DEADLINE 2020

How cities will get the job done

C40 CITIES
CLIMATE LEADERSHIP GROUP

ARUP

An analysis of the contribution C40 cities can make to delivering the Paris Agreement objective of limiting global temperature rise to 1.5 degrees.

DONORS

This report has been delivered through a collaborative partnership between C40 and Arup, the global consultancy firm. Arup has worked with C40 since 2009 to develop strategic analysis and research that is central to progressing our understanding of how cities contribute to climate change mitigation and adaptation. This is why in June 2015, Arup announced a major partnership with C40, committing $1 million of professional support over three years to help cities take meaningful action against climate change.

This partnership is founded on Arup's independent and evidence-based approach, alongside C40's longstanding belief in "measurement for management". The partnership supports a strong analytical research agenda while helping city actors to identify opportunities, collaborate and develop practical solutions to accelerate and expand action on climate change.

C40 offers special thanks to CIFF as the part funder for this critical piece of research.

CORE FUNDERS

The Children's Investment Fund Foundation (CIFF) is an independent, philanthropic organisation. Our staff and Trustees combine the best of business and the best of development, bringing a wealth of experience from both sectors to CIFF's work. We aim to demonstrably improve the lives of children in developing countries by achieving large-scale, sustainable impact. We believe that every child deserves to survive, thrive and mature into adulthood in a supportive and safe environment. However, climate change disproportionately affects children living in poverty in developing countries. A key focus for CIFF is climate-smart urbanisation.

Bloomberg Philanthropies works in more than 120 countries around the world to ensure better, longer lives for the greatest number of people. The organization focuses on five key areas for creating lasting change: Arts, Education, Environment, Government Innovation and Public Health. Bloomberg Philanthropies encompasses all of Michael R. Bloomberg's charitable activities, including his foundation and his personal giving. In 2015, Bloomberg Philanthropies distributed over half a billion dollars. For more information, please visit bloomberg.org or follow us on Facebook, Instagram, Snapchat, and Twitter @BloombergDotOrg.

Realdania is a modern philanthropic association that works to create quality of life and benefit the common good by improving the built environment: cities, buildings and the built heritage. Realdania grew out of a 150 year old mortgage credit association whose credit activities were sold off in 2000. Over the past 13 years Realdania has engaged in a total project value of approximately EUR 3.7 billion. Realdania's grants accounted for EUR 1.9 billion.

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FOREWORDS

C40

The Paris Agreement was rightly heralded as a major diplomatic breakthrough, as for the first time every nation on Earth recognized the need to tackle climate change and agreed upon a target to limit global warming. Cities from all around the world, gathered for the first time at the City Hall Summit, played a decisive role in this collective endeavor. We salute the leaders of national governments for reaching this agreement and ratifying it so quickly.

Now the challenge is to turn aspiration into action.

C40 mayors, representing 25 per cent of global GDP and more than 650 million citizens, are committed to urgent and impactful action on climate change. Mayors understand that cities are where the impacts of climate change will hit hardest, but also that climate action can drive economic growth and prosperity.

But, what does delivering on the Paris Agreement look like on the ground in cities? C40 is proud to publish *Deadline 2020: How cities will get the job done*, to answer this very question.

The results are eye-opening. C40 cities must undertake an unprecedented increase in the pace and scale of climate action, doing 125% more than they have in the last decade by 2020. To help cities achieve this ambitious goal, over the next four years, C40 will redouble its efforts to leverage our networks and overcome barriers, such lack of finance.

A decade of action by C40 members, now representing 90 of the world's leading megacities, demonstrates that mayors have the experience and capacity to tackle climate change. We have collaborated for years across geographical and cultural boundaries to work towards this common purpose of a climate safe future for all urban citizens.

The Paris Agreement and the action it aims to unlock, remain fragile however, and as 2016 draws to a close the political landscape remains uncertain, particularly at the national level. Now more than ever cities' leadership, vision and above all decisive action is required.

We hope this research can galvanize discussion and focus minds – in city halls across the world and for all those who work with cities – to accelerate the pace and scale of action.

A climate safe future is possible, but only if we act now.

EDUARDO PAES

Mayor of Rio de Janeiro
C40 Chair

ANNE HIDALGO

Mayor of Paris
C40 Chair-elect

Arup: Gregory Hodkinson, Arup Chairman

As a signatory to the 2015 Paris Pledge for Action, Arup joined the C40 cities and other non-state actors in a shared commitment to limit global temperature rises to less than 2 degrees Celsius.

It is to the credit of the signatory states and ratifying parties to the Paris Agreement that the agreement has come into force in less than a year. However, once again, it is cities that have demonstrated their agility and the speed by which they can act, committing to the most ambitious element of the Paris Agreement, and setting out the exact means by which they will get there.

I have said before that we have only one generation to save our cities, but actually, as our *Deadline 2020* research shows us, the timeline for necessary action is far shorter than this. The decisions we all make now, and the plans we set in motion within the next four years will determine the futures of our children and grandchildren.

Collaboration is without doubt the key to achieving these ambitions, and we stand ready to work with cities, governments, and civil society to turn ambition into action.

This report shows us exactly what this kind of ambition looks like at a city-scale, and sets the tone for the years to come. The pace and scale of climate action must more than triple, such that by mid-century, C40 cities are carbon-neutral, and on the pathway to negative net emissions. This will require a wholesale reconfiguration of how we produce, store and use energy, interact with our urban environments, and use our infrastructure.

I am proud that Arup is working at the forefront of these efforts, providing the C40 and its group of climate-leading cities with access to the necessary technical assistance and guidance to enable them to drive change at a truly global scale.

GREGORY HODKINSON

Arup Chairman

EXECUTIVE SUMMARY

A routemap to turn the aspirations of the Paris Agreement into reality

The Paris Agreement commits signatories to "holding the increase in the global average temperature to well below 2 degrees above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5 degrees above pre-industrial levels." So what does limiting temperature rise to 1.5 degrees really mean? While nations consider their options, this report, *Deadline 2020*, presents a detailed pathway of what C40 cities' need to do to play their part in converting the COP21 Paris Agreement from aspiration into reality.

Research and analysis for this report has identified C40 cities' share of the remaining global carbon budgets to 2100, for 1.5 and 2 degree[I] temperature rise scenarios. Target emissions trajectories have been established for 84[II] individual member cities that enable these budgets to be met. The work outlines some of the city-specific action pathways necessary to meet the target trajectories, laying out clearly the pace, scale and prioritisation of action needed between now and the end of the century.

The analysis will be provided to C40 members and will be the basis for discussion about future C40 action.

Deadline 2020: four years to get on track

The overriding and deeply significant finding of the work is that the next *4 years will determine whether or not the world's megacities can deliver their part of the ambition of the Paris Agreement*. Without action by cities the Paris Agreement can not realistically be delivered. The business-as-usual path of C40 cities' emissions needs to 'bend' from an increase of 35% by 2020, to peak at only a further 5% higher than current emissions. This "bending of the curve" is required now to ensure that in the coming decades the necessary reductions remain feasible, given that actions can take many years to mature and reach full scale.

Contraction and convergence

To remain within a 1.5 degree temperature rise, average per capita emissions across C40 cities need to drop from over 5 tCO_2e per capita today to around 2.9 tCO_2e per capita by 2030. For wealthier, high-emitting cities that means an immediate and steep decline. Many fast developing cities can maintain their current levels for up to a decade, and in a small number of cases there is some scope for emissions per person to rise slightly before they eventually fall to zero. But every city needs to diverge considerably from its current business as usual pathway.

Cities are critical to delivering a climate safe future

Over half the emissions savings identified in this routemap can be delivered directly or through collaboration by C40 city governments. If the action pathway outlined in this document is pioneered by C40 cities, and then adopted by cities globally, action within urban areas would deliver around 40% of the savings needed to achieve the ambition of the Paris Agreement. Cities are therefore critical to delivering a climate safe future.

I This report uses "1.5 degrees" and "2 degrees" as shorthand for scenarios that limit global warming to less than 1.5°C and 2°C above pre-industrial levels respectively
II The number of C40 member cities at the time of analysis, which is lower than the number of members at the time of publication. See methodological report for full list of included cities www.arup.com/deadline

DEADLINE 2020: HEADLINE FINDINGS

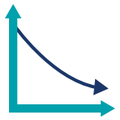
NATIONS AGREE TO LIMIT GLOBAL WARMING TO 1.5C°

HEADLINE FINDING 1

Deadline 2020 presents the first significant pathway for relating the ambition of the Paris Agreement to action on the ground.

This would allow C40 cities, representing 650 million people and 25% of the world's GDP, to deliver individual emissions trajectories consistent with limiting global temperature rise to 1.5 degrees.

5.1 TCO_2 / PERSON TODAY,
2.9 TCO_2 / PERSON BY 2030



HEADLINE FINDING 2

To remain within a 1.5 degree temperature rise, **average per capita emissions across C40 cities would need to drop from over 5 tCO_2e per capita today to around 2.9 tCO_2e per capita by 2030.**

Doing so would keep cities on a trajectory consistent with either 1.5 or 2 degrees of warming, it is only after 2030 that these trajectories diverge.

HEADLINE FINDING 3

As C40 cities age and grow they will need to invest in renewing and expanding infrastructure, and working to enhance the quality of life of citizens.

From 2016 to 2050, over $1 trillion investment is required across all C40 cities to meet the ambition of the Paris Agreement through new climate action.

$375 billion of this investment is needed over the next four years alone.

WE HAVE FOUR YEARS TO CHANGE THE WORLD

14,000 MORE CLIMATE ACTIONS 2020

HEADLINE FINDING 4

DEADLINE 2020: ACTION TAKEN IN THE NEXT FOUR YEARS WILL DETERMINE IF IT IS POSSIBLE FOR CITIES TO GET ON THE TRAJECTORY REQUIRED TO MEET THE AMBITION OF THE PARIS AGREEMENT.

If sufficient action is not taken over this period, limiting temperature increases to below 1.5 degrees will be impossible. C40 cities collectively delivered nearly 11,000 climate actions between 2005 and 2016. In the four years to 2020, an additional 14,000 actions are required. This represents an additional 125% in less than half the time.

HEADLINE FINDING 5

Wealthier, high carbon cities must deliver the largest savings between 2017-2020.

As of 2017, cities with GDP over $15,000 per capita must begin to reduce their per capita emissions immediately.
Of the 14,000 new actions that are required from 2016-2020, 71% should be taken by cities that need to immediately decrease per capita emissions.

HEADLINE FINDING 6

Mayors can deliver or influence just over half of the savings needed to put C40 cities on a 1.5 degree trajectory.

That includes a total of 525 $GtCO_2e$ by 2100, either through direct action or via collaboration with partners such as the private sector.

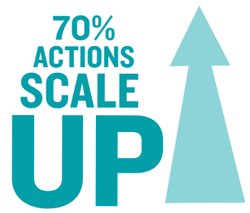
C40 MAYORS CAN AND WILL ACT

HEADLINE FINDING 7

If action involving city governments can deliver just over half of the GHG savings needed, then **action to deliver structural changes from outside cities (i.e. electrical grid de-carbonisation), must start to have a significant impact from** 2023 at the latest. This will take over as the dominant driver of urban GHG reductions after 2030.

HEADLINE FINDING 8

Even with all required actions taken as per city trajectories, **substantial carbon sequestration will also be required by national governments** if cities are to stay on a 1.5 degree trajectory post 2050.



HEADLINE FINDING 9

Action by C40 cities can have huge magnification: If all cities with a population greater than 100,000 adopted the ambition for C40 cities set out in this report, they could save 863 $GtCO_2e$ globally by 2050.

BY 2100, THEY COULD HAVE SAVED UP TO THE EQUIVALENT OF 40% OF THE REDUCTIONS NECESSARY FOR A 1.5 DEGREE SCENARIO.

CITIES CAN DELIVER UP TO 40% OF SAVINGS NEEDED FOR 1.5 DEGREE WORLD

DEADLINE 2020: PROCESS TO PATHWAYS

1 GLOBAL BUDGET 1870-2100

Emissions today:
C40 Cities: **2.4 $GtCO_2e$**
Global: **47 $GtCO_2e$**

Remaining global emissions budget to 2100:
387 $GtCO_2e$ for 1.5 degrees

How much of this remaining budget should be allocated to C40 cities?

2.4 $GtCO_2e$ **387**
47 $GtCO_2e$ **$GtCO_2e$**

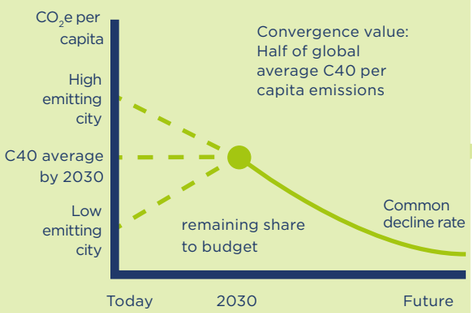
2 ESTIMATING THE C40 CITY SHARE OF THE BUDGET

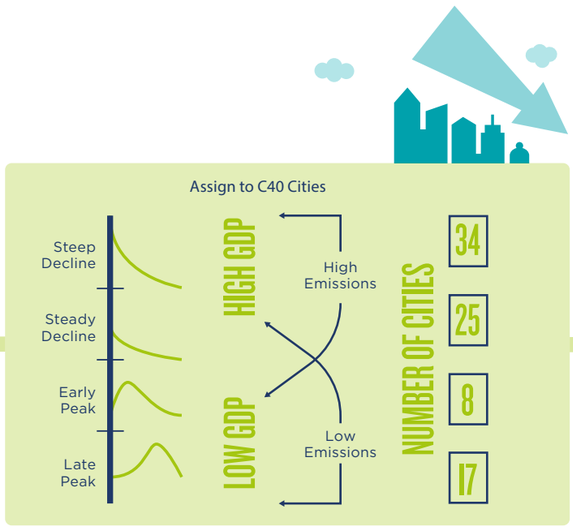
CONVERGENCE AND CONTRACTION

Our chosen method for developing a "fair share" budget for the C40 cities. This takes into account the issues of:

Equality **Responsibility** **Capacity**

This budget is calculated by assuming cities' per capita emissions (and those of the rest of the world) converge linearly to a common value, then everyone declines to zero at a common rate depending on the remaining budget.





4 TARGET TRJECTORY

Each city is assigned one of four per capita emissions reduction trajectory typologies based on their current emissions per capita and GDP per capita. The characteristics of these four trajectories are flexed to share the burden between cities and achieve rapid emissions reductions across cities.

HOW DO C40 CITIES COLLABORATE?

C40 Share =6% of Global Budget by 2100

22 $GtCO_2e$

3 C40 BUDGET

This method gives us a budget of 22 $GtCO_2e$, 6% of the global budget to 2100.

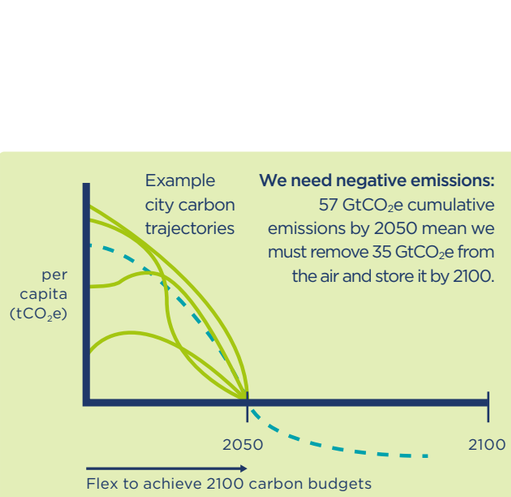
Now, how do C40 cities collaborate to ensure this collective budget is not exceeded?

5 CLIMATE ACTIONS TO DELIVER TRAJECTORY

C40 – ARUP PARTNERSHIP CLIMATE ACTION PATHWAYS MODEL (2CAP)

The 2CAP model is used to investigate the actions required by cities, and the external factors (such as electrical grid decarbonisation)necessary to achieve each city's target trajectory.

What actions give a Target Trajectory?



We need negative emissions:
57 $GtCO_2e$ cumulative emissions by 2050 mean we must remove 35 $GtCO_2e$ from the air and store it by 2100.

34,000 ACTIONS IN PLACE BY 2030
ZERO CARBON ENERGY BY 2050
14,000 ACTIONS INITIATED BY 2020

-35$GtCO_2e$

NEGATIVE EMISSIONS REQUIRED BETWEEN 2050 AND 2100

See Appendix A for more detail, and associated Technical Report for full detailed methodology

CHAPTER 1

INTRODUCTION

I.1 C40 CITIES CLIMATE LEADERSHIP GROUP

The C40 Cities Climate Leadership Group (C40), now in its 11th year, connects more than 86[III] of the world's greatest cities, representing over 650 million people and one quarter of the global economy. Created and led by cities, C40 is focused on tackling climate change and driving urban action that reduces greenhouse gas emissions and climate risks, while increasing the health, wellbeing and economic opportunities of urban citizens.

I.2 A C40 ACTION PATHWAY FOR DELIVERING AGAINST THE PARIS AGREEMENT

This report presents a routemap that would allow C40 cities to meet the aims and ambitions of the Paris Agreement. That agreement commits signatories to "holding the increase in the global average temperature to well below 2 degrees above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 degrees above pre-industrial levels."

Research and analysis, carried out as part of C40 and Arup's $2 million research partnership, has identified C40 cities' share of the remaining global carbon budgets to 2100, for 1.5 and 2 degree[IV] temperature rise scenarios. Target emissions trajectories have been established for 84[V] individual member cities that enable these budgets to be met. The work outlines some of the city-specific action pathways to meet the target trajectories, laying out clearly the pace, scale and prioritisation of action needed over the next 5 years and beyond.

The findings will inform C40's support to cities over the coming years and help to focus city decision-making on the action that matters most. Furthermore, this provides a precedent for nations and other actors to follow, to chart their own pathway towards world compliance with the Paris Agreement.

I.3 THIS PROJECT: NOT A STATIC BLUEPRINT BUT THE START OF A COLLECTIVE JOURNEY

Deadline 2020 is an evolving blueprint, not a static or perfect prescription, to which all partners are invited to contribute. *Deadline 2020* is based on the best currently available evidence, however more and better data will continue to become available, allowing refinement of the goals and approaches. This plan is the first stage in an ongoing process of measurement and prioritisation that C40 will lead over the coming decade to refine its action pathway. We have published all the evidence, methods, assumptions and analysis, and welcome suggestions for improvement.

C40, Arup and our partners have a number of work streams underway that aim to close some of these key knowledge gaps in the coming years. This work is in part delivered as a call for evidence that seeks to gather further data and insight on the elements that make up *Deadline 2020* thinking.

Call for Evidence: A work in progress seeking your review and input

V2020 Homepage: www.C40.org/research

All the assumptions, methods and outputs of the *Deadline 2020* project are published in detail online. Both as a technical paper and as full data sheets covering all non-confidential inputs. We invite all partners to read and review these, and provide comments and recommendations for improvement, as well as links to other relevant work and data. The data sheets provide, for every assumption, a section for comments and suggestions, which can be uploaded at the online page.

All stakeholders, be they city administrations, Non-Governmental Organisations, civil society, business or private citizens are invited to visit the *Deadline 2020* homepage[VI].

III At the time of publication, with member numbers increasing steadily
IV This report uses "1.5 degrees" and "2 degrees" as shorthand for scenarios that limit global warming to less than 1.5°C and 2°C above pre-industrial levels respectively
V The number of C40 member cities at the time of analysis, which is lower than the number of members at the time of publication. See methodological report for full list of included cities www.arup.com/deadline
VI www.C40.org/research

CHAPTER 2

ONE YEAR ON FROM THE PARIS AGREEMENT

2.1 WE HAVE THE COMMITMENT, NOW IMPLEMENTATION AT SCALE IS URGENTLY NEEDED

The COP21 Paris Agreement was a historic, global achievement and a turning point for humankind.

In recognition of this, and in accordance with the Paris Agreement and the Paris Pledge[1] for non-state actors, C40 believes firmly that compliance with all the elements of the Paris Agreement should be the primary aim of our member cities going forward.

What does limiting temperature rises to 1.5 degrees really mean? How fast must we decarbonise our energy supplies? Is this possible in the face of expected economic growth? What types of actions are needed and how fast? How much will it cost? Who must drive and deliver these actions? What does this raised ambition on mitigation mean for our plans to adapt? We are left with many unanswered questions about how to deliver on the breathtaking ambition of the Paris Agreement.

The Agreement entered into force on November 4, 2016, shifting the focus to the hard work of implementing the ambitious, collective action required to realise its aspirations. While nations continue considering what this all means, the world's megacities are planning their response. This is C40's proposal with *Deadline 2020*. It is a global pathway of city-level, inclusive climate action, that would put cities on a trajectory consistent with the ambitions of the Paris Agreement from now until the end of the century.

2.2 THE WINDOW FOR ACTION IS FAST DISAPPEARING

It is vital to remember that irreversible climate change is already underway, and the impacts are already being felt around the world. Global temperatures have already increased by 1 degree Celsius from pre-industrial levels.[2] Atmospheric CO_2 levels are *already* above 400 parts per million (ppm),[3] far exceeding the 350 ppm deemed to be "safe".[4] These facts emphasise the incredible urgency with which we need to act if the ambitions agreed in Paris are to be met.

Recent C40 research shows that, based on current trends of consumption and infrastructure development, within five years the world will have "locked-in" sufficient future emissions to exceed 2 degrees. A third of these emissions will be determined by cities, making them pivotal actors in any solution.

2.3 CITIES WILL BEAR THE BRUNT OF INACTION

'The impacts of climate change are no longer subtle. They are playing out before us, in real time.'[5]

In addition to efforts to reduce carbon emissions, preparations must be made to deal with the impacts of climate change.

The IPCC fifth assessment (AR5) reported that urban climate change risks are increasing, and identified that "much of the key and emerging global climate risks are concentrated in urban centres". In C40 and Arup's 2015 Climate Action in Megacities report, 98% of cities reported that climate change poses a current and/or future risk to their city. As shown on page 20 - C40 Cities Regional Climate Risks, C40 cities report that they are currently experiencing a range of very serious hazards as a result of climate change. All cities report that some of hazards they face will become more serious and more frequent as the climate changes. The potential impacts on people, infrastructure, environments, and local and national economies would be even more profound.

The ambition of the Paris Agreement and of *Deadline 2020* is to limit warming to 1.5 degrees, but the risk of further increases in temperature remains significant. Unless preventative action is taken, climate change-related natural disasters have been estimated to put at risk 1.3 billion people by 2050 and assets worth $158 trillion – double the total annual output of the global economy.[6]

In addition to efforts to reduce carbon emissions, preparations must be made to deal with the impacts of climate change. In recognition of this the Paris Agreement commits signatory nations to a common effort of "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change". Urban centres are vital sources of adaptation solutions, essential to successful global climate change adaptation. C40 is building on a decade of proven leadership and success to support our member cities in their transformative adaptation efforts.

C40 CITIES REGIONAL CLIMATE RISKS

TORONTO

Focus: Extreme winters

While the overall climate is warming the potential for extreme winter conditions is also increasing in frequency. Extreme winter conditions can increase demand on the energy sector resulting in brownouts and blackouts. Various health effects arise from periods of cold weather exposure, including frostnip, frostbite and hypothermia, with vulnerable populations particularly at risk. Extreme weather also puts stress on public infrastructure including roads and other transportation services.

NORTH AMERICA

82 MILLION BY 2020

- FLASH/SURFACE FLOOD (HIGH)
- HEAT WAVE (HIGH)
- RAIN STORM (MODERATE)

LATIN AMERICA

114 MILLION BY 2020

- HEAT WAVE (HIGH)
- FLASH/SURFACE FLOOD (HIGH)
- LANDSLIDE (HIGH)

MODERATE

HIGH

VERY HIGH

EXTREME

RIO DE JANEIRO

Focus: Landslide

Severe storms, leading to landslides and flooding episodes represent a serious risk to Rio's population, due to the city's steep topography and informal settlements. The increased frequency of rainfall especially in summer is likely to lead to more frequent landslides in the future. Rio has a tragic history of life and property landslides losses due to landslide. These also have severe social and public health consequences. To address these risks, the city created the Centro de Operações Rio to anticipate risks and alert the responsible sectors to take the required measures to avoid serious impacts.

COPENHAGEN

Focus: Costs of climate change

In the summer of 2011, in 2014 and again in 2015, there have been torrential downpours in Copenhagen. If UN Intergovernmental Panel on Climate Change (IPCC) projections prove accurate, the costs of damage over the next 100 years could reach DKK 16 billion. This is considered a conservative estimate. Before the downpour in the summer of 2014, the cost of damage from extreme rainfall events already totalled DKK 6 – 9 billion over the past 6 years.

EUROPE

84 MILLION BY 2020

- HEAT WAVE (MODERATE)
- RAIN STORM (MODERATE)
- EXTREME HOT DAYS (VERY HIGH)

SOUTH & WEST ASIA

139 MILLION BY 2020

- FLASH/SURFACE FLOOD (HIGH)
- HEAT WAVE (MODERATE)
- DROUGHT (EXTREME)

KOLKATA

Focus: Informal settlement

Kolkata Municipal Corporation, the most important ULB in Kolkata Metropolitan Area, is currently ranked as the third most vulnerable city in the world from coastal flooding. Kolkata Metropolitan Area's slums are highly vulnerable to floods and cyclones because of poor construction materials, weak social structures and their vulnerable locations. For example, some are located in zones that were previously low-lying wetlands surrounded by vast water bodies into which sewage flows from the city.

AFRICA

74 MILLION BY 2020

- FLASH/SURFACE FLOOD (HIGH)
- EXTREME HOT DAYS (HIGH)
- DROUGHT (VERY HIGH)

CAPE TOWN

Focus: Food

The impacts of water scarcity on agricultural productivity will affect food production and supplies. This could increase the price of food and result in food scarcity, particularly for Cape Town's most vulnerable communities. The potential collapse of the agricultural sector and ecosystem services in the Western Cape could also lead to an increase in in-migration from rural areas to the city. This could test the city's already stretched service delivery capacity and resources, placing further pressures on employment opportunities and resource pricing.

CHANGWON

Focus: Typhoon

Between 2000 and 2013, Changwon experienced fifteen typhoons. Combined with rainstorms, these caused inundation of buildings, roads and farmlands, as well as blackouts. More than 11,000 buildings were damaged. Anticipating the affect of climate change on extreme events such as typhoons is very challenging, as they are complex climate events and occur sporadically. Changwon has therefore not been able to anticipate the future impact of severe wind in its vulnerability assessments, despite its significance.

EAST ASIA

165 MILLION BY 2020

- RAIN STORM (MODERATE)
- DROUGHT (MODERATE)
- EXTREME HOT DAYS (EXTREME)

SOUTHEAST ASIA & OCEANIA

65 MILLION BY 2020

- FLASH/SURFACE FLOOD (HIGH)
- EXTREME HOT DAYS (VERY HIGH)
- DROUGHT (MODERATE)

BANGKOK

Focus: Flood and sea level rise

The most significant hazard Bangkok is facing is flooding. Bangkok is located in the Chao Phraya River Basin, which has an average elevation of only 1-2 meters above the mean sea level and includes some areas that are under sea level due to land subsidence.

Bangkok has experienced severe flooding almost once every 3 – 5 years. This is likely to become more severe as the climate changes and sea level rises. Flooding affects the functioning of the city causing power failure, water supply shortage, transportation disruption, choked sanitation function, diseases and stress, and solid waste and wastewater pollution.

CHAPTER 3

HOW C40 CITIES CAN DELIVER ON THE AMBITION OF THE PARIS AGREEMENT

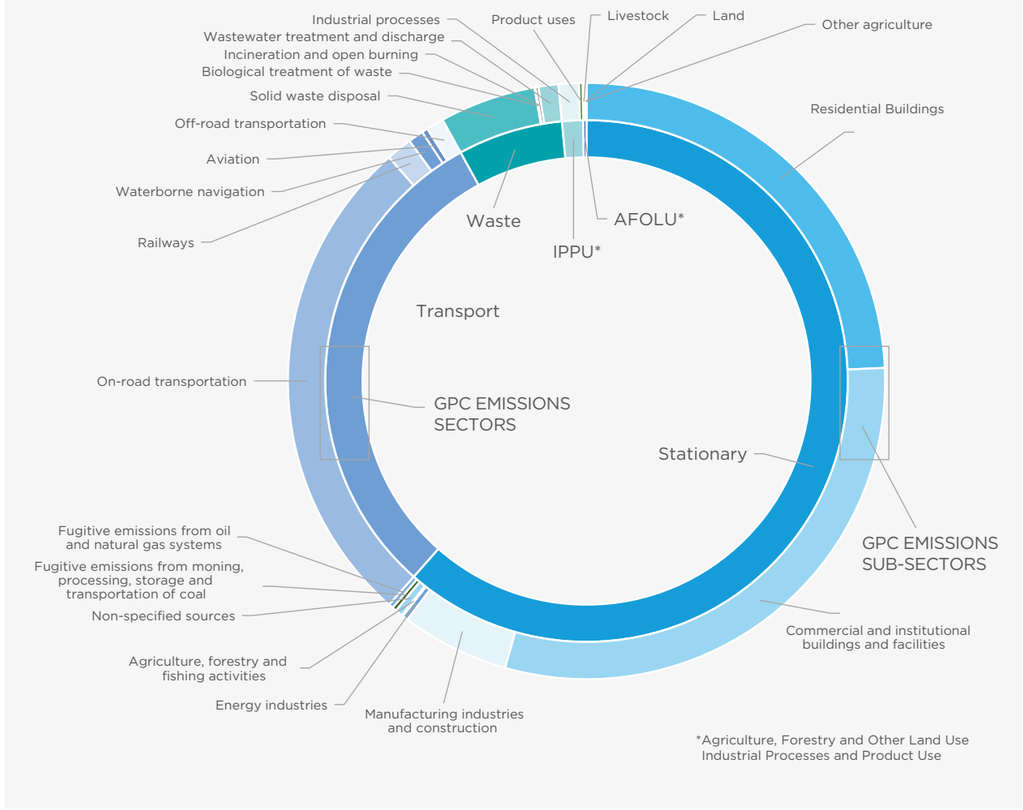
CARBON BUDGET

To meet the global carbon budget that would keep global temperature rise to 1.5°degrees, we must achieve rapid and dramatic cuts in greenhouse gas emissions. This will require wholesale transformation of long-entrenched industrial processes, transportation modes, energy generation techniques, land use planning, and economic models, enabling us to shift away from the high-emissions activities we have adopted.

3.1 EMISSIONS OF C40 CITIES TODAY

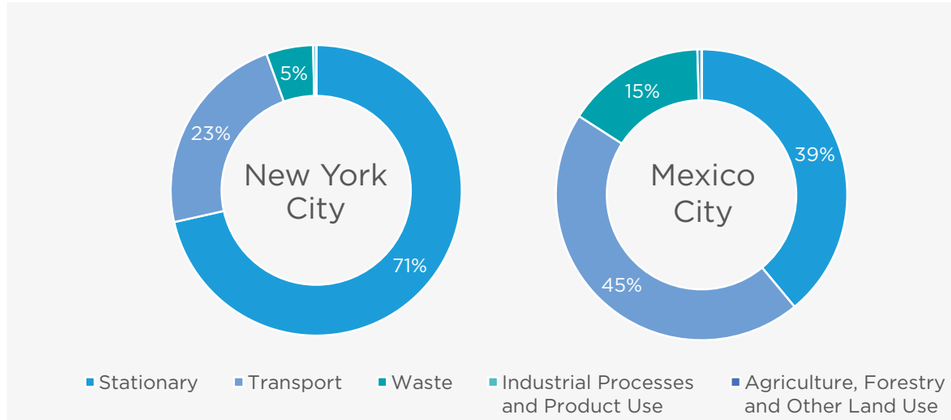
In 2015, the 84 C40 cities covered by this research emitted 2.4 $GtCO_2e$ of greenhouse gases. As Figure 1 and Figure 2 illustrate, these emissions are dominated by stationary and transport emissions sources.[VII] While magnitudes may vary from city to city and region to region, average emissions breakdowns are remarkably similar at the high level.

Figure 1. C40 cities' GHG emissions sources. Based on the GPC inventories of 30 cities, with remaining cities mapped on a per capita emissions basis. Categories for the inner ring are the GPC main sectors, for the outer ring are the full list of GPC sub-sectors. Where these are shown as zero, this may be due to a current lack of available data at city-level.



VII According to Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories (GPC) categories.

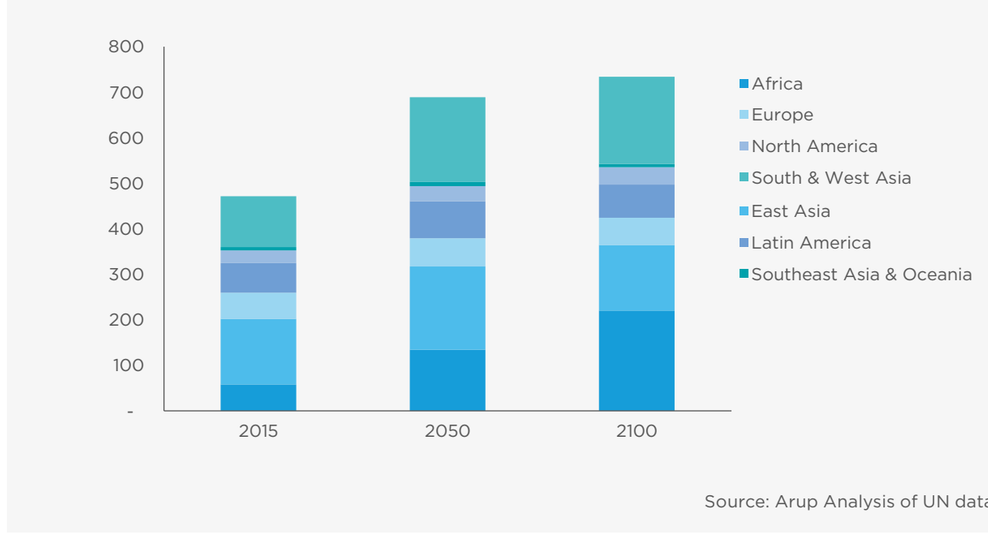
Figure 2. Comparison of two C40 cities' emissions sources.



3.2 HOW EMISSIONS WILL INCREASE IF WE DON'T TAKE ACTION

C40 cities, home to over half a billion people today, are set to see their population boom to nearly 800 million by 2100.[VIII] These cities represent 650 million people and a quarter of today's global GDP.

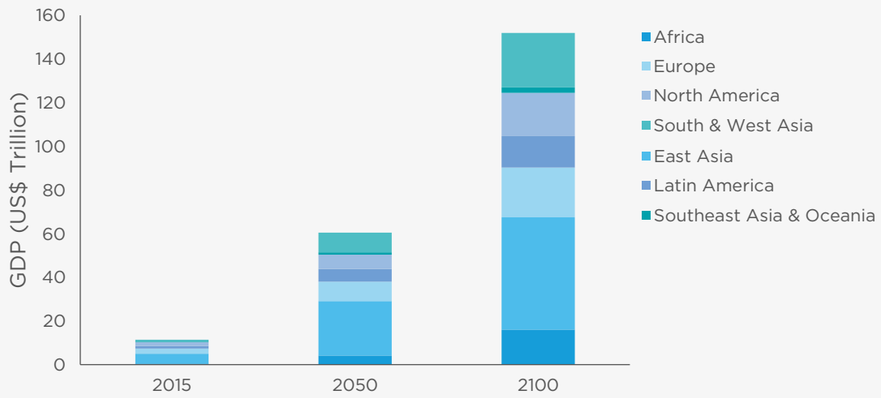
Figure 3. Projected population growth in current C40 cities.



Source: Arup Analysis of UN data[7]

VIII The city data used in this analysis is based on the mayor's jurisdictional area.

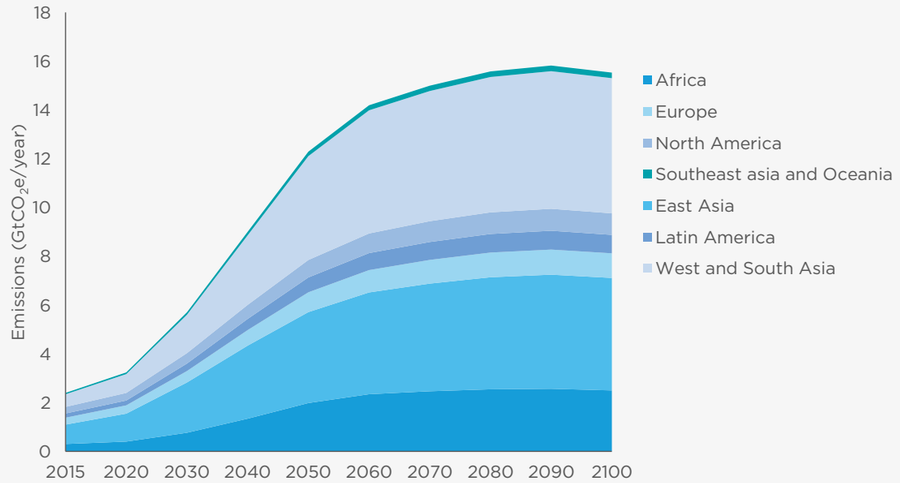
Figure 4. Projected economic growth in current C40 cities.



Source: Arup analysis of Economist Intelligence Unit data[8]

In the absence of measures to limit growth, anticipated economic and population booms will drive up emissions levels significantly over the coming decades. Figure 5 shows the modelled results for a Business as Usual (BAU) emissions trajectory of C40 cities, broken down by region. As the graph shows, if no further climate action is taken, and expected trends continue for population and GDP growth, with similar improvements to energy efficiency, we can expect annual emissions to increase by more than seven times by 2100. Importantly in the context of C40 cities, those East Asia and South and West Asia, with their particularly large populations, are expected to contribute the greatest to BAU emissions out to 2100. This demonstrates a need to focus efforts and support on these regions, while recognising that some of these cities may be the least well-equipped to deliver the scale of action required.

Figure 5. Projected business as usual GHG growth in current C40 cities.



Source: Arup analysis

Defining the Business as Usual (BAU) trajectory

This study defines the BAU scenario as the case where C40 cities' population and GDP growth to 2100 continue as projected, with similar improvements to energy efficiency as have been observed historically. At the same time, the carbon intensity of consumed energy is not assumed to improve beyond existing levels. As such, the BAU scenario can be thought of as a "no further climate action" scenario; that is, a worst-case view. Consistent with concepts used in the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5), this method is discussed further in Appendix A and the accompanying methodological paper for this research.

Consumption-based city emissions

For the purposes of this study, where city carbon budgets have been developed based on total global emissions levels, it can be justified that these city carbon budgets are based on emissions inventories of Scope 1 and 2 emissions only. That is, the direct emissions from combustion of fuels for heating, transportation etc. (Scope 1); and indirect emissions from consumption of purchased electricity, heat or steam (Scope 2).

This approach is consistent with the way data is reported by C40 cities as per the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories (GPC). It also places focus on actions and initiatives that can be made at city level Scope 1 and 2 categories, which can be thought of as "production-based"[IX] emissions that are under the scope of influence of city governments and their inhabitants.

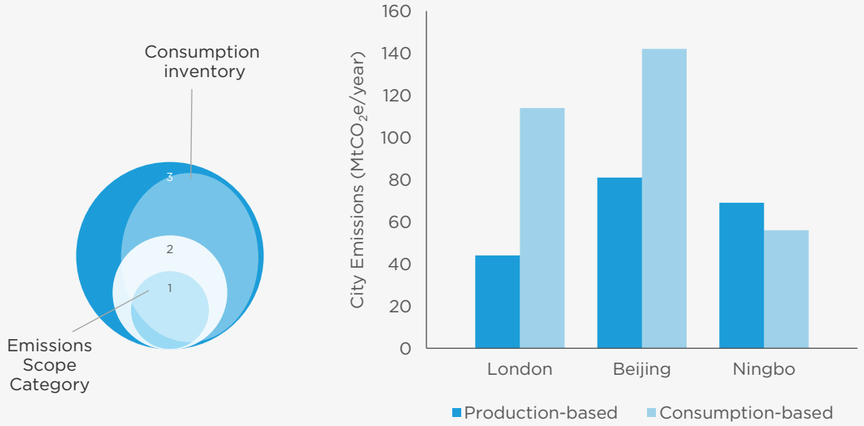
Another useful and important concept with regard to global greenhouse gas mitigation is "consumption-based" emissions accounting. This recognises the direct *and* lifecycle emissions associated with the goods and services consumed by city residents. The approach is boundary free, meaning that the emissions associated with goods and services are accounted for and attributed to the consuming city (as opposed to the producing entity) wherever in the world they arise.

Perspective on consumption-based emissions inventories is illustrated by Figure 6. They can be sizeable and of a scale equal to or larger than the Scope 1 and 2 inventories, particularly where cities rely on goods (such as food/drink, clothes, electronic items, building materials, vehicles, etc.) produced outside their boundaries.

Some cities, however, which are net exporters of goods or services, or which have a particular developmental profile, may have smaller consumption-based inventories compared with their Scope 1 and 2 emissions. In either case, considering consumption-based emissions provides cities with a wider lens to understand their burden on the global climate, and enables them to frame further action to minimise their impacts.

Scope 3 emissions is often used to describe a city's indirect emissions associated with activities outside its governmental boundary. They will include a component that can be described as consumption based (e.g. bananas delivered into the city for food consumption), but are also associated with emissions that occur due to a city's activities that are not consumption driven (e.g. textile material supplied to a clothing firm in a city which is manufacturing shirts for export to a market beyond its boundary). This distinction is important because it shows that consumption and scope 3 emissions categories are different but share a common element.

Figure 6. Examples of consumption-based inventories for cities.[9]



C40, Arup, The University of Leeds, and The University of New South Wales are currently developing comprehensive consumption-based emissions inventories of 80 C40 cities, with the results of this study due before the end of 2017.

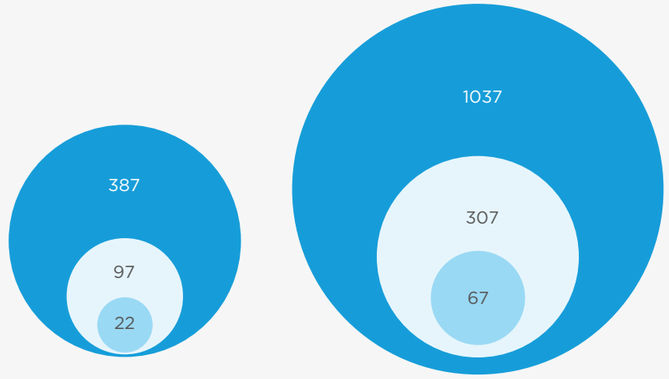
IX Noting that indirect emissions from electricity are often not actually produced in / by cities themselves

3.3 C40 CITIES' REMAINING CARBON BUDGET

Using a "contraction and convergence" carbon budgeting approach, we have established C40 cities' shares of overall global carbon budgets.[X] The global carbon budgets used represent a 66% chance of limiting global temperature rises to 1.5 degrees and 2 degrees.[XI] A summary of this methodology can be found in Appendix A, with full detail in the methodological paper accompanying this report.

As shown in Figure 7, the carbon budgets for C40 cities are 22 and 67 $GtCO_2e$ for 1.5 and 2 degree scenarios, respectively. Achieving these budgets will be no mean feat; the 1.5 degree scenario implies that at current rates (2.4 $GtCO_2e$ per year) the C40 emissions budget would be consumed in less than ten years. [XII]

Figure 7. C40 cities' share of the global carbon budget for 1.5 (left) and 2 degree (right) temperature rise scenarios. "All Cities" refers to existing cities with populations of 100,000 or more. The carbon budgets provided are for 2016 to 2100.



3.4 SHARING THE REMAINING BUDGET

With an overall budget established for C40, each member city was assigned to one of four trajectory groups defined by specific city characteristics, as illustrated in Figure 8.

A threshold GDP per capita value of $15,000[XIII] was used to categorise the cities into either "Peaking" or "Declining" per capita emissions groups.

Cities' current emissions per capita were then used to further subdivide cities into one of four categories:

- *"Steep Decline"* – Cities with a GDP per capita over $15,000 and emissions above the average for C40 (emissions need to be immediately and rapidly reduced and the city is sufficiently developed to do so).
- *"Steady Decline"* – Cities with a GDP per capita over $15,000 but emissions lower than the average for C40, (the city is sufficiently developed to immediately reduce emissions, but a less rapid rate of reduction is required than for the Steep Decline group).

X Note the carbon budget is inclusive of all greenhouse gas emissions reported within the IPCC AR5 report. Throughout this report the term "carbon budget" is used to refer to a GHG budget in units of carbon dioxide equivalent.
XI We note that this same confidence threshold cannot apply to C40's own budgets
XII www.arup.com/deadline
XIII This aligns with United Nations (UN) development classification for countries moving from low income to middle income. The UN officially uses Gross National Product (GNP) as a measure to classify development status but this data is not currently available consistently at a city scale.

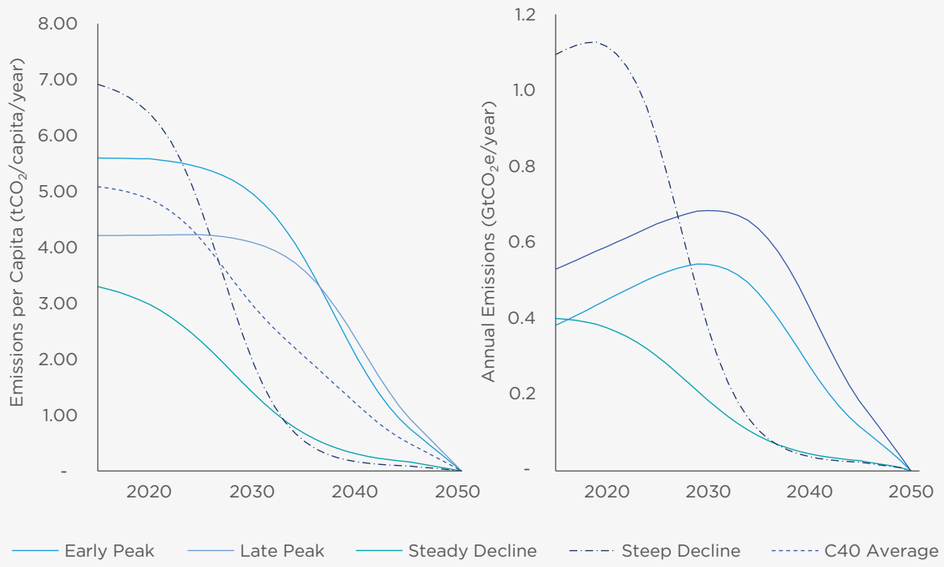
- *"Early Peak"* – Cities with GDP per capita below $15,000 and higher than average emissions per capita, (an early emissions peak is required, although the city's development status means that decline cannot be immediate).
- *"Late Peak"* – Cities with a GDP per capita below $15,000 and lower than average emissions per capita (a slightly later emissions peak is possible).

Combined with each city's projected population growth out to 2100, these trajectories create an overall C40 carbon trajectory that member cities need to follow to secure their contribution to limiting global temperature rises to 1.5 degrees.

Table 1. Assigned emissions per capita reduction typologies for select C40 cities. Based on self-reported data via GPC. Cities marked with * reported via CDP.

GHG/Capita	GDP/capita	Assigned typology	Example cities
High	High	*Steep Decline*	*Toronto* *Melbourne* *New York City*
	Low	*Early Peak*	*Cape Town* *Durban**
Low	High	*Steady Decline*	*Stockholm* *Seoul** *London*
	Low	*Late Peak*	*Quito* *Caracas** *Amman*

Figure 8. Projected average emissions per capita (left) and total annual emissions (right) for the four typologies under the 1.5 degree scenario.

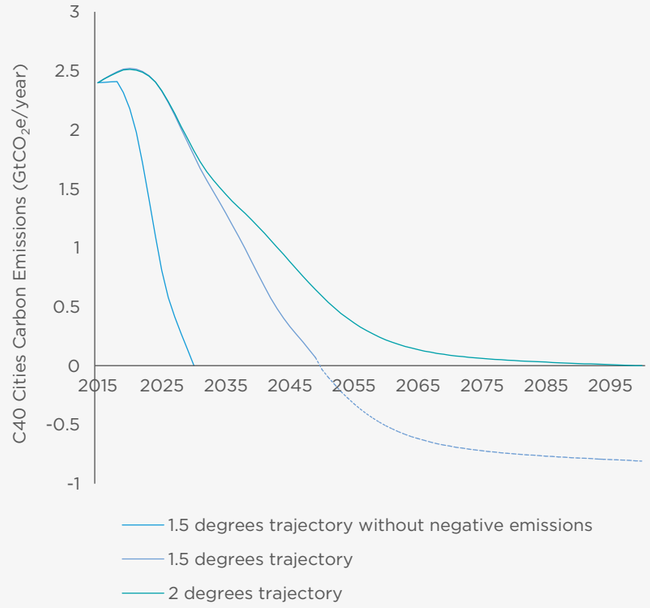


As can be seen from Figure 8, on average Early and Late Peak cities do not increase their emissions levels per capita from 2016 onwards. However once population growth is factored in, on average these cities continue growing their overall emissions until between 2030 and 2035. While wealthier high carbon emitting cities account for much higher emission levels today and towards 2020, by 2035 these cities must be producing negligible emissions.

As indicated in Figure 8, the vast majority of C40 cities must ensure that from 2016, per capita emissions either drop or at least do not increase any further. While this is true on average, there will be some exceptions. Within the Late Peak group there will be a small number of cities with very low per capita emissions today, and these would be expected to increase their per capita emissions briefly since they are starting at such a low level.

3.5 THE C40 CARBON TRAJECTORY FOR 1.5 IS CONSISTENT WITH 2.0 UNTIL 2030

Figure 9. Total C40 trajectories to 2100 to remain within 1.5 and 2 degree emissions budgets.

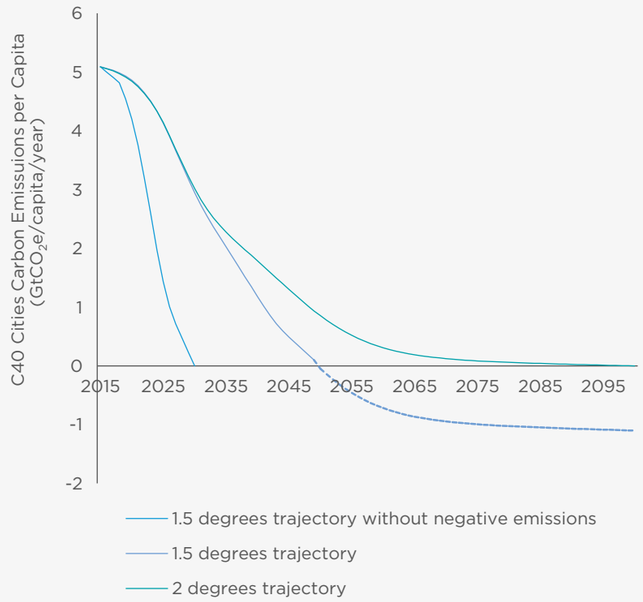


The 1.5 degree trajectory is consistent with the 2.0 degree trajectory until 2030

As can be seen in Figure 9, the 1.5 degree with negative emissions and 2 degree scenarios are largely the same until 2030, diverging somewhat thereafter, with the 1.5 degree scenario requiring continued steep emissions reductions.

Importantly, the 1.5 degree target trajectory hits zero emissions by 2050 and must continue to 2100 with *negative* emissions. Negative emissions technologies (such as bio-energy carbon capture and storage) are likely to be required to ensure that the 53 $GtCO_2e$ emitted by 2050 in the 1.5 degree scenario is reduced in line with the 22 $GtCO_2e$ budget by 2100. A total of 31 $GtCO_2e$ must be removed from the atmosphere during this time period. Since carbon capture and storage is not yet widely employed, there is an enormous amount of work to be done to make this trajectory a reality. Without negative emissions, our calculations suggest that zero net emissions would need to be reached in C40 cities as early as 2030. The concept of negative emissions is discussed in later sections and in the methodological paper.

Figure 10. C40 cities' emissions per capita trajectories to 2100 to remain within 1.5 and 2 degree budgets.



While there is uncertainty in the means by which we will maintain a negative emissions trajectory, we can observe that the 1.5 and 2 degree scenarios are essentially identical up to 2030, and therefore actions put in place today for a 1.5 degree scenario can also be consistent with a 2 degree scenario.

Table 2. Average per capita emissions figures for C40 cities in 1.5 and 2 degree target trajectories.

	Emissions per capita in 2020 (tCO_2e)	Emissions per capita in 2030 (tCO_2e)	Emissions per capita in 2050 (tCO_2e)
1.5 degrees	4.9	2.9	0.0
2 degrees	4.8	3.0	0.9

Estimating Carbon Trajectories and Targets

The targets and budgets presented are viewed as appropriate for the C40 group of cities today, based on the available evidence. Due to the constituent elements of the analysis, they will not be directly transferable to other sectors or even groups of cities, and so should only be used as guiding targets. As outturn emissions evolve in the future, it may be necessary to re-evaluate these target trajectories.

3.6 THE SCALE OF C40'S CHALLENGE: THE SAVINGS NEEDED TO DELIVER THIS TRAJECTORY

The next stage in our analysis is to determine the savings needed across the C40 network of cities, and within every individual city, compared with a business as usual (BAU) scenario.

We have developed detailed trajectories for each C40 city, however these are presented only in aggregate in this report.

3.6.1 VOLUME OF SAVINGS

Table 3 presents two perspectives on the volume of emissions savings necessary under the 1.5 and 2 degree modelled scenarios. Emissions reductions at the beginning of each decade to 2050 are shown against both the 2015 baseline (which is static), but also against the BAU in that year.

As part of the target trajectory, it is expected that aggregate C40 emissions will continue to increase year-on-year to a peak of 2.5 $GtCO_2e$ in 2020. Thereafter, a target of a 24-26% reduction on 2015 emissions levels by 2030 is assumed for both temperature rise scenarios (Table 3). The 1.5 degree scenario must continue with this pace of decline from 2030 to 2050, with C40 cities averaging net-zero emissions by mid-century. When compared to the BAU projection in each year, it is evident that the volume of savings is even higher.

Table 3. C40 cities' projected emissions savings per capita versus 2015 baseline year for 1.5 and 2 degree scenarios.

	Savings against 2015 emissions		Savings against BAU emissions per year	
	1.5 degree scenario	2 degree scenario	1.5 degree scenario	2 degree scenario
2020 saving	-5%	-5%	22%	22%
2030 saving	26%	24%	69%	68%
2040 saving	68%	51%	91%	87%
2050 saving	100%	78%	100%	95%

Table 4. Cumulative savings against BAU trajectory by typology, 1.5 degree scenario.

Typology	Early peak	Late peak	Steady decline	Steep decline
Cities per Typology	8	17	25	34
Cumulative Savings vs. BAU	($GtCO_2e$)	($GtCO_2e$)	($GtCO_2e$)	($GtCO_2e$)
2020	0.2	0.5	0.2	1.0
2030	2.8	5.9	3.1	13.2
2050	34.5	58.7	20.3	81.6
2100	250.9	336.3	86.4	316.5

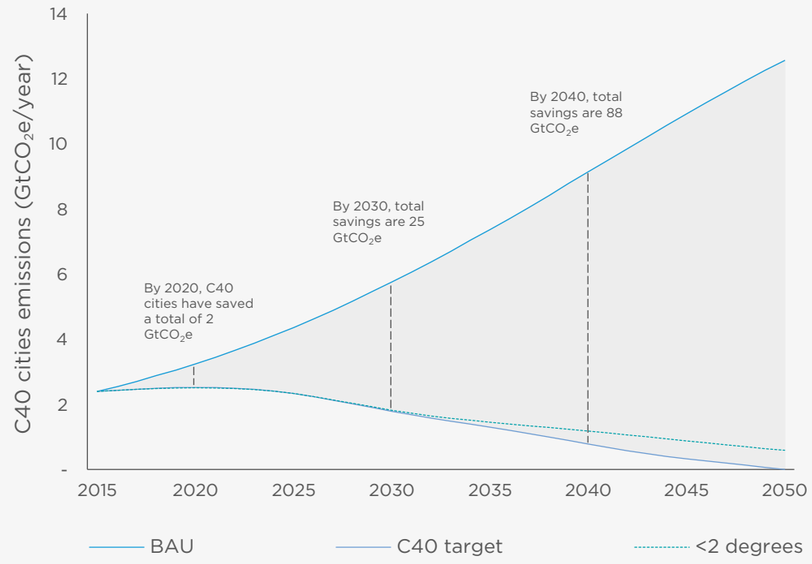
Table 4 illustrates that cities grouped in either the Steep Decline or Late Peak typologies need to make the largest overall savings from their BAU trajectories (as a proportion of all C40 cities total).

By reading across the rows in Table 4, one can compare the overall volume of savings by city group, and hence the level of effort or action required. Cities with a Steep Decline trajectory are required to make considerably larger savings in the early years. By 2020, these cities need to save between two and five times as much as any other typology group. By 2050, however, the Peaking cities need to take a step change through transformative action. They will benefit from the lessons learned by the Declining cities, reducing per-capita emissions in the later decades at similar paces to Declining cities in the early decades.

In 2020, C40 cities' annual emissions target is 0.7 $GtCO_2e$ per year below the BAU emissions, requiring a cumulative saving from 2015 of 1.9 $GtCO_2e$ (Figure 11).

The target gap widens over the years, stretching from a difference in annual emissions between the BAU and the target trajectory of 0.7 $GtCO_2e$ in 2020, to 12 $GtCO_2e$ in 2050. Cumulative savings correspondingly increase from 2 $GtCO_2e$ by 2020 to 196 $GtCO_2e$ by 2050. Further milestones are highlighted in Figure 11.

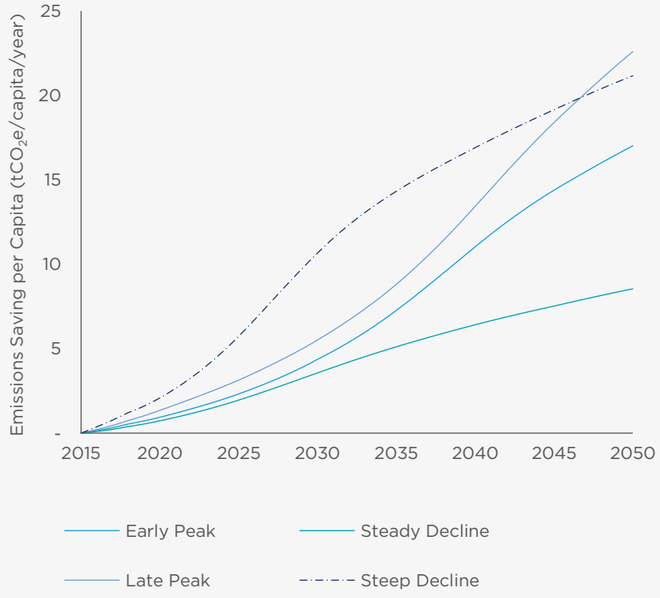
Figure 11: C40 cities' emissions per capita target trajectories vs BAU.



The intensity of savings

The per capita emissions savings are also important to consider, as they provide a further indication of the intensity of action needed. They indicate the amount of "effort" required per citizen (directly or on their behalf) to shift their city's trajectory downwards.

Figure 12: Projected emissions savings per capita against BAU for all typologies.



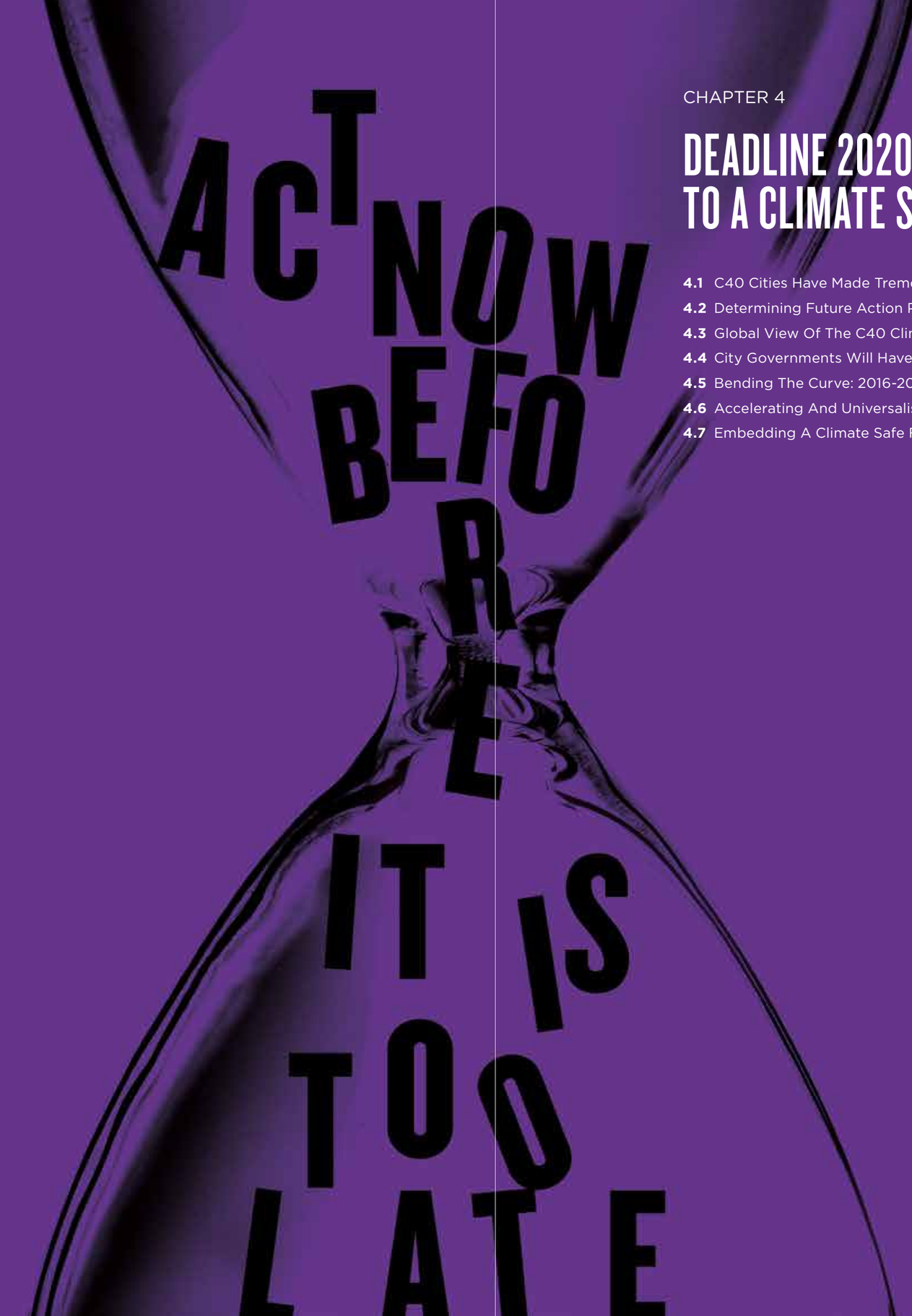
The target trajectories aim to split the responsibility of absolute emissions reduction between the city classifications. However, it is also clear that, when aiming for zero, significant reductions must be made across every typology. Although there is already divergence, in the years up to 2020 all typologies share similar reductions over the BAU in per capita terms.

The challenge will not be easy for most cities

The trajectories envision developed cities taking the bulk of the burden in the first 15 years, in both per capita and absolute terms. Steep Decline cities, in particular, deliver the greatest per-capita savings up to 2045, and deliver around twice as great a reduction versus the BAU as the other typologies by 2030. In years of peak reduction some Steep Decline cities will need to achieve year-on-year reductions of up to 25%.

While Peaking cities must already slow their per capita emissions growth in early years, after a reprieve they too must start to reduce in per capita terms, with both Early and Late Peak cities needing absolute per capita savings similar to the Steep Decline cities by 2050. It is important to note, therefore, that **it is in all cities' interests to begin reducing per capita emissions as soon as possible.** The later the reductions commence, the steeper the rates of reduction that are required in later years, in both per capita and absolute emissions terms. This can be observed in Figure 8, where the decline rates of Peaking cities in later years must be almost as steep as those from Steep Decline cities in their early years to achieve zero emissions by 2050.

With a limited carbon budget, and a narrow timescale to deliver it, it is clear that robust, ambitious action is required. The next section sets out the role that C40 cities will play in delivering this action.



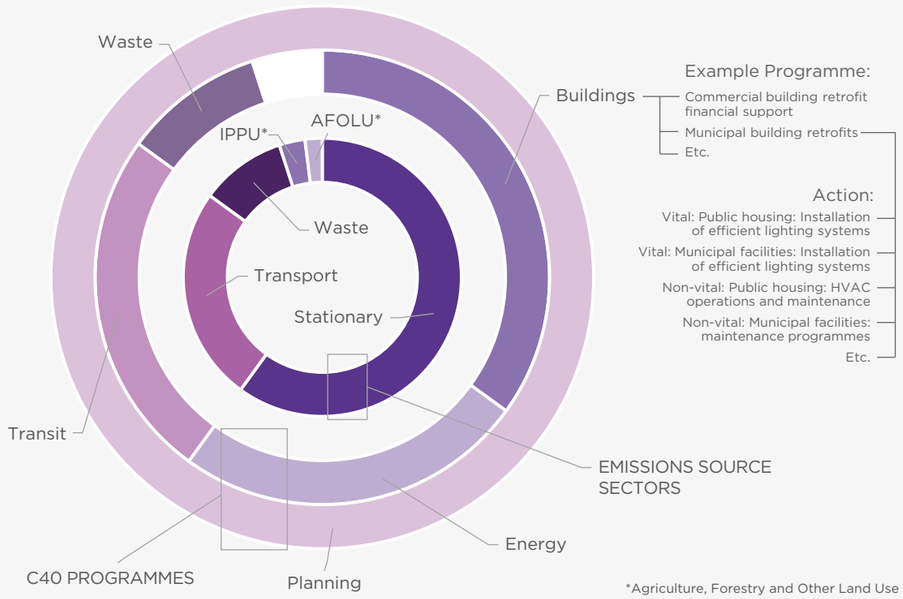
CHAPTER 4

DEADLINE 2020: A PATHWAY TO A CLIMATE SAFE WORLD

Deadline 2020 presents a pathway for how C40 cities could set themselves on a trajectory to deliver on the ambition of the Paris Agreement. The emissions reduction potential of 62 programmes were modelled, comprising over 400 climate actions. City by city, trajectories were developed to identify what action must be taken and in what order, to enable all cities to contribute to the 1.5 degree ambition. This provides each C40 city with a pathway to prioritise the next steps of progression along the C40 target trajectory (Section 3.5)

The steps cities can take to reduce carbon emissions have been split into sectors, programmes, and then specific actions. The 62 programmes (as defined by C40), cover five Sectors – Energy; Buildings; Transport; Waste; and Urban Planning,[XIV] encompassing a range of emissions sources as outlined in Figure 13 below. Actions within the programmes are divided into "vital" (crucial for the success of the Programme) and "non-vital" (non-essential but supporting), and the same action may feature in more than one programme. 410 possible actions are grouped into 62 programmes covering five sectors. These five sectors encompass all city emissions sources. 12 data points are recorded per city action, including scale, lever, cost, emissions savings, and networking mechanism. Refer to CAM 3.052 for further detail on C40's climate action framework.

Figure 13. Mapping GPC emissions classification to the C40 climate action sectors and programme areas.

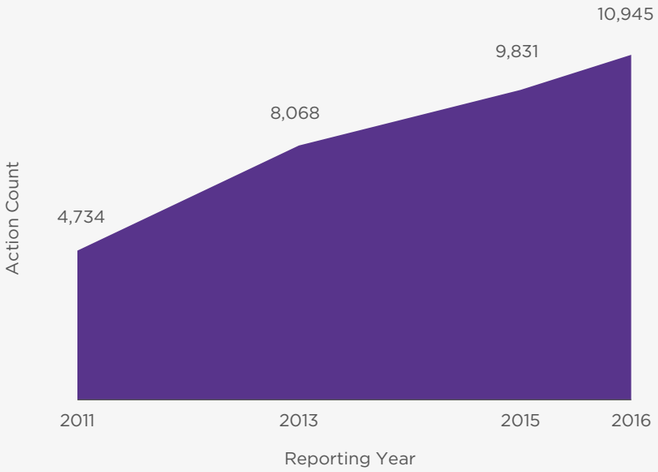


XIV Note, these differ from the GPC sectors outlined in Chapter 2. The GPC sectors are used to establish the emissions inventories for the C40 cities, whereas the C40 Sectors have been selected as they best fit the C40 Programmes.

4.1 C40 CITIES HAVE MADE TREMENDOUS PROGRESS SO FAR

Before exploring where city action might develop going forward, it is helpful to consider the successful and expanding actions that are already underway in C40 cities. C40 collects data on the climate actions that cities are taking. At COP21 in Paris, C40 launched the 3rd issue of *Climate Action in Megacities 3.0 (CAM 3.0)*. The report presents a definitive assessment of how mayors of the world's leading cities have taken action on climate change since the COP15 Copenhagen climate talks in 2009. Since then, cities have reported that 11,000 actions are already underway in C40 cities.

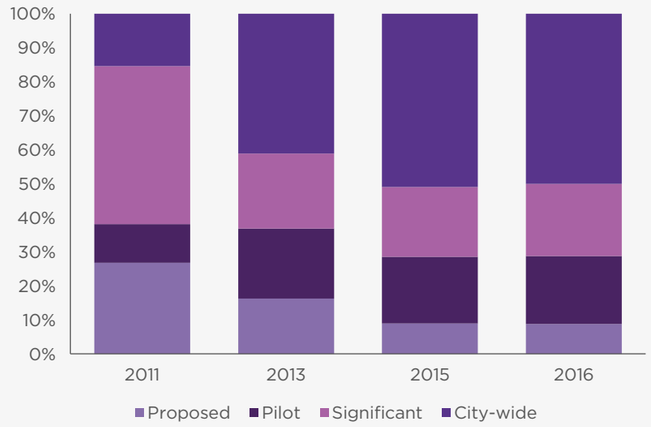
Figure 14. Increase in reported action in C40 cities since 2011.



In 2011, nearly 40% of actions were only at the proposal or pilot stage and only 15% were fully rolled-out at a city-wide scale. In 2016, half of these actions are being delivered at a city-wide scale – an increase of 260% – and a further 20% are being delivered at a significant scale. As this evidence shows, cities have experimented, shared, piloted, learned, collaborated, invested, and are now moving forward with delivering an unprecedented, truly global wave of effective action on climate change.

Furthermore, 80% of actions reported in 2016 are planned for further expansion by cities, up from around 40% in 2011, indicating rising confidence among city leaders that their current climate actions will be effective.

Figure 15. Increase in reported action in C40 cities since 2011.



4.2 DETERMINING FUTURE ACTION PATHWAYS

The rest of this chapter considers how C40 cities can build on the huge momentum created to date, to achieve the carbon trajectories outlined in Section 3, which are necessary to put the Paris Agreement on track for delivery.

The important factors that have been considered when examining the appropriate action pathway for each C40 city include:

- **Actions taken to date by each city:** the existing C40 baseline inventory of actions, sourced from four Climate Action in Megacities surveys including, most importantly, the scale of the action being taken.
- **Modelled impact of the action:** given the short time remaining to deliver reductions, it is vital that the most impactful actions are prioritised. Carbon abatement potential for each possible action has been assessed.
- **Time to develop action to scale:** assumed minimum roll-out times for actions to progress from planning and pilot stages through to full transformative, city-wide scale.
- **Mayoral power:** data sourced since 2011 on the levels of control or influence over up to 70 city assets and functions, such as levying taxes or energy procurement.
- **Replicability:** an index capturing a particular action's incidence in a certain region, providing an indication of its ease of application in other, similar cities.

The modelling undertaken in support of this work considers all these factors (see methodological paper for detail[XV]). The resulting pathways are explored below.

Notably, other than potential emissions savings, other benefits or risks associated with each action have not yet been included in the analysis. Both the funding required per action and the other benefits (such as creation of new jobs) have not been included in the current model at this stage, but it is intended that they will be added at a later date.

XV www.arup.com/deadline

The C40-Arup Partnership Climate Action Pathways (2CAP) Model

The scenarios discussed in *Deadline 2020* are the outputs of C40 and Arup's Climate Action Pathways (2CAP) model. The 2CAP model was developed to take on board the wealth of city data that C40 has collected since Climate Action in Megacities 1.0 in 2011. It enables a consistent, impartial assessment of the necessary programmes of action that cities need to take in order to meet their assigned emissions targets. Further detail of the model's structure and assumptions are presented in Appendix A, and the companion methodological report.

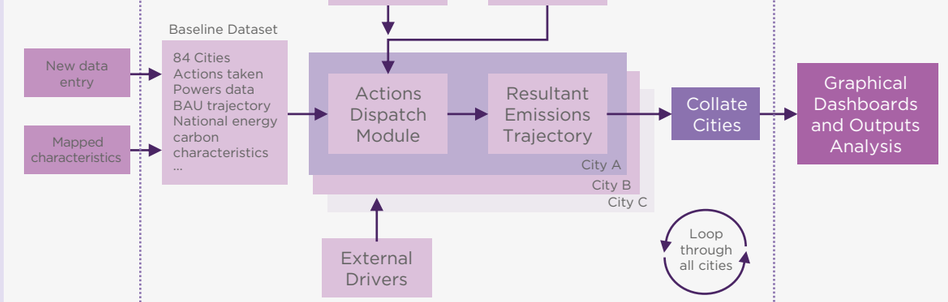
Taking action: How 2CAP prioritises action

2CAP takes into account a detailed set of city characteristics data to establish a 2015 baseline for each city, as well as a BAU emissions trajectory. This baseline includes data on population and GDP with respective growth rates, emissions inventories, reported existing climate actions, cities' levels of power over assets and functions, and sector fuel mixes. Programmes and actions are dispatched according to pre-defined criteria (below) such that the resultant emissions trajectory follows the target as closely as possible.

Dispatching programmes and actions: key model steps

- Potential Score calculated for each action (city-specific) based on carbon impact on full roll-out in full roll-out year, city power over relevant assets, and application of action in similar cities.
- Programmes of action ranked according to Potential Score of their constituent Vital and Non-Vital actions.
- Starting from the highest-ranked programme, dispatch vital actions to deliver savings over BAU commensurate with target trajectory (savings assessed in year of full action roll-out).
- Once non-vital actions are reached, dispatch these until savings are not as great as the potential in the next highest-ranked programme.
- Actions, once dispatched, scale up at their full city-wide scale over an action-specific roll-out period.

2CAP Model Functionality



4.3 GLOBAL VIEW OF THE C40 CLIMATE ACTION PATHWAY

Based on data collected in 2016, we know that C40 cities are already taking nearly 11,000 actions to mitigate and adapt to climate change. But within just four years, **14,000** additional actions will have to be in the pipeline across C40's membership, moving from planning and pilot stages to full transformative, city-wide initiatives. On average, this is over 140 actions initiated per city per year to 2020.

With an overarching target trajectory established for C40 (Section 3), the question arises: what does a 1.5 degree routemap actually look like for C40 cities, including the timelines for specific programmes, and when the actions within those programmes must be delivered?

The next four years are critical

The findings show that the next four years are critical; the target trajectory requires emissions to be reduced by 32% compared with a BAU trajectory by 2020. This reduction equates to 2 $GtCO_2e$ of avoided emissions, putting cities on track to deliver their carbon budgets. The highest percentage of actions that must be taken are in the Buildings and Transit Sectors. Taking these actions and ensuring 54% are at city-wide scale by 2020 (Figure 18) is fundamental to reaching zero emissions by 2050.

Figure 16. Comparison of historically reported actions with estimated future requirements for C40 cities, 1.5 degree scenario. Note, adaptation actions are not modelled because methods to quantify and measure the impact of adaptation action are still under development.

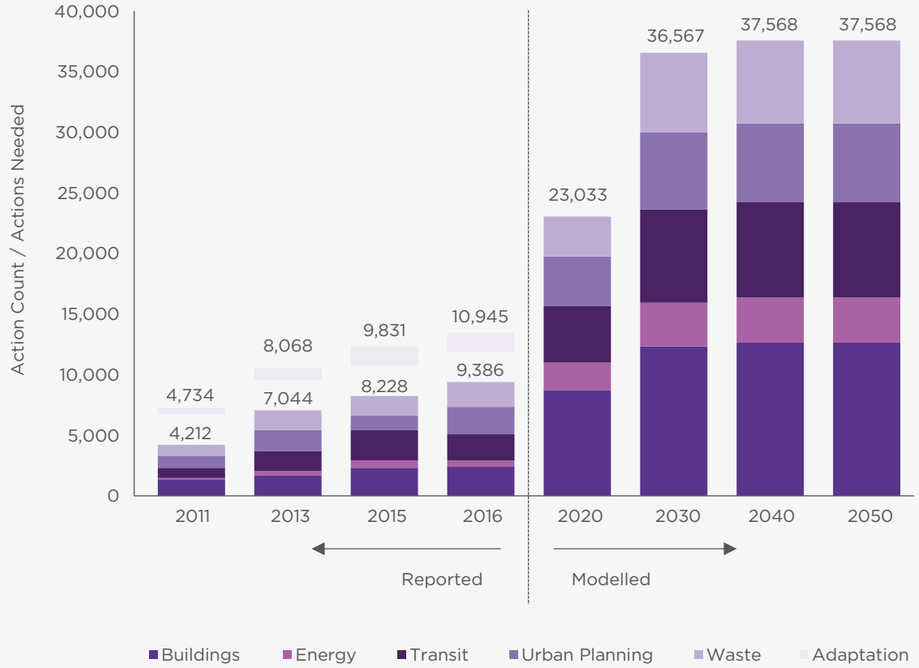
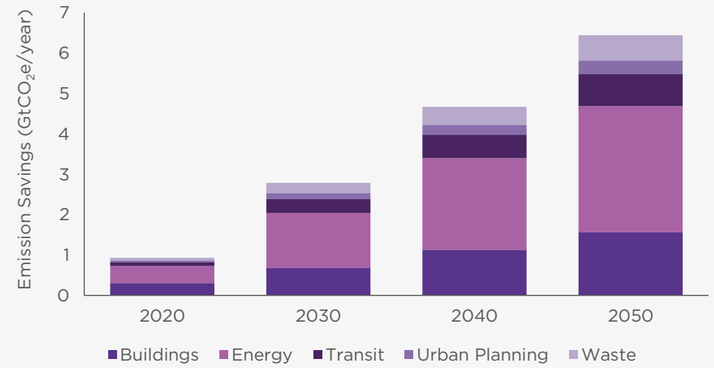


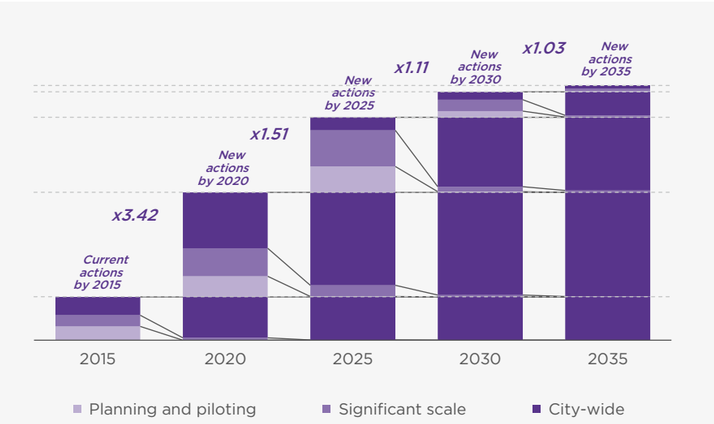
Figure 17. Estimated emissions savings per year versus BAU achieved by C40 cities to 2050, 1.5 degree scenario.



Figures 17 and Figure 18 confirm the scale of the challenge. While comprehensive plans and strategies are still being drawn up across many of the C40 cities, the volume of action taken from 2016 - 2020 needs to increase by over three times today's levels (Figure 18). Meanwhile, actions already underway today must nearly all ramp up to a city-wide scale by 2020. Figure 18 shows the five-yearly growth in action needed (as multipliers), and also demonstrates the pace with which actions started in the intervening time periods need to shift from planning and piloting phases (light shades) to city-wide (darkest shades).

Beyond 2020, another 50% increase in action will be required by 2025, and a drive for city-wide action continued. Annual savings versus the BAU trajectory must more than double between 2020 and 2030, with urban energy programmes making up the vast majority of emissions reductions (Figure 17).

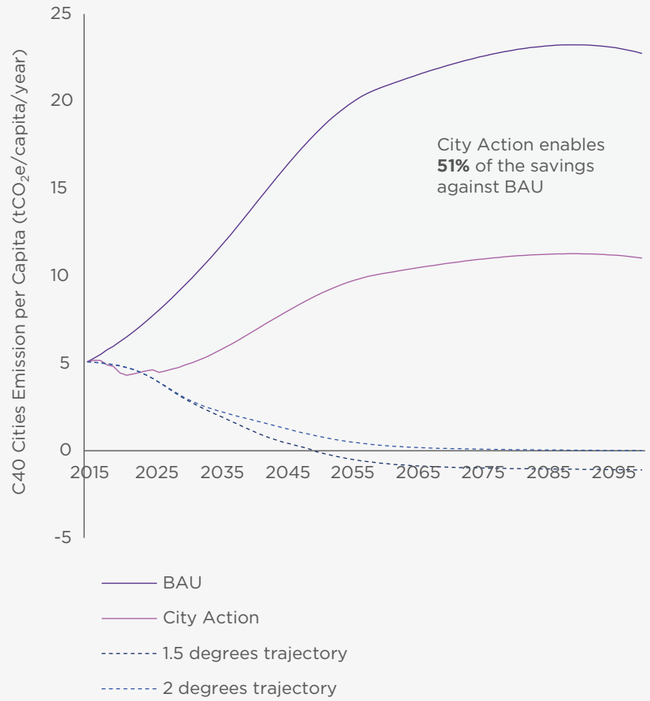
Figure 18. Breakdown of scale of actions being taken up to 2050 with growth in Action count annotated.



4.4 CITY GOVERNMENTS WILL HAVE A PIVOTAL ROLE AS ACTOR AND CONVENOR

Examining the impact of the action path demonstrates that C40 cities can achieve a very significant proportion of the necessary reduction against their BAU. According to this research, 51% of the emissions reductions needed to put C40 cities on a path consistent with the Paris Agreement can be delivered through "City Action", that is action within those cities and over which city governments could have some influence (see call-out box). This translates to 525 $GtCO_2e$ saved between 2015 and 2100 out of a target of just over 1,000 $GtCO_2e$. Those remaining emissions reductions will need to be achieved from regional and national initiatives outside of cities, including delivering a net-zero emissions energy and electricity supply and, from 2050 onwards, by achieving net-negative emissions (discussed in later sections).

Figure 19. City Action compared against BAU and target trajectories. Excludes benefits of grid decarbonisation.



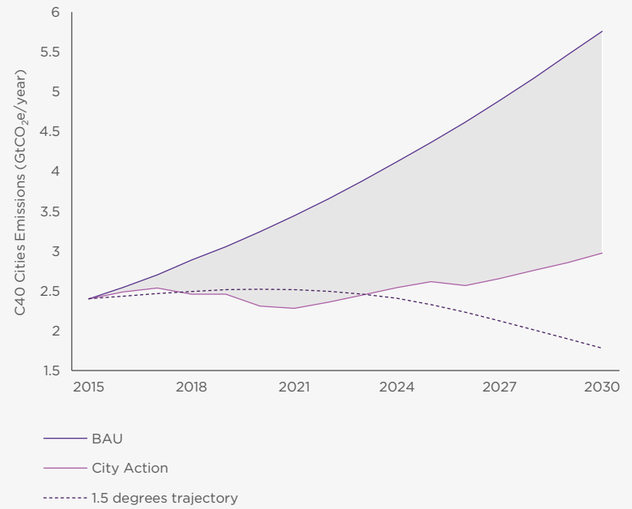
Cities can begin on the target pathway alone, but collaboration soon becomes necessary. As shown in Figure 20, a shortfall in emissions reduction versus the BAU does not start till 2023, meaning cities can drive City Action alone to set themselves on the right path. C40 cities still deliver approximately 85% of cumulative emissions savings by 2030, a total of 21 out of the 25 $GtCO_2e$ saved over this period.

City Action

In this study "City Action" refers to the direct actions taken by city governments, such as investments in infrastructure. It also refers to interventions and changes that they can influence within their city boundaries (particularly where they do not necessarily own or operate assets, for example). These are the actions described in the Climate Action in Megacities framework.

The graphs illustrating City Action do not include the benefits of additional energy decarbonisation and electrification from city carbon trajectories.

Figure 20. City Action driving emissions reduction up to 2023.



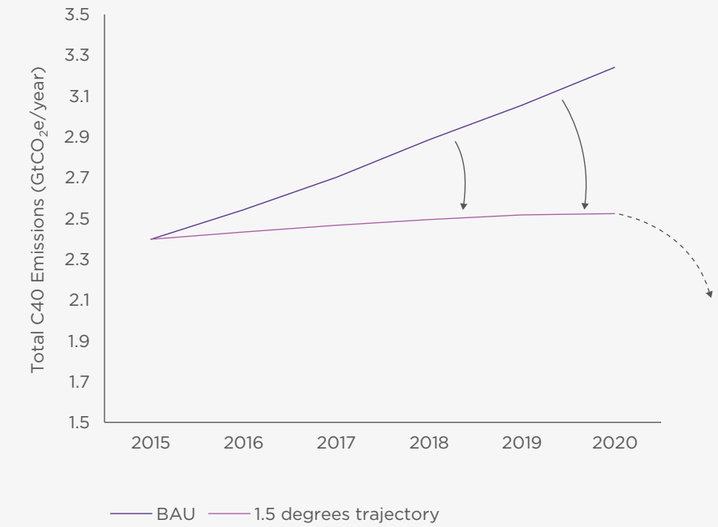
City action alone is not enough to deliver 1.5 or 2 degrees

Figure 19 shows that City Action alone is unlikely to be sufficient to deliver on either a 1.5 or 2 degree scenario. Collaboration with external partners and wider stakeholders will be crucial to deliver the further transitions necessary. Beyond 2023, Figure 20 shows that while their actions continue to deliver savings against the BAU, on their own cities cannot deliver on the steep, aggressive trajectories necessary for both 1.5 and 2 degree scenarios.

4.5 BENDING THE CURVE: 2016-2020

The actions taken and set in motion over the next four years will determine whether cities' ambitions are realised. As illustrated in Figure 21, efforts will be required to divert the BAU path of C40 cities' emissions, from an increase of 35% between now and 2020. This represents a cumulative avoidance of 1.9 $GtCO_2e$ in this early period.

Figure 21. Bending the curve: emissions reductions necessary from the BAU by 2020, for 1.5 degree scenario. Note y-axis does not start at zero.



The modest net increase in total C40 emissions to 2020 sets the stage for a multilateral emissions decline of unprecedented ambition. Due to the long lead-in times for actions, 12,000 actions – or on average 143 actions per C40 city – must be initiated by 2017 alone to enable the necessary emissions reductions in later years. As discussed in C40's research on carbon "lock-in" , it can take a number of years from a climate action's commencement until its full benefits are realised; most of the newly initiated actions indicated above will not deliver carbon savings in year one.

At the same time, 5,800 actions that are already being taken by C40 cities must be expanded as quickly as practicable, with 95% to be at a city-wide scale by 2020. Expanding these existing actions (69 actions per city on average) will be the crucial step to delivering the nearer-term savings.

By 2020, C40 average per capita emissions should have contracted from 5.1 tCO_2e/capita in 2015 to 4.86 tCO_2e/capita, counteracting a 10% increase in total population during this period. Meanwhile, a total of 23,000 actions must be underway (Figure 16).

City typologies

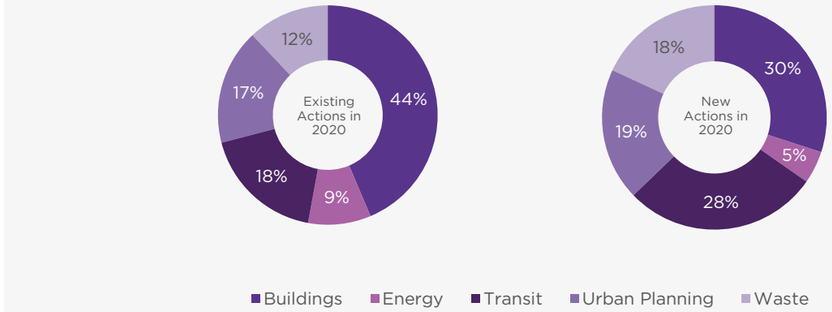
The majority (63%) of the emissions reductions achieved by 2020 come from cities assigned an immediately declining emissions trajectory. Of the 1.9 $GtCO_2e$ emissions saved over BAU, 1.0 $GtCO_2e$ is saved by Steep Decline emissions trajectory cities and 0.2 $GtCO_2e$ is saved by Steady Decline cities.

Much of the burden for emissions reduction up to 2020 falls on cities in the Steep Decline typology, with 53% of the total savings in this period attributed to this group, or 1.0 $GtCO_2e$. However, as already discussed, the ambitions of *Deadline 2020* mean that even in this early time period, cities that are able to slightly grow their emissions per capita levels (Peaking trajectories), must still work hard to reduce emissions.

Sectors

The pathway to 2020 sees the expansion of a broad mix of Action across Sectors, with the majority of action in the Buildings Sector, as seen in Figure 22. Between 2016 and 2020, action in the Transit Sector should expand, whilst the percentage of action in the Buildings Sector should reduce compared with the existing split. All sectors, however, see a growth in action across C40 cities.

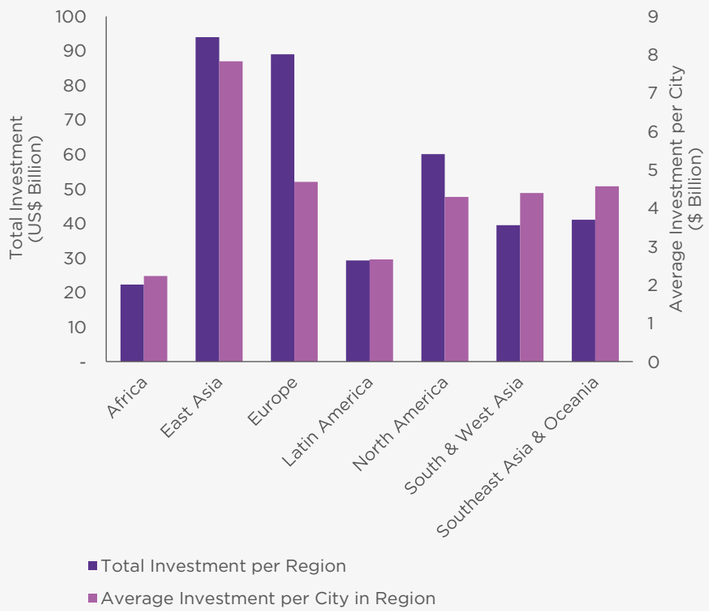
Figure 22. Comparison of sector action focus for actions already underway in 2015 and continued (left), and those initiated up to 2020 (right).



Investment

Discussed further in Section 6.3, the period up to 2020 will see some of the greatest investments committed by cities to climate action. As much as $375 billion – nearly 30% of the investment required to 2050 – must be committed across all cities by 2020. Depending on the power structure in cities, this commitment must come from city administrations themselves, or other stakeholders, such as utilities, the private sector, or indeed tax payers.

Figure 23. Regional investment requirements to 2020 for C40 cities.



Up to 2020, Europe is the region requiring the greatest levels of total investment at $110 billion, as shown in Figure 23. Whilst this is somewhat driven by the large representation of European cities in the C40, it is also a reflection of the early savings necessary in a number of cities. On a per-city basis, however, the East Asia region requires the greatest amount of capital commitments at $6.7 billion on average, closely followed by Southeast Asia & Oceania. So, despite these regions having a number of cities on Peaking trajectories, this does not preclude them from needing to fund significant action today.

Win-win

By 2020, all C40 cities are committed to producing detailed Climate Change Action Plans (CCAPs) setting out their strategies for achieving the targets in this report and beyond. By this stage, the path ahead will be clear, supported by the continued research of C40, its partners, and wider stakeholders.

4.6 ACCELERATING AND UNIVERSALISING REDUCTIONS: 2020-2030

The proposal for the decade between 2020 and 2030 is much the same as that for the years to 2020: increase the number of actions being taken across cities, and increase the scale of those already underway.

Actions initiation and scaling

An additional 13,500 actions must be initiated in the decade from 2020 to 2030, representing a 59% increase compared with the actions inventory in 2020. This means that as much as 160 actions per city, per year must be initiated to maintain ambition, with almost 3,000 kicking off in 2023 alone. Shown in Figure 24, this represents a year-on-year increase of 13%.

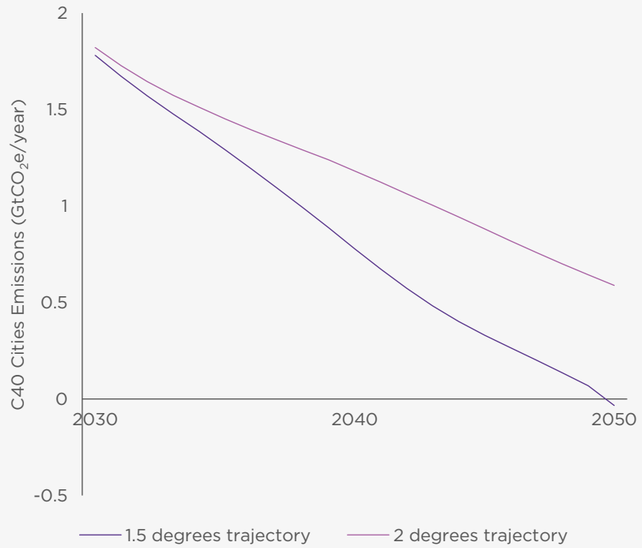
34% of the actions already underway by 2020, but not yet at a city-wide scale, must continue to grow their levels of penetration to full city-wide scale. By 2030, no more than 10% of all actions in place should be smaller than a city-wide scale. During this time period, average new actions per city are largely similar across the different typologies.

Figure 24. Tracking growth in new actions necessary to deliver 2020 – 2030 trajectory.

4.7 EMBEDDING A CLIMATE SAFE FUTURE: BEYOND 2030

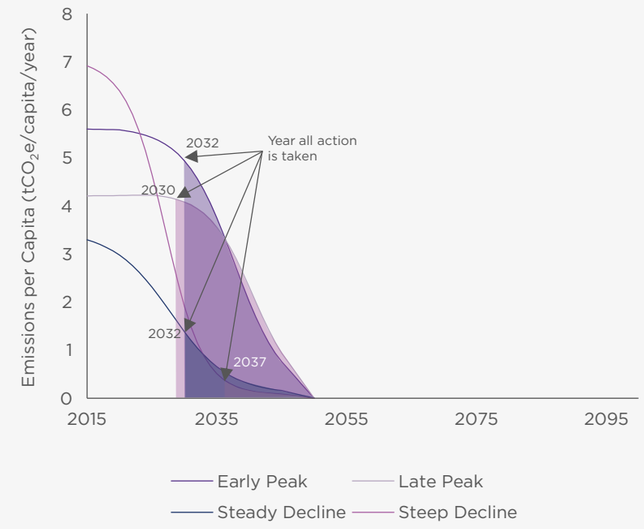
Moving beyond 2030, we see the divergence of the 1.5 and 2 degree trajectories. Achieving 1.5 degrees requires the continuation of ambition and efforts across all sectors, maintaining the rate of absolute emissions reduction.

Figure 25. Divergence of 1.5 and 2 degree target trajectories beyond 2030.



97% of actions needed through to 2050 should have already been started by 2030; the intervening years are primarily for scaling up investment and roll-out. By 2032, every city in the Early Peak, Late Peak and Steady Decline trajectory groups should have initiated all available action (Figure 26). From this year onwards, these cities solely rely on the decarbonisation of energy supply to achieve net zero emissions by 2050. Across all typologies, all currently available city climate actions should be taken by 2037.

Figure 26. Years by which all actions are taken for each city typology.



CHAPTER 5

THE PATHWAY SECTOR BY SECTOR

NÖ REWIND

The following sections present the pathway cities should follow in each of the five sectors and the profile of each of the C40 regions.

To demonstrate the potential impacts of action delivered at the city level, the graphs in this section do not include the savings achieved once electrical grid decarbonisation and electrification are factored in. Discussed further in Sections 7.1 and 7.2, these two elements are crucial to achieving a 1.5 degree trajectory.

5.1 THE URBAN PLANNING PATHWAY

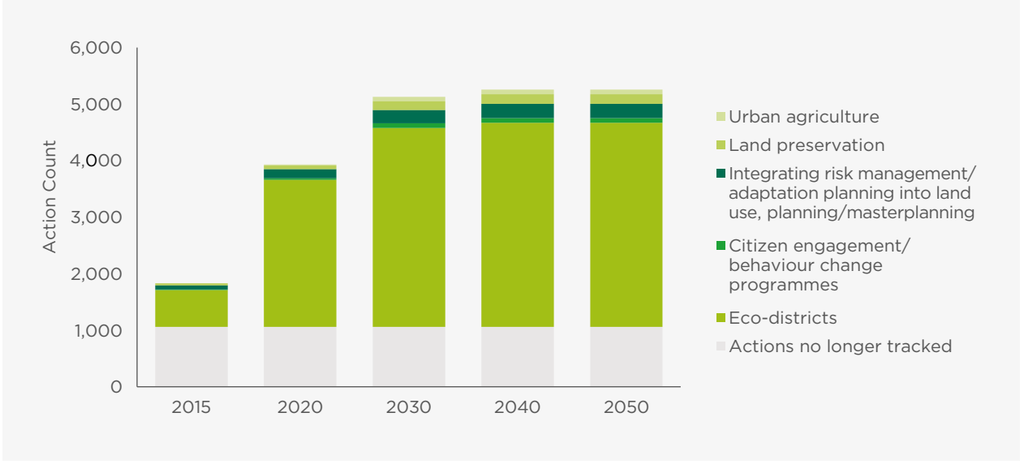
Land use planning decisions made today are critical to delivering a low carbon future, particularly because these activities have impacts across all other city sectors. They determine how and where our cities grow, whether through new-build construction, retrofit or regeneration, whether in dense, walkable neighbourhoods, connected to transportation and heating and cooling infrastructure or sprawling, isolated and car dependent. These actions have a strong long-term impact on the effectiveness of climate efforts in transport, buildings, energy and waste.

Currently, urban sprawl costs the United States alone nearly US$400 billion annually and is expected to contribute to 60% of the global energy consumption growth of cities. Urban sprawl also exacerbates the effects of social exclusion linked to the increase of slums and gated communities.[11] By approaching this challenge holistically and in an integrated manner, cities can reduce global infrastructure requirements by more than US$3 trillion over the next 15 years, delivering an annual abatement of 0.3GtCO_2e by 2030 and 0.5GtCO_2e by 2050.[12] When cities link their land use planning decisions to their climate action plans, they are better able to deliver both in a strategic, integrated manner, often much more cost effectively. When done separately, the economies of scale and opportunities presented at the early stages of planning are missed and only achieved through more expensive efforts.

The opportunities for cities in this sector focus on delivering the development of compact, connected, and coordinated cities. This enables significant indirect emissions savings and compounds the effects of the direct operational emissions savings achieved in the main emissions sectors. The fact that land use planning typically delivers savings through its enabling impact on other sectors makes calculating those impacts very complex. For this reason, in this study they have not been separated out and estimated independently. Instead they are considered part of what enables the other sectors to deliver their savings. This will be the subject of further research at C40 to unpack and present these savings.

To take advantage of the opportunities land use planning provides in achieving a 1.5 degree future, key actions are to prioritize land use plans and decisions, linking them with climate action.

Figure 27. The breakdown of Urban Planning Programmes that cities must deliver.



5.1.1 URBAN PLANNING AND ADAPTATION

As the climate changes, the appropriate land uses within a city are likely to change. Well-designed urban development can reduce climate risk by minimising the concentrations of people or assets in areas of extreme risk. Alternately, poor land use planning can amplify climate impacts, for example by increasing the areas of impermeable surfaces which could worsen the impact of a flood.

When implementing eco-districts and aiming for compact, connected development planners should consider:

- Banning future or further development in high risk zones
- Limiting development types or specifying considerations for development in areas where climate risks are moderate
- Approving temporary development while risks remain moderate, and re-evaluating the risk over time to change or remove temporary uses
- Applying development controls that can reduce the risk, such as setbacks, minimum floor heights, maximum densities, cool technologies, permeable areas etc.
- Strategic location of critical infrastructure such as hospitals, schools, evacuation routes and shelters, police and emergency services etc.
- Buy-back, acquisition or moving existing development in high risk zones

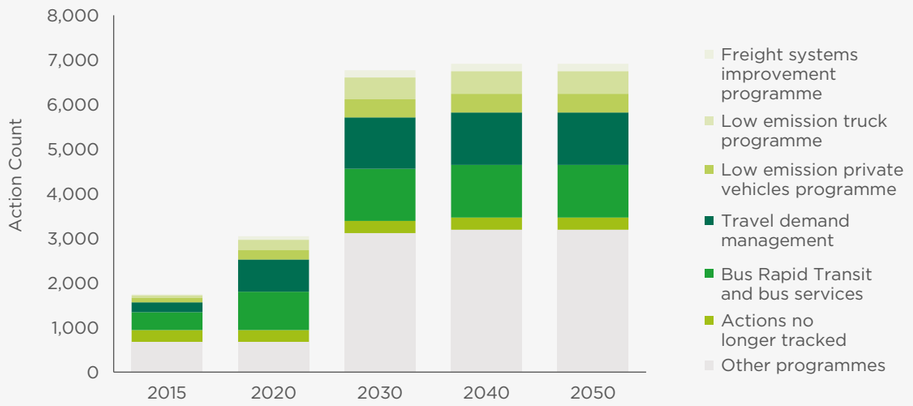
5.2 THE TRANSIT PATHWAY

The Transit Sector covers emissions arising from public and private transport, whether on road, rail, water or air. With 73% of C40 cities' measured transport emissions arising from the direct combustion of fuels, the sector presents possibly the greatest challenge for emissions reductions. Overall strategies for emissions reduction comprise of demand reduction and efficiency, and switching to low-carbon fuels or electrification. The means by which cities can effect these changes are diverse, and C40 Transit initiatives are broken down into a range of programmes.

5.2.1 PROGRAMMES

Figure 28 shows the breakdown of actions that must be taken within the Transit sector between 2016 and 2050. Cities should focus their immediate attention on Bus Rapid Transit and improvements to bus services, shifting to low emission fleets and establishing low emissions zones. From early 2020 there will also be a greater need to scale up travel demand management solutions.

Figure 28. The volume of Transit Sector Programmes that cities must take.



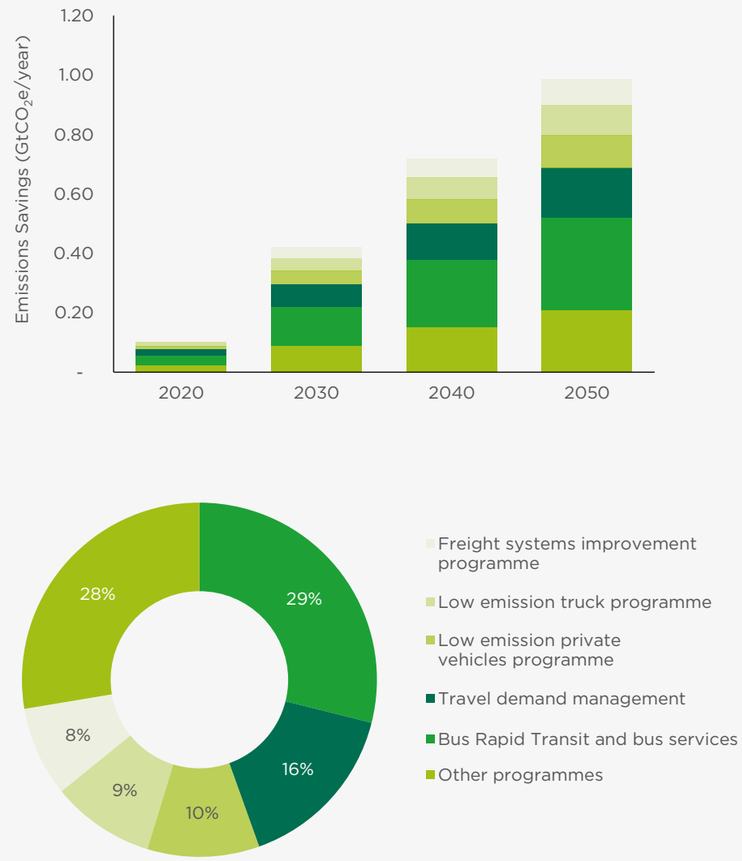
5.2.2 TRANSIT PROGRAMMES BY IMPACT

The Transit programmes start to deliver significant emissions reductions by 2030 as actions build to a Transformative scale. Cities that drive programmes more aggressively to a City-wide scale could deliver savings sooner. The top five programmes by impact are:

- Bus Rapid Transit Services and Bus Services
- Travel Demand Management
- Low Emissions Private Vehicles Programme
- Low Emissions Truck Programme
- Freight Systems Improvement Programme.

In 2030, emissions savings against the BAU would total 340 $MtCO_2e$, nearly doubling by 2040 to 640 $MtCO_2e$.

Figure 29. Emissions savings against BAU from Transport Programmes.



The Bus Rapid Transit and Bus Services Programme is shown to be the most effective programme in emissions reduction terms, delivering just over a third of all potential savings from in-city action. Actions within this programme include improving public transport infrastructure, services to attract users, as well as fuel switching to low carbon energy sources. The emissions reduction is particularly affected by driving a modal shift from private vehicle use to more carbon efficient public transport.

Travel Demand Management is the next most successful in reducing emissions across C40 cities, with emissions reductions of 17%. This programme involves a range of initiatives such as car sharing, congestion charging zones, parking restrictions and cycle hire programmes which together can reduce energy consumption for transport.

Low Emission Private Vehicles and Low Emission Truck Programmes together contribute to just over one fifth of the emissions savings. This highlights the need for cities to encourage city residents and industry to make more sustainable vehicle choices. Actions within these programmes are dominated by financial incentives including lower registration fees and rebates for switching to vehicles with low carbon fuel.

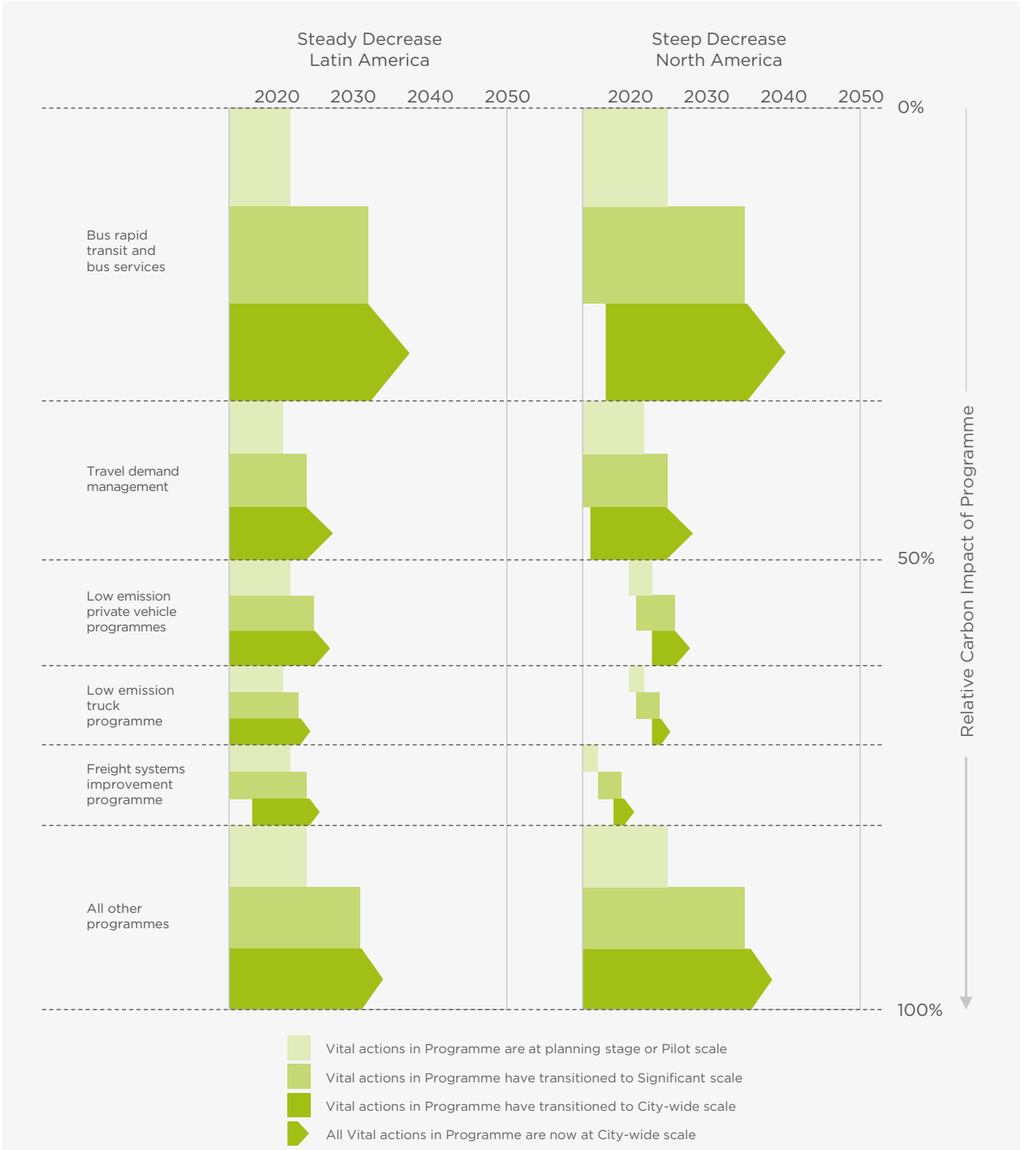
The Freight Systems Improvement Programme delivers another 9% of total emissions savings. Key actions in this programme include freight consolidation centres and real time information for logistics. The reduction of freight journeys within the city is important to alleviate congestion. Other potential actions include offering alternative infrastructure, for example using cargo bikes for last mile delivery.

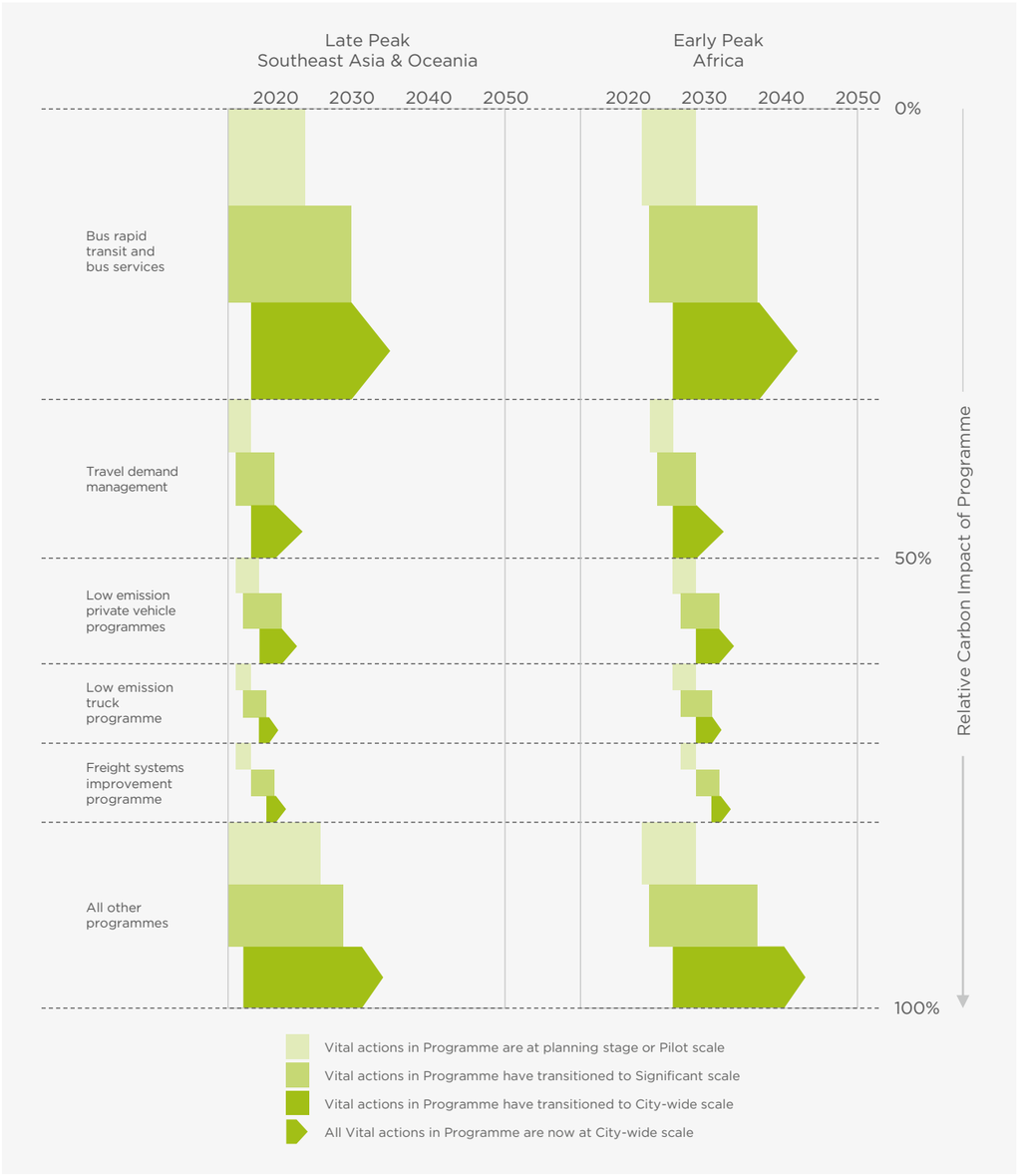
Other programmes not in the top five, such as those related to rail and active mobility, contribute a further 28% to the Sector's cumulative savings.

5.2.3 CITY-SPECIFIC PROGRAMME DELIVERY TIMELINES

The deployment of programmes differs by city according to their assigned trajectory, starting emissions per capita and their starting point in terms of programmes already being taken. As can be seen from the charts below, the North America, Latin America, and Southeast Asia & Oceania example cities are likely to have instigated the most high-impact (largest savings in carbon terms, as shown by the height of the chart rows) Transit Programmes by 2015. The African example city, meanwhile, shows a steadier programme delivery, not needing to fully kick-off the highest impact Transit programme, Bus Rapid Transit and Bus Services Programme until 2025.

Overall by 2030, these cities need to have reached a city-wide scale on most of the key programmes in order to deliver the emissions savings described above.





Programme Delivery Timelines

These programme delivery timeline charts are used to display dispatch and completion of programmes in terms of implementation scale (planning and piloting, significant, or city-wide) as well as proportional contribution to total sector emissions. As such, each Programme is of a different length and height. The duration of a Programme is determined by the first year and last year that any vital actions within the Programme are taken. As such, certain actions may be completed prior to Programme end. The four case study cities displayed represent each of the assigned typologies (see Section 3.4 for more detail on the basis of typology assignment) in the following order from left to right: Steep Decline, Steady Decline, Early Peak and Late Peak. The exact timings of Programme delivery should not be taken as prescriptive. Rather, they serve to highlight the level of activity required by cities within those typologies to set themselves on a climate safe path over the next ten years. Note that programmes contain many actions and therefore the dispatch order of specific actions may differ across the case study cities.

5.2.4 TRANSIT AND ADAPTATION

A well-functioning and inclusive transport system underpins the connectivity of a climate resilient city – providing evacuation routes during extreme events, allowing communities to connect more easily, and individuals to access employment, health and community services. Decisions taken today, on the location and design of transport infrastructure, will affect how well the system adapts to climate change far into the future.

To ensure the actions outlined in this chapter are climate resilient, city governments need to consider future climate conditions. For example, constructing BRT systems:

- With materials that are more resilient to higher temperatures and CO_2 concentrations
- In locations safe from increased precipitation, flooding and landslip
- That include green and blue infrastructure to ensure the routes are cool, well drained, helping further reduce greenhouse gas emissions and improving air quality.
- That can respond to extreme events, through changes to routes, increased services or improved travel information services.

5.3 THE ENERGY PATHWAY

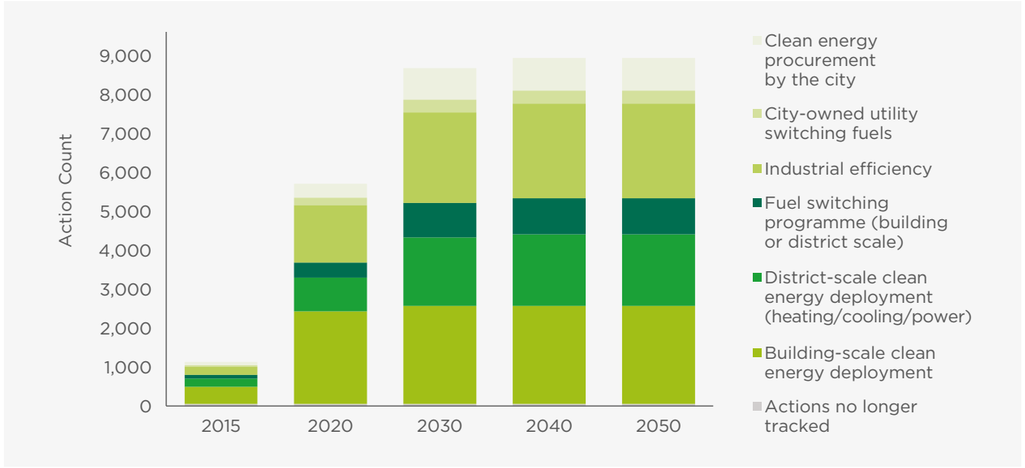
The energy aspect of the *Deadline 2020* pathway deals primarily with emissions associated with the *supply* of energy to our domestic, commercial and industrial buildings. C40 cities' carbon data shows that 29% of C40 city buildings'[XVI] emissions are associated with the supply of electricity. The supply-side of the emissions reduction pathway focuses on switching to cleaner, more efficient energy sources, and more efficient industrial processes.

5.3.1 PROGRAMMES

Figure 30 shows the breakdown of programmes that must be implemented within the Energy Sector between 2016 and 2050. By 2020, over 4,500 actions need to have been taken in the Energy Sector across C40 cities. Most of the remaining necessary actions need to be initiated in the next ten years, reaching 90% deployment. Cities must therefore focus on deploying Building-scale and District clean energy solutions, and Industrial efficiency.

XVI Taken here as the "stationary" emissions category from cities with available GPC data

Figure 30. The breakdown of energy programmes that cities must deliver.



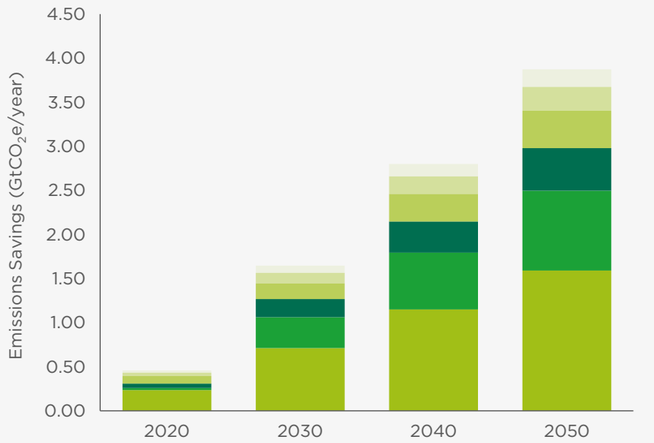
5.3.2 ENERGY PROGRAMMES BY IMPACT

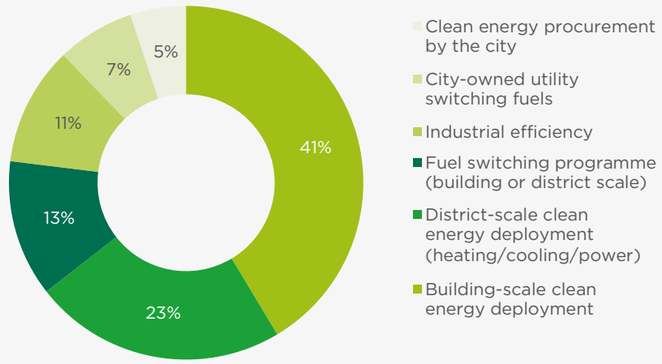
By 2050, C40 cities can deliver emissions savings of up to 3.5 $GtCO_2e$ through Energy Programmes alone. The top programmes by impact are:

- Building Scale Clean Energy Deployment
- District-scale Clean Energy Deployment (heating/cooling/power)
- Fuel Switching Programmes (building or district scale)
- City-owned Utility Switching Fuels
- Fuel Switching Programme
- Industrial Efficiency

Apart from Industrial Efficiency, all are programmes focused on increasing uptake of low carbon generation in buildings

Figure 31. Emissions savings against BAU from energy programmes.





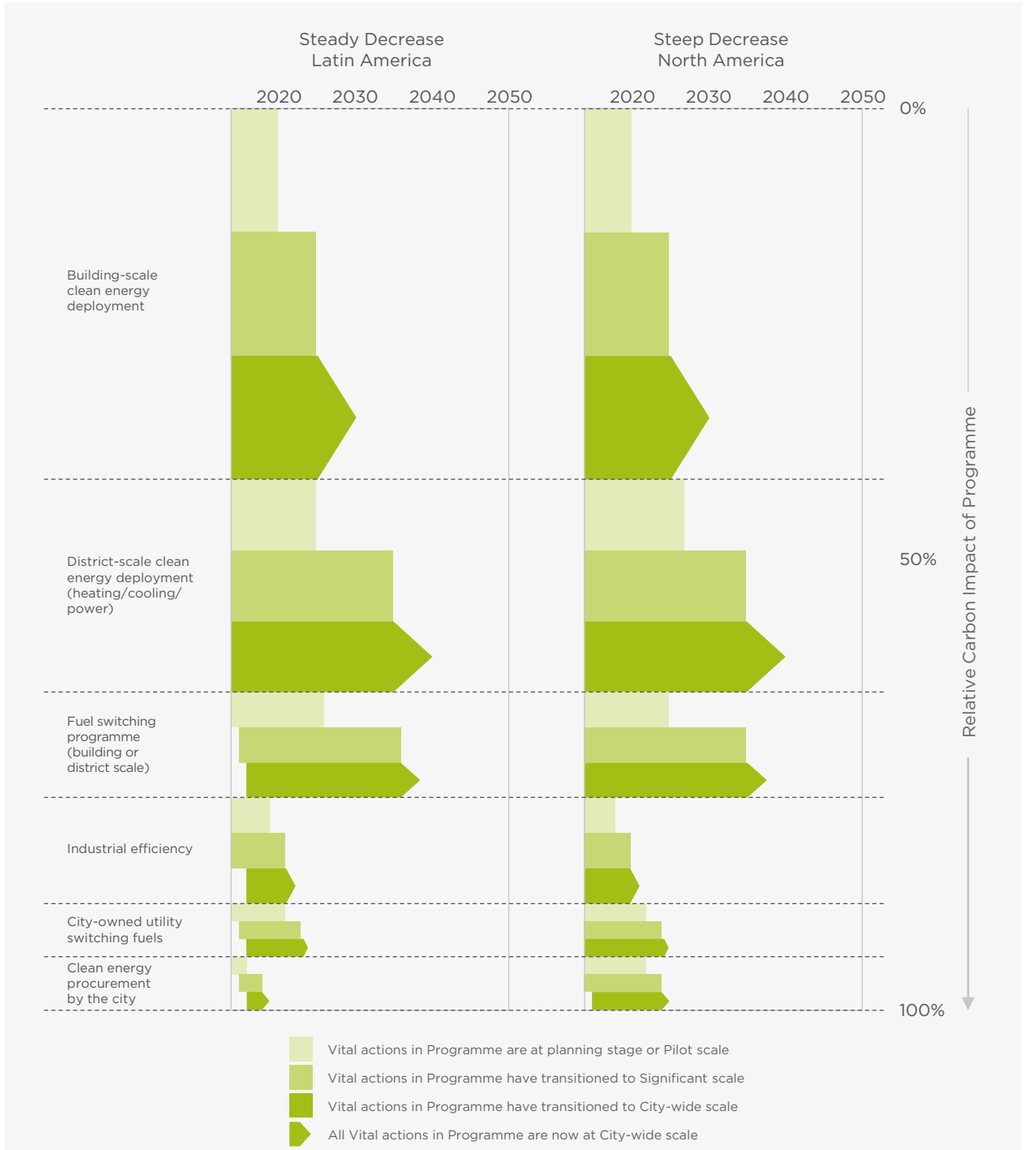
As shown in Figure 31, by far the highest impact Programme is Building-Scale Clean Energy Deployment which delivers two fifths of total emissions savings. This finding highlights the significant opportunity for buildings to be equipped with renewable and low carbon generation such as photovoltaic panels, solar thermal and heat pumps. Cities can support this through planning regulations and financial incentives that target commercial and residential buildings.

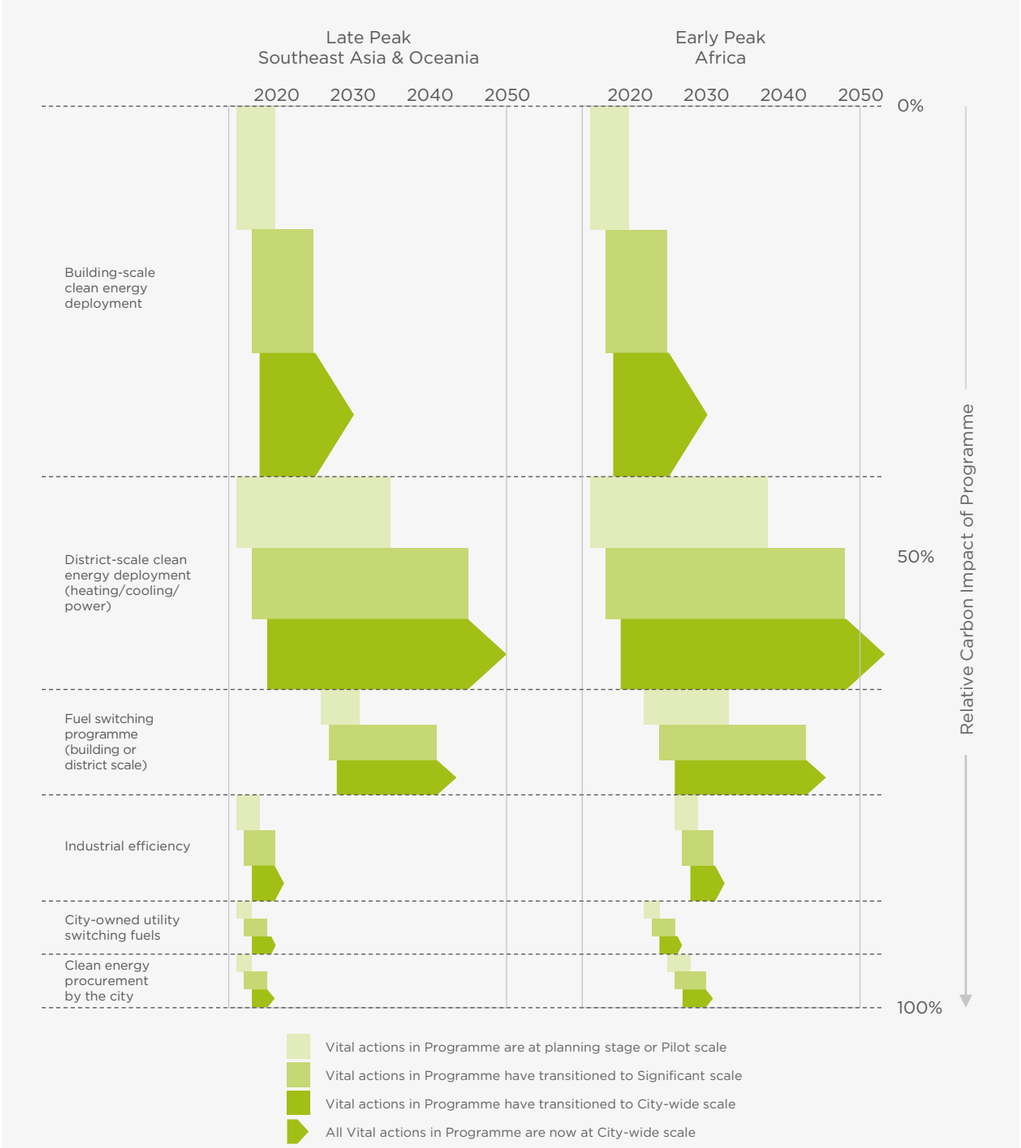
District Scale Clean Energy Deployment is also effective, contributing just over 20% of emissions reduction potential. Heat networks and micro-grids delivering energy to multiple buildings offer the opportunity for rapid scaling of low carbon generation. District heating and cooling networks are however constrained by the need for high demand density to be viable. Similar to the programme above, regulatory powers and investment incentives are needed to realise the potential savings.

5.3.3 CITY-SPECIFIC PROGRAMME DELIVERY TIMELINE

Within the case study cities, the highest impact programme is Building-Scale Clean Energy Deployment. This action should be initiated across all cities by 2017 and reach city-wide scale in all cities by 2028.

The North and Latin American example cities are, in effect, already rolling out most of the programmes, certainly those with greatest emissions reduction potential. Overall their profiles are very similar. The District-Scale Clean Energy Deployment Programme has a long implementation phase, taking up to 45 years to fully scale to city-wide in the case of the African example city, and therefore needs to be initiated as soon as possible.





5.3.4 ENERGY AND ADAPTATION

The impacts of climate change on the Energy Sector are among the most critical for city infrastructure, economy and populations. Energy ensures functioning transport systems, water supplies, waste services, hospitals, schools and public buildings, heating and cooling for residential and commercial properties, and underpins economic activity.

Building and district scale clean energy solutions can contribute significantly to urban energy resilience. By distributing energy production, a city can become more resilient to extreme events that occur at a neighbourhood level. Local energy production can be less exposed to supply chain risks as fuel is located on-site. However, the design, construction and operation of clean energy solutions must consider the realities of the future operating climate. They should be designed to cope with higher average and extreme temperatures, higher winds, flooding, and changes in availability of water. For example, storage batteries and other power facilities should be located above flood lines (not in basements), and power systems need to ensure they have sufficient cooling capacity to deal with higher future temperatures.

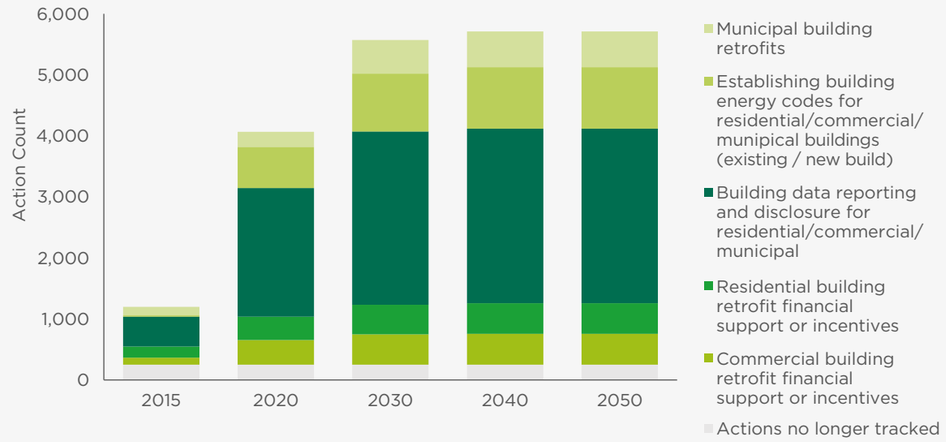
5.4 THE BUILDINGS PATHWAY

As mentioned in Section 5.3, emissions reductions as part of the buildings pathway are primarily focussed on the demand side of the problem; reducing *demand* for electricity use in lighting, ventilation, cooling, and other services, as well as enabling buildings to utilise cleaner energy sources.

5.4.1 PROGRAMMES

Figure 32 shows the breakdown of programmes that must be taken within the Buildings Sector between 2016 and 2050. As illustrated, cities should prioritise the retrofitting of existing building stock, as well as establishing building energy codes and encouraging data reporting across new and existing estates. It is critical that most actions are deployed within the next 4 years, reaching 71% of total actions taken by 2020.

Figure 32. The breakdown of Buildings Sector Programmes that cities must deliver.

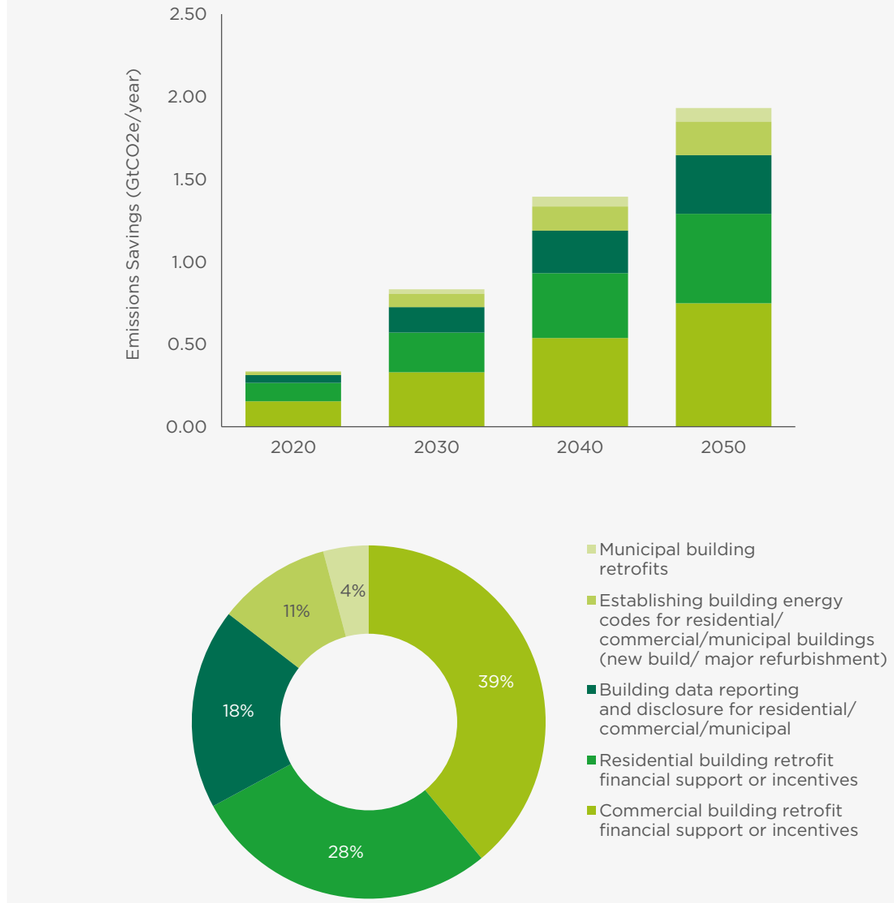


5.4.2 BUILDINGS PROGRAMMES BY IMPACT

As illustrated in Figure 33, the Buildings Programmes start to deliver significant emissions reductions by 2030 as actions expand to a city-wide scale. The top programmes by impact are:

- Commercial Building Retrofit Financial Support or Incentives
- Residential Building Retrofit Financial Support or Incentives
- Building Data Reporting and Disclosure for Residential / Commercial / Municipal
- Establishing Building Energy Codes for Residential / Commercial / Municipal Buildings (new & existing)
- Municipal Building Retrofits

Figure 33. Emissions savings against BAU from Buildings Sector Programmes.



The highest impact programmes within the Buildings Sector can be split into two distinct types:

1. Establishing data reporting and codes affecting new and existing buildings
2. Driving energy efficiency improvements for existing buildings

As can be seen in Figure 33, Commercial Building Retrofit Financial Support or Incentives and Residential Building Retrofit Financial Support or Incentives together deliver 70% of sector emissions savings. These programmes are about enabling the major energy consumers in a city to drastically reduce energy consumption through building fabric improvements, better HVAC systems and operation of these, as well as installing energy efficient lighting and appliances.

The Building Data Reporting and Disclosure programme achieves 17% of emissions savings through a host of actions affecting new and existing residential, commercial and municipal buildings which include:

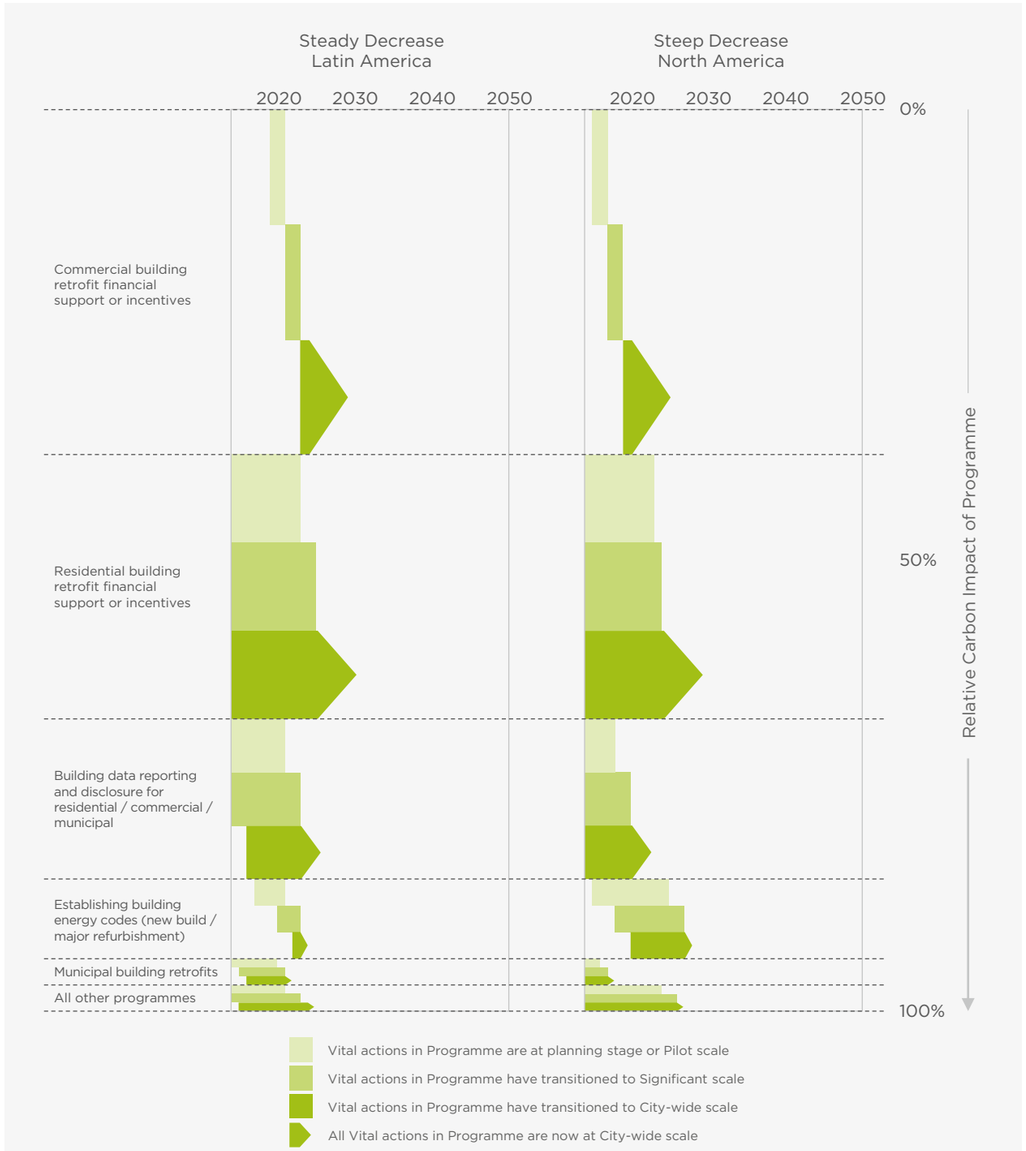
- Buildings benchmarking
- Audits and advice
- Energy performance ratings and standards
- Energy performance certification

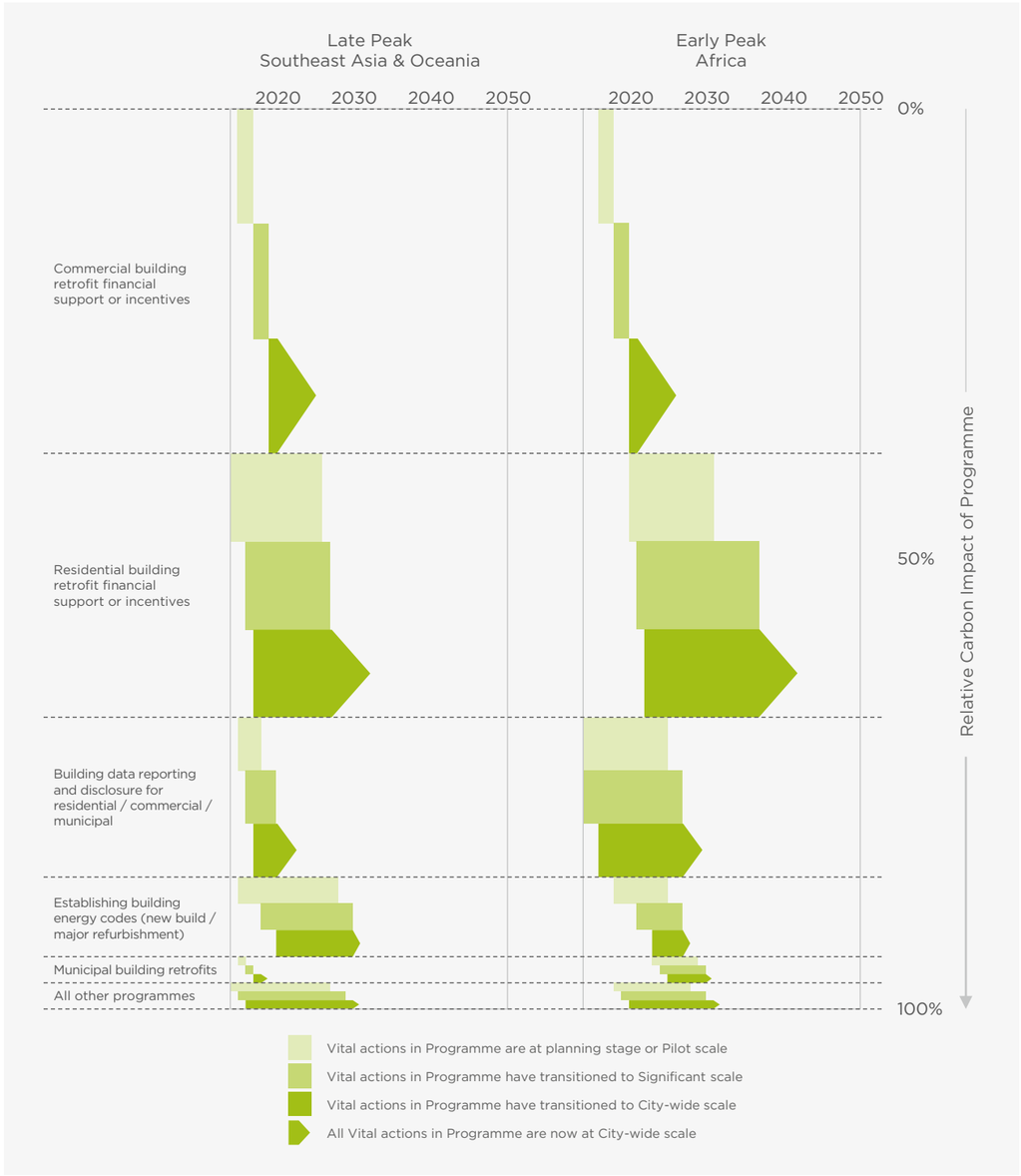
These indirect measures enable tenants and property owners to be more informed about the energy profile of buildings, and establish energy efficiency as an indicator of building quality, eventually raising the standard across the building stock.

5.4.3 CITY-SPECIFIC PROGRAMME DELIVERY TIMELINE

Amongst the case study cities, the Residential Building Retrofit Financial Support or Incentives should be the earliest programme to be completed. The North and South America, and Southeast Asia & Oceania example cities are effectively already rolling out many actions within this programme, although the Southeast Asia & Oceania example city is only at planning and piloting stage.

The delivery of the Commercial Building Retrofit Financial Support or Incentives programme is not yet taking place across any of the case study cities, however by 2017, most of the cities are should start and expand these quickly to a city-wide scale. Building Data Reporting and Disclosure for Residential / Commercial / Municipal Buildings programme is another critical programme that cities should commence within the next two years.





5.4.4 BUILDINGS AND ADAPTATION

The resilience of the Buildings Sector can greatly impact the ability of people to cope with changes in the climate. Effective heating and cooling systems can allow residents to live comfortably even where there is extreme heat or cold.

Building retrofits that address energy efficiency can be designed to be highly complementary as adaptive measures. For example, green, brown or white roofs can reduce energy consumption, but also provide improved ability to deal with higher temperatures. Water efficiency measures can also reduce emissions, while at the same time improving the residents' ability to cope with driers conditions. More permeable surfaces and water recycling can also improve capacity to manage storms and flood. Additionally, there are opportunities to incorporate resilience measures while implementing emission reduction retrofits.

5.5 THE WASTE PATHWAY

Waste emissions make up a relatively small proportion of C40 cities' inventories, however this may be explained by the reporting methods used. Under the current reporting structure, most of the actions not related to waste disposal, such as waste reduction and avoidance, compost utilisation and recycling, are attributed to other sectors like energy, agriculture, or industry. Nevertheless, to achieve a 1.5 degree future, these emissions cannot be ignored, and must be reduced to net zero.

Success in managing emissions in the Waste Sector will require a systemic shift in cities. This means transitioning from managing residual waste, to a sustainable materials management vision that can bring GHG reductions far greater than the current total emissions reported, with actions focused on waste prevention and reduction and improved recycling.[14]

Methane mitigation (landfill gas capture and utilisation) and avoidance (diverting food and green waste from landfills) can also contribute to limiting global temperature rise, (87 times more powerful than CO_2 over a 20 year period). It is estimated that up to 25% of the current global warming has been caused by methane.[15]

In parallel, cities will need to implement the structural changes that will move them from managing waste into materials and resources management. It has been estimated that a cross sectoral approach through sustainable materials management and the development of the circular economy can cut the emissions gap in half, as current reductions commitments will not be sufficient to limit global warming to 1.5 degrees.[16]

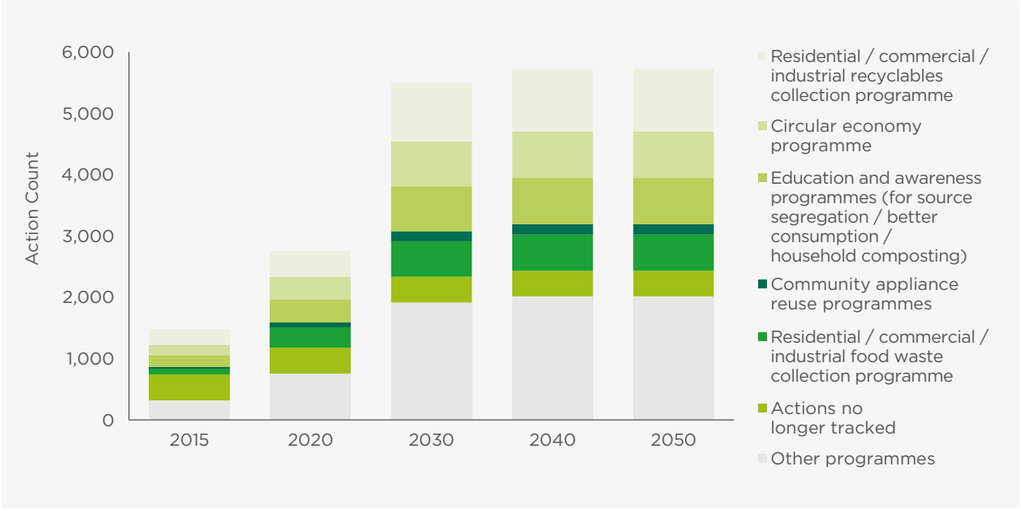
5.5.1 PROGRAMMES

Figure 34 shows the breakdown of programmes that must be taken within the waste sector between 2016 and 2050. The following programmes require the greatest effort in terms of actions needed:

- Residential / Commercial / Industrial recyclables collection programme
- Education and awareness programmes
- Circular economy programme
- Waste Management system cost monitoring programme (waste fees, pay as you throw, property taxes, container limits).

The first three programmes are focused on demand reduction, and the latter on tackling landfill management to capture methane emissions.

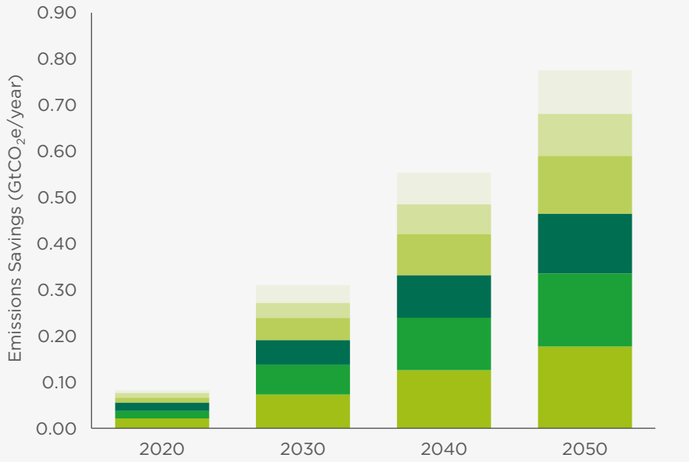
Figure 34. The breakdown of Waste Programmes that cities must deliver.

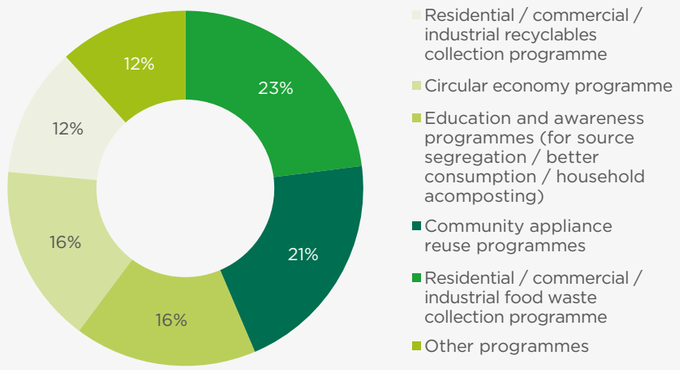


5.5.2 WASTE PROGRAMMES BY IMPACT

Within Waste Programmes, there is a more even spread in emissions reduction across different programmes. Figure 35 shows that the greatest emissions savings are associated with programmes that reduce waste sent to landfill. These programmes include improving city collection of recyclables and food waste, alongside incentivising source segregation in households and businesses alike.

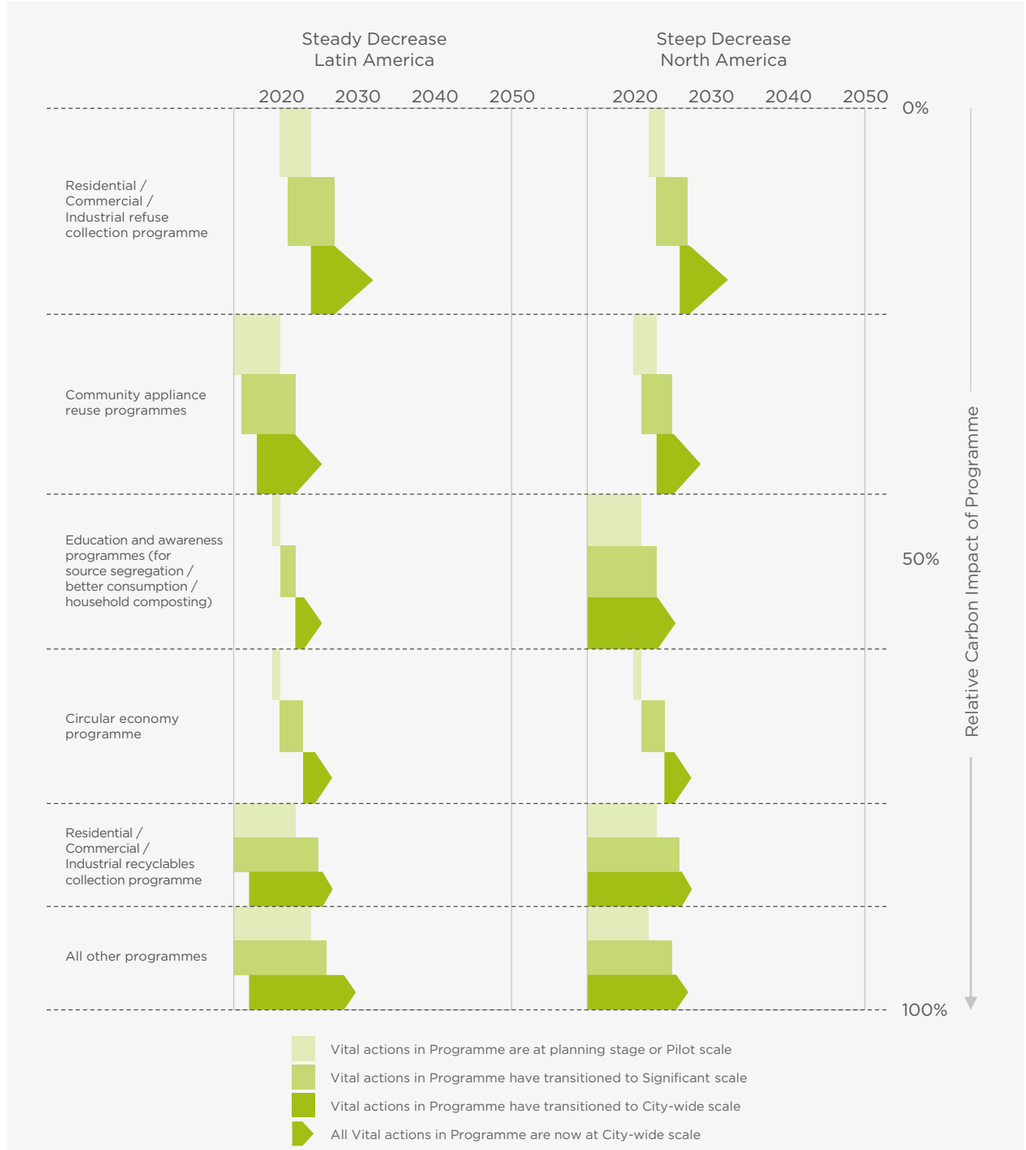
Figure 35. Emission savings against BAU from buildings programmes.

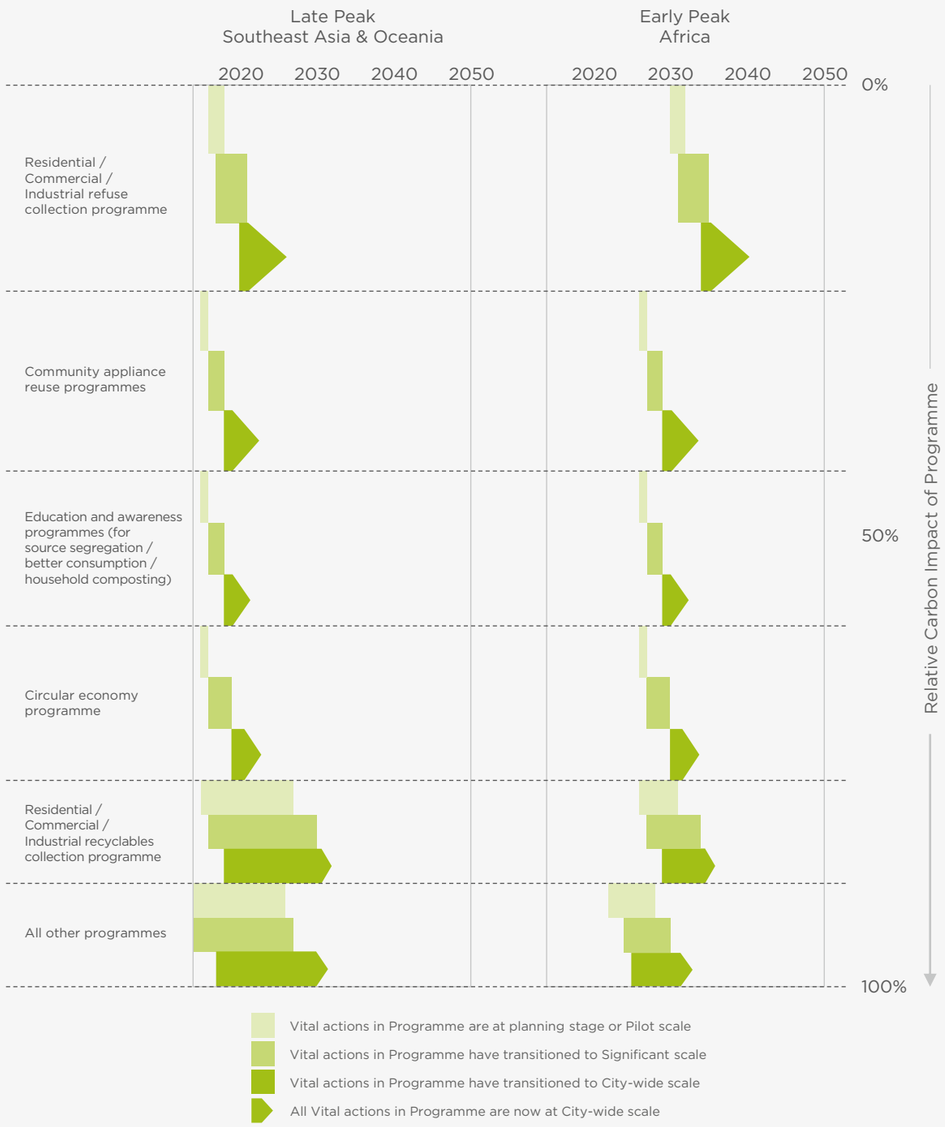




The programme with the biggest impact in terms of emissions reduction, as shown in Figure 35, is the Residential / Commercial / Industrial Food Waste Collection Programme, which comprises 23% of the emissions reduction potential for the Waste Sector. This programme includes actions such as encouraging household composting and landfill gas management of collected food waste.

Similar emissions savings are achieved by the Community Appliance Reuse Programme which includes actions such as proactive collection of dry recyclables and compostable waste by the city government.





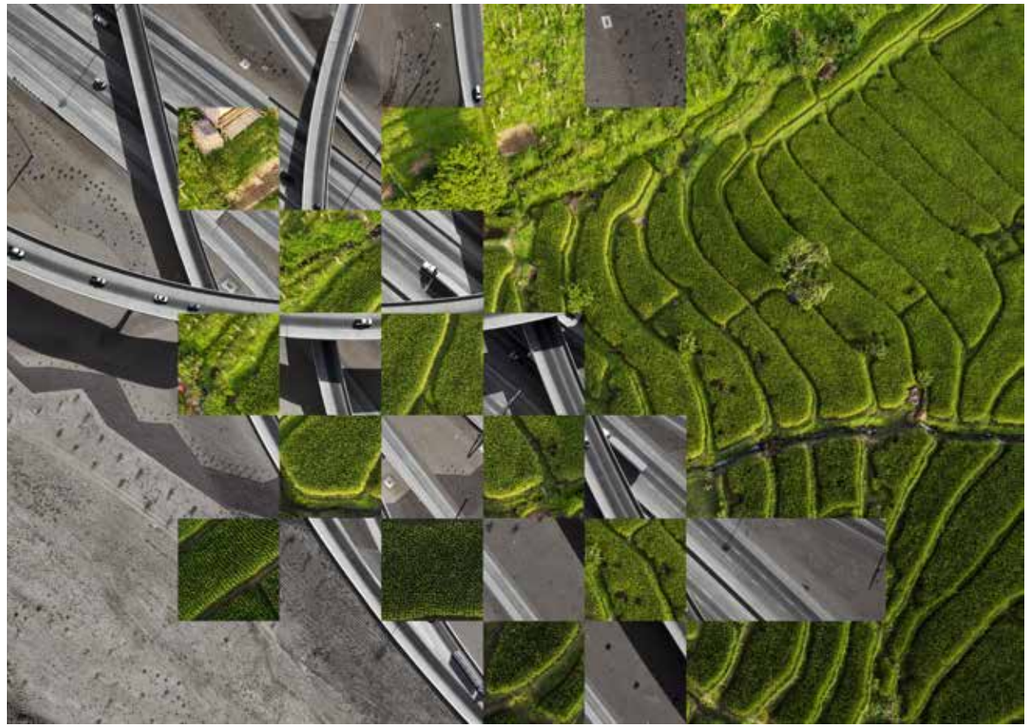
5.5.3 CITY-SPECIFIC PROGRAMME DELIVERY TIMELINE

Programmes in the Waste Sector have a slightly less urgent dispatch profile, with the example cities in North and South America not starting on the highest impact Programme until 2022. The Programme Residential / Commercial / Industrial Recyclables Collection is shown to be a greater priority amongst these cities, either because they have already started this programme or will be starting in the next two years (Southeast Asia & Oceania example city). The African example city's Programme delivery is later than the other cities because waste emissions represent a very small percentage of its total emissions. Nevertheless, actions to capture and avoid methane are urgent, given the tremendous global warming potential of methane in the short term.

5.5.4 WASTE AND ADAPTATION

As climate change impacts the occurrence of extreme events, it will be even more critical to ensure that cities have effective and robust waste management systems. Waste management is essential to the health and hygiene of the city and its residents. This is particularly true during and after extreme events, when access to clean water is vital and impacts on waste collection and disposal can potentially cause secondary health crises.

The design and operation of waste management systems must be sensitive to changes in future climate. Diverting waste from landfill through recycling initiatives and circular economy approaches can assist in improving the resilience of the city to future climate change; landfill concentrates vulnerability to climate change by creating potential flood and contamination risks.



CHAPTER 6

ACCESSING C40 CITIES' CONTRIBUTION TO THE PARIS AGREEMENT

TOGETHER

Having established a routemap it is now crucial to understand how C40 city leaders and their staff will deliver the programmes outlined above. This section discusses the approach that the C40 will use to support cities drastically upscale their climate actions (as described in Section 4); the vital role of other stakeholders in delivering this huge potential; and the scale of funding required to do so.

6.1 HOW C40 WILL UNLOCK ACTION IN CITIES

C40 will support member cities to achieve their targets by engaging mayoral leadership; providing technical assistance to set and deliver robust emissions inventories, targets and plans; facilitating peer to peer exchange of best practice; removing barriers to action; and achieving a strong collective voice.

Engaging mayoral leadership

C40 was created by mayors and derives ongoing strength from that ongoing mayoral leadership. C40 will work to ensure that by 2020 each mayor has published a robust climate action plan consistent with achieving the Paris Agreement target of a maximum global temperature rise of 1.5 degrees Celsius. In addition, C40 will also increase our direct support to those mayors who wish to take prominent positions on the international stage in support of climate action, providing dedicated communications and briefing support.

Supporting cities to prepare robust climate inventories, targets and plans

To set targets to deliver the Paris Agreement, cities first need to understand what constraining global temperature rise to 1.5 degrees would entail. This is what *Deadline 2020* aims to provide. It will not be possible to deliver effective emissions reduction/avoidance strategies if cities are not simultaneously made more resilient to the ever-growing impacts of climate change. Supporting climate adaptation efforts is, therefore, a critical part of C40's approach, including through the provision of our Climate Risk Adaptation Framework and Taxonomy (CRAFT).

Accelerating action through peer-to-peer exchange and ramping up direct support

What differentiates C40 from other international political organisations is that C40 cities have demonstrated how to make competition and collaboration work in tandem. The 17 sector-specific networks are the bedrock of this collaboration. C40 will expand the number of networks we offer, providing the opportunity for peer-to-peer exchange in the areas where there is greatest potential for cutting emissions and reducing climate risk.

C40 will concentrate additional resources on providing complementary direct support to individual cities. In particular, C40 will offer dedicated staff to join city hall teams working in the areas where our data shows there is greatest opportunity for emissions reduction/avoidance.

Removing barriers to climate action

C40's research with Arup has identified a number of barriers to effective city climate action. In particular, many C40 cities are unable to attract the finance they need to deliver low carbon infrastructure. The C40 Cities Finance Facility (CFF) will provide $20m of support by 2020 to help unlock and access to up to $1bn of additional capital funding, by providing the connections, advice and legal/financial support that enables cities to develop more financeable projects.

Many mayors still struggle to win political and popular support for climate action. C40 will provide mayors with the evidence base to show that low carbon development will raise living standards faster, and embed stronger economic development. Similarly, through our partnership with The New Climate Economy Cities Programme we will develop the evidence base for why higher tiers of government should empower climate action in cities and engage national and regional political leaders to help achieve this. C40's City Solutions Platform will help to overcome the barriers that procurement rules can create to stronger working with businesses, by providing a neutral space where city governments can access private sector strategic intelligence before formal tendering begins.

Recognising that many of the barriers that prevent cities from accessing finance for infrastructure projects are caused by decisions of the international community and national governments, C40 launched a Call for Action on Municipal Infrastructure Finance.

Delivering global thought leadership, agenda setting communications and world class events

Cities are now, rightly, at the leading edge of global efforts to tackle climate change. Greater responsibilities accrue as a result, and so C40 will devote more resources to our city diplomacy efforts, including fully representing its members in global initiatives such as the **Global Covenant of Mayors**, Global Climate Action Agenda, and the IPCC. We will also increase engagement with other non-state actors, particularly the Climate Group States and Regions, R20 and We Mean Business, as well as city-network partners, ICLEI and UCLG.

One of the ways in which C40 mayors can exercise their collective strength is to send clear signals to markets, as they did when 26 mayors signed the Clean Bus Declaration. In the next Business Plan period C40 will seek to support at least one similar **market-shifting** declaration per year, backing up commitments made by mayors with targeted lobbying campaigns and partnership with organisations representing business.

C40 has played an influential role in achieving greater global recognition for mayors' climate leadership. To support efforts to raise the profile of C40's collective voice even further, C40's communications team will bring together a **network of communications leaders** across member cities, equipped with regular briefings, communications templates on key issues, and opportunities to profile their cities efforts.

Finally, C40 will continue to celebrate city successes in tackling climate change by ensuring our biannual Mayors' Summit remains the most important event on the city diplomacy calendar, delivering a regional summit in each of our regions over the business plan period, and embedding our annual C40 Cities Awards as the premier international city awards event.

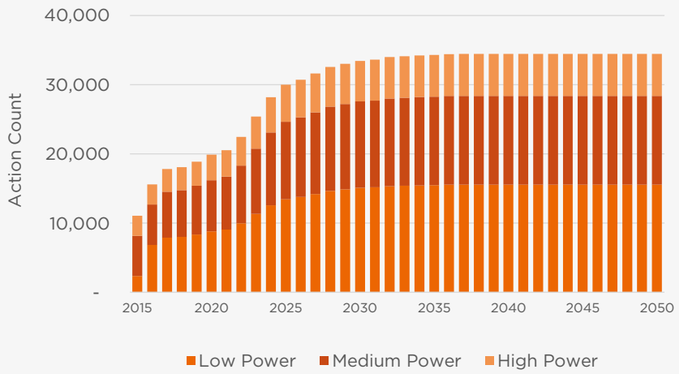
6.2 URBAN PARTNERS: ACTION IN CITIES, BUT NOT BY CITIES ALONE

City governments will have varying degrees of power and control over different Sectors and specific climate actions. However, in order to develop a clear implementation plan for cities it is key to understand what powers cities have over assets and functions within a specific Programme that can enable them to take immediate action.

Research carried out by Arup and C40 in 2015 revealed that the capacity to collaborate with other actors may be as important to cities' climate action as having direct control over city assets and services.[17] Partnerships with other cities, national governments, private businesses, investors and civil society are critical to help cities deliver climate action.

As we have already seen (Section 4.4), of the considerable future emissions reductions required for a 1.5 degree future, city governments are positioned to deliver over half of these. From Figure 36 we see that 18% of the 34,000 actions that will need to be in place by 2030 are already related to assets or functions where cities have high power; cities are in a position to initiate these actions unilaterally, as soon as possible.

Figure 36. Power breakdown of the actions taken by all 84 cities under the 1.5 degree trajectory.

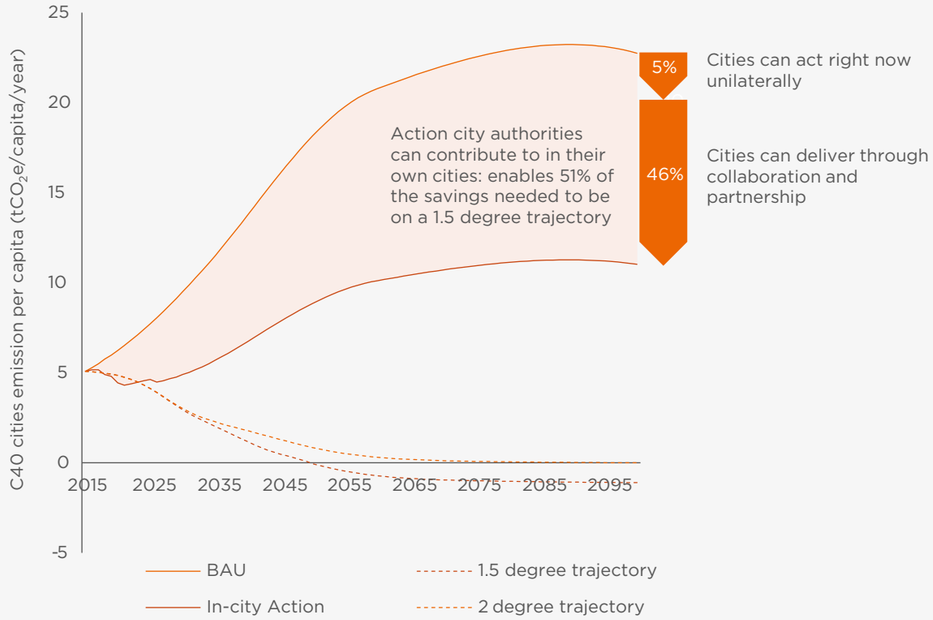


No Power actions include some asset classes where cities have not provided power data

27,000 further actions to be delivered up to 2030 will require a mixture of cities leveraging their networks, stakeholders, and partnerships, and collaborating to drive change. This could require, for example, leveraging finance and technical expertise from the private sector, or engaging with sub-national government to roll-out a project on an inter-city scale.

In terms of emissions impact (see Figure 37), the High Power actions that cities have the ability to initiate unilaterally translate to 10% of the total impact that city authorities can contribute to in their own cities. When excluding the benefits of grid decarbonisation, this translates to 5% of total reductions required against the BAU.

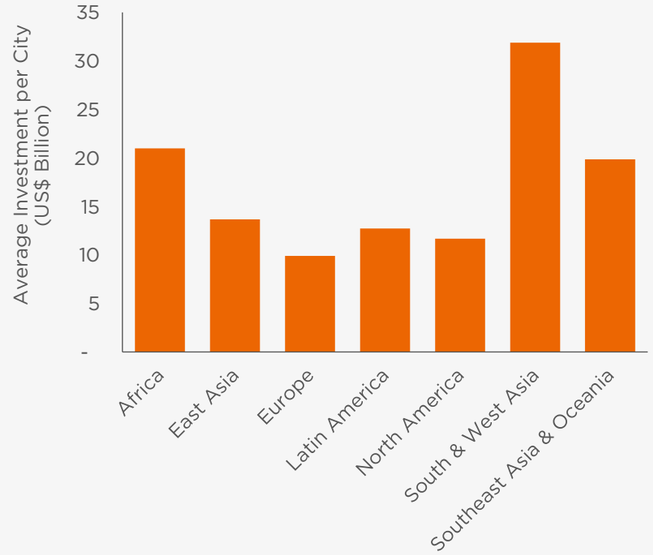
Figure 37. How far City Action can get us.



6.3 FUNDING THE C40 CITY CONTRIBUTION TO DELIVERING THE PARIS AGREEMENT

As C40 cities age and grow they will need to invest in renewing and expanding infrastructure, and working to enhance the lot of their citizens. While the data is not yet complete, initial estimates suggest that the city-level actions necessary to deliver the *Deadline 2020* vision across the C40 cities could require investment of over $1 trillion to 2050. Just under half of this is required by 2020.[XVII] Average total investment across the C40 cities of over US$50 billion per year may be required up to and beyond 2030 to move onto a 1.5 degree trajectory. On a per-city basis, Figure 38 shows that US$10-30 billion will be required by 2050 depending on the region, with African and South & West Asian cities needing the most.

Figure 38. Regional breakdown of average investment requirements to 2050 for C40 cities under 1.5 degree scenario.



Cities will therefore be required to manage significant pipelines of investment, leveraging funding from a range of parties and employing innovative financing mechanisms to deliver infrastructure and policy. As Figure 38 shows, a significant burden will be placed on C40 cities in developing nations, potentially those with lower access to capital. Cities will look to international institutions, national governments and private investors to support them in fulfilling their *Deadline 2020* responsibilities. To this end, the C40 Cities Finance Facility (Section 6.1) is also ready to assist.

XVII These figures are based on action cost information supplied by cities in 2014 - 2016 C40 Climate Action in Megacities data returns, extrapolated for all cities' modelled action profiles. Further data collection will be necessary to firm up these estimates.

CHAPTER 7

PLUGGING THE GAP: WHERE CITIES MUST RELY ON OTHERS

Partnerships and collaboration within cities will be fundamental to delivering the *Deadline 2020* action pathway, but this will not be enough without wider enabling infrastructure. Cities will need to compel those who work beyond their administrative boundaries, collaborating with regional and national-level actors and others to ensure the national and the international infrastructure that supplies them is also transformed to meet future targets.

To deliver a 1.5 degree trajectory, or even 2 degrees in the longer term, zero carbon emissions must be achieved in all C40 cities (Section 3.5). This can only be achieved by ensuring all energy use in cities is zero carbon. As noted by Jeffrey Sachs and other experts, there is a growing consensus that this will only be achievable through complete electrification of our cities, followed by ensuring all that electricity is generated from zero carbon sources. Finally, given the very small remaining carbon budget if we are to limit global temperature rise to no more than 1.5 degrees, there will inevitably be a need for carbon sequestration, or negative emissions solutions.

7.1 ELECTRIFYING OUR CITIES

A zero-emissions 2050 is incompatible with the continued unabated combustion of fossil fuels. This points to the need to phase out the burning of gas and oil in our homes, offices and factories, and diesel and gasoline in our vehicles.

Today, electricity only supplies 15% of total global primary energy.[18] While electricity is not currently "zero" carbon, its ability to act as a vector for low-carbon energy means that, under the right conditions, an electrification transition will deliver decarbonisation of those services.

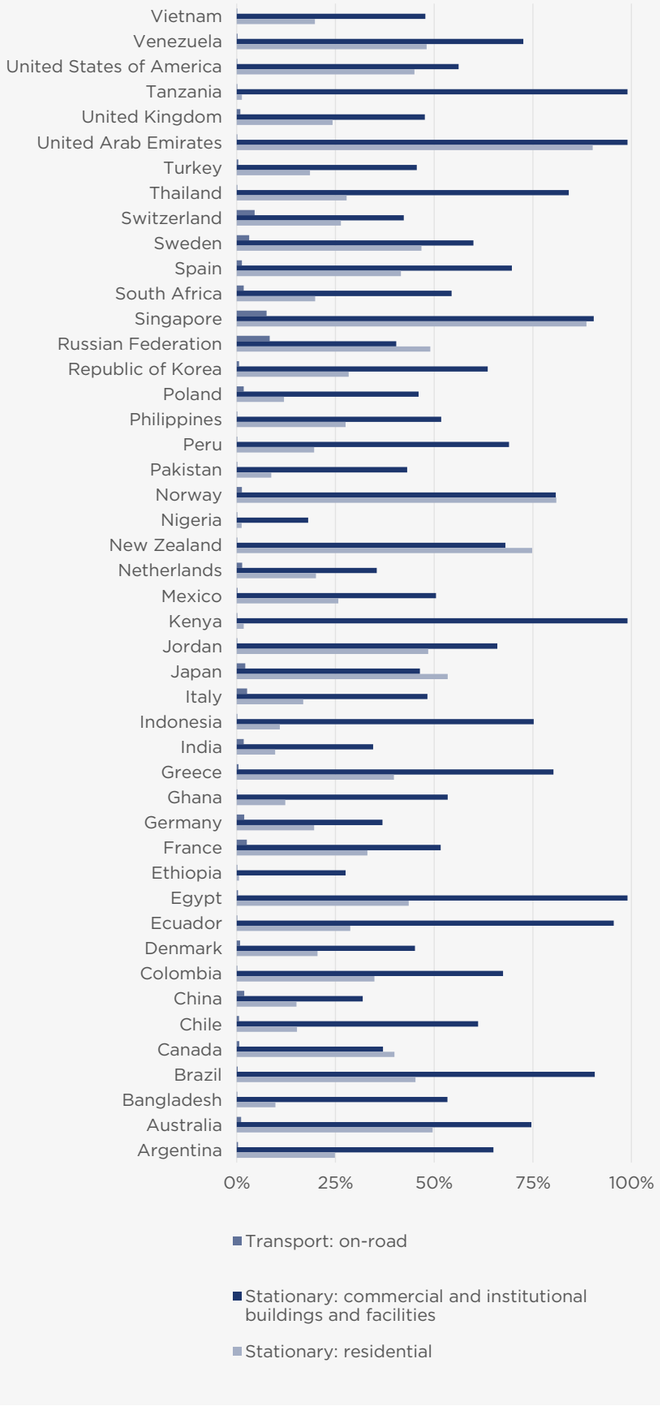
The stage is set for this transition at a city-level, with cities ready to roll out electric taxis (e.g. London), buses (e.g. Shenzhen[19]), and public electric car clubs (e.g. Paris[20]); ride-hailing companies aggressively pursuing autonomous vehicle technologies (e.g. Uber, Lyft); and major car companies (e.g. General Motors, Volkswagen) and challengers (e.g. Tesla, BYD) poised to deliver mass-market electric vehicles. However, at present the rate of electrification in C40 countries (not cities) is well below 10% in the vast majority of cases; the challenge in this transition is therefore substantial.

Meanwhile, electric heating technologies like heat pumps (for direct heating provision, or harvesting of waste heat) are increasingly gaining traction at domestic, commercial, and district scales,[21] while domestic solar panel and battery storage costs are seeing rapid declines alongside the utility-scale offerings. Coupled with an exponentially growing internet of things, the necessary ingredients are in place for smart, all-electric, even off-grid buildings.

An electrified future is no longer a distant dream, as the analysis indicates that cities must act now to get onto a 1.5 degree pathway, driving and enabling the shift away from fossil fuels. Example actions and programmes in this endeavour includes:

- Low-emissions transport zones
- City-wide roll-out of charging stations
- Support for zero-carbon public transit
- Incentives for electric heating (such as heat pumps), coupled with energy efficiency and demand reduction measures such as insulation retrofit
- Equipment scrappage schemes.

Figure 39. Electrification rates for three GPC emissions sectors and all countries with C40 cities.[22]



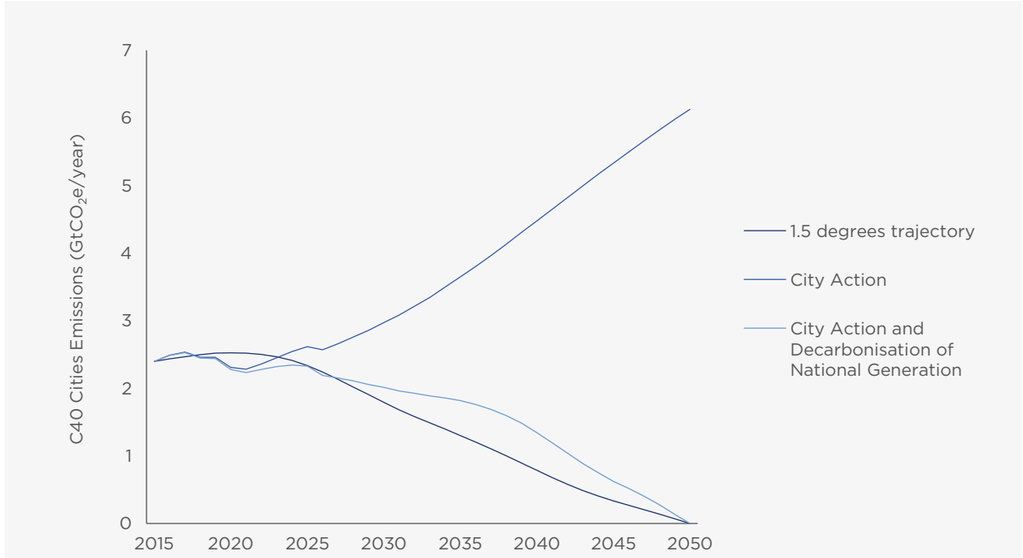
7.2 DECARBONISATION OF OUR ENERGY SUPPLY

It is crucial to note that the ability of C40 cities to achieve their trajectories relies entirely on one major action at the national level: decarbonisation of energy, primarily as electricity. **Without this, every C40 city will miss its target.** Without support from national decarbonisation of centralised generation C40 cities will emit just under 92 $GtCO_2e$ between now and 2050, despite their best efforts. To stay within the 1.5 degree scenario, C40 cities have a carbon budget of 22 $GtCO_2e$ to 2100.

To ensure that the target of zero emissions per capita is achieved by 2050, national electrical systems need to decarbonise at an average rate of 1.5% every year. This represents a doubling of past rates in the last three years.[23]

Figure 40 illustrates the importance of national governments mobilising to decarbonise the grid. If C40 cities follow the *Deadline 2020* vision but there is low rate of decarbonisation, they will significantly deviate from the 1.5 degree trajectory.

Figure 40. Total C40 Cities Emissions: All Trajectories.

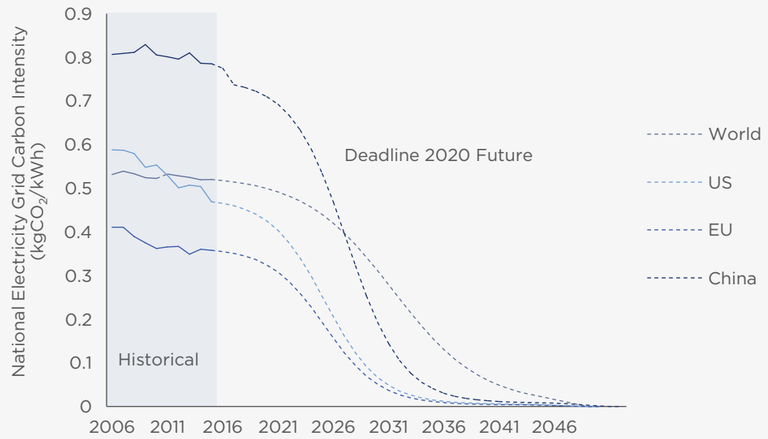


Currently, 40% of global energy-related CO_2 emissions arise from electricity generation processes[24], therefore radical decarbonisation of the grid is crucial. Cities can encourage this themselves, especially via the promotion of decentralised energy generation. Indeed, numerous cities have already set targets to source 100% renewable energy between 2015 and 2050.[25]

Ultimately, to deliver wholesale system change, national governments have just as great a responsibility as cities. As the electrification described in Section 7 progresses, it is likely that electrical demand will increase significantly, requiring additional generation capacity to support this transition.

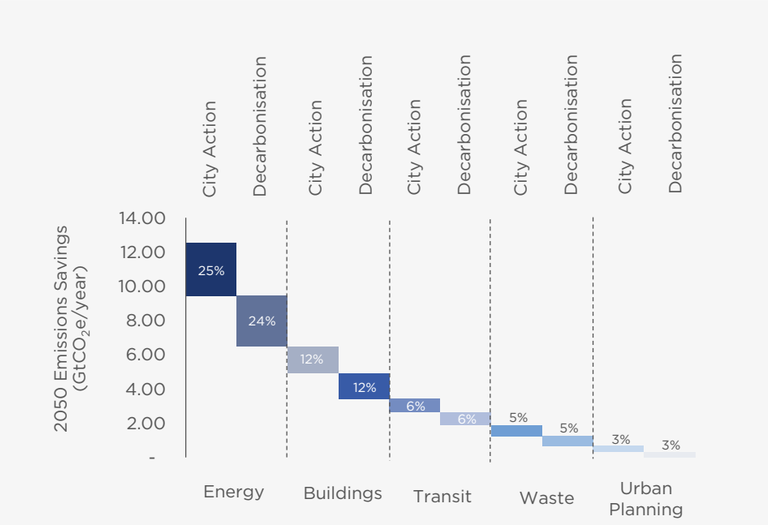
For many cities, full decarbonisation of electricity is still likely to be dependent on more centralised systems operating at a national level. Large-scale energy networks will transfer low-carbon power to our cities – for instance from offshore wind or nuclear plants, carbon capture and storage (CCS) plants, from energy storage facilities, or from inter-connectors to other countries. National governments have a great responsibility in setting policy and vision, mobilising investment, and working with cities to ensure that their Paris pledges translate to meaningful emissions reduction.

Figure 41. Illustration of Historic and *Deadline 2020* projected necessary rates of decarbonisation.



The importance of decarbonisation of energy is illustrated in Figure 42. In 2050, the contribution of City Action to the necessary emissions reductions is almost the same as the contribution from decarbonisation activities in all sectors.

Figure 42. Breakdown of the role of City Action and decarbonisation of energy supply for key city sectors in 2050, 1.5 degree scenario.



7.3 ACHIEVING NEGATIVE EMISSIONS

As already discussed, to reach zero in 2050, it is also likely that negative emissions technologies must be in place and operating at scale, expanding into the future. So how do we move beyond zero emissions? This research shows that a climate-safe future may now rely on CO_2 removal technologies, sometimes known as "negative-emissions" technologies. This is the case for both 1.5 and 2 degree scenarios, where CO_2 removal from the atmosphere must at least compensate for the continued emissions of other greenhouse gases (from agriculture and fossil fuel extraction, for example), which may be far more difficult to eliminate.[37]

In global 1.5 degree scenarios, negative emissions will also be necessary to compensate for emissions arising during the transition to zero net emissions. Up until 2050, C40's 1.5 degree target trajectory emits 53 $GtCO_2e$. Therefore, bringing net emissions within the 22 $GtCO_2e$ by 2100 budget for 1.5 degrees requires the net removal of 31 $GtCO_2e$ from the atmosphere between 2050 and 2100.

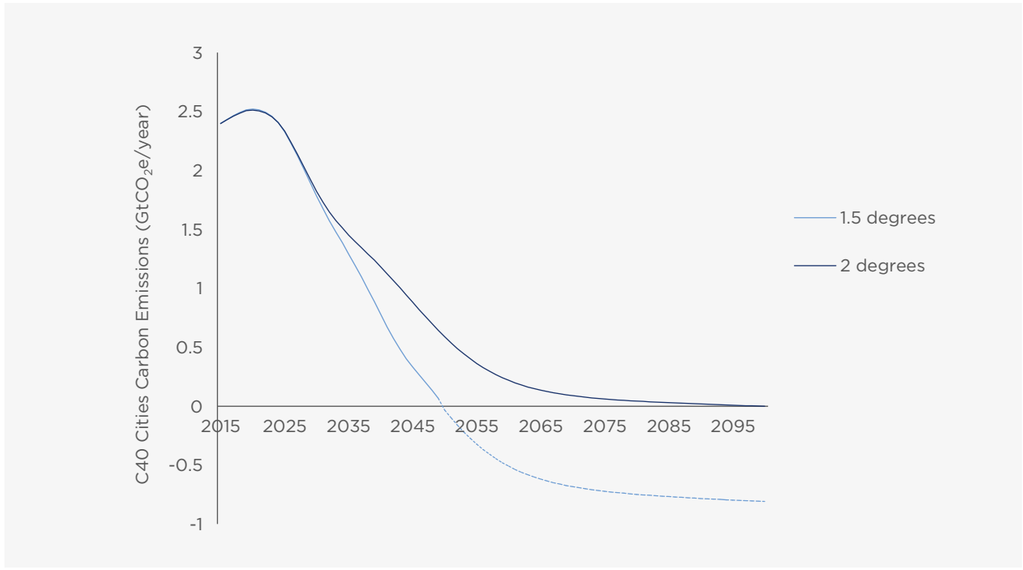
A range of negative emissions technologies is currently under scientific research and evaluation. These capture CO_2 from the air directly or indirectly, and permanently store it in underground reservoirs or in other stable forms for geological timescales.[26] These technologies rely on the effective global implementation of Carbon Capture and Storage (CCS) technologies. CCS coupled with bio-energy (BECCS) is currently believed to be the most economically efficient negative emissions solution because useable energy is a by-product of the process.

BECCS and all other negative emissions technologies will require the development of sizeable new infrastructures, and very high ongoing operational costs. While subject to considerable uncertainty and sensitivity to external factors, our estimates indicate that C40 cities (or national governments on their behalf, to make up for previous emissions by those cities) could be expected to spend between US $2.1 and $3.9 trillion on BECCS between 2050 and 2100 to meet their 1.5 degree budget.[27]

BECCS also presents challenges for land-use, with its bio-energy feedstock potentially competing with food crops. Alternative, non-competing technologies might result in C40 cities spending up to $5.4 trillion.[27]

Questions remain regarding the financing of interventions on such a scale; it would appear logical for the greatest burden to be placed on economically stronger nations. As seen in Figure 43, net removals of CO_2 could be as much as 50% of today's emissions.

Figure 43. Challenges associated with negative emissions.



7.4 PUTTING IT ALL TOGETHER: CUMULATIVE SAVINGS MEAN C40 CITIES CAN MEET COP21 PARIS AMBITION

Combining all of the above considerations, the story of the *Deadline 2020* can be *summarised* in the image, Figure 44.

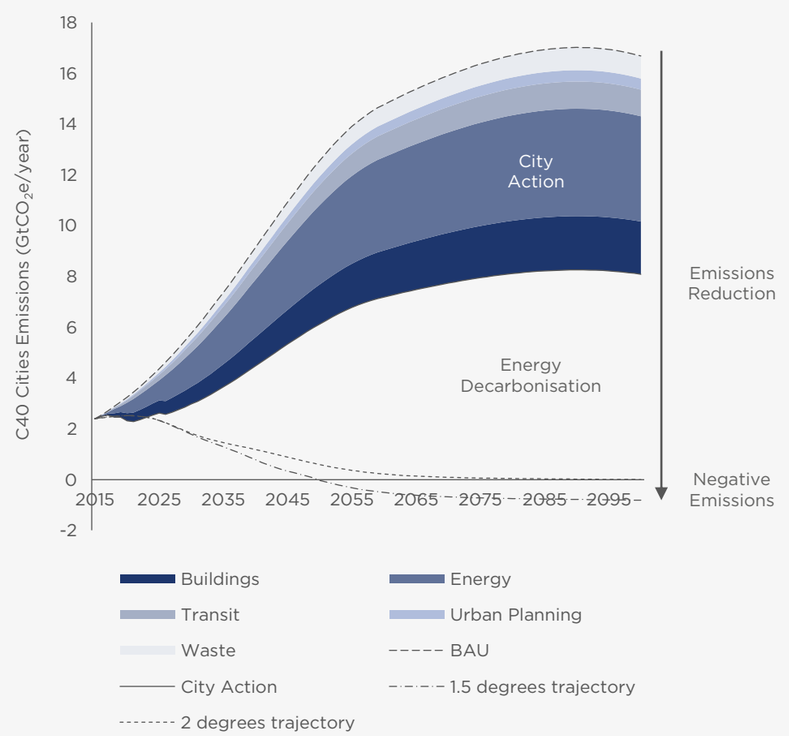
From a starting point of 2.4 $GtCO_2e$, C40 greenhouse gas emissions in 2015 have the potential to rise almost sevenfold by 2100 if no further climate action is taken, under the business as usual case. A carbon budget consistent with the aspirations of the Paris Agreement of 22 $GtCO_2e$ by 2100 will allow the C40 cities to show their commitment to a 1.5 degree future. The emissions trajectory necessary to achieve this requires C40 cities to be net zero carbon by 2050, and contributing to global negative emissions efforts, removing 31 $GtCO_2e$ from the atmosphere in the second half of the century.

City commitments to climate action enable C40 cities to save a total of just over 500 $GtCO_2e$ versus the BAU trajectory by 2100 with City Action. However, while this represents an impressive 51% of the savings necessary, cities will be reliant on external actors and events to achieve the full transition to zero and beyond.

Of the 51% of reductions achieved through city Action, 20% of the necessary actions can be implemented by cities unilaterally, while the remaining 80% can be delivered through a combination of collaboration and partnerships.

Zero carbon energy and electricity are required to hit the 2050 target, while negative emissions technologies on industrial scales will be necessary for net CO_2 removal.

Figure 44. The *Deadline 2020* Story.



CHAPTER 8

DEADLINE 2020 AS BLUEPRINT FOR WORLDWIDE DELIVERY OF PARIS AGREEMENT

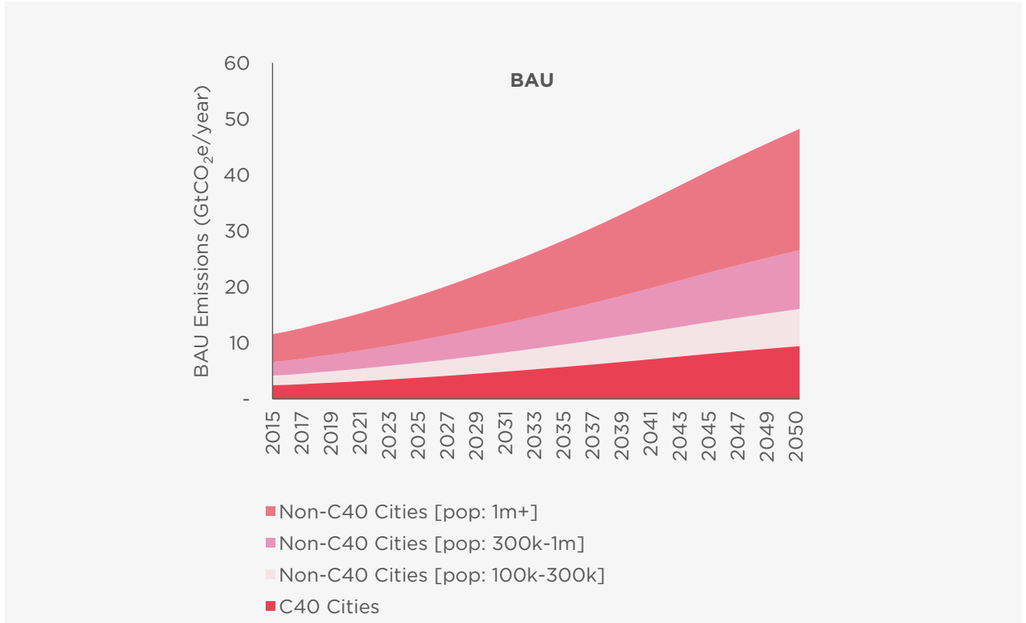
While C40's 86 cities influence 20% of global carbon emissions, the world's urban areas already account for more than 70% of global carbon emissions.

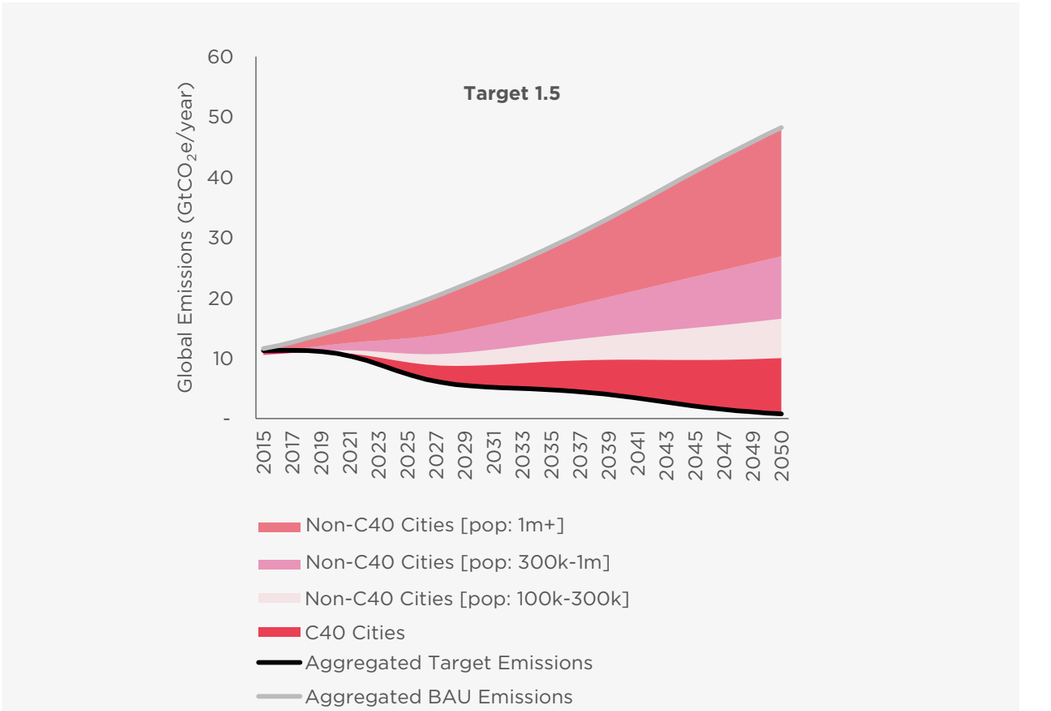
C40 is a leadership group of some of the world's largest, most empowered and most ambitious cities. C40 cities are able to introduce innovative technologies, test financing mechanisms and pioneer more ambitious actions in a way that other smaller, fast growing cities cannot. These lessons and newly developed best practices can then be shared with the rest of the world's cities. As pioneering leaders across the world, the C40 cities can amplify the impact of breakthroughs and successes within the C40 network.

Therefore in developing the vision for this work, we must also directly consider how the investment, innovation and lessons learned in delivering our vision for 2020 and beyond can benefit the global urban community.

So what would be the implications if all cities in the world followed *Deadline 2020* goals? If all cities with a population greater than 100,000 joined C40's *Deadline 2020* there would be the potential to save 800 $GtCO_2e$ (Figure 45) by 2050. By 2100, savings equivalent to 40% of the global reductions against BAU required for a 1.5 degree scenario could be delivered in these cities.[XVIII] As Figure 45 shows, while all city sizes have growing impacts in the BAU scenario, the most significant city grouping is those cities with populations of over 1 million today. These cities likewise will make the greatest contribution to emissions reductions in a 1.5 degree target scenario. The time to take action is now, and all these cities can also act by 2020 to help create a climate-safe world.

Figure 45. Global city BAU emissions projections (left) and savings achievable when following C40 1.5 degree target trajectories (right) (including energy decarbonisation) **Cities includes urban settlements with populations above 100,000.*





The above graph and statistics were developed based on a high-level city pairing exercise carried out on a dataset of over 3,000 cities with populations in 2016 of over 100,000, and include the effects of future population and GDP growth. These cities were paired with the C40 cities that best matched their core characteristics, including geography, climate, GDP and population growth rates, where available. This exercise illustrates that out of 49 mapped C40 cities, two thirds of emissions, from over 2,000 cities, are linked to just ten C40 cities.

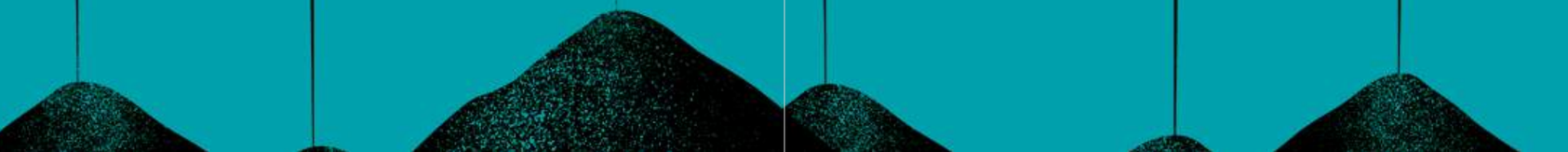
All but one of these top ten cities are from states in the global south. This shows both the importance of these regions in overall future global emissions mitigation, but also, crucially, the important leadership role for these nine cities. By setting an example through ambitious climate action, they have the potential to influence emissions reductions by orders of magnitude beyond their own, charting a path of climate-safe development that will influence the lives of millions.

XVIII Note, no negative emissions have been assumed for non-C40 cities, although these will likely be necessary to meet a 1.5 degree scenario.

CHAPTER 9

CONCLUSIONS

WE MUST ACT NOW



In summary, the concluding findings of the *Deadline 2020* project are as follows:

1. **C40 Research presents the first significant pathway for relating the ambition of the Paris Agreement to action on the ground.** One that would allow C40 cities, representing 650 million people and 25% of the world's GDP, to deliver their own emissions trajectories consistent with limiting global to 1.5 degrees.

2. To stay within 1.5 degrees, average per capita emissions across C40 cities would need to drop from over 5 tCO_2e per capita today to around 2.9 tCO_2e per capita by 2030. Doing so would keep cities on a trajectory consistent with either 1.5 or 2 degrees of warming, it is only after 2030 that these trajectories diverge.

3. **Mayors can deliver or influence just over half of the savings needed to put C40 cities on a 1.5 degree trajectory, a total of 525 $GtCO_2e$ by 2100.** Either through their own direct action or through collaborating with partners such as the private sector.

4. **Deadline 2020:** Action in the next four years will determine if it is possible for cities to get on the trajectory required to meet the ambitions of the Paris Agreement. If sufficient action is not taken over this period, limiting temperature increases to below 1.5 degrees will be impossible. C40 cities collectively delivered nearly 11,000 climate actions between 2005 and 2016. In the four years to 2020, an additional 14,000 actions are required. This represents an additional 125% in less than half the time.

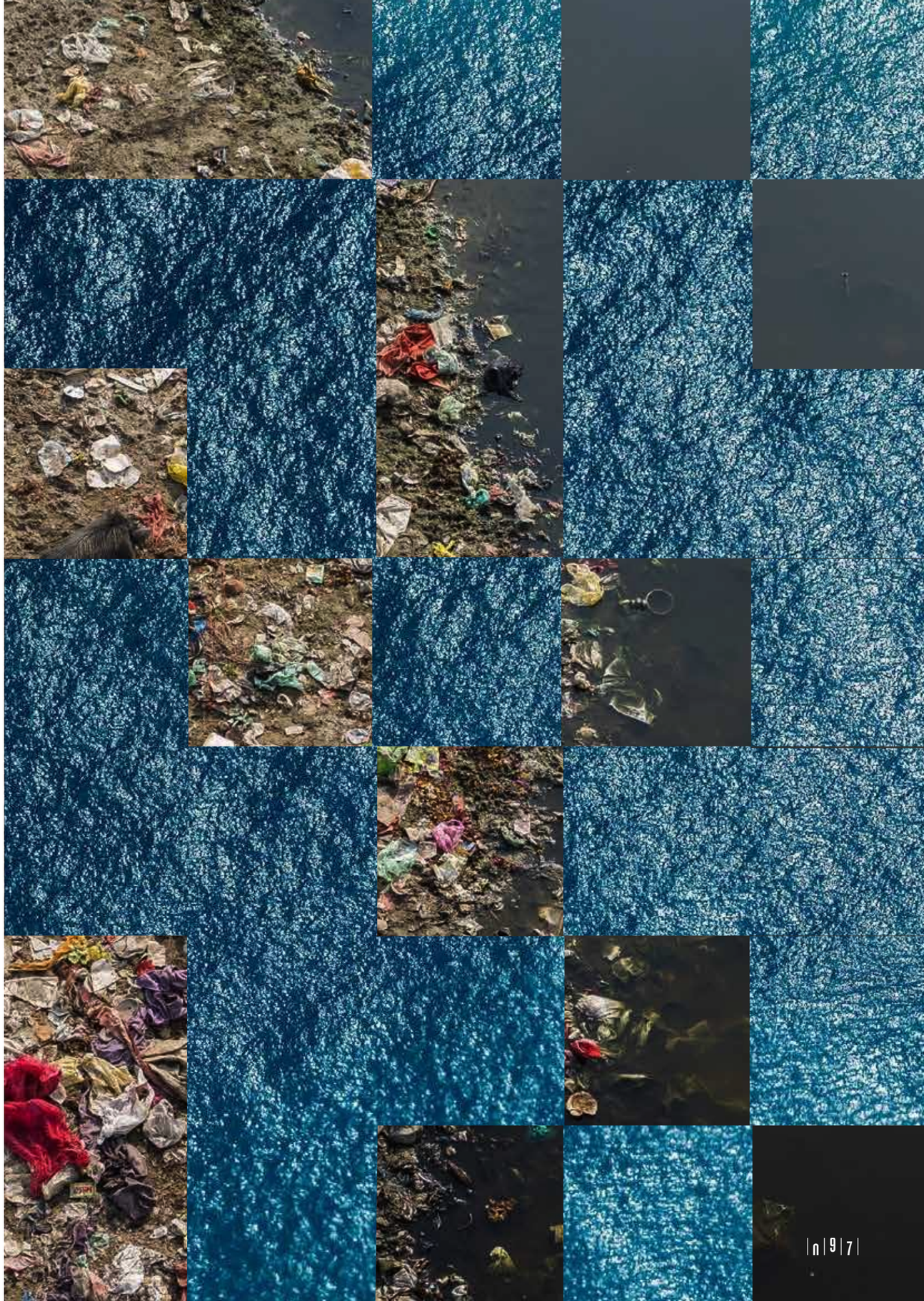
5. Wealthier, high carbon cities must deliver the largest savings between 2017-2020. As of 2017, cities with GDP over $15,000 per capita must begin to reduce their per capita emissions immediately. Of the 14,000 new actions that are required from 2016-2020, 71% should be taken by cities that need to immediately decrease per capita emissions.

6. As C40 cities age and grow they will need to invest in renewing and expanding infrastructure, and working to enhance the lot of their citizens. From 2016 to 2050, over $1 trillion of this investment is required across all C40 cities to meet the ambition of the Paris Agreement through new climate action. **$375 billion of this investment is needed over the next four years alone** to take the climate action required.

7. If action involving city governments can deliver just over half of the GHG savings needed, then action to deliver structural changes from outside cities (i.e. electrical grid decarbonisation), must start to have a significant impact from 2023 at the latest. This will become the dominant driver of urban GHG reductions after 2030.

8. Substantial carbon sequestration will be required by national governments if cities are to stay on a 1.5 degree trajectory post 2050.

9. **If all cities adopted the roadmap set out in this report for C40 cities, it would deliver 40% of the emission reductions required to keep temperature rise below 1.5 degrees:** Action by C40 cities can have huge magnification. If all cities with a population greater than 100,000 adopted the ambition for C40 cities set out in this report, there would be the potential to save 863 $GtCO_2$ globally by 2050. By 2100, they could have saved up to the equivalent of 40% of the reductions necessary for a 1.5 degree scenario.



APPENDIX A: METHODOLOGY

A1 INTRODUCTION

This appendix summarises the overall methodology for the *Deadline 2020* study according to four stages of analysis:

1. Compiling the baseline emissions of C40 cities (Section A2)
2. Establishing the aggregate C40 Carbon budgets (Section A3)
3. Deriving city target emissions trajectories (Section A4)
4. City Action pathway modelling (Section A5)
5. Key common data collected for this Study (Section A6)

A more complete and detailed report on assumptions, calculations and analysis can be found in the *Deadline 2020* Methodology Report.

A2 BASELINING C40 CITIES

Baseline C40 city emissions are the starting point for the analysis carried out within *Deadline 2020* (this Study), providing a baseline from which projections can be made. For the purposes of this Study, baseline greenhouse gas (GHG) emissions and sectoral profiles are defined as total scope I and II emissions of each of the 84 C40 cities[XIX] in 2015 and their proportional split across key sectors respectively.

The sectors of interest were aligned with those used in the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories (GPC)[XX] categories, namely:

- Stationary Energy
- Transportation
- Waste
- Industrial process and product use
- Agriculture, forestry and other land use.

Scope III emissions have not been included within the baseline data because of the risk of double counting emissions in the cities being considered. A lack of available Scope III data was also a driver for this decision, although this could feature in future research.

The total territorial emissions data were either sourced from GPC or Carbon Disclosure Project (CDP)[XXI] inventories, prioritising GPC data due to higher available sectoral resolutions. The reported year of emissions data ranged from 2009 to 2015, so where necessary, data was normalised to the year 2015 using an annual city GDP[XXII] growth rate (see Section A6.2 on sources).

For cities lacking data on total emissions and / or sectoral split, a "mapping" process was carried out whereby these cities (referred to as Secondary cities) were "mapped" to the most similar city within the C40 sample with available data (these cities are referred to as Primary cities). The pairing of cities was made using a number of demographic, climatic and socioeconomic indicators.

We note that detailed, GPC-compliant emissions inventories are currently being compiled for all C40 cities. The approach developed to generate emissions data for all C40 cities is a working solution to facilitate understanding of the scale of the challenge, prior to obtaining full GPC-compliant emissions inventories from all C40 cities, whereupon it will be appropriate to refresh this analysis.

XIX At the time of analysis; C40 membership has since increased
XX A comprehensive City-level carbon accounting method based on the Greenhouse Gas Protocol (GHG Protocol) http://www.ghgprotocol.org/city-accounting/
XXI A secondary source of self-reported city emissions data used when GPC data is unavailable https://www.cdp.net/en-US/Pages/HomePage.aspx
XXII City GDP is used throughout this appendix to refer to the gross domestic product of the city as opposed to national GDP

A3 C40 CITIES' CARBON BUDGET

The purpose of the Study is to understand the level of City Action needed to stay within a climate-safe temperature target. To achieve this, the C40 cities permissible cumulative GHG emissions were derived, establishing the overarching "C40 carbon budget" for 84 cities.

A3.1 GLOBAL CARBON BUDGET

Two target maximum temperature increases were considered to reflect the target and aspiration set out in the Paris Agreement – 2 and 1.5 degrees Celsius of warming beyond pre-industrial levels. Following a review of published global carbon budgets, those from the Intergovernmental Panel on Climate Change (IPCC)[28] were selected for this study. These carbon budgets represent cumulative GHG emissions consistent with a 66% probability of limiting warming to below 1.5 and 2 degrees.

These figures were adjusted to the period 2016 to 2100 by subtracting historic GHG emissions for both CO_2[29] and non-CO_2[30] sources.

A3.2 CARBON BUDGETING

Key steps to allocate a "fair" proportion of the global carbon budgets to C40 cities from 2016 to 2100 were:

1. Understanding the context for allocation of budgets to sub-global entities and a snapshot of existing approaches developed by the scientific community, governmental and non-governmental organisations.
2. We evaluated this information and developed a decision matrix to select a suitable approach for this Study.
3. Finally, we calculated the C40 carbon budget consistent with both 1.5 and 2 degrees using the preferred approach for allocation.

While individual city budgets are implicit in many of the methodologies described, a key concept to note is that the budgets discussed refer to a single, overall budget for the bloc of C40 cities; individual city budgets are described in Section A4.

A3.2.1 CONTRACTION AND CONVERGENCE

According to a number of authoritative sources[31,32,33], the following principles dominate debate on fair allocation of carbon budgets:

1. **Equality**, based on an understanding that human beings should have equal rights
2. **Responsibility** for contributing to climate change, linked to the 'polluter pays' principle
3. **Capacity** to contribute to solving the problem (also described as capacity to pay).

Following a literature review, seven approaches were identified and their suitability tested according to a number of criteria including how well they embedded the principles listed above and their feasibility. The Contraction & convergence (C&C)[XXIII] approach – developed by the Global Commons Institute (GCI) – was chosen.

By this approach, C40 cities must converge by a certain date to equal emissions per capita with the rest of the world. During the "adaptation" period up to the year of convergence, the C40 city emissions per capita can increase/decrease linearly up to or down to the global average.

The convergence date was set at 2030 in response to reflections within the literature that a convergence year much later would not benefit developing countries because they are not given additional allowances to grow emissions per capita (or, in other words, they have unconstrained economic development).[34]

A3.2.2 FINAL C40 BUDGETS

The 2030 convergence emissions per capita value chosen was 3.2 tCO_2e per capita, equal to half the current global emissions per capita (6.4 tCO_2e)[35], as well as consistent with 2030 global emissions per capita under an ambitious below 2 degree pathway (as per IPCC AR5, 430-480ppm range[35]).

The C40 budgets for scenarios consistent with below 1.5 degrees and 2 degrees were estimated at 22 $GtCO_2e$ and 57 $GtCO_2e$ to 2100 respectively.

One important difference regarding the 1.5 degree scenario was that it was assumed that the only possible means to achieve this target would require negative emissions.[36] There is no specific date for when GHG emissions turn negative, but later years will require far greater negative emissions subsequently to keep total emissions within budget. This assumption is consistent with research published in Nature Climate Change.[36], showing that emissions should hit zero by ~2050.[XXIV] Negative emissions technologies (such as bio-energy carbon capture and storage) are likely to be needed such that emissions of 53 $GtCO_2e$ to 2050 in the 1.5 degree scenario are reduced to the 22 $GtCO_2e$ budget by 2100, resulting in a total of 31 $GtCO_2e$ removed from the atmosphere over this time period.

XXIII GCI. (2005). CGI Briefing: "Contraction & Convergence". CGI.
XXIV Note that the IPCC did not model emissions trajectories consistent with a carbon budget with 66% probability of limiting warming to below 1.5 degrees.

A4 C40 CITIES EMISSIONS TRAJECTORIES

Two emissions trajectories were developed for each city, a business as usual (BAU) trajectory and a target per capita emissions trajectory.

A4.1 DEVELOPING BAU TRAJECTORIES

For the purposes of this work, the BAU trajectory is defined as the emissions pathway for a scenario in which "no further climate action" is taken.

The "Kaya identity" was used in order to develop city specific BAU trajectories. This is the methodology adopted by the IPCC to develop baseline pathways.[37,38] The Kaya identity states that a geographical entity's emissions are defined by its population, economic output, energy efficiency of economy and carbon intensity of energy.

The first three variables: population, city GDP per capita and energy per unit, were projected forwards based on available forecasts from sources including the UN[XXV], Economist Intelligence Unit[XXV] and IPCC[38].

A key variable in terms of framing a "no further climate action" BAU scenario is the assumption that energy production will not transition from being dominated by fossil fuel sources to low carbon alternatives. As such, the carbon intensity of energy was treated as constant between 2016 and 2100.

It is important to recognise that this particular definition of a BAU case is just one of many potential options. Others could include, for example, forward projections based on existing climate policies at local, regional and national levels. However, the definition used here is useful, as it does not rely on interpretation of the likely effectiveness of policy, and is able to be calculated highly consistently across the membership of C40. It is noted however, that this represents a worst-case scenario, as recent international political activity indicates it is unlikely that global carbon intensities will not improve.

A4.2 TARGET EMISSIONS TRAJECTORIES

The target trajectories are city-specific per capita emissions trajectories, which in aggregate, enable C40 cities to meet the overall C40 carbon budget consistent with a given target temperature rise scenario, i.e. 1.5 or 2 degrees (see Section A3). They enable division of the C40 carbon budget between cities according to development levels and capacity to act.

To generate trajectories, C40 cities were grouped into one of four "typologies" based on baseline emissions levels and city GDP per capita, as shown in Table 5. These criteria serve to reflect the discourse on historic responsibility for emissions and financial capacity described in Section A3.2 whilst responding to the demands on emissions reduction imposed by each carbon budget.

In this way, C40 and Arup took into consideration the capacity of cities in each of the trajectory groups to act and the need for appropriate "burden sharing" between developed and developing nations.

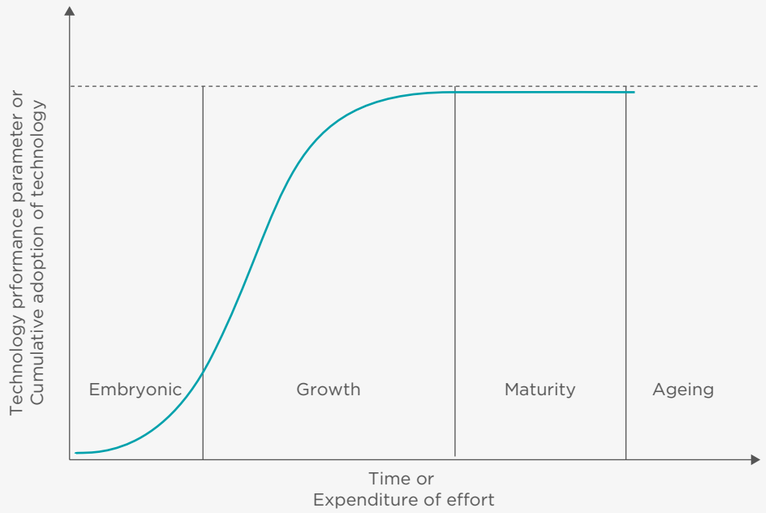
XXV More details on sources can be found in Section A6.

Table 5. Methodology for assigning city typologies. Cities with * based on data reported through CDP.

GHG/Capita	GDP/capita	Assigned typology	Example cities
High	High	*Steep Decline*	*Toronto* *Melbourne* *New York City*
	Low	*Late Peak*	*Cape Town* *Durban**
Low	High	*Steady Decline*	*Stockholm* *Seoul** *London*
	Low	*Late Peak*	*Quito* *Caracas** *Amman*

Each of the four trajectories relates to an "S-curve", commonly used to model technology adoption and more recently proposed as a valid means of modelling emissions trajectories[39]. This function governs the overall shape of the trajectory, and is scaled according to the cities' baseline emissions. An example S-curve is shown below (Figure 46).

Figure 46. Example S-curve function.[40]



The function variables were developed through an iterative process that considered the following factors:

1. The maximum rate of emissions decrease: this was an important consideration because the final trajectories needed to have a plausible year-on-year reduction rate. Although it is very hard to predict what this value might be, the maximum value used to develop these trajectories was a 20% annual reduction.
2. Growth rate until emissions are expected to drop: it was found that allowing peaking cities to increase their emissions on a per capita basis either meant they had to peak very soon or declining cities had to reduce emissions at a very fast rate. This resulted partly because developing countries still have a very fast population growth, meaning that a flat per capita emissions still results in very large overall emissions growth.
3. Peak year: similar to the growth rate, deciding on a peak year for each category was a balance between allowing developing cities sufficient time before reductions are required and not assigning unrealistic reduction rates to developed cities.

The resulting key differentiating factors between the typologies are shown in the table below.

Table 6. Peak years assigned for city typologies.

Trajectory	Peak Year	Trend up to peak year	Rate of emissions decrease
Steady decline	2016	n/a	Steady
Steep decline	2016	n/a	Steep
Early Peak	2020	Linear increase	Steady post peak year
Late Peak	2025	Linear increase	Steady post peak year

Absolute emissions trajectories were obtained for each city by multiplying the annual emissions per capita by projected population in the corresponding year.

Variables within the mathematical functions were varied until the aggregate emissions matched a given target carbon budget whilst maintaining the characteristics defining the typologies shown in Table 6.

A5 2CAP

The C40-Arup Partnership Climate Action Pathways (2CAP) model is the tool developed by Arup to project an Actions pathway for each C40 city which meets the respective city's target trajectory (see Section A4).

City by city, the model functions by dispatching Actions in an order dictated by the 2CAP logic and these Actions result in emissions reduction against the BAU trajectory of the city.

For the purposes of this study, the list of Actions was taken from the C40 Climate Action definitions, totalling 410 Actions (not including Adaptation). Through the Climate Action in Megacities studies[52], data is available on the deployment of those Actions, the reach of these across the cities (referred to as scale, see Section 0) and ability to initiate Actions (referred to as a city's power, see Section A5.2).

A5.1 MODEL LOGIC

The functionality of the model is best summarised by the following logical sequence it adopts:

1. Programmes are ranked by highest score. Each programme is the sum of Actions which are scored by three criteria: carbon saving potential, city power level over Action and Replicability scores. These criteria are explained in more detail in Section A5.2. The model dispatches Actions within the programmes in accordance with their rank.
2. Within programmes, Actions were dispatched according to a ranking driven by a Vital/Non-vital (explained in Section A5.2.4) categorisation and scored based on the criteria stated above. The model prioritises programmes with Vital Actions whose sum has a higher score than each Non-vital Action in a higher ranked programme.
3. Dispatch of Actions leads to a calculation of the emissions reduction against the BAU from each Action. These Actions are scaled to a "city-wide" (see Section 0) scale over time. The rate of this roll out determined the emissions reduction over time.
4. Decarbonisation of energy (electricity or heat) was an overlay on the model which enabled greater emissions reduction by assuming each C40 nation will make efforts to decarbonise energy supply at a national level. This intervention was not captured in Actions because it occurs outside the city boundary.

A5.2 PROGRAMME AND ACTION RANKING

This section describes the inputs for Steps 1 and 2 above.

A5.2.1 CARBON SAVING POTENTIAL

The carbon saving potential (or impact score) was defined as the greatest potential saving (in percent versus BAU emissions) from an Action deployed across the city (e.g. a Buildings Sector Action affecting all residential buildings).

XXVI Due to the number of references, these are not included here. For a full list see the full Methodological Report.

For most Actions, values for carbon saving potential were sourced from analysis using the World Bank's CURB modelling tool.[41] At the time of carrying out this Study, values were available for a single city, which was used as a generic example. This process holds scope for future development as more city-specific CURB inventories become available. Nevertheless, as emissions savings are converted to percentage reductions, this method is still relevant to cities with different absolute emissions breakdowns and magnitudes.

Some Actions' emissions saving potential was not available through the CURB model. In these cases, percentage savings were developed based on first principles analysis or through external sources[XXVI].

A5.2.2 POWERS

The C40 Powers database contains information on city Powers for over 70 city 'Assets' and 'Functions'. There is a maximum power score of 12 and this is broken down into four main categories, each with a score from 0-3, where 3 is the highest level of power:

1. Own / operate
2. Set / Enforce Policies and Regulation
3. Control Budget
4. Set Vision

Those cities without powers information, were mapped using the method developed for baseline emissions (see Section A2).

A5.2.3 REPLICABILITY

An Action's Replicability is a measure of how regularly a particular Action is reported in the CAM database within a particular region. If an Action is being taken by multiple other cities, it is assumed that knowledge can be shared amongst networks to enable more cities to take an Action. This logic gives actions that are being taken frequently a higher Replicability weighting score.

A5.2.4 VITAL / NON-VITAL ACTION

The categorisation of Actions as Vital and Non-Vital was carried out by C40. This labelling reflects the relative importance of an Action in a particular programme. Vital Actions must be taken for a programme to be delivered, whereas non-vital Actions are not mandatory.

A5.3 EMISSIONS REDUCTION CALCULATION

To calculate the emissions reduction of an Action, its emissions saving potential was multiplied by the corresponding BAU emissions of the sector in that year. We found that the Actions' reduction was either dependent or independent of other actions. As such, two broad categories of Actions were defined:

1. **Product Actions:** These are Actions where the absolute emissions reduction potential is affected by the introduction of another Action. Emissions reduction from these actions are multiplied by each other to determine the overall emissions saving. Within Product Actions, we have identified two types of action that categorise how the emissions reduction is achieved. **Direct** emissions reduction Actions describe those where the exact emissions reduction can be quantified from the Action being taken. **Enabling** Actions are those where the exact emissions reduction is harder to quantify but it is very likely that through the introduction of these Actions emissions are reduced, albeit indirectly.
2. **Sum Actions:** The emissions reduction potential of a Sum action is completely independent of the impacts of other Actions. The total emissions reduction potential of a city taking several Sum Actions is the sum of them. Two examples of Sum Actions are 'Rooftop Farming' and 'Tree planting / afforestation'.

As 2CAP dispatches an Action, the emissions saving potential is staggered over a feasible roll-out period to full deployment across the city. The roll-out time was based on an assessment of the bare-minimum years taken to bring an Action from "Pilot & planning" stage through to implementation across parts of the city (referred to as "Significant") to the whole city (referred to as "City-wide"). At each of these scales, a proportion of the emissions saving potential was applied to reflect the scale of reduction achieved.

A5.4 EXTERNAL DRIVERS OF EMISSIONS REDUCTION

As indicated in Section A5.1, decarbonisation of energy supply was incorporated as an additional driver on top of the city Actions. This national-level decarbonisation was necessary to meet the city target trajectories.

Grid decarbonisation was incorporated using two trajectories:

1. The electrification of cities: each city's electricity-dependent emissions were modelled as increasing over time using an S-curve (see Section A4.2 on S-curves) starting from the national baseline level of electrification in sectors. This data was sourced from the IEA[42].
2. Grid decarbonisation rate: national utility electricity grid decarbonisation rates for each city were modelled over time using a decreasing S-curve (see Section A4.2 on S-curves).

A6 KEY COMMON DATA INPUTS

Existing and future population and city GDP data were key inputs for the analysis in this Study. As such, the sources and any manipulation of data is described below.

A6.1 POPULATION

A multi-source approach was adopted to obtain both current and future city populations due to no single source covering all cities. Population data was collected to align with the emissions reporting boundaries of cities. In general, this coincided with administrative boundaries. In a number of cities, areas of mayoral jurisdiction are considerably smaller than the areas traditionally thought of when one considers a city boundary.

Key data sources were self-reported city GPC and CDP data, and UN[43] and regional government statistics.[44,45,46]

Population was projected until 2100 using a combination of UN city specific annual growth rates[47] and national annual growth rates[48].

A6.2 CITY GDP

The 2015 baseline city GDPs were derived from the following two sources in order of preference:

- The Brookings Institution data[49] – this data provided city GDP for the metropolitan urban area in 2014 for 70 cities. These were adjusted to the year 2015 using annual city GDP growth rates.
- The Economist Intelligence Unit (EIU)[50] national GDP – these were converted into national per capita figures using the UN national population estimates and then multiplied by city population to give a city GDP.

The GDPs of cities were projected using annual city GDP per capita derived from the EIU for each year up to 2050. Average annual city GDP growth from 2050 to 2100 was based on a forecast for national GDP growth by the OECD[51].

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