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Benefits of Climate Action

Salvador: Benefits of Upgrading the Municipal Bus Fleet

A report prepared by BuroHappold for C40 Cities
Climate Leadership Group

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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 for a 1.5 degree world

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 Salvador, from the municipality upgrading a significant proportion of its bus fleet (28%), from EURO II to EURO VI emissions standards. However, it is important to note that C40 policy strongly promotes exploration of options for upgrading to electric buses – in order to achieve carbon and air quality gains together with 'total cost of ownership' savings[1].

The central findings from some high-level scenario analysis suggests that while the gains associated with moving from Euro VI to Electric are modest (but significant) in terms of reducing pollutants that are prejudicial to health, they are important in terms of reducing pollutants that are prejudicial to climate change. In this context, therefore, the risks of locking-in to combustion engine technology are high because the capital investments are only likely to be made once in a generation. Since the real choice is between moving from Euro II to Electric or from Euro II to Euro VI, it is important to take the most impactful action as possible, at the widest scale possible, and at the earliest opportunity possible.

Both scenarios fall in line with Salvador's climate and economic development strategy. However, making the leap towards electrification will provide unparalleled environmental gains for Salvador, as the city positions itself away from fossil-fuel dependency, whilst vastly improving air-quality and the well-being of its citizens.

Recent studies conducted by the International Council on Clean Transportation (ICCT) have addressed the potentially lower long-term operational costs of electric buses compared to their diesel-powered counterparts. Their analysis of Latin American cities such as: Sao Paulo, Santiago, Buenos Aires, Bogota, Mexico City, and Lima, argues the case that 'total cost of ownership' of pure electric buses is 14% lower than EURO VI buses, and 16% less for EURO IV[1]. C40 acknowledges the current market limitations to purchasing electric vehicles, and is currently working to help facilitate viable solutions.

[1] ICCT, 2017 https://www.theicct.org/sites/default/files/publications/Soot-Free-Bus-Financing_ICCT-Report_11102017_vF.pdf

The following summaries capture the estimated benefits from the core action of upgrading 20% of the total municipal bus fleet to Euro VI grade vehicles (650 vehicles from a total of 3245 municipal buses on the road). These results indicate where additional benefits can be achieved when the whole STCO fleet (2,348) is upgraded, and/or the upgrade itself is to fully electric vehicles. These ambitious scenarios have been considered in more detail, demonstrating significant outcomes, in Section 4.3.

ENVIRONMENTAL

Approximately **2.3% reduction in** overall non-background PM2.5

Potentially **rising to 8.5%** if the whole STCO fleet is upgraded to electric.

No reduction in city-wide CO_2 emissions associated with the upgrade to Euro VI compliance

Potentially **changing to a 5.03% reduction** in overall city-wide CO2 emissions if the entire STCO fleet is upgraded to electric.

SOCIAL

10 deaths averted annually across the total population

Potentially rising to **39 deaths averted** if the entire STCO fleet was upgraded to electric

Life expectancy increased by **2 days per person** across the total population.

Potentially rising to **8 days** if the entire STCO fleet was upgraded to electric

ECONOMIC

BRL 19.4 Million - Approximate costs avoided due to mortality from change in PM2.5 levels

Potentially rising to **BRL 72 million** if the entire STCO fleet was upgraded to electric

BRL 4,000 - Approximate costs avoided due to respiratory hospital admissions from change in PM2.5 levels

BRL 6,000 - Approximate costs avoided due to cardiovascular hospital admissions from change in PM2.5 levels

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 (NO2), which can be harmful to health	DEFRA
NO_X	NO2 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}	PM10 is defined as the mass concentration of particles of generally less than 10 µg aerodynamic diameter.	COMEAP

	This fraction can enter the lungs. PM10 includes PM2.5.	
$PM_{2.5}$	PM2.5 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, PM2.5 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

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. This report presents the latest findings of this ongoing research.

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 actors within city government 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, unlocking a greater speed and scale of action required to achieve climate safe, liveable cities.

1.1 THIS REPORT

This report outlines the initial findings from the benefits analysis conducted on Salvador, wherein the city government provided insights into their vision for significantly upgrading the city's bus fleet from its current standard – equivalent to EURO II – to that of EURO VI.

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 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 this specific climate action in Salvador. The financial gains that are then accrued from these improvements in public health will also be estimated.

2 SALVADOR'S ACTION AGENDA

Salvador are now looking to progress to phase 2 of their Municipal bus renewal strategy as part of their urban climate action. In 2015, 885 of the municipality's STCO diesel-powered buses were upgraded to an equivalent of EURO V emissions standards. The city is now looking to renew an additional 650 buses. The dominant proposal is that these buses be upgraded to EURO VI emissions standards, however an alternative scenario is that of an electrification of the city's bus fleet. Whilst both options will provide a marked improvement to Salvador's air-quality, by opting to begin the transition to electric, Salvador will be diminishing further lock-in to fossil-fuel, bring about unparalleled CO2 reductions, and all with the potential for lower 'total ownership costs'[2] of the vehicles themselves. Whether a greater or fewer number of buses are replaced, remains contingent on which scenario is decided upon.

At the time of writing this report, phase 2 is intended to commence in 2018 and will also be taking place on the same STCO bus system. The STCO system has a total fleet of 2,348 buses, and total distance of 563,776km is travelled per day – an average distance of 240km/day is travelled by each bus. The capacity of the new buses will remain the same as the previous fleet, and the upgrade itself has been forecast to cost the municipality around BRL400m (equal to approximately US$120m). As well as the STCO bus system, the municipality operates the STEC and Metropolitano bus systems, the combined total of this public fleet (3,245) and the city's private buses amounts to 9,103 buses on the streets of Salvador[3]. The STCO Bus system has a fleet of 535 lines – providing city-wide coverage – and is split into three core urban districts: Plataforna, Otima, and Salvador Norte. According to the municipality's recent estimates, roughly 65% of daily journeys on public transport are taken on the STCO bus system[4].

The analysis presented within this report is solely focussed on addressing the public health and financial gains associated from implementing an environmental 'air-quality' action – in this case, upgrading 650 STCO buses. This upgrade of 650 will be assessed in relation to what the municipality can potentially (directly) impact – i.e. the entire 3,245 municipal bus fleet – all the while has recognising that there are an additional 5,868 private buses on the streets of Salvador. The analysis has been refined in the light of what data has been available.

A particularly exciting element of the action when looking forward, is the scope for augmenting the intervention beyond this initial phase of renewal. The 885 buses already upgraded account for just 38% of the STCO fleet, and only 10% of all buses on the streets of Salvador – both private and municipal. Similarly, the 650 buses proposed for phase 2 account for a further 28% of the STCO system, and 7% of the total bus fleet of Salvador.

Not only can the environmental performance of the city's bus service be improved through the upgrade of the bus fleet, but complimentary measures incentivising the use of these buses, and dis-incentivising the use of fossil-fuel emitting private vehicles, can also play a

[2] ICCT, 2017 https://www.theicct.org/sites/default/files/publications/Soot-Free-Bus-Financing_ICCT-Report_11102017_vF.pdf
[3] Table of vehicle fleets: https://cidades.ibge.gov.br/painel/frota.php?codmun=292740&lang=_EN
[4] Plano De Mobilidade Sustentavel De Salvador (2017): http://www.planmob.salvador.ba.gov.br/images/consulte/planmob/PlanMob-Salvador-Apresentao-do-Diagnstico-da-Mobilidade-de-Salvador----160817---Compacta.pdf

pivotal role in augmenting the positive environment, social, and economic benefits achievable. When looking at capital costs specifically, an upgrade to Euro VI may appear more cost effective, but as noted in the executive summary, long-term considering should extend to both capital and operational expenditure. When doing so, electric buses can then be deployed as a more cost-effective option due to their lower operational costs relative to their petroleum-fuelled counterparts. The empirical evidence should inform this decision, addressing both capital and operational cost for transitioning, as well as determining which of the pollutants – CO_2, $PM_{2.5}$, or NO_2 – are highest priority.

By the nature of this action being a road-based intervention, it is on the streets of Salvador where the impacts will be most strongly felt. Therefore, the geographic location of the city's monitoring stations – and their proximity to roads – will greatly affect the empirical robustness of any further evaluations undertaken.

Aim of action

Firstly, Salvador have engaged with this action as the city looks to leverage a more socially and environmentally transformative agenda, one that holds the improvement of citizen well-being at its heart. This project falls in-line with 'The Salvador 500 Plan', a long-term development strategy for the city up to 2049. Salvador's vision over this period is to embrace climate action as an economic development directive, seeking to control the city's heat expansion, air pollution, and thermal radiation. The Municipal Administration acknowledges the need to both: take action over climate issues, as well as explore options for more accurate health and air-quality data. Balancing these concerns has become increasingly vital when building public support for climate action.

Moreover, Salvador acknowledges the specific needs to diminish the city's greenhouse gas emissions produced by the transportation sector – roughly accounting for 74% of total emissions[5]. Upgrading the municipal bus fleet has become a popular and effective method of intervention by city administrations across the globe, and in that regard Salvador look to replicate this success and lead by example in the region.

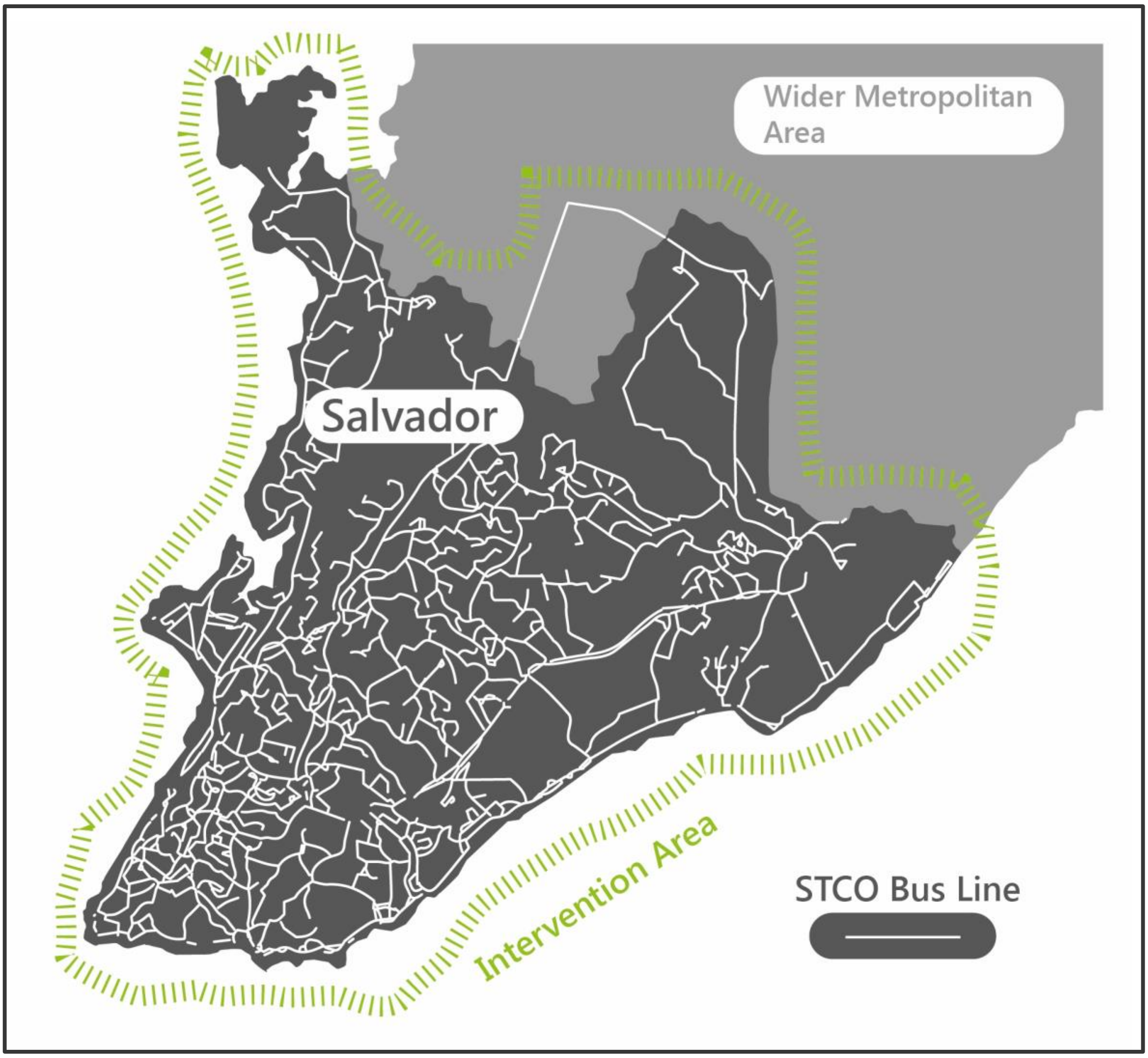
Aim of measuring the benefits of this action

Salvador wants to use the results from benefits measurement in order to:

1. Facilitate the understanding of the strong relation between air quality and human health;
2. Support public policies to foster a truly transformational action which will improve the citizens' health through improved air quality; and
3. Help policymakers in achieving the targets of the comprehensive Salvador 500 Plan

[5] Emissoes Dos Gases Do Efeito Estufa (2016): http://www.sustentabilidade.salvador.ba.gov.br/wp-content/uploads/2016/06/inventario-de-emissoes-de-gases-final-compressed.pdf?download=1

Location and scale



Time scales

The upgrade of the bus fleet is set to take place in 2018.

Future plans:

885 buses have already been replaced, around 650 more have been proposed for phase 2 of the municipal fleet upgrade. The future trajectory for the action will depend on how far the parameters are set for scale (i.e. number of buses replaced) and intensity (i.e. whether the standard is EURO VI or electric).

3 BENEFITS OF UPGRADING SALVADOR'S BUS FLEET

3.1 ENVIRONMENTAL BENEFITS

The extent of the environmental benefits for upgrading Salvador's buses depends on whether Salvador decide to invest in electric vehicles or consolidate a combustion-engine based fleet. The EURO code emissions standards have, thus far, focussed on reduction of emissions from toxic pollutants although this may change in the future. According to the UK Government's calculations, EURO II buses have a lower CO_2 exhaust emission factor (618.2 g/km) than their EURO VI counterparts (636.6 g/km).

Therefore, unless Salvador commit to implementing electric bus renewals, the action in question appears likely to be climate-negative as there will be a small increase in bus-generated CO_2, rather than the decrease that might have been expected. The range of impacts Salvador's action could have is captured below:

Quantity of Buses Upgraded	Level of Upgrade	% Change in Municipal Bus-Related CO2	% Change in Total Bus-Related CO2 (private and municipal buses)	% Change in Overall City-Generated CO2		
				MODEL 1	MODEL 2	MODEL 3
650	EURO VI	0.60	0.21	0.02	0.03	0.04
2348	EURO VI	2.10	0.75	0.08	0.12	0.15
650	Electric	-20.00	-7.13	-0.80	-1.10	-1.39
2348	Electric	-72.40	-25.81	-2.90	-3.97	-5.03

Buses account for between 15.7-27.2% of Transport-related CO2 Emissions in Brazilian cities
Municipal buses account for 35.6% of all buses in Salvador
Transport accounts for 71.6% of overall CO2 emissions in Salvador

Model 1: Bus CO2 emissions = 15.7% of Transport-related CO2 emissions
Model 2: Bus CO2 Emissions = 21.5% of Transport-related CO2 Emissions
Model 3: Bus CO2 Emissions = 27.2% of Transport-related CO2 Emissions

The above scenarios have been developed using the transport emissions data provided by the city[6], as well as an IPEA Brazilian government report on transport emissions in Brazil's major urban centres[7]. Due to the lack of precise data, the IPEA report models CO_2 emissions by vehicle type according to a 'worst-case' and a 'best-case' assumption, being that 1) public transport journeys are equal in length to individual trips, or 2) public transport journeys are double the length of individual trips. Scenario 1 results in buses taking a 15.7% share of transport related CO_2 emissions, whilst Scenario 2 apportions buses with a share of 27.2%. In recognising the real-world situation will reside somewhere in-between, our analysis has taken an average of two (21.5%) in order to create a third scenario (Model 2 above).

[6] GHG_Salvador_2013_GPC_Final_20170615: Spreadsheet in C40 Link on page29.
[7] IPEA report (2011): http://www.en.ipea.gov.br/agencia/images/stories/PDFs/TDs/td_1606.pdf

The above table illustrates how an upgrade to any EURO code will result in a marginal increase in CO_2 – due to EURO II having a lower emission factor than EURO VI (g/km) – and so further makes the case for leapfrogging to electric buses. A core assumption has been made, in that all of the 9,103 buses on Salvador's roads have been modelled as emitting equally, therefore in knowing municipal buses account for 35.65% of all buses, we have assumed that they also account for 35.65% of the CO_2 emissions. Based on conversations with the city, it has also been assumed that the existing, pre-upgrade, vehicles are Euro II compliant but not Euro III compliant[8].

Under the above logic, models 1-3 further drive the evidence-base that shifting to an electric upgrade programme for the 650 buses could deliver a ***total CO_2 emissions reduction of between -0.8% and -5.03%*** (depending on which of the three models is closest to reality). Importantly in the short term, a shift to electrifying the entire STCO bus fleet will mean an impressive 72.3% reduction in municipal bus-generate CO_2 emissions, setting an essential precedent for the private sector to follow.

In terms of air quality, the current estimates for Salvador's action forecast a 2.3% reduction in non-background $PM_{2.5}$, whereas non-background NOx is reduced by 4.2%.

3.1.1 OVERVIEW OF DATA AND ASSUMPTION

The analysis undertaken was guided by Salvador's relatively comprehensive pollution data. The city's environmental sensor network consists of 8 monitoring stations – listed below – each recording pollutant concentrations every 15 minutes. This then meant that the analysis was able to draw upon extremely accurate average levels for NO_2, NO_X, and $PM_{2.5}$.

Monitoring Stations:

- Paralela-CAB
- Campo Grande
- Dique de Tororo
- Rio Vermelho
- Piraja
- Avenue ACM/Detran
- Itaigara
- Avenue Barros Rei

Whilst minimal manipulation was required for the pollutant calculations – i.e. simply converting PM_{10} to $PM_{2.5}$ [9]– significant assumptions needed to be made regarding the emission source apportionment of the pollutants. Whilst the city had recent data on sectoral emissions, determining the contribution of buses towards the different pollutants (NO_2, CO_2, and $PM_{2.5}$) required interpretation of the figures displayed in the 2010 study on vehicle emissions in the metropolitan region of Salvador[5].

A key assumption that has been made relates to the geographical extent of the 'intervention area' within Salvador. As we are currently unaware of whether some, or all, of the STCO system will be affected by the action, we have presumed the entire system is affected by the action. Therefore, as the system covers the entire city, we recognised the whole city as the action's "intervention area". If more precise information was to become available regarding specific routes that will be effected by the bus renewal, the analysis will

[8] Euro III vehicles emit greater quantities of CO2 than Euro II and slightly more than Euro Iv, V and VI. Thus, an upgrade from Euro II to Euro VI would be marginally climate-negative but an upgrade from Euro III to Euro VI would be marginally climate-positive.

[9] According to the WHO, when converting PM10 to PM2.5 in the region of Salvador de Bahia, a conversion coefficient of 0.54 is suggested. i.e. 10mg/m3 PM10 = 5.4mg/m3 PM2.5.

then be able to focus the impacts on a smaller scale and population, and could demonstrate a higher magnitude per capita.

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)[10,11]. 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 real-world emissions 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.

3.1.2 KEY FINDINGS

Due to Salvador's action, there is a 2.3% reduction of the non-background $PM_{2.5}$ concentration, leading to the city's average being reduced by 0.1µg/m³ to 13.7µg/m³. This reduction means that Salvador's action diminishes the gap between the city's average concentration levels (13.8 µg/m³), and the WHO air-quality guideline recommended $PM_{2.5}$ maximum of 10µg/m³. This gain in air-quality accounts for about 2.6% of the difference between Salvador's actual level and the WHO recommended maximum, demonstrating encouraging progress for further enhancement. Furthermore, in the context of bus renewals this is significant since all buses only account for 1.1% of vehicles on the road in Salvador[12].

Global example:

When addressing wider environmental benefits, studies conducted within the UK concluded that placing buses at the centre of an air-quality strategy is crucial for the solution of air quality problems. The aim in the process is to reduce the number of emissions per passenger which is obviously more achievable by making buses more efficient. It has been evidenced that Euro VI diesel buses release less emissions than a Euro VI car and that NOx emissions from diesel buses have been reduced by a factor of 20 from 2004-2017 in the UK[13].

[10] "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
[11] IVL - Remote sensing testing: "Measurement of bus emissions 2010-2015" http://www.ivl.se/download/18.29aef808155c0d7f0504cb/1472802397237/B2254.pdf
[12] Calculated using table: https://cidades.ibge.gov.br/painel/frota.php?codmun=292740&lang=_EN
[13] Begg (2017) 'Improving air Quality in towns: http://www.greenerjourneys.com/wp-content/uploads/2017/04/Improving-Air-Quality-in-Towns-and-Cities-PROF-DAVID-BEGG-Final.pdf

3.2 SOCIAL BENEFITS

The social benefits from implementing Salvador's municipal bus upgrades are significant, in that the aversion of 10 deaths and 5 hospital admissions, and a total of 187 life years gained, are all associated with the city's decrease in $PM_{2.5}$ concentration. Life expectancy is also boosted by an average of 2 days per individual across the entire city population, as an alternative measure of improved public health.

3.2.1 OVERVIEW OF INPUT DATA AND ASSUMPTIONS

The population and health data was comprehensive and relatively consistent with one another. Deaths and hospital admissions per age and gender were available for 2015, whilst population per age and gender was also available for 2015 via the government portal[14]. The most significant manipulation of the data related to the translation of the UK VOLY value (£36,431) into BRL, using an OECD-Data purchasing power parity (PPP) conversion-rate[15].

Measuring the impacts on morbidity was relatively straightforward due to readily available data on respiratory- and CVD-related hospital admissions on a monthly basis.

3.2.2 KEY FINDINGS

Every year Brazil experiences 25,000 deaths due to poor outdoor air quality[16], largely driven by pollution within cities. Proportional to Salvador's size, it may be estimated that the city experiences approximately 350 outdoor air-quality related deaths due to pollutants. In the context of the city's current action to implement 650 EURO VI buses, the 10 deaths averted equate to approximately 3% of the city's annual air quality related deaths.

Global example:

An additional wider social benefit associated with municipal bus strategies, relates to the improvements in wellbeing and safety. Studies conducted in the USA have concluded that investments in public bus systems often lead to improved well-being and safety – particularly within congested CBDs[17]. As these interventions produce environments that are five-times safer through reduced traffic casualties per capita in relation, as well as concluding that bus journeys themselves are ten-times safer per mile to travel than car.

[14] 2015 Population per age and gender: http://www.tabnet.saude.salvador.ba.gov.br/tabcgi.exe?tabpop/populacao.def
[15] OECD Purchasing Power Paritry (PPP): https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm
[16] Copenhagen Consensus Article: http://www.copenhagenconsensus.com/publication/brazil-perspectives-air-pollution
[17] American Public Transport Association (2016) 'The hidden traffic safety solution: public transportation: https://trid.trb.org/view.aspx?id=1422707

3.3 ECONOMIC BENEFITS

The economic value from improved health outcomes associated with implementation of Salvador's bus renewal is best expressed in terms of 'life years gained'. In that sense, the main benefit to Salvador's economy is accrued from the deaths averted and the incident reservation of productivity from the surviving population. There are also significant estimated healthcare cost savings, for both respiratory- and CVD-related hospital admissions.

3.3.1 OVERVIEW OF DATA AND ASSUMPTION

In the absence of Salvador-specific Values of Life Years (VOLY), the mortality costs avoided – i.e. the value of the life-years retained by society and Salvador's economy – were derived using proxy values from the UK and then converted in Brazilian Real (BRL) at purchasing power parity (PPP). By contrast however, the morbidity values, including specific annual averages for both respiratory- and CVD-related hospital admission costs, were calculated using locally generated data on healthcare costs associated with both ailments.

3.3.2 KEY FINDINGS

Through implementing Salvador's action, the city stands to save significant healthcare costs through the volume of hospital admissions averted. According to the reductions in $PM_{2.5}$, around BRL 19,000,000 in economic gains will be made due to the number of 'life years' saved. Furthermore, due to the aversion of 6 hospital admissions, around BRL 10,000 will be directly saved in healthcare costs.

4 COMMENTARY AND POTENTIAL POLICY INSIGHTS

4.1 MAIN OBSERVATIONS

The core observation emerging from the analysis of Salvador's action, revolves around the balancing of back-casting the completed action – 885 buses from EURO II to EURO V – and forecasting the proposed second phase of the project – 650 buses from EURO II to EURO VI.

Consideration should be given to leap-frogging the EURO standards and the environmental and social benefits accrued from doing so, contrasted with the higher capital costs of both more expensive electric buses, and the charging infrastructure required. Further studies may be required to establish the trade-offs between incurring the short-term costs of electrification and the provision of appropriate charging infrastructure against the significant estimated long-term savings associated with the buses operation.

4.2 OPPORTUNITIES FOR SCALING UP OR SPEEDING UP

The opportunities for scaling- and speeding-up the positive benefits mainly relate to:

1. Enhancing the bus upgrade to a fully-electric vehicle upgrade
2. Accompanying the bus upgrade with complimentary transport policies around incentivising public transport (over private car use), as well as promoting walking and cycling.

The first opportunity for Salvador to leap-frog EURO emissions standards and invest directly in an electric fleet is broadly characterised by 4 main factors:

- The environmental, social, and economic gains accrued from eliminating exhaust pollutants
- Avoiding lock-in to carbon-based transport in the long-term
- Higher capital costs in the short-term, both directly in that electric buses are more expensive, and indirectly as the city would then need to invest in the appropriate charging infrastructure.
- Potentially lower operational costs in the longer term, as a recently published ICCT study argues the case that 'total cost of ownership' of pure electric buses is 14% lower than their EURO VI counterparts (16% less for EURO IV).[18]

The potential scale at which Salvador could implement electric buses, and the pace at which this transition could happen, will ultimately depend on how the city can navigate the above challenges in the short-term, whilst eliciting the long-term benefits.

Beyond this, a successful bus intervention at the city-level will provide an important foundation for further extending a clean transport regime to the wider metropolitan, and Bahia provincial scales.

[18] ICCT, 2017 https://www.theicct.org/sites/default/files/publications/Soot-Free-Bus-Financing_ICCT-Report_11102017_vF.pdf

The second opportunity – relating to policies that accompany the bus renewal – will play a vital role in capturing the core environmental, social, and economic outputs, as well as maximising the wider benefits. For example, in order to fully accrue the efficiency gains that cleaner buses provide, pollution per passenger will only be reduced if the use of buses in opposition to cars are incentivised.

Global example:

A successful strategy in this field has been to use reduced journey times as an incentive, by implementing bus-only lanes. A study conducted in Santiago, Chile, concluded that the establishment of bus-only lanes reduced total transportation times by 10-25%, and the buses themselves were 40% faster due to the reduction in congestion and the allocation of distinct bus-lanes[19].

4.3 SCENARIO ANALYSIS

In order to more accurately forecast the potential environmental, social, and economic gains Salvador could experience through the augmentation of the city's action, this investigation modelled 4 scenarios in which: 1) the number of buses replaced, or 2) the 'level of upgrade', were either individually or collectively adjusted. Four scenarios (A to D) were developed as specified below:

A. **650 buses** upgraded from **EURO II to EURO VI**
B. **650 buses** upgraded from **EURO II to Electric**
C. **2348 buses** [Whole STCO] upgraded from **EURO II to EURO VI**
D. **2348 buses** [Whole STCO upgraded from **EURO II to Electric**

These scenarios were modelled at high level for both pollutants ($PM_{2.5}$ and NO_2) and the results are captured in the tables on the following page. By inspection it may be observed that the health outcomes associated with implementing an action for a larger number of vehicles (scaling-up) increase broadly in line with the number of vehicles included in the initiative.

The extra-over health enhancements associated with moving to fully electric instead of Euro VI are significant but more modest when compared with scaling-up. This is perhaps unsurprising given that Euro VI represents a stringent emissions standard and the proportion of the city's non-background pollutants associated with the buses is estimated at no more than 15% for $PM_{2.5}$ and 21% for NO_2.

As has been demonstrated in Section 3.1 earlier, the climate benefits from the initial action, upgrading to Euro VI compliant vehicles are negligible or even negative. Thus, it may be concluded that the optimal outcome would be to move to a fully electric fleet, which would likely yield significant operational cost-savings in addition to the health and climate benefits.

[19] For Clean Air and a Safe Climate Future (2015) https://www.huffingtonpost.com/marcelo-mena/for-clean-air-and-a-safe-_b_7689278.html

It is also evident that scaling up initiatives to cover as much of, or all, of the city network will be fundamental to securing the collective suite of benefits available to the city.

PM2.5

ID	SYSTEM CHANGE			AIR-QUALITY IMPROVEMENT	HEALTH BENEFITS			MONETARY BENEFITS	
Scenario	No. of Fleet Affected	From	To	Reduction in Non-Background PM2.5 (%)	Deaths Averted	Life Years Gained	Hospital Admissions Averted	Economic Gain (Mortality Aversion)	Total Costs Avoided (Hospital Admissions)
A	650	II	VI	2.3%	10	187	5	BRL 19,373,000	BRL 10,000
B	650	II	E	2.3%	11	192	5	BRL 19,921,000	BRL 11,000
C	2348 [Whole STCO]	II	VI	8.2%	38	676	15	BRL 69,950,000	BRL 36,000
D	2348 [Whole STCO]	II	E	8.5%	39	695	18	BRL 71,923,000	BRL 37,000

NO2

ID	SYSTEM CHANGE			AIR-QUALITY IMPROVEMENT	HEALTH BENEFITS			MONETARY BENEFITS	
Scenario	No. of Fleet Affected	From	To	Reduction in Non-Background NO2 (%)	Deaths Averted	Life Years Gained	Hospital Admissions Averted	Economic Gain (Mortality Aversion)	Total Costs Avoided (Hospital Admissions)
A	650	II	VI	4.2%	23	414	6	BRL 42,895,000	BRL 9,000
B	650	II	E	4.2%	23	415	6	BRL 42,923,000	BRL 9,000
C	2348 [Whole STCO]	II	VI	15.2%	83	1495	21	BRL 154,797,000	BRL 34,000
D	2348 [Whole STCO]	II	E	15.2%	83	1496	21	BRL 154,898,000	BRL 34,000

4.4 FUTURE DATA COLLECTION ACTIVITIES

The three main suggestions for further data collection are:

1. Confirm which lines on the STCO are being affected by the bus upgrade – if not all.
2. Further data should be accumulated on the remainder of the municipal fleet – the STEC and Metropolitano lines – in order to more accurately model the source apportionment of all emissions from the buses allocated for renewal.
3. With municipal buses only accounting for 35.65% of all buses, there will need to be a further emissions-data collection on the private buses to better understand whether a municipal upgrade is disproportionately affecting above or below its physical share of the city's total fleet.
4. Determining a locally derived VOLY in order to gain a more accurate representation of the real costs averted through life years saved.

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 Salvador'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 Salvador'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

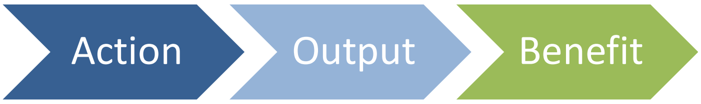
5.2 PLANNING THE OVERALL BENEFITS ANALYSIS PROCESS

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 a municipal bus replacement intervention in Salvador.



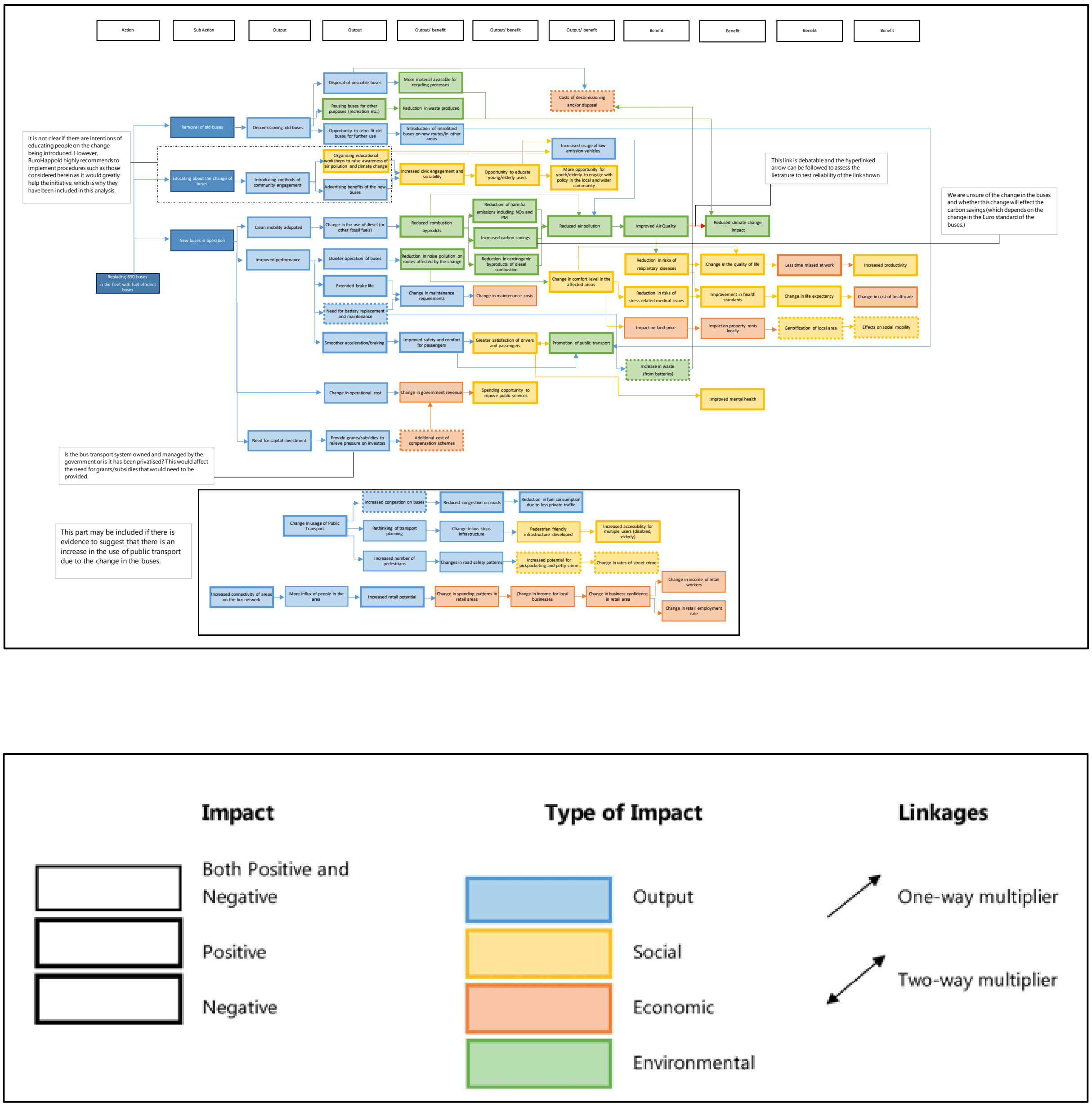


Figure 1 Benefits Pathways for Bus Replacements in Salvador. For high resolution version of the image please see supporting links in Appendix A

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 Salvador included:

ACTION DATA

- Emission factors for EURO II and EURO VI standard buses – as well as fully electrified buses.
- Proportion of bus fleet allocated for upgrade (650 buses).
- Bus system relevant to the upgrade (STCO) – including specific bus routes/city coverage.

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
- Source apportionment of NO2 and PM2.5 for terrestrial transport

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

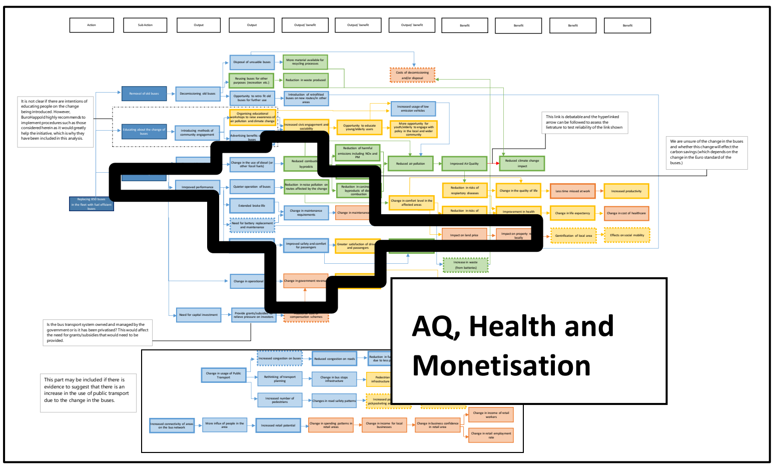
City data was combined with multipliers and proxy data from wider research to estimate the benefits of upgrading a proportion of the bus fleet to a EURO VI emission standard. Three types of measurement were used to estimate the benefits:

- **Monetisation** – economic multipliers were used to convert health benefits, into a monetary value.
- **Quantification** – utilising data from Salvador, 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 Salvador 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

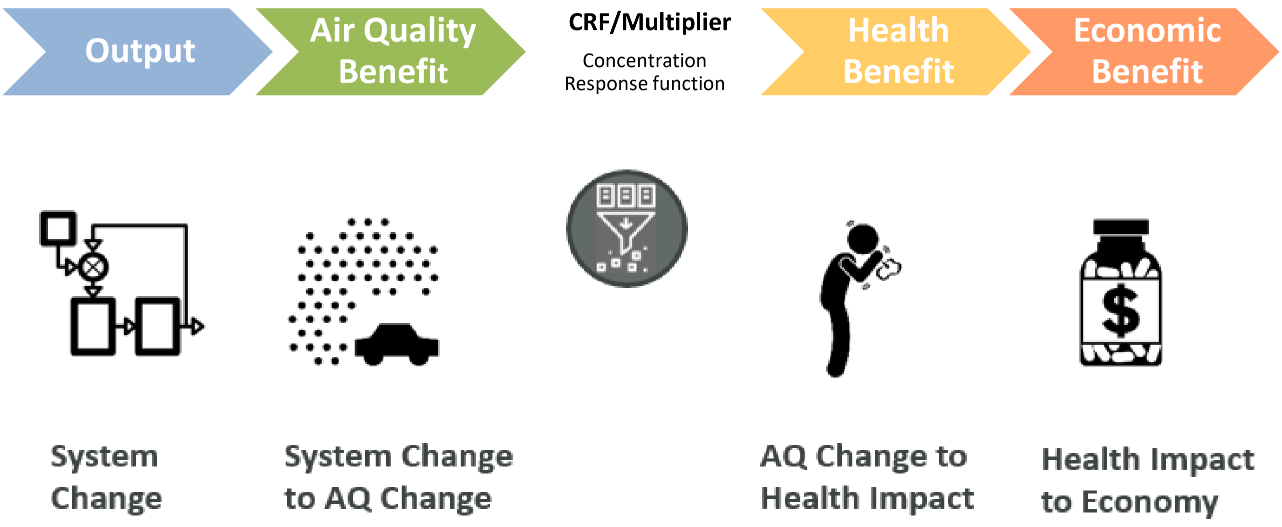
This section provides an overview of the specific analytical process to evaluate the air-quality related health impacts from urban climate actions.

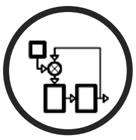
In order to measure impacts of a given action, it is important to understand the links between action, outputs, and benefits. This section will summarise the interrelations between the different elements of the calculation process –system change (action), air quality change (output/benefit), health outcomes (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 PM2.5, and NO2. 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

Selecting a concentration response function (CRF)

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 NO2 and PM2.5 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).

Applying the selected CRF

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 Salvador specifically, three main limitations have arisen out of the investigation:

1. Data gaps in terms of the 885 buses that were previously replaced in 2015, and how if there had been 'before and after' data on that action, a clearer back-casting could have been made on its impact. A more rigorous comparison could therefore also have been made between that action, and the proposed action of a further 650 buses to EURO VI/electric.
2. The inclusion of proxy values – specifically regarding VOLYs and the utilisation of a UK value in the absence of a Brazilian one.
3. The precise data regarding the specific bus routes that the replacement vehicles would be traveling down was unavailable. The entire STCO bus system was then assumed, even though only 28% of the fleet is set to be replaced. This could impact on the accuracy of the intervention area allocated if the upgraded buses were, in reality, limited to a fixed number of bus routes. The model has been set up to address the difference between a whole city impact and an intervention area impact – as there are often heightened benefits within a localised intervention area as the same improvement in AQ is occurring in a smaller area and on a smaller population. Therefore, if more accurate data regarding the specific routes of the upgraded buses was made available, the model could be used to recalculate a more precise impact at a local 'intervention area' scale compared to a wider impact across the whole city and its population.

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