MARCH 2018

Benefits of Climate Action

Santiago: Benefits of replacing domestic wood burning stoves with more efficient versions

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 Santiago, from replacing wood burning stoves with more efficient ones in two small, pilot area in the Alhué commune: Talami and El Asiento. The aim is to show the benefits from these pilots in order to inform wider roll-out across the city. As the headline findings below show, air quality and health gains are significant, demonstrating that major benefits can be gained from implementation at city-wide scale.

Furthermore, the social impact of the analysed action is expected to be extremely beneficial for younger (<3 years old) and older elements of the population, which are exposed to higher health risks as they generally spend most of their day at home.

ENVIRONMENTAL IMPACT

Approximately **16% reduction** in overall non-background outdoor $PM_{2.5}$ concentrations

SOCIAL IMPACT

Life expectancy increased by **117 days** for households affected by the action

Life expectancy increased by **97 days** for people living in the intervention area

ECONOMIC IMPACT

CLP 13.92 Million Approximate costs avoided due to reduced premature mortality from change in $PM_{2.5}$ levels in the intervention area

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 (NO_X)	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. PM10 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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Area Calidad del Aire y Cambio Climatico de la Seremi del Medio Ambiente Region Metropolitana

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 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 describes the findings from the benefits analysis prepared for the city of Santiago, for which the city government provided insights into the benefits of the ongoing process of replacing wood burning stoves in two areas-Talami and El Asiento- in the Alhué commune.

Section 2 describes the context of the 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 Santiago. The monetised gains that are then accrued through these improvements in public health will also be estimated.

2 SANTIAGO'S ACTION AGENDA

The city of Santiago has a history of high levels of concentrations of coarse and fine Particulate Matter (PM), with use of firewood being a key contributor to these levels. According to the latest emission inventory (2014), the residential sector is responsible for about 35% of the total $PM_{2.5}$ emissions. It is interesting to note that, the 120,000 wood-burning stoves in the Santiago Metropolitan Region (SMR) produce almost 95% of the total residential sector emissions. Those figures suggest that indoor air quality is one of the main challenges in Santiago.

Current policy pertaining to the use of wood stoves is the "Atmospheric prevention and Decontamination Plan" (PPDA in Spanish). This regulatory instrument complies with national standards for particulate matter in Santiago Metropolitan Region (SRM). The included regulation for use of wood for residential heating includes a Regional Emission Standard for wood stoves sold in Santiago, and the prohibition of use of any wood-burning appliances during barred 'air quality days'.

The climate action in Talami and El Aseinto represents a specific action amongst a wider suite of interventions. Amongst the regulations aimed at control of wood-burning appliances in the Region, the PPDA includes:

- Total prohibition of the use of wood burning stoves and appliances in the Greater Santiago City, allowing use of pellet devices for heating;
- New stricter emission standard for new wood-burning stoves;
- Regional restriction and prohibition for the use of wood-burning appliances during days with critical levels of PM;
- Incentives to the use of renewable energy for residential consumption of electricity and heating.

The replacement of wood burning stoves with more efficient stoves targets houses that are predominantly constructed of a light material, wood, and adobe. A total of 100 buildings and families are already benefitting from the project.

The analysis presented within this report is solely focussed on calculating and analysing the health and monetised benefits from implementing an environmental "air-quality" action- in this case, replacing traditional wood-burning stoves in in the Alhué *Communa*. It will however make reference to other areas where necessary, and other environmental interventions where relevant.

Aim of action

The primary rationale for the reduction of wood burning practices is captured within the name of the future regulation document: "Santiago Respira" (Breathe Santiago). Santiago Respira is a comprehensive decontamination plan developed by the city in order to reduce air pollution, with a special focus on $PM_{2.5}$ - considered the most dangerous pollutant for people's health. The main measures of the plan are directed towards transportation systems (i.e. promoting stricter regulations on emissions standard and upgrading

Transantiago fleet upgrade to Euro VI norms), industrial (i.e. establishing new emission standards) and residential sectors (i.e. prohibition of the use of heaters and wood burning stoves). In addition, the city is creating a “Green Fund” to support emission compensation projects. At the time of writing, the plan is at its preliminary stage and the city is currently running workshops and seminars for public consultations.

The specific action analysed in this report is a measure related to the residential sector and it is intended that people will benefit in two important areas:

- Indoor pollution will be reduced via replacement of stoves, decreasing exposure within the home;
- Outdoor emission reduced within the Santiago basin, cutting background exposure as well as reducing CO2 emissions into wider environment.

Beyond the expected climate change impact, this action may be fostered to improve inclusivity and social equality in the city, as the use of wood-burning stoves is known to be more prevalent in families with lower socioeconomic status and in low-income areas. Thus, this policy is targeted at improving health outcomes for those in the lower-income segments of society. Specifically, the action will be more beneficial for younger (<3 years old) and elderly population which have a higher health risk as they generally spend most of their day at home.

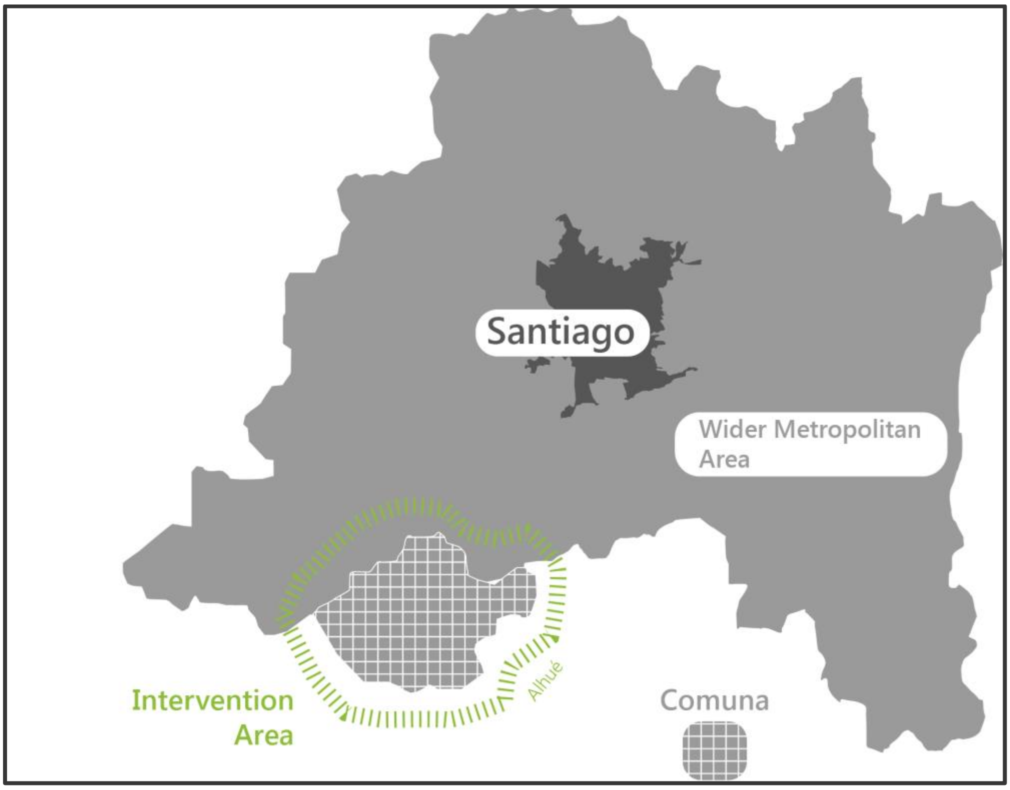
Aim of measuring the benefits of this action

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

1. Provide a policy evaluation tool to city’s authorities;
2. Use the results from the pilot projects in Talami and El Asiento to foster the adoption of a similar action in the whole metropolitan area.
3. Boost other actions anticipated in the “SantiagoRespira” Development Plan

Location and scale

The action will take place in Talami and El Asiento, two small areas in the Alhué *Communa.* Results from the pilots will be used to support similar actions in Santiago and across the metropolitan region.



Time scales

Phase I started in late 2017. The new decontamination plan has a time horizon and implementation of 10 years, from 2017 to 2027.

Future plans:

The pilot programme started in late 2017 and is affecting 100 households in Talami and El Asiento, Aluhé commune. In the long-run (2017-2027) the city aims to replace between 5,000 to 10,000 wood burning stoves.

3 BENEFITS OF REPLACING WOOD-BURNING STOVES

In calculating the benefits arising from the replacement of wood-burning stoves it is important to note that the analysis draws a distinction between the quality of the air inside the affected properties (indoor) and the quality of the air in the urban environment (outdoor). Emissions from wood-burning stoves affect both indoor and outdoor air quality so we have developed a methodology that seeks to take both impacts into account in the clearest manner possible. Citizens who live in the households directly impacted by the change will experience lower levels of indoor PM concentration and lower levels of outdoor PM concentration. Citizens who do not live in the affected households but reside in the same district (the intervention area) will experience lower levels of outdoor PM concentration.

3.1 ENVIRONMENTAL BENEFITS

The extent of the environmental benefits for prohibiting the wood-burning stoves in the two areas depends largely on the proportion of CO_2 emissions that is being reduced. After the proposed action, the CO_2 saved from the combustion equate to roughly 187 tonnes per year. In determining the eventual net carbon gain, a pivotal role is played by the adoption of renewable energy for residential consumption of electricity. As non-renewable sources produce both carbon and pollutants which have negative impacts on human health, the promotion of renewable sources of energy (i.e. solar power) in place of fossil fuels is crucial to achieving combined positive climate change and air quality impacts.

In terms of air quality, the current estimates for Santiago's action forecast a 16% reduction in non-background outdoor $PM_{2.5}$ concentrations.

3.1.1 OVERVIEW OF DATA AND ASSUMPTION

The analysis was guided by Santiago's relatively comprehensive pollution data. The city's environmental sensor network consists of 13 monitoring – Cerrillos, Cerrillos I, Cerro Navia, El Bosque, Independencia, La Florida, Las Condes, Pudanhuel, Puente Alto, Quilicura, Quilicura I, Parque O'Higgins, Talagante – each recording $PM_{2.5}$ concentrations every hour. However, $PM_{2.5}$ data collection and analysis was limited to the Talagante station due its proximity to the intervention area.

The action takes place in two small areas in the Alhué *Comuna* - namely Talami and El Asiento. The total intervention area covers approximatively 3 km^2 and includes 130 households, 90 of which are located in El Asiento. However, only 100 households will replace the wood-burning stoves with more efficient ones. Whilst average outdoor pollution and source apportionment values were readily available, a minor assumption was made in relation to the indoor average $PM_{2.5}$ concentration - a value from a pilot study[1] conducted in

[1] "Evaluacion del impacto de la calidad del aire interior, confort ambiental y eficiencia energetica dentro de las viviendas beneficiadas del recambio en la region de Aysen" Estudio solicitado por la Subsecretaría del Medio Ambiente Región de Aysén, 2015

the Aysen region was used as a proxy to define the annual indoor average $PM_{2.5}$ concentrations.

A key assumption was made to estimate the percentage reduction in $PM_{2.5}$ after the action. In order to calculate the reduction of the indoor concentration, a 29% reduction in indoor concentrations has been assumed. This value is based on a proxy value taken from a study that analysed a similar action in the Aysen region[2].;

Similarly, the change in the outdoor concentration (16%), has been estimated following two intermediate steps. Firstly, a 59% reduction in outdoor concentrations has been estimated by calculating the ratio between the reduction in indoor concentration and the non-indoor concentrations[3]. Lastly, this figure have been in indoor and outdoor concentrations multiplied by the percentage of houses affected by the action (77%).

3.1.2 KEY FINDINGS

Due to Santiago's action, a 16 % reduction is calculated in the overall non-background outdoor $PM_{2.5}$ concentration, as the city's average is decreased by 2.7µg/m³ to 13.9 µg/m³. This reduction means that Santiago's action diminishes the gap between the city's actual concentration (22.64 µg/m³), and the WHO air-quality guideline recommended $PM_{2.5}$ maximum of 10µg/m³. This gain in air-quality accounts for about 21% of the difference between Santiago's actual level and the WHO recommended, illustrating encouraging progress for further enhancement.

As a result of the action, indoor $PM_{2.5}$ concentration for effected households is reduced by 10.3 µg/m³ to 33.7 µg/m³. The gain in indoor air quality accounts for about 30% of the difference between the pre-action indoor level and the WHO guidelines.[4]

Global example:

When addressing wider environmental benefits, studies conducted in three Andean Peruvian[5] communities concluded that the introduction of better quality (electric) stoves in the targeted households drastically reduced personal exposures and kitchen area concentrations for carbon monoxide by 41% and 59% respectively. More significantly, personal $PM_{2.5}$ exposures reduced by 70% while kitchen area concentrations reduced by 78%.

[2] The study measured the impact of replacing wood-burning stoves with more efficient ones in three different households throughout March to November - assuming no burning activities during the other months. Air quality was monitored before and after the introduction of new stoves

[3] Note that the non-indoor concentrations is given by the difference between the average indoor and the average outdoor concentrations

[4] Note that the WHO indoor air quality limit value is equal to the outdoor limit value. In fact, according to the WHO, there isn't enough evidence to discriminate between the two.

[5] Fitzgerald C. et al. (2012) Testing the effectiveness of two improved cookstove interventions in the Santiago de Chuco Province of Peru. Science of the Total Environment, 420 (2012), pp. 54-64

3.2 SOCIAL BENEFITS

The social benefits associated with replacing highly emitting wood-burning stoves with more efficient ones can be significant, resulting in **0.7** life years gained through the local decrease in $PM_{2.5}$ concentration. Although such a figures might seem low, it is significant in the context of the small size of the population affected by the pilot action (100 households for less than 300 people).

3.2.1 OVERVIEW OF DATA AND ASSUMPTION

The population and health data were comprehensive and relatively consistent with one another. Data were collected for the entire Santiago metropolitan area and have then been scaled down by considering the percentage of the city living in the intervention area. Deaths and population per age and gender were available for 2015, whereas hospital admissions per age refer to a 2012 dataset. Hospital admission data was not available by gender so assumptions were made regarding the gender split according to the male-to-female ratio in the Santiago metropolitan area

The social benefits are calculated by applying the CRFs to the $PM_{2.5}$ fall generated by the action. Following the WHO methodology, in this study the CRFs developed for outdoor studies are applied equally to calculate the health impacts of an indoor air quality action.

While people living in the intervention area but not in an affected household are exposed only to an outdoor $PM_{2.5}$ reduction, people living in the affected households are directly exposed to both indoor and outdoor $PM_{2.5}$ change.

For people living in the intervention area but not an affected household, the CRFs is simply applied to the outdoor average fall in $PM_{2.5}$ concentrations.

For people living in the affected houses and exposed to both the indoor and outdoor $PM_{2.5}$, a time-weighted average approach has been applied in order to derive the overall exposure to $PM_{2.5}$. It is assumed that the people taking part in the programme, spend, on average, 25% of their day outdoors and the remaining 75% indoors. Following this approach, it is possible to derive an approximate value – in this case 10.31 $\mu g/m^3$- which captures the overall reduction of exposure to $PM_{2.5}$ for the affected households. The CRFs are then applied to this value to calculate the health impact for the affected households.

3.2.2 KEY FINDINGS

After the implementation of the action, strongly positive results are achieved in terms of life expectancy at birth which is boosted by 97 days per individual in the intervention area and by 117 day for the effected households.

Every year Chile experiences 4,000 premature deaths and 127,000 emergency health consultations due to poor outdoor air quality. Statistically, the intervention area experiences an estimated 0.06 outdoor air-quality related deaths due to pollutants such as $PM_{2.5}$ and NO_2. Since, in reality, the number

of deaths experienced by a community must be an integer value, this number is, in fact, a measure of risk. In that regard, the value of 0.04 deaths averted due to the action, represent a significant reduction (more than a 50% fall) in the risk rate for the area.

3.3 ECONOMIC BENEFITS

The economic benefits from implementing Santiago's wood-burning stoves renewal mainly revolve around the major benefits accrued in terms of VOLYs preserved. In that sense, the main benefit to Santiago's economy is accrued from the deaths averted and the resulting gain in productivity from the surviving population. Once the action is implemented at a larger scale, significant healthcare cost savings, with both respiratory- and CVD-related hospital admissions, can be achieved in Santiago.

3.3.1 OVERVIEW OF DATA AND ASSUMPTION

In the absence of locally-specific values for the value of a life year in the city of Santiago, the value of the averted deaths have been developed using proxy values from the United Kingdom then converted to Chilean pesos using the purchasing power parity exchange rate[6]. This value would be more accurate if a locally generated VOLY can be obtained for the study.

However, the morbidity data, including specific annual averages for both respiratory- and CVD-related hospital admission costs, has been calculated using accurate local healthcare costs for both ailments. Note that the estimation of hospital admission costs has been made by considering just the direct costs-which include expenses for hospitalization, medicines and other medical services- for public hospitals.

Note that the average costs for admission in private hospital increase by almost 50% for both CVD- and respiratory-related diseases. This analysis uses the value of public hospital admissions, as private healthcare covers a smaller amount of the population and therefore is not a representative measure.

This results in a cautious, under-estimate of morbidity costs as indirect costs and private healthcare costs are excluded.

3.3.2 KEY FINDINGS

Through implementing this action, the city may save some healthcare costs through the volume of hospital admissions averted. However, due to the extremely small sample size associated with the pilot project, the real values of these savings are likely to be close to zero. Specifically, according to the

[6] https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm

model there is potential to save CLP 915 for every respiratory-related hospital admission and CLP 5981 for every CVD-related hospital admission.

However, if the action is rolled out across the whole Santiago metropolitan area, the economic impacts would be significant. In fact, the respiratory- and CVD-related hospital admissions averted due to the reduction in $PM_{2.5}$ concentrations are valued at CLP 711,002 and CLP 1.44 Million.

Similarly, the action would generate an economic value of CLP 381.5 billion associated to the life years gained.

4 COMMENTARY AND POTENTIAL POLICY INSIGHTS

4.1 MAIN OBSERVATIONS

The introduction of this change in the city is likely to secure a clear health benefit for citizens but it should be noted that any accompanying climate change mitigation impact will depend on the type and amount of fuel used by the replacement cook stoves. Whilst the focus of this report has been specificially on the pilot project to upgrade from one type of wood-burning stove to another, more efficient model, it is clear that alternative options exist, in which households could be switched across to electrical systems instead.

Two key factors need to be considered:

Risk of 'rebound' - The action as stated will ensure more efficient use of fuel (wood) and the assumption for this study has been that the quantity of fuel burnt will not increase. However there is a risk that fuel use will increase due to the 'rebound effect' resulting from the fall in quantity (and therefore price) of fuel required for any particular use. If the rebound effect does occur and fuel use increases this could mean that not all the theoretical efficiency savings would be secured. There is anecdotal evidence from other projects in the city suggesting that where cook stoves were replaced with more efficient stoves but still using the same fuel type (wood), there was a strong 'rebound effect' – perhaps reflecting a pent-up demand for space heating in colder months.

Regional and national energy generation - The rebound effect is less strong when there is a change in fuel type (e.g. from a wood to electric cook stove). In the light of this, there is some evidence in favour of Santiago moving to replace wood burning stoves with a different system altogether (i.e. electric cooking and space heating). A general switch from combustion of wood to electricity for domestic heating and cooking would be preferable from a climate change mitigation perspective, **provided that the electricity being consumed has been generated from renewable sources**.

Aside from the energy generation challenge, it should be noted that pursuing this strategy will likely need to overcome practical challenges (relating to electricity supply) and cultural challenges (relating to the long-standing convention of using wood-burning stoves for domestic heating). The pilot projects are being undertaken in areas far from the centre of the metropolitan area. In the core urban areas the economies of scale are likely to be different to those in the sub-urban or rural locations. Determining in what ways these different contexts will offer opportunities to drive the climate action will require further detailed studies . These early pilot projects offer strong opportunities to collect valuable real data that can replace the assumptions made in this analysis and be used to calibrate and evaluate future larger scale actions in a range of contexts.

4.2 OPPORTUNITIES FOR SCALING UP OR SPEEDING UP

Opportunities to speed-up or scale-up the accrual of benefits from this action in Santiago present themselves in three distinct forms

- Ban all wood-burning stoves in the area and replace them with low-carbon, renewable electric stoves.

  The method of producing electricity is crucial when switching from wood-burning stoves to electric. The use of renewable and clean energy sources is critical to generate a positive climate impact. Furthermore electrification using polluting energy sources will result in air pollution from electricity generation, potentially cancelling out air quality and health gains through the cook stove replacements.

- Expand the action across the city

  This study has demonstrated that there is significant health benefits that accrue at the household level, and at the local intervention-area level, with implementation of this project. The study has also demonstrated that, as for most such projects, if it is not implemented on a citywide scale then it is unlikely to deliver a citywide, or population level, impact. It is expected that this pilot project can support city-wide implementation.

- Replicate the action in other cities and build social acceptability across the region.

  Santiago is not alone in facing this challenge. Many other cities in the Latin America region and further afield have concluded that wood-burning presents material health risks that have previously been ignored. Working with other cities in the region could help to build acceptability in Chile as well as deliver wider benefits. Of course, if the wider actions can be focussed on switching to cleaner fuel altogether then the climate and health benefits will be magnified significantly.

4.3 FUTURE DATA COLLECTION ACTIVITIES

The main suggestions for further data collection are:

- Determining a locally derived VOLY in order to gain a more accurate representation of the real value delivered through the avoided life years lost
- Direct measurement of indoor air concentration before and after the pilot in the Alhué Communa
- Survey data to collect household fuel usage.

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 Santiago'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 Santiago'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

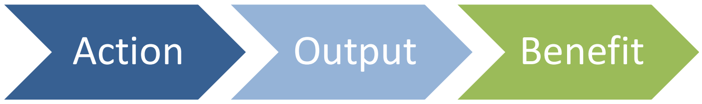
5.2 PLANNING THE OVERALL BENEFITS ANALYSIS PROCESS

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 replacement of traditional wood-burning stoves with more efficient ones.



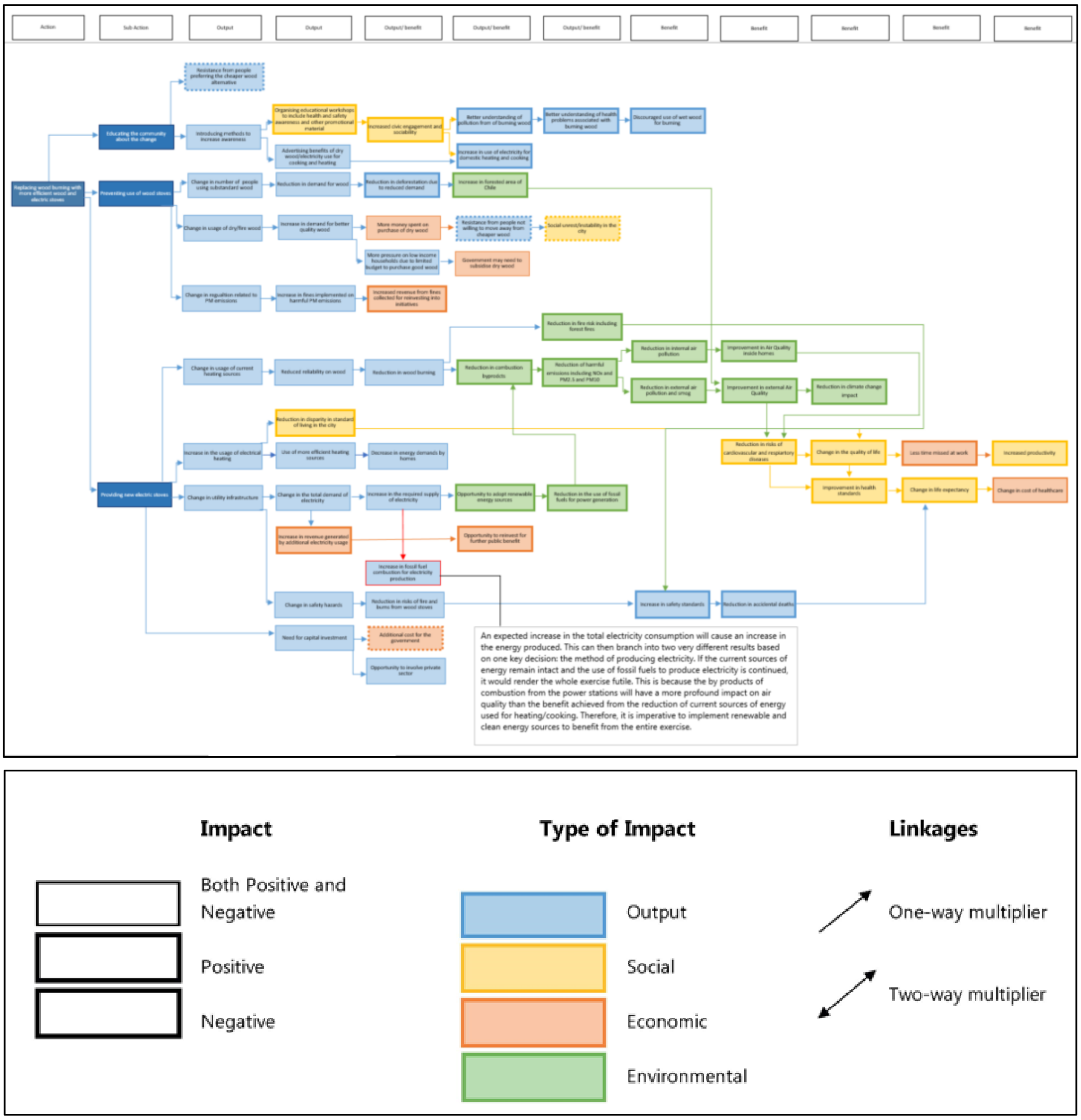


Figure 1 Benefits Pathways for replacing wood-burning stoves in Santiago. For high resolution version of the image please see supporting links in Appendix A

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 Santiago included:

ACTION DATA

- Number of households affected by the action
- Number of people affected by the action
- Wood burnt per year

POLLUTANT DATA

- CO_2 (tonnes/year)
- $PM_{2.5}$ (g/µm^3): background concentration and annual average
- Source apportionment of $PM_{2.5}$ for residential sector
- Indoor $PM_{2.5}$ concentrations

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

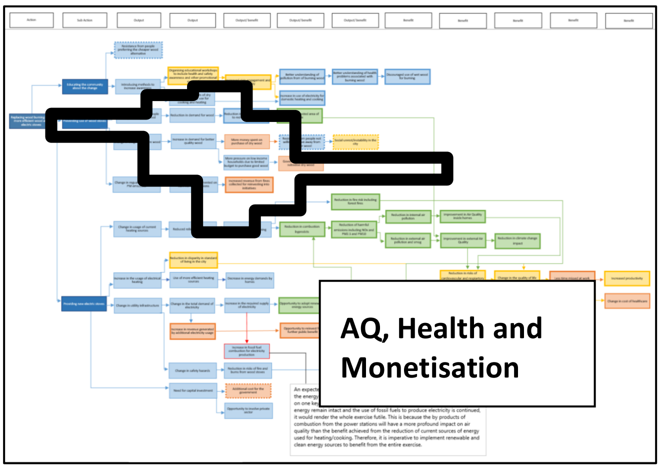
City data was combined with multipliers and proxy data from wider research to estimate the benefits of replacing wood-burning stoves with more effi Three types of measurement were used to estimate the benefits:

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

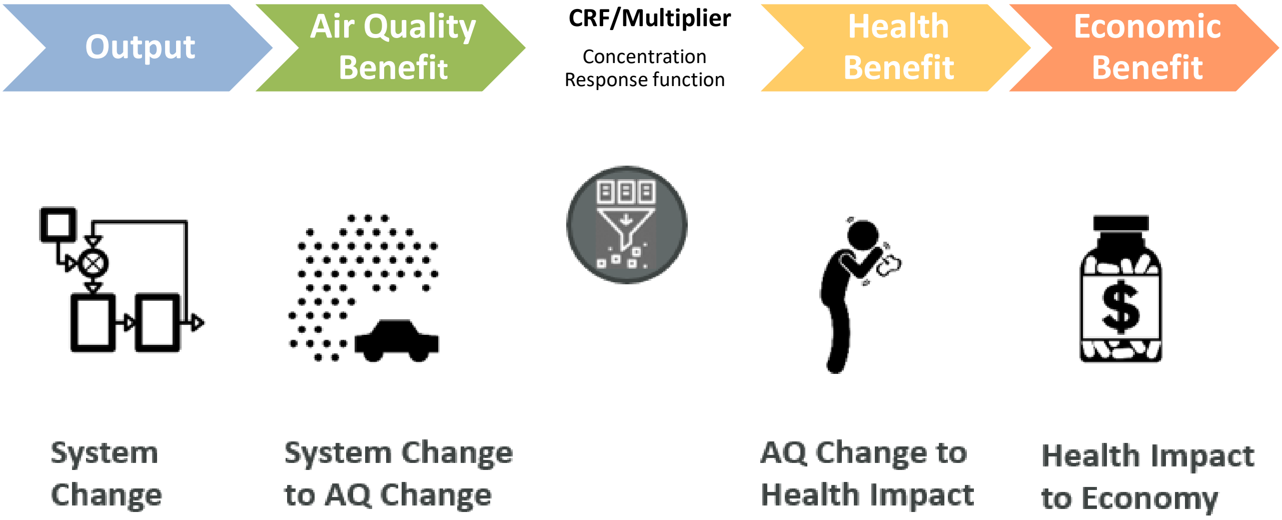
This section provides an overview of the specific analytical process to evaluate the air-quality related health impacts from urban climate actions.

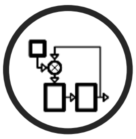
In order to measure impacts of a given action, it is important to understand the links between action, outputs, and benefits. This section will summarise the interrelations between the different elements of the calculation process –system change (action), air quality change (output/benefit), health outcomes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



5.3.1 OVERVIEW OF PROCESS

This diagram summarises the analytical process:

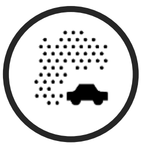




5.3.2 DEFINING THE SYSTEM CHANGE

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.



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 $PM_{2.5}$. This is because changes in this pollutant carry the most significant impacts in terms of health outcomes and relate to the system change being addressed by the selected action. For each pollutant, 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 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).

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 Santiago specifically, the following are the main limitations that have arisen out of the investigation:

1. The inclusion of proxy values- specifically regarding VOLYs and the utilization of an UK value in the absence of a Chilean one.
2. The small sample size for the project – which means that confidence intervals for the measured values are likely to be larger than would be desirable.

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