C40 Climate Leadership Initiative

Guidance Manual

Measuring the Benefits of Climate Action:
Air Quality and Health

June 2018

Overview

This manual provides a step-by-step guide for cities to work through the process of calculating the air-quality related health benefits from urban climate actions.

The guide covers:

- Reduced risk of premature death (impact on mortality) from $PM_{2.5}$ and NO_x
- Reduced air quality related hospital admissions (impact on morbidity) from $PM_{2.5}$ and NO_x

The guide is supported by a template excel spreadsheet.

Background

C40 Benefits of Inclusive Climate Action research programme

This guide for cities to measure the air quality and health benefits from climate action is part of C40's benefits research programme. The aims of C40's benefits research programme are to:

(1) Enable cities to measure the wider benefits of climate action;
(2) Make a stronger case for action;
(3) Use this to gain political and financial support for climate actions.

The benefits research programme supports cities to not only tackle the challenge of climate change but also, realise the important benefits of doing so:

- Tackling climate change - C40 Cities must deliver 14,000 actions by 2020 in order to reach net zero emissions by 2050 to achieve the Paris Agreement's ambition of a 1.5-degree world.
- The benefits of climate action - From green jobs and growth, to active, happier lives and cleaner air and water, climate actions can have an immediate and tangible impact on people's lives.

Climate, Air Quality and Health

As part of the benefits research programme, C40 and Johnson & Johnson have formed a partnership specifically looking at the benefits of tackling climate change and air pollution, with a particular focus on health impacts.

Contents

ACRONYMS AND TERMINOLOGY

AQ	Air Quality
COMEAP	UK Government Committee on the Medical Effects of Air Pollution
CRF	Concentration Response Function
CVD	Cardiovascular Disease
DEFRA	UK Government Department for Environment, Food & Rural Affairs
HRAPIE	World Health Organisation project on the Health Risks of Air Pollution in Europe
LYL	Life Years Lost
VHA	Value of Statistical Hospital Admissions
VOLY	Value of Life Years

Term	Definition	Source
μg/m³	A measure of concentration in terms of mass per unit volume. A concentration of 1 μg/m³ means that one cubic metre of air contains one microgram of pollutant.	DEFRA, UK Government
Background concentration	Concentration of pollutants not explicitly emitted by local sources, but transported into the considered area. Background concentrations will not be altered by any city action as these levels are imported.	BuroHappold | C40
Cardiovascular Disease	Disease related to the heart and circulation. Includes stroke and problems with arteries or veins in other parts of the body not just the heart.	King's College London
Concentration	The amount of a pollutant in a given volume of air. Generally expressed in microgram per cubic metre (μg/m³).	BuroHappold | C40
Concentration Response Function	A quantitative relationship between the concentration of a pollutant and an increased risk of an effect on health (in this case, mortality & morbidity)	BuroHappold | C40
Emission	Direct release of a pollutant into the atmosphere from a specific source in a specific time interval. Generally expressed in tons per year (tn /y).	BuroHappold | C40
Intervention Area	The area within the respective city that is being directly affected by the implementation of a city-action. Defining the boundary of this area will range dramatically depending on the type of action being deployed - for example, the area of a Low Emission Zone, or the combined area of new BRT corridors.	BuroHappold | C40
Life Expectancy at Birth	A valid and meaningful expression of mortality effects for both the impact of reduced pollution and the burden of current pollution. Note this is incomplete as an expression of the mortality effect in the current population as it does not cover effects on other ages.	BuroHappold | C40
Life Years Lost	Life Year represents one year lived for one person. Usually added up over the population and a specific duration, allows quantification of changes in timing of deaths. Life	BuroHappold | C40

	Years Lost is a result of deaths and represents the population mortality burden.	
Life-Tables	Tables which show, for each age, the probability that a person will die before their next birthday (is given by 1 year age groups).	COMEAP
Morbidity	Rate of disease in the population	BuroHappold | C40
Mortality	Number of deaths in the population	BuroHappold | C40
NO_2	Nitric oxide (NO) is mainly derived from road transport emissions and other combustion processes such as the electricity supply industry. NO is not considered to be harmful to health. However, once released to the atmosphere, NO is usually very rapidly oxidized, mainly by ozone (O_3), to nitrogen dioxide (NO_2), which can be harmful to health	DEFRA
Non-Background Concentration	The non-background concentration represents the total portion of pollutants that can possibly be impacted by a city action. This value is calculated by subtracting the background from the average concentration – what remains indicates the city's contribution to its average pollutant levels.	BuroHappold | C40
NO_X	NO_2 and NO are both oxides of nitrogen and together are referred to as nitrogen oxides (NOx)	DEFRA
Number of Attributable Deaths	A valid and meaningful way of capturing some important aspects of the mortality burden, across the whole population in any one particular year, of current levels of pollution, if we set aside some of the complexities of how quickly air pollution affects mortality risks. To emphasize that the number of deaths derived are not a number of deaths for which the sole cause is air pollution, we prefer an expression of the results as "an effect equivalent to a specific number of deaths at typical ages". It is incomplete without reference also to associated loss of life. The Committee considered it inadvisable to use annual numbers of deaths for assessing the impacts of pollution reduction, because these vary year by year in response to population dynamics resulting from reduced death rates.	COMEAP

PM	Particulate Matter - Collection of solid and liquid particles found in the air.	BuroHappold | C40
PM_{10}	PM_{10} is defined as the mass concentration of particles of generally less than 10 µg aerodynamic diameter. This fraction can enter the lungs. PM_{10} includes $PM_{2.5}$.	COMEAP
$PM_{2.5}$	$PM_{2.5}$ is defined as the mass per cubic metre of airborne particles passing through the inlet of a size selective sampler with a transmission efficiency of 50% at an aerodynamic diameter of 2.5 µg. In practice, $PM_{2.5}$ represents the mass concentration of all particles of generally less than 2.5 µg aerodynamic diameter. Often referred to as fine particles. This fraction can penetrate deep into the lungs.	COMEAP
Respiratory Disease	Diseases related to the lungs.	King's College London
Total Population Survival Time (life-years gained or lost)	A valid and meaningful way of expressing mortality effects of both the impact and burden questions, and is the most comprehensive way of capturing the full effects. There are difficulties in communication. The concept of a 'life-year' is not a difficult one to grasp, but it is difficult to interpret the very large numbers of life-years involved in total population survival. However, it is the most relevant index for policy analysis.	COMEAP
Value of Life Years	The monetary value of a year of life lost. It is based on studies that assess the willingness to pay for reducing mortality risks associated with air pollution	King's College London
Value of Statistical Hospital Admissions	The monetary value of a hospital admission	BuroHappold | C40
Whole City Area	The area of the entire urban scale within which the specific action is taking place. Usually determined by urban municipal boundaries.	BuroHappold | C40

The Analytical Process

The analytical process will be covered in three parts:

Part A will focus on planning the analysis in the specific context of your city, identifying actions and benefits that are appropriate to your policy aims. We advise following a simple decision-making process that will help you determine how best to conduct your analysis.

Part B will cover the concepts relating to the analysis itself, describing the interrelations between the various components of the causal chain, or 'action pathway' – action, outputs, outcomes, and impacts. The analysis follows five consecutive stages:

1. Defining an action in terms of its key parameters (action)
2. Determining what the air quality change will be (output)
3. Linking the air quality change to health changes (outcome)
4. Determining what the health changes will be (benefits)
5. Considering ways to monetise health outcomes (benefits)

Part C provides a step-by-step guide to calculating the benefits using the spreadsheet tool provided. Formulas will be explained and any specific issues around units or data will be captured in this section.

A. Planning the Analysis in Context

Before you start collecting and analysing data it is important to make sure the analysis is appropriate for the specific context of your city, and that it will deliver the results you need to drive more climate action.

This section provides simple steps that will help you:

- Understand the process before starting
- Assess the data you need for the analysis and whether this is available
- Plan the specific methodology and define action
- Consider which benefits to measure – what will most influence decision-making?
- Filter actions - check that the action will have the desired impact

Understand the overall methodology from data inputs to health outcomes

Understanding the overall methodology for calculating health benefits is a critical first step in planning the analysis that you will undertake. The methodology is summarised here and set out in detail in the next sections; make sure you read and understand the whole process before you start data collection and analysis.

Identify the action pathway that you want to measure

Draw a causal chain to map out all the outputs and benefits that may result from your action. Then identify which are the priority benefits that will be most useful to measure. Consider:

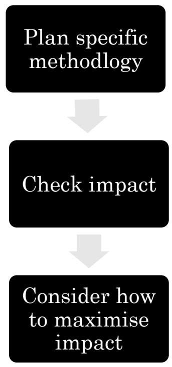
- Does the analysis address key city challenges or deliver city objectives?
- Who are the key stakeholders? What are their priorities? Are we measuring the benefits that people care most about?

Assess the data needed and available

Once you understand the process think about what data you will need, what data you have or are likely to be able to obtain and what data is not available. Consider whether data gaps can be filled with proxy data from similar actions in your city or elsewhere. Based on this, assess if the analysis you want to undertake is likely to be feasible.

- Use the causal chain to help identify what action, outputs and benefit data you need
- Discuss with your team, other departments and other organisations to identify all the data available

Plan the specific methodology and check impact

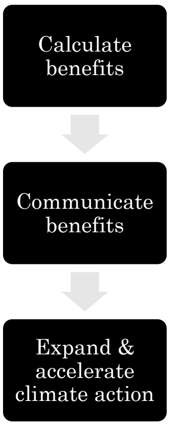


Once you have identified the action, priority benefits, and data available, you should plan the <u>specific</u> methodology you will use. Clarify exactly how the action will be defined, set out data collection, look ahead to how you will present the findings, who to and why. Consider which health outcomes can remain in their raw state (i.e. deaths averted), and which will need to be monetised (i.e. value of hospital admissions averted).

Finally, before you undertake full data collection and analysis, undertake a high-level sectoral analysis to check the potential level of impact - see the example on the following page.

Consider if the results of your high-level analysis represent a positive and tangible outcome and whether the action could be scaled-up. For example, would it make more sense to evaluate it for local- or city-level impacts? How might this compare to other urban actions competing for funding?

Calculate and communicate benefits



Now you are ready to collect and analyse data. Once you have obtained the results make sure you use them to help drive more climate action!

Creating an action plan will help better articulate the roadmap for using these results to drive action. Within such a plan, you should seek to cover:

- Any further data analysis required
- Knowledge sharing with the wider team and parallel departments / private entities
- Identifying barriers to communication / implementation
- Gaining political and financial support for action and scaling-up that action

Example high-level sectoral analysis

Municipal bus-fleet fuel efficiency upgrade	**Data**	**Potential Source**
Number of buses upgraded	1,200	*Add source*
Total number of buses in use	2,400	*Add source*
Transport emissions as a share of total city/region emissions	70%	*Add source*
Road-based transport as a share of all transport emissions	70%	*Add source*
Bus fleet as a share of road-based transport	10%	*Add source*
Proportion of bus fleet being targeted by specific action	50%	*Add source*
Maximum possible reduction in emissions from upgrade	50%	*Add source*
Maximum possible change in emissions arising from action at city-wide level = 0.7 x 0.7 x 0.1 x 0.5 x 0.5 = 0.01225	**1.23%**	*Add source*

This represents a positive and tangible outcome, but could the action be scaled-up? Would it make more sense to evaluate it for local-level impacts? How might this compare to other urban actions competing for funding?

For example, scaling-up could involve more buses being upgraded and/or upgrading these buses to electric rather than just cleaner fossil-fuel standards. Moreover, speeding-up becomes a key element here also, where mobilising action quicker will also help accrue the environmental, social, and economic benefits more immediately.

In order to achieve maximum health benefits and incident economic gains, these questions around scaling-up become fundamental. Where possible, cities should look to visualise the 'scaled-up' scenario as early as possible, so that the "end goal" becomes an initial aim rather than a secondary thought.

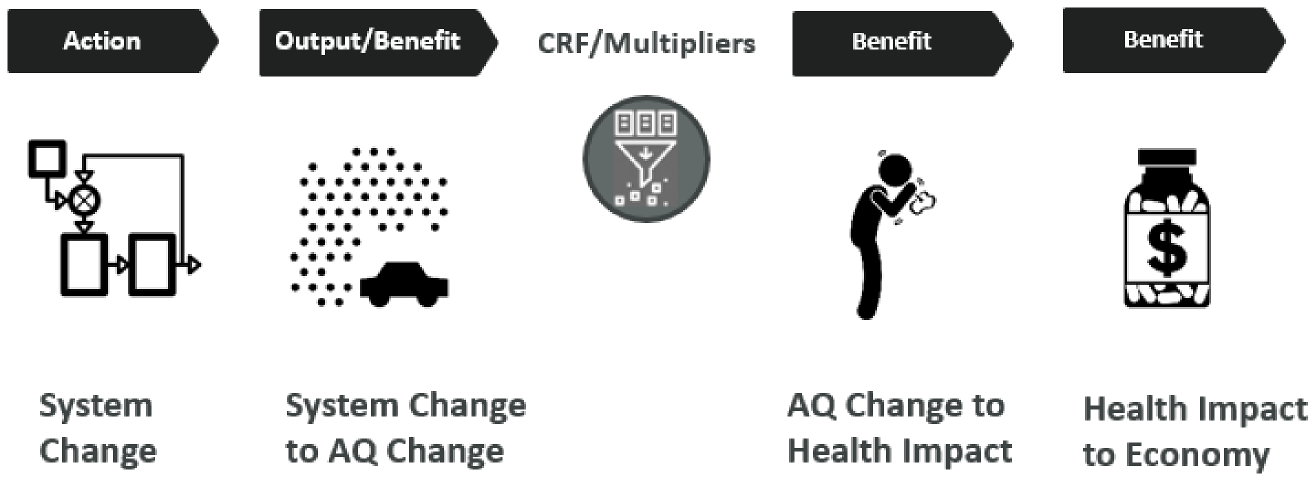
B. The Analytical Process

This section provides an overview of the analytical process to evaluate the air-quality related health impacts from urban climate actions.

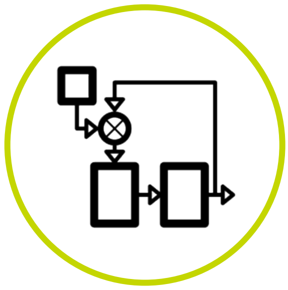
In order to measure impacts of a given action, it is important to understand the links between action, outputs, and benefits. This section will summarise the interrelations between the different elements of the calculation process – system change (action), air quality change (output/benefit), health outcomes (benefits), health impact to economy (benefits)

Process

This diagram summarises the analytical process:



Defining the system change



SYSTEM CHANGE

System change refers to a change in the main elements of the system or systems related to the action being measured. For example, introducing a 'low emission zone' may trigger changes in the city's travel system including: reductions of the number of cars on the road, changes to citizens' travel behaviour, initiatives to encourage alternative (public) transport modes, etc.

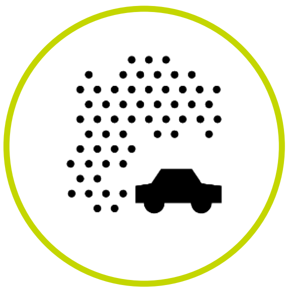
Understanding system change requires careful consideration of how the action will impact on other elements of the system or other related systems.

An important step is to determine how three different action-related scenarios might be defined. For this project we are using the following terms:

- **No action** scenario
- **With action** scenario
- **Enhanced action** scenario

It is important to state that the difference between the 'no-action' scenario and the 'with action' scenario is the most effective way of determining the impact of implementing the action. We can use the enhanced action scenario to determine the potential value of scaling-up the action.

From system change to air quality change



AIR QUALITY CHANGE

Once the system change is understood, the air quality impacts caused by these changes can be measured.

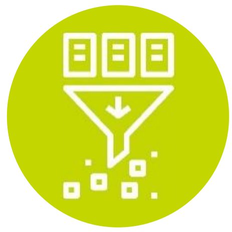
Changes in air quality can be quantified in both emissions and concentrations. The concentration of a given pollutant in the environment is a function of multiple factors including climatic conditions and all sources of emissions.

Within this study we are primarily concerned with $PM_{2.5}$, and NO_2. This is because changes in these pollutants carry the most significant impacts in terms of health outcomes. For each of these pollutants, there will be multiple sources located both in the city and in the surrounding region. Concentrations arising from sources outside the city can be significant and are termed background concentration.

A fall in emissions from an urban system will normally lead to a commensurate fall in concentration levels but only as far as the background levels. It is important to know the "without action" concentration levels for this analysis, in order to recognise the 'before and after' situation.

From air quality change to health impact

Selecting a concentration response function (CRF)



CONCENTRATION RESPONSE FUNCTION

The link between the change in air quality and the health impact is represented by what is termed a 'concentration response function' (CRF). CRFs are established through epidemiological studies and define a predicted change in a specific health risk in response to a change in the concentration of a specific pollutant. Thus, selecting the appropriate CRF will depend on the availability of:

- Concentrations data for specific pollutants
- Underlying population health-risk data

The CRFs used in this study link changes in concentrations of NO_2 and $PM_{2.5}$ with changes in risk of premature death/mortality (from all causes) and cardiovascular and respiratory hospital admissions (as measures of risk of disease/morbidity).

Applying the selected CRF

HEALTH IMPACT

Once the appropriate CRFs have been selected, they need to be applied to the baseline population health data in order to:

- Define a change in risk (due to the change in AQ)
- Estimate the change in death/mortality and disease/morbidity in the population.

Life-tables are used to calculate the changes in risk and the number of people suffering from a disease by gender and age group for a given population. Recognising these differences becomes crucial in order to fully realise the impacts of AQ changes across population demographics.

Health benefit monetisation

MONETISATION

In the last step of the process, the city may wish to evaluate wider economic and financial benefits deriving from the identified health impacts. The impact from mortality can be monetised by multiplying the avoided Life Years Lost (LYL) by the Value of a Life Year (VOLY). The impact from morbidity can be monetised by multiplying the hospital admissions averted by the Value of a Statistical Hospital Admission (VHA).

C. Calculating the Benefits

Having described the overall analytical process in Parts A and B, Part C is dedicated to step-by-step guidance through the measurement process using the 'Calculation Template' excel spreadsheet that has been provided.

Please note it is vital that you record your assumptions regarding the data you are using when progressing with the analysis. This may include:

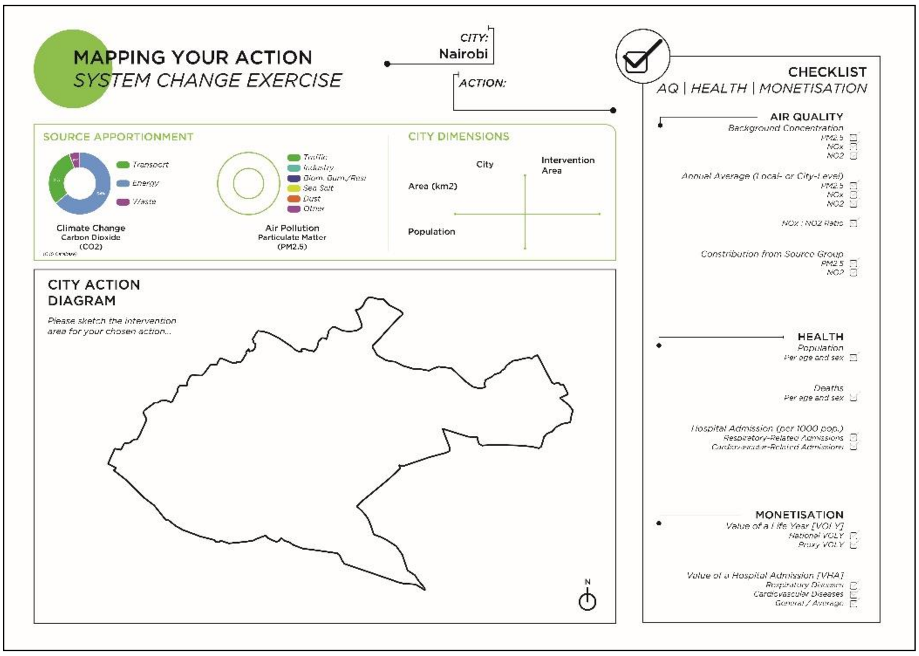
- **Data:** Date of the study (that the data is taken from).
- **Source:** Source of the data (reliability, rigour, etc.)
- **Manipulation:** Any manipulation you may carry out to get the data in the correct format, i.e. unit conversion, weighting, etc.
- **Proxy Data:** Caution and rigour when using proxy data is key. Please also record the uncertainties you can identify in using the specific proxy data.
- **Transparency:** Transparency is vital when using different data sets and from various sources, as it logs accountability for the various data points. Therefore, any further queries over that data point is traceable.
- **Communication and Collaboration:** Cross-departmental communication and collaboration to unlock and validate data sets.
- **Best Available Data:** Perfect data does not exist and there will always be data gaps and limitations. Cities should use the best available data they have and record uncertainties and assumptions. There will always be data gaps and limitations, cities should undertake analysis with the data they have and sensible proxy data. At the same time, we should of course work to improve available data, and we encourage cities to work in parallel to improve data collection and address key data gaps.

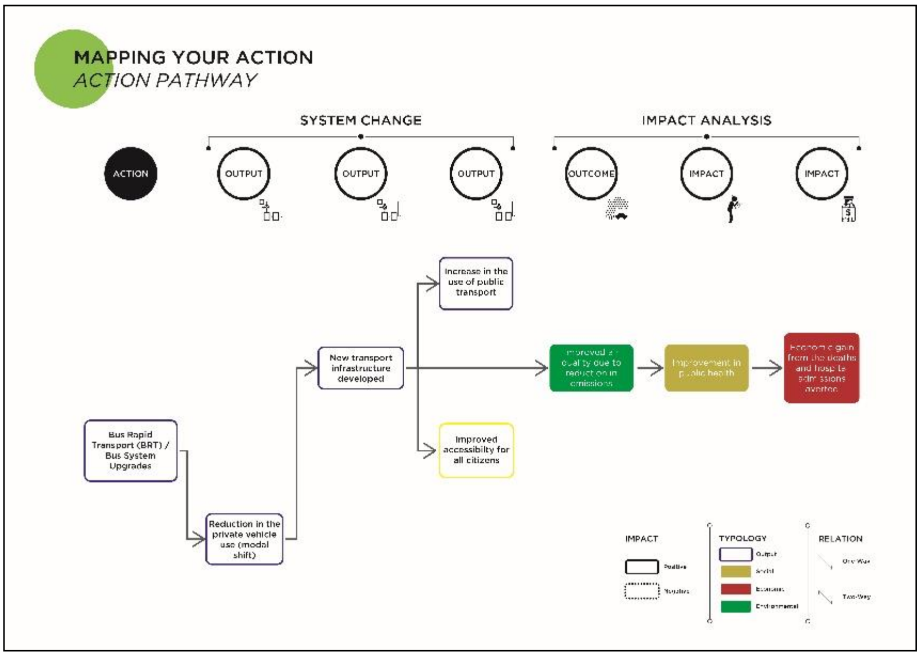
Defining the system change

Defining the system change is the fundamental first-step in the analysis process, and it will involve unique considerations for each city and each action.

In order to simplify and clarify this process, a canvas has been designed to capture the understanding of the system change. It is encouraged that the canvas is completed collectively through a multidisciplinary/cross-departmental team. Below is an example of the canvas.

For the spreadsheet tool, it will be essential to arrive at a measurement of the change in activity, and therefore the emissions associated with the action.





Calculating air quality change

Once the system change has been identified, it is crucial to evaluate its impact on AQ. This section aims to guide the city through the essential steps to quantify AQ change, by calculating the difference between 'expected levels of pollutant concentration', before, and after the action has been implemented. The specific pollutants under consideration in this example are $PM_{2.5}$ and NO_2.

Because each pollutant results in different health outcomes, and will respond differently to a given climate action, $PM_{2.5}$ and NO_2 will be analysed in different tabs.

Please note that in this part of the analysis there are two key data inputs which require careful consideration. These include (for each pollutant):

- Average Concentration (City/Intervention Area)
- Background Concentration (City/Intervention Area)

When selecting a data point for these pollutants it is important to understand how and where the data was collected from as the results can be significantly different. Sensors where readings are taken from can be located in various parts of the city (i.e. roadside, parks/public spaces, residential areas, transport hubs). It is therefore vital when selecting average concentration to take readings from the most representative sites in relation to the intended action.

Pollutant data may be available in your city in a number of different formats and units. Please ensure you use a robust conversion factor if using other units. These may also vary depending on the context. Examples of different formats may include parts per billion (ppb) instead of Microgram per Cubic Meter (µg/m³), or measuring $PM_{2.5}$ emissions in 'opacity'.

Equally, for data regarding background concentration, it is vital to ensure that the background data is representative of the real/true background concentration value for the city and does not include a materially higher or lower value.

Ensuring accuracy and rigour when selecting this data is fundamental. The most significant benefits from a given action can be felt through the change in *non-background concentration,* (average concentration deducted from the background concentration). This value is particularly sensitive to inaccuracies as it strongly correlates with the change in health impact and ultimately economic benefits.

It is therefore advisable to choose the pollutant data carefully and consider the location of sensors where readings are derived from. It is also advisable that these measures are tested and validated by relevant experts in your team.

The following steps, will allow the city to fill out the first section of the spreadsheet.

For $PM_{2.5}$

Step 1: Measure Baseline (Whole City)

To fully understand the impact of the selected action, pre-action data needs to be compared with post-action data. Pre-action data represents the baseline scenario and provides a measure of $PM_{2.5}$ concentration before the action is implemented.

Baseline data is collected on a city-wide scale, and refers to a pre-action year. Input your pre-action data:

- Total city area, expressed in km^2
- Average $PM_{2.5}$ concentration in the city, expressed in $\mu g/m^3$
- Background $PM_{2.5}$ concentration, expressed in $\mu g/m^3$
- Non-background $PM_{2.5}$ concentration (city-wide), expressed in $\mu g/m^3$
- Contribution to total concentration from source group, expressed in percentage. The source group could be roads, industry or, more generally, the representative sector from each action.

If your city doesn't collect $PM_{2.5}$ data, you can obtain a proxy by multiplying the PM_{10} figures by a conversion factor. As a general rule, $PM_{2.5}$ represents between 30% and 80% of PM_{10}. You may find a more specific conversion from: http://www.who.int/quantifying_ehimpacts/national/countryprofile/AAP_PM_database_May2014.xls

1. Calculate Change in Air Quality (PM2.5)

Step 1: Air quality baseline

Air quality baseline (Whole city)	Units	City Data
Area	km^2	2466
Average PM2.5 Concentration	$\mu g/m^3$	16
Background PM2.5 Concentration	$\mu g/m^3$	13
Non-background PM2.5 Concentration (City Wide)	$\mu g/m^3$	**3.0**
% Contribution to non-background concentration from Source Group (i.e. Roads, Buses, Industry, Other)	%	50.0%

Step 1: Measure Baseline (Intervention Area)

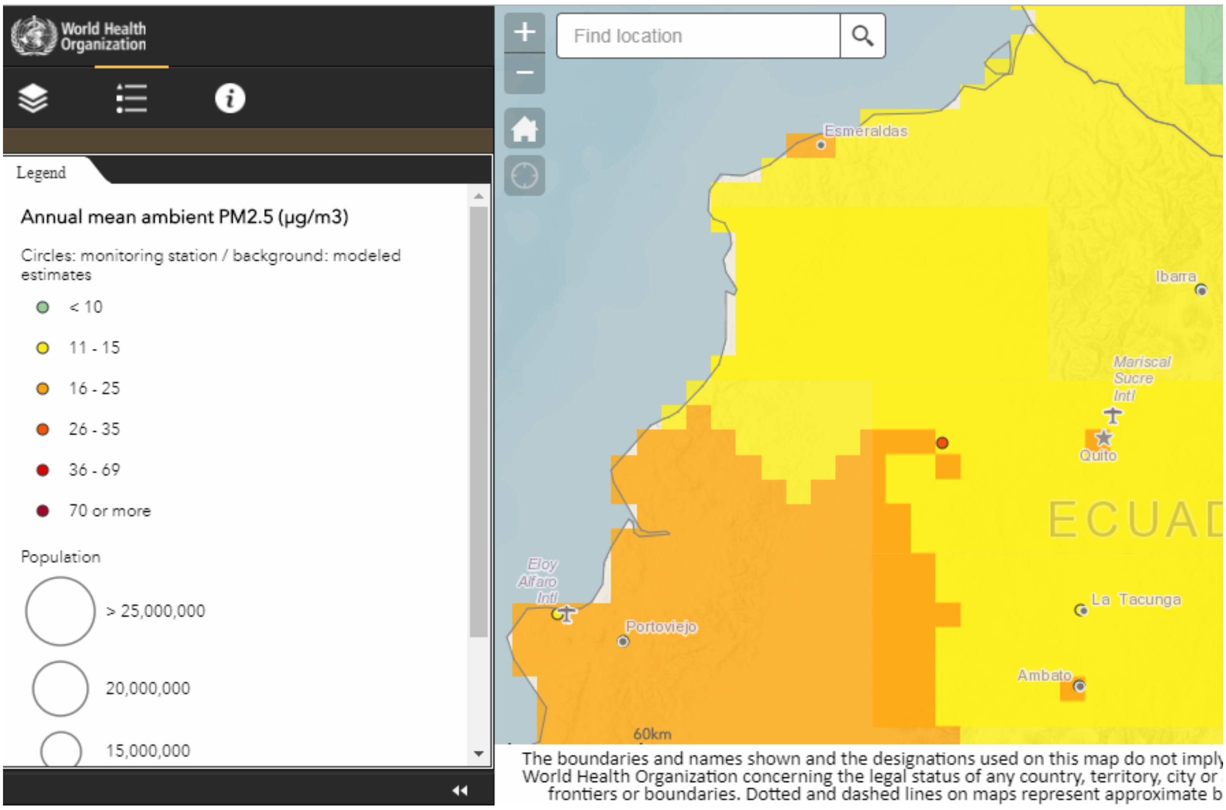
To understand the extent of an action's impacts and benefits, you must first acknowledge the physical boundary of the action, and thus the area affected.

- Intervention area, expressed in km^2
- Average $PM_{2.5}$ concentration in the intervention area
- Non-background $PM_{2.5}$ concentration (Intervention Area)
- If your action is city-wide then the intervention area will be the same as the city area and this step is not required.

There are a number of ways to identify the intervention area. These will vary for individual actions, i.e. for BRT this may be the BRT corridors and for LEZs this may be the area of jurisdiction and enforcement.

Air quality baseline (Intervention area)	Units	City Data
Area	km^2	250
Intervention to city area ratio		0.10
Average PM2.5 Concentration	µg/m³	18
Non-background PM2.5 Concentration (Intervention Area)	µg/m³	5.0

Please note, if you don't know the $PM_{2.5}$ background concentration or average concentration, you can use the following link http://maps.who.int/airpollution/



Step 2: Measure after action

This step focuses primarily on the impact from intervention/intervention area and it refers to $PM_{2.5}$ concentration observed or expected after the action has been implemented.

- What change will occur as a result of your action? i.e. estimate the reduction in emissions that your action will lead to.
- What impact will this have on the emissions from the Source group you are targeting? What proportion of total emissions from Source group does the reduction in emissions due to your action represent?
- This is the figure we will use in the spreadsheet to calculate impact on overall $PM_{2.5}$ emissions.
- For example, implementing an LEZ will lead to a reduction in higher polluting vehicles, this will lead to a reduction in emissions calculated as a proportion of total emissions from the transport source group.
- % reduction in $PM_{2.5}$ emissions from Source group due to action (i.e. Roads, Buses, Industry, Other).

In order to arrive at % reduction in $PM_{2.5}$ emissions from Source group due to action, you may need to carry out specific analysis regarding the impact of the action (please see a LEZ example on the last tab of the spreadsheet). The system change process should assist with obtaining an indicative assumption for this value.

Step 2: Effect of action		
Percentage change (Intervention Area)	**Units**	**City Data**
% reduction in PM2.5 emissions from Source group due to action (i.e. Roads, Buses, Industry, Other)	%	20.0%

Step 3: Calculate the change in Air Quality

In order to measure the link between the system change and AQ change, each city needs to determine:

- % change in non-background $PM_{2.5}$ concentrations in the intervention area
- What is the average change in $PM_{2.5}$ concentration in the whole city caused by the action
- What is the change in $PM_{2.5}$ concentration in the intervention area deriving from the action

Refer to column E in the spreadsheet for the formula needed for each of the above outputs.

The output obtained at this stage, will be used in Section 2 *"Apply Concentration Response Function"* to link the change in pollutant level with the change in health condition.

Step 3: Calculate the change in Air Quality		
Effect on air quality (Intervention area)	**Units**	**City Data**
% change in non-background PM2.5 concentrations	%	10.0%
Reduction in non-background PM2.5 concentrations	µg/m³	0.500
Effect on air quality (Whole city)	**Units**	**City Data**
% change in non-background PM2.5 concentrations	µg/m³	1.01%
Reduction in non-background PM2.5 concentrations	µg/m³	0.0304

For NO_2

Step 1a: Measure Baseline (Whole city)

As for $PM_{2.5}$, NO_x and NO_2 pre-action data need to be compared with post-action data. Pre-action data represents the baseline scenario and provides a snapshot of NO_x and NO_2 concentration before the action implementation.

Baseline data are collected city-wide and refer to pre-action. Input your pre-action data in the spreadsheet as follows:

- Total Area expressed in km^2
- Average NO_x Concentration
- Average NO_2 Concentration
- Background NO_x Concentration
- Background NO_2 Concentration
- NO_x Non-Background concentration
- % Contribution to non-background concentration from Source Group (i.e. Roads, Buses, Industry, Other)

If cities don't have any of the above data, they may be able to access this from:

- ***European Cities*** *can download this data from* *here* *[link below]* *https://www.eea.europa.eu/data-and-maps/data/#c0=5&c11=&c5=all&b_start=0*
- ***Non-European Cities*** *should coordinate with the national Environment Ministry, Meteorological Agency or with other relevant organizations that may hold this data.*

Note that NO_2 is the pollutant that has the most significant and studied health impact. Emissions calculations may start with NO_x but this data can be used to derive NO_2 values.

1. Calculate Change in Air Quality (NO2)		
Step 1: Air quality baseline		
Air quality baseline (Whole city)	**Units**	**City Data**
Area	km^2	2466
Average NOx Concentration	µg/m³	60
Average NO2 Concentration	µg/m³	40
Background NOx Concentration	µg/m³	15
Background NO2 Concentration	µg/m³	10
NOx Non-Background concentration	µg/m³	**45**
% Contribution to non-background concentration from Source Group (i.e. Roads, Buses, Industry, Other)	%	50%

Step 1b: Measure Baseline (Intervention Area)

- Intervention area, expressed in km^2
- Average NO_x Concentration
- NO_x Non-Background concentration
- Average NO_2 Concentration

Air quality baseline (Intervention area)	**Units**	**City Data**
Area	km^2	20
Intervention to city area ratio		**0.01**
Average NOx Concentration	µg/m³	70
NOx Non-Background concentration	µg/m³	**55**
Average NO2 Concentration	µg/m³	50

Step 2: Measure after action

This step is solely focused on the impact from intervention/intervention area and it refers to NO_2 and NO_x concentration observed or expected after the action has been implemented. Intervention area, expressed in km^2

- % reduction in NO_x emissions from Source group due to action (i.e. Roads, Buses Industry, Other)
- NO_2: NO_x ratio (City Wide)
- NO_2: NO_x ratio (Intervention Area)
- % change in non-background NO_x emissions in intervention area

- % change in non-background NO_x emissions across whole city

Step 2: Effect of action		
Percentage change (Intervention Area)	**Units**	**City Data**
% reduction in NOx concentration from Source group due to action (i.e Roads, Buses Industry, Other)	%	20%

Step 3: Calculate the change in Air Quality

In order to measure the link between the change in the system generated by the action and the AQ change, each city needs to determine:

- The change in NO_2 concentration in the whole city given by the change in NO_x adjusted by the NO_x to NO_2 ratio in the city
- The change in NO_2 concentration in the intervention area given by the change in NO_x adjusted by the NO_x to NO_2 ratio in the intervention area

Refer to column E in the spreadsheet to know the formula needed for each of the above outputs.

The output obtained at this stage will be used in Section 2 *"Apply Concentration Response Function"* to link the observed change in NO_2 with the change in health condition.

NO_x is given by the mixture of two pollutants: NO and NO_2. The two pollutants are involved in chemical reactions after they are emitted and NO can be converted to NO_2 and vice versa.

Changes in concentration in NO_x are used to estimate changes in concentration of NO_2.

In doing so, we assume that the NO_x:NO_2 ratio remains constant after the intervention.

In effect, we are assuming that the chemical behaviour is the same before and after the action.

Note that this assumption can become less accurate when the action creates a larger change in NO_x concentrations.

Step 3: Calculate the change in Air Quality		
Effect on air quality (Intervention Area)	**Units**	**City Data**
NO2: NOx ratio (Intervention Area)		0.71
% change in non-background NOx concentration	%	10.0%
Reduction in non-background NOx concentration	µg/m³	5.5
Reduction in non-background NO2 concentration	µg/m³	3.93
Effect on air quality (Whole city)	**Units**	**City Data**
NO2: NOx ratio (City Wide)		0.67
% change in non-background NOx concentration	%	0.08%
Reduction in non-background NOx concentration	µg/m³	0.04
Reduction in non-background NO2 concentration	µg/m³	0.02

Concentration response functions (CRF)

Concentration–response functions (CRFs) are also known as risk coefficients. They refer to a quantitative relationship between the change in concentration of a pollutant and the change in risk of an effect on health, based on effects estimates reported from epidemiological studies.

For the purposes of this study, a number of reliable, globally used and recognised CRFs have been selected and validated by leading experts in the field. The CRFs selected are primarily linked to two key pollutants and the respective response functions for death rates (mortality) and disease rates (morbidity) in terms of hospital admissions brought forward. These CRFs are captured in the table below and the relevant source highlighted.

Impact Pathway	Pollutant	CRF (% Change in Risk Rate per 10 µg/m³ change in Pollutant Concentration)	Source
Death rates (Mortality)	NO_2	5.5%	HRAPIE
Respiratory hospital admission (Morbidity)	NO_2	1.8%	HRAPIE
Death rate (Mortality)	$P.M_{2.5}$	6.0%	COMEAP
Respiratory hospital admission (Morbidity)	$P.M_{2.5}$	1.9%	HRAPIE
Cardiovascular disease hospital admission (Morbidity)	$P.M_{2.5}$	0.9%	HRAPIE

In 2015, COMEAP (the UK Government Committee on the Medical Effects of Air Pollutants) recommended that when the coefficient for concentrations of NO_2 and mortality is combined with an assessment of health impacts on the basis of $PM_{2.5}$, a percentage reduction needs to be applied to the NO_2 coefficient to avoid double-counting.

COMEAP's recommendation was that the NO_2 coefficient should be reduced by up to 33% to take account of double-counting of effects associated with $PM_{2.5}$.

From air quality change to health impact

Since everyone dies eventually, no lives are ever saved by reducing environmental exposures. Deaths are delayed, resulting in increased life expectancy.

These measures are averages or aggregates across the population; it is less well understood how the effects are distributed among individuals.

Having now gathered output data – in the form of changes in pollutant concentrations – this next step involves translating this into a change in health burden. Understanding the correlation between air quality and health is a complex process, and therefore to accurately address the link, we must first consider the various pollutants and their corresponding health impacts.

The health impact of each pollutant – NO_2 and $PM_{2.5}$ – needs to be measured separately, as they have different effects. The suggested method for calculating the impacts of these differing pollutants is through the use of 'Life Tables'.

Life tables are a spreadsheet system used for health impact assessments. They can be used for predictions of the patterns of mortality and life expectancy ensuing from a change in mortality rates, deriving from a given action / intervention. Within the context of this study they will be used to link the change in air quality with the resulting impact on health outcomes.

Using these functions, changes in pollutant exposure, defined by the relevant CRF, may be translated into changes in:

- Attributable deaths - Deaths caused by air pollution (please refer to the terminology list for full definition)
- Life years lived by the population - Life Year represents one year lived for one person in this scenario it is calculated as a total number across the population.
- Life expectancy of individuals

The various indicators used for valuing the air quality impact on health are largely encapsulated within the study as two crucial metrics: 1) morbidity; and 2) mortality.

The following steps will allow you to fill out the third section '3. Calculate health benefit of change in AQ' of the spreadsheet. The same steps outlined below for $PM_{2.5}$ should be repeated for NO_2.

Step 1: Input Population Health Data

To perform a complete life-table prediction of impacts on mortality, you need to start with age and gender-specific population and age and gender-specific all-cause mortality (deaths per year) data for your city.

Tab – '*Input_Population Health Data*' of the spreadsheet contains a sample data set of this information. Ensure that replacement city specific data follows the same format when inputting into the spreadsheet.

In addition, input the total population at city level and intervention area into *'Step 1: Measure baseline (Population)'.*

Note for % of population within Intervention Area - this must be <100%. Input 99.9999% if your intervention area is equal to the city area.

If city-level population health data is unavailable then national-level data can be used as a proxy, provided it is scaled down appropriately. If you are finding it difficult to access national-level data, there are a number of international data-sets you may wish to access. Web-links to these are provided in the spreadsheet document. You can also use gender and/or age weighted scaling from national to city data to provide more accurate results, this is especially useful where city gender and age profile may vary significantly from the national profile

3. Calculate health impact of change in AQ		
Step 1: Baseline Population		
Population data	**Units**	**City Data**
Total Population (City wide)	people	8,787,892
% of population within Intervention Area	%	20.0%

Once data is inserted, you should check the following tabs where life table calculations are processed to ensure there are no errors or broken links. If there are, undo the inputs in order to determine where the error originated. Key calculation cells will be locked in order to avoid accidental overwriting and errors.

<< CHECK life table tabs to ensure no links are broken.

The life tables operate using the baseline Population Health data and there is no need for manual calculations by the user.

Why use life tables?

- Deaths are not 'saved' by reducing air pollution but are shifted to older ages
- It is preferable to estimate changes in life expectancy and life years
- Life table can model changes in population age structure

Number of attributable deaths is a valid and meaningful way of capturing some important aspects of mortality, across the population in any given year and related to current levels of pollution. This is if we accept the complexities related to how quickly air pollution affects mortality risks.

It is therefore important to emphasize that the number of deaths are not number of deaths for which the sole cause is air pollution. It is not recommended to use annual numbers of deaths for assessing the impacts of pollution reduction, because these vary year by year in response to population dynamics and as a result of reduced death rates (COMEAP, 2010).

Step 2: Calculate the Impact on Health (Death/Mortality)

2a. Avoided Attributable deaths

The first component of calculating mortality uses the CRFs to calculate the avoided attributable deaths and does not involve any input from the life tables. Please follow the methodology outlined in column E of the spreadsheet.

Step 2: Calculate the Health Impacts - Mortality		
Deaths (Intervention Area)	**Units**	**City Data**
Attributable deaths averted (Male)	people	1.3
Attributable deaths averted (Female)	people	1.4
Attributable deaths averted (Total)	people	2.7
Deaths (Whole city)	**Units**	**City Data**
Attributable deaths averted (Male)	people	1.7
Attributable deaths averted (Female)	people	1.7
Attributable deaths averted (Total)	people	3.4

2b. Life Years Lost/Gained

The second measure of mortality uses the outputs from the life table analysis to calculate the life years gained by the population.

Using Life-Years Lost (LYL) [or *Gained*] is a valid and meaningful way of expressing mortality effects – in terms of both the impact and burden questions. It is therefore the most comprehensive way of capturing the full effects or an action on health. However, there are difficulties in communication. The concept of a 'life-year' is straight-forward, but it can be difficult to interpret the very large numbers of life-years involved in total population survival. However, it is the most relevant index for policy analysis (COMEAP, 2010).

The 'life year' is not a complex concept – we celebrate a year of life lived each time we celebrate a birthday.

The metric is appropriate for policy evaluation and cost-benefit analysis, because monetary values can be given to life-years and incorporated into the analysis.

The concept can be extended to take account not only of survival, but of years lived in good or poor health using concepts such as Quality Adjusted Life-Year (QALY) measurement (UK National Institute for Health and Clinical Excellence, 2010).

This manual will not address the use of QALYs.

Life years (Intervention Area)	**Units**	**City Data**
Life years gained (Male)	Life Years	**11.5**
Life years gained (Female)	Life Years	**8.8**
Life years gained (Total)	Life Years	**20.3**
Life years (Whole city)	**Units**	**City Data**
Life years gained (Male)	Life Years	**14.2**
Life years gained (Female)	Life Years	**11.0**
Life years gained (Total)	Life Years	**25.2**

2c. Life Expectancy

The third component of calculating mortality also uses the outputs from the life table analysis to calculate the life expectancy gained.

The impact of pollution reduction on life expectancy has been expressed in terms of life expectancy from birth. This impact on life expectancy was calculated by comparing the predicted life expectancy based on mortality rates with the predicted life expectancy when mortality rates have changed with the reduction in particulate air pollution.

Life expectancy (Intervention Area)	**Units**	**City Data**
Life expectancy gained at birth (years)	Years	0.02
Life expectancy gained at birth (days)	Days	6
Life expectancy (City Area)	**Units**	**City Data**
Life expectancy gained (years)	Years	0.00
Life expectancy gained (days)	Days	1

Step 3: Calculate the Impact on Health (Disease/Morbidity)

3a. Hospital Admissions Averted

If your city does not have baseline data for hospital admissions relating to cardiovascular disease or respiratory issues, then you will be unable to proceed with calculating changes in morbidity unless you can find proxy data on the rate of hospital admissions from another city with similar profile to yours. If proxy data is used, please ensure transparency and outline potential risks and uncertainties it may carry.

The first component of converting changes in air quality into morbidity benefits, involve understanding how air quality enhancements translate into 'hospital admissions averted'. Here we are concerned with the hospital admissions relating to either: 1) Cardiovascular Diseases (CVD); or 2) Respiratory issues. Again, we are concerned with $PM_{2.5}$ and NO_2 as both of these pollutants hold the most significance when dealing with morbidity indicators.

The CRFs in the spreadsheet are used to determine the impact that $PM_{2.5}$ will have on both cardio-vascular and respiratory-related hospital admissions, whilst they are limited to determining how NO_2 relates to respiratory-related hospital admissions only.

Understanding air quality and the link to morbidity involves recognising the **short term** situation regarding hospital admissions. The long term is uncertain, however we know there is a strong correlation between peaks in daily pollution and hospital admissions brought forward. Similarly, improving AQ pushes hospital admissions back, which can be considered a positive health outcome.

The CRFs provided are used for calculating 'hospital admissions brought forward/averted', and can be calculated using the steps in column E. Life tables are not required, you simply need to use baseline data for the Hospital admissions averted from the 'Input Population and Health Data' tab.

Step 3: Calculate the Health Impact - Morbidity		
Hospital Admissions (Intervention Area)	**Units**	**City Data**
Respiratory admissions averted (Male)	Admissions	1
Respiratory admissions averted (Female)	Admissions	1
Respiratory admissions averted (Total)	Admissions	3
Cardiovascular admissions averted (Male)	Admissions	1
Cardiovascular admissions averted (Female)	Admissions	1
Cardiovascular admissions averted (Total)	Admissions	1
Hospital Admissions (City Area)	**Units**	**City Data**
Respiratory admissions averted (Male)	Admissions	2
Respiratory admissions averted (Female)	Admissions	2
Respiratory admissions averted (Total)	Admissions	3
Cardiovascular admissions averted (Male)	Admissions	1
Cardiovascular admissions averted (Female)	Admissions	1
Cardiovascular admissions averted (Total)	Admissions	2

Monetisation of health impacts

The ultimate health impact deriving from the action can be monetised to catch wider economical and financial benefits. More specifically, this is achieved through two different indicators for mortality and morbidity, which have been identified in the Value of Life Years Lost (VOLY) and in the Value of a statistical Hospital Admissions (VHA), respectively. In this part, the fourth and last section of the spreadsheet will be covered.

While the impact from mortality can be monetised by multiplying the LYG by the VOLY; the impact from morbidity can be monetised by multiplying the Hospital admissions averted by the VHA.

The selected methodologies for monetising mortality and morbidity refers to the whole population. However, if data exists, the city should use specific age-group data:

- VOLY figures change over time as people get older;
- VHA figures vary by age and type of illness.

There are other, more complex methods of linking health outcomes to monetised or economic outcomes. These are less universally accepted and will not be covered in this manual.

4. Monetized health impacts		
Step 1: Calculate the monetised impact - Mortality		
Mortality Indicator		**City Data**
VOLY (Value of a Life Year) per year	£/Year	£36,431
Monetised benefit - Mortality		**City Data**
Costs avoided (Male)	£/Year	**£417,271**
Costs avoided (Female)	£/Year	**£321,759**
Costs avoided (Total)	£/Year	**£739,031**
Step 2: Calculate the monetised impact - Morbidity		
Morbidity Indicator		**City Data**
VHA (Value of a statistical Hospital Admission) Respiratory	£/per Admission	£6,912.00
VHA (Value of a statistical Hospital Admission) Cardiovascular disease	£/per Admission	£6,704.00
Monetised benefit - Morbidity (Respiratory)		**City Data**
Costs avoided (Male)	£	**£9,012**
Costs avoided (Female)	£	**£8,957**
Costs avoided (Total)	£	**£17,969**
Monetised benefit - Morbidity (Cardiovascular Disease)		**City Data**
Costs avoided (Male)	£	**£4,590**
Costs avoided (Female)	£	**£3,513**
Costs avoided (Total)	£	**£8,103**