pollution>.

also considered adults over the age of 65 (57%), pregnant women (52%), all children (42%) and/or all adults (29%) to be at greater risk from air pollution.

The general public interviews also highlighted there might be preconceived associations with the term 'at risk', for example, people might interpret these as long-term risks, or risks faced due to their proximity to a pollution source or other factors beyond their health status.

RSQ3.2-3.3: How widely used/well recognised is the DAQI by people at increased risk from air pollution or the general population (through what channels, if at all, is this user group receiving information)?

We have considered the evidence available of public interest on and/or concern for air quality. Defra's 2023 Survey on Attitudes to the Environment²⁵ suggests that 89% of the survey participants reported at least some concern about air quality. This is broadly aligned with the findings from the survey undertaken for this Study, which found that around 94% of a nationally representative sample of 1,001 individuals residing in England had low, medium or high interest in air quality in their neighbourhoods.

Despite this, the available data on historical access to the digital DAQI services, such as the UK AIR website, the @DefraUKAir account on X/Twitter and the daily air pollution email bulletin, suggests that a very small number of people access the DAQI services directly.

The UK AIR website has upwards of two million visits per calendar year. Around a third of these visits occurred through direct access to the website (e.g., through bookmarks), around half through an organic search (e.g., through search engines), over 10% through referrals (e.g., other government sites, local government sites, news outlets, and under 5% through social media (e.g., X/twitter). The site visitors are primarily based in the UK and might primarily be from the general public given that they are predominantly accessing the site from a public domain. The number of unique visitors is uncertain. Three scenarios of average user frequency are considered based on the observed data and available evidence from the survey. Our mid-point estimate of unique users is based on an average frequency of use that is twice per week, a lower bound assumes a daily visit on average, and an upper bound assumes two visits/year per user, resulting in an uncertain estimate of 27,500 (5,000-1,200,000) potential unique visitors to the UK website²⁶.

The number of followers on X/Twitter has steadily increased since the launch of the account in 2012, reaching ~8,700 followers in May 2024. There are three tweets a day during days with lower levels of air pollution and more than three tweets per day during episodes of elevated air pollution, with around 100-250 impressions for each tweet. For example, during the week commencing 11 March 2024, impressions of each tweet ranged between 112-217. Finally, around 500 people subscribe to the daily air pollution email bulletin at present, and the evidence available suggests that there is some but limited use of the free automated telephone air pollution services.

However, a review of digital air quality information found that, since the DAQI was updated in 2010, there has been an increase in websites and digital applications displaying air quality information. This facilitated broader access to air quality information across the UK. In

²⁵ Defra, Kantar (2023). Survey on Attitudes to the Environment -Wave 2. Available at: <https://scienceresearch.defra.gov.uk/ProjectDetails?ProjectId=20907>

²⁶ This is based on number of visits to the UK-AIR sites in 2023 and the assumption that visitors tend to engage with the site from daily to weekly, based on the findings from the survey.

particular, the research found that there are currently 146 key air quality information platforms.²⁷ The review also identified that these 146 third-party sites often relied upon a few 'data providers', that is, the source of the data or messaging; and that Defra's UK AIR website was found to be the most common 'data provider'. The research undertaken for this study into the communication and/or access channels for the DAQI services also identified that the DAQI has facilitated the proliferation of several independent private and public air quality information services for the general public, health and care professionals, etc. For example, map/navigation applications, search engines, public and private weather applications, public and private local sites (e.g., LondonAir, OxonAir, Birmingham Real Time Air Quality, Air Quality in England, etc²⁸), news channels on TV, news websites, social media.

In summary, this evidence suggests that, whilst there is a very small number of direct users of the DAQI services, there are many third-party sites and applications providing air quality information, which have facilitated indirect access to the DAQI information.

These findings are supported by the conclusions reached from analysing the evidence collected through the online survey and interviews conducted in this Study, which is summarised in the following paragraphs.

The survey conducted for this study found that 58% of a sample of 'at-risk' people (n=907), 36% of a national representative sample of the general population (n=1,001), and 18% of a sample of digitally excluded individuals (n=100) exhibited awareness of the DAQI services, reporting to have seen similar information to one of the DAQI visuals. This indicates that, although the number of air quality information services has increased significantly since the DAQI was last updated in 2010, the majority of the people (73%, n=1,001) might remain unaware and are still not viewing the DAQI nor alternative air quality information services. This is in line with the findings of a similar previous study by Verian²⁹.

In addition, a relatively lower proportion of participants said they use at least one of the DAQI information services: 51% of the 'at-risk' participants (n=907), 27% of the 'general population' participants (n=1,001) and 2% of the 'digitally excluded' participants (n=100). Across all survey participants, the most frequently used service was the UK AIR Defra website (18.5%), followed by X/Twitter (12.0%), free automated telephone air pollution services (11.7%), daily air pollution bulletins (9.1%) and 3.4% said they used others.

These percentages of people who have said that they access these services within the survey are higher than would be expected, based on the number of people visiting the UK AIR webpage, following the X/Twitter page, subscribed to the e-mail bulletins and/or accessing the automated telephone services. However, interviewees suggested that they mostly accessed air quality information through a third-party service, such as when looking at a navigation and/or weather application.

Thus, given the available data on direct traffic and use of DAQI services, it was concluded as likely that survey participants might have considered third-party services to be a part of

²⁷ Grieve A, Dr Schulte K, Brighty A, Francis W. (2024). UK Digital Air Quality Information Landscapes Review (page 15)

²⁸ Examples of third-party air quality information websites include LondonAir: <https://londonair.org.uk/LondonAir/Default.aspx>, OxonAir: <https://www.oxonair.uk/>, Birmingham Real Time Air Quality interactive map https://www.birmingham.gov.uk/info/20076/pollution/1276/air_pollution/3; Air Quality in England: <https://www.airqualityengland.co.uk/>

²⁹ Defra (pending publication)

the DAQI, especially given that Defra and the DAQI are often referred and/or reported as their main source.

Interviewees from both the general population and at-risk groups (n=21) said they used the DAQI and alternative air quality information services infrequently. One at-risk interviewee mentioned they only use the service when they feel any associated health symptoms and/or hear of an air pollution event on the news. On average, survey participants from both the at-risk and general population groups who used the DAQI or similar services (n=805) reported doing so between 1-3 times per week.

Air quality and health experts interviewed for this study reported being generally familiar with the DAQI albeit they do not use it directly within their role. Several of these interviewees did use third-party services, often developed by their own employer (e.g., local authority sites, internal resources developed based air quality information, etc).

Both the interviews and survey responses suggested that there is a much lower awareness and thus access of the DAQI's 'Recommended Actions and Health Advice'. Over 70% of the survey respondents (n=1,538) had not seen or had seen but not accessed these recommendations and advice, and around 6% reported checking them 'regularly'. Again, people from the at-risk group are more likely to have seen and/or accessed these 'recommended actions'. In more detail:

- *At-risk group*: Survey participants from the 'at-risk' group were more likely to access and/or regularly check the accompanying health advice provided by the DAQI. Around 30% of these respondents who were familiar with the 'DAQI visuals' and at least one of the DAQI information services (n=777) said they had seen and accessed the accompanying health messages or checked them regularly.
- *General population group*: Survey participants in the 'general population' group were relatively less likely to access and/or regularly check the accompanying health advice provided by the DAQI. Around 20% of these respondents who were familiar with the 'DAQI visuals' and at least one of the DAQI information services (n=709) said they had seen and accessed the accompanying health messages or checked these regularly.

RSQ3.4: What, if any, barriers exist that reduce or prevent access to the DAQI?

According to the literature and evidence from surveys and interviews, the most common barriers for people who might access or wish to access the DAQI could be: 1) a lack of awareness; 2) a lack of time; 3) lack of prioritisation of air pollution risks, and/or 4) finding their way to/through the UK AIR website pages.

Survey participants who were interested in air quality but had not accessed nor were familiar with the DAQI (n=97) struggled to: a) find time (>30% of respondents) and/or b) their way through the DAQI website (~20% of respondents). Around 20% of survey respondents suggested that accessing the DAQI was not their priority, and under 10% noted that they follow other air quality alerts or information services.

Interviewees shared their thoughts on a range of barriers they face in accessing and/or using the DAQI, including a lack of awareness, training and/or understanding of the air quality information, a lack of time/prioritisation, the limited accessibility or not straight forward and memorable ways to access this information (e.g., not linked to commonly used applications), etc. Another barrier appears to be the lack of awareness of the health risks posed by episodes of 'high levels' of air pollution.

The literature suggests that the risk perception of individuals regarding air quality could be a barrier to accessing the DAQI (for instance, an individual may not perceive themselves as being at risk, which acts as a barrier to accessing the DAQI)^{30,31}. However, according to the survey results, the majority of respondents were able to correctly identify themselves at-risk or not at-risk of air pollution more often than not.

Asthma + Lung UK also cite that DAQI alerts are out of date when compared to the short-term legal limit for NO₂; for example, the NO₂ levels must reach 400µg/m³ for three consecutive hours in order to trigger an alert, which is twice the 1-hour mean of 200 µg/m³.³² Furthermore, alerts may be inaccurate or simply too late, that is, arriving after the air quality event it is warning of, with individuals with lung conditions having begun to experience symptoms before they receive the alert.³³ In addition, the DAQI does not account for indoor concentrations, which may have a higher contribution to overall exposure compared to outdoor concentrations³⁴.

Digital inequality has been identified as another potential barrier to accessing the DAQI for a small, but potentially at-risk group of people, as air quality information services are primarily online³⁵. This is corroborated by the 'digitally excluded' group of survey respondents, ~80% of whom (n=100) had not seen information similar to the 'DAQI visuals'

³⁰ 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.

³¹ Bickerstaff K, Walker G (2001) Participatory local governance and transport planning. *Environment and Planning A* 33(3): 431–451. 25 See 8.

³² Asthma + Lung UK (2020). Alerting the Nation: Improving the way information is used to protect the most vulnerable from air pollution. Available at: https://www.asthmaandlung.org.uk/sites/default/files/Alerting%20the%20Nation%20Report_v4.pdf

³³ Asthma + Lung UK (2020). Alerting the Nation: Improving the way information is used to protect the most vulnerable from air pollution.

³⁴ Ferguson L, Taylor J, Symonds P, Davies M, Dimitroulopoulou S. (2023). Analysis of inequalities in personal exposure to PM_{2.5}: 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.

³⁵ 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.

before and only 2% of whom were somewhat or very familiar with the DAQI or used at least one of the DAQI information services.

Finally, expert feedback from the Theory of Change workshop highlighted that DAQI readings other than “green” (meaning low air pollution) are rare, which could reduce engagement and thus continued access as people do not perceive there to be a risk from air pollution. For example, general public interviewees could not recall ever experiencing a ‘high’ pollution event.

RSQ3.5: What, if any, facilitators have helped to broaden access to the DAQI?

Enablers for accessing air quality information services include the use of a wide variety of information-dissemination channels, in particular, integrating the information into third-party user friendly and commonly used digital/mobile applications³⁶ such as, navigation/map or weather applications. Several survey respondents and interviewees reported that they access DAQI information indirectly through weather and navigation applications, Met Office, news reports and local air quality websites. This suggests that linking the DAQI to commonly used and relevant digital applications could help facilitate awareness and access to air quality information services at least based on the DAQI. Some air quality and health experts stated they would refer patients and businesses to the DAQI to stay informed of air pollution risks, which could be potential enablers of access.

Some experts also pointed to communication and programmes in health and care settings and educational spaces as facilitators which might have already helped and could help further in broadening access.

4.5 CERQ4 UNDERSTANDING

The survey and interview evidence gathered suggests that more than half of the users might understand the DAQI in the way that it was intended, and an even higher proportion might understand the air pollution scoring and colour-coding.

RSQ4.1: To what extent do DAQI users’ understanding of what the DAQI is communicating align with the message it is designed to communicate?

Overall, the evidence suggests that the majority of its users understood the DAQI and its data in line with what it is designed to communicate. The understanding of interview and survey participants was tested. Participants were presented with a hypothetical DAQI notification and they were asked to interpret this. In both cases, the majority of participants correctly interpreted the air quality information (i.e., air pollution is lower or higher). More specifically, 58% of at-risk respondents (n=907), and 52% 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 participants understood what the DAQI is reporting in terms of air pollution levels (i.e., some regions of England were showcasing high levels of air pollution and were coloured amber, red or purple based on the definition of the DAQI), but interpreted this incorrectly to mean that even these high ratings were not a

³⁶ Larkin A, Hystad P. (2017). 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.

cause for concern and that any person residing in England should continue about their daily activities without any adjustments. When presented with the 'Recommended Actions and Health Advice', survey and interview participants also reported a broad understanding (reporting in the survey an average of 3 out of 5, where 0 is no understanding and 5 is very high understanding).

In a qualitative study conducted by Verian for Defra in 2024 as part of the AQIS review, the DAQI was found to be generally understood. However, people expressed a desire for deeper explanatory information on the methodology underpinning the DAQI³⁷. Literature and interview findings also suggest there being a reported inclination for more information on the DAQI methodology, which could come into conflict with the views of other users and experts who valued simplicity. For example, the in-depth interviews also suggested that people might have a much weaker understanding of the methodology and data underpinning the DAQI and some interviewees expressed a desire for further explanation.

RSQ4.2: To what extent does the way data is visualised in the DAQI contribute to, or limit [at risk/general population] users?

Across the literature review, survey and interviews, the data visualisation in the DAQI was found to contribute to the users' understanding of the air quality information. There was a particular emphasis on the intuitiveness of the PRAG style system, with one interviewee stating, "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". The Verian study also found that a traffic light approach leads to better data comprehension.

Survey participants were asked about their preferences for different map layouts, which had varying area granularity and colour coding. Around half (47%) of survey respondents expressed their preference for a map that presented the UK divided into regions, with air quality scores aggregated and clear geographic boundaries. Respondents commented that this visualisation was easy to interpret superficially, with the clear area boundaries and discrete regional data aiding their understanding. However, 34% of respondents expressed a preference for a UK map with colour graduations that reflected higher location-based granularity, so that they could determine air quality in their precise location.

One issue of note with the data visualisation is its accessibility to those who are colour blind or visually impaired. One interviewee with colour blindness mentioned that they could not distinguish the colour graduations of the PRAG system and would benefit from data labels. Similar feedback was received from the survey.

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?

The language used was identified as a factor that played a role in the DAQI users' understanding of the air quality information and recommended actions. In the Theory of Change workshop, experts fed back that the technical language used could be a hindrance for people's understanding of the DAQI messaging. Both the literature review and the interviews further suggested that the use of overcomplicated technical language may be an issue in the DAQI, with one interviewee mentioning: "*Sometimes the glossary of terms is*

³⁷ Defra (pending publication)

confusing; for example, the explanation of a term may include words that I cannot understand...”, which would ultimately affect the users’ engagement with the DAQI.

RSQ4.4: To what extent do DAQI users understand the advice associated with different DAQI readings?

In general, the level of awareness of the health recommendations and advice was low. However, when presented with the ‘Recommended Actions and Health Advice’, interview and survey participants appear to report a relatively good comprehension.

The literature review found that health advice related to air quality information can be difficult to interpret, especially when technical terms are used. Both the Verian³⁸ study and a study published by Defra in 2012 on individuals’ interpretation of air quality information³⁹ recommended that health advice should be written with clarity, relevance and focus. Specifically related to the advice in the DAQI, the survey participants reported a relatively good understanding upon being presented with the guidance (3 out of 5, on average, where 5 is a complete understanding). Similarly, interviewees generally gave affirmative answers when asked whether they find the DAQI ‘Recommended Actions and Health Advice’ easy to understand. There was at least one exception in which an interviewee did suggest that the overall messaging could be improved by adding further clarification and specification, arguing that oversimplification could introduce ambiguity in interpretation. On the topic of technical language, this was mentioned as a point of issue by a small number of the general population interviewees. Air quality and health expert interviewees found the advice understandable albeit concluded that improvements could be made.

Overall, the evidence points to a good level of understanding of the DAQI ‘Recommended Actions and Health Advice’ although improvements could be made in terms of specificity and clarity. Additionally, there could be effort made to improve the accessibility of the language used in the health advice and the DAQI in general.

RSQ4.5: What, if any, barriers exist that have hindered users from correctly interpreting the DAQI?

Similar barriers to correctly interpreting the DAQI were identified in the literature review, survey and interviews. The literature suggested that complex, professional language could hinder the users’ ability to understand the DAQI and that simple language must be used to maximise understandability. This finding was also supported through the interviews finding, with one interviewee stating that the DAQI uses words that they do not understand.

Both the survey and the interview highlighted that the PRAG has some accessibility issues for people with colour blindness. One interviewee with colour blindness stated that they could not differentiate between the colour graduations on the map and would benefit from data labelling.

The interviews underlined that barriers are not universal and what may be a barrier for one person could be a facilitator for another. Six of the general population interviewees felt that their understanding of the DAQI was impeded by their lack of understanding of the

³⁸ Defra (pending publication)

³⁹ Defra. (2012). Individuals’ interpretation of air quality information, Available at: <https://core.ac.uk/download/pdf/188253313.pdf>

methodology and reasoning behind the Index and would like this information to be more easily accessible. The majority of these requests related to how the scoring had been assigned, including more detail about the breakpoints between low and high bands and, in some cases, people wanted to understand which pollutant had driven the rating. Conversely, other interviewees valued the simplicity of the Index and visuals and would even prefer it to be even more straightforward. One interviewee found the accompanying information confusing.

RSQ4.6: What, if any, facilitators have supported users' understanding of the DAQI?

Evidence from the literature review, survey and interviews agreed that the primary facilitator to people's understanding of the DAQI information is the scoring and traffic light PRAG system, with greener colours indicating relatively lower levels of air pollution and purple/redder colours indicating relatively higher levels of air pollution. In particular, the messaging from the interviews suggests that the PRAG system is intuitive, with little effort needed by users to understand it.

The findings from the survey suggests that the majority of people benefitted from less granular geographical visualisation, with air pollution scores aggregated per UK region being preferred due to its simplistic design. Others preferred the design of a simplified map, but still welcomed the possibility of finding more detailed information about their exact location, for example, through a post-code-based search function.

4.6 CERQ5 CHANGE OF BEHAVIOUR

The literature review, survey and interview findings suggest that people appear responsive to air quality notifications and willing to enact the 'Recommended Actions and Health Advice' provided by the DAQI. However, the extent to which people will, in fact, enact any behavioural modifications remains uncertain.

RSQ5.1-5.2: To what extent do at risk and/or general users change their behaviour based on a [moderate and/or high/very high] DAQI reading?

The survey evidence suggests that around half of the 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 [1-1.5 times] to make adjustments to their daily activities, when compared to those not perceiving themselves at risk (51% when compared to 40%, respectively –a difference that is statistically significant). That is, it is more likely that people who identify themselves at risk might make some adjustments to their day (20-30% more of a chance they would reduce their activity outdoors).

There are groups of people who appear to be responsive and willing to 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 adjusting 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.

Interviewees also appeared willing to modify their behaviour in the event of 'very high' air pollution notification. However, none of the interviewees could recall ever experiencing an alert.

Whilst people might be willing, the extent to which people might change their behaviour upon an air pollution alert remains uncertain. A study by D'Antoni *et al.* (2019)⁴⁰, suggests that people's adherence to health advice in response to poor air quality is dependent on many factors, and standard air quality notifications alone are not enough to facilitate behaviour modifications. Furthermore, the paper also concluded that people in general are more receptive to changing their behaviour when receiving personalised information as opposed to generic health advice.

RSQ5.3: What if any barriers exist (in terms of capability, opportunity or motivation) that prevent users from enacting DAQI – advice?

A range of potential barriers were identified in the literature, survey and interviews.

In a study by D'Antoni *et al.*⁴¹, the barriers to enacting advice identified included: 1) lack of understanding of the indices; 2) being exposed to health messages that reduced both concern about air pollution and perceived susceptibility; 3) perceived lack of self-efficacy/locus of control; and 4) a lack of time. In the Verian study, similar barriers were identified including: 1) low levels of knowledge; 2) limited access and reduced flexibility; and 3) limited options to enact some of the 'recommended actions and health advice'.

The primary barriers to behavioural change identified by the survey responses are: 1) a lack of understanding of information provided (noting that 42% of at-risk and 48% of the general population and digitally excluded sample groups did not understand the air quality information provided correctly, also supported by interview findings); 2) a lack of awareness and understanding of what can be done (with 72% of the survey respondents either not having seen or having seen but not accessed the 'recommended actions and health advice', and 20% or more of the survey respondents having a low or no understanding of these messages, depending on the scenario); 3) a lack of discretionary time; and 4) low priority given to air quality issues. The latter two barriers have been identified through the analysis of the survey evidence, especially concerning other barriers pertaining to accessing and using air quality information altogether. The survey also suggests that these two barriers

⁴⁰ 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://linkinghub.elsevier.com/retrieve/pii/S0160412018321871>

⁴¹ D'Antoni *et al.* (2017). Psychosocial and demographic predictors of adherence and non-adherence to health advice accompanying air quality warning systems: a systematic review; Available at: <https://pubmed.ncbi.nlm.nih.gov/28938911/>

might be affected by age, employment status, type of employment, income and other socio-economic factors.

Interviews of experts and the general public highlighted a range of similar factors that either prevented people from checking the daily air quality information as part of their daily routine and/or enacting any advice. The two interrelated barriers were the discretion to spend their time how they would like (i.e., ownership about what people can do with their time and when), and the subsequent prioritisation of the discretionary time they have available.

Survey and interview participants reported having limited discretion over their time in a given day due to responsibilities such as work, family life, health and income. These factors reduce the freedom that people have to adjust their behaviour in response to DAQI readings. Several interviewees expressed that they would not refrain from going outdoors based on DAQI readings, but they may adjust their exercise habits or locations, which reflects the areas of their lives over which people have more control. Air quality and health experts interviewed also considered that people (and/or patients) with more agency over their own lives (typically due to age and socio-economic factors) might be more able to modify their behaviour.

Interviewees also reported having to make choices regarding how they spend the limited time that they do have discretion over on a daily basis. One interviewee commenting *“It’s one of those things where I am like ‘oh I should look at [the DAQI]’, but I just never get round to it. There are a lot of things to keep abreast of.”* Although interviewees and survey participants showed a high interest and/or concern for air pollution, they also reported, especially through interviews, having other demands on their time they might prioritise instead, such as sports, news, other health issues and leisure. This underlines the importance of making the DAQI as easily and readily accessible as possible, so that it can be incorporated into the daily lives of people with little effort and time cost.

The survey found that awareness of the ‘Recommended Actions and Health Advice’ was low. 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 resource⁴². Moreover, even if people were viewing the daily air quality information, they might not know what actions to enact or how to respond, thus limiting any behaviour modification. Along these lines, in one interview, a person used the weather application to access air quality information and commented that the advice given was too vague, preventing them to understand and consider what they might do in response to the air quality ratings.

RSQ5.4: What if any facilitators exist that have helped users to enacting DAQI advice?

The extent to which users have enacted DAQI advice is uncertain, thus, so are the facilitators of enacting behavioural modifications. However, evidence from the survey and interviews suggests that providing clear, and targeted advice to individuals in a manner that is understandable and concrete could be a facilitator to enacting advice. Similarly, integrating the information and advice into commonly used applications could facilitate enacting it (e.g., evidence does point to a relatively lower direct use of the DAQI when compared to more commonly used digital applications that also contain air quality information such as

⁴² Asthma + Lung UK (2022). Alerting the Nation. Available at: https://www.asthmaandlung.org.uk/sites/default/files/Alerting%20the%20Nation%20Report_v4.pdf

navigation/map and/or weather applications). This is a facilitator of access and could too be a facilitator of enacting advice if it is integrated as well.

RSQ5.5: In what way, if any, does alert frequency impact adherence to advice?

The extent to which alert frequency may affect adherence to advice remains unknown, although the literature^{43,44} suggests that unnecessary and avoidable notifications (e.g., on green ratings) could lead to alert fatigue and increased disengagement, which could reduce adherence to advice.

D'Antoni *et al.* (2017)⁴⁵ reviewed evidence concerning the psychosocial and demographic predictors of adherence and non-adherence to health advice accompanying air quality warning systems. They found that people often do not adhere to health advice when it accompanies air quality alerts. Barriers to adherence that were identified include a lack of understanding of the indices, the receipt of health messaging that lowered their concern, a feeling of limited agency over the impacts of air pollution, a reliance on sensory queues and a lack of time. Facilitators identified included awareness of where to monitor air quality alerts, connecting one's symptoms to air pollution, perceived severity of air pollution, and receiving advice from healthcare professionals.

There is a broader range of literature⁴⁶ 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). The findings in the literature 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, which is generally, or more often than not, 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 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. This is an area that could benefit from further investigation.

4.7 CERQ6 SOUNDNESS OF ADVICE

As noted, the research undertaken suggests that the 'Recommended Actions and Health Advice' provided by the DAQI are no longer fully aligned with the latest evidence and understanding of the mitigative actions that individuals should take during episodes of elevated air pollution.

⁴³ 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. Available at: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6881214/>

⁴⁴ 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.* Available at: <https://medinform.jmir.org/2022/10/e40511>

⁴⁵ 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. Available at: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5610416/>

⁴⁶ 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). Available at: <https://doi.org/10.1007/s40521-023-00351-8>

RSQ6.1, 6.3 and 6.5: To what extent does the health literature support the assumption that reducing strenuous outdoor physical activity at [moderate/high/very high] levels of air pollution is likely to reduce the severity of symptoms in at risk groups? Or similarly for reducing physical exertion in the case of the general population?

Reducing strenuous outdoor physical activity by at risk individuals and physical exertion by the general population during elevated episodes of air pollution could alleviate the severity of symptoms at the time, and this is more likely to be the case for at risk individuals. However, the evidence supporting this is limited.

Meta-analysis of epidemiological studies has demonstrated 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.⁴⁷ However, the review for AQIS on ‘Physical Activity and exposure to air pollution’⁴⁸ 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 studies that looked at the health effects without a control (no physical activity) group were also focused on healthy individuals. Therefore, from the literature alone there is little evidence to show whether reducing outdoor physical activity during elevated levels of air pollution reduces the severity of symptoms, particularly in at risk groups.

Air quality and health experts interviewed for this study agreed that reducing strenuous outdoor physical activity for at-risk people and/or physical exertion for the general population during periods of high pollution could reduce the severity of symptoms but had some concerns about current DAQI ‘Recommended Actions and Health Advice’. The experts worried that the current language could have the potential to discourage physical activity and thought this could have a negative impact on overall health.

Moreover, other factors play a role in the extent to which the severity of symptoms and/or adverse health outcomes that could be mitigated through a result from a reduction in outdoor activity. For example, replacing physical activity outdoors for indoor spaces lacking air filtering and/or air pollution and thus with air that is similarly polluted would not necessarily achieve the intended outcomes and impacts. Again, this is a gap in the literature.

RSQ6.2, 6.4 and 6.6: To what extent can reducing strenuous outdoor physical activity at [moderate/high/very high] levels of air pollution be considered to have a net positive health for at risk individuals? Or similarly for reducing physical exertion in the case of the general population?

The available literature and expert interviewees suggest that reducing outdoor physical activity performed by at risk individuals and physical exertion performed by the general population during episodes of elevated air pollution might not have an overall net positive effect on people’s health (e.g., lung function, etc.). Instead, continuing to conduct physical activity outdoors might be overall beneficial to health, even if short-term symptoms linked to air pollution arise. This said, experts interviewed for this evaluation noted that the

⁴⁷ Global Initiative for Asthma, (2020). Global Strategy for Asthma Management 2020. Available at: [GINA Full Report 2020 Front Cover ONLY \(ginasthma.org\)](https://ginasthma.org/)

⁴⁸ Physical Activity and exposure to air pollution, Panagi et al., unpublished.

consequences of reducing outdoor physical activity would depend on individual circumstances.

The available literature suggests that even in highly polluted environments, physical activity has a positive effect on human health in the long term. In the shorter term, these benefits may be reduced or absent. Overall, despite these limitations, the available evidence thus suggests that outdoor physical activity in polluted areas could still have a beneficial effect on the health of at-risk people and may be even more likely to have a net positive impact on the general population.

The WHO Expert Consultation on Personal Interventions and Risk Communication on Air Pollution recommended that advice should not discourage physical activity altogether, but to adjust it to minimise exposure to air pollution for those at risk, since physical activity has beneficial effects on health⁴⁹. The Expert Consultation also stated that even if the air quality does not reach the guideline values recommended by the WHO (i.e., “good” air quality), the health benefits of physical activity are maintained. This conclusion was supported by the review for AQIS on ‘Physical Activity and exposure to air pollution’⁵⁰.

The air quality and health experts interviewed for this study agreed that physical activity is crucial for long-term health and were concerned that the current DAQI ‘Recommended Actions and Health Advice’ could discourage physical activity among the population. It was emphasised that there is currently not enough evidence to justify advising individuals to reduce or avoid exercise, and reducing physical activity levels in the population could have a net negative impact on health.

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)?

A meta-analysis of epidemiological studies conducted by the Global Initiative for Asthma (GINA) 2020 found correlation between the levels of air pollution and the exacerbation of asthma symptoms, observed through changes in patterns and volume of emergency visits and hospitalisations⁵¹.

Studies that investigate frequency of use of inhalers demonstrated that their use increased during periods of higher air pollution, suggesting at least a perception of relieving symptoms.^{52,53,54} Survey responses for this evaluation suggest that the majority of medical inhaler users (n=1,001) modify their behaviour by increasing their frequency of use when air quality is poor, which they perceive to be helpful (e.g., preventing sickness, symptoms, etc).

⁴⁹ World Health Organization (2020). Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, page 38.

⁵⁰ Physical Activity and exposure to air pollution, Panagi et al., unpublished.

⁵¹ Global Strategy for Asthma Management 2020 [GINA Full Report 2020 Front Cover ONLY \(ginasthma.org\)](https://ginasthma.org/)

⁵² Šcibor et al. (2022). “Associations between Daily Ambient Air Pollution and Pulmonary Function, Asthma Symptom Occurrence, and Quick-Relief Inhaler Use among Asthma Patients”, Int. J. Environ. Res. Public Health 2022, 19(8), 4852; Available at: <https://doi.org/10.3390/ijerph19084852>

⁵³ Pepper et al. (2020). “Geospatial-temporal analysis of the impact of ozone on asthma rescue inhaler use”, Environment International 136 (2020) 105; Available at: <https://doi.org/10.1016/j.envint.2019.105331>

⁵⁴ Bennett Stothers, B.Kin. (2020). “Examining the Effect of Salbutamol Use in Ozone Air Pollution by People with Asthma and/or Exercise Induced Bronchoconstriction”, The University of British Columbia, 2020, Available at: <https://open.library.ubc.ca/soa/cIRcle/collections/ubctheses/24/items/1.0416295>

In a relatively lower number of cases, even increasing the frequency of inhaler use does not suffice.

Several experts interviewed agreed with the use of the reliever (blue) inhaler during elevated pollution episodes; however, they were concerned that the current wording of the guidance misses the opportunity to encourage asthma patients to follow their asthma management plans, which is the most up-to-date NHS advice.

Overall, it is considered that adjusting the use of the reliever (blue) inhalers in line with individual NHS asthma management plans and/or following medical advice could likely reduce the severity of symptoms faced by asthmatics during episodes of elevated air pollution.

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?

The available literature and expert interviews suggest that, while increased use of reliever (blue) inhaler during elevated air pollution episodes might reduce the severity of asthma symptoms at the time, this may or may not result in a net positive health impact on at risk individuals in the longer term.

There is not a wide base of literature on the effect of reliever inhaler usage on respiratory symptoms caused by air pollution; most available studies have 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 (including on overall health). Therefore, it is not possible to determine from the literature whether increased inhaler usage likely has a net positive health impact.

Healthcare experts generally agreed with increased use of the reliever inhaler during elevated pollution episodes to relieve symptoms; however, some noted concerns that the 'Recommended Actions and Health Advice' is not up to date with current NHS advice on asthma management, which could result in a net negative impact on health. The NHS bundle of care for children and young people with asthma is clear that the use of either short- or long-acting inhalers in isolation carries additional risks and that poor adherence to preventer treatments can be associated with worse outcomes.⁵⁵ Concerns raised by experts regarding increased use of reliever inhalers included increasing reliance / dependence on the reliever inhaler and overuse, which can lead to muscle pain or weakness, headaches, dizziness, etc. A patient's overuse of the reliever inhaler could also mean that their asthma is not well controlled. As a result of this, we conclude that health care experts thought the current DAQI advice regarding reliever inhalers would not necessarily have a net positive health impact.

RSQ6.9: Are there any known or likely unintended consequences arising from the current health advice?

The literature, expert interviews and a survey of people residing in England have provided insights into potential unintended consequences from the advice.

⁵⁵ NHS England. Available at: <https://www.england.nhs.uk/publication/national-bundle-of-care-for-children-and-young-people-with-asthma/>

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 Air Pollution Index that has no unintended consequences (i.e., discouraging outdoor physical activity) is justified*”⁵⁶. 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.⁵⁷ Some studies have explored unintended consequences. For example, one quasi-experimental study found that alert announcements reduced asthma-related emergency department visits by 25% but had no effect on deaths from cardiovascular or respiratory diseases, or hospital visits for cardiovascular disease.⁵⁸

Experts interviewed for this evaluation suggested that alarming individuals and causing them to stay indoors and reduce levels of physical activity might not necessarily reduce their exposure to elevated levels of air pollution and could have negative knock-on effects on their physical and mental health and wellbeing. Around half of all survey participants also 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.

Experts also noted that increasing the use of reliever inhalers could increase their reliance or dependence, and overuse can lead to, e.g., muscle pain or weakness, headaches, and dizziness. Experts highlighted a list of other possible unintended consequences, such as economic losses, increased isolation, and loneliness. As mentioned previously, this is supported by NHS publications, which note that “asthma deaths are largely attributable to avoidable factors, [including an] over-reliance upon [blue] reliever inhalers and under-prescription or use of preventer medications. The use of either short or long-acting relievers in isolation has been identified as a particular risk. Poor adherence to preventer treatments from any cause, intentional or non-intentional, is associated with worse outcomes.”⁵⁹

Finally, again, some experts were also concerned that the DAQI’s focus on the short-term health effects during episodes of air pollution (instead of more long-term risks) could also have unintended consequences, such as a misunderstanding that ‘everything is well’ from a green rating, when in fact people face a larger, cumulative risk they might need to account for and/or consider when they go about their lives.

5. EVALUATION CONCLUSIONS

A qualitative, theory-based evaluation approach has been employed to develop conclusions on the DAQI’s levels of appropriateness and effectiveness, based on the analysis of the literature, survey and interview evidence.

⁵⁶ World Health Organization (2020). Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, page 38. Available at <https://iris.who.int/bitstream/handle/10665/333781/9789240000278-eng.pdf?sequence=1>

⁵⁷ World Health Organization (2020). Personal Interventions and Risk Communication on Air Pollution, Summary report of a WHO Expert Consultation, 12–14 February 2019, Geneva, Switzerland, page 31. Available at: <https://iris.who.int/bitstream/handle/10665/333781/9789240000278-eng.pdf?sequence=1>

⁵⁸ Chen et al. (2018). “Effect of air quality alerts on human health: a regression discontinuity analysis in Toronto, Canada”. *Lancet Planet Health* 2(1): e19–26. Available at: [https://doi.org/10.1016/S2542-5196\(17\)30185-7](https://doi.org/10.1016/S2542-5196(17)30185-7)

⁵⁹ NHS England (2021). National bundle of care for children and young people with asthma. Available at: <https://www.england.nhs.uk/publication/national-bundle-of-care-for-children-and-young-people-with-asthma/>

5.1 THE APPROPRIATENESS OF THE DAQI

Firstly, the **level of appropriateness** of the DAQI has been assessed by using the research findings to qualitatively rate the extent to which the DAQI services are reliable, methodologically and technically valid and accurate, accessible and understandable, from a score of 0 (none) to +5 (completely). The qualitative assessment complemented by a brief summary of evidentiary support is presented in the Table 5-1 below.

Table 5-1 The DAQI’s level of appropriateness

Level of...	Rating	Summary of the evidentiary support
Reliability	3.0	Research findings suggest that the DAQI ratings and recommendations are broadly reliable at the UK regional level, based on generally complete and accurate evidence. Using the data at postcode level may, however, be less precise and accurate, and thus less reliable. Moreover, the ‘Recommended Actions and Health Advice’ are not always aligned with the latest evidence and could result in unintended consequences. This results in a score of +3.0 out of 5, with +5.0 being completely reliable.
Validity and accuracy (methodological/technical)	4.0	Findings suggest the methodology employed is generally valid and accurate, and overall, an appropriate means for highlighting short-term risks posed by real world conditions into an overall measure of air quality. There are some areas for potential refinement. As a result, a score of +4.0 out of 5 is concluded, with +5.0 being completely valid and accurate.
Accessibility	2.0	<p>There are digital and non-digital DAQI services that are available and free for people to access. No general issues have been identified pertaining accessibility technically. Using scores (1-10) and colour (e.g., PRAG ratings) in visuals together can improve the accessibility also for individuals who are colour blind. Overall, the evidence suggests that technical accessibility would be high, with at least a +4 out of 5, acknowledging some potential areas for improvement.</p> <p>In practice, around ~500 people subscribe to the air pollution email bulletin, under 9,000 people follow the @DefraUKAIR page on X/Twitter, and over 2 million visits to the UK AIR website in a calendar year, which leads to an uncertain estimate of 27,500 (5,000-1,200,000) unique visitors depending on the potential levels of frequency in a given calendar year⁶⁰.</p> <p>The evidence available also suggests there has been a proliferation of third-party air quality information services, which people might consider a part of the DAQI, which people might be accessing. 2,008 England-based residents over 18 years of age were surveyed and 21 people were interviewed in-depth: around half of survey</p>

⁶⁰ This is based on number of visits to the UK AIR sites in 2023 and the assumption that visitors tend to engage with the site from twice per week, daily or twice per year respectively.

Level of...	Rating	Summary of the evidentiary support
		<p>participants who perceived themselves at risk and around a third of everyone else appears to have accessed one or more of the DAQI services and/or similar services.</p> <p>This evidence and the interview outputs suggests that, whilst a small proportion of people might be accessing the DAQI services directly, a larger proportion of people might access similar third-party services that build on the DAQI and the underpinning evidence (e.g., local authority, independent and third sector sites, applications, etc.), which contribute to the accessibility of air quality information in England.</p> <p>Overall, this indicates the majority of people (~70%, n=1,001) might not be accessing air quality services, and those who do access air quality information services might be doing so through third party applications or platforms (e.g., map/navigation applications).</p> <p>Finally, on average, 86% of survey participants who were aware and familiar with DAQI or similar air quality information services reported that these services are 'easy to access', where 86% is the weighted average proportion of those who find it 'easy to access' across each service.</p> <p>Based on the evidence presented in this report and summarised above, a score of +2.0 out of 5 is concluded, where +5.0 would be accessible and accessed by 90-100% of people.</p>
Understandability	2.5	<p>Interview evidence has highlighted that people might generally lack awareness and knowledge of the complex language and concepts pertaining to air quality. The DAQI, however, has found a relatively simplified approach to sharing information with the target population through a 1-10 scoring and PRAG-rating and/or colour-coding system that appears relatively easy to understand.</p> <p>Around half of survey participants (N=2,008) interpret the DAQI correctly and an additional 20% of survey participants understand what the DAQI is reporting in terms of air pollution but do not find high ratings a cause for concern from a health perspective. That is, the majority of people understand the scoring/colour coding system and acknowledge there might be a risk, and a lower proportion understanding the associated health concern or implications. Interviewees also found the DAQI scoring/colour coding understandable. Moreover, both survey participants and interviewees are more likely to understand the recommended actions than otherwise.</p> <p>Whilst people appear to understand some aspects of the DAQI such as the scores and colour-coding, there are other important aspects which are not always correctly interpreted by the audience, especially concerning the health implications of elevated air pollution. Thus, a score of +2.5 out of 5 is concluded, where +5.0</p>

Level of...	Rating	Summary of the evidentiary support
		would be a complete and correct understanding by 90-100% of the people.
Appropriateness	2.9	An average score of +2.9 out of 5 is concluded overall, thus suggesting the DAQI is broadly appropriate with areas for potential improvement, especially pertaining to accessibility and understandability.

In conclusion, the evaluation has found that the DAQI is broadly appropriate with areas of potential improvement. That is, the DAQI is generally a reliable, valid and accurate, accessible and understandable source of air quality information. Section 6 outlines a set of recommendations for potential improvement of the DAQI in the future.

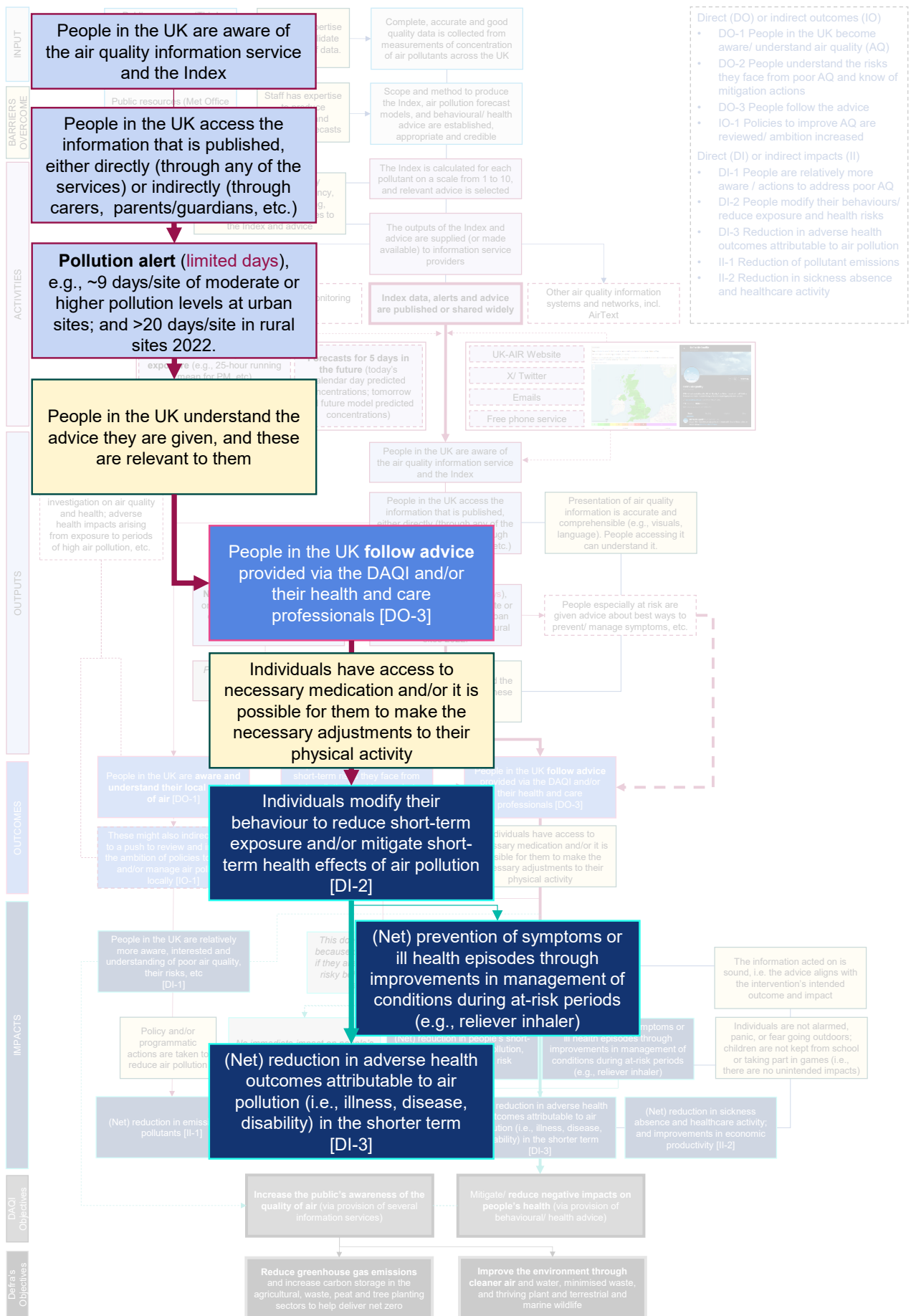
5.2 THE EFFECTIVENESS OF THE DAQI

Secondly, the **level of effectiveness** of the DAQI has been assessed by consideration of the direct and/or indirect contribution of the DAQI services to the levels of:

- Awareness of air pollution levels and access to the DAQI,
- Understanding of the levels of air pollution and the DAQI notifications,
- Behaviour modifications, and
- Mitigation of symptoms (or adverse health effects) attributable to acute exposure to elevated air pollution.

These four dimensions represent four key steps or parts of main causal chain of the Theory of Change that would lead to the principal intended effects, which are to facilitate behavioural modifications based on local air quality conditions that can reduce the risk of individuals experiencing adverse health effects from acute exposure to air pollution. This is illustrated in the Figure 5-1 below, noting that the complete Theory of Change can be found in the ‘Appendix Report’.

Figure 5-1 DAQI Theory of Change snapshot focussed on the main causal chain of intended impacts (Please find the complete TOC in the 'Appendix Report')



Box 5-1 Alternative description of the “DAQI Theory of Change snapshot focussed on the main causal chain of intended impacts”

The Figure 5-1 above presents a visual of the main causal chain of intended impacts of the core components investigated as part of the evaluation of the DAQI’s effectiveness. The following list sets out the outputs, assumptions, outcomes and impacts that are part of this main causal chain of intended impacts:

- People in the UK are aware of the air quality information service and the Index.
- Pollution alert (limited days), e.g., ~9 days/site of moderate or higher pollution levels at urban sites; and >20 days/site in rural sites 2022.
- People in the UK understand the advice they are given, and these are relevant to them.
- People in the UK follow advice provided via the DAQI and/or their health and care professionals
- Individuals have access to necessary medication and/or it is possible for them to make the necessary adjustments to their physical activity.
- Individuals modify their behaviour to reduce short-term exposure and/or mitigate short-term health effects of air pollution
- (Net) prevention of symptoms or ill health episodes through improvements in management of conditions during at-risk periods (e.g., reliever inhaler)
- (Net) reduction in adverse health outcomes attributable to air pollution (i.e., illness, disease, disability) in the shorter term

The extent to which this evidence supports this main causal chain of impact of the DAQI’s TOC is considered in the following paragraphs.

A qualitative, contribution-based evaluation approach has been employed to establish the extent to which the DAQI services **contributed, directly or indirectly** to the levels of 1) awareness and access to air pollution information services, 2) understanding of the levels of air pollution and alerts, 3) any behaviour modification, and 4) the mitigation of symptoms or adverse health effects.

The evidence identified in the literature, the survey and interviews has been reviewed and analysed to develop conclusions against each of the four key parts of the main causal chain of the Theory of Change to establish a qualitative rating between none (0) to high (+5) levels and conclude on the extent to which the DAQI might be effective in contributing towards achieving the intended impacts. The assessment is summarised in the Table 5-2 below.

Table 5-2 The DAQI’s level of effectiveness

Level of...	Rating	Summary of evidentiary support
Awareness of air pollution levels and	2.0	As mentioned previously, around ~500 people subscribe to emails, under 9,000 people follow the @DefraUKAIR page on X/Twitter, and over 2 million visits to the UK AIR website in a calendar year, which leads to an uncertain estimate of 27,500

Level of...	Rating	Summary of evidentiary support
access to the DAQI		<p>(5,000-1,200,000) unique visitors depending on the potential levels of frequency in a given calendar year⁶¹.</p> <p>The evidence available also suggests there has been a proliferation of third-party air quality information services, which people might consider a part of the DAQI, which people might be accessing. 2,008 England-based residents over 18 years of age were surveyed and 21 people were interviewed in-depth: around half of survey participants who perceived themselves at risk and around a third of everyone else appears to have accessed one or more of the DAQI services and/or similar services.</p> <p>This evidence and the interview outputs suggests that, whilst a small proportion of people might be accessing the DAQI services directly, a larger proportion of people might access similar third-party services that build on the DAQI and the underpinning evidence (e.g., local authority, independent and third sector sites, applications, etc.), which contribute to the accessibility of air quality information in England.</p> <p>Overall, this indicates the majority of people (~70%, n=1,001) might not be accessing air quality services, and those who do access air quality information services might be doing so through third party applications or platforms (e.g., map/navigation applications).</p> <p>For DAQI or similar service users, the frequency of access varies. More than 3/4 of survey participants who use a service engaged with their service of choice at least once a week.</p> <p>Finally, on average, 86% of survey participants who were aware and familiar with DAQI or similar air quality information services reported that these services are 'easy to access'.</p> <p>Overall, the evidence suggests there is some awareness of air pollution and access to the DAQI, albeit this is partial. Thus, a score of +2.5 out of 5 or lower is concluded on the levels of awareness of air pollution and access to the DAQI, where +5.0 would represent 90-100% awareness of air pollution and 90-100% access to the DAQI.</p>
Understanding of the levels of air pollution and the DAQI	2.5	<p>As mentioned previously, around half of survey participants (N=2,008) interpret the DAQI correctly and an additional 20% of survey participants understand what the DAQI is reporting in terms of air pollution but do not find high ratings a cause for concern from a health perspective. That is, the majority of people understand the scoring/colour coding system and acknowledge there might be a risk, and a lower proportion understanding the associated health concern or implications. Interviewees also</p>

⁶¹ This is based on number of visits to the UK AIR sites in 2023 and the assumption that visitors tend to engage with the site from twice per week, daily or twice per year respectively.

Level of...	Rating	Summary of evidentiary support
notification s		<p>found the DAQI scoring/ colour-coding understandable. Moreover, both survey participants and interviewees are more likely to understand the recommended actions than otherwise.</p> <p>Whilst people appear to understand some aspects of the DAQI at high level, there are other important aspects which are not always correctly interpreted, especially concerning the health concern and implications of elevated air pollution. Thus, a score of +2.5 out of 5 or lower is concluded, where +5.0 would be a complete and correct understanding by 90-100% of people.</p>
Behaviour modification	1.0	<p>People appear responsive to air quality notifications and willing to enact the ‘Recommended Actions and Health Advice’ provided by the DAQI. However, the extent to which people will, in fact, enact any behavioural modifications remains uncertain.</p> <p>Interviewees could not remember having encountered a moderate, high or very high air pollution event in the past and could not recall having modified their behaviour in the past.</p> <p>Both interviewees and survey respondents reported willingness to change their behaviour if they were notified of elevated air pollution levels, especially so when they perceived themselves at risk, e.g., carrying and/or using medication accordingly. Around 70% of survey participants who use/have inhalers (N=1,011) report adjusting 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. More broadly, around half of the survey participants (N=2,008) reported they 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.</p> <p>However, the evidence does point to there being a higher individual desire to modify behaviour when compared to actually enacting any modifications upon receiving an air pollution notification. For example, even though more than 75% of survey participants reported an interest in the quality of air in their neighbourhood, under 40% were aware, and fewer (~35%) participants used at least one air quality information service.</p> <p>In addition, published research suggests that people’s adherence to health advice in response to poor air quality is dependent on many factors, and standard air quality notifications alone are not enough to facilitate behaviour modifications.</p> <p>Finally, there is limited awareness of the ‘Recommended Actions and Health Advice’ set out by the DAQI – around 5% of people reported checking these regularly and 15% or more have seen and accessed them at least once. Third-party air pollution information services do not always include recommended</p>

Level of...	Rating	Summary of evidentiary support
		<p>actions. In general, a small proportion of people appear to be engaging with the recommendations, and thus many may not know or be prepared to act in the event of a ‘moderate’, ‘high’ or ‘very high’ air pollution notification.</p> <p>In summary, based on the secondary and primary available evidence, it is considered that 2.5%-20.0% of the people regularly accessing and understanding the DAQI or third-party services might consider taking action⁶². Moreover, based on the survey-based relationship between the levels of ‘interest’ and ‘access’ to air quality information services (i.e., around half of those interested are accessing air quality information services), it might be considered reasonable to assume that half of these (i.e., 1%-10.0% of these group of people), at most, might enact any behaviour modification. Please note that only a proportion of people access and understand the DAQI.</p> <p>Thus, a score of up to +1.0 out of 5 is concluded, where +5.0 would be complete (90-100% of both at-risk and general populations) willingness and actual modification of behaviours in the event of ‘moderate’, ‘high’ or ‘very high’ air pollution notifications.</p>
<p>Mitigation of symptoms attributable to acute exposure to elevated air pollution</p>	<p>0.5</p>	<p>The evidence suggests that the DAQI’s contribution to behaviour modifications and thus additional mitigation of symptoms might be relatively limited, especially directly due to low engagement to the ‘Recommended Actions and Health Advice’.</p> <p>Even for the small proportion of people who might be checking the ‘Recommended Actions and Health Advice’, experts highlighted that they might not have sufficient discretion over their time and thus might not be able to modify their daily activities, such as going to work, dropping children to school, etc, even if they wanted to.</p> <p>Moreover, if these people who engage with the ‘Recommended Actions and Health Advice’ have sufficient discretion to follow the advice, the result might not always lead to the mitigation of adverse health effects attributable to acute exposure to elevated air pollution. Some evidence, for example, points to the net benefits of physical activity even during elevated air pollution episodes. Experts interviewed for this evaluation also agree that discouraging physical activity might not lead to net positive effect on overall health and wellbeing, especially in the longer term.</p> <p>Following the ‘advice’ could result in unintended consequences, which would limit any mitigation of symptoms. For example, staying indoors might not necessarily result in a reduction in</p>

⁶² Please recall from Section 4.6: “The survey evidence suggests that around half of the 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.”

Level of...	Rating	Summary of evidentiary support
		<p>exposure to elevated air pollution, especially if these indoor spaces have no air filtering/ air conditioning.</p> <p>The DAQI thus has the potential for additional, indirect contributions to mitigating adverse health effects of acute exposure to air pollution by raising awareness of air pollution directly and/or through third party services. Awareness can in itself result in behavioural modifications especially when combined with other actions such as educational and/or health and care programmes.</p> <p>For example, people with asthma might not find it necessary to engage with the ‘Recommended Actions and Health Advice’ to understand the actions they must take in the event of elevated air pollution. Thus, by raising awareness of the potential air pollution in days ahead, the DAQI could be contributing to behavioural modifications to these individuals all the same, resulting in the mitigation of symptoms they could otherwise have faced from being unprepared and/or being exposed to elevated levels of air pollution unknowingly.</p> <p>Studies that investigate frequency of use of inhalers demonstrated that their use increased during periods of higher air pollution, which may suggest a perception of relieving symptoms. Survey responses suggest that the majority of medical inhaler users (N=1,011) modify their behaviour by increasing their frequency of use when air quality is poor, which they perceive 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. Further, misuse of inhalers (such as overuse of reliever, blue inhalers) can result in negative unintended health consequences, which may or may not outweigh the immediate health benefits perceived by inhaler users.</p> <p>In summary, the DAQI appears to make some contributions directly and/or indirectly to raising awareness of air pollution, and/or directly encouraging people to prepare for the days ahead in a way that would limit their exposure. The evidence is limited; however, it suggests that this contribution would be low in terms of behaviour modification and potentially lower in terms of mitigating health symptoms that could be faced especially by people at risk.</p> <p>Thus, a score of +0.5 out of 5 is concluded, where +5.0 would be complete (90-100% of people) mitigation of attributable adverse health effects from acute exposure to elevated air pollution.</p>

Level of...	Rating	Summary of evidentiary support
Effectiveness	1.5	An average score of +1.5 out of 5.0 (or lower) is concluded overall. This suggests that DAQI might not be effective at achieving its intended impacts, especially concerning its contribution to behaviour modifications and mitigation of symptoms or adverse health effects attributable to people’s acute exposure to elevated air pollution.

Based on the evaluation research findings, the evaluation has found that, generally, the DAQI might not be effective at achieving the intended outcomes and impacts. That is, the DAQI might not, generally and by itself, result in a reduction of health risks faced by individuals nor mitigate adverse health effects from their acute exposure to elevated air pollution. Section 6 outlines a set of recommendations for potential improvement of the DAQI in the future.

In conclusion, Defra’s Daily Air Quality Index services providing air quality information and recommended actions and health advice are appropriate, with some areas for potential improvement. However, the DAQI services might not be effective at achieving behaviour modifications that could reduce the risk faced by individuals nor mitigating any adverse health effects from their acute exposure to elevated air pollution.

6. RECOMMENDATIONS

Having conducted the evaluation of the DAQI, this section outlines a set of recommendations on improvements to the air quality information system, structured in two categories, those which would seek to improve the appropriateness and others focussing on the effectiveness of the DAQI. This section then concludes with a section detailing the limitations of this study and further research that could be undertaken to enhance the findings of this study.

6.1 IMPROVING APPROPRIATENESS

Overall, it was concluded that the DAQI is broadly appropriate, with areas of improvement pertaining to its reliability, methodological validity and accuracy, and especially so concerning its accessibility and understandability. Recommendations against each of these areas are set out below, based on expert input, feedback collected through in-depth interviews and the survey, as well as the available literature.

6.1.1 Reliability

The data provided on the DAQI is reliable at the regional level, but improvements could be made to achieve more accuracy and precision at the local level. Advances in technology can also be helpful in this regard. Finally, expert feedback also suggested that the ‘Recommended actions and health advice’ provided on the DAQI webpage has some shortcomings.

Three main recommendations have thus been identified to improve the DAQI’s reliability:

- **#1 Defra should improve the current spatial resolution of the forecasting model that is used to provide the DAQI notifications on a postcode level.** The current resolution is insufficient for the desired reliability at such granular levels.
- **#2 Defra could enhance the forecasting approach by drawing on technological advances.** For example:
 - 2.i) Artificial Intelligence (AI) and Machine Learning Models (MLM) to introduce additional checks to the provisional AURN data used in models to remove any outlier data points, which will improve the quality of the data used in the forecasting.
 - 2.ii) MLM could be used to improve the forecasting. The inclusion of site-specific forecasts at monitoring stations could run in parallel with the model forecast and/or presenting the worst-case DAQI from both the regional and local projected forecasts for the zone/area.
 - 2.iii) Explore the use of AI and satellite data to be used in future forecast models to improve accuracy.
- **#3 Defra, in collaboration with relevant stakeholders, should update the ‘Recommended actions and health advice’ to reflect the latest evidence and minimise negative unintended consequences.**
 - 3.i) Physical activity (outdoors or otherwise) should not be discouraged. The recommended actions should be updated to reflect this, and any suggestion to avoiding physical activity should be removed. Moreover, Step 2 of the DAQI recommended actions: “*If you may be at risk, and are planning strenuous physical activity outdoors, check the air pollution forecast*”, should remove the phrase “*and are planning strenuous physical activity outdoors*”.
 - 3.ii) Advice on inhaler use should refer to asthma management plans, as this is the latest guidance from the NHS (even though only a small proportion of asthmatics might have a plan at present); and/or refer to health care professionals such as General Practitioners.
 - 3.iii) More broadly, it has been identified that targeted and professional advice would be most reliable, but also more likely to result in behavioural modifications. Thus, it is recommended to consider making an explicit referral to health care professionals such as General Practitioners and/or integrating the DAQI alert system into health and care services.
 - 3.iv) Introduce advice for people to monitor their health symptoms for a day or more after an elevated air pollution episode.

6.1.2 Methodological validity and accuracy

The DAQI services were found to be generally valid and accurate, and from a methodological perspective at the current time there are no recommended changes. However, it is recommended that research is monitored for potential future updates across the following areas, to maintain the DAQI’s validity:

- The pollutants that are included within the DAQI. For example, pollutants such as black carbon and volatile organic compounds might need to be included if evidence becomes available to do so.
- The breakpoints if additional research is available. Further exploration as to whether the breakpoints should be updated might be warranted, to reflect the latest WHO

guidelines or short-term health effects. This would likely need further evidence to support any changes to the bandings.

- The combined effects of short-term pollutant exposures on human health. If further evidence becomes available on the combined effects of short-term pollutant exposure, it might warrant the adjustment to the current methodology so that these can be taken into account into the DAQI. This was an area that experts interviewed for this study thought should be considered but recognised there is insufficient evidence at this time to do so effectively.

6.1.3 Accessibility

On the one hand, the primary reasons for preventing access to the DAQI services were a lack of awareness, a lack of time and/or prioritisation of air pollution risks, and, finally, finding the way through air quality web pages or services, especially when they are not commonly used by people. On the other, the proliferation of third-party air quality services such as navigation/map and weather apps, news outlets, and other sites and applications run by private and public organisations have facilitated and, in fact, broadened access to air quality information that is based or linked to the DAQI.

In this context, it is recommended that:

- **#4 Defra should build on existing third-party air quality information services, collaborating with their providers** for an effective and assured use of the methodologies, evidence and/or information they are currently drawing from. This would improve the reliability of these third-party services and potentially strengthen their reach to broader audiences. Moreover, third-party air quality information services do not generally include health advice. This could also be addressed through closer collaboration with the providers of these services.
- **#5 Defra and UKHSA should collaborate with health and care providers and/or educational facilities to integrate the use of the DAQI in their services, particularly targeting at-risk individuals**; similar to an approach developed by the Greater London Authority (GLA) and partners. The GLA sends alerts when there are moderate or high pollution events directly to the health care providers and educational facilities, allowing them to provide direct tailored advice of actions.
- **#6 Defra should review and potentially expand the communication channels of the DAQI, based on the latest trends and developments**, for example:
 - Joining TikTok or Instagram or similar platforms, and using more interactive, engaging messaging around air quality could improve the public's general understanding of the harm air pollution can cause and target younger generations.
 - Including air pollution messaging as part of weather channels or TV weather broadcast when air pollution is moderate, high, or very high, with brief statements on effects to health, could reach older generations, enable them to access information more easily, and limit information fatigue/overload.

Defra could also use this expanded, stakeholder network and reach to promote air quality events and increase the public's awareness and knowledge about the effects of air pollution.

- **#7 Defra should make minor adjustments to the visual display of the DAQI information, by including scores (1-10) in addition to the colour-coding or PRAG rating,** so to improve the accessibility for people who are colourblind.

In summary, it is considered that people's awareness of air pollution and their access and/or use of DAQI notifications would improve if these could become part of the mainstream through the integration of this information into commonly used resources such as map/navigation applications and the broadcast of weather forecast, for example, issuing moderate, high or very high air pollution notifications or alerts alongside the weather forecast and/or notifications of heat waves and/or the pollen count.

6.1.4 Understandability

The DAQI scorings 1-10 and colour-coding or rating appear to be well understood. No changes are recommended to these, apart from the improvement mentioned above (in the accessibility section).

There are potential areas of improvement concerning the language used on the website and/or other DAQI services to improve people's understanding of the health risks from acute exposure to elevated air pollution. It is thus recommended that:

#8 Defra should include additional text suitable for a lay person in the DAQI services, accommodating people of different ages, interest levels, education, and backgrounds, and that any messaging is as practical as possible for clarity and ease of understanding. More particularly:

- 8.i) The language used on the website and/or other DAQI services should be simplified and updated to laypersons terms that would enable a broader understanding of the air quality information and any recommended actions. Clear signposting to additional, more technical information should be easy to follow on the website or other services for those who might be interested. The more technical information should be understandable by a person who is not an expert in the field.
- 8.ii) The definition and use of 'at-risk' should be made less ambiguous by replacing any reference of "at-risk" with a more specific definition of who those people might be, such as referring to them directly as 'individuals with lung or heart problems' or something simpler yet more specific, that does not leave as much room for interpretation.
- 8.iii) The recommended actions for people at risk should be simple, clear, and actionable, focussing on at-risk people, for example, go see a doctor if..., carry your blue inhaler with you and follow your doctor's advice, plan your route to walk near less congested roads, exercise outdoors before or after rush hour, etc.
- 8.iv) If the 'Recommended Actions and Health Advice' retain references to "physical activity", the terminology referring to different levels of activity should be aligned with the NHS: the term "strenuous" and others should be replaced with terms such as "moderate" and "vigorous".
- 8.v) The use of predictive language reflecting the uncertainty of the forecasts could improve the trustworthiness of the messaging, for example, replacing 'moderate levels of air pollution' with 'possible moderate levels of air pollution'.

6.2 IMPROVING EFFECTIVENESS

The evaluation concluded that, generally, the DAQI might not be effective at achieving the intended outcomes and impacts. That is, the DAQI might not, generally and by itself, result in a reduction of health risk faced by individuals nor mitigate adverse health effects from their acute exposure to elevated air pollution.

Additional recommendations have been developed to improve upon this, by addressing issues identified in the DAQI's contribution to behaviour modification and the mitigating adverse health effects of acute exposure to elevated air pollution.

6.2.1 Behaviour modification

Based on the survey responses, people appear generally willing to modify their behaviours, especially if they are aware of 'high' or 'very high' air pollution episodes. However, there are barriers preventing them from doing so, such as people's lack of understanding of the level of risk they might face; the limitations to people's discretion over their time; and the lack of prioritisation of actions to reduce this risk. It is thus recommended that:

- **#9 Defra (and/or other providers of air quality information that Defra collaborates with) should review the visuals to limit 'green fatigue' and only issue notifications and alerts when the air pollution is 'high' or 'very high' (and potentially 'moderate') to improve engagement with the information and adherence to the advice.** This could be similar to heat wave notifications (as receiving very frequent and 'unnecessary' notifications that suggest there is no air pollution, i.e., green ratings, can cause 'alert fatigue' and lack of interest). It would be most effective for air quality services to be integrated and/or coordinated so that users are not bombarded and instead, ideally, one (or more consistent) notifications are issued to each person, or person at risk.
- **#10 Defra should develop and implement a communication and/or educational plan alongside the DAQI publications to: i) raise the profile of air pollution risks amongst UK residents, and ii) improve people's understanding of what elevated episodes of air pollution could mean to their health in practical terms in the short-term (and the health of their dependents), and potentially over the longer term.** This could elevate the priority people give to air pollution information, especially for those at a relatively higher risk, such as people with heart or lung problems.
- **#11 In addition to providing understandable and actionable 'recommended actions and health advice' for people to consider during elevated air pollution episodes, Defra should also include more contextual information that can help people enact any action;** for example, detailing where there might be pollution hotspots, and/or periods/hours that are likely to have the highest pollution concentration. For example, if NO₂ were the cause of the alert, any recommended actions could suggest avoiding roads with high congestion during rush hour periods; if ozone were the cause of the alert, recommended actions could note that the levels of pollution might be highest during the afternoon, and concentrations could drop after sundown. This additional information could improve the likelihood that people may be able to adjust their daily plans.
- **#12 Defra should explore actions that people with limited discretion over their time might be able to take to reduce their acute exposure to elevated air pollution.**

- **#13 Defra should explore approaches to issue dynamic and tailored messages to people.** These might in fact be more implementable through the collaboration and/or integration of air quality information services across a range of relevant stakeholders (broadcasters, navigation/map system providers, local government, the NHS, etc.).

6.2.2 Mitigation of symptoms

In the context of the DAQI or similar services, improving accessibility and understandability, as well as the design of the DAQI to enhance adherence to a set of clearer and more concrete 'Recommended Actions and Health Advice' would have positive spillover effects on the extent to which the DAQI might contribute to mitigating symptoms from the acute exposure to elevated air pollution. Additional collaboration and/or integration with health and care providers, educational institutions and even employers could facilitate more effective behaviour modification, which might as a result improve the mitigation of any symptoms or adverse health effects attributable to air pollution. No additional recommendations have been identified at this end stage of the DAQI's Theory of Change.

6.3 LIMITATIONS AND FURTHER RESEARCH OPPORTUNITIES

This study has some limitations, inherent to this type of primary research requiring a sampling exercise and reporting (rather than observation) of people's behaviours and understanding. Some but not all of the limitations include:

- When undertaking people surveys, their responses can be affected by unconscious positive bias linked to the people's desire to 'do the right thing', but not necessarily the action they take in reality.
- 21 people from the general public were interviewed in depth, and only four appeared to be using the DAQI. As expected, this is a very limited sample to support robust conclusions, especially pertaining to whether people might actually understand the DAQI and/or make changes to their behaviour upon receiving a DAQI notification.
- The online survey targeted around 2,000 people, which is a larger and complementary sample of information. People were able to offer insights into their 'synthetic' level of understanding of the DAQI, that is, based on reading and engaging with information presented in the survey. People also reported on their intention to modify their behaviours in different air pollution scenarios. However, this does not signify that people would enact such intentions. Thus, additional evidence collected on behaviour changes remains limited.
- More specific to this particular study, there are a large number of similar air quality information websites and services that mention the DAQI on their website, which could have caused confusion from respondents when they were asked questions about their awareness and/or use of UK AIR DAQI services.

There are thus opportunities for further research, including but not only:

- A more detailed investigation into people's behaviour modifications, if any, which result from accessing the DAQI and/or other third-party air quality services based on the DAQI (ideally, through at least partly observational research). For example, users could be engaged during high or very high alerts or notifications, and/or a brief questionnaire could be linked to the webpage, so that 'users' are asked, especially

during high or very high alerts, to report whether they are following the DAQI 'recommended actions and health advice' or not, and if not, what they might be doing about the elevated air pollution episode.

- In-depth, qualitative research (such as interviews of a larger, random sample of individuals) could expand the collective understanding of which air quality information services people are accessing most (e.g., DAQI and/or third-party), as well as how, when and why.
- Another research study could investigate further the way in which DAQI or similar services are currently integrated into the NHS and whether and how they could be integrated effectively, particularly relating to asthma clinics and cardiovascular services.



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