CBI Economics

Quantifying the benefits of reducing nitrogen dioxide

Methodology document to accompany the "Breathing Life" report series

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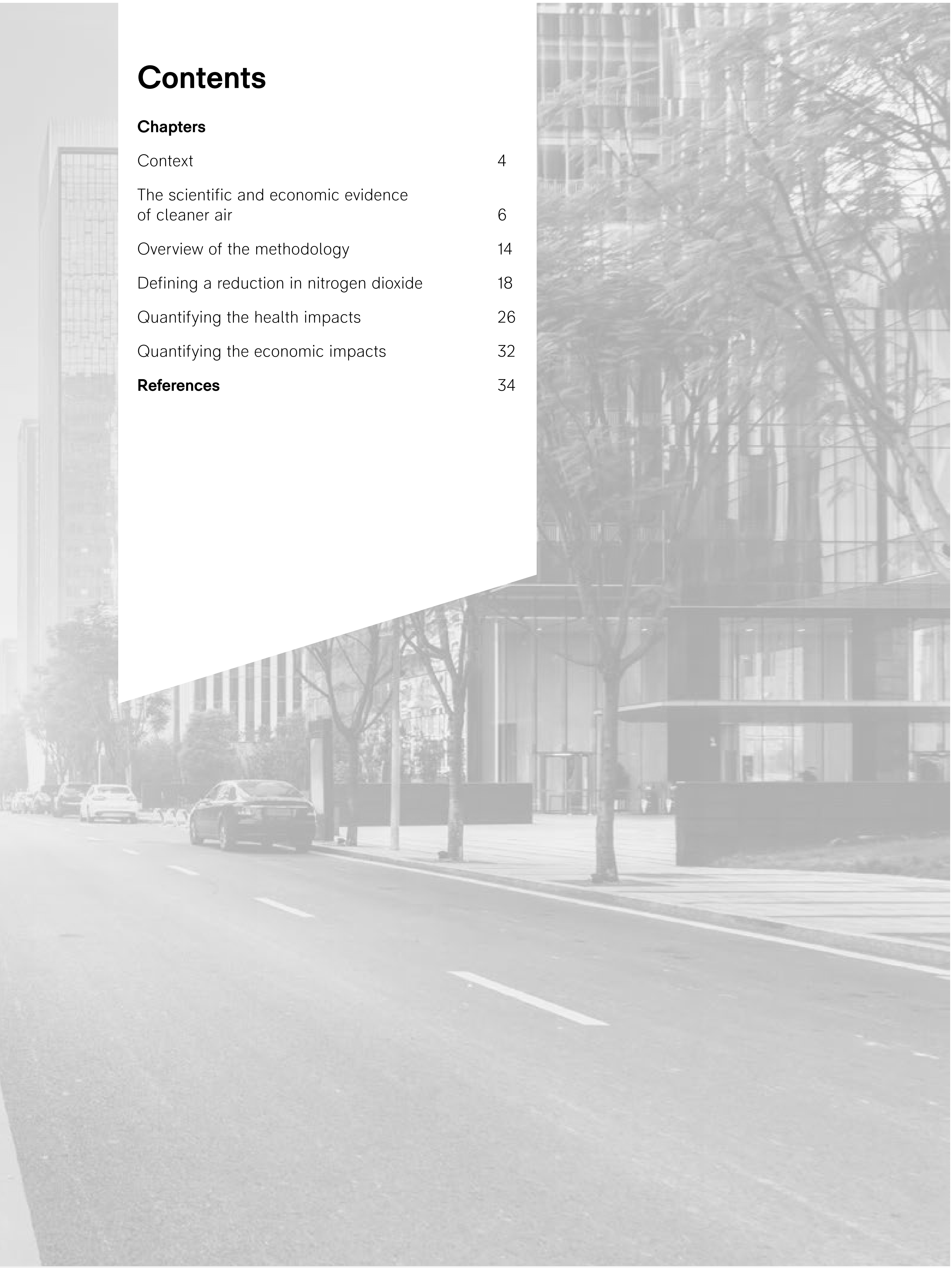
Commissioned by

CLEAN AIR FUND

Contents

Chapters



Context

Background to the study

Clean air matters because it contributes towards people's health and the natural environment. This is important to sustain habitable spaces, a healthy workforce, and a prosperous society. Emerging evidence shows that improved air quality can have large intergenerational consequences including increased educational attainment.[1] It is therefore clear that clean air impacts individuals across all sections of society now and in the future.

The UK has statutory obligations to meet national air quality objectives for five pollutants and is currently not meeting its targets for nitrogen dioxide (NO_2) in several local areas. Nitrogen oxides (NOx) are a group of gases, made up of both NO and NO_2, that are predominantly formed during the combustion of fossil fuels, with road transport comprising 33% of NOx in 2019.[2]

Because of this, higher concentrations of NO_2 are typically found in pockets of the country close to busy roads, often within city centres. Therefore, in a bid to tackle the UK's high NO_2 levels, the government created a plan in 2017 that includes both national and local action.[3] This included an action mandating the introduction of Clean Air Zones (CAZ) for some cities, with the publication of a CAZ Framework for local authorities to follow.[4]

In this context, the Clean Air Fund (CAF) has commissioned CBI Economics to quantify the economic benefits of reducing NO_2 concentrations in eight cities: Birmingham, Bristol, Greater Manchester, Liverpool, London, Newcastle, Portsmouth, and Sheffield, to help build the economic case for the implementation of CAZs within these cities. This study follows a previous study undertaken by CBI Economics and commissioned by CAF, *Breathing Life into the UK Economy*, which quantified the economic benefit of reaching the World Health Organisation's (WHO) air quality guidelines.[5]

Purpose of this document

The findings of this latest study are set out in eight city briefings that capture the health and economic benefits associated with reducing NO_2 in each of the cities. The purpose of this document is to provide a detailed account of the methodology, data sources and assumptions that underpin the analysis in these briefings.

The remainder of this document provides a literature review of the scientific and economic evidence that informed the final methodology, as well as a detailed account of the methodology deployed to derive the results. This includes the development of the baseline and counterfactual scenarios, as well as the assumptions used to estimate the health and associated economic impacts.

Acknowledgements

We would like to thank Ricardo Energy and Environment, who provided empirical support and advice throughout the project, including the baseline NO_2 concentration data and a comprehensive review of the CAZ feasibility studies.

We would also like to acknowledge the independent advice we received on the methodology provided by Dr Heather Walton, School of Public Health/ Environmental Research Group, Imperial College London via Imperial Projects.

The scientific and economic evidence of cleaner air

It is important that any modelling exercise which seeks to estimate the productivity benefits of tackling the air pollution problem across UK cities is grounded in scientific and economic evidence. Therefore, to develop a methodology, two areas of academic literature were reviewed to identify the theory and the evidence necessary to undertake the analysis:

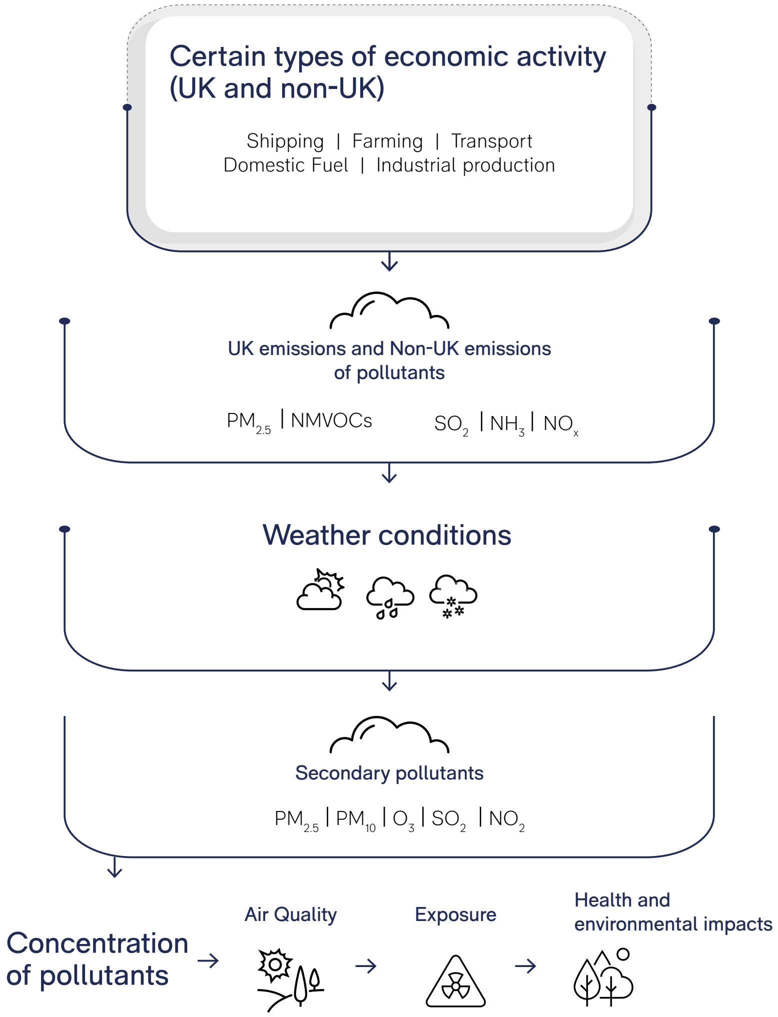
1) **Evidence from science:** The science provides an understanding of how air pollution leads to adverse outcomes on the population and the environment.

2) **The economic theory:** Economic theory provides an understanding of the channels through which air pollution impacts the productive capacity of the economy including its impact on labour, capital, and land.

Relationship between air quality, health outcomes and the environment

Air quality is a key contributor to the health of a nation's population and its natural environment. **Exhibit 1** shows the process by which air pollution from human activity leads to a deterioration in air quality and ultimately adverse impacts on public health and the environment.

Exhibit 1 How air pollution impacts public health and the environment



Activities such as industrial processes, shipping, and transport release emissions of pollutants into the atmosphere. These emissions are then transported across borders, meaning that air pollution in the UK is caused by activity in the UK and from elsewhere in the world.[6]

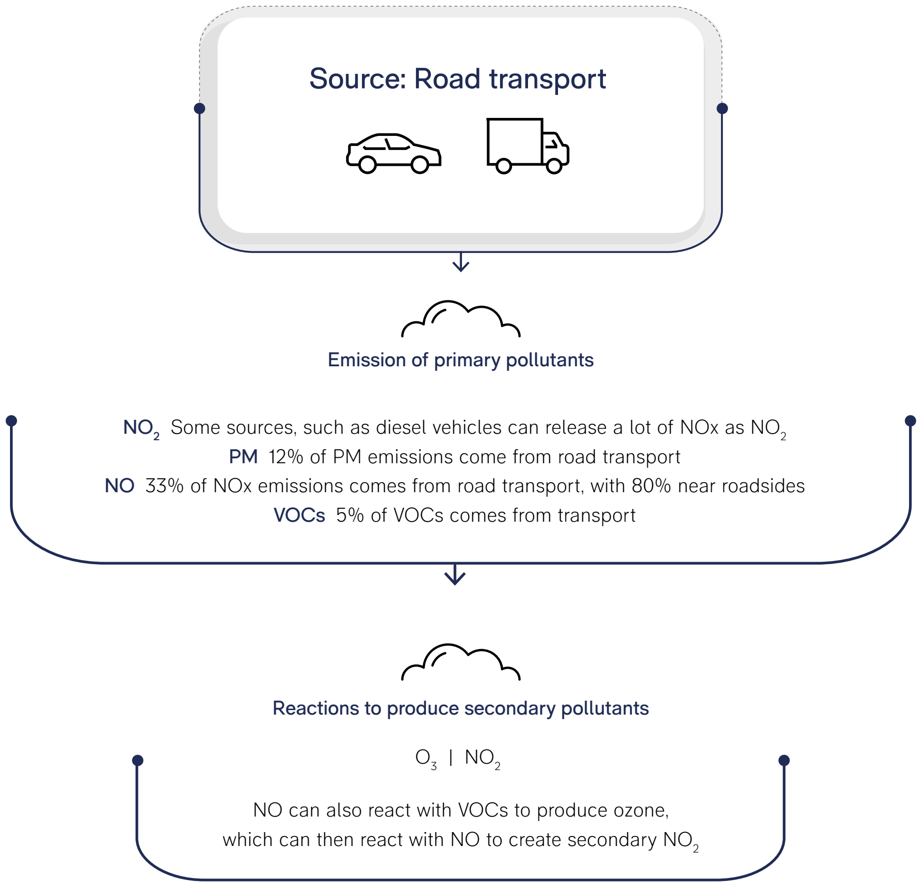
These pollutants can also react to form new compounds, or secondary pollutants, which can be even more damaging than the direct emissions. Scientific evidence finds five pollutants to be the most damaging to health and the environment: particulate matter (in particular PM_{10} and $PM_{2.5}$), ozone (O_3), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2).[7] Evidence also shows that high concentration levels of these pollutants in local areas can lead to unequal exposure to individuals, and are more significant in contributing to adverse health and environmental outcomes than national emissions levels.[8] For example, road transport from cars and lorries is now posing a major threat to air quality in the UK.[9] Therefore, air quality is judged on both overall levels of emissions and the concentration of pollutants.

The interaction of NO_2 with other pollutants

The scope of this analysis was limited to NO_2, since it is the pollutant most impacted by the introduction of a CAZ policy. However, air pollution usually exists in the form of a complex mixture and therefore, it is difficult to estimate the health risk caused by a single pollutant.[10] However, research suggests that NO_2 is emitted with other pollutants, especially $PM_{2.5}$.[11] Because of this interconnectedness, it can be difficult to disentangle NO_2 from other pollutants when assigning the cause of poor health outcomes such as chronic mortality.

For instance, road transport has been linked to several pollutants other than NO_2. NO_X emissions from burning fossil fuels are mainly as NO, but some sources can release NO_X as NO_2. These primary NO_2 emissions are typically caused by diesel vehicles (especially when moving slowly) and can make up as much as 25% of the total NO_X emissions.[12] **Exhibit 2** shows how other pollutants such as particulate matter (PM) are also caused by road transport, and how ground-level ozone can be generated as a secondary pollutant through a reaction between NO_2 and volatile organic compounds (VOCs). As a result of these interactions, policies such as a CAZ can have primary and secondary effects on several pollutants.

Exhibit 2 How air pollution impacts public health and the environment



The impact of pollution on health outcomes and the environment

Air pollutants have been linked to several health conditions resulting in increased hospital admissions and premature deaths. Pollutants such as PM_{10} and $PM_{2.5}$ penetrate the lungs, which can cause respiratory impacts, including lung cancer. They can also lead to cardiovascular and cerebrovascular health conditions such as heart disease.[13] It is estimated that poor air quality contributes towards 19% of all cardiovascular deaths and 29% of all lung cancer deaths.[14,15] Evidence also shows that air pollutants contribute towards climate change, causing harm to natural habitats and ecosystems.[16,17,18,19]

The concepts of morbidity and mortality

In human health sciences the terms 'morbidity' and 'mortality' are frequently used to describe the health outcomes of a population.

'Morbidity' refers to having a particular illness or the rate of disease in a particular population.

'Mortality' refers to having died or the number of deaths in a particular population due to a particular cause.

Economic theory underpinning the impact channels of air quality

Health and environmental outcomes caused by poor air quality impact the economy through its effect on, what economists refer to as, the three factors of production: land, labour, and capital (buildings and machinery).

The economic theory underpinning the three factors of production

Economic theory argues that firms produce a desired level of a good or service at the lowest possible cost using a combination of inputs. These inputs can include time spent in work, buildings, machinery, raw materials, land, and other natural resources. These are categorised into three factors of production: labour, capital and land.

These factors of production are then reflected in the production function:

$$Y = P_l \times Q_l + P_k \times Q_k + P_z \times Q_z$$

Where Y is output, P is price, Q is quantity, L is labour, K is capital and Z is land.

When choosing the combination of inputs to use, firms consider the cost of each factor, as well as the efficiency of that input (also known as the productivity).

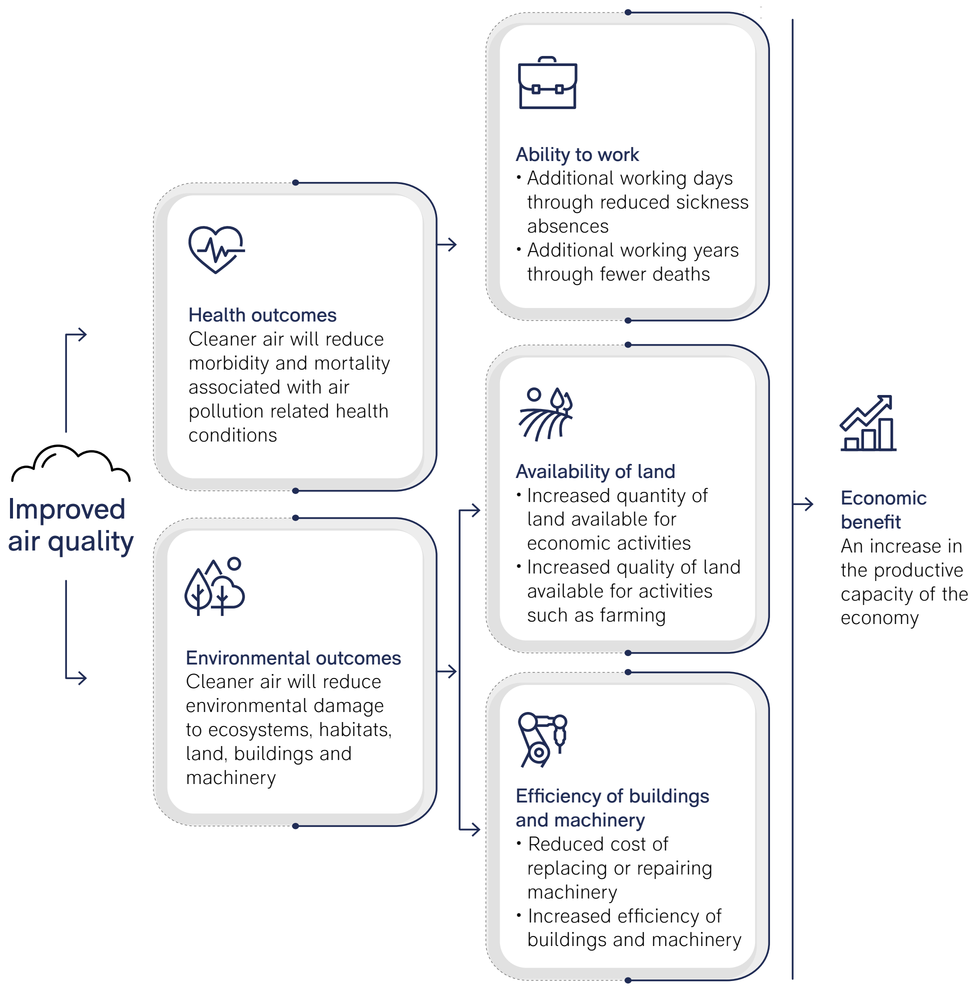
Productivity is typically measured as output per one unit of input. An increase in labour productivity, for example, represents an increase in the output produced by one worker.

The World Bank estimates that air pollution cost the global economy $225bn (approx. £180bn) in lost labour income in 2013, and a Department for Environment, Food and Rural Affairs (Defra) study in the UK found a cost of around £2.7bn as a result of pollutant levels in 2012.[20,21] Improving air quality can therefore have a range of economic benefits through the channels set out in **Exhibit 3**.

In the first instance a healthier population increases the number of people available for work by reducing premature deaths caused by poor air quality and making those skills available to the economy. In addition, workers are less likely to suffer sickness from poor air quality, reducing sickness absences and increasing their available hours for work.[22] There is also evidence that air quality can impact an individual's concentration levels and therefore affect their performance at work.[23] This effect has also been linked to the performance of those out of work, such as children taking exams, affecting their long-term productivity, and earning potential.[24]

At the same time, a cleaner environment will increase the availability of land, as well as the useful life of buildings and machinery.[25] For example, a machine that relies on air as an input will be more effective with cleaner air and have lower on-going maintenance costs.

Exhibit 3 The links between air quality and the economy



Both the availability of these inputs and their quality (or efficiency) will therefore impact a country's ability to produce goods and services. Changes in the quantity and quality of inputs will impact decisions by firms and individuals over many years, which could result in adjustments to the structure of an economy. For example, as labour becomes more productive its price will increase (i.e. wage levels). As wages rise, firms may choose to substitute labour for other factors of production, such as through investment in capital equipment. Over time this will change the allocation of inputs used in the production process.

As well as those channels demonstrated in **Exhibit 3**, there are also expected to be a range of social benefits, including the impact on health systems. A study by Public Health England (PHE) estimated that between 2017 and 2025 the total cost to the NHS and social care system in England due to $PM_{2.5}$ and NO_2 was £1.6bn.[26,27] However, this study focuses solely on estimating the economic benefits of improving air quality through the labour force impacts, and therefore does not seek to estimate the potential impact to public health and social services.

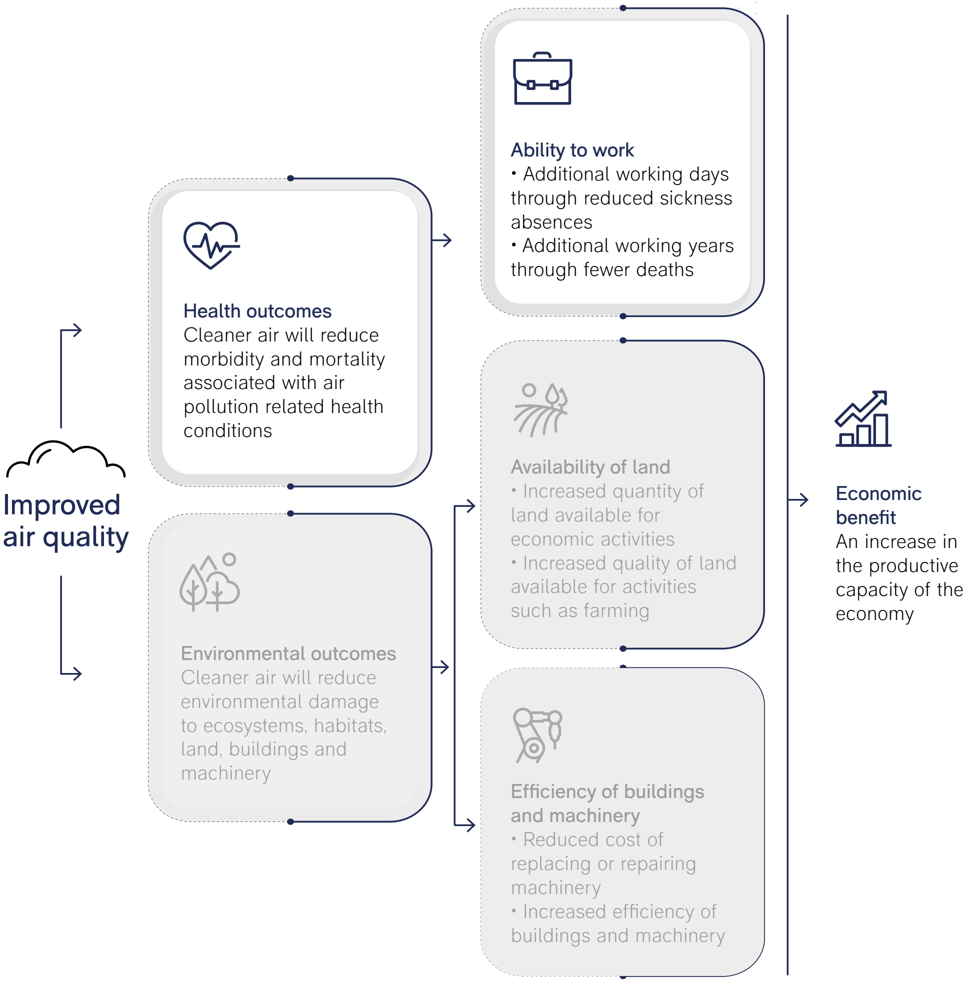
Overview of the methodology

The scope of the economic analysis

After establishing the scientific and economic evidence underpinning the relationship between clean air and economic value, a methodology was designed to capture these impacts. While the theory demonstrates that air quality is likely to affect all three factors of production (labour, capital, and land), the evidence is greatest for the impact of air quality on public health, and subsequently on the health of the workforce. In addition, there is much more evidence relating to the health impacts of air pollution on workers, with evidence allowing for the quantification of the impact on other factors of production such as land, buildings, and machinery, much more limited.

Furthermore, quantifying the longer-term effects associated with improving air quality requires an understanding of how government policy would evolve over time, the resulting change in business and consumer behaviour, and the trajectory of the economy, all of which are highly uncertain. Therefore, the CBI Economics analysis focuses on the immediate impact of improving air quality on the workforce, and its subsequent impact on the productive capacity of the economy. This is demonstrated by **Exhibit 4.**

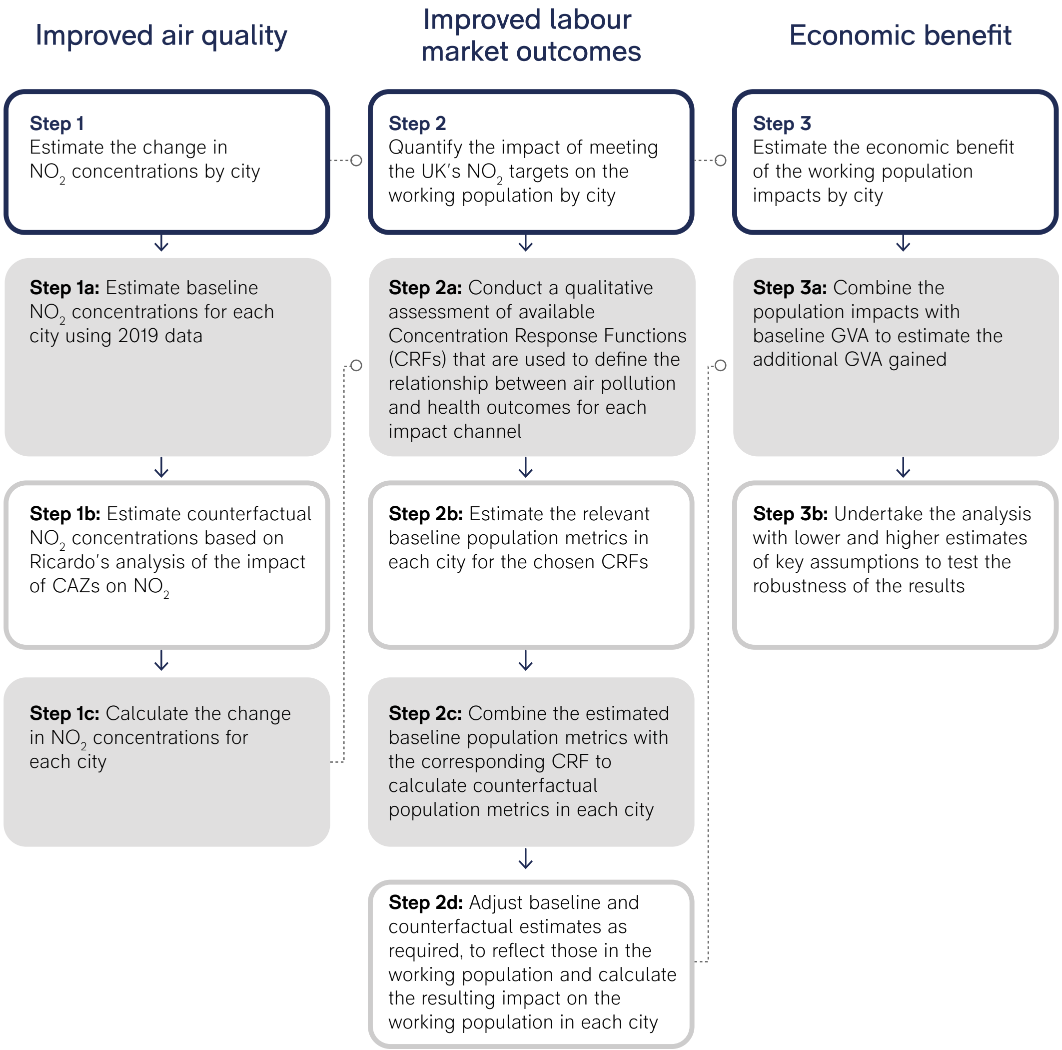
Exhibit 4 The scope of the economic analysis



An overview of the three-step approach to quantification

To quantify the economic benefits of a reduction in NO_2 specifically, CBI Economics analysis uses an economic model that follows the three steps set out in **Exhibit 5**. Each of these steps is explained in detail in the subsequent sections.

Exhibit 5 An overview of the methodology



The methodology first estimates the change in NO_2 concentrations in each city before quantifying the impact of this change on health outcomes and ultimately on the working population. This is then monetised using Gross Value Added (GVA) data to estimate the economic benefits of the estimated reduction in NO_2.

Defining a reduction in nitrogen dioxide

The purpose of this study is to assess a state of the world where CAZs enable the eight cities of interest to reach the UK's statutory NO_2 targets. This requires a baseline and a counterfactual for NO_2 concentrations, which can be described at a high-level as:

- **The baseline:** The annual and 1-hour mean of NO_2 concentrations for 2019 in each of the eight cities.
- **The counterfactual:** The annual and 1-hour mean of NO_2 concentrations in 2019 reduced by the estimated impact of the CAZ D.

The baseline NO_2 concentration values were provided by Ricardo Environment and Energy (henceforth: Ricardo) using 2019 air quality data at the local authority level. **Table 1** provides an overview of the measurement techniques used for the baseline and counterfactuals in London and the other seven cities.

The baseline values were calculated by taking the average of all roadside sites, whereas the counterfactuals were produced by analysing the feasibility studies carried out across a range of cities, where available, of the potential impact of implementing a CAZ. However, given the unique characteristics of London, and the availability of outturn data from the implementation of the April 2019 Ultra Low Emission Zone (ULEZ), a larger reduction in NO_2 was used.

Table 1 Overview of baseline and counterfactual

	London	Other cities
Baseline	Annual average of all sites	Annual average of all sites
Counterfactual	Reduction of 10 $\mu g/m^3$	Reduction of 5 $\mu g/m^3$

Estimating baseline NO_2 concentrations by city

Defining a baseline for NO_2 concentrations is important for two reasons. First, it demonstrates the scale of the challenge for each city and how far away the estimates are from the UK's statutory limit values. Second, it helps to provide some sensitivity analysis using a variation of monitoring sites where a CAZ might be most effective.

The UK currently has two statutory limit values for NO_2 based on the annual mean and the 1-hour mean, as shown in **Table 2**, and therefore it was necessary to derive a baseline for both measures.

Table 2 UK statutory NO_2 limit values

Pollutant measure	UK limit value
NO_2 annual mean	40 μ g/m^3
NO_2 1-hour mean	200 μ g/m^3

Methodology and data sources used to estimate the NO_2 baseline

To estimate the NO_2 baseline values in each of the eight cities, Ricardo reviewed the publicly available local authority and national automatic network monitoring data, as well as the 2019 national Pollution Climate Mapping (PCM) roadside modelling data for each of the cities:

1. **Monitoring data:** NO_2 concentrations measured at automatic monitoring sites were collated for 2019. The monitoring sites included are either part of the UK Automatic Urban and Rural Network or local authority monitoring data which has been approved by Ricardo's Calibration Club.
2. **PCM roads model data:** Road links included in the UK national Pollution Climate Mapping model for the eight cities have been collected from the 2018 model estimates of 2019 concentrations (latest available at the time of analysis). The PCM roads model provides concentrations on major roads in the UK at a distance of 4m from the kerb.

This data was then averaged for roadside sites as this is where a CAZ would be most beneficial. While there are also sites that measure urban background for pollutants, the rationale for considering roadside sites alone is that the measures underpinning a CAZ policy, such as charges for highly polluting vehicles, will predominantly impact roadsides.

In deriving the baseline values, the data has been selected to ensure it is spatially representative of the road network across the cities in scope.

Results for the annual NO_2 baseline

As illustrated in **Table 3**, a range of values were calculated for each city, including the annual average, and the maximum and minimum NO_2 concentrations. To understand the number of locations driving the average and therefore identify the poor air quality hotspots, several other values were calculated: the annual average concentration for those sites exceeding the national NO_2 limit value of 40.4 $\mu g/m^3$ and those just below the limit value, at 36 $\mu g/m^3$.

As the average concentrations are dominated by the PCM roads model, the latter range is provided as UK best practice guidance states that the error of concentrations produced from air quality models should be within 10% of the limit value for NO_2.[28] This means the error for modelled concentrations should be 4 $\mu g/m^3$ and therefore by setting the limit to 36 $\mu g/m^3$ Ricardo was also able to identify locations at risk of exceedance.

Table 3 Summary of limit values across eight cities in 2019 for the annual mean

City	Average NO_2 (μg/m³)	Minimum NO_2 (μg/m³)	Maximum NO_2 (μg/m³)	Average NO_2 (sites > 40.4 μg/m³)	No. locations > 40.4 μg/m³	Average NO_2 (sites 36 μg/m³)	No. locations > 36 μg/m³
Birmingham	31	17	55	45	17	42	34
Bristol	28	15	66	46	6	42	15
Greater Manchester	31	22	59	45	9	41	22
Liverpool	29	18	49	44	5	39	21
London (Outside ULEZ)	36	18	78	49	422	45	659
Newcastle	29	16	52	44	8	41	17
Portsmouth	30	17	45	43	2	40	5
Sheffield	29	18	46	43	7	40	17

Source: Ricardo analysis

Taking the average NO_2 concentration values across the roadside sites in each city for the annual mean measure results in a baseline value below the statutory target of 40 μ g/m³, despite each city reporting non-compliance in the latest Defra assessment in 2019.[29] This is because within one city there will be some sites meeting the legal limit value and others exceeding, but to be reported as compliant for a whole city, each of the monitoring sites must be within compliance of the limit value of 40 μ g/m³.

In each of the cities analysed for this study, the maximum concentrations exceed the annual limit value resulting in non-compliance. As a result, these cities have been tasked with reducing concentrations and carrying out a CAZ feasibility study. As shown by **Table 3**, the magnitude of this exceedance ranges from 5 μ g/m³ (Portsmouth) to 38 μ g/m³ (London outside current ULEZ).

Results for the hourly NO_2 baseline

A limitation of the PCM model is that it only provides values for the annual average NO_2 concentrations. Therefore, to assess the short-term NO_2 concentrations only, publicly available data from monitoring sites can be utilised.

To estimate the hourly mean, Ricardo derived a linear regression between the annual average NO_2 concentrations and the maximum hourly NO_2 concentrations using sites from all assessment cities (excluding London) to estimate maximum hourly NO_2 concentrations for all sites. London was excluded from the dataset as it had previously been shown to have a different pollution climate to other locations. This relationship was then used to estimate the maximum hourly mean from the PCM model concentrations.

The maximum hourly values estimated using the linear regression predict no exceedances of the 1-hour NO_2 limit value as shown by **Table 4**, which is in line with Defra's latest air quality assessment.[30] The estimation of the hourly concentrations using the linear regression approach is a simplified assumption and using measured data would be a more robust approach. However, measured data was not available for all cities.

An alternative method to identify locations exceeding the 1-hour NO_2 limit value is suggested by UK best practice technical guidance, which states that exceedances for the hourly NO_2 limit are unlikely to occur when the annual mean for NO_2 is less than 60 $\mu g/m^3$.[31] Based on the latter estimation method, exceedances of the short-term limit value is unlikely for the majority of assessment cities, except for Bristol and London where the maximum annual average NO_2 concentrations are greater than 60 $\mu g/m^3$ as shown in **Table 3.**

Table 4 Estimated maximum hourly NO_2 concentration for each of the assessment cities

City	Maximum Hourly NO_2 using linear regression (μg/m³)	Compliance with 1-hour limit value predicted using Technical Guidance
Birmingham	133	Compliant
Bristol	120	Non-compliant
Greater Manchester	130	Compliant
Liverpool	122	Compliant
London (Outside ULEZ)	147	Non-compliant
Newcastle	124	Compliant
Portsmouth	127	Compliant
Sheffield	125	Compliant

Source: Ricardo analysis

Estimating the counterfactual for NO_2 concentrations

To estimate the health benefits from the introduction of a CAZ, an estimate is required for the resulting reduction in NO_2. In the *Breathing Life into the UK Economy* report, the counterfactual was simply the UK's statutory limit values. However, given the annual average values for all eight cities are already below 40 μ g/m³, it was not possible to use the limit value as the counterfactual for this study.

Instead, Ricardo reviewed the publicly available CAZ feasibility studies to identify the change in modelled concentrations for scenarios relating to the implementation of a category D CAZ.[32] **Table 5** demonstrates the potential reduction in NO_2 across the cities that have modelled the impact of a CAZ D. Across these studies, the average change in concentrations for cities implementing a CAZ D is 5 μ g/m³. At the time of the analysis the following studies were published: Bath, Birmingham, Caerphilly, Cardiff, Derby, Liverpool, Greater Manchester, Newcastle and Portsmouth. This means a feasibility study was not available for the following cities within scope of this analysis: Sheffield and Bristol.

Table 5 Reduction in annual NO_2 modelled after implementation of a CAZ D[33]

CAZ City	Assessment Year	Average reduction in NO_2 after introduction of a CAZ D (μg/m³)
Bath	2021	12.2
Birmingham	2020	1.7
Caerphilly	2022	2.3
Cardiff	2021	2.1
Derby	2020	4.7
Liverpool	2022	5.0
Manchester	2021	9.5
Newcastle	2021	3.1
	Average	**5.3**

Source: Ricardo analysis of CAZ feasibility studies

The average (5 μ g/m³) counterfactual value was used by CBI Economics for the economic analysis. However, this average may underestimate the impacts of the CAZ in for example Bath and Greater Manchester. In these cities there may be an older fleet, a greater proportion of heavy goods vehicles, or a greater number of people predicted to upgrade their vehicle to a lower-emitting one because of the CAZ. This could be related to the proportion of the city area designated as a CAZ, all of which would lead to the impact of the CAZ being greater than other cities.

Furthermore, due to the difference in the economic and pollution climate between London and other UK cities, a different approach was taken to estimate the counterfactual. For London, Ricardo drew upon the ULEZ expansion report which provides an estimated range of reduction of between 5 and 15 μ g/m³ in a scenario where the ULEZ is expanded.[34] The average of this reduction has been applied (10 μ g/m³) for the purposes of this analysis.

As a result, the counterfactual for each of the cities was defined as a reduction of 10 μ g/m³ for London, in the area outside the current ULEZ, and a reduction of 5 μ g/m³ for the remaining seven cities.

Quantifying the health impacts

The next stage of the analysis is to quantify the health impacts resulting from the estimated reduction in NO_2 defined by the baseline and the counterfactual. This requires an understanding of the different channels through which an improvement in air quality impacts health outcomes in the population and the evidence available to quantify these.

Air quality impact channels

Evidence from academic studies, including Defra (2014), explains that air quality impacts the workforce through the following channels:[35]

- **Mortality:** Deaths in the working population prematurely remove a worker from employment, reducing the number of productive years over their lifetime. While mortality predominantly falls in the non-working population, in 2018 around 15% of all deaths occurred in the 16-64 age cohort, which accounts for 96% of employment.[36] Therefore, preventing premature deaths is expected to have a significant impact on the workforce.
- **Absenteeism:** Morbidity in the working population can lead to absences from work due to sickness and hospital admissions. In 2018, 141m working days were lost due to sickness absences, an average of 4.4 days per employee.[37] Fan and Grainger (2019) found an annual increase in $PM_{2.5}$ leads to a decrease in hours worked among 16 to 75 year olds.[38] Fewer hours worked comes at a cost to business. A study by CIPD finds that on average sickness absences cost businesses £554 per employee each year.[39] As a result, preventing sickness could have a large impact on the workforce and on business.
- **Absenteeism due to dependents:** Morbidity in the dependents of workers, such as children, also leads to work absences. Combining the average school days in a year with the number of pupils and the sickness absence rate indicates that 32m school days were lost due to sickness in 2018 in the UK. Where workers have direct responsibility to care for these children, preventing sickness in children could therefore have an impact on their available working hours. Several studies have found an association between air pollution and a reduction in labour supply due to caring responsibilities.[40,41]

- **Presenteeism:** Morbidity in the working population could also lead to workers attending work when ill, which can reduce productivity levels on a given workday. Defra (2014) suggests that the productivity loss of workers on presenteeism days could be around 20%. Reducing the number of days that people are ill at work is therefore expected to increase a worker's productivity on a given workday. Studies such as Zivin and Neidell (2012) have found a negative relationship between pollutant concentrations and worker productivity.[42]
- **Early retirement:** Chronic conditions in the working population could lead to early retirement, removing a worker prematurely from employment. Several studies have linked chronic obstructive pulmonary disease (COPD) to early retirement, with an international survey by Fletcher et. al finding that 20% of those in the working age population with COPD took early retirement.[43]

Identifying the NO_2 impact channels

To quantify the resulting health impacts from a change in pollutants, the approach most often used in health impact assessments and cost-benefit analysis (CBA) is concentration response functions (CRFs). A CRF provides an estimate of the change in a health outcome attributable to a given change in the concentration of an air pollutant. The CRFs are then combined with the relevant UK baseline disease rates and population data to estimate the change in the health of the UK workforce following a change in air quality.

Several CRFs are available in the literature and it was therefore necessary to conduct a qualitative assessment to identify the CRFs most suitable for the CBI Economics analysis. Given the focus of this study is on NO_2 in isolation, it was also important to understand which impacts would be realised by an improvement in NO_2 only. Academic evidence indicates that these impact channels are not all determined by each pollutant. For example, evidence indicates that the interaction between PM and NO_2 often means the health impact of NO_2 is captured by the health impacts of PM.

To do this, a set of sources were drawn upon:

- Evidence from the scientific literature demonstrating the most important pollutants in determining each of the impact channels of interest.
- The WHO 2013 Health Risks of Air Pollution in Europe (HRAPIE) project report that recommends a set of CRFs for use in air pollution CBA in Europe.[44]
- The Committee on the Medical Effects of Air Pollutants (COMEAP) 2018 report which provided an updated set of recommendation of CRFs to quantify the impact of air pollution of health outcomes.[45]

A summary of the CRFs available for NO_2 is set out in **Table 6**, including the rationale for each CRF from the HRAPIE report and an assessment by CBI Economics to inform those to take forward for quantification. The HRAPIE study classifies their recommended CRFs from A* to B. Where a CRF falls within Group A, this indicates sufficient data available to enable a reliable quantification of the effects of a given air pollutant on the health outcome of interest. A CRF categorised as Group B demonstrates that there remains some uncertainty about the precision of the data used to quantify the effects between the pollutant and the health outcome. Finally, an asterisk denotes that the effects are additive.

Table 6 Summary of potential CRFs to take forward for quantification

Measure	Pathway	Impact Channel	Effect metric (per 10 μg/m³)	HRAPIE rationale	CBI Economics assessment
Annual mean	All-cause mortality, adult populations	Chronic mortality	0.6% to 1.3% **Source:** COMEAP, 2018	HRAPIE recommendation is 5.5% for NO^2 annual mean > 20 μ g/m³ then can use 5.5%. However, we use the COMEAP recommendation which was updated in 2018.	Updated recommendation by COMEAP based on NO_2 alone. Omitted in the previous analysis due to the risk of double counting with PM, but as PM is not included in this analysis there is less risk of double counting.
Annual mean	Prevalence of bronchitis symptoms in asthmatic children aged 5–14 years	Absenteeism due to morbidity in dependents	2.1% per 1 μ g/m³ **Source:** Lai et al. (2009)	Group B*. Based on only one available longitudinal study providing NO_2 coefficient adjusted for other pollutants.	The base of asthmatic children in the UK is 5-10%, however regional data for asthma prevalence across all age groups is available from Public Health England. If used this would have to inform the working days lost due to dependent sickness, however data is unavailable on the prevalence of bronchitis symptoms in children.
1-hour mean	Acute mortality, in workforce	Acute mortality	0.3% **Source:** Samoli et al., 2009	Group A* using the PM_{10} adjusted 0.27% estimate.	This CRF was used in the previous analysis, however the CRF used was slightly lower at 0.27% once adjusted for PM_{10} impact and was the recommendation of the HARPIE project. However, as this analysis considers NO_2 only, the unadjusted NO_2 CRF can be used.
1-hour mean	Hospital admissions for respiratory disease, all ages	Worker absenteeism	0.15% **Source:** WHO, 2013	Group A. Alternative to the estimates based on 24-hour NO_2 average (preferred due to availability of more studies).	Recommended by the HARPIE project in Group A. Including this figure for all respiratory illnesses implies it would impact the working age populations as well as dependents for instance those who walk to school in cities.

CRFs taken forward for quantification

After undertaking additional research surrounding the shortlist of CRFs and exploring the availability of data required, two CRFs were taken forward for quantification. These two CRFs allow for an estimation of both the long-term and the short-term impacts of NO_2 and have been summarised in **Table 7.**

As of result, this study quantifies the impact of an improvement in NO_2 through two impact channels:

- **Chronic mortality** – reducing NO_2 will prevent some individuals from dying prematurely from health conditions associated with air pollution meaning these individuals will remain in the labour force for a longer period.
- **Worker absenteeism due to hospital admissions** – reducing NO_2 will lead to fewer sickness days from work due to respiratory hospital admissions.

Table 7 Final CRFs taken forward for quantification

Measure	Pathway	Impact Channel	Effect metric per 10 μg/m^3	Source	Description
Annual mean	All-cause mortality, adult populations	Chronic mortality	0.6% to 1.3%	COMEAP, 2018	This CRF was omitted in the previous analysis, however given the impact of PM is not included in this model there is less risk of double counting. The chronic mortality CRF has been used as this is expected to also capture the measure of acute deaths due to NO_2 concentrations.
1-hour mean	Hospital admissions for respiratory disease, all ages	Worker absenteeism	0.15%	WHO, 2013	Including this figure for all respiratory illnesses implies it would impact the working age populations as well as dependents for instance those who walk to school in cities.

On this basis, this study does not quantify the following impact channels due to limited academic evidence:

- **Absenteeism due to dependents** – reducing NO_2 will improve the health of children and the elderly, and reduce the need for workers to take time off for caring responsibilities.
- **Worker presenteeism** – reducing NO_2 will reduce the likelihood of pollution-induced illness such as coughs and thereby improve worker productivity.
- **Working days lost due to worker illness** – reducing NO_2 will minimise the frequency of sickness absence days, not severe enough for hospital admission.

The air quality data used in the analysis was from roadside sites only. The CAZ policy targets emissions from road transport and hence the air quality impacts of the scheme will be experienced predominantly at roadside sites. While the largest reductions in NO_2 will be observed at roadside sites there will likely be reductions, albeit smaller, at other site types, such as background sites, as a result of the policy. In the context of CRFs, air quality data from urban background sites are often used for short-term exposure studies. Long-term exposure studies use modelled concentrations at subjects' residence, which may or may not be beside a road. However, given that the CAZ policy will predominately impact roadside sites, it was understood this air quality data would best represent the maximum concentration change. This does add to uncertainty for use of the short-term CRFs. Ideally, the population living beside roads would have been used for the health impact calculations, but this is not easy to obtain. The results may therefore be overestimated to some degree. On the other hand, those who do not live beside roads do travel along them, for at least some periods of time.

Estimating the change in health outcomes following a reduction in NO_2

The change in concentration in each city after the implementation of a CAZ is combined with the appropriate CRF and the baseline health data for 2019 to estimate the impact for a given μ g/m^3 reduction in NO_2.

Given a non-linear relationship between a reduction in air pollution and the health outcomes, additional adjustments were made in the analysis. To account for this, logarithmic calculations were used to adjust the CRF estimates to a new concentration increment. This log adjustment value was then combined with the baseline deaths to estimate the attributable deaths caused by air pollution.

As shown by **Table 7**, two estimates were used for the CRF relating to chronic mortality which produced an upper and lower bound estimate for each city. This was because there is a degree of uncertainty on the appropriate CRF in the COMEAP 2018 report, where the Committee members had differing views as to whether a Risk Ratio of 1.013 or 1.006 was the correct value to use. Therefore, both CRFs were taken forward to enable us to produce a range of values, which can be used as part of our sensitivity analysis. When using these CRFs in impact analysis, the COMEAP report identifies a cut-off for NO_2 concentrations at 0 μ g/m^3 and 5 μ g/m^3 . However, given the analysis is assessing the impact of a change in concentration where the concentration levels are far in exceedance of the cut-offs, this did not effect the methodology.

Given the static nature of the analysis, the change in the number of deaths assumes there is no lag between exposure and the effect of cleaner air caused by the CAZ. In a dynamic analysis that accounts for demographic, policy, and economic changes over time, it would be necessary to use lifetables that account for changes in life years overtime. Therefore, while the resulting value provides an estimate of the annual change in deaths, in practice the cumulative effect of increased survival will change with the size and age structure of the population. This means that the resulting health impacts per annum will reduce over time, which a static analysis is unable to capture. Therefore, interpreting the health impacts as an annual impact should be taken with caution.

Quantifying the economic benefit

The final stage of the analysis is to quantify the health impacts of improved air quality into an economic impact. The focus of the analysis is to estimate the economic benefit of a healthier and more productive workforce to each city's local economy.

Quantifying the impact on the working population

The previous step combines the change in concentration value from Step 1 with the relevant CRF and the corresponding population and baseline disease rate data to estimate the population impact of the reduction in NO_2. This provided results on the number of deaths prevented and the reduction in hospital admissions. To understand the impact this would have on the workforce only and subsequently quantify the economic benefit, it was therefore necessary to make subsequent adjustments for the working population. A summary of the data sources and adjustments made for each of the impact channels is shown in **Table 8.**

Table 8 Data sources and adjustments by impact channel

Channel	CRF used	Data source	Adjustments
Chronic mortality	All-cause deaths, age 30+	Deaths registered in England and Wales in 2019, ONS	• An initial adjustment was required to estimate life years gained. An estimate of 11.4 average life years lost was taken from COMEAP (2018).[46] • To adjust this to working years gained, an adjustment factor was estimated by combining the share of deaths by age cohort with the employment rate.[47]
Employee absenteeism	Hospital admissions, respiratory diseases all ages	Emergency hospital admission for respiratory disease all ages 2018/19, PHE	• An additional adjustment was made to include the average length of stay in hospital for respiratory disease using PHE data by city.[48] • To adjust for the working age population, the share of hospital admissions of individuals ages 15-64 in English NHS hospitals was assumed across all cities.

Applying these adjustments to the health impacts provides two estimates relating to the working population:

- Number of working years gained due to preventing mortality within the working population; and
- Number of working days gained due to preventing hospital admissions associated with exposure to NO_2.

These estimates were then combined with a set of assumptions on hours worked each year and on a given day to provide an estimate of working hours gained.

The results for working days gained due to fewer hospital admissions should be interpreted as a minimum. The CRF estimates the number of admissions due to workers being admitted to hospital, without the assumption that a worker would usually spend time at home before and/or after hospitalisation. Time lost due to reduced productivity is also not captured in the analysis. It is plausible that a worker adversely affected by air pollution may produce less work before deciding to take sickness leave, or when returning to work after a hospital admission. Restricting the analysis to worker hospitalisations also means that we do not capture working days lost as a result of looking after children or elderly dependents who have been impacted by air pollution.

Estimating the economic benefit of workforce impacts

These workforce impacts will result in a greater level of production in the economy since workers are able to generate more goods or services each year. To monetise this impact, data on GVA, a measure of the value of goods and services produced in an economy, is combined with the workforce impacts.[49] The economic benefit of improved air quality therefore reflects the value a worker generates that goes above and beyond the additional hours worked and the wages they are paid.

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49. GVA is a measure of the additional value in the economy that is generated through the production of goods and services from using a set of inputs including labour

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