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Benefits of Climate Action

Barcelona: Benefits of the Low Emission Zone

A report prepared by BuroHappold for C40 Cities
Climate Leadership Group

CONTENTS

EXECUTIVE SUMMARY

C40's enabling research programme on the benefits of inclusive climate action aims to support cities to not only tackle the challenge of climate change but more importantly realise the benefits of doing so.

The time for urgent climate action - C40 Cities must deliver 14,000 actions by 2020 in order to reach net zero emissions by 2050 to achieve the Paris Agreement's aspiration.

The benefits of climate action - from green jobs and growth, to active, happier lives and cleaner air and water, have an immediate, tangible impact on people's lives.

Inclusive climate action provides opportunities – to tackle multiple mayoral priorities simultaneously and deliver multiple benefits to all segments of the population, and ultimately result in more transformational climate solutions.

This report summarises the benefits for the city of Barcelona from implementing a **Low Emission Zone (LEZ) that restricts access to specific areas to particular vehicles.**

The implementation of the LEZ represents a crucial technical action to improve air quality in the city and ultimately generate higher level of carbon emissions savings. Through the LEZ, the city will reduce the number of most polluting vehicles circulating in the city and the level of the major pollutants are estimated to decrease. At the same time, the more stringent regulations are expected to drive mode-shift by increasing the number of people cycling, walking or using public and shared transportation modes.

The study showed that upgrading the fleet to less polluting vehicles supports climate change mitigation. In the current scenario, the positive carbon emission savings suggest a strong link between air quality and climate change and encourage the city to support more specific actions in order to promote behavioural change in the population and the creation of intermodal transportation facilities.

Results showed in the report refer to a moderate scenario, however different options are explored throughout the sections.[1]

The benefits are measured in terms of environmental, social and economic impacts. Once the action is implemented, the concentrations of the major pollutants ($PM_{2.5}$ and NO_2) are expected to change within a matter of days. Changes in morbidity indicators (in this case, hospital admissions) would be expected to be observed almost immediately while changes in mortality rates would be expected to take longer to manifest.

[1] Scenarios are based on modal shift modelled by the city. The moderate scenario assumes a reduction in number of trips made by car, taxi, motorcycle and truck. An optimistic scenario assumes an additional decrease of private vehicles and an increase in the number of trips made by buses. A conservative scenario assumes that after the action the number of cars and taxis would remain the same, the number of buses will slightly increase but the number of motorcycles and trucks will increase significantly.

The figures below show the indicative impacts under a moderate scenario by 2020 (the moderate scenario is the most cautious/medium range scenario):

ENVIRONMENTAL IMPACT

Approximately **12.5% reduction** in overall non-background NO_2

Approximately **26% reduction** in overall non-background $PM_{2.5}$

Potentially rising to **38% reduction** in overall non-background $PM_{2.5}$ in an augmented scenario

Approximately **4% reduction** in carbon emissions from the road sector

SOCIAL IMPACT

94 deaths averted annually across the total population

Potentially rising to **139 deaths averted annually** across the total population in an augmented scenario

Life expectancy increased by **10 days per person** across the total population

Potentially rising to **15 days per person** across the total population

ECONOMIC IMPACT

€ 135,000 - Approximate costs avoided due to less respiratory hospital admissions from change in $PM_{2.5}$ levels

Potentially rising to **€ 199,000** in an augmented scenario

€ 89,000 - Approximate costs avoided due to less CVD hospital admissions from change in $PM_{2.5}$levels

Potentially rising to **€ 130,000** in an augmented scenario

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	WHO 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
Background concentration	Concentration of pollutants not explicitly emitted by local sources, but transported into the considered area.	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.	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.	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 Years Lost is a result of deaths and represents the population mortality burden.	BuroHappold | C40
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 (O3), to nitrogen dioxide (NO_2), which can be harmful to health	DEFRA
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.	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

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IMPORTANT NOTE

All information provided in this study is to illustrate the process and methodology used for the analysis discussed in the document.

BuroHappold is not making a recommendation, as to whether to proceed with a specific course of action within this study and accepts no responsibility for the realisation of prospective social, environmental, economic or financial outcomes. Actual results are likely to be different from those shown in the analysis because of inaccuracies in the input data, uncertainties relating to the underlying evidence and the fact that events and circumstances frequently do not occur as expected, and the differences may be material.

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1 INTRODUCTION

The C40 Cities Climate Leadership Group (C40) has a mission to enable cities to develop and implement policies and programmes that generate measurable reductions in greenhouse gas emissions and climate risks. In particular, following the ratification of the Paris Agreement, C40 is committed to ensuring that cities play their part in keeping the world within 1.5ºC of warming compared with pre-industrial temperatures, through direct action within the city limits. In support of this mission, C40 has launched a three-year research programme focused on articulating the Benefits of Climate Action and enabling cities to quantify and communicate those benefits in a compelling way that will drive the acceleration and expansion of climate action.

C40 and Johnson & Johnson have formed a partnership under a common goal of addressing issues surrounding urban air quality and its relationship to health. This partnership is designed to ‘connect the dots’ between improved air quality within cities, and measurably improved health amongst citizens. The alliance intends to initiate, consolidate or enhance implementable climate actions that align low-carbon and sustainable development with improved health outcomes. C40 seeks to support aligned climate and health actions, speeding up and scaling up positive impacts. The city-scale provides an evidence-base broad enough to remain significant, but focused enough to make a difference on the ground. This helps city government staff make the case for action at both a political and financial level.

We have collected and analysed raw data from each city and combined it with evidence from existing literature and tools to identify replicable methods for measuring benefits. The findings will be shared with a wider group of cities through C40’s network programmes, enabling enhanced testing of the approach. The aim is to enable C40 cities to effectively and efficiently measure the wider benefits of climate action, here specifically air quality, accelerating action required to achieve climate safe, liveable cities.

1.1 THIS REPORT

This report outlines the initial findings from the benefits analysis prepared for the city of Barcelona, drawing on data and information provided by the city with regard to the Low Emission Zone (LEZ) currently being implemented.

Section 2 describes the context of the LEZ intervention. Section 3 describes the key findings of the study, including an overview of the input data used together with a record of relevant assumptions. Section 4 provides an overview of potential policy insights and opportunities for scaling up the selected action. Section 5 describes the methodology used to develop the analysis, including any significant limitations.

The work described in this report is focussed exclusively on the air-quality related health benefits associated with a single, specific, climate action in Barcelona. The monetised benefits that may be considered to arise from these improvements in public health will also be estimated.

2 BARCELONA'S ACTION AGENDA

In November 2016, the city of Barcelona approved a government measure against air pollution. The mission of this measure is to improve air Quality in the urban area and it contains 8 axis of implementations being one of the most significant the creation of a LEZ. However, the administrative boundaries of the city do not correspond with the limits of the metropolitan area, where other municipalities are implementing similar actions under the leadership and coordination of AMB.

As a result, the LEZ area will be implemented in three distinct but related zones:

An urban low emission zone restricting access to the intra ring road including the whole residential area of Barcelona and the neighbour municipalities of Hospitalet de Llobregat and Sant Adrià del Besòs and a small part of Esplugues de Llobregat and Cornellà de Llobregat. The LEZ is already in place and restrictions apply for high levels of pollution events and will become permanent from January 2020.

A metropolitan low emission zone with similar restrictions applied to the rest of municipalities (up to 36) to be progressively in place, scheduled for 2025.

As well, due to specific situations additional measures will apply to improve air quality in smaller sensitive areas.

Aligning to the European emission standards, the DGT (Dirección General de Tráfico) has developed a label system to identify the pollution potential of each vehicle. With this action, the city intends to promote the circulation of environmentally friendly vehicles (Label B, C, Eco and Zero emission) and to ban the more polluting ones (No Label).

This report, and the analytical work it summarises, will focus on the health impacts of the LEZ only (the second bullet point above), but will make reference to the other zones as necessary. The approach and methodology from this study can be applied to other zones in the Barcelona area or wider across Spain.

In addition to the definition of restriction zones, Ajuntament de Barcelona intend to implement additional actions that will complement the LEZs, such as the improvement of public transport and sustainable mobility and projects intended to reduce or optimise vehicle traffic associated with urban freight or logistics. These actions have been taken into account when calculating the impact and benefit from the LEZ but it has not been possible to evaluate the impact of the additional actions during the course of this engagement.

A particularly noteworthy aspect of the proposed programme of actions is the creation of incentives for those citizens who take their polluting cars off the road in the form of unlimited public transport passes for 3 years.

The health impacts of the actions will be monitored under a programme of air quality monitoring undertaken by the Barcelona Public Health Agency (ASPB). Thus, it is anticipated that the preliminary findings included in this report will be further developed through the operation of the zones.

Aim of action

Barcelona have engaged with this action to boost citizen health through the improvement of air quality. As shown in the Barcelona Health Report 2016 annual values for the major pollutants exceeded WHO limits in the urban areas. In addition, in recent years, the level of major pollutants have been following a decreasing trend, however the absolute values are still high. Specifically, the action is seeking to reduce emissions by 2020, through a planned urban transformation and reorganization.

In addition to the Barcelona Air Quality Improvement Plan (2015-2018), the city has developed a strategy, which has citizen's health and their quality of life at its heart, to significantly tackle air quality through the creation of a cleaner mobility system. In addition to the low emission zones and the removal of high-emitting vehicles, Barcelona's redevelopment strategy is seeking to extend bicycle lanes, pedestrian areas and expand the new urban model of superblocks.

By 2020, the most polluting vehicles will be forbidden in the low emission zone area and a direct impact is anticipated in terms of improved air quality and reduced carbon emissions. Clear and quantified estimates of the health impacts arising from addressing poor quality in Barcelona will be crucial to the promotion of the action and, ultimately, to expand it to the neighbouring municipalities.

Aim of measuring the benefits of this action

Barcelona want to use the results from benefits measurement in order to:

1. Improve air quality as identified in the Barcelona Health Report 2015 as one the main challenges in health.
2. Reinforce the actions that have already started within the city
3. Help engage different stakeholders, from citizens to schools and associations, as well as public and private sectors within the city

Location and scale

The map below shows the extent of the urban Low Emission Zone (LEZ) in place. The ZBE covers the whole residential area of Barcelona and, partially, the neighbour municipalities of Hospitalet de Llobregat, Sant Adrià del Besòs, Esplugues de Llobregat and Cornellà de Llobregat.

Time scales

Starting from the 1st of December 2017, Barcelona is restricting the circulation of un-labelled vehicles during days on which atmospheric pollution episodes due to NO_2 are occurring. The protocol for such episodes is provided on the Ajuntament de Barcelona website and determines the threshold levels of pollutants (200 µg/m^3 for NO_2 per hour) as well as other measures to be implemented (including the augmentation of public transport services). At the time of writing, motorcycles, trucks, coaches, buses and vans are exempt.

Commencing on the 1st January 2020, the restrictions will apply permanently to most polluting vehicles on workdays from, 7am to 8 pm, regardless of whether the atmospheric pollution is above or below the threshold values.

Future plans:

Further to complementary actions in specific sectors carried by the city, the metropolitan Administration aims to extend the restrictions adopted in the LEZ to the entire metropolitan area, comprising 36 municipalities in total. The future trajectory for the action will depend mainly on the promotion of zero emissions-electric vehicles and enhanced public transport services.

In 2030, only zero emission vehicles will be allowed to circulate in restricted areas.

3 BENEFITS OF BARCELONA'S LEZ

3.1 SYSTEM CHANGE

The following section provides a summary of the input data used to build a relatively simple model developed to test three different scenarios: moderate, conservative and optimistic. These scenarios have been developed and informed through discussions, data and experts knowledge of local city staff.

Each scenario is characterized by two dimensions:

- Expected change in number of vehicles per label type representing the number of people who upgrade to a less polluting vehicle;
- Expected modal shift from the action representing the number of people who will switch from driving to other forms of transport

Results showed in this section, are based on the fixed assumption that after the action, there will be a full replacement of "No Label" vehicles with "Label C" vehicles. Please refer to the table below for a full explanation of the number of vehicle by label type baseline

Expected change in number of vehicles per label type

Number of vehicle by label type	**Before the action**						**After the action**					
	No Label	**B**	**C**	**Eco**	**0**	**N/A**	**No Label**	**B**	**C**	**Eco**	**0**	**N/A**
Motorcycles	**20%**	43%	24%	4%	0%	9%	0%	43%	**44%**	4%	0%	9%
Petrol Car	**23%**	43%	31%	1%	0%	1%	0%	43%	**54%**	1%	0%	1%
Diesel Car	**23%**	43%	31%	1%	0%	1%	0%	43%	**54%**	1%	0%	1%
LDV - petrol	**25%**	67%	7%	0%	1%	0%	0%	67%	**31%**	0%	1%	0%
LDV - diesel	**25%**	67%	7%	0%	1%	0%	0%	67%	**31%**	0%	1%	0%
MDV	**20%**	43%	24%	4%	0%	9%	0%	43%	**44%**	4%	0%	9%
HDVs	**20%**	43%	24%	4%	0%	9%	0%	43%	**44%**	4%	0%	9%
Urban bus	**20%**	43%	24%	4%	0%	9%	0%	43%	**44%**	4%	0%	9%
Intercity bus	**20%**	43%	24%	4%	0%	9%	0%	43%	**44%**	4%	0%	9%

LDV: Light-Duty Vehicle ; MDV: Medium-Duty Vehicle ; HDV: Heavy-Duty Vehicle

As well as assumptions about vehicle label type, assumptions have been made about the modal shift-measured in terms of vehicle-kilometres. These assumptions have been modelled by the city's staff, based on their expectations for project outcomes in 2020.

Note that the redistribution showed in the table above is kept constant across three different scenarios while the modal shift varies across the three scenarios.

In the moderate scenario, the analysis assumes a modal shift in which the traffic from taxis and cars will decrease by 10% and 4% respectively. At the same time, it is assumed that motorcycle and buses will both increase by 6%.

The optimistic scenario is characterized by a situation in which the percentage of buses double, the percentage of circulating taxis and motorcycles decrease by half and cars are reduced by 10 percentage points.

The more conservative scenario assumes the action will have no impact on vehicles km driven by car and taxis, and a higher use of motorcycle and trucks.

Expected modal shift

	Vehicle-kilometre % change:2020		
	Conservative	Moderate	Optimistic
Bus	**6%**	**6%**	**12%**
Taxy	**0%**	**-10%**	**-20%**
Car	**0%**	**-4%**	**-14%**
Motorcycle	**16%**	**6%**	**-3%**
Van/Truck	**12%**	**8%**	**3%**

Refer to section 3.5 for a table summarizing the environmental, social and economic outcomes across the three different modal shift scenarios.

Refer to section 4.3 to explore a more augmented scenario, where the number of vehicles per label type will be allowed to vary.

3.2 ENVIRONMENTAL BENEFITS

The extent of the environmental benefits for implementing Barcelona's LEZ depends largely on the proportion of vehicles upgrading to Label C, Eco and ultimately to Zero emission label. In the current scenario, where it is assumed that all the most polluting vehicles (the no-label vehicles) will upgrade to the label C, there is an expected 4% reduction in CO_2 emissions from the road source.

In determining the eventual net carbon saving, citizen's behavioural change will play an important role. While there may be moderate carbon emissions avoided associated with the adoption of more fuel-efficient vehicles by far the greatest reductions in carbon emissions will be associated with large-scale switch to non-motorised modes of transport, namely walking and biking.

In terms of air quality, the current estimates for Barcelona's action indicate a 26% reduction in $PM_{2.5}$ (non-background) or a 12.5% reduction in NO_2. In addition, the action will decrease the carbon emission from traffic by 4%.

3.2.1 OVERVIEW OF DATA AND ASSUMPTION

The analysis is based on pollution data ($PM_{2.5}$ and NO_2) collected from the monitoring stations distributed throughout Barcelona. The city has a monitoring system that consists of 11 stations, each constantly measuring either one or both pollutants.

Monitoring Stations list:

	PM_{10}	$PM_{2.5}$	NO_2	Classification
Gràcia-Sant Gervasi	✓	✓	✓	Traffic
Poblenou	✓	✓	✓	Urban
Sants	✓		✓	Urban
Eixample	✓	✓	✓	Traffic
Zona Universitaria	✓	✓		Urban
Plaça Universitat	✓	✓		Traffic
Vall d'Hebron	✓	✓	✓	Urban
IES Verdaguer	✓			Urban
IES Goya	✓	✓		Suburban
Ciutadella			✓	Urban
Palau Reial			✓	Urban

According to standards and because the station classified as "traffic" provide a direct measure of pollution in one or more roads, they have been removed from the calculation when estimating $PM_{2.5}$ and NO_2 average concentrations in the city.

Note that $PM_{2.5}$ background concentration has been calculated using figures from the non-urban station located in Montseny, while NO_X background concentration has been estimated by using a proxy value from London.

In assembling a mathematical model of the system change, one additional main assumption was made. It is assumed that due to the action, there will be a redistribution of the type of vehicles circulating in the intervention area, but there will not be a reduction in terms of number of vehicles.

More specifically, it is assumed that all the vehicles classified as "No label" – petrol vehicles registered before 2000 and diesel vehicles registered before 2006 - will upgrade to the "Label C" - petrol Euro 4, 5, 6 and diesel Euro 6.

Note that this is the baseline scenario assumed throughout the analysis.

It is important to note the impact of the now well-known discrepancy between the real-world performance and the claimed performance of vehicles previously understood to have met European Union standards for vehicle emissions (Euro Codes)[2]. For this study, the team have modelled the change in tail-pipe emission from vehicular transport using the COPERT 5 software developed with finance and technical support from the European Environment Agency. Earlier versions of this software tool did not take into account the discrepancies since they were either unknown or poorly understood. Edition 5 (Version 0.1067), which has been used for this study, does take into account RWEs as far as possible, although there are some known inaccuracies that will be addressed in future editions. The technical team are satisfied that this is the preferred approach to this particular challenge although it is recognised that there are other software packages available for the same purpose. Generally, the use of RWEs tests is preferred to fully lab tests as the degree of underestimation for air quality and health impacts is lowered. As testing regimes improve and real-world data improves it is expected that residual underestimates in air quality and health impacts will be diminished further.

3.2.2 KEY FINDINGS

Our calculations indicate that after the implementation of the action, there is a 1.04 µg/m³ fall in the average $PM_{2.5}$ concentration in the intervention area. The resulting $PM_{2.5}$ value of about 12 µg/m³, is close to the WHO's recommended value (10 µg/m³) and thus, the action may be said to contribute materially to closing the gap. The improvement in air quality accounts for approximately 35% of the difference between Barcelona's actual level and the WHO recommended maximum level, indicating strong progress. As shown in the following tables, there is an additional fall when an optimistic scenario is take into account.

Global example:

Studies conducted in Germany[3] concluded that there is a positive relation between the implementation of LEZs and a fall in urban PM levels. When comparing different cities, it has been found that the cities implementing other air quality policies without LEZs, did not experience a significant decrease in atmospheric pollution. In addition, there is a direct and positive relationship between the area affected by the policy and the outcome. The larger the area, the higher the impact.

[2] TNO, 2014: NOx and PM emissions of a Mercedes Citaro Euro VI bus in urban operation
https://www.tno.nl/media/3442/nox_pm_emissions_mercedes_citaro_euro_vi_bus_tno_2014_r11307.pdf
IVL, 2016: Measurement of bus emissions 2010-2015
http://www.ivl.se/download/18.29aef808155c0d7f0504cb/1472802397237/B2254.pdf

[3] Wolff, H (2013) Keep your clunker in the suburb: low-emission zones and adoption of green vehicles. The Economic Journal, 124, 57

3.3 SOCIAL BENEFITS

The social benefits from implementing a LEZ in Barcelona are significant, in that an estimated 83 deaths and 58 hospital admissions are averted in the intervention area. Using a different measure of improved mortality outcomes, 515 life years are gained across the population in the intervention area. It may also be observed that life expectancy at birth – an alternative measure of improved mortality outcomes – is boosted by 10 days (per person).

3.3.1 OVERVIEW OF INPUT DATA AND ASSUMPTIONS

The social benefits of the action is measured in terms of mortality and morbidity, where the first is expressed in the terms of total number of deaths and the latter is expressed in terms of respiratory- and CVD-related hospital admissions.

Whilst population and number of deaths were readily available by age and gender, some multi-step calculations were needed to establish the hospital admission by age group and to estimate the hospital admissions per 1000 population. In order to distribute the hospital admission observation across the different ages, a London sample-distribution has been used. Specifically, data from London has been used to estimate an "age to hospitalization profile", this profile has then been applied to the total number of hospitalization cases in Barcelona.

3.3.2 KEY FINDINGS

After the implementation of the action, the whole city is expected to benefit from 94 deaths averted in relation to $PM_{2.5}$ reduction. Alternatively, the reduction in NO_x/NO_2 from implementing the LEZ translates to 266 deaths averted in the city.

The implementation of the LEZ has a high impact in terms of 66 hospital admissions averted under the $PM_{2.5}$ calculations across the population. Alternatively, 116 NO_2 related respiratory admissions are estimate to be averted.

As shown in the following tables, those figures increase materially when an optimistic scenario is considered.

Global example:

A wider social benefit associated with the action may be considered to be the general improvement of citizen's wellbeing. Studies conducted in London[4] show that for patients most exposed to the LEZ area, the medical consultation for respiratory illnesses reduced by a value of 5% to 10% and drug prescription for asthma decreased significantly.

[4] The London Low Emission Zone Baseline Study, 2011. https://www.healtheffects.org/publication/london-low-emission-zone-baseline-study

3.4 ECONOMIC BENEFITS

For this analysis, the economic benefits from implementing Barcelona's LEZ have been derived from the value of both respiratory- and CVD-related hospital admissions.

Significant healthcare cost savings have been calculated, through consideration of the numbers of those admissions that have not been brought forward.

3.4.1 OVERVIEW OF DATA AND ASSUMPTION

At the time of writing, considering monetisation of morbidity costs, it has not been possible to ascertain statistical average costs for respiratory- and CDV-related hospital admissions. Therefore, the monetised values for morbidity are derived using proxies from the UK. Should these values be established for Barcelona, they can, of course, be used instead to amend the calculated monetised values.

3.4.2 KEY FINDINGS

The LEZ implementation action will deliver economic benefit. It is expected that Barcelona will achieve significant healthcare savings. The respiratory- and CVD-related hospital admission averted due to the reduction in $PM_{2.5}$ concentrations are valued at €135,000* and €89,000 respectively. Alternatively, if we consider savings due to the reductions in NO_2 , costs avoided for respiratory-related hospital admissions are estimated at the higher value €394,000*.

*Although they pertain to the same population, these two values should not be summed due to the uncertainty around overlapping effects from $PM_{2.5}$ and NO_2 concentrations.

Note that in an optimistic scenario, the costs saved due to the action, increase significantly. Refer to the table below for a comprehensive summary of results in different scenarios.

3.5 RESULTS SUMMARY

The following tables show the environmental, social and economic benefits according to the modal-shift based scenario. The results discussed in this section showed that in a moderate scenario, there are positive outcomes across the three dimensions (Air Quality, Health Outcomes and Economic Benefits). However, the promotion of more sustainable travel modes is essential to create higher and more significant impact in terms of air quality and health.

Summary results for mode shift scenarios-$PM_{2.5}$ and NO_2

$PM_{2.5}$		AQ Benefits	Health Benefits			
		Reduction in non-background $PM_{2.5}$ (%)	Deaths Averted	Life Years Gained	Life Expectancy	Cost avoided (morbidity)
Conservative	Intervention	24%	76	471	9	
	City	**22%**	**86**	**531**	**9**	€ 205,000
Moderate	Intervention	26%	83	515	10	
	City	**24%**	**94**	**581**	**10**	€ 224,000
Optimistic	Intervention	28%	90	554	11	
	City	**26%**	**101**	**624**	**11**	€ 241,000

NO2		AQ Benefits	Health Benefits			
		Reduction in non-background NO_2 (%)	Deaths Averted	Life Years Gained	Life Expectancy	Cost avoided (morbidity)
Conservative	Intervention	12%	221	1356	27	
	City	**11%**	**249**	**1529**	**26**	€ 370,000
Moderate	Intervention	13%	236	1455	28	
	City	**12%**	**266**	**1629**	**28**	€ 394,000
Optimistic	Intervention	13%	246	1506	30	
	City	**12%**	**277**	**1698**	**29**	€ 411,000

4 COMMENTARY AND POTENTIAL POLICY INSIGHTS

This section of the report provides some general commentary on the above findings as they relate to the wider context of changes to the urban systems in Barcelona.

4.1 MAIN OBSERVATIONS

The introduction of the LEZ is likely to have significant positive health impacts through promotion of less polluting motorised transportation but further additional benefits will be achieved if citizens can be persuaded to switch away from motorised transportation altogether.

It is important to note that the analysis conducted has estimated benefits predicated on two types of switch in motorised transportation arising from the introduction of the LEZ. These are i) the change of vehicles from more polluting to less polluting and ii) the change of transportation mode from individual to common (or public).

The study has not sought to analyse an explicit switch from motorised to non-motorised transportation. This is because Ajuntament de Barcelona is currently in the process of implementing a suite of measures that are targeted at supporting citizens in moving towards non-motorised transportation and the outcomes of these initiatives are not yet well modelled. These measures include efforts to create safer and faster routes for bicycles, and faster routes for buses (which encourage walking for significant journey segments). It is believed that there is a strong opportunity to persuade segments of the population who switched to motorcycles in recent years (reversing a general trend away from motorcycles in Western Europe) to switch to bicycles instead.

Penalising motorised transportation through measures such as the LEZ will certainly drive some road users to non-motorised transportation but without reviewing the supporting measures in detail it is not possible to determine how many.

Thus, for this study, the analysis has focussed on the health benefits arising from switch only between categories of motorised vehicle. It is recognised, therefore, that the improvement in air quality arising from the action (and the associated health benefit) is likely to be an underestimate if the measures to persuade road users to move to non-motorised transportation are expected to be successful to any significant degree. Future studies carried out following implementation of the support measures for non-motorised transportation will benefit from actual data on modal switching.

The study highlights the differences in outcomes for different pollutants resulting from the same action. Whilst CO_2 emissions are reduced by a modest amount due to the action (approximately 4% of the city's total annual emissions), total $PM_{2.5}$ concentrations are reduced by around 24% and brought very close to the WHO limit value of 10 µg/m³, NO_2 concentrations are reduced by an estimated 12% also.

As noted, the introduction of a LEZ forms part of a wider suite of activities targeted at the overall reduction of transportation-related pollution and at the delivery of more effective transportation systems for citizens. The suite of transport-related measures form part of a wider plan of action adopted in 2011 (the 2011-2020 Barcelona, Energy, Climate Change and Air Quality Plan), which is currently under review and being updated under the Climate Plan project. As the LEZ measures are developed and further enhanced in the years that follow, it is evident that the ways in which these measures are developed should be informed by the overall objectives of the city to align, or prioritise, air quality targets and greenhouse emissions targets. Different enhancements will deliver different levels of reduction for different pollutants and these decisions will be political as well as scientific.

4.2 OPPORTUNITIES FOR SCALING UP OR SPEEDING UP

Opportunities to speed-up or scale-up the accrual of benefits from the LEZ action in Barcelona present themselves in three distinct forms:

- Tightening or enhancing the categorisation of vehicles permitted to enter the LEZ

  Current plans will permit Category B vehicles to enter the zone. It is difficult to predict how many no-label vehicles will be replaced by Category C or higher vehicles and how many will be replaced by Category B vehicles. Those Category B vehicles represent almost 50% of the circulating fleet and they are considered to progressively disappear when more strict measures come closer, being one of the most relevant the scenario of Fossil Fuel Free city at 2030,when a significant part of the city should accomplish the target.

  Of course, at present, fossil-fuel-free vehicles are still responsible for significant quantities of non-exhaust-derived $PM_{2.5}$, through break and tyre generated particulates, which means that unless motorised transportation is eliminated there will always be residual levels of non-background PM2.5 (best estimates at present approximate tyre and break generated $PM_{2.5}$ at around 35% of total $PM_{2.5}$ from vehicles).

- Expanding the geographic areas covered by the zone

  Current plans exclude two districts of the city from the LEZ restrictions. One of these districts is characterised by the industrial port related activity. The other is a forest area, characterised by lower levels of pollutant concentrations due to environmental factors. In spite of this, the first area will still contribute materially to the total emissions in the city. Thus, the accelerated inclusion of the industrial district into the LEZ would increase the impact of the action.

  Looking beyond the urban area under the current jurisdiction of Ajuntament de Barcelona, other local administrations are considering restrictions at different levels of implementation. The leadership of the metropolitan administration AMB will be crucial to reach the 2025 target to extend the LEZ to the rest of municipalities within the metropolitan area.

- Emphasizing further modal shift and the reduction of motorised transportation in the city.

  As noted previously, if greater incentives to adopt non-motorised transportation options are put in place in parallel to the implementation of the Barcelona LEZ and other LEZ initiatives the climate and health benefits are likely to be greater. Timing will also be important because of the longevity of vehicle fleets. People who chose to invest in new vehicles are less likely to consider alternative modes of transportation for some time after the investment.

Thus, the opportunities for Barcelona to promote the actions against pollution (of which the LEZ is major component) can be characterised as having a broad range of social, environmental and monetary benefits and as offering a visible and genuinely impactful platform to which other initiatives may be linked or aligned (such as the Fossil-Fuel-Free-Streets declaration).

4.3 AUGMENTED SCENARIO

This section provides an overview of the potential environmental, social and economic impacts in the city when the action is scaled up from the baseline[5] assumption. The augmented scenarios are modelled to capture the additional improvements in air quality and health when the number of vehicles per label type varies[6].

The three augmented scenarios capture the city expectations and are shown in the table below:

Scenarios for number of vehicles per label type:

SCENARIO 1: 50% Label C and 50% Eco	No Label	B	C	Eco	0	N/A
Motorcycles	0%	**43%**	**34%**	**14%**	0%	9%
Petrol Car	0%	**43%**	**43%**	**13%**	0%	1%
Diesel Car	0%	**43%**	**43%**	**13%**	0%	1%
LDV - petrol	0%	**67%**	**19%**	**13%**	1%	0%
LDV - diesel	0%	**67%**	**19%**	**13%**	1%	0%
MDV	0%	**43%**	**34%**	**14%**	0%	9%
HDVs	0%	**43%**	**34%**	**14%**	0%	9%
Urban bus	0%	**43%**	**34%**	**14%**	0%	9%
Intercity bus	0%	**43%**	**34%**	**14%**	0%	9%

SCENARIO 2: Label B distribution by 2025	No Label	B	C	Eco	0	N/A
Motorcycles	0%	**25%**	**38%**	**26%**	2%	9%
Petrol Car	0%	**25%**	**47%**	**25%**	2%	1%
Diesel Car	0%	**25%**	**44%**	**28%**	2%	1%
LDV - petrol	0%	**40%**	**24%**	**32%**	4%	0%
LDV - diesel	0%	**40%**	**24%**	**32%**	4%	0%
MDV	0%	**25%**	**38%**	**26%**	2%	9%
HDVs	0%	**25%**	**38%**	**26%**	2%	9%
Urban bus	0%	**25%**	**38%**	**26%**	2%	9%
Intercity bus	0%	**25%**	**38%**	**26%**	2%	9%

[5] As mentioned in Section 3.2.1 the baseline scenario have been developed assuming that after the action all No Label vehicles will move to Label C.

[6] Note that in this section the mode-shift is kept fixed in the moderate scenario and the vehicles per label type is allows to move within three different scenarios.

SCENARIO 3: Label B distribution by 2030	No Label	B	C	Eco	0	N/A
Motorcycles	0%	**15%**	**29%**	**37%**	10%	9%
Petrol Car	0%	**15%**	**36%**	**36%**	12%	1%
Diesel Car	0%	**15%**	**26%**	**38%**	20%	1%
LDV - petrol	0%	**23%**	**19%**	**44%**	14%	0%
LDV - diesel	0%	**23%**	**19%**	**44%**	14%	0%
MDV	0%	**15%**	**29%**	**37%**	10%	9%
HDVs	0%	**15%**	**29%**	**37%**	10%	9%
Urban bus	0%	**11%**	**22%**	**38%**	20%	9%
Intercity bus	0%	**15%**	**22%**	**44%**	10%	9%

Whilst Scenario 1 captures the city expectation to remove No Label cars and to re-distribute them in equal proportions to Label C and Eco; Scenarios 2 and 3 captures a general upgrade of the circulating fleet to less polluting vehicles by 2025 (mostly Label C and Eco)and by 2030 (mostly Eco a Zero Label).

Analysing the table below, it may be observed that the air quality and health outcomes associated with more 'ambitious' scenarios, incorporating and upgrade to less polluting vehicles across the board, are extremely promising for both $PM_{2.5}$ and NO_2.

The gains associated with the adoption of less polluting vehicles by 2030 are significant, especially in terms of deaths averted, which are almost doubled, and life expectancy, which increases by 50% when we draw on the outcomes related to $PM_{2.5}$.

Summary results for vehicle per label type scenarios-$PM_{2.5}$ and NO_2

$PM_{2.5}$		**AQ Benefits**	**Health Benefits**			
		Reduction in non-background $PM_{2.5}$ (%)	Deaths Averted	Life Years Gained	Life Expectancy	Cost avoided (morbidity)
Scenario 1	Intervention	27%	85	528	10	
	City	25%	**96**	595	**10**	€ 229,000
Scenario 2	Intervention	33%	105	650	13	
	City	30%	119	732	13	€ 283,000
Scenario 3	Intervention	38%	123	758	15	
	City	36%	**139**	855	**15**	€ 330,000

NO_2		AQ Benefits	Health Benefits			
		Reduction in non-background NO2 (%)	Deaths Averted	Life Years Gained	Life Expectancy	Cost avoided (morbidity)
Scenario 1	Intervention	13%	241.8	1480	29	
	City	12%	**272**	1669	**29**	€ 404,000
Scenario 2	Intervention	20%	382	2319	45	
	City	19%	430	2614	45	€ 636,000
Scenario 3	Intervention	28%	540	3249	64	
	City	26%	**609**	3662	**63**	€ 896,000

Note that the results and comments showed in this report are limited to a few scenarios, but the structure of the spreadsheet -used throughout the whole process- allows the city to make as many combinations as possible between the modal-shift and vehicles distribution per label type components.

4.4 FUTURE DATA COLLECTION ACTIVITIES

The four main suggestion for further data collection are as follows.

1. Empirical or survey data representing the modal shifts associated with the action (both between modes of motorised transportation and from motorised to non-motorised)
2. Empirical or survey data representing the numbers of vehicles and vehicle-kilometres for different emissions labels.
3. Determining the values of statistical hospital admissions costs for respiratory- and CVD-related hospital admissions.

5 APPROACH

5.1 METHODOLOGY

For each climate action there are a number of steps that have been taken to assess the air quality related health impacts. These are described briefly below and will be elaborated for the specific context of the Barcelona's action in following sections. The steps below represent the core actions to be taken for a full analysis but these steps should be preceded by some preparatory steps.

The methodology will be covered in two key parts:

Section 4.2 will focus on planning the analysis process based on the overall C40 benefits analysis process, identifying actions and benefits that are appropriate to Barcelona's policy aims. The process describes the interrelations between the various components of the 'casual chain' – inputs, outputs, benefits.

Section 4.3 will cover the concepts specific to the analysis of air quality and its related health impacts. The analysis follows five consecutive stages:

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

5.2 PLANNING THE OVERALL BENEFITS ANALYSIS PROCESS

Reconciling scientific complexity and the necessity of facilitating rapid action in cities: Please note the technical team recognise the complexity of air quality and health science and have sought to undertake top-level analysis in a manner that can be relatively easily reproduced by participating cities without arriving at indefensible figures. This reflects C40's desire to support swift, evidence-based, climate action in cities. Acting on this principle means finding ways to take scientifically sound measures based on available knowledge and with suitable sensitivity checks to account for potential further developments of the field.

5.2.1 BENEFITS PATHWAY

Benefits pathways are a useful way to map out the benefits emerging from air quality actions. An action is any intervention on the ground that leads to a change in social, economic and/or environmental conditions, e.g. a Low Emission Zone, a BRT system, cleaner municipal bus replacement, etc. The output of this intervention is the physical or observable change that it brings about, e.g. an increase in number of people using public transportation, or decrease in number of vehicles within a given area.

Finally, the outcome is the benefit of this change to the city or population, e.g. a reduction in level of pollutants in the city, an increase in life expectancy. An output can also be a benefit in itself. The diagram below illustrates the possible outputs and outcomes/benefits associated with the LEZ in Barcelona.

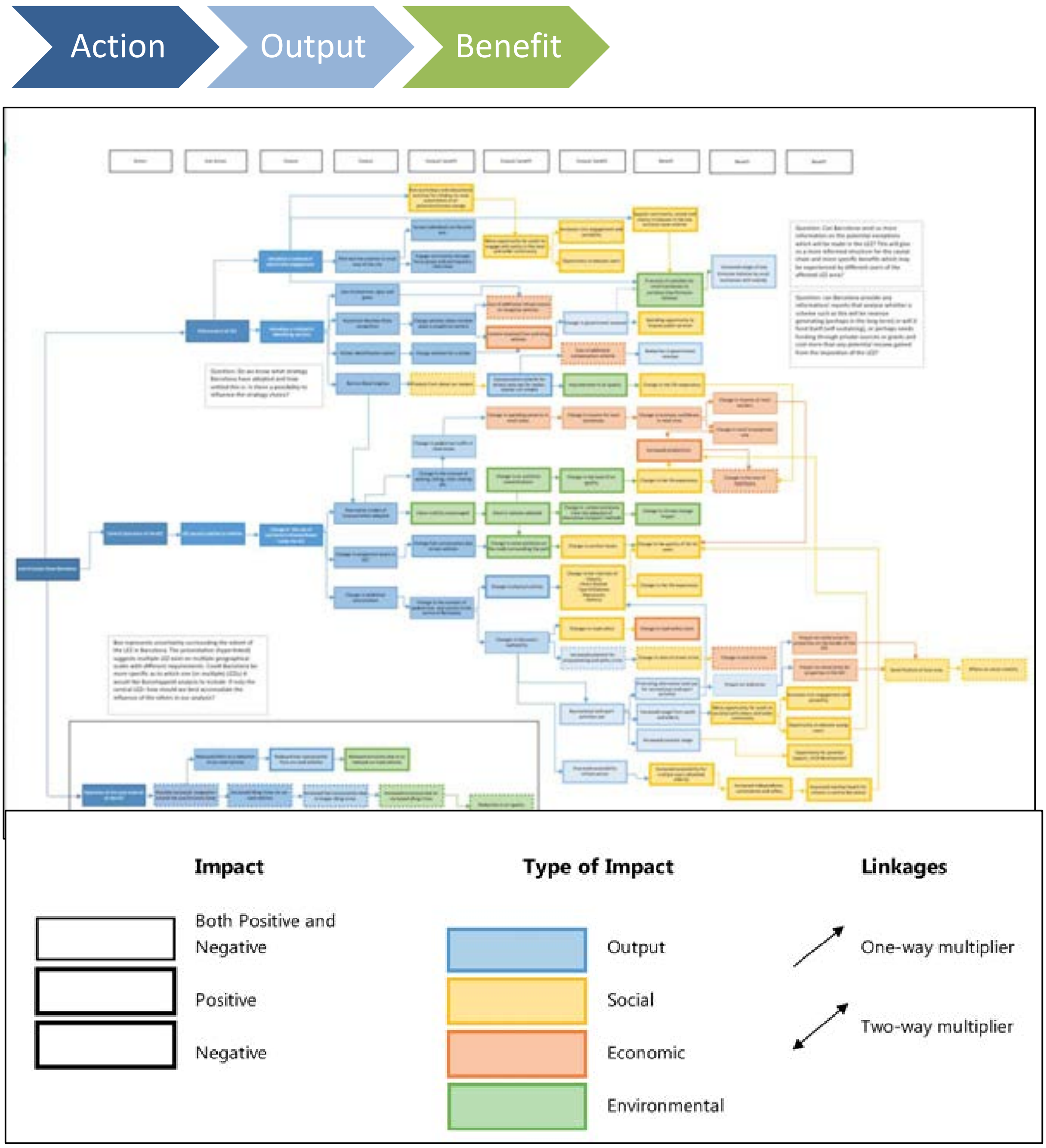


Figure 1 Benefits Pathways for Barcelona's LEZ. For high resolution version of the image please see supporting links in Appendix A

5.2.2 LITERATURE REVIEW

To support the benefits pathway the C40 and BuroHappold project team conducted an extensive literature review to identify list of available literature from other cities and similar research that could be used to support the causal links between the action and the anticipated outputs and benefits. This helped build a more complete picture of potential benefits. See Appendix A for a full list of literature.

Please note it is important to understand which benefits are the priority for the city, before commencing data collection. This keeps data collection and analysis targeted on the benefits that are likely to be most valuable or persuasive for city stakeholders.

5.2.3 DATA COLLECTION

Based on the prioritised benefits, the city team completed a data collection template to provide data from before and after the intervention. The data collected covered all elements of the benefits pathway: action, output and outcome. Collecting pre- and post-intervention data is essential for understanding the change over time, and any available time-series data can be particularly useful.

The key data requested from Barcelona included:

ACTION DATA

- Number of vehicles circulating in Barcelona classified by label type
- Emission factors by traffic type
- Proportion of vehicles upgrading to label C
- Change in the distance travelled by each vehicle after the action

POLLUTANT DATA

- NO_2 (g/µm^3): background concentration and annual average
- NO_X (g/µm^3): background concentration and annual average
- CO_2 (tonnes/year)
- $PM_{2.5}$ (g/µm^3): background concentration and annual average
- Contribution from roads to the non-background concentrations ($PM_{2.5}$ and NO_2)

HEALTH DATA

- Annual deaths per age and gender
- Annual population per age and gender
- Respiratory-related hospital admissions per age and gender
- Cardiovascular Disease-related hospital admissions per age and gender
- Annual average Value of a respiratory-related hospital admission
- Annual average Value of a cardiovascular disease-related hospital admission

5.2.4 DATA GAP ANALYSIS

The data provided by the city team was reviewed and gaps in the data were identified against the essential data required to measure the benefits for this study. Gaps were discussed with the city to understand what further local information might be available to fill any of these gaps, and which gaps should be addressed through a literature review (e.g. using proxy data and benchmarks). See section 3.1.1, 3.2.1, and 3.3.1 for further elaboration on the specific data gaps and assumptions made in response.

5.2.5 DATA ANALYSIS

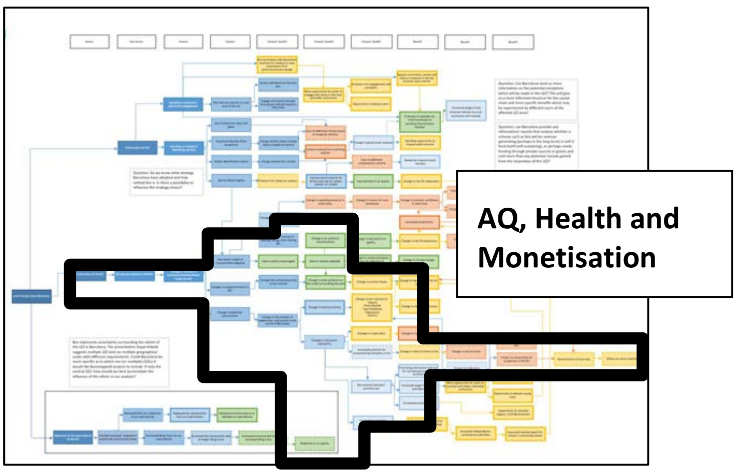
City data was combined with multipliers and proxy data from wider research to estimate the benefits of upgrading a proportion of the bus fleet to a EURO VI emission standard. Three types of measurement were used to estimate the benefits:

- **Monetisation** – economic multipliers were used to convert health benefits, into a monetary value.
- **Quantification** – utilising data from Barcelona, the change in air pollution as a result of the action - for a number of pollutants was calculated; and Life tables, were used to estimate the associated health benefits of the action from reduced air pollution.
- **Illustration** – based on research about other cities, examples of interventions in other cities were used to provide an indication of what the benefits in Barcelona might be. Illustration is particularly useful in cases where local city data is not available, but an indication of potential benefits is still needed.

5.3 THE ANALYTICAL BENEFITS PROCESS FOR AQ AND HEALTH

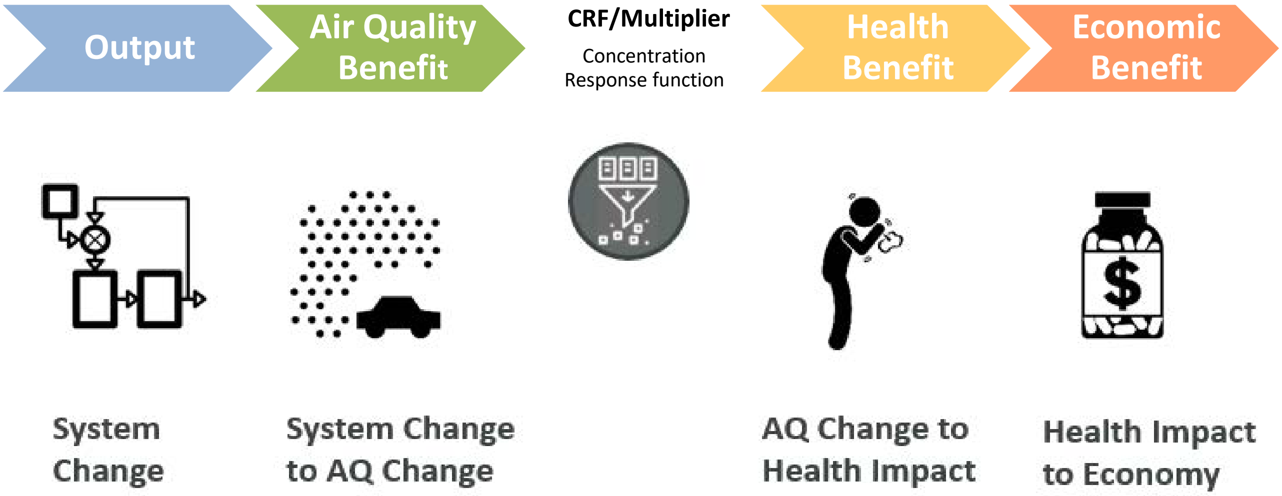
This section provides an overview of the specific analytical process to evaluate the air-quality related health impacts from urban climate actions.

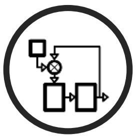
In order to measure impacts of a given action, it is important to understand the links between action, outputs, and benefits. This section will summarise the interrelations between the different elements of the calculation process –system change (action), air quality change (output/benefit), health outcomes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



5.3.1 OVERVIEW OF PROCESS

This diagram summarises the analytical process:





5.3.2 DEFINING THE SYSTEM CHANGE

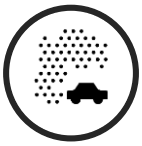
System change refers to a change in the main elements of the system or systems related to the action being measured. For example, introducing a ‘low emission zone’ may trigger changes in the city’s travel system including: reductions of the number of cars on the road, changes to citizens’ travel behaviour, 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 may seem obvious but 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.



5.3.3 FROM SYSTEM CHANGE TO 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.

5.3.4 FROM AIR QUALITY CHANGE TO HEALTH IMPACT

<u>Selecting a concentration response function (CRF)</u>

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 mortality (from all causes) and cardiovascular and respiratory hospital admissions (as measures of risk of disease/morbidity).

<u>Applying the selected CRF</u>

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.

5.3.5 HEALTH BENEFIT 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 Admissions.

5.4 LIMITATIONS

When looking at the case of Barcelona specifically, three main limitations has arisen out of the investigation:

1. The inclusion of proxy values from UK-specifically regarding VOLY, morbidity and value for respiratory- and CVD-related hospital admissions.
2. The results showed in this report are based on the assumption that after the action, the “No Label” vehicles will disappear and will be 100% replaced by “Label C” vehicles. A scenario-based analysis has been conducted to identify potential outcome of scaling-up the action; however, a precise distribution of the vehicles after the action would have provided a better understanding of the actual outcomes.
3. In addition, the model does not reflect the intended reduction of vehicles circulating in the city as a result of stricter regulations on the circulating fleet and measures to promote use of non-motorised transportation.
4. Lastly, it is worth to mention that air quality change have been calculated by using COPERT emission factors. Whilst COPERT methodology is the best official data to measure emission factors, there may be some instances of underestimating emissions from certain vehicles and, as a result, over-estimating the health benefits of the action as measured. Of course, other inaccuracies may offset this.

6 APPENDIX A: ALL SUPPORTING DOCUMENTS

All supporting documents can be found in the link below. These documents include:

- Barcelona Action Causal Diagram
- Barcelona Action Literature Review
- Barcelona Action Analysis Spreadsheet

Link to Files: https://c40.box.com/s/40ackzk63nwppgqd4cq8yvu1l88bsa52

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