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Benefits of Climate Action

Johannesburg: Benefits of the electrification of informal settlements in Alexandra and Diepsloot

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 potential benefits scenarios for the city of Johannesburg, from the electrification of informal settlements located in Alexandra and Diepsloot.[1]

The aim is to show the benefits from this two informal settlements in order to inform wider roll-out across the 181 informal settlements in the city. As the headlines below show, air quality and health gains are significant. However, to achieve combined climate change and air quality impacts, it is crucial to implement renewable and clean energy sources.

Please note that the analysis considers three different scenarios:

1. "pessimistic" scenario where just 30% of the households will be electrified
2. "realistic" scenario where 50% of the households will be electrified
3. "optimistic" scenario where 80% of the households will be electrified

[1] It is important to note that the findings of this study are currently based on data that captures the potential impact of an action of this nature. The absence of a number of critical data sets, mean findings from this report should not be used in place of city findings. Recommendations on key data gaps have been captured in the report and communicated to the city of Johannesburg. It is advised that these data gaps are filled and findings from the analysis updated to reflect 'real' city/action benefits.

The following table summarises the benefits associated with a realistic scenario and provide the potential benefits that may be associated with an optimistic scenario

ENVIRONMENTAL

Approximatively **8.2% reduction** in overall non-background $PM_{2.5}$ in a moderate scenario

Potentially rising to a **13% reduction** in overall non-background $PM_{2.5}$ when an optimistic scenario is considered

SOCIAL

72 deaths averted for the 50% household affected by the action

Potentially rising to **120 deaths averted** in an optimistic scenario

Life expectancy increased by **254 days per person** across the affected households

Potentially rising to **264 days per person** in an optimistic scenario

ECONOMIC

R 453.7 Million

Approximate costs avoided due to mortality from change in $PM_{2.5}$ levels.

Potentially rising to **R 752 Million** in an optimistic scenario

R 2.8Million

Approximate costs avoided due to respiratory hospital admissions from change in $PM_{2.5}$ levels.

Potentially rising to **R 4.7 Million** in an optimistic scenario

R 739.9 Thousand

Approximate costs avoided due to cardiovascular hospital admissions from change in $PM_{2.5}$ levels

Potentially rising to **R 1.2 Million** in an optimistic scenario

ACRONYMS AND TERMINOLOGY

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

Term	Definition	Source
μg/m³	A measure of concentration in terms of mass per unit volume. A concentration of 1 μg/m³ means that one cubic metre of air contains one microgram of pollutant.	DEFRA
Background concentration	Concentration of pollutants not explicitly emitted by local sources, but transported into the considered area.	BuroHappold | C40
Cardiovascular Disease	Disease related to the heart and circulation. Includes stroke and problems with arteries or veins in other parts of the body not just the heart.	King's College London
Concentration	The amount of a pollutant in a given volume of air. Generally expressed in microgram per cubic metre (μg/m³).	BuroHappold | C40
Concentration Response Function	A quantitative relationship between the concentration of a pollutant and an increased risk of an effect on health (in this case, mortality & morbidity)	BuroHappold | C40
Emission	Direct release of a pollutant into the atmosphere from a specific source in a specific time interval. Generally expressed in tons per year (tn /y).	BuroHappold | C40

Intervention Area	The area within the respective city that is being directly affected by the implementation of a city-action.	BuroHappold | C40
Life Expectancy at Birth	A valid and meaningful expression of mortality effects for both the impact of reduced pollution and the burden of current pollution.	BuroHappold | C40
Life Years Lost	Life Year represents one year lived for one person. Usually added up over the population and a specific duration, allows quantification of changes in timing of deaths. Life Years Lost is a result of deaths and represents the population mortality burden.	BuroHappold | C40
Life-Tables	Tables which show, for each age, the probability that a person will die before their next birthday (is given by 1 year age groups).	COMEAP
Morbidity	Rate of disease in the population	BuroHappold | C40
Mortality	Number of deaths in the population	BuroHappold | C40
NO_2	Nitric oxide (NO) is mainly derived from road transport emissions and other combustion processes such as the electricity supply industry. NO is not considered to be harmful to health. However, once released to the atmosphere, NO is usually very rapidly oxidized, mainly by ozone (O3), to nitrogen dioxide (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}	PM_{10} is defined as the mass concentration of particles of generally less than 10 µg aerodynamic diameter. This fraction can enter the lungs. PM_{10} includes $PM_{2.5}$.	COMEAP

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

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Musa Mahlatji

Mpho Nekhwalivhe

<city to complete with additional participants>

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 outlines the initial findings from the benefits analysis conducted on Johannesburg, whereby the city government provided insights into their vision for electrifying two informal settlements, namely Alexandra and Diepsloot.

Section 2 describes the context for Johannesburg electrifying the two settlements. Section 3 illustrates the key findings of the study including an overview of data and assumptions. Section 4 illustrates the processes behind the analysis, including methodologies and limitations.

The work described in this report is focussed exclusively on the air-quality related health benefits associated with this specific climate action in Johannesburg. The financial gains that are then accrued from these improvements in public health are also be estimated.

2 JOHANNESBURG'S ACTION AGENDA

The specific climate action in Johannesburg is the electrification of informal settlements in two neighbourhoods, Alexandra and Diepsloot. Local government statistics estimate there are approximately 64,000 households in the former[2] and 63,000 in the latter[3].

National statistics show an overall rapidly growing city with population increasing by an average of 121,000 every year between 2001 and 2011 with 43,000 new homes added every year in the same period. Finally, the City of Johannesburg (CoJ) is expected to double in size by 2040[4].

Increasing population and economic growth are often related with increasing demand for water, electricity and liquid fuel. Johannesburg is not an exception and it is experiencing an increase in the total electricity consumption.

According to the latest Greenhouse Gas Emissions Inventory, electricity is the primary source of energy in the city and the residential sector generates about 29% of the total CO_2 emissions. Homes accounted for 41% of the overall electricity consumption in the city, which is mainly used for cooking, heating and lighting purposes[5]. Other energy sources used for cooking, heating and lighting are paraffin, coal and wood. In low-income areas - such as Alexandra, Diepsloot, Orange Farm and Soweto- where rapid urbanization and the growth of informal settlements have resulted in backlogs in the distribution of basic services -such as electricity and waste removal- the use of these other sources of energy is much more common.

This study covers two informal settlements Alexandra and Diepsloot, where the majority of these settlements are connected via illegal and often rudimentary means, which translate to a high exposure to unsafe bare wires and to a stronger electricity supply pressure faced by the powered grid. In order to control and reduce the mentioned risks, the city is examining alternative sources of energy, including supply within informal settlements. In fact, Johannesburg embarked upon a program to electrify all informal settlements in the city by 2020. The interventions involve the instalment of network infrastructures, such as unexposed wires and safety compliant materials, conforming to electrification standards and specifications (NRS, SANS, Section 101)[6]. The major emphasis of the installation is to impact upon household heating and cooking, removing the need for burning coal, wood and paraffin within the home.

City Power, the city energy provider, have already successfully executed a number of service delivery initiatives and projects in the 2013/14. For example, electrification of 2,151 households in a number of areas including Rabie Ridge, Tshepisong and Alexandra. Moreover, City Power -in-conjunction with CoJ Housing Department- is in the early stages of

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[2] http://www.statssa.gov.za/?page_id=4286&id=11305
[3] http://www.statssa.gov.za/?page_id=4286&id=11294
[4] "Joburg 2040 Growth and Development strategy" http://www.joburg.org.za/gds2040/pdfs/joburg2040_gds.pdf
[5]"Greenhouse Gas Emissions Inventory For the City of Johannesburg. Global Protocol for Community-scale Greenhouse Gas Emissions (GPC)"
More detailed information are available but not publicly accessible. Please add the percentage of fuel consumption whenever you will be able to access the energy report.
[6] CityPower Johannesburg Updated Business Plan 2016-2021

exploring hybrid systems, including the use of solar panels (PV) and gas cylinders. It is planned that the solar panels will feed back into grid during load shedding[7], as and when required. Due to the high capital expenditure, the cost of renewable energy infrastructure might represent a major challenge at the beginning of the project. However, it is argued that, after the initial investment, this will generate future benefits as the operational costs start to decrease. In addition, the development of a renewable energy system will make the city less exposed to prices fluctuations associated with fossil fuels. For the purposes of this study, it is assumed that electrification in Alexandra and Diepsloot- commenced in 2015- will be completed before 2020. Even though several households in the two informal settlements have already been electrified, the lack of data represents a drawback when building a baseline for the action. For this reason, in the absence of directly measured values, different scenarios will be explored.

The scenarios developed to test the impact and benefits of this action assumes that the action will directly impact between 30-80% of the households in each area. Results shown in this part of the report are based on a moderate scenario where 50% of the households will receive electrification. However, the analysis considers a "pessimistic" scenario were just 30% of the households will be electrified and an "optimistic" scenario which will affect 80% of the households in the local area.

However, it is not clear what proportion of households will benefit from off grid renewable energy supply

Aim of action

The rationale for electrification of Alexandra and Diepsloot is multifaceted, the primary being the city's desire of understanding the relationship between the lack of electricity supply and the usage of polluting fossil fuels.

The action aims to reduce the use of wood, paraffin and coal to generate heat and can ultimately reduce $PM_{2.5}$ emissions from domestic fuel burning.

Households in the informal settlements will benefit from the action in two important areas:

- Indoor air quality inside the homes will be greatly improved as the direct and prolonged exposure of the families to harmful pollutants is avoided.
- Outdoor emission reduced and exposure of citizens in the area to harmful pollutants is avoided.

Therefore, to achieve combined climate change and air quality impacts, it is crucial to implement renewable and clean energy sources- as non-renewable sources produce both carbon and pollutants which have negative impacts on human health. In fact, if electricity is sourced with fossil fuels, the by-products of combustion from the power stations will have a more profound impact on air quality than the benefit achieved from the reduction of current sources of energy.

Beyond the reduction of $PM_{2.5}$ there are further political and economic reasons why this action is being taken. Illegal connection causes major frequent detrimental impact upon

[7] http://loadshedding.eskom.co.za/loadshedding/description

large surrounding areas, such as overloading and loss of power, revenue losses and electrical losses. City Power, in conjunction with third parties, continuously remove illegal connections which requires substantial labour resources. In addition, these connections and non-payment of rates diminish the revenue base of the city to provide services.

As well as reducing exposure to $PM_{2.5}$, the electrification actions are likely to reduce injury (and occasional death), caused by contact with bare cables and unsafe installation of associated infrastructures.

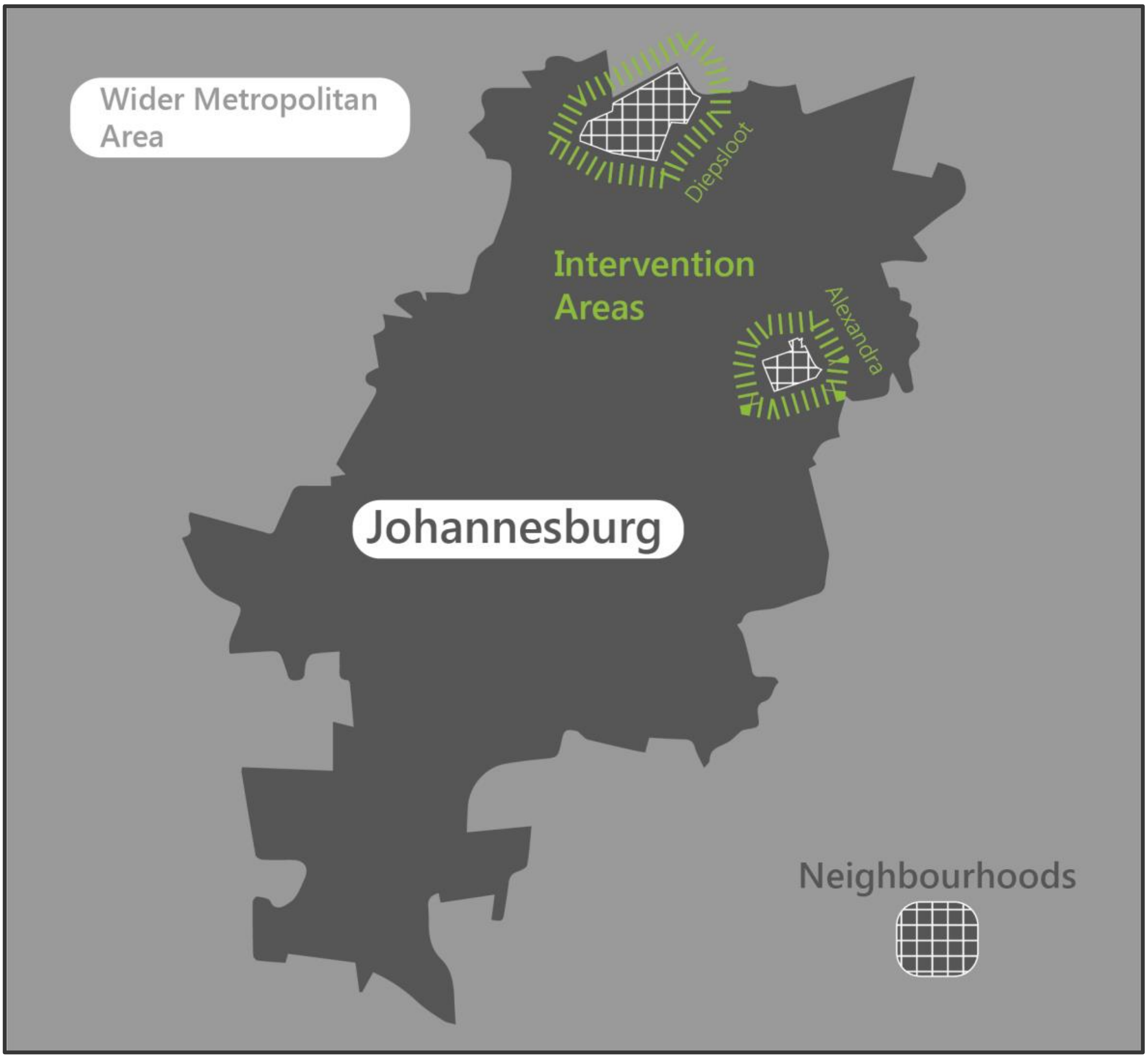
Aim of measuring the benefits of this action

Johannesburg aims to use the results from benefits measurements in order to:

1. Provide a tool to policy makers to undertake cost-benefit analysis when adopting air quality and climate change actions
2. Create evidence to motivate the adoption of similar actions in other parts of the city
3. Support the city in the implementation of the Air Quality Management Plan across the city.

Location and scale

The total intervention area is around 19 km^2 spread between Alexandra and Diepsloot townships which cover 7 km^2 and 12 km^2 respectively. In a moderate scenario, where 50% of the total households will be electrified, the total population affected by the action is expected to be around 63,310 people.



Time scale

The Air Quality Management Plan (AQMP) was released in 2016 and the project was targeted to start during the last financial year (July 2017-June 2018). At the time of writing, due to lack of detailed information, the number of household already affected by the action is not well identified. However, the programme is strongly supported by the mayor who, after his election in 2016, made a commitment to expand the coverage in the two initial settlements and to reach all informal settlements by 2021.

Future plans:

The city is moving towards a pro-poor agenda and the electrification of informal settlements have been identified as a crucial area to reduce income and social inequality. By 2021, Johannesburg is planning to provide electricity to the 181 informal settlements and to cover 100% of the households.

3 BENEFITS OF THE ELECTRIFICATION OF TWO INFORMAL SETTLEMENTS

3.1 ENVIRONMENTAL BENEFITS

The environmental benefits for electrifying the two informal settlements depends largely on the energy sources implemented. In fact, the promotion of renewable energy sources in place of fossil fuels is crucial to reduce CO_2 emissions. Wider benefits of renewables are linked with the reduction of the risk of blackouts and brownouts. In fact, after the action the demand for energy is likely to increase and could exceed the existing capacity of the network. Thus, the promotion of renewable energy systems could avoid power disruption through energy storage and off-grid supply.

In terms of air quality, the current estimates for Johannesburg's action forecast a reduction in $PM_{2.5}$ that range between 4.95% when 30% of the households are affected by the action, and 13.2% when 80% of the households are affected.

3.1.1 OVERVIEW OF DATA AND ASSUMPTION

The analysis was conducted by collecting pollution data directly from the monitoring station located in the intervention area: Alexandra and Diepsloot. In order to provide an accurate annual average for $PM_{2.5}$ a number of manipulations of the raw data needed to be made. Specifically, PM_{10} data from Diepsloot were converted to $PM_{2.5}$. The final figure is given by the average of the median values in the two monitoring stations. Whilst data for Alexandra are considerably recent (October 2016- January 2017), values for Diepsloot refer to the 2011-2013 period. Note that pollution data were available at a local level, while sectoral emissions contribution was calculated by using data for the entire Gauteng region.

Indoor $PM_{2.5}$ have been calculated by using estimations of the fuel burnt per year for heating purposes,. $PM_{2.5}$ emission factors from the city's Air Quality Management Plan (2016) have been applied to the different fuels (wood, paraffin and coal) and lastly, a weighted average of 19.4 $\mu g/m^3$ have been calculated. The weighted average is based on the assumption that people living in the household spend 50% of their time indoor and the rest outdoor. Even though the methodology behind those calculations is strong, a survey to measure indoor concentrations could provide more accurate information.

Critical assumptions were made in order to identify the total number of households affected by the action. The best understanding is that not all the households would be electrified in the first phase, therefore three different scenarios have been considered.

In addition, it is estimated that after the action all the household previously relying on wood, paraffin and coal, will switch to electricity - predicting a 100% reduction in $PM_{2.5}$ contribution from the mentioned pollutants.

Note that the intervention area is here identified as the sum of the total extension of Alexandra and Diepsloot.

Please note that this section could be more accurate when the following figures will be updated:

- $PM_{2.5}$ values from Diepsloot and Alexandra monitoring stations measured in the same time-frame
- Indoor $PM_{2.5}$ concentration
- Local or regional sectoral concentration

3.1.2 KEY FINDINGS

In a moderate scenario, Johannesburg's action could lead to an 8.24% reduction of the non-background $PM_{2.5}$ concentration, leading to the effected household's average being reduced by 10.3 µg/m³.

The outdoor air-quality gain for the local area is expected to fall by 1.25 µg/m³. This reduction means that Johannesburg's action diminishes the gap between the city's average concentration levels (36 µg/m³), and the WHO air-quality guideline recommended $PM_{2.5}$ maximum of 10µg/m³. The improvement in outdoor air quality accounts for approximately 4.8% of the difference between the city's actual level and the WHO recommended maximum level.

In addition, the indoor air quality in the local area is expected to fall by 19.4 µg/m³. This improvement in indoor air quality accounts for approximately 43% of the difference between the city's actual level and the WHO recommended maximum level.

As shown in the table below, there is an additional 0.75µg/m³ fall in the local area when an optimistic scenario is taken into account.

	PESSIMISTIC 30%	MODERATE 50%	OPTIMISTIC 80%
% change in non-background outdoor $PM_{2.5}$ concentrations	4.95%	8.24%	13.19%
Outdoor average $PM_{2.5}$ concentrations reduction (Local area)	0.75 µg/m³	1.25 µg/m³	2.00 µg/m³
Indoor average $PM_{2.5}$ concentrations (Local area)	19.4 µg/m³	19.4 µg/m³	19.4 µg/m³
Time-weighted average fall in $PM_{2.5}$ concentrations (affected Households - impact of indoor and outdoor changes)	10.1 µg/m³	10.3 µg/m³	10.7 µg/m³

3.2 SOCIAL BENEFITS

The social benefits from the electrification of informal settlements in Johannesburg are significant, in that the annual aversion of 72 deaths and 63 hospital admissions for the affected households, as well as 1,491 life years gained, are all associated with the decrease in $PM_{2.5}$ concentration. Life expectancy is also boosted by 254 days per individual across the effected households.

3.2.1 OVERVIEW OF INPUT DATA AND ASSUMPTIONS

Population and death data were collected from the United Nations Data Retrieval System. Both refer to 2011 and provide a breakdown by age and gender. Deaths data revealed a significant number of “unknown sex” and “unknown age” which accounted for almost 20% of the total deaths, and data manipulation was required to distribute the observations within male and female across the different age groups. Therefore, the national sex and age ratios were used to estimate the total deaths proportionally.

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

While people living in the intervention area are exposed only to an outdoor $PM_{2.5}$ reduction, people living in the effected households are exposed to both indoor and outdoor $PM_{2.5}$ change (although not at the same time).

For people living in the intervention area, the CRFs is simply applied to the outdoor average fall in $PM_{2.5}$ concentrations.

For people 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, 50% of their day outdoors and the remaining 50% indoors. Following this approach, it is possible to derive an approximate value –in this case 10.3 $\mu g/m^3$- which captures the overall reduction of exposure to $PM_{2.5}$ for the effected households. The CRFs are then applied to this value to calculate the health impact for the effected households.

At the time of writing this report, there was no data available regarding hospital admissions for the city of Johannesburg. For this reason, proxies for respiratory- and CVD- related hospital admissions are derived from the UK hospital admissions rates. It should be noted that the hospital admissions levels in the UK and in South Africa may differ for a variety of social, economic and cultural reasons. Even though the UK rate-per 1000 population- is a reasonable proxy, the collection of local data is highly recommended in the pursuit of more accurate figures.

While it is still acceptable to use South African population figures, the analysis would been more accurate if the city could collect national hospital admissions for cardiovascular and respiratory diseases.

3.2.2 KEY FINDINGS

Every year, South Africa experiences 20,000 premature deaths[8] due to poor air quality. Proportional to Alexandra and Diepsloot, the two informal settlements are potentially experiencing roughly 137 air-quality related deaths due to $PM_{2.5}$ levels. Under a moderate scenario, 72 deaths could be averted, equal to roughly 42% of the annual air quality related deaths. In an optimistic scenario, with 120 deaths averted, this percentage would almost double to around 88%.

In addition, the effected households could improve their life expectancy from a minimum of 254 days (in a moderate scenario) to a maximum of 264 days (in an optimistic scenario).

Effected Households	PESSIMISTIC 30%	MODERATE 50%	OPTIMISTIC 80%
Attributable deaths averted Total	42	72	120
Life Years Gained Total	873	1491	2472
Life expectancy (Days)	248	254	264

Global example:

An additional wider social benefit associated with the electrification of the informal settlements, relates to improvements in wellbeing and safety. Research conducted in other informal settlements in the Gauteng province[9] show that a safe access to electricity reduces the risk of electrocution from open cables and wires. In addition, access to electricity is associated with an increase in the standard of living and with a reduction in the social disparity between different parts of the city.

[8] https://mg.co.za/article/2016-09-12-00-air-pollution-kills-20-000-per-year-in-south-africa-as-many-as-in-traffic
[9] http://www.buffalocitymetro.gov.za/Home/ArticleId/98/mahlangu-informal-settlements-electrified

3.3 ECONOMIC BENEFITS

The economic benefits from implementing Johannesburg's action mainly revolve around the major costs avoided in terms of VOLYs preserved. In that sense, the main benefit to Johannesburg's economy is accrued from the deaths averted and the resulting gain in productivity from the surviving population. There are also significant healthcare cost savings, with both respiratory- and CVD-related hospital admissions avoided.

3.3.1 OVERVIEW OF DATA AND ASSUMPTION

In the absence of Johannesburg specific VOLY values, the mortality costs avoided, the value of the averted deaths have been derived from proxy values from the United Kingdom. Similarly, local respiratory and CVD-related hospital admissions were not available and proxies value from the UK were used. The UK values have been converted in South African Rand by using exchange rates adjusted by the country's purchasing power parity (PPP) for 2016[10].

It is important to note that these values are currently used as a proxy for this study and further efforts should be made to obtain and substitute these values with local figures and recalculate the associated cost savings. Specifically local figures should be used for (where local figures are not available regional or national can be used and would provide a better proxy than UK figures):

- VOLY
- Value of hospital admissions for cardiovascular and respiratory diseases

3.3.2 KEY FINDINGS

Through implementing Johannesburg's action, the city will save significant healthcare costs through the volume of hospital admissions averted. According to the reductions in $PM_{2.5}$, R 3.6 Million worth of healthcare savings will be made through hospital admissions avoided.

In addition, the action will generate an economic value of R 453.7 Million associated to the life years gained by the effected households after the electrification programme.

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

4 COMMENTARY AND POTENTIAL POLICY INSIGHTS

4.1 MAIN OBSERVATIONS

The electrification of the two informal settlements is likely to improve health, safety and wellbeing of the people living in the area. However, when implementing the action it is crucial to take into account the trade-off between improvement in air quality and GHG savings.

4.2 OPPORTUNITIES FOR SCALING UP OR SPEEDING UP

Opportunities to speed-up or scale-up the positive benefits from the action, mainly denotes to:

- Once the access to electricity is secured, additional benefits could be achieved by banning the use of wood, paraffin and coal for heating and cooking purposes.

  At the same time, the evaluation of the method of producing electricity is crucial when promoting the action. In fact, the implementation of renewable energy (i.e. solar and wind power) is crucial to guarantee a positive climate outcome.

- Expand the action across other informal settlements in the city.

  The study has demonstrated that the action generates profound health benefits at the household level and at the intervention-area level. In Johannesburg, the number of people living in informal settlements is extremely high and more positive outcomes can be achieved if all the informal settlements are electrified. Therefore, the magnitude of the impact is expected to increase if the electrification is implemented at a city-level and at a regional-level.

4.3 FUTURE DATA COLLECTION ACTIVITIES

The main suggestions for further data collection include:

- Survey data to collect average indoor concentration
- Time-series pollution data for Alexandra and Diepsloot
- Sectorial concentrations rather than emissions
- Local values for hospital admissions
- Local statistics for respiratory and CVD- related hospital admission
- A locally derived VOLY and Value of Hospital Admission

In all cases, collecting data across a larger number of dwellings and households would be hugely advantageous.

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 Johannesburg'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 Johannesburg'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

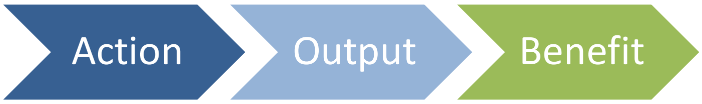
5.2 PLANNING THE OVERALL BENEFITS ANALYSIS PROCESS

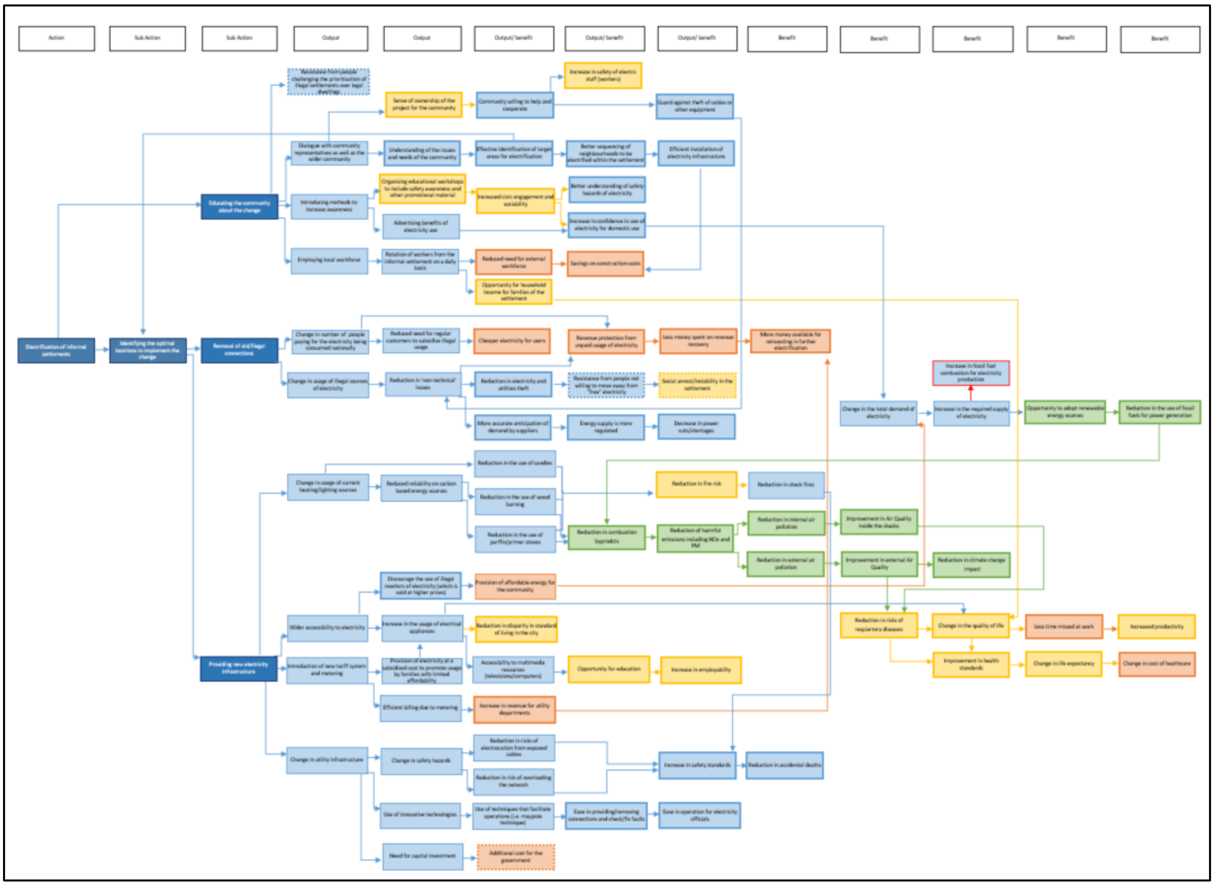
Reconciling scientific complexity and the necessity of facilitating rapid action in cities: Please note the technical team recognise the complexity of air quality and health science and have sought to undertake top-level analysis in a manner that can be relatively easily reproduced by participating cities 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 electrification of informal settlements in Johannesburg.





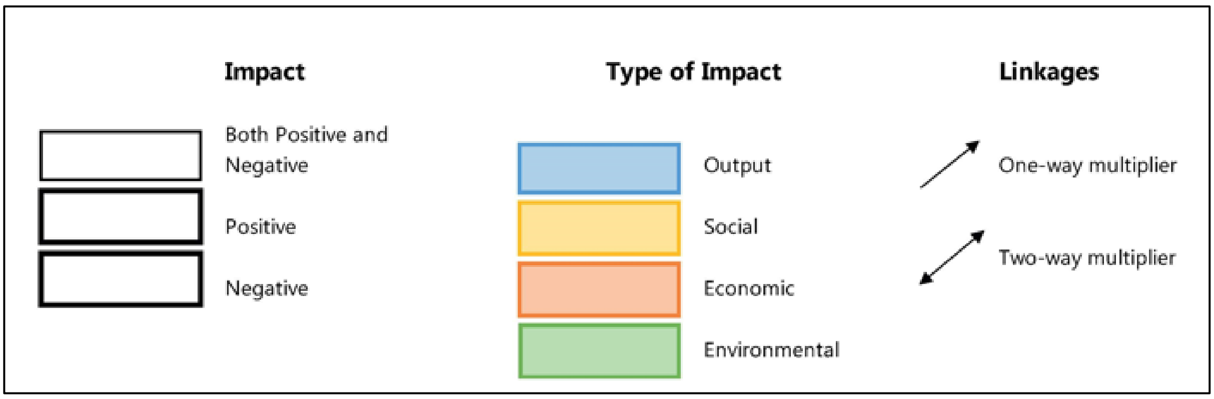


Figure 1 Benefits Pathways for electrification of informal; settlements in Johannesburg. For high resolution version of the image please see supporting links in Appendix A

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 Johannesburg included:

ACTION DATA

- Number of household in the two informal settlements
- Proportion of households using each fuel,
- Fuel 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 domestic sector

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

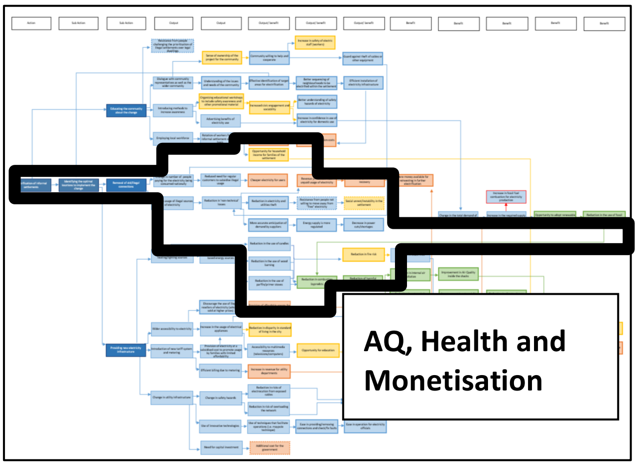
City data was combined with multipliers and proxy data from wider research to estimate the benefits of upgrading a proportion of the bus fleet to a EURO VI emission standard. Three types of measurement were used to estimate the benefits:

- **Monetisation** – economic multipliers were used to convert health benefits, into a monetary value.
- **Quantification** – utilising data from Johannesburg, 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 Johannesburg might be. Illustration is particularly useful in cases where local city data is not available, but an indication of potential benefits is still needed.

5.3 THE ANALYTICAL BENEFITS PROCESS FOR AQ AND HEALTH

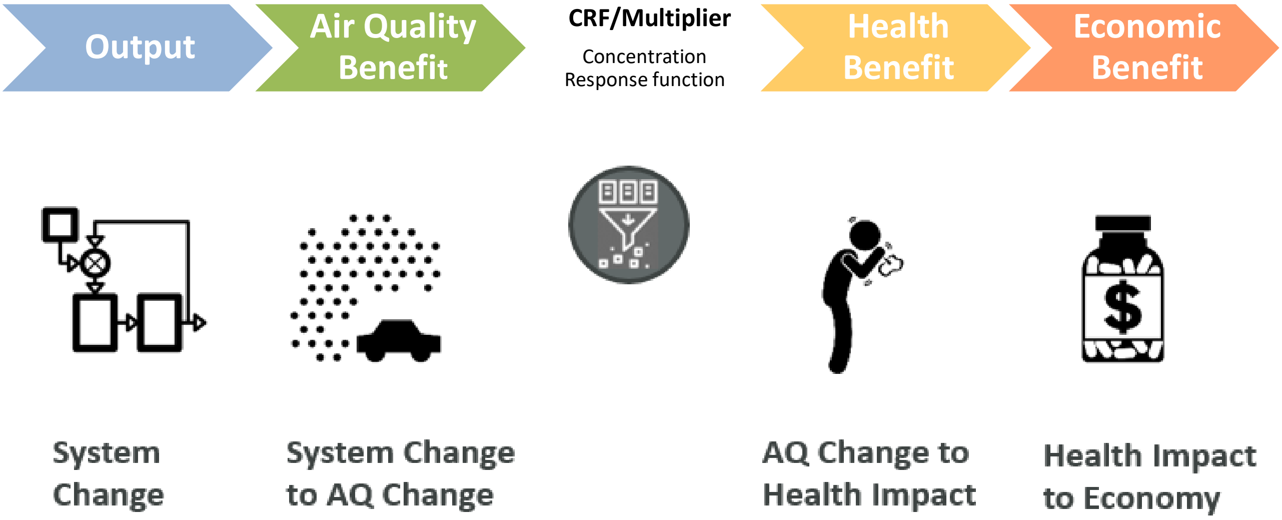
This section provides an overview of the specific analytical process to evaluate the air-quality related health impacts from urban climate actions.

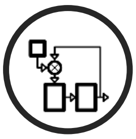
In order to measure impacts of a given action, it is important to understand the links between action, outputs, and benefits. This section will summarise the interrelations between the different elements of the calculation process –system change (action), air quality change (output/benefit), health outcomes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



5.3.1 OVERVIEW OF PROCESS

This diagram summarises the analytical process:





5.3.2 DEFINING THE SYSTEM CHANGE

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

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

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

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

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

5.3.3 FROM SYSTEM CHANGE TO AIR QUALITY CHANGE

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

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

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

A fall in emissions from an urban system will normally lead to a commensurate fall in concentration levels but only as far as the background levels. It is important to know the without action concentration levels for this analysis.

5.3.4 FROM AIR QUALITY CHANGE TO HEALTH IMPACT

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 Johannesburg specifically, two main limitations have arisen out of the investigation:

1. Data gaps in terms of the number of household directly affected by the action. A more accurate analysis could have been made if the precise number of the houses was available. The current assumption-50% of the houses will be electrified- impacts the accuracy of the intervention area and of the number of household affected.

   In addition, knowing the exact number of the houses electrified could be useful at a later stage conduct a “before and after” analysis and evaluate the actual outcome of the study.

2. The inclusion of proxy values – specifically regarding hospital admissions, VOLY, hospital admissions- and the utilisation of a UK value in the absence of a south-African one.

6 APPENDIX A: ALL SUPPORTING DOCUMENTS

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

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

Link to Files: