CBI Economics

Breathing life into the UK economy

Quantifying the economic benefits of cleaner air

September 2020

Commissioned by

CLEAN AIR FUND

Contents

Executive Summary

Air quality is a shared societal challenge. It matters to the health of a country's citizens and to the state of our natural environment. With better air quality businesses will benefit from a healthier workforce and more productive capital assets which in turn lead to a more prosperous economy with greater resilience to economic shocks.

The coronavirus pandemic has shown the important link between human health and the health of our economy. Businesses cannot exist without human ingenuity and the work of a healthy workforce to produce the goods and services on which we all rely. Nor can they exist without a vibrant consumer market to generate the demand to fuel their firm's income.

Improving air quality in the UK to meet World Health Organisation (WHO) guidelines could result in significant economic and social benefit. Studies have estimated that poor air quality contributes towards 19% of all cardiovascular deaths and 29% of all lung cancer deaths. These health impacts increase costs to public health services but also have a substantial economic cost. The World Bank estimates that air pollution alone cost the global economy $225 billion (approx. £180 billion) in lost labour income in 2013. In 2018 the UK missed several of its national air quality objectives which already fall behind the guidelines recommended by the WHO for 'safe' air.

£1.6 billion
economic benefit to the UK economy per year

17,000
deaths prevented per year

3 million
working days gained per year

CBI Economics analysis, commissioned by the Clean Air Fund, finds that the UK economy could benefit to the tune of £1.6 billion each year if it were to achieve the guidelines set by the WHO for air quality.

CBI Economics analysis finds that reducing mortality and disease linked to poor air quality will lead to fewer deaths, fewer work absences and less days an individual attends work ill. Not only does this benefit the individuals and their friends, families and communities, but a healthier nation brings with it important economic benefits from retaining the skills and experience of those people. The analysis by CBI Economics finds that:

- By reducing mortality and diseases linked to poor air quality, **almost 17,000 premature deaths could be prevented each year.**
- With these individuals living and working longer, **the UK could gain almost 40,000 productive years, which is estimated to provide a £1 billion economic gain in the first year** and an even larger benefit in future years as the individual is prevented from retiring early due to ill health.
- The **UK could also stand to gain an additional three million working days** by reducing morbidity associated with poor air quality.
- Due to a reduction in personal illness or that of dependents, as well as a reduction in the number of days workers go to work ill, **an improvement in air quality will reduce work absences, with the UK estimated to gain close to £600 million as a result.**
- This not only benefits the UK economy but individual workers too. Together, **fewer premature deaths and illnesses associated with poor air quality could increase UK earnings by £900 million each year.**
- Our cities and towns have a large part to play in improving air quality and the health of the UK. While densely populated areas typically have further to go to meet the WHO's guidelines, they also stand to gain considerably. Pre-COVID-19 pollution levels in London, coupled with the size of its economy and population, means **London is estimated to account for close to a third of the potential overall benefit to the UK economy.**

Aside from the human health impacts, air quality also affects the productivity of our land and natural environment. For example, affecting yields from the agricultural industry. It can also affect the performance of a firm's capital equipment, increasing maintenance costs or shortening the life of assets.

It is clear from the evidence that an improvement in air quality creates a healthier nation, which can significantly increase the productive capacity of an economy, with the benefits shared amongst individuals, business, and government across the UK. As the economy and society start to recover from the coronavirus pandemic there will be important lessons to learn about the link between health and economic resilience. A green economic recovery is now needed, where economic success goes hand in hand with a healthy nation and cleaner air.

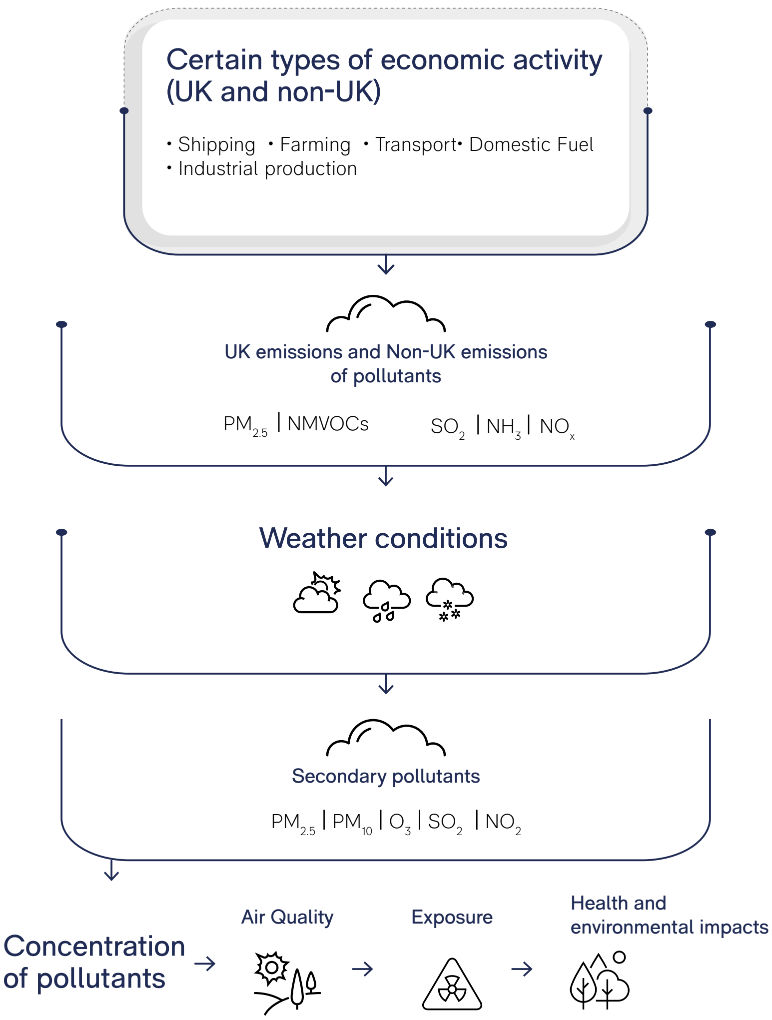
The context for cleaner air

Scientific and economic evidence present the case while ambitious targets linked to health outcomes provide the means of improving air quality.

Scientific evidence demonstrates the importance of air quality to health and environmental outcomes

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 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 found in the UK is caused by activity in the UK and from elsewhere in the world.[1]

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 (PM_{10} and $PM_{2.5}$), ozone (O_3), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2).[2] Evidence also shows that concentration levels of these pollutants in local areas are in fact more significant in contributing to adverse health and environmental outcomes than national emissions levels. Road transport from cars and lorries now poses a major threat to air quality in the UK.[3] Therefore, air quality is judged on both overall levels of emissions and the concentration of pollutants.

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 and enter the bloodstream, which can cause cardiovascular, cerebrovascular and respiratory impacts including lung cancer and heart disease.[4] It is estimated that poor air quality contributes towards 19% of all cardiovascular deaths and 29% of all lung cancer deaths.[5,6]

Evidence also shows that air pollutants contribute towards climate change, causing harm to natural habitats and ecosystems.[7,8,9,10]

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.

Poor air quality also impacts the economic health of our society

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 World Bank estimates that air pollution cost the global economy $225 billion (approx. £180 billion) 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 £2.7 billion as a result of pollutant levels in 2012.[11,12,13] Improving air quality can therefore have a range of economic benefits through the channels set out in Exhibit 2.

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:

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

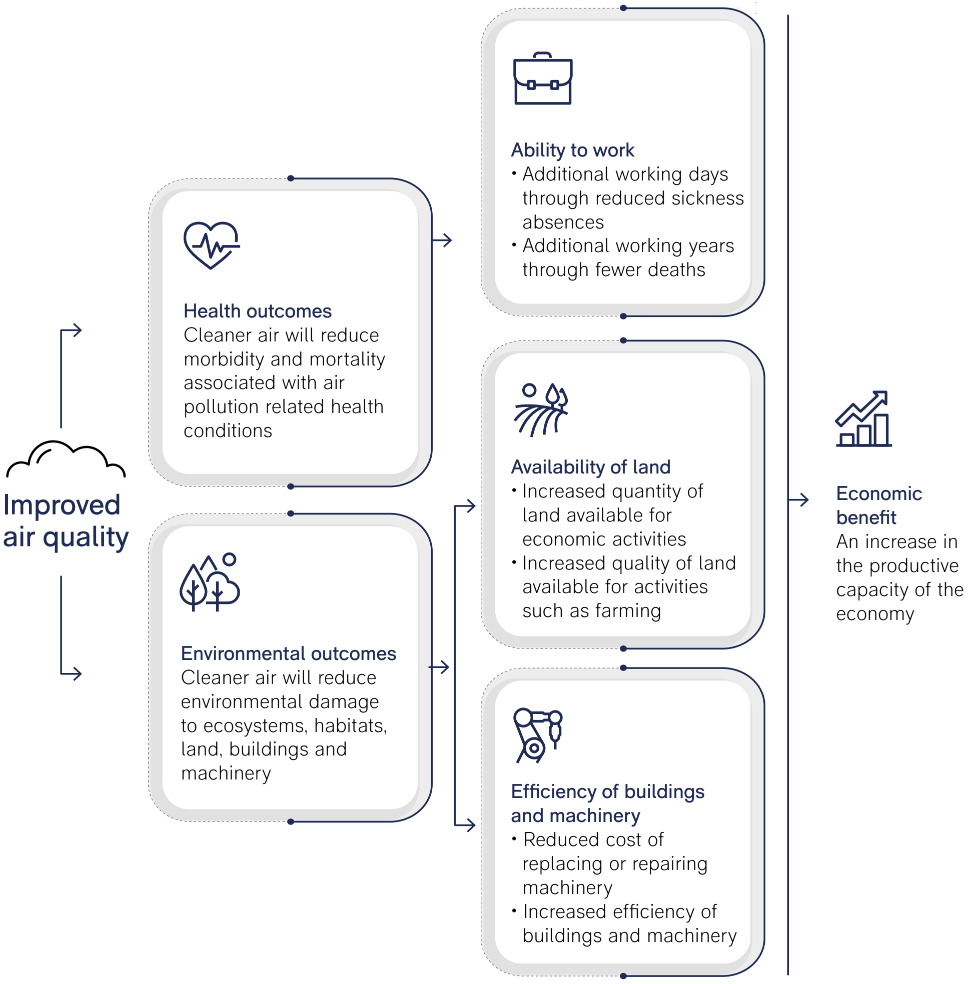
Where Y is output, P is price, Q is quantity, L is labour, K is capital and Z is land.

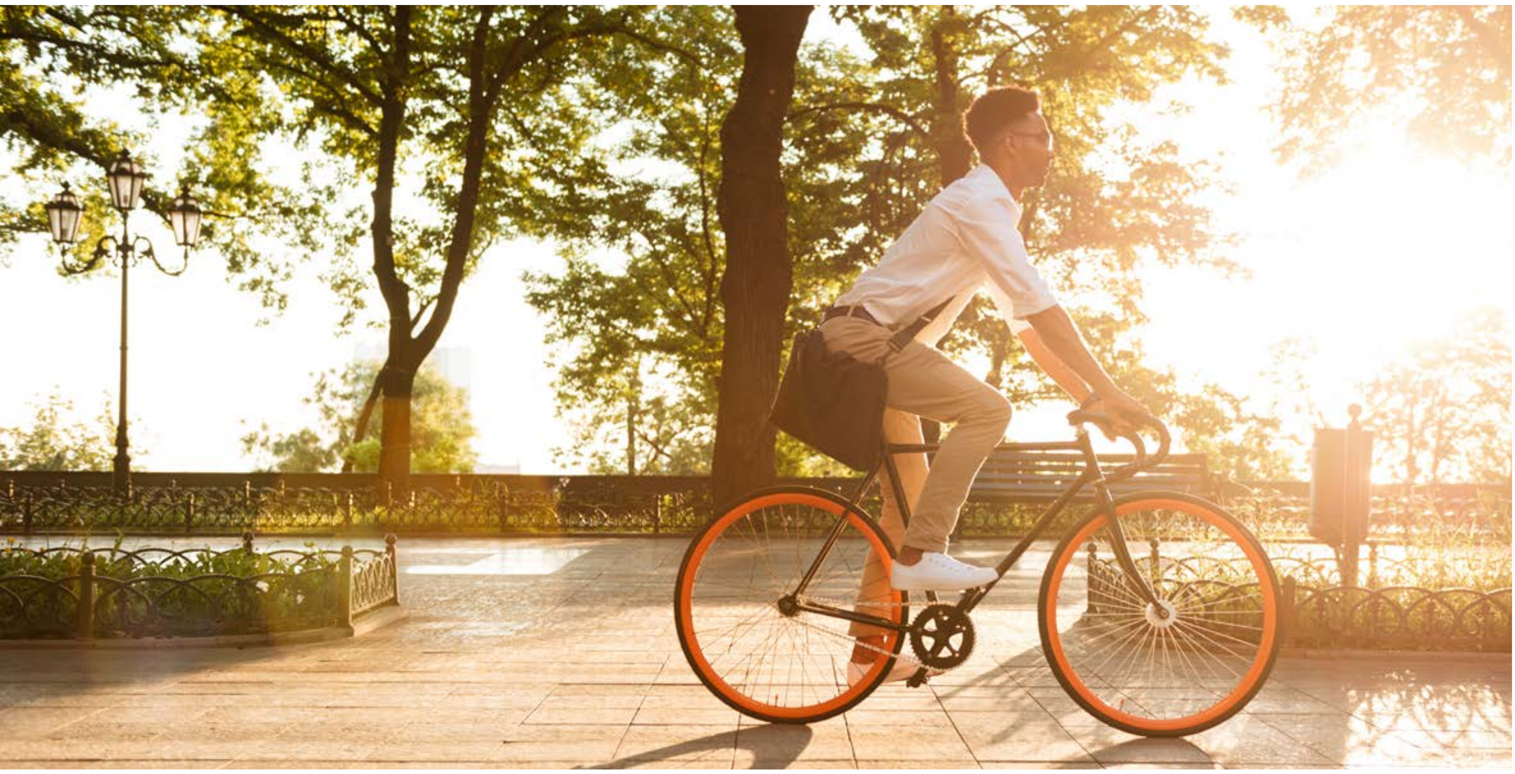
When choosing the combination of inputs to use, firms consider the cost of each factor, as well as the efficiency of that input (also known as the productivity).

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.

As well as those channels demonstrated in Exhibit 2, 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 £1.6 billion.[14] The remainder of this report focuses solely on estimating the economic benefits of improving air quality rather than providing an estimate of potential savings to public health and social services.

Exhibit 2 The links between air quality and the economy





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 thus increasing their available hours for work.[15] There is also evidence that air quality can impact an individual's concentration levels and therefore affect their performance at work.[16] 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.[17]

At the same time, a cleaner environment will increase the availability of land, as well as the useful life of buildings and machinery.[18] 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.

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.

Many countries now monitor and control air quality

The social and economic cost of poor air quality is a growing concern across the world. The World Health Organization (WHO) has set an international agenda to reduce the number of deaths from air pollution by two thirds by 2030, contributing towards several of the Sustainable Development Goals (SDGs), as well as goals set by the Paris Agreement on climate change.[19] As a result, many countries have taken steps to monitor and control air quality.

One approach taken by governments is to set emissions reduction targets for the most harmful pollutants. However, as the scientific evidence shows, reducing emissions of pollutants only goes part of the way in improving air quality as it is exposure to high concentrations of pollutants that is linked to the most significant adverse effects.[20] As a result, the UK (and many other countries) have now adopted statutory targets for both emissions and concentration levels.

In 2018 the UK was not meeting its statutory air quality objectives and would only have been compliant with one of the WHO's guidelines

The UK has statutory obligations to meet national air quality objectives and objectives set by the European Directive for concentration levels of the five pollutants found to be the most damaging.[21] In its latest assessment in 2018, the UK was in breach of several of its objectives.[22]

As part of the UK government's plan to tackle this, in 2019 the government set out its Clean Air Strategy, with the Environment Bill set to provide the legislative framework.[23] At a local level, some local authorities have also announced the introduction of clean air zones with the aim of improving local air quality. Clean air zones were due to be launched in Bath, Birmingham, and Leeds in 2020, but have since been postponed until at least early 2021.[24]

At an international level, the WHO has produced air quality guidelines that recommend nine concentration limits for the most harmful pollutants based on their latest assessment of the level of exposure most likely to lead to adverse impacts.[25] These limits set out what 'safe' air looks like and go further than the UK's current set of concentration targets. For example, the UK's concentration limit for the annual mean of $PM_{2.5}$ is more than double the WHO guideline, 25 $\mu g/m^3$ and 10 $\mu g/m^3$ respectively (where $\mu g/m^3$ is the unit of measurement for air pollution). See Exhibit 13 in Appendix 1 for a full comparison of the UK's current targets and the WHO's guidelines.

The air quality section of the Environment Bill commits the government to set a legally binding target for $PM_{2.5}$ before October 2022.[26] However, the government's ambition beyond $PM_{2.5}$ is unclear as other pollutants are not mentioned in the Environment Bill.

Exhibit 3 assesses the UK's performance in 2018 against each of WHO's nine measures according to the concentration values set by the UK's existing statutory obligations, and those recommended by the WHO. As some targets are not measured in the UK, it was not possible to make the comparison for two of the measures: the 24-hour mean for $PM_{2.5}$ and the 10 minute mean for SO_2.

Of the seven measures assessed, in 2018 the UK met five of the targets according to its existing statutory obligations, but if the target values were instead based on the WHO's guidelines, the UK would have only met one objective in 2018. See Appendix 1 for more detail on how this assessment was conducted.

Exhibit 3 UK's performance against current targets and WHO guidelines 2018[27]

Pollutant	Measure	Performance against current targets	Performance against WHO guidelines
PM_{10}	24 hour mean	✔ Met in all zones	✘ Exceeding target in 29 zones
	Annual mean	✔ Met in all zones	✘ Exceeding target in 24 zones
$PM_{2.5}$	24 hour mean	No current target	✘ Exceeding target in 40 zones
	Annual mean	✔ Met in all zones	✘ Exceeding target in 38 zones
O_3	Annual mean of daily max 8 hour	✔ Met in all zones	✔ Met in all zones
NO_2	1 hour mean	✘ Exceeding target in two zones (London, South Wales)	✘ Exceeding target in 11 zones
	Annual mean	✘ Exceeding target in 36 zones	✘ Exceeding target in 36 zones
SO_2	24 hour mean	✔ Met in all zones	✘ Exceeding target in 4 zones
	10 min mean	Not measured in the UK	Not measured in the UK

Source: Air Pollution in the UK 2018: Compliance Assessment Summary and CBI Economics analysis

Addressing the need for more evidence on the economic benefits of cleaner air

The scientific evidence and economic theory demonstrate the cost of poor air quality to human health, the environment, and the economy. However, there remains a gap in the evidence in quantifying the economic benefits to the UK economy of meeting the more ambitious WHO guidelines for air quality. While the UK is likely to have already realised some benefits by reducing emissions and concentrations to their current levels, it could go much further by moving towards the WHO guidelines of 'safe' air.

PHE finds that a 1 $\mu g/m^3$ reduction in air pollution in England could prevent around 50,900 cases of coronary heart disease and other conditions over an 18-year period.[28, 29] However, there is limited evidence in the UK regarding the associated economic benefits of preventing these health outcomes following an improvement in air quality.

A 2011 study by the US Environmental Protection Agency examined the costs and benefits of reducing emissions under the Clean Air Act following a government intervention programme and found that benefits could reach $2 trillion (approx. £1.6 trillion) by 2020 (from a program that started in 1990) at a cost of $65 billion (approx. £52.4 billion).[30,31] However, while this can provide an indication of the potential scale of the benefits, differences in healthcare systems, industry mix, population sizes and population densities often mean studies in other countries are not directly applicable to the UK.

In this context the purpose of the analysis in this report, undertaken by *CBI Economics* and commissioned by the Clean Air Fund, is to quantify the economic benefits of adopting the air quality guidelines set by the WHO to:

- Complement the existing evidence base on the link between improved air quality and health outcomes;
- Address the gap in the existing evidence base pertaining to the economic benefits associated with preventing these health outcomes in the UK; and
- Quantify specifically a scenario where improved air quality is defined as the UK meeting the WHO's guidelines for ambient air quality.

The remainder of this report sets out the approach taken by *CBI Economics* to undertake this analysis, as well as the key findings.

A methodology to estimate the economic benefits of cleaner air

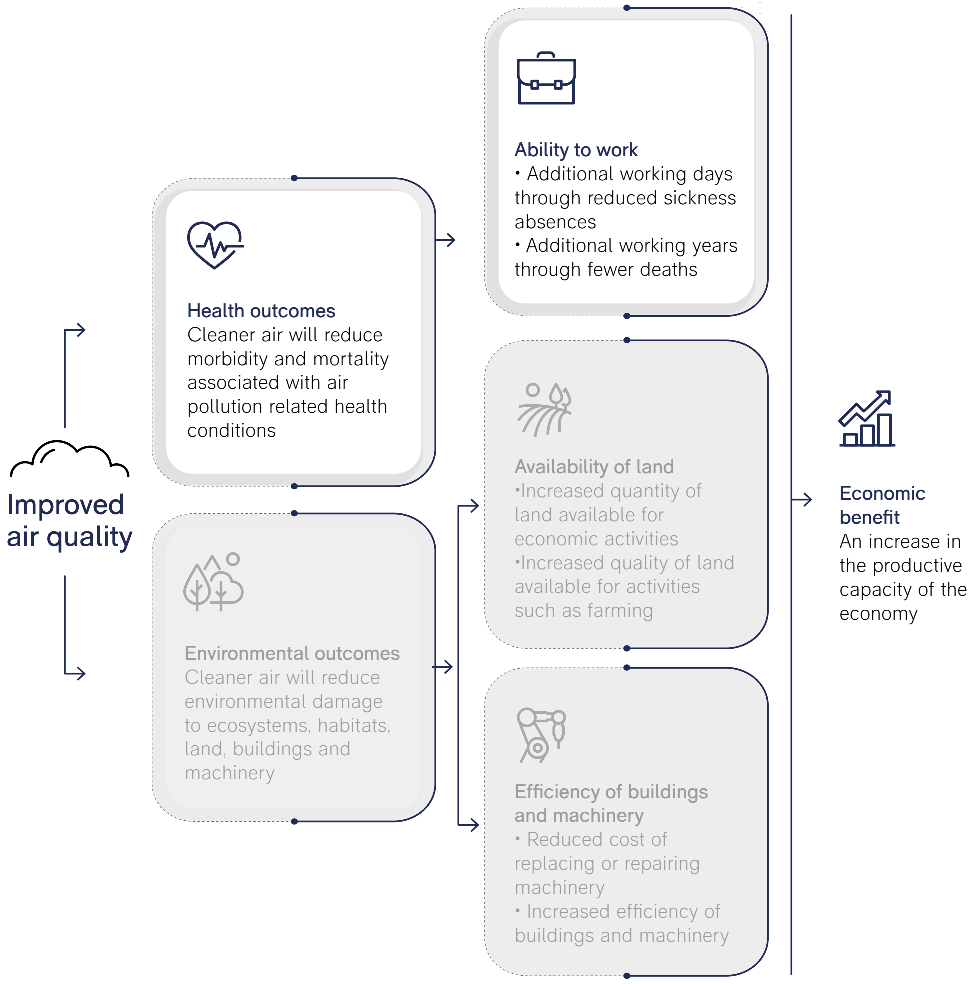
By focusing on the impact of improving air quality on the health of the UK's workforce the economic benefits of meeting the WHO's guidelines can be quantified.

Evidence is strongest for the impact air quality has on workers

While 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.

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 analysis in this report 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 quantification



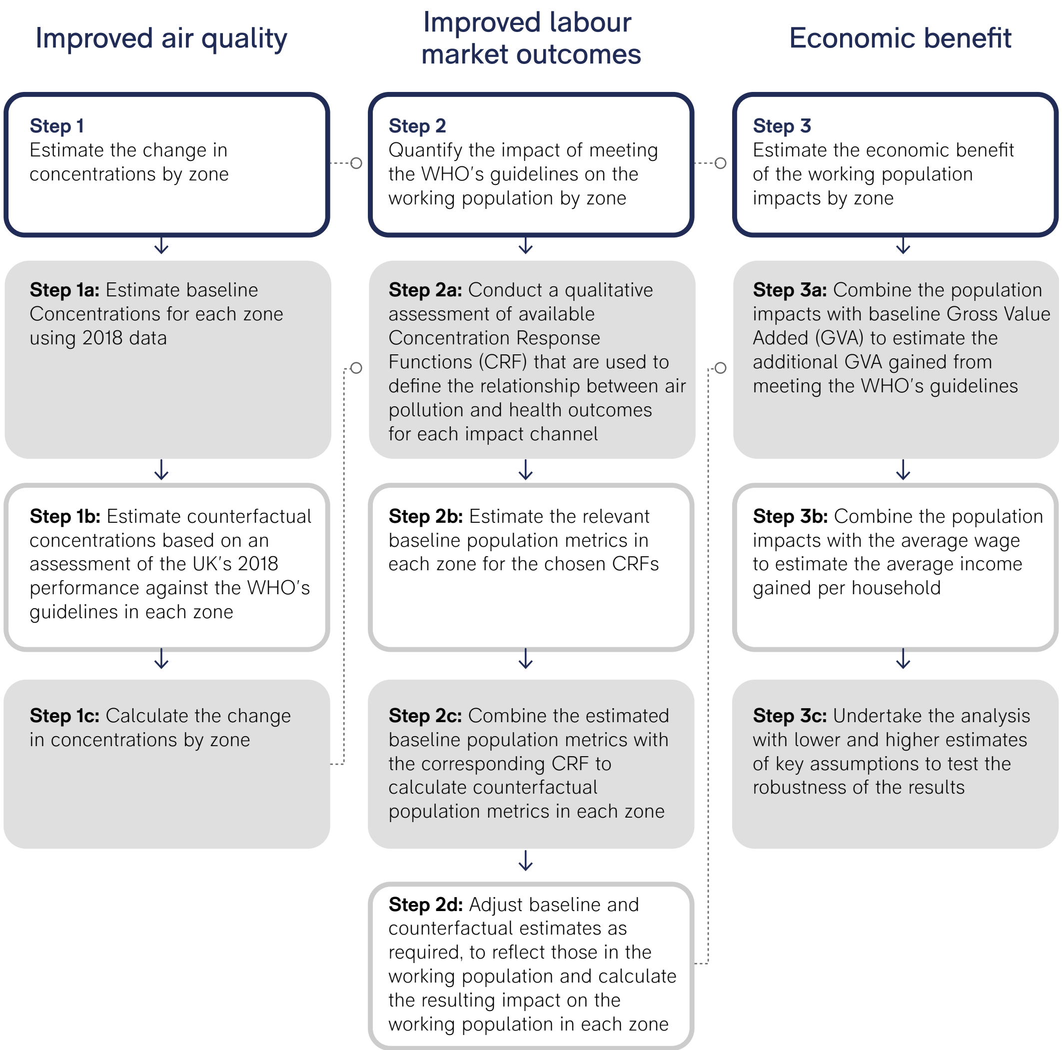
Quantifying the economic impact of reaching the WHO air quality guidelines

For the purposes of this report an improvement in air quality is defined as the UK meeting the WHO's more ambitious pollutant concentration guidelines for ambient air quality, using data from 2018 as a baseline for comparison. While both overall emissions levels and concentrations are important for understanding UK air quality, the analysis in this report only evaluates the impact of a change in concentration levels because:

- The science and health literature demonstrate that it is the concentration of pollutants that matters the most for health outcomes; and
- There is a clear gap between the UK's current concentration targets and those recommended by the WHO as demonstrated by the *CBI Economics* analysis in Exhibit 3.

To quantify the economic benefits of better air quality through its impact on the workforce, the analysis by *CBI Economics* uses an economic model that follows the three steps set out in Exhibit 5. More detail on the various elements of the methodology can be found in the appendices.

Exhibit 5 An overview of the methodology



Setting a baseline and a counterfactual

This analysis compares a baseline with a counterfactual scenario for the eight pollutant measures set out in Exhibit 3 that are currently monitored in the UK.[32] The two scenarios are defined as:

- **The baseline:** 2018 concentration values based on data availability
- **The counterfactual:** the WHO's concentration guidelines for ambient air quality in zones where the UK is currently not meeting these targets

To assess compliance with its current targets, the UK is geographically divided into 43 zones, with overall compliance based on meeting the targets in every zone. It is unclear if the UK would take this same approach in a scenario where it adopts the WHO's guidelines. However, to ensure comparability with the baseline values, the analysis assumes this would be the case and has therefore been undertaken at the zone level.

The assessment by *CBI Economics* shown in Exhibit 3 finds that in 2018 the UK would only have met one of the WHO's guidelines, the target for O_3.[33] As a result, O_3 is not included as part of this analysis. The values to be assessed are therefore the difference between the concentration value in the baseline and the estimated counterfactual values for the remaining seven pollutant measures.

Quantifying the impact on the working population

The estimated reduction in pollutant concentrations in line with meeting the WHO's guidelines will lead to an improvement in health outcomes, which in turn affects the working population. Evidence from academic studies, including Defra (2014), explains that health outcomes impact the workforce through the following channels:

- **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.[34] 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, 141 million working days were lost due to sickness absences, an average of 4.4 days per employee.[35] 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.[36] Fewer hours worked comes at a cost to business. A study by the Chartered Institute of Personnel and Development (CIPD) finds that on average sickness absences cost businesses £554 per employee each year.[37] 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 32 million 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.[38, 39]
- **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 people attend work ill 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.[40]

- **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. (2011) finding that 20% of those in the working age population with COPD took early retirement. [41]

The approach most often used in health impact assessments and cost-benefit analysis (CBA) to quantify these impact channels 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. For instance, Hoek et al. (2013) find a CRF of 6% for mortality which means a 10 μ gm^3 increase in the annual mean for $PM_{2.5}$ leads to a 6% increase in all-cause mortality.[42] A CRF was identified for each of the pollutant-health outcome combinations as set out in Appendix 2.

The CRFs are then combined with the relevant UK population data to estimate the change in the health of the UK workforce following a change in air quality. In some cases, it was necessary to adjust the results to reflect the working population. Appendix 3 provides a detailed explanation of the data sources and assumptions used for each of the pollutant-heath outcome combinations.

Estimating the economic benefit of workforce impacts

Improving the health of the UK's workforce will impact the economy through several channels. For example, fewer sickness days associated with a reduction in morbidity linked to $PM_{2.5}$ results in an increase in the number of productive working days and reduced mortality increases the working years of those individuals affected. 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 Gross Value Added (GVA), a measure of the value of goods and services produced in an economy, is combined with the workforce impacts.[43] 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.

The economic benefits of clean air

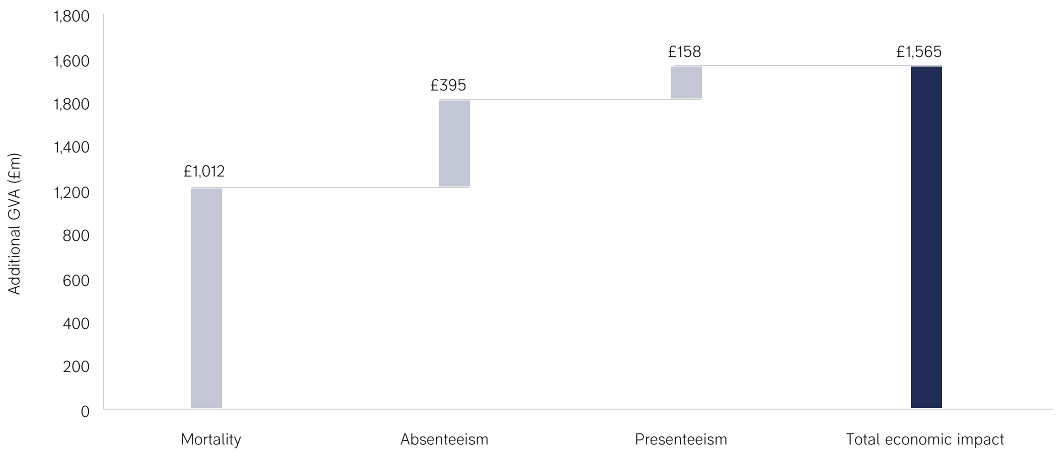
Analysis by CBI Economics finds that by preventing 17,000 deaths and providing 3 million additional working days, meeting the WHO's air quality guidelines could provide a £1.6bn benefit to the UK economy each year.

Improving air quality could generate a £1.6 billion benefit to the UK economy each year

Applying the methodology described in the previous section, analysis by *CBI Economics* finds that adopting the WHO's guidelines for ambient air quality in the UK will prevent premature deaths and reduce morbidity associated with air pollution. This reduction in morbidity and mortality increases the number of people in work, as well as the productive hours of those workers each year. Assuming full employment, meaning that these extra days and years can be put to immediate use, this increases the total production in the economy. This analysis finds that an increase in production could provide a £1.6 billion benefit to the UK economy in the first year.[44]

Exhibit 6 demonstrates how this benefit is broken down between the three workforce impact channels that have been assessed (mortality, absenteeism and presenteeism), where absenteeism includes absences due to both a worker's own illness and the illness of their dependents.

Exhibit 6 GVA impact by workforce impact



Source: CBI Economics analysis

Preventing mortality is expected to have the largest impact, at just over £1 billion. One factor driving this is that scientific evidence links mortality to several of the pollutants. As a result, the analysis in this report includes the impact of $PM_{2.5}$ on chronic mortality, and the impact of NO_2 and SO_2 on acute mortality. Consequently, reducing concentrations of all three of these pollutants will have an additive effect on the working population and subsequently on the economy. In addition, the analysis in this report assumes that where deaths are prevented in the working population, an additional full working year will be realised in the first year of impact.

City spotlight: London[45]

Analysis by *CBI Economics* finds that improving air quality in London would provide an economic benefit of almost £500 million per year to the local economy, which is just under a third of the benefit the UK would experience. This is driven by a combination of factors:

- London accounts for one of the highest shares of air pollution related deaths in the UK by region, with 8% of UK deaths taking place in the capital. The regions making up the highest proportions of deaths are the South East and East of England (12% and 9% respectively).
- London is one of the regions furthest away from reaching the WHO's concentration guideline for $PM_{2.5}$ and NO_2, two of the pollutants most associated with mortality, which is the channel that generates the largest economic benefit.
- London accounts for the highest share of the working population, with 14% of those in employment in the UK employed in London, and the highest GVA per worker which means that a given working year or day gained in London generates a larger economic benefit than in other regions.

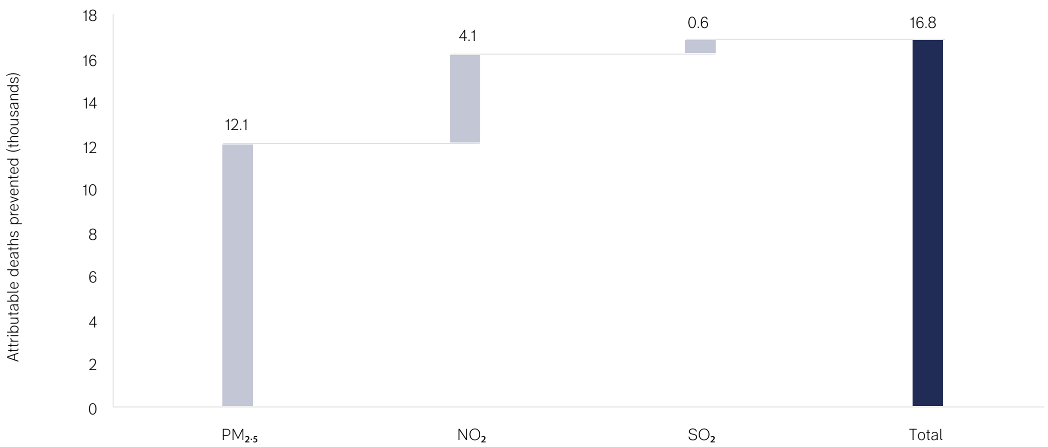
Improving air quality could prevent almost 17,000 premature deaths each year

Through a reduction in mortality from diseases linked to poor air quality, the UK could prevent almost 17,000 premature deaths each year. The scientific evidence finds that on average an additional 11.8 years of life are gained for each premature death prevented.[46]

When this is combined with data on the size of the working population, this translates to almost 40,000 additional working years gained. As the analysis in this report only considers the impact of a single year (i.e. one year's worth of premature deaths prevented) the cumulative effect to the economy over several years would be even greater.

Reductions in the concentration of $PM_{2.5}$ provides the largest impact on deaths prevented and working years gained because it is more prevalent across the UK than other pollutants. The evidence also shows that $PM_{2.5}$ has a larger impact on mortality rates than NO_2 and SO_2 (the CRF elasticity is 6%, 0.27% and 0.6% respectively).

Exhibit 7 Deaths prevented by pollutant



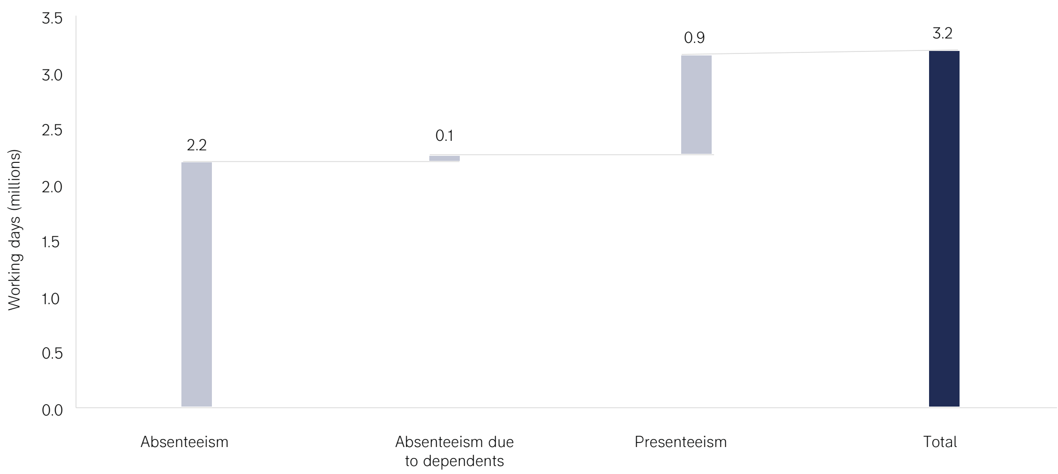
Source: CBI Economics analysis

SO_2 provides the smallest impact as the results are only based on concentration values from four zones. This is because there are only 27 monitoring sites across the UK that record SO_2 concentrations (across 20 zones), with only four zones currently missing the WHO's guideline for SO_2. This compares to 24 zones that are not meeting the WHO target for $PM_{2.5}$ and 11 zones for NO_2 based on analysis by *CBI Economics*.

Three million working days could be gained each year from better air quality

Preventing cases of acute and chronic morbidity will result in fewer absences from work due to the worker's own health or the health of their dependents, as well as fewer days where an employee attends work whilst ill, increasing the number of days where they work at full capacity. A combination of these three channels is estimated to result in three million additional working days gained each year in a scenario where the UK meets the WHO's air pollution concentration guideline.

Exhibit 8 Working days gained by morbidity channel



Source: CBI Economics analysis

The analysis in this report includes the absenteeism due to dependents channel, which Defra (2014) excludes due to uncertainty around the CRF as it is based on a US study and therefore not directly applicable to the UK. However, the analysis applied in this report is likely to be an underestimate as it only considers child dependents, and does not consider other caring responsibilities such as the elderly or other family members. It also represents just over 2% of total working days gained, and therefore is not a significant contributor towards the results.

As with the Defra (2014) study, the analysis in this report excludes the benefits of preventing early retirement. While there is likely to be an impact from this channel, there are significant uncertainties surrounding the CRF, as well as other assumptions that would be required to undertake the analysis. Therefore, this impact channel has been excluded from the total economic benefit.

Reducing concentration levels of $PM_{2.5}$ would have the greatest economic impact

As demonstrated by Exhibit 9, a reduction in concentrations of $PM_{2.5}$ is estimated to provide the largest benefit of £1.3 billion per year once the WHO guidelines are met. $PM_{2.5}$ has been linked to multiple health conditions, contributing towards many related cases and premature deaths. Concentrations of $PM_{2.5}$ can therefore impact the workforce through several channels, including chronic mortality, employee absenteeism and employee presenteeism.

In addition, scientific evidence demonstrates that increasing or reducing concentration levels of $PM_{2.5}$ has a much larger impact than other pollutants. For example, Hoek et. al (2013) estimate that a change in the annual mean of $PM_{2.5}$ of 10 units leads to a 6% change in the number of deaths in a population.[47] Whereas, Katsouyanni (2006) estimates that the same change in the one hour mean of NO_2 leads to a 0.3% change in deaths.[48]

Exhibit 9 GVA impact by pollutant

Source: CBI Economics analysis

City spotlight: Manchester[49]

Improving air quality in Manchester is estimated to generate a £28 million per year benefit to the local economy through the following channels:

- Cleaner air would reduce the number of air pollution related deaths in the workforce by 290 and generate a gain of £16 million.
- By meeting the WHO's air quality guidelines, the Greater Manchester region could gain over 80,000 working days, at an estimated benefit of £12 million.
- Almost the entirety of the economic gain comes from a reduction in $PM_{2.5}$ as Manchester has further to go to meet the WHO's guidelines for $PM_{2.5}$. This demonstrates the value that can be derived from tackling concentration levels of a single pollutant.

Large economic gains can be achieved by reducing NO_2 concentrations

While a given change in NO_2 concentrations is estimated to lead to a smaller change in deaths, the resulting change in NO_2 concentrations estimated in the analysis in this report is much larger than for $PM_{2.5}$, which is why NO_2 still provides a sizeable impact of £253 million. The assessment carried out for this report indicates that the UK would not be compliant with the WHO's one hour mean guideline for NO_2 in 11 of its 43 zones, a large increase from only two zones based on the UK's current targets.

Densely populated areas such as cities are expected to benefit the most from improved air quality

As discussed in the methodology section, the analysis by *CBI Economics* was undertaken at the zone level, which provides insight into how improving air quality could impact local economies. Of the 43 zones, there are 28 agglomeration zones based on urban areas, and 17 non-agglomeration zones. The 28 urban areas alone are estimated to account for almost a third (29%) of prevented deaths and over a third (38%) of additional working days.

As cities tend to be more densely populated than rural areas, with a larger share of the population working and resulting higher levels of economic activity, urban areas are estimated to contribute over 40% of the total economic benefit generated by improving air quality, almost £700 million.

Four cities have been considered in more detail as part of the *CBI Economics* analysis: London, Manchester, Bristol and Birmingham. London is estimated to provide the largest benefit due to its population size and the size of its economy, and because it is one of the regions furthest away from reaching the WHO's guidelines. Bristol is estimated to contribute the smallest benefit of these four cities, mainly because of its relative size in economic terms, but also because it is estimated to already be meeting the WHO's guideline for NO_2, which is a large contributor to premature deaths.

City spotlight: Bristol

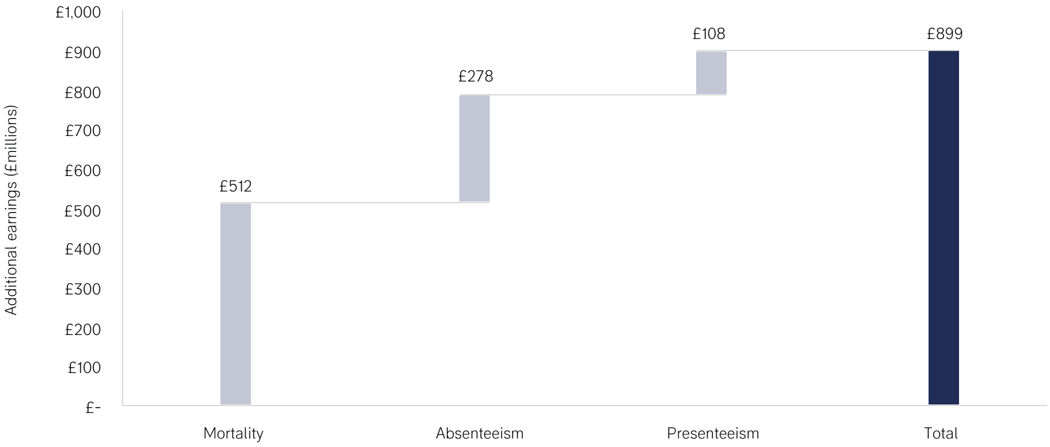
Improving air quality in Bristol is estimated to provide a £7 million benefit to the local economy every year. This benefit is predominantly driven by fewer premature deaths and fewer sickness days, with an estimated 60 deaths prevented and a gain of almost 16,000 working days from fewer work absences due to air pollution related health conditions each year.

UK workers could benefit from an additional £900m in earnings from better air quality

To understand the potential benefit to those individuals who will be directly impacted by an improvement in air quality, the analysis by *CBI Economics* estimates how additional working years and days could translate into additional earnings for employees. For instance, an employee that lives and, thus, works for a longer number of years following an improvement in air quality, will earn wages for the additional time they spend in work.

This analysis estimates that an improvement in air quality could provide an additional £900 million in employee earnings.[50] Differences in average wages earned by workers in each region, as well as its pollution levels, creates variation across regions. London is estimated to provide over £200 million of this benefit, predominantly driven by fewer premature deaths and higher average wages.

Exhibit 10 Earnings gained by workforce impact



Source: CBI Economics analysis

City spotlight: Birmingham[51]

Improving air quality in Birmingham is estimated to provide a £25 million per year benefit to the local economy. While this is similar in magnitude to Manchester, the factors driving this are slightly different. Birmingham is further away from reaching the WHO's guidelines for $PM_{2.5}$ than Manchester, which is the main contributor to the workforce impact channels that have been considered as part of the analysis by *CBI Economics*. Therefore, even though Birmingham contributes a smaller share of employment to the UK than Manchester, with a smaller proportion of the population working (43% compared to 47% in Manchester),[52] this is offset by the difference in pollution levels.

The impact of the coronavirus response on air quality

Unprecedented government action, coupled with changes in business and consumer behaviour, is having a short-term impact on air quality but the long-term implications are unknown.

The response to coronavirus has had a dramatic impact on air quality in the short-term

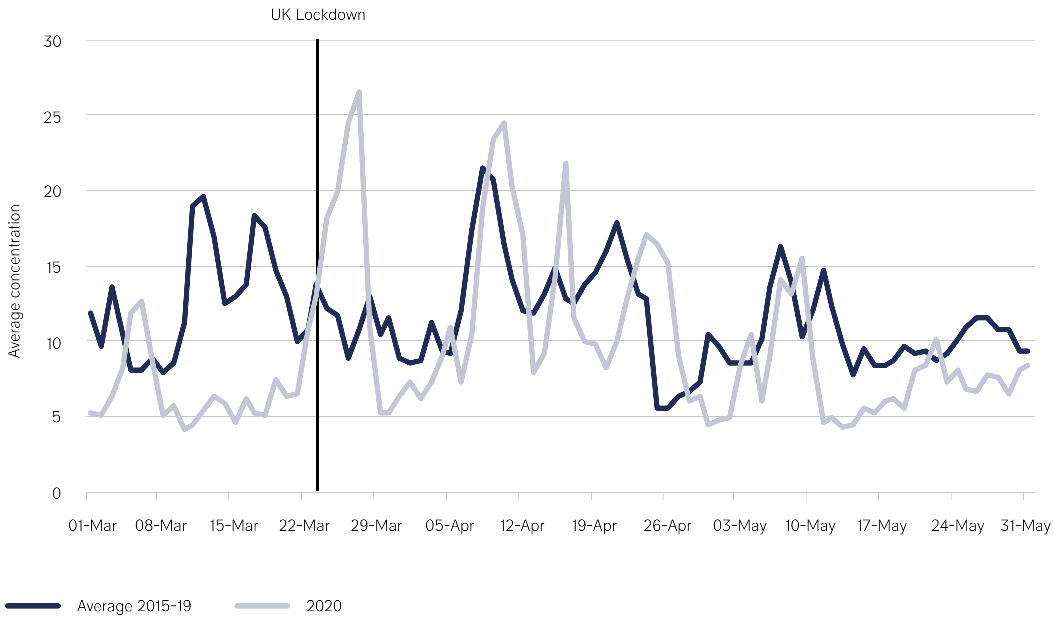
The government's response to the coronavirus pandemic has involved unprecedented action to control the virus, coupled with an extensive range of economic support measures. With large parts of the economy shut down, there has been a sharp fall in economic activity. The latest data from the ONS shows the economy contracted by 20.4% in April, the largest single month decline the UK has ever seen.[53]

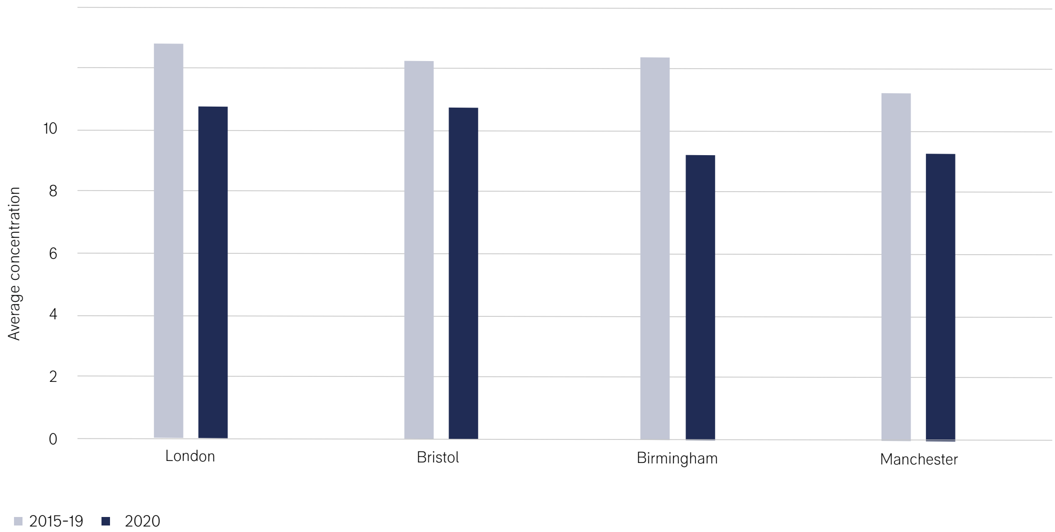
As fewer people travel to work, go shopping or engage in other leisure activities, there has been a significant observed impact on air quality in the short-term.

Data shows concentrations of pollutants have varied since the lockdown began

Exhibit 11 shows a marked spike in unadjusted concentrations of $PM_{2.5}$ as the lockdown was announced, unusual for that time of the year, followed by a sustained period of below trend levels over the month of May.[54] Across some UK cities there has also been a sharp fall in $PM_{2.5}$ concentrations compared to the average across the period 2015 to 2019. The largest drop was seen in Birmingham, with a 25% decrease in the average $PM_{2.5}$ concentration, followed by Manchester (-17%) and London (-16%).

Exhibit 11 Average $PM_{2.5}$ concentration in the UK and selected cities (1st March to 31st May)





Source: UK-AIR, Department for Environment, Food and Rural Affairs

Air pollution concentrations can fluctuate significantly because of differences in human activity and weather conditions, and therefore interpretation of this data should be taken with caution. Changes in $PM_{2.5}$ concentrations have varied across regions, making it more difficult to develop UK-wide conclusions on the link between the response to coronavirus and air pollution.

This is highlighted in a review by the Air Quality Expert Group (AQEG) who found evidence that concentrations for $PM_{2.5}$ increased in many cities during the early lockdown period (17th March to 29th April) compared with earlier in the year. However, when comparing the same period to the five-year average they find the evidence is inconclusive since $PM_{2.5}$ increased in some cities and fell in others.

The AQEG also found evidence that mean NO_2 fell by 20-30% during the lockdown, after adjusting for meteorological conditions.[55] In London specifically, a study by King's College London found that reductions in traffic have contributed towards a 22% reduction in NO_2 levels on London roads, but also noted that PM_{10} and $PM_{2.5}$ concentrations were higher after lockdown than at any time in 2020 to date.[56, 57]

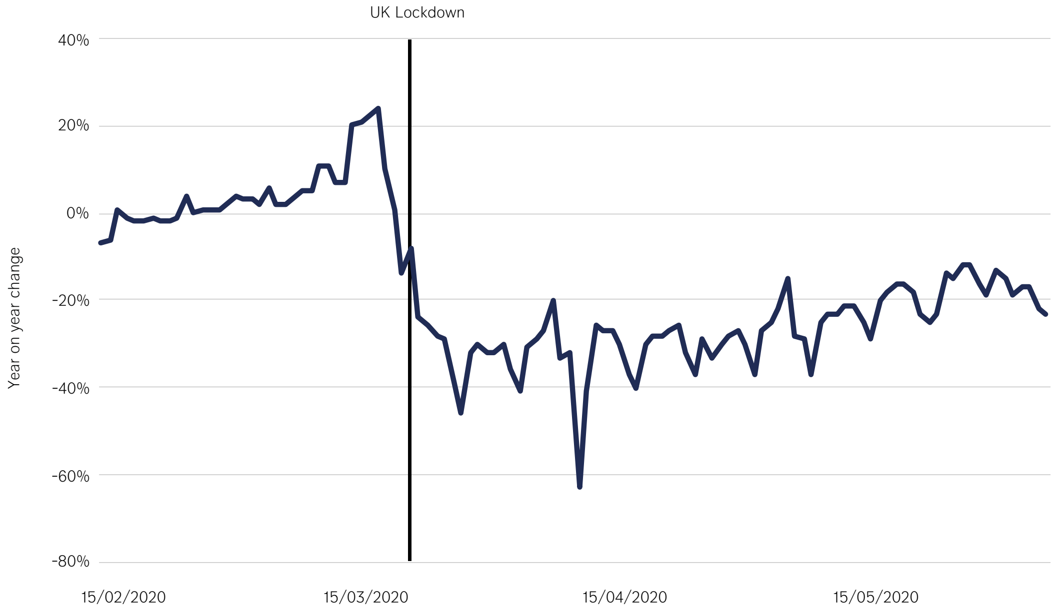
Across the EU, data shows a dramatic fall in the average concentration level of NO_2 across many capital cities in March 2020 compared to the same period in 2017, dropping by more than 50% in some cities.[58] The various reports and analyses illustrate the difficulty of determining the degree of change in pollutant concentrations during the lockdown, though all indicate a noticeable difference in urban locations.

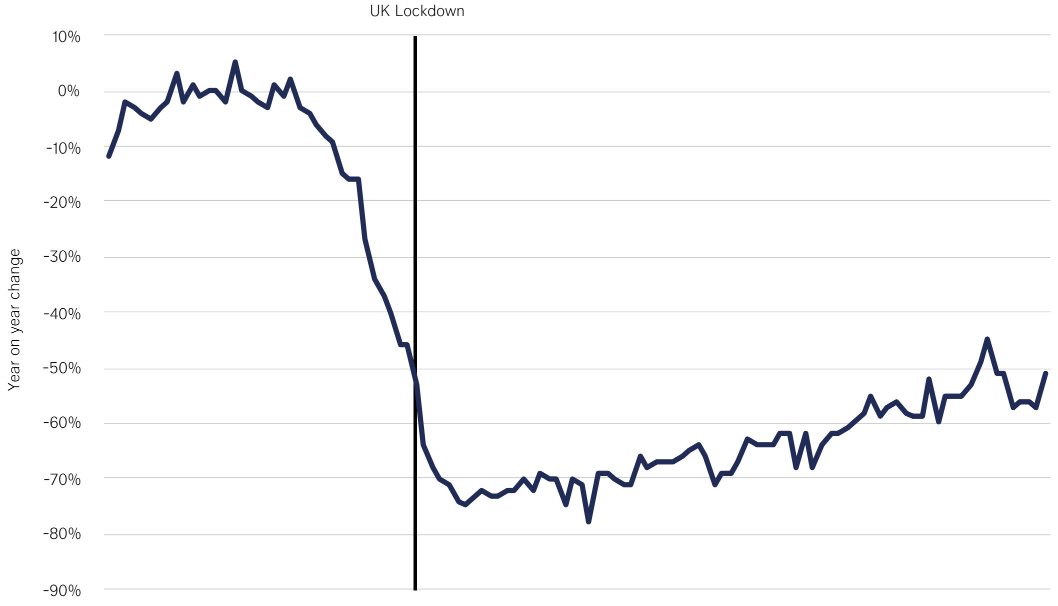
A decline in mobility and transport is likely to be a significant factor

A decline in mobility and transport following the lockdown is likely to be a significant factor in the change in concentration levels. With people less likely to use private and public transport, emissions from these sources are likely to have reduced.

Exhibit 12 shows the decline in mobility pre-dated the government's official lockdown, as measures were already in place discouraging the public from non-essential travel. The same trend has also been observed across European Cities. The Citymapper Mobility Index provides an illustrative example of changes in non-car travel across major cities, showing a steep fall towards the end of March when these cities were in some form of lockdown.[59]

Exhibit 12 UK community mobility changes





Source: Google LLC "Google COVID-19 Community Mobility Reports"

Lower emissions from businesses may also have contributed to short term changes in air quality

In addition to transportation, there are several other changes that have taken place following the lockdown that are likely to play a key role in air quality:

- **A fall in industrial production:** Pollutants are often co-emitted with carbon missions such as carbon dioxide. Recent figures show that daily carbon emissions from industrial processes, such as manufacturing and construction, fell by 68% under current lockdown measures.[60] Of the 5,316 businesses responding to the ONS's COVID-19 business survey, 25% reported they had temporarily closed or paused trading for the period 23rd March to 5th April 2020.[61]
- **Commercial energy consumption:** Research from Birmingham University found that the lockdown announcement caused an immediate 5-10% reduction in electricity demand, to levels not seen since 1975.[62] By the end of April 2020, electricity demand in the UK had fallen by a fifth.[63]
- **A fall in activity in the aviation sector:** The Department for Transport estimated air traffic in the UK fell by 92% on the same period in 2019 in the initial weeks of the lockdown.[64]

The long-term impact is uncertain, but key themes are emerging

While several factors are likely contributing towards the short-term changes in air quality, it is too early to tell what the long-term impacts will be. As industries resume operations and restrictions on the movement of individuals ease, some activities may revert to pre-COVID levels, resulting in only temporary changes in air quality. However, changes in consumer and business behaviour may have longer lasting implications.

Two areas to consider are:

- **The impact on health outcomes.** Studies are already emerging assessing the link between air quality and vulnerability to COVID-19. A Harvard study found that a 1 $\mu g/m^3$ increase in $PM_{2.5}$ is associated with an 8% increase in the COVID-19 death rate.[65] While this study does not imply direct causation, it highlights an understanding that exposure to high levels of air pollutions can risk susceptibility to a respiratory illness such as coronavirus. However, a review of emerging evidence in this area by the AQEG found that while a link between air pollution and mortality from chronic disease is generally well-evidenced, there is no consensus surrounding the pollutant responsible or the magnitude of the effect for coronavirus in particular.[66] Furthermore, a recent survey by the Clean Air Fund found that 54% think the statement 'Living in a high-pollution area makes it harder for an individual to recover from COVID-19' is true'.[67]

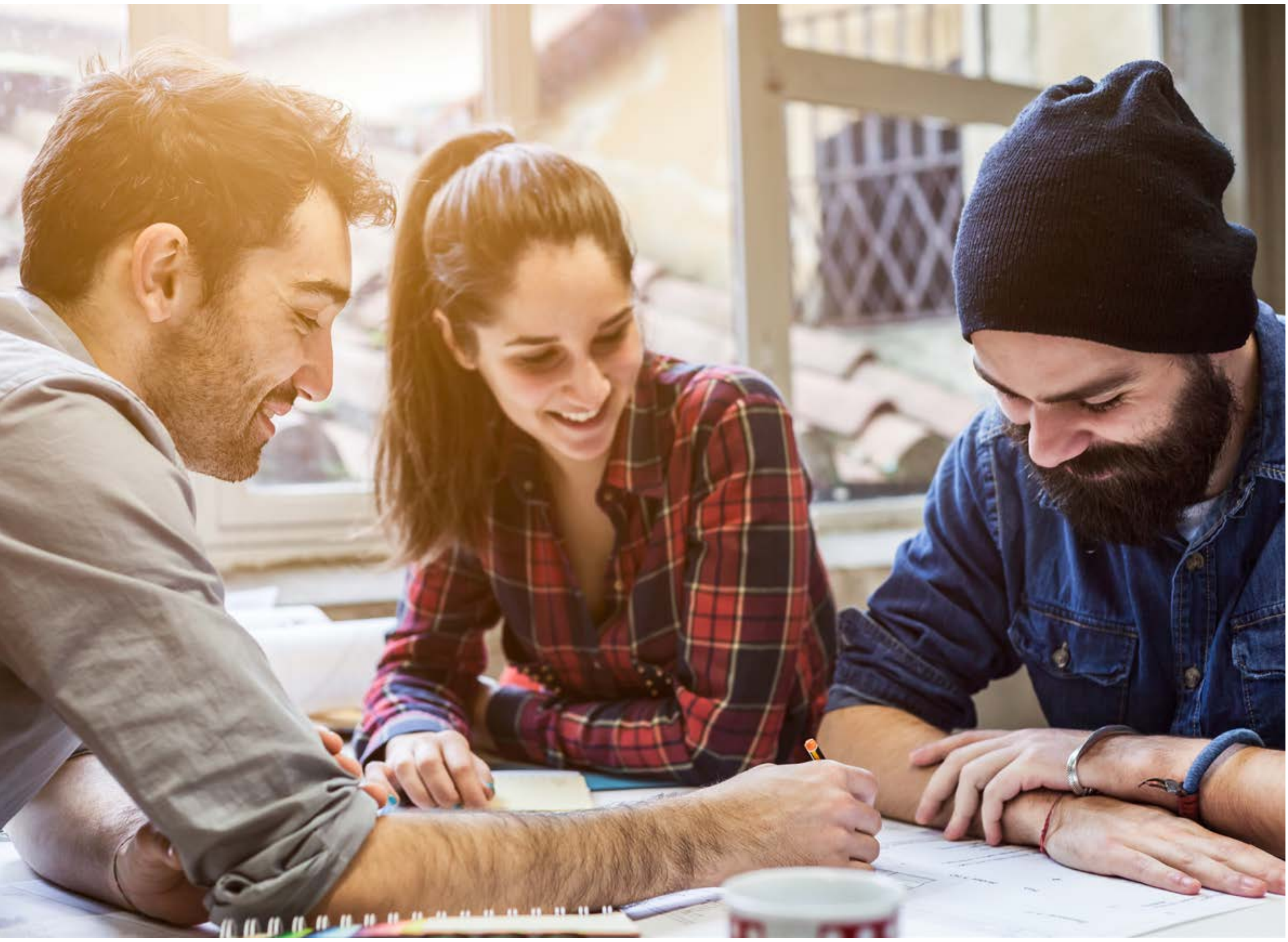
- **The material impacts on technology adoption and working practices.** While the full effect of these impacts will likely be observed over a longer period of time, there are clear indications that the lockdown has accelerated technology adoption for many businesses.[68] In addition, many businesses have been forced to change their working practices, with over 40% of the UK workforce working remotely in May 2020.[69] These changes may become embedded in workplace practices. One study finds that remote working has the potential to increase productivity by 13% and improve work satisfaction for those with a preference for remote working.[70] A shift towards home working and fewer commuting journeys would have implications for air quality, though improvements in air quality resulting from a reduction in the use of public transport could be offset by an increase in car use.

Final remarks

The analysis in this report focuses solely on the additional economic value created from an improvement in air quality rather than a full Cost Benefit Analysis (CBA). As a result, *CBI Economics* findings are a conservative estimate of the economic benefits. The analysis by *CBI Economics* does not seek to quantify the following costs and benefits that could be analysed as part of a CBA:

- **Preventing early retirement:** While there is likely to be a workforce impact from preventing early retirement from chronic morbidity, this impact channel has been excluded from the total economic benefit. Uncertainty around the CRF and the set of assumptions required to conduct the analysis is expected to result in an overestimate of the economic benefit of preventing early retirement. If the CRF and the set of assumptions set of in Appendix 3 were applied to the data, the impact from preventing early retirement could generate an additional 2,800 working years and an associated economic benefit of £167 million.[71]
- **Non-market value of mortality and morbidity:** There is a large caring and volunteering sector that is likely to benefit from improved health outcomes associated with better air quality in the same way improved health outcomes in the workforce increases business productivity. Defra (2014) seeks to capture the impact of air pollution on this sector's productivity. However, they do not include these impacts as part of their estimated impact on GDP, and they have therefore not been captured in the analysis in this report. An assessment of total welfare losses as in Ciscar et al. (2014) would be needed to capture the total economic and societal impacts.[72]
- **Abatement costs:** The cost of reducing air pollution when pollution levels are in breach of statutory obligations are called 'abatement costs'. As this study does not focus on the policy changes required to reach the WHO's guidelines, we did not factor in these costs. However, these costs would be important when producing a CBA of a set of policy actions to reach the WHO guidelines as in Vrontisi et al (2016).[73]

- **Healthcare impacts:** Improving health outcomes is likely to reduce healthcare costs, whereas a reduction in deaths could increase healthcare costs in the future as people live longer. PHE, considering healthcare costs alone, estimated that between 2017 and 2025 the total cost to the NHS and social care in England due to $PM_{2.5}$ and NO_2 is £1.6 billion.[74] These two different impacts are expected to occur over a much longer time than the analysis in this report considers, and this impact has therefore not been estimated.
- **Consumption impacts:** Improved health and labour market outcomes are expected to increase disposable incomes and as a result increase consumption, which contributes towards economic growth. In addition, improved air quality could directly impact consumption through an increase in footfall to UK high streets as the local amenity of these locations is increased. While there is expected to be an impact on consumption, evidence on these impacts is limited and would require further study. This has therefore not been considered as part of the analysis in this report



Appendix 1

Estimating the baseline and counterfactual values

The first step in the methodology requires an estimate of the baseline and the counterfactual values for each of the pollutants and their corresponding measures. The counterfactual (i.e. the alternative state of the world to be tested) is a world in which the UK is meeting WHO guidelines set out in the WHO's 2005 air quality guidelines. These are based on scientific evidence on the concentration levels that would protect public health.[75]

Unlike the WHO guidelines, the UK's current air quality targets impose a statutory obligation on the government to meet an upper limit for pollutant concentrations. Exhibit 13 sets out the WHO's guidelines and the current targets in the UK, where there is an equivalent target.

Exhibit 13 WHO guidelines and current UK targets for concentrations

Pollutant	Measure	WHO guidelines	Current UK Targets
PM_{10}	24 hour mean	50 μ g/m³	50 μ g/m³ not to be exceeded more than 35 times per year
	Annual mean	20 μ g/m³	40 μ g/m³
$PM_{2.5}$	24 hour mean	25 μ g/m³	No current target
	Annual mean	10 μ g/m³	25 μ g/m³
O_3	8 hour mean	100 μ g/m³	100 μ g/m³ not to be exceeded more than 10 times a year
NO_2	1 hour mean	200 μ g/m³	200 μ g/m³ not to be exceeded more than 18 times a year
	Annual mean	40 μ g/m³	40 μ g/m³
SO_2	10min mean	500 μ g/m³	No current target, UK current target is based on 15min mean[76]
	24 hour mean	20 μ g/m³	125 μ g/m³ not to be exceeded more than 3 times a year (24 hour mean)

To assess compliance with the UK's current targets, the UK is geographically split into 43 zones. The values are determined through a modelling exercise conducted by Defra and Ricardo based on data from the relevant monitoring sites in each zone. There are different measures for each of the pollutants to capture the differences in health risk between short-term and long-term exposure. For example, targets for PM_{10} include both a 24 hour mean (short-term exposure measure) and an annual mean (long-term exposure measure). This modelling exercise provides annual values to ascertain whether a target was reached in a given year. As a result, measured data available from UK-AIR is based on the requirements of the assessment.

Therefore, to ensure comparability between the baseline and the counterfactual values, it is necessary to assess the UK's current performance against the WHO guidelines based on concentration values for 2018. This provides an understanding of how the UK would have performed in 2018 in a scenario where the UK's targets were equivalent to the WHO guidelines. While modelled values are publicly available for some measures, for others this would require additional modelling. In these cases, the project team carried out its own assessment to estimate the counterfactual values.

The following criteria details the approach and is summarised in Exhibit 14:

- **Where modelled data is available:** The modelled data is sourced directly from Ricardo and the assessment is based on these modelled values. Modelled values are for the annual mean of $PM_{2.5}$, PM_{10} and NO_2. Modelled values for the annual mean of the daily max 8 hour mean for O_3 is available directly through UK-AIR.
- **Where modelled data is unavailable:** Modelled data is unavailable for the short-term measures and therefore requires an independent assessment. Publicly available data from UK-AIR on concentration levels at all monitoring stations for a given pollutant throughout 2018 is used. Typically, data is recorded daily or hourly and therefore requires an assessment to reach an annual value. The assessment involved the following steps:
    - The maximum concentration value in each monitoring station is selected from the time series data for 2018 as the representative measure for that single station.
    - All monitoring sites with a concentration value are then matched to their corresponding zone. If a zone contains more than one monitoring station, the maximum value from the corresponding monitoring station is selected.
    - This results in a maximum concentration value or a nil value if no station records concentrations in that zone.

This method does not consider the difference in time of day or the time of year, which comprehensive modelling would account for. It therefore assumes that, if a monitoring site recorded a concentration value above the target at any point in a given year, then the corresponding zone would be non-compliant with the WHO guideline.

Exhibit 14 Pollutants by data source and zones

Pollutant		Current assessment	Modelled (Y/N)	Data source	Monitoring sites	# zones	WHO assessment
PM_{10}	24 hour mean	Met in all zones	N	Daily mean, UK Air	84	36	Exceeding target in 29 zones
	Annual mean	Met in all zones	Y	Ricardo	-	43	Exceeding target in 24 zones
$PM_{2.5}$	24 hour mean	No current target	N	Daily mean, UK Air	79	41	Exceeding target in 40 zones
	Annual mean	Met in all zones	Y	Ricardo	-	43	Exceeding target in 38 zones
O_3	8 hour mean	Met in all zones	N	Daily max 8 hour running mean, UK Air	75	43	Met in all zones
NO_2	1 hour mean	Exceeding target in two zones (London, South Wales)	N	Hourly measurement, UK Air	157	43	Exceeding target in 11 zones
	Annual mean	Exceeding target in 36 zones	Y	Ricardo	-	43	Exceeding target in 36 zones
SO_2	24 hour mean	Met in all zones	N	Daily mean, UK Air	27	20	Exceeding target in 4 zones

Source: CBI Economics analysis

There is scarcity of data available on SO_2 for the 24-hour mean. This is due to very few monitoring stations reporting data, which subsequently results in data availability for only 20 of the 43 zones. Monitoring obligations are based on EU air quality directives and the number of monitoring sites required in each zone is dependent on the population and the background levels of pollution. If background levels are low, there may be no obligation to monitor air pollutant in that zone, which is likely the case with SO_2.

Between 1990 and 2017, SO_2 emissions declined by 95%, because of a steady reduction in the use of coal and fuel oil in all sectors of the UK economy and improved abatement technology.[77] The UK is required to publish an assessment of background pollution levels by zone and pollutant every five years in order to determine monitoring requirements. It is therefore concluded that the data provides a reasonable representation of SO_2 prevalence in the UK and would not result in an underestimation of the impact of improving SO_2 concentrations.

Appendix 2

Identifying the CRFs to use in the analysis

A range of CRFs are available in the literature and it was therefore necessary to conduct a qualitative assessment to identify the CRFs most suitable for the analysis. 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 HRAPIE project (2013) that recommends a set of CRFs for use in air pollution CBA in Europe. [78]
- A study by Defra (2014) that recommends a set of CRFs to use when quantifying the impact of air pollution on productivity.[79]

Exhibit 15 provides a summary of the pollutant measures where the WHO has set a recommended target based on the latest scientific evidence. Whilst all of these measures are important for health outcomes and, as a result, for the workforce it was not necessary to quantify the impact of each measure for reasons set out in the table. For instance, while sufficient data was available to include O_3 in the analysis in this report, it was clear that, since the UK is already meeting the WHO guidelines for this pollutant, inclusion would show no impact.

Exhibit 15 Pollutant measures quantified

Pollutant	Measure	Quantified	Rationale	Impact Channels
PM_{10}	24 hour mean	No	Evidence shows long-term exposure to $PM_{2.5}$ is a stronger risk factor for mortality than PM_{10}. There is, however, evidence of the short-term effects of PM_{10} on respiratory health. However, the CRF recommended by HRAPIE (2013) is based on asthma in children which is accounted for by the SDL CRF.	
PM_{10}	Annual mean	Yes		Retirement and dependents
$PM_{2.5}$	24 hour mean	No	$PM_{2.5}$ has been found to be both important for morbidity and mortality, with strong evidence indicating that long-term exposure is the most important in adult chronic mortality and in morbidity. Therefore, the annual mean is used for both of these channels as also including the 24 hour mean would risks double counting. Excluding this is therefore likely to produce a conservative impact of $PM_{2.5}$.	
$PM_{2.5}$	Annual mean	Yes		Absenteeism, presenteeism, and chronic mortality
NO_2	1 hour	Yes	Evidence that NO_2 can lead to acute mortality independently of PM (COMEAP, 2015; DEFRA, 2014).	Acute mortality
NO_2	Annual mean	No	No CRFs have been recommended by HRAPIE or Defra as there is limited evidence that NO_2 leads to chronic mortality independent of PM.	
O_3	8 hour mean	No	Modelled data suggests the UK is already meeting the WHO target so there will be no impact.	
SO_2	24 hour mean	Yes		Acute mortality
SO_2	10 min mean	No	10 min mean is not measured in the UK and there is currently no UK target and therefore it was no possible to include this in the analysis.	

Once a framework was set confirming the pollutants and corresponding impact channels, the next step was to identify the most appropriate CRFs to use for the analysis in this report. The wealth of CRFs available in the literature meant there were multiple population metrics to measure the impact of a change in a given pollutant. Exhibit 16 illustrates the final CRFs used with the appropriate impact channel and the relevant effect metric.

Exhibit 16 CRFs used in the analysis

Impact channel	Pollutant	Cause metric (per 10 µgm-3)	Effect metric		Source
Chronic mortality	$PM_{2.5}$	Annual average	All-cause mortality	6%	Hoek et al, 2013[80]
Acute mortality in workforce	NO_2	1-hour mean	All-cause mortality	0.27%	Katsouyanni et. al, 2009[81]
Acute mortality in workforce	O_3	8-hour mean	All-cause mortality	0.29%	Katsouyanni et. al, 2009[82]
Acute mortality in workforce	SO_2		Mortality	0.6%	DEFRA, 2020[83]
Employee absenteeism	$PM_{2.5}$	Annual average	Working days lost (WDL)	4.6%	Ostro, 1987[84]
Early retirement	PM_{10}	Annual average	New cases of chronic bronchitis	11.7%	WHO, 2013[85]
Employee presenteeism	$PM_{2.5}$	Annual average	All cause RADs	4.7%	Ostro, 1987[86]
Absence due to morbidity in dependents	PM_{10}	Annual mean	All-cause school days lost (SDL)	4%	Ransom and Pope, 1992[87]

Exhibit 17 summarises the additional CRFs which were considered but not taken forward for the *CBI Economics* analysis from the HRAPIE (2013) and Defra (2014) studies. Since only one CRF was required for a given pollutant and health outcome combination, the remaining CRFs were not included either because of the robustness outlined in the aforementioned reports, limitations with data availability on the effect metric or because of a confounding impact which can often be the case with NO_2 and particle matter.

Exhibit 17 Additional CRFs from HARPIE and Defra not taken forward

Impact channel	Pollutant	Caused metric (per 10 µgm-3)	Effect metric		Source
Employee absenteeism	NO_2	Annual mean	Respiratory hospital admissions	0.5%	DEFRA, 2020[88]
Employee presenteeism	$PM_{2.5}$	Annual mean	Type 2 diabetes incidence	10%	PHE, 2018[89]
Employee absenteeism	$PM_{2.5}$	Annual mean	Lung cancer incidence	9%	PHE, 2018[90]
Absence due to morbidity in dependents	PM_{10}	Annual mean	all cause infant mortality	4%	Woodruff, Grillo and Schoendorf, 1997[91]
Employee absenteeism	PM_{10}	Annual mean	New cases of chronic bronchitis	11.7%	Abbey et al 1995a; 1995b[92, 93] and Schindler et al., 2009[94]
Employee absenteeism	$PM_{2.5}$	Daily mean	All age hospital admission, cardiovascular diseases (CVDs)	0.91%	WHO, 2013[95]
Employee absenteeism	$PM_{2.5}$	Daily mean	All age hospital admission, respiratory disease	1.9%	WHO, 2013[96]
Chronic mortality	O_3	8-hour mean	Morality, age 30+ years	1.4%	Jerrett et al., 2009[97]
Employee absenteeism	O_3	8-hour mean	Hospital admission age 65+	0.89%	Katsouyanni et. al, 2009[98]
Employee presenteeism	O_3	8-hour mean	All ages	1.54%	Ostro and Rothschild 1989[99]
Employee absenteeism	NO_2	1-hour mean	All ages, hospital admission	0.15%	WHO, 2013[100]

Appendix 3

Data and assumptions used to estimate the impact of air quality on the working population

As described in the main body of the report, step 2 of the methodology combines the change in concentration value from step 1 with the relevant CRF and the corresponding population data to estimate the population impact of the change in concentration. In some cases, it was necessary to make subsequent adjustments to this estimate to ensure the estimate only reflects those in the working population. This depends on the form of the CRF. A summary of the data sources and adjustments made for each of the impact channels is shown in Exhibit 18.

Exhibit 18 Data sources and adjustments by impact channel

Channel	CRF used	Data source	Adjustments
Chronic mortality ($PM_{2.5}$)	All-cause deaths, age 30+	Deaths registered in England and Wales in 2018, ONS; Deaths registered in Scotland, NRS; Deaths registers in Northern Ireland, NISRA.	• An initial adjustment was required to estimate life years gained. An estimate of 11.8 average life years lost was taken from COMEAP (2010).[101] • 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.[102]
Acute mortality (NO_2, SO_2)	All-cause deaths, age 30+	As above	As above
Employee absenteeism (acute morbidity, $PM_{2.5}$)	Working days lost (WDL) due to sickness absence	Number of WDL through sickness absence in 2018, ONS Labour Force Survey	No adjustments were necessary as WDL relates directly to the working population
Early retirement (chronic morbidity, PM_{10})	New cases of chronic bronchitis	Number of people newly diagnosed with COPD per 100,000 in 2012, British Lung Foundation (BLF) combined with 2018 population data	• To estimate the share of new cases in the working population, an adjustment factor was estimated based on new cases of COPD from BLF, 2012 by age cohort • A second adjustment was necessary to reflect those workers with COPD who would retire early. Fletcher et. al (2011) provide an estimate of 20%.[103] • To adjust this to working years gained required an estimate of average

Channel	CRF used	Data source	Adjustments
			working years lost per person from early retirement. Fletcher et. al (2011) find the average age of early retirement to be 54, combined with a retirement age of 65, this provides an average off 11 years lost.
Employee presenteeism (acute morbidity, $PM_{2.5}$)	Restricted activity days (RADs)	Average RAD per person per year due to illness in 2011[104], ONS General Lifestyle Survey combined with average WDL per person per year in 2018 and 2018 employment data[105] provides a baseline for RADs-WDL	• To estimate the share of those RADs-WDL that fall when a person is in work and can therefore defined as presenteeism days, an adjustment is made based on the average share of working days each year[106] • To estimate the total working days gained from reducing presenteeism days, an adjustment of 20% is applied based on Defra (2014) who reviewed a series of studies on presenteeism and found that on average a person is 20% less productive on a presenteeism days than a normal work day
Employee absenteeism due to dependents (acute morbidity, $PM_{2.5}$)	School days lost (SDL) due to sickness	Baseline SDL is estimated by combining average school days in a year with the number of school pupils in 2018 and an absence rate due to sickness from the ONS, the Scottish Government, StatsWales and the Northern Ireland Department of Education	To capture only school days gained that will translate into working days gained, two adjustments have been made: • An adjustment for the proportion of children living in working families based on household data from the ONS Labour Force Survey, which shows in 2018 60% of children under 16 lived in working households • A further adjustment was made to account for instances where working families may have other arrangements that mean they do not need to take a day off work. This is based on an assumption of 36% from Palmer et al (2010) and Defra (2014).

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24. See: **https://www.gov.uk/guidance/driving-in-a-clean-air-zone**
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26. To note that while the WHO targets also include a target for the 10-minute mean of SO_2, this is currently not measured in the UK and therefore data was unavailable to make an assessment.
27. PHE found a 1 μ g/m3 reduction in fine particulate air pollution in England could prevent around 50,900 cases of coronary heart disease, 16,500 strokes, 9,300 cases of asthma and 4,200 lung cancers over an 18-year period.
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31. The UK does not currently monitor the 10-minute mean for SO_2 and therefore this measure is not included in the CBI Economics analysis.
32. Concentration values for O_3 are based on the modelled annual mean of the daily maximum 8 hour mean from UK-AIR, which shows all monitoring sites recorded a concentration less than the current and WHO target of 100 μ g/m³
33. ONS Labour Force Survey
34. Ibid
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40. Fletcher, Upton, Taylor-Fishwick, et al. (2011) COPD uncovered: an international survey on the impact of chronic obstructive pulmonary disease [COPD] on a working age population. BMC Public Health. 2011;11:612.
41. Hoek G. et al (2013) 'Long-term air pollution exposure and cardio- respiratory mortality: a review'; Environ Health. 2013 May 28; 12(1):43
42. 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
43. The impact of preventing mortality will also have an economic impact in future years, so the total benefit of the additional working years has been spread across the average number of working years and discounted to provide an estimate of the impact of preventing mortality in the first year.
44. The estimates for London are based on analysis conducted by CBI Economics for the Greater London Urban Area as per the zone boundaries for the UK's air pollution assessment. This area includes all London boroughs.
45. COMEAP (2010), The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom.
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47. Katsouyanni, K on behalf of the APHEA Group Aphea Project: Air Pollution and Health: A European Approach, Epidemiology: November 2006 - Volume 17 - Issue 6 - p S19
48. Manchester refers to the Greater Manchester Urban Area zone, which also includes Stockport, Bolton, Bury, Oldham, Salford, Tameside, Trafford, Wigan.
49. This is based on the average wage per worker in each of the 43 zones. The data contains gross hourly and annual mean earnings from the ONS's Annual Survey of Hours and Earnings at the local authority level.
50. Estimates for Birmingham are based on the West Midlands Urban Area zone which also includes Walsall.
51. This is based on 2018 employment and population data sourced from the ONS.
52. **https://www.ons.gov.uk/economy/grossdomesticproductgdp/bulletins/gdpmonthlyestimateuk/april2020#gdp-fell-by-204-in-april-2020**
53. The measures were calculated by taking a simple average of daily $PM_{2.5}$ concentrations across 88 monitoring sites between 1st March and 31st May for each year between 2015 and 2020 inclusive. Another average was taken of the mean values between 2015 and 2019.
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105. This is based on 225 working days from the ONS, which assuming a 365 day year provides an adjustment of 61%.

CBI Economics

This report was produced by CBI Economics and commissioned by the Clean Air Fund using modelling by CBI Economics based on input data from a variety of sources.

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