OPPORTUNITY 2030: BENEFITS OF CLIMATE ACTION IN CITIES

Quantifying the benefits of city-level measures in buildings, transport and energy supply

NEW CLIMATE INSTITUTE

C40 CITIES CLIMATE LEADERSHIP GROUP

Project number
16026

AUTHORS

Thomas Day

Sofia Gonzales-Zuñiga

Niklas Höhne

Hanna Fekete

Sebastian Sterl

Frederic Hans

Antoine Warembourg

Anda Anica

Pieter van Breevoort

ACKNOWLEDGEMENTS

C40 Team

Thomas Bailey and Cristina Mendonça, including review contributions from Wenwen Chen, Ilan Cuperstein, Rachel Huxley, Laura Jay, Guillaume Joly, Caterina Sarfatti, Irene Skoula, Lucila Spotorno, Manuel Olivera, Tim Pryce, Zack Tofias, Júlia López Ventura, Caroline Watson, Pengfei Xie.

Coalition for Urban Transitions

We would like to thank the members of the Coalition for Urban Transitions who reviewed this work: Sarah Colenbrander, Catlyne Haddaoui and Nick Godfrey

Case studies were also supported by staff from the following C40 Cities

London, Qingdao, Rio de Janeiro, Seattle, Toronto

Disclaimer

The views and assumptions expressed in this report represent the views of the authors and not necessarily those of the research financer.

Cover pictures:
Kabukicho, Shinjuku, Japan, Ryoji Iwata (Pixabay)
Milan, Igor Saveliev (Pixabay)
New York, hnelson57 (Pixabay)
Paris, 12019 (Pixabay)

Download the report
http://newclimate.org/publications/

http://www.c40.org/research

PROJECT PARTNERS

NewClimate Institute for Climate Policy and Global Sustainability (NCI)

NCI generates ideas on climate change and drives their implementation. We raise ambition for action against climate change and support sustainable development through research, policy design and knowledge sharing.

C40 Cities Climate Leadership Group (C40)

C40 connects more than 90 of the world's greatest cities, representing 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.

This project was funded by:

Bloomberg Philanthropies

Contacts for this report

Thomas Day, NewClimate Institute, t.day@newclimate.org

Cristina Mendonça, C40 Cities Climate Leadership Group, research@c40.org

>>>>>>>>>>>>>>>>>>>>>>>>>

PROJECT PARTNERS AND ASSOCIATED WORK

The Opportunity 2030 project is not isolated but builds upon and contributes towards other related activities from the partner organisations.

NewClimate Institute currently works directly with national and subnational governments of several developing countries to support the assessment of the wider impacts of climate relevant actions, and to integrate these wider considerations into their sector-level and climate change planning.

The Ambition to Action project[1] supports the governments of Kenya, Argentina, Thailand and Indonesia with the assessment of the impacts of low carbon energy sector pathways, whilst the Capacity Building for Climate Change project includes impact analysis as a component in support packages for the further development of climate policy in Georgia and Mongolia, including at the national and subnational level.

C40 Cities Climate Leadership Group (C40) operates a dedicated Inclusive Climate Action Research Programme to build the evidence base for the benefits of inclusive climate actions. It supports C40 member cities to implement climate actions that are equitable and fully accessible to the city's population in all its territory, thereby delivering the maximum potential emission and risk reductions while maximising its wider benefits. The research program has three areas:

- Coordination, standardisation and mobilisation of global efforts on benefits research: the programme aims to establish a common set of principles, taxonomy and pathways for relating climate action to other key urban priorities like equity, health and prosperity[2].
- Measuring city benefits: determining the impacts and benefits of actions in specific cities to equip cities with the data they need to establish a case for action[3].
- Communicating the case for action: supporting cities to use the evidence effectively to secure political and financial support

The Coalition for Urban Transitions[4], is a major international initiative which supports national decision-makers to unlock the power of cities for enhanced national economic, social, and environmental performance, including reducing the risk of climate change. The Coalition is hosted by the World Resources Institute (WRI) Ross Center for Sustainable Cities and jointly managed by C40 Cities Climate Leadership Group and WRI, and is a special initiative of New Climate Economy (NCE). The Opportunity 2030 project builds on the Coalition's efforts to demonstrate the economic case for ambitious climate mitigation in cities, and thereby galvanise action by national governments.

[1] Further information on the Ambition to Action project is available at http://ambitiontoaction.net/
[2] See further information on the C40 & Ramboll research report (RAMBOLL & C40, 2018).
[3] See further information on the C40 benefits work at http://www.c40.org/benefits
[4] See further information on the Coalition for Urban Transitions at http://www.coalitionforurbantransitions.org/home/about

TABLE OF CONTENTS

EXECUTIVE SUMMARY

A fundamental challenge for establishing the case for climate action in cities is the lack of suitable knowledge, evidence and calculation tools to understand the wider benefits of climate action and the interlinkages between other urban agendas, including other social and economic priorities such as poverty alleviation. This report presents analysis on the impacts of climate action through energy efficiency retrofit in residential buildings, enhanced bus networks and services, and district-scale renewable energy in major global regions, based on the development and utilisation of new impact assessment methodology tools; a summary of the analysis results is presented in Table 1.

Evidence from this research demonstrates socioeconomic and health-related benefits of climate actions, broadening current definitions of societal well-being for decision- and policymakers.

Table 1. Summary of key impacts of enhanced action for climate change mitigation measures in cities.

MEASURE	CLIMATE AND DEVELOPMENT IMPACTS
Energy efficiency retrofit of residential buildings in the European Union and North America (section 4) Under an enhanced building retrofit scenario, policy measures would be implemented to push for building renovations that would take final energy demand to the level of new efficient buildings, consuming no more than 22 kWh/m²/yr for spatial heating and cooling. Under this scenario, the retrofit rate increases from the present 1.4% to 3% per year, resulting in efficiency improvements of 64% in the European Union and of 55% in North America.	Deeper retrofit results in a far greater volume of job creation, including local jobs for unskilled, skilled and professionals. Depending on the financing structure and the duration of the payback period, the eventual annual cost savings can be great enough to effectively increase the annual savings rate of households by significant volumes. Specific impacts include: • Reduction of annual GHG emissions by over 120 $MtCO_2e$ in the European Union and 80 $MtCO_2e$ in North America, by 2030. • Creation of over 1 million jobs sustained over the period 2015-2030 in urban areas of the European Union, and approximately 1.3 million in North America, equivalent to approximately 4% of unemployed persons in the European Union, and 12% in the United States in 2017. The enhanced action scenario will increase the demand for skilled and professional workers, driving incentives for improved education and staff training opportunities. • The average annual energy demand for spatial heating and cooling of all households in the regions may be 25-29% lower in 2030 (compared to a 2% reduction under the reference scenario). • Households could effectively increase their annual household savings by approximately 60% in the European Union and 10% in North America by 2030. The significant difference between the regions is owing to the considerably lower prices of energy in North America. • Disposable income of a European household in the lowest income quintile could increase by 4.9%, while a North American household in the lowest income quintile could increase its disposable income by 3.1%.
Enhanced bus networks and bus services in North America and Latin America (section 5) Under an enhanced bus networks scenario, bus network lengths and service frequency are increased up to 2030 by 100% in Latin America and 300% in North America, the proportion of bus routes that operate on dedicated lanes is increased to 22-24%, and the share of low- and zero-carbon bus technologies reaches a 100% share of the bus vehicle stock by 2030.	Projected developments in the transport sector in North America and Latin America may cause premature mortality associated with air pollution to increase to over 250,000 annual deaths in cities across the two regions, whilst road traffic fatalities in these cities will also increase to over 180,000 per year. Action for enhanced bus networks and services would lead to a significant shift: • The reduction of vehicle traffic in cities will cause a reduction in annual GHG emissions in 2030 by approximately 80 $MtCO_2e$ in North America and 40 $MtCO_2e$ in Latin America. • The share of private light duty vehicles (LDV) in the urban transport mix may reduce by 22% in North America and by 35% in Latin America, compared to the reference scenario. • The reduction of vehicle emissions in cities will also cause a reduction in exposures to excessive ambient air pollution, leading to the prevention of over 6,000 premature deaths per year in North America and over 30,000 premature deaths per year in Latin America, compared to the reference scenario. • The reduction of traffic volumes will reduce the frequency of road traffic accidents, leading to the prevention of over 6,000 fatalities per year in North America and over 50,000 fatalities per year in Latin America, compared to the reference scenario. • The introduction of dedicated private bus lanes could reduce the commute times of the average public transport user by 9-10%, equivalent to a total potential annual time saving of 1.8 billion hours for commuters in North America and 7.5 billion hours for commuters in Latin America.
District heating and cooling in China and Africa (section 6) An *enhanced action scenario* for district heating in China could see the district heating network further expanded and transitioned to more waste heat recovery, renewable energy and CHP. The prospects for the penetration of district cooling in Africa and China remain highly uncertain. The use of renewable energy powered district cooling systems could supply a moderate portion of urban cooling demand in 2030.	Investments in district-scale renewable energy systems can create jobs for local workers and may result in significant improvements in air quality and prevention of related premature mortality. Impacts for energy security from fossil fuel imports depend entirely on the energy sources of the specific country, but can result in major economic gain for countries with high fossil fuel imports for their energy sectors. For district heating in China: • The reduction in combustion of fossil fuels for heat in cities will cause a reduction in GHG emissions of approximately 600 $MtCO_2e$ in 2030. • Exposures to excessive ambient air pollution will also be reduced, leading to the prevention of over 100,000 premature deaths per year in 2030, compared to the reference scenario. • Further expansion of district heating generation capacity and pipeline installation will employ more than 715,000 more people in 2030, than those working in the sector in 2014. This is more than 235,000 additional jobs in 2030 compared to the reference scenario. For district cooling in China and Africa: • The reduction of electricity consumption may reduce emissions by over 200 $MtCO_2e$ and by 21-42 $MtCO_2e$ in Africa, in 2030. • The reduction of air pollutant emissions may lead to the prevention of 15,000 premature deaths per year China and 11,000-21,000 premature deaths per year in Africa, compared to the reference scenario. • Installation and maintenance of pipelines for district heating could lead to an estimated 150,000 jobs in China, and 41,000-82,000 jobs in Africa, in 2030.

EVIDENCE FROM THIS RESEARCH DEMONSTRATES SOCIOECONOMIC AND HEALTH-RELATED BENEFITS OF CLIMATE ACTIONS, BROADENING CURRENT DEFINITIONS OF SOCIETAL WELL-BEING FOR DECISION- AND POLICYMAKERS.

The actions assessed in this report, if implementation is carefully planned, can be a particularly pro-poor measures:

- For **residential building retrofit**, the scale of potential job creation in the European Union and North America is equivalent to 4-12% of the unemployed populations in these regions. Reduced energy expenditures can boost household disposable incomes of the lowest income quintile in North America by a rate that is six times greater than the impact for the highest income quintile. For lower-income households who spend a highly significant portion of their income on energy bills, energy efficiency retrofits have the potential to alleviate not only energy poverty but also general economic poverty.
- Measures for **enhanced bus networks** and services could result in especially improved mobility and accessibility to city services for lower-income groups, whose potential travel demand may have been curtailed in the past due to lack of access to public transport and inability to afford private transportation.
- Enhancements in ambient air pollution and energy security through ***renewable based district heating and cooling*** can also have proportionally larger benefits for lower income groups: low income households usually have the greatest vulnerability to air pollution and sick-building syndrome, whilst improved equity in reliable and affordable heating and cooling in urban areas is especially likely to benefits low-income households, where service quality is usually most in need of improvement.

The findings from this report present an evidence base for accelerated action for climate change mitigation measures. It equips city, national governments, private sector and citizens with several reasons for a joint collaborative effort toward the goals of low carbon development.

This report will be followed-up by an extended work, complementing this first analysis to include assessments at the global scale. The results of this second phase of the work will be made available by the end of the third quarter of 2018, including through an online interactive dashboard.

All methodological details, assumptions and limitations of the Opportunity 2030 project analysis are published in an accompanying methodological report, available online. Readers are encouraged to engage in, critically review and further build upon the methodologies and results in this report, and to make use of the content where possible as a tool for moving towards more holistic and participatory planning for sustainable development in cities.

01

STRATEGIC OBJECTIVES OF THE OPPORTUNITY 2030 PROJECT

The objectives of the 2015 Paris Agreement to limit global temperature increase to well below 2 °C, pursue efforts towards 1.5 °C, and to decarbonise the global economy in the second half of the century, will require a paradigm shift and a shifting of the trillions to infrastructure and investments for a low carbon economy. *Deadline 2020* (ARUP & C40 Cities 2016) demonstrated that immediate action in cities is critical for achieving the goals of the Paris Agreement and ensuring a climate safe future.

Despite these evidences and urgency for action, *Unlocking City Action* (C40, 2015) indicates that cities face significant barriers for **establishing a robust case** for climate action, ensuring that a plan/policy is well designed and will have positive outcomes, and ensuring that this can be verified and demonstrated.

A fundamental challenge for establishing the case is the lack of suitable knowledge, evidence and calculation tools to understand the wider benefits of climate action and the interlinkages between other urban agendas, including other social and economic priorities such as poverty alleviation. Even when the case is established, another major barrier persists which is **making the case**, ensuring the buy-in of the necessary urban and national stakeholders, being able to communicate these benefits in a way that reaches citizens and all other stakeholders. The purpose of this project is to directly address some of the key barriers for the integration of wider impacts and benefits into sector-level planning in cities, by clearly identifying the links between the climate agenda and various development agendas, demonstrating the scale of significance through the quantitative assessment of various measures in several regions, and further developing the methodologies for the evaluation of these impacts, expanding it for the global level and making the results accessible to the general public.

This report presents the first phase of this project to change the way city stakeholders relate to climate action, by **establishing the case** for action, providing the evidence on how climate action is interrelated with and delivers outcomes for health, prosperity and other development agendas. Analysis on the impacts of climate action through **energy efficiency retrofit in residential buildings, enhanced bus networks, and district-scale renewable energy** in major global regions, based on the development and utilisation of new impact assessment methodology tools, are presented in the chapters of this report. These three impacts were selected as they provide the biggest opportunities for cities to accelerate the reduction of their carbon emissions in the short term up to 2020 based on C40 Research (ARUP & C40 Cities 2016 and McKinsey & C40, 2017).

Readers are encouraged to engage in, criticise and further build upon the methodologies and results in this report, and to make use of the content where possible as a tool for moving towards more holistic and participatory planning for sustainable development in cities.

This report will be followed-up by an extended work, complementing this first analysis to include assessments at the global scale. The results of this second phase of the work will be made available by the end of the third quarter of 2018, via an online interactive dashboard and will also be accompanied by a concise thought leadership report summary for policy makers and the general public. The completion of this phase will contribute to **making the case** for climate action. It makes these impacts and benefits, and the tools for their evaluation, more understandable and accessible to city-level and national decision makers, civil society organisations, researchers, individuals and all urban stakeholders.

A FUNDAMENTAL CHALLENGE FOR ESTABLISHING THE CASE IS THE LACK OF SUITABLE KNOWLEDGE, EVIDENCE AND CALCULATION TOOLS TO UNDERSTAND THE WIDER BENEFITS OF CLIMATE ACTION AND THE INTERLINKAGES BETWEEN OTHER URBAN AGENDAS.

>>>>>>>>>>>>>>>>>>>>>>>>>

02

CLIMATE CHANGE ACTION IN CITIES AND THE ROLE OF IMPACT ANALYSIS FOR PLANNING

>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

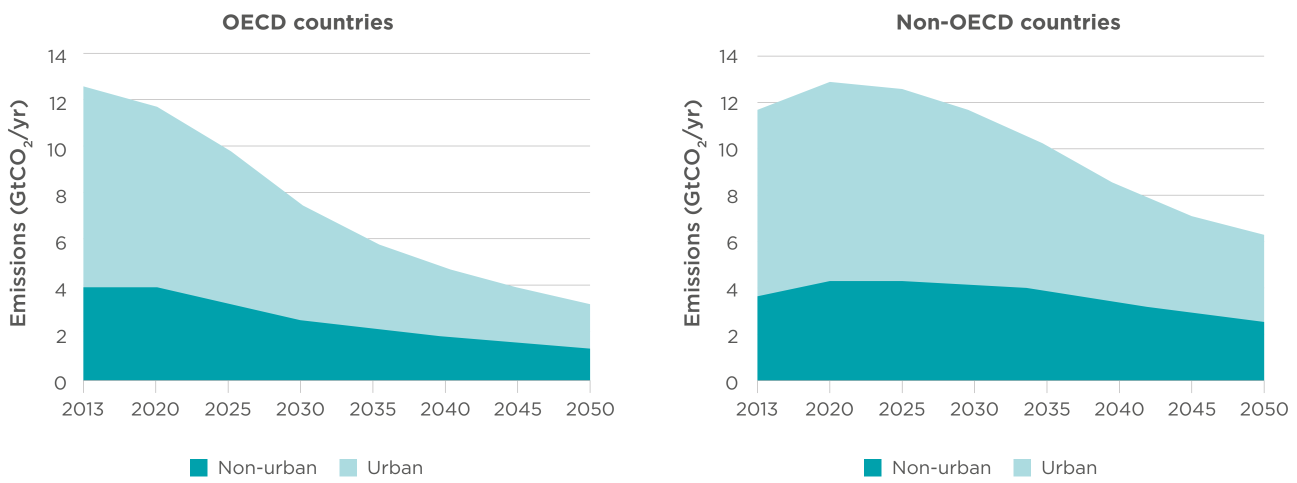
2.1 IMPORTANCE OF CITIES IN DELIVERING A CLIMATE SAFE FUTURE

In the global effort to reduce emissions and contain the threat of global warming, it is on the local scale that a great deal of action will need to happen; subnational governance will play a pivotal role in implementing measures on the ground that help to reduce emissions in cities (van Staden & Musco 2010), where more than half of the world's population currently live (UNDESA 2014).

In this context, the urgency and scale of actions within urban areas are crucial to deliver the ambition of the Paris Agreement ((ARUP & C40 Cities 2016). The role of cities in mitigating and adapting to climate change is expected to become ever more important, as the world's population living in urban areas is expected to rise by 2.5 billion people by 2050—nearly equal to the expected total population growth worldwide by 2050 (UN 2015)—and because the GDP of cities is projected to rise even faster (ARUP & C40 Cities 2016). While it is uncertain exactly how much of global greenhouse gas emissions can be attributed to cities, estimates of as high as 80% are to be found in literature (Hoornweg et al. 2011). Typically, the correlation between a country's level of urbanisation and its emissions of GHGs is positive; and many cities have per-capita emission intensities that far exceed that of the country as a whole, or, indeed, of other countries/regions that are among the world's largest per-capita emitters, such as the USA and the EU (Hoornweg et al. 2011; Kennedy et al. 2009).

Scenarios of limiting global temperature rise to 2°C, such as the IEA's Energy Technology Perspectives (ETP), foresee a stronger role for cities in reducing energy related emissions in the coming decades than for non-urban areas. As Figure 1 exemplifies, this is the case for both developed and developing regions[5] (IEA 2016b). Globally, the reductions necessary by 2050 (compared to 2013 levels) amount to more than 60% for urban areas, and around 40% for non-urban areas. For urban areas in developed countries, this level would have to be almost 80%, as compared to roughly 50% in developing countries.

Figure 1. Energy-related emissions (both from direct energy use and electricity generation) in the 2016 IEA ETP 2°C scenario, by urban/non-urban and OECD/non-OECD (IEA 2016b).

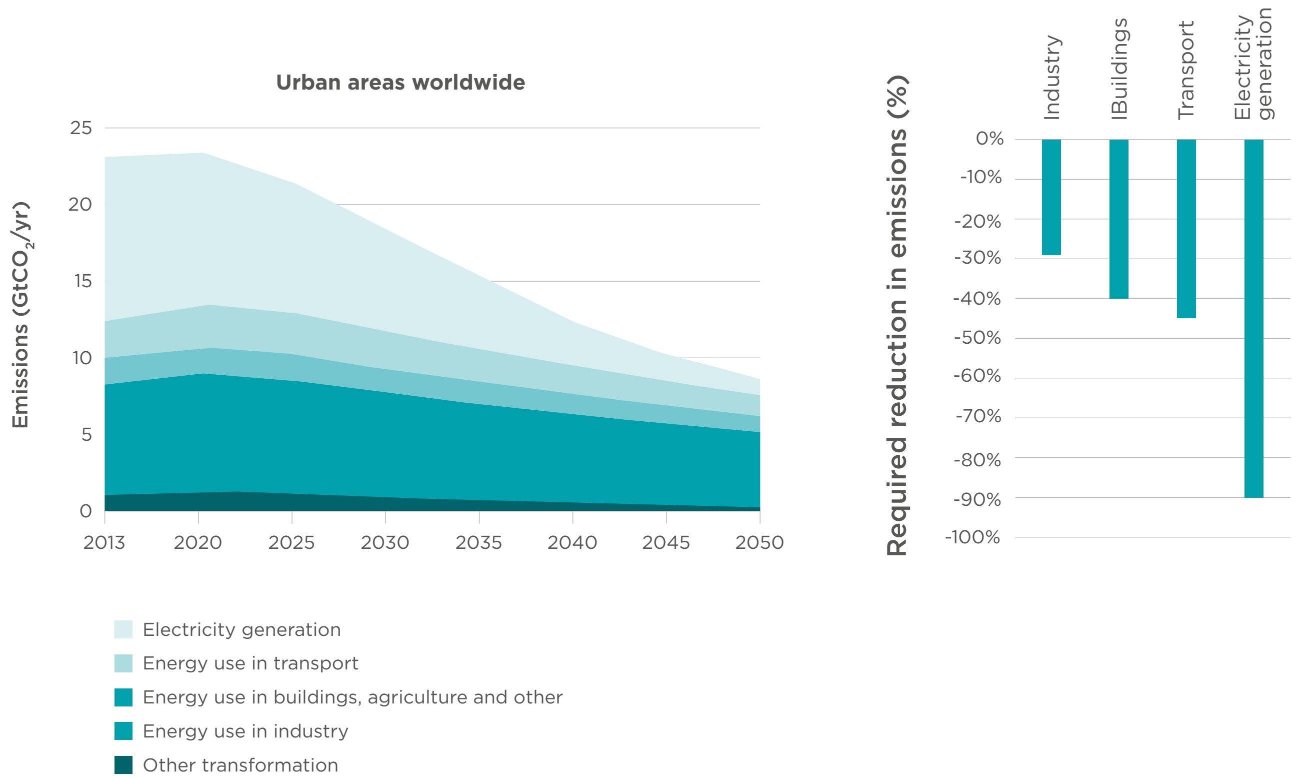


These reductions in energy-related emissions will need to be distributed across various emission sources. The ETP implies that the largest potential, and the highest need for fast mitigation, is in the power sector, with up to 90% reduction of emissions required by 2050. This could be addressed through a combination of energy efficiency measures and renewable energy generation in rural and urban areas.

But other types of energy use, which may have very different patterns in urban as compared to non-urban areas, will need to reduce emissions by up to 30%-50% as well, as Figure 2 demonstrates. This means that strong shifts in energy use patterns in buildings, transport and industry in urban areas worldwide will need to happen to enable fast transitions to pathways that achieve such cuts in emissions.

[5] Here represented by OECD and non-OECD countries, respectively.

Figure 2. Required reductions of emissions from electricity generation and various types of end-uses in urban areas worldwide in the 2°C scenario of (IEA 2016b). (Left): Emissions under the ETP's 2°C scenario in urban areas worldwide. (Right) The required reductions in emissions by 2050 compared to 2013 levels in this scenario for four categories.



Ambitious mitigation outcomes are dependent on the implementation of various measures including a shift to cleaner fuels in direct thermal combustion (e.g. for heating in buildings through a shift to district-level energy supply and renewable energy technologies), a drive for electrification in all energy end-use sectors along with decarbonisation of power production, the implementation of measures to increase efficiency and reduce energetic losses (e.g. renovation of buildings; implementation of energy codes for new buildings; efficiency improvement drives in industry; circular economy measures to reduce waste, increase recycling, and decrease demand for high-carbon products), and the implementation of incentives or policies to optimise activity levels of high emission activities (e.g. improved transport demand management and a shift to public transport to limit the number of kilometres driven; or replacements of emission-intensive materials, such as steel or cement, with alternatives).

The results above are based on a 2°C trajectory, as corresponding 1.5°C trajectories are currently not available[6]. The *Deadline 2020* report from ARUP and C40, estimate that per-capita emissions in the C40 cities[7] would have to drop from 5 tCO_2e per capita in 2015, to around 2.9 tCO_2e per capita by 2030, and to carbon neutrality by 2050 (ARUP & C40 Cities 2016). This is, for example, roughly equivalent to the current per-capita emissions of the average inhabitant of Peru or Indonesia (Climate Action Tracker 2016). The *Deadline 2020* report (ARUP & C40 Cities 2016) presents detailed differentiated pathways towards reaching the necessary reductions based on cities' current per-capita GDP and emission levels.

[6] The ETP 2017 has a 1.75°C scenario, but this does not include an urban/non-urban split.
[7] The report covered 84 C40 Cities.

>>>>>>>>>>>>>>>>>>>>>>>>>>>

2.2 ACTION FOR CLIMATE, HEALTH AND PROSPERITY

It is sometimes perceived that the pursuance of climate change mitigation action represents a burden which may conflict with the development agenda. These concerns are often drawn from the observation that greenhouse gas (GHG) emissions were historically coupled to economic development. However, recent trends have proven that further economic development did not depend on increasing GHG emissions: global trends for GHG emissions and GDP growth were decoupled from one another in 2015 (Olivier et al. 2016) and 2016 (IEA 2016a).

The misconception that the climate agenda represents a burden to the development agenda may also arise from the understanding that resources which are spent on measures for climate action entail significant opportunity costs, in that they are not available for other uses. This perception derives largely from the fragmentation of sustainable development issues; climate change planning, in particular, is often a process which is fragmented from planning for other development objectives at the national and subnational level. Measures for the decarbonisation of the economy are often planned and assessed in isolation, in climate- and environment-related policy silos, where decarbonisation is the major objective and the comparative direct capital costs of measures is the primary assessment criteria. Mitigation options may be prioritised in these silos for perceived cost-effectiveness, with attempts to integrate these concepts into sector strategy at a later stage. When significant developments are observed in climate change policy, often these are not driven by the climate change planning, but by various aspects the city-level and national development agendas which happen to have synergies with climate change mitigation outcomes. These planning and policy making processes can be made more efficient it there is a greater understanding of the synergies: integrated development approaches, which simultaneously advance multiple benefits across the three dimensions of sustainable development (social, environmental and economic)(PAGE 2016), can ensure that resources are invested efficiently in ways that maximise the synergies between various development priorities, of which climate change mitigation is one.

Table 2 demonstrates some of the synergies between three important measures for climate action that are analysed in this report, and a selection of the Sustainable Development Goals (SDGs). This offers only an introductory insight: the potential synergies between climate change mitigation and adaptation and other development objectives at the city level are numerous, and dependent on local context. Through these synergies, the climate change mitigation and adaptation agenda is increasingly being seen as an opportunity for cities and national governments, rather than a burden, in many sectors. It is increasingly understood that climate change action can also be action for health and prosperity. Decarbonisation of the energy supply sector and measures to improve energy efficiency can create opportunities for scores of local jobs, and for the development of new local industries, whilst the link to climate change mitigation outcomes may enhance access to international technical and financial assistance to support these developments. Many investments in low carbon technologies and infrastructure may create opportunities for highly specialised industries and workers, meaning that significant portions of these opportunities are subject to first-mover advantages, incentivising a race to the top approach to embarking on the low carbon transition.

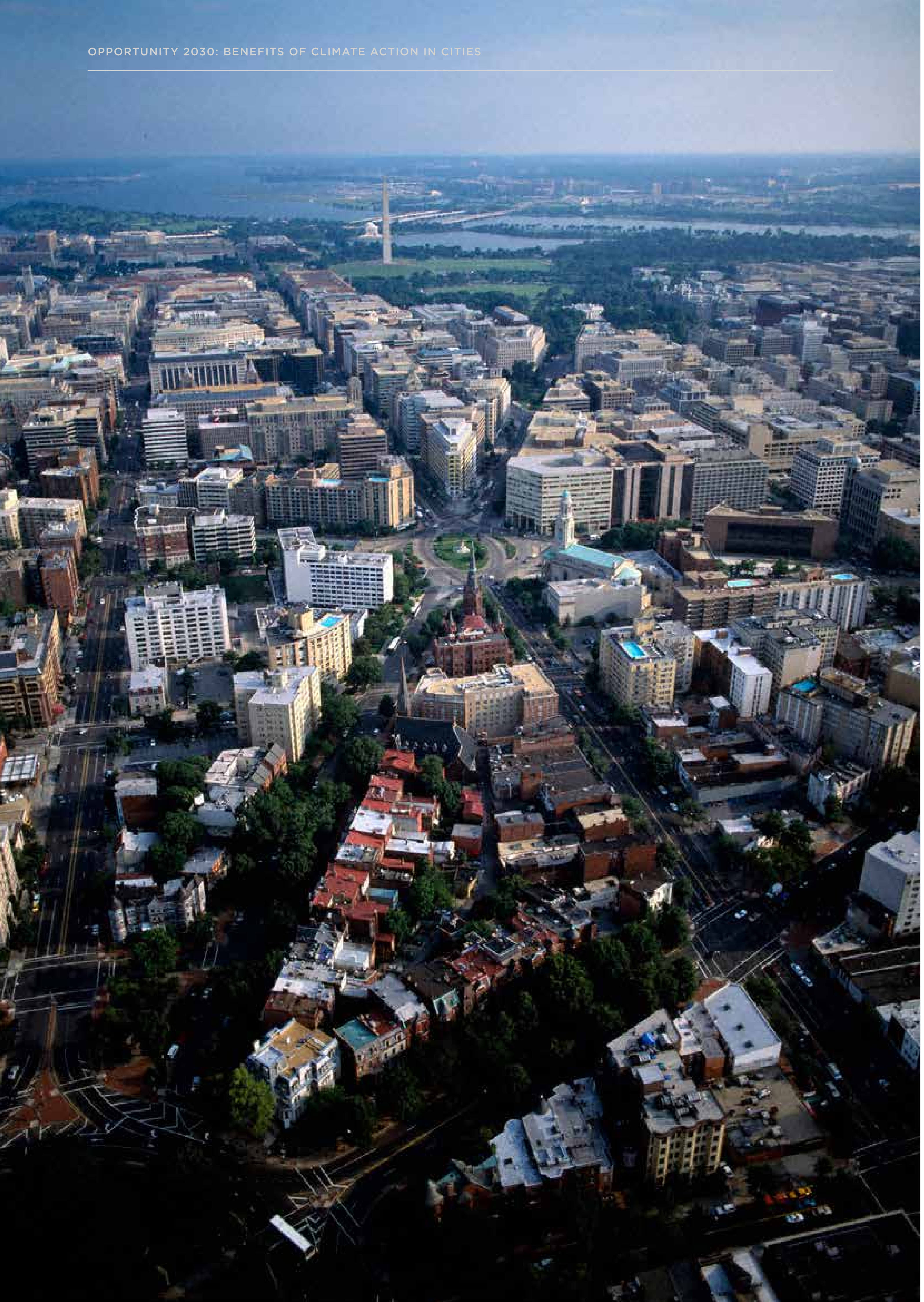
A deep understanding of how climate actions are linked with the SDGs, which is a fundamental step to establish the case for climate action, has been at the core of a recent global research effort led by C40 and Ramboll. The development of an Urban Climate Action Impacts Framework, supported by 15 C40 member cities and experts from sixteen NGOs, international governmental organisations, consultancies, and think tank organisations that are promoting sustainable and resilient urban development, illustrates how urban life is highly interconnected, where the environment, society and economy all impact each other (both positively and negatively) in complex dynamics (RAMBOLL & C40, 2018).

IT IS INCREASINGLY UNDERSTOOD THAT CLIMATE CHANGE ACTION CAN ALSO BE ACTION FOR HEALTH AND PROSPERITY.

Table 2. Demonstration of some selected synergies between climate and development agendas[8].

SUSTAINABLE DEVELOPMENT GOALS (SDGs)	TYPICAL MEASURES FOR CLIMATE CHANGE ACTION AND LINKAGES TO SDGs		
	ENERGY SUPPLY (renewable and decentralised technologies)	ENERGY EFFICIENCY (e.g. in buildings and industry)	TRANSPORT (modal shift to public transport)
1. NO POVERTY	▲ Energy access boosts productivity & participation	▲ Reduce household energy bills	▲ Accessibility and mobility for poorer communities
3. GOOD HEALTH AND WELL-BEING	▲ Reduce air pollution and health risks	▲ Reduce indoor air pollution and sick building syndrome	▲ Reduce air pollution and health risks; potential physical activity benefits
4. QUALITY EDUCATION	▲ Enhance conditions for learning	▲ Enhance conditions for learning	▲ Enhance access to educational institutions
5. GENDER EQUALITY	▲ Successful introduction of programmes for reducing emissions depends on empowerment and participation of women in the household		▲ Increased accessibility for marginalised groups and people
7. AFFORDABLE AND CLEAN ENERGY	▲▼ Energy security (affordability depends on policy options)	▲ Reduce energy consumption and bills	
8. DECENT WORK AND ECONOMIC GROWTH	▲▼ Creation of decent jobs and new industries (Depends on policy options to avoid adverse outcomes of job losses in older industries)		
9. INDUSTRY, INNOVATION AND INFRASTRUCTURE	▲ Catalyse local enterprise and industries	▲ Improve efficiency and competitiveness of industry	▲ Develop long-term, sustainable infrastructure
10. REDUCED INEQUALITIES	▲ Decentralised energy favours access for marginalised communities	▲ Energy expenditure burden is greater for lower income groups	▲▼ Lower income groups most disadvantaged for mobility (depends on policies to prevent gentrification)
11. SUSTAINABLE CITIES AND COMMUNITIES	▲ Technology suitable for long-term needs of cities and inhabitants	▲ Investments extend useable lifetime of built environment	▲ Infrastructure suitable for long-term needs of cities and inhabitants
13. CLIMATE ACTION	▲ Decarbonise cities; improve resilience to natural hazards	▲ Decarbonise cities; improve resilience to extreme weather	▲ Decarbonise cities

[8] For additional information on how climate actions are linked with the SDGs, please refer to the Urban Climate Action Impacts Framework (RAMBOLL & C40, 2018)



2.3 ROLE AND STATUS OF SOCIO-ECONOMIC IMPACT AND BENEFIT ANALYSIS FOR CITIES

Cities face a great challenge in establishing and making the case for climate action, in the face of other development priorities. Whilst the direct upfront capital costs of climate change mitigation and adaptation in cities are increasingly well understood in developed and developing country regions alike, decision making and investment planning is hindered by enormous uncertainty in the indirect costs and the positive impacts of these measures, as well as for alternative pathways.

These *indirect costs* and *positive impacts* of climate change mitigation measures, which are often termed the *co-benefits*, *co-costs*, or *broader impacts* of climate change action, have become a highly important area of investigation for city level and national governments, and for the international research community, in recent years. It is increasingly recognised that there are highly significant linkages between options for sustainable infrastructure development and other national and subnational objectives, including for various Sustainable Development Goals (SDGs), such as for health outcomes, welfare, economic growth, poverty alleviation and equity indicators, amongst others, as described in section 2.2.

An appreciation of the wider impacts of measures for sustainable and low-carbon infrastructure can better inform integrated planning for sustainable development in cities, in which pathways for specific sectors may be planned to maximise the synergies between different development priorities, rather than looking at upfront capital costs in isolation. Developments in the understanding of these impacts are leading, in some cases, to an observable paradigm shift from 'effort sharing' to an increasing degree of 'opportunity sharing' (IASS 2017).

Several cities are known to have adopted climate friendly solutions upon thorough assessment of the broader impacts: policy choice for transportation in London is supported by comprehensive data on transportation and its impacts on local air pollution (Mayor of London 2017a), whilst the Clean Heat Programme in New York City was also driven by concerns over the impacts of air pollution (NYC City Government 2016). Mexico City has issued green bonds to finance climate action, driven by health and economic incentives (Global Opportunity Explorer 2017).

Despite several positive examples, such impacts often do not enter quantitative decision-support frameworks in cities (Dubash et al. 2014), although many attempts to quantify the externalities indicate that the scale of their significance should be compelling; Anil et al. (2016) estimated that the economic impacts of sustainable infrastructure investments in the energy sector may be 15 times greater than the capital costs of the technology deployment, whilst Sudmant et al. (2016) found that actions for a transition to a low carbon economy in cities could bring direct economic benefits in the order of USD 16.6 trillion by 2050. It has been demonstrated that the incorporation of co-impacts can significantly change the outcome of economic assessments for decision making (Dubash et al. 2014).

Several significant barriers often persist to prevent the appropriate consideration of wider impacts and co-benefits for integrated sustainable development planning in cities: the inter-linkages between options for sector pathways and their impacts on other sectors and objectives may not have been identified or well understood; in the case that there is an awareness of these inter-linkages, the scale of significance of potential impacts may be unknown; even in the case that inter-linkages and their significance are generally appreciated, methodological means for their assessment and integration in decision making processes are lacking.

City-level and national governments could benefit from further research and development of knowledge on the wider impacts of climate change actions in cities, as well as simplified and transparent methods for assessing these impacts (Dubash et al. 2014). Better information can impact the perceived costs and risks for private- and public-sector decision makers, whilst civil society organisations (CSOs) could also benefit from more robust and widely reviewed methodologies to bring more credibility to their arguments.

Whilst there is a clear and important role for impact and benefit analysis of potential low carbon measures for urban planners and city-level decision makers, such analysis can also assist the international research and decision-making community in determining the role for non-state and subnational actors in the global climate change mitigation effort. To date, national action remains the primary focus of the research community and the international negotiations, although there is an increasing volume of evidence that subnational and non-state action may have highly significant potential for climate change mitigation ambition raising, and that many of the opportunities associated with such actions may also be more tangible and relevant for subnational actors.

Enhanced understanding on the opportunities for cities and their role in the global mitigation effort may also have important implications for the volume of climate and development finance available to subnational actors.

03

APPROACH OF THIS ANALYSIS

3.1 SCOPE OF REPORT

The authors of this report have built on the available literature to develop methodologies for the quantitative assessment of several impacts, for three potential measures for climate change action in cities. The following sections (sections 4, 5 and 7) include an overview of these three measures, looking at the importance of the measures in cities for climate change action, the various potential impacts, and the results of the quantitative analysis for two or three benefits per measure. The impact quantification assessment for each measure is conducted for cities in two relevant regions.

Table 3 provides an overview of the measures, impacts and regions included within this report. In addition to these specific impacts, the GHG emission potential reduction for each measure was also assessed.

Table 3. Overview of analysis scope.

MEASURE	CITY-LEVEL SPECIFIC IMPACTS ASSESSED	REGIONS
Energy efficiency retrofit of residential buildings (section 4) The implementation of measures to improve the structural thermal energy performance of urban residential building structures, to reduce energy demand for spatial heating and cooling.	**Job creation,** focusing on the net direct and indirect impacts in the construction sector, the construction material supply chain, the energy supply sector and induced impacts (section 4.5.2). **Household cost savings and wealth indicators,** focusing on reduced energy expenditure in relation to annual disposable income and savings rates for different income quintiles (section 4.5.3).	European Union; North America
Enhanced bus networks (section 5) Incentivising the use of public transport through enhancements to the length of the bus network, the frequency of bus services, the usage of dedicated bus lanes / bus rapid transit (BRT), and the uptake of zero carbon technologies.	**Outdoor air pollution and health impacts,** focusing on all cause premature mortality from excessive exposure to air pollutants (section 5.5.1). **Road traffic accident fatalities,** focusing on fatalities caused by volumes of vehicle traffic on public roadways (section 5.5.2). **Available personal time,** measured through potential commuter time savings, focusing on the potential for savings from the segregation of bus lanes from public roadways (section 5.5.3).	North America; Latin America
District heating and cooling (section 6)	**Job creation,** focusing on the net direct impacts in the construction sector and the energy supply sector (section 6.5.1). **Outdoor air pollution and health impacts,** focusing on all cause premature mortality from excessive exposure to fine particulate matter (section 6.5.2) **Enhanced energy security,** focusing on reduced reliance on fossil fuel imports (section 6.5.3).	China; Africa

These measures, impacts and regions were selected for analysis based upon insights from C40 research (ARUP & C40 Cities 2016) on the most relevant and high impact issues for decision makers in the short term up to 2020, as well as feasibility of the quantitative analysis. Measures are also aligned with another recent research that analyses the biggest opportunities for cities to accelerate the reduction of their carbon emissions (McKinsey & C40 Cities 2017).

3.2 METHODOLOGICAL APPROACH

This section contains a brief description of the methodological approach used for the analysis. Annex I includes a flow chart summary of the methodological steps for the quantitative assessment of these impacts, whilst full details are included in the separate technical methodological document.

Development of calculation tools

The analysis for the impacts of three measures was conducted through the development of new bottom-up quantitative calculation tools, built on the available literature. These tools were developed specifically for this research report, building upon previous work from the project team and the wider literature where possible.

Links between various actions (policy stimuli) and eventual outcomes and impacts were mapped, with scientific literature consulted for methods to assess the various cause-effect relationships between the various steps mapped between the stimuli and the outcome.

Since several of the topics addressed in this research are new and not broadly covered in the literature to date, some assumptions have been required to navigate highly complex issues and overcome the lack of available data.

The full methodologies employed for these tools are transparently documented in the technical methodology document, including all assumptions and simplifications, so that they can be criticised, built upon and their use replicated by researchers and decision makers alike. It is hoped that future research can build on this further, improving the calculation tools and making them suitable for open access publication.

Scenarios analysed

The analysis of impacts in this report looks at the aggregated impacts of actions for cities in regions. For example, in an analysis of the impacts of energy efficiency retrofit in North America, it is assumed that the measures are implemented in all urban areas of the region, with the results aggregated at the regional level. Aggregated results are also scaled to the average 1-million population city, and for the C40 network cities in the region.

The analysis focuses on two distinct scenarios for each measure for climate action:

- Firstly, a *reference scenario*, was constructed to project what may happen in cities in the case that current policies and trends persist and are not advanced upon. The definition of this scenario is variable between the sectors analysed in this report, depending on the sources used for inputs for the various measures: input parameters may be drawn from studies and databases that describe *current policy* scenarios, *reference cases*, or *business as usual* scenarios, and the specific definitions of these scenarios across different studies may vary to some extent.
- Secondly, an *enhanced action scenario* (EAS) was constructed based on actions that are assumed to be compatible with the fulfilment of the objectives of the Paris Agreement, to limit global temperature increase to well below 2 °C. In the case that studies or datasets identifying explicit 2 °C and 1.5 °C pathways were not available for specific measures, scenarios were identified which were understood to represent general high ambition and/or Paris Agreement compatibility, whilst also being realistic. In the case that the gap in the literature does not allow for the identification of such scenarios, multiple illustrative scenarios are indicated along with their emissions implications. Further details are found in the methodological technical note.

04

ENERGY EFFICIENCY RETROFIT FOR RESIDENTIAL BUILDINGS

>>>>>>>>>>>>>>>>>>>>>>>>>

SUMMARY OF RESULTS FOR RESIDENTIAL ENERGY EFFICIENCY RETROFIT

Under a *reference scenario*, residential energy efficiency retrofits will develop marginally until 2030 in both the European Union and North America. This shallow renovation pathway represents an average rate of retrofit of approximately 1.4% for both regions, resulting in a reduction of residential energy use of 10% from efficiency improvements.

An *enhanced building retrofit scenario* (ES), where policy measures would be implemented to push for building renovations that would take final energy demand to the level of new efficient buildings, consuming no more than 22 kWh/m^2/yr for spatial heating and cooling. Under this scenario, the retrofit rate increases to 3% per year, resulting in efficiency improvements of 64% in the European Union and of 55% in North America. This would result in the reduction of annual GHG emissions by over 120 $MtCO_2e$ in the European Union and 80 $MtCO_2e$ in North America, by 2030. The potential impacts of the enhanced action scenario are estimated to be:

- Creation of over 1 million jobs sustained over the period 2015-2030 in urban areas of the European Union, and approximately 1.3 million in North America, equivalent to approximately 4% of unemployed persons in the European Union, and 12% in the United States in 2017. The enhanced action scenario will increase the demand for skilled and professional workers, driving incentives for improved education and staff training opportunities.
- The average annual energy demand for spatial heating and cooling of all households in the regions may be 25-29% lower in 2030 (compared to a 2% reduction under the reference scenario).
- Households could effectively increase their annual household savings by approximately 60% in the European Union and 10% in North America by 2030. The significant difference between the regions is owing to the considerably lower prices of energy in North America.
- Disposable income of a European household in the lowest income quintile could increase by 4.9%, while a North American household in the lowest income quintile could increase its disposable income by 3.1%.

In 2013, the total global building stock floor space was around 212 billion m^2; approximately 60% of this floor space was to be found in urban areas, of which the residential sector accounted for 75%. Projections show that the global urban building floor area is expected to double by 2050 (IEA 2016c), due to increasing rates of urbanisation, particularly in developing countries, and expected increases in average household floor area associated with increased household wealth (IEA 2016c).

Vast proportions of the global residential building stock in urban areas worldwide are characterised by extremely poor energy efficiency performance. Many buildings remain in their original state, long beyond their intended lifespans, and are unfit for purpose. This creates a major burden for building occupants through excessive expenditure on energy and poor comfort levels, amongst other grievances.

This chapter focuses on the analysis of residential energy efficiency retrofits, which for the scope of this study is defined as the implementation of measures to improve the thermal energy performance of urban residential building structures, to reduce energy demand for spatial heating and cooling. Potential measures for residential energy efficiency retrofit include, for example, weatherisation of windows and doors, wall insulation, renovation and insulation of roofing, installation of building elements to manage solar heat gains, and structural adjustments to optimise thermal flows, modern building automation and control, amongst others. These measures are not mutually exclusive and would be best implemented as a package, given the many overlaps between them. Beyond this scope, several other measures for energy in buildings could lead to significant emission reductions and further benefits, such as enhanced efficiency of lighting and appliances, as well as building integrated renewable energy generation.

>>>>>>>>>>>>>>>>>>>>>>>>>

4.1 INTRODUCING PATHWAYS AS AN EVIDENCE BASED APPROACH TO IDENTIFYING IMPACTS

Energy consumption for spatial heating and cooling in residential buildings in urban areas is projected to increase by approximately 50% by 2050 (IEA 2016c), driven by increasing rates of urbanisation. This projected trend is in stark contrast to the maturity of available technologies for the decarbonisation of the building sector, and the required progress in decarbonisation of the sector up to 2030 for a 2°C or 1.5°C compatible pathway. Improving energy efficiency in buildings entails one of the greatest untapped cost-efficient sources of mitigation potential up to 2030 (Lucon et al. 2014; UNEP 2009; EEFIG 2015). Rogelj et al. (2015) found that the targets of the Paris Agreement would require direct emissions in the building sector to be reduced by 70-90% between 2010 and 2050.

Similarly, Becqué et al. (2016) and the *Deadline 2020* report (ARUP & C40 Cities 2016) highlight that improving the energy efficiency of buildings, is one of the fastest and most cost-effective ways of reducing carbon emissions and improving local economic development, air quality, and public health. The *Deadline 2020* report finds that there is urgent need for pre-2020 action in the residential building sector, particularly through the retrofitting of the existing building stock: across the cities in the C40 network, support and incentive programmes for residential building retrofit could reduce emissions by approximately 0.7 $GtCO_2e$, making this one of the highest potential impact programmes (ARUP & C40 Cities 2016).

Energy efficiency retrofit of residential buildings is particularly relevant in countries that have already experienced high rates of urbanisation, population growth and economic development. In these countries, the majority of the future building stock has already built and is standing, with emission pathways largely dependent on improvements to these structures. In contrast, for countries currently experiencing or projected to go through rapid urban expansion, presently standing buildings may represent only a small portion of the future building stock and policies aimed at optimising new constructions may be even more relevant. Focusing on the areas of greater relevance, this chapter addresses the potential for residential building retrofit primarily in OECD country regions.

> "From Rogers Park to Trumbull Park, buildings around the City are taking part in Retrofit Chicago and showing they can work together to reduce emissions, save money and put people to work. The findings from the NewClimate Institute and C40 research support what we know to be true in Chicago: that innovative initiative like retrofitting save energy, reduce costs and improve building performance, all while driving creation of clean 21st-century jobs."
>
> **Mayor Emanuel**
> City of Chicago

>>>>>>>>>>>>>>>>>>>>>>>>>

4.2 POTENTIAL IMPACTS OF RESIDENTIAL BUILDING RETROFIT MEASURES

Improvements in the urban environment can entail a broad range of benefits for urban populations who interact with the built environment on a continuous basis. Table 4 gives an overview of some of the key potential impacts from building retrofits including considerations on equity. Both positive ("+") and negative ("–") impacts are listed.

Table 4. Overview of some potential direct and indirect impacts from residential building retrofit.

TYPE OF IMPACTS	EXAMPLES OF OUTCOMES AND SPECIFIC IMPACTS	EQUITY CONSIDERATIONS
Social impacts (Health and safety impacts)	+ Health benefits from better air quality from less fossil fuel burning and minimisation of the heat island effect + Reduced morbidity due to better lighting and mould abatement + Safety from new building tech with latest standards, minimising risk for accidents, fire or intrusion	Low income households often have greater exposure to air pollution and extreme temperature events.
Social impacts (Quality of Life and Urban Liveability, Culture and Institutions)	+ Increased ease of use and control of renovated buildings by users + Increased living comfort and well-being through ability to maintain comfortable temperatures + Direct assistance to low-income households in the case of EE programmes for social housing – Construction work can result in temporary discomfort for local residents	Lower-income groups are generally the most likely to live in uncomfortable conditions due to energy poverty, and have most to gain from improvements. Enhanced building retrofit can play a role in the alleviation of not only energy poverty but also general economic poverty in lower-income households.
Economic impacts (Individuals)	+ Reduced expenditure on fuel and electricity and reduced energy poverty + Reduced (financial) exposure to energy price fluctuations + Increased property values for buildings with high efficiency standards + Learning and productivity benefits through avoided "sick building syndrome" – Opportunity cost of large capital investments	Cost savings for reduced energy consumption result in a proportionally greater increase in household savings for lower income households, although impacts for households depends on the financing model, which depends on the policy options and ownership. Higher retrofit rates could increase the chance that lower income groups are included in retrofit activity.
Economic impacts (wider economy)	+ Creation of unskilled, skilled and professional jobs + Cost savings and enhanced energy security through reduced dependence on fossil fuels + Increased economic activity through technical innovation for energy efficient solutions and new business opportunities + Reduced spending on energy in public buildings + Reduced national healthcare spend due to enhanced health and safety – Opportunity cost of large capital investments – Reducing energy consumption may result in job losses in the energy supply sector	Measures to implement building retrofits should be implemented with sufficient considerations to maximise opportunities for local and unskilled staff to avoid adverse outcomes for lower-income groups.
Environmental impacts	+ Improved air quality (indoor and outdoor) + Reduced noise pollution + Reduced greenhouse gas emissions + Micro-ecosystem services supported through better potential for urban vegetation on walls and roofs – Cost savings from reduced energy consumption could be spent on carbon intensive activities	Low income households are often the most adversely affected by indoor and outdoor air pollution, as well as by heat waves and cold spells due to greater exposure.

Source: Authors' elaboration based on Ferreira & Almeida (2015), Ürge-Vorsatz et al. (2009), IEA (2014), Copenhagen Economics (2012) and Heffner & Campbell (2011).

>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

4.3 SCOPE OF ANALYSIS

Regions

The analysis of benefits and impacts for energy efficiency retrofit of existing residential buildings is presented in this report for cities within the **European Union** and **North America**. These regions were selected while keeping in mind that building retrofits will have much more significant impacts in cities, where the building stock has already been established and is ageing compared to cities with high rates of construction or where most of the building stock is still to be built. If inefficient building infrastructure that is already in place in Global North cities, is left in operation until the end of its average technical lifetime, it will have already "committed" significant amount of the carbon budget (Erickson & Tempest 2015). The current situation of the residential building stock in the selected regions is presented in Table 5.

While the overview in Table 5 indicates that there are considerable similarities in the residential building stocks of the European Union and North America, the regions also have distinctions. Residential units are considerably larger in North America, where the residential floor space per capita is approximately 73 m^2, compared to 43 m^2 in the European Union. Final energy demand and direct emissions from residential buildings per capita are also 52% and 45% higher in North America, respectively. These differences are owed to differences between the regions in population density and land space available; retail energy prices, which are considerably lower in North America; and behavioural trends. Nevertheless, Table 5 shows that energy poverty remains an important issue for large segments of the population in both regions.

Approximately 1-1.4% of the residential building stock in both regions is retrofitted annually, with relatively minor depths of retrofit (Ürge-Vorsatz et al. 2012). Policies to require a more advanced retrofit rate do not exist for residential buildings in either region, although the European Union's 2010 Energy Performance of Buildings Directive (EPBD) and 2012 Energy Efficiency Directive (EED) require member states to up the rate of retrofit for public buildings to 3% and to prepare national renovation strategies for the entire building stock beyond 2020.

Table 5. Current situation of the existing residential building stock in the EU and North America.

	EUROPEAN UNION[9]	NORTH AMERICA[9]
Floor space (residential buildings)	22 billion m^2 in 2013, 75% in urban areas (European Commission, 2016)	26.5 billion m^2 in 2013, 83% in urban areas (IEA, 2013)
Final energy demand (residential buildings)	3,384 TWh in 2013 (IEA 2016b): 68% spatial heating, <1% cooling (European Commission 2016).	3,600 TWh in 2013 (IEA 2016b): 46% spatial heating, 8% cooling
Average annual specific consumption	153 kWh/m^2 in 2013 (European Commission 2016).	135 kWh/m^2 in 2013 (IEA 2016b).
Energy related emissions of residential buildings	Direct emissions of 373 $MtCO_2e$ in 2014 (IEA/OECD 2017), 78% of which for spatial heating and cooling.	Direct emissions of approximately 390 $MtCO_2e$ in 2014 (IEA/OECD 2017), 76% of which for spatial heating and cooling.
Retrofitting activity	Average rate of retrofit approximately 1.4% in European Union and North America in 2013 (based on IEA/OECD (2017). Retrofit rate in European Union member states ranges from 1.6% in Austria to 0.1% in Poland (European Commission 2016).	
Energy poverty	125 million people cannot afford suitable indoor thermal comfort; >10% of population cannot keep up with energy bill payments; >15% of population live in buildings with leaking roofs or damp walls; 20% of population live in buildings which are not adequately cool in summer (Csiba et al. 2016)	Approximately 48 million people in the United States and more than 3 million people in Canada are estimated to be in conditions of energy poverty (Fraser Institute 2016); (Gridmates 2016) defined as excessive expenditure on energy or unaffordable access to energy.

[9] The average numbers presented here are taken as reference, keeping in mind that these values vary widely across different countries/states within the same region.

Scenario parameters

The analysis for the potential of residential building retrofits is based on the developments of the following levers:

- **Renovation rate:** The rate of retrofit indicates the proportion of the building stock which is retrofitted each year, as a percentage. A retrofit rate of 1.4% indicates that 1.4% of the residential building stock is retrofitted in a single year, meaning that it would take more than 70 years for the entire existing building stock to be retrofitted.
- **Efficiency improvement through renovation:** Based on the current situation in the European Union and North America, and the required pathways for compatibility with the Paris Agreement objectives in OECD countries, we analysed two scenarios for this study: a Reference (Ref) scenario and an enhanced action scenario (EAS). The enhanced retrofit scenario is likely to be compatible with the objective of the Paris Agreement to limit average global temperature increase to "well below 2°C. Table 5 introduces the scenarios which are analysed for the European Union and North America in this study[10].

Section 4.4 provides further details on the assumptions taken for the levers in each of the scenarios assessed in this analysis.

Impacts

For the purpose of clarity, we include a description of the terms that are used throughout this section:

- **Household:** A household is composed of the group of people living in the same dwelling space.
- **Energy efficiency retrofits:** implementation of measures that will contribute to improve the thermal energy performance of urban residential buildings, reducing energy demand for spatial heating and cooling.
- **Household disposable income:** total income of household occupants combined, after taxes.
- **Household energy expenditure:** household's final consumption expenditure devoted to electricity, gas and other housing fuels for spatial heating and cooling needs.
- **Household saving rate:** financial resources households have available each year after all expenditure from essential needs for use towards increasing assets and making investments.

This study focuses on the impacts of energy efficiency retrofit scenarios in the urban residential building sector for **net job creation** and **household savings and wealth** indicators needed for implementation. These impacts were selected for analysis based upon analysis from C40 and input from C40 cities on the most relevant issues for decision makers, providing important arguments for action, as well as feasibility of the quantitative analysis[11].

- **Job creation** is assessed with regards to the net employment impact including estimated creation and losses of jobs in various sectors.
- For **household wealth indicators**, the impacts of retrofit are assessed with regards to the impact on the household's final consumption space heating and cooling, and thus its effects on household asset accumulation and investment potential (annual savings rate).

Further, the investment requirements for implementation are estimated with regards to the upfront capital costs of measures in the scenarios. Greenhouse gas emission reductions are also assessed.

[10] For full details on the methodological steps to define the scenarios and its variables for the quantitative assessment of the impacts, please refer to the separate technical methodological document.

[11] For full details on the methodological steps for the quantitative assessment of these impacts, please refer to the separate *Technical Note document*.

>>>>>>>>>>>>>>>>>>>>>>>>>

4.4 SCENARIOS FOR ENHANCED ACTION

Table 6 gives an overview of the scenarios and assumptions taken for the analysis of impacts of residential building retrofit measures in the European Union and North America.

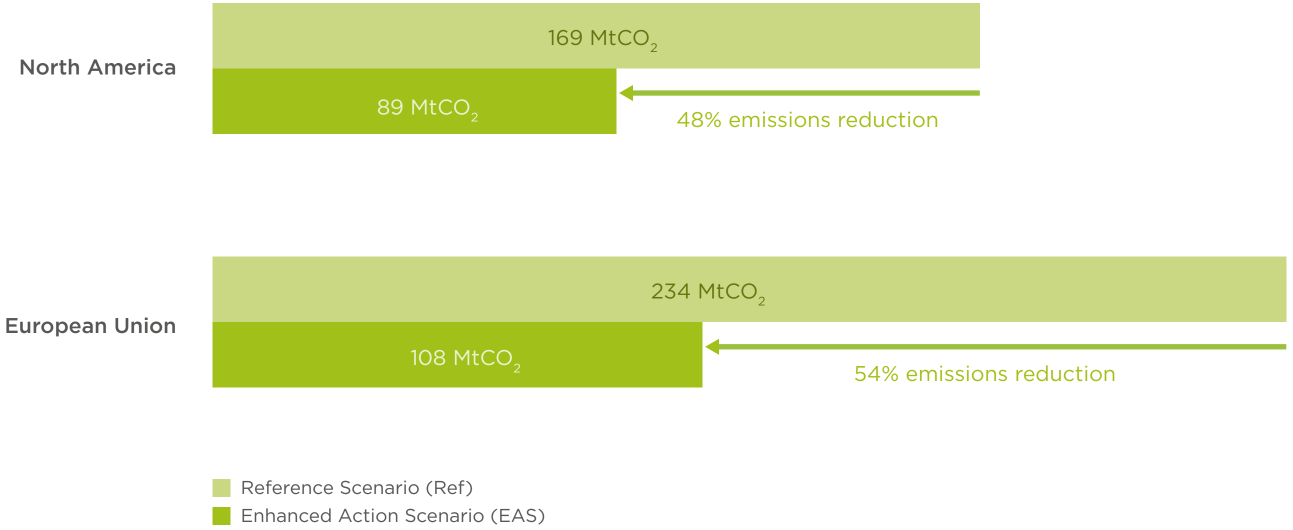
Table 6. Scenarios for analysis of impacts of residential building retrofit measures.

REFERENCE SCENARIO (2015-2030)		
For OECD regions, a fair representation of business-as-usual developments assumes a shallow renovation pathway, in which minor retrofit measures –resulting in 10% energy efficiency improvements– are standard for retrofitting activity up to 2030 (based on IEA/OECD (2017) and Ürge-Vorsatz et al. (2012).		
	EUROPEAN UNION	NORTH AMERICA
Renovation rate (%)	1.4% per year by 2025	1.4% per year by 2025
Efficiency improvement through renovation (%)	10% (final energy consumption of 95 kWh/m² by 2020)	10% (final energy consumption of 63 kWh/m² by 2020)

ENHANCED ACTION SCENARIO (EAS) (2015-2030)		
Under this scenario, policy measures would be implemented to reduce energy consumption through renovations to the extent that final energy demand for heating and cooling in the average renovated building matches that of new residential buildings, consuming no more than 22 kWh/m² each year for spatial heating and cooling (nearly zero energy buildings according to BPIE (2016)). The retrofit rate increases to 3% per year as needed to meet 2°C targets (based on IEA (2016b)). This scenario assumes that these changes are made in phases: the depth of retrofit is increased uniformly from the current to the target levels between 2015 and 2020, whilst the rate or retrofit increases from the current to the target levels between 2020 and 2025, to be sustained thereafter up to 2030.		
	EUROPEAN UNION	NORTH AMERICA
Target renovation rate (%)	3.0% per year by 2025	3.0% per year by 2025
Target efficiency improvement through renovation (%)	80% (final energy consumption of 22 kWh/m² by 2020)	68% (final energy consumption of 22 kWh/m² by 2020)

Under the enhanced action scenario, Table 6 shows that measures will increase the energy efficiency of the renovated buildings after 2020 by 80% in the EU and by 68% in North America. Figure 3 shows that this would result in the reduction of GHG emissions for spatial cooling and heating in the buildings sector by 126 $MtCO_2e$ in the European Union and 80 $MtCO_2e$ in North America, compared to the reference scenario. This is equivalent to approximately 0.24 tCO_2e per capita in urban areas in both North America and the European Union. This is in line with the Paris Agreement compatible scenarios of the *Deadline 2020* report (ARUP & C40 Cities 2016), which report average per capita emission reductions of around 0.2-0.3 tCO_2e for 31 major cities in North America in Europe in 2030.

Figure 3. Emissions reduction from energy reduction for spatial heating and cooling in the urban residential building stock by 2030.



>>>>>>>>>>>>>>>>>>>>>>>>>

4.5 QUANTIFIED IMPACTS OF RESIDENTIAL BUILDING RETROFIT

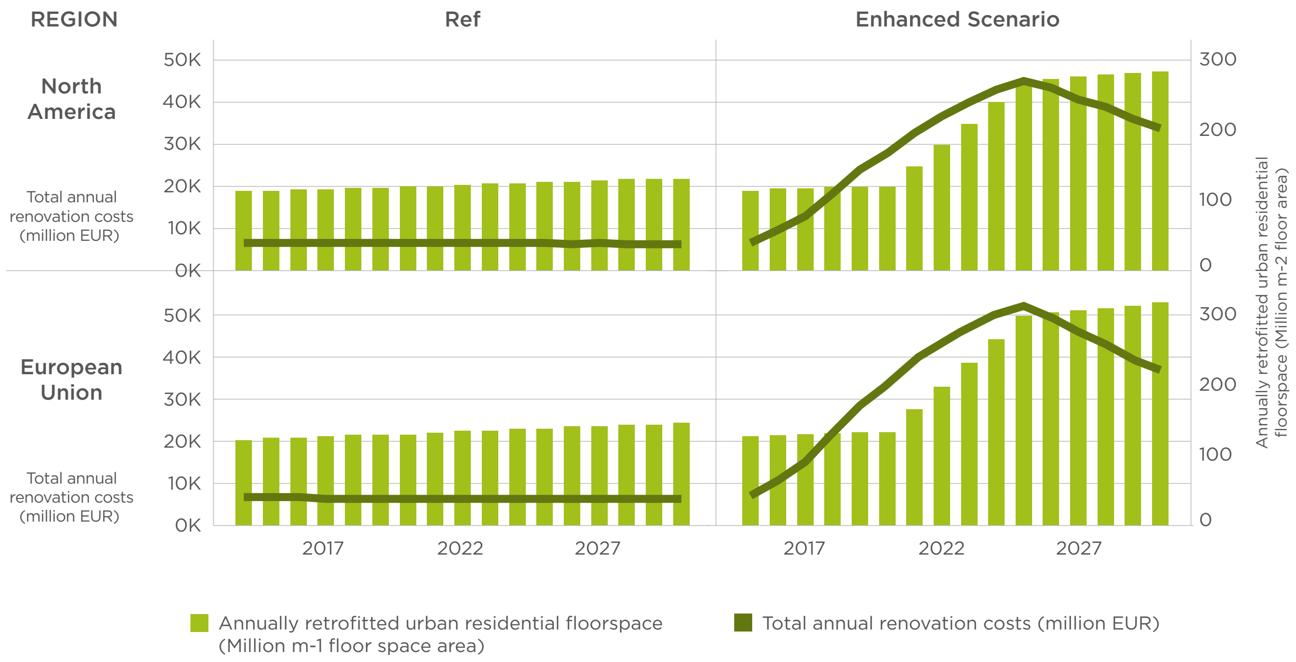
4.5.1 Retrofit activity and investments

The policy environment and economic circumstances of both the European Union and North America has led to the incentivisation of only minimal retrofit activity; with a retrofit rate of approximately 1.4% of the building stock and relatively minor depths of retrofit. According to our calculations, an estimated EUR 12 billion were invested in the retrofit of approximately 210 million m^2 of urban residential building floor space in 2014 in the EU. In North America, an estimated EUR 20 billion was invested in retrofitting around 309 million m^2 of urban residential building floor space in the same year (assuming a retrofit rate of 1.4% for both regions)[12]. Under the reference scenario, the floor space area retrofitted each year and the depth of renovations are not projected to change significantly in either region, whilst the investment costs may decrease marginally due to the learning curve of technologies.

Figure 4 shows that, in contrast to the reference trajectory, the enhanced action scenario, which incorporates an increase in the rate and depth of retrofit, would increase the floor space retrofitted each year by 2025 to over 500 million m^2 in the European Union and over 750 million m^2 in North America, with this rate of retrofit sustained towards 2030 and further into the future. Annual investment needs would increase many times over in both regions to an average of approximately EUR 60 billion per year in the European Union and EUR 90 billion per year in the United States for the period between 2015 and 2030 in both cases. The significantly higher investment requirements in the enhanced retrofit scenario is due not only to the increased floor space under retrofit, but also the greater depth of the renovation measures, which demands more advanced materials and skills.

Figure 4 also shows that the investment needs will decrease between 2025 and 2030 due to the reducing costs of technologies and building practices and assuming that the retrofit activity is sustained after reaching the 3% rate of retrofit in 2025. If investment flows could be maintained at their 2025 levels, this drop between 2025 and 2030 indicates that there may be room to further increase the ambition for enhanced retrofit rates, or in other areas of the building sector and the construction industry.

Figure 4. Comparison of scenarios for activity and investment in retrofitting (average over time period 2015-2030) for North America and the European Union.



[12] For more details on the calculations behind the retrofit activity and investments, please refer to the separate *Technical Note document*.

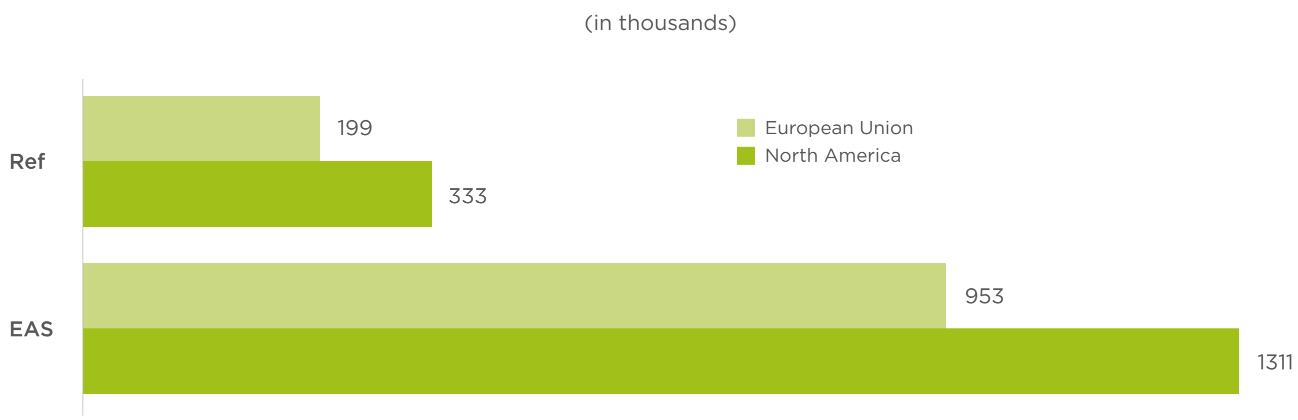
4.5.2 Job creation

Investments in energy efficiency shift patterns within an economy in two major ways, both of which can stimulate a net increase in employment. First, the investment in energy efficiency upgrades stimulates the creation of jobs as the project is carried out. The initial expenditure drives direct, indirect, and induced jobs in the near term in labour-intensive industries such as construction, engineering, maintenance, and contracting. The deeper the renovation, the greater the costs, the labour needs and the job creation impacts. Indirect jobs are subsequently created in various stages of the supply chain. Secondly, money that could be saved from lower energy bills, and earned by the newly employed workers, is re-spent locally, creating induced jobs in a wide variety of service and retail industries (Bell 2011)[13].

For the most part, these jobs are local in nature; measures to improve energy efficiency have to take place at the site where the buildings stand (Janssen & Staniaszek 2012). Measures are typically implemented through engineering, construction and installation companies from the local or semi-local economy (Torregrossa n.d.).

Figure 5 and Figure 6 provide an overview of the employment impacts of the reference scenario and enhanced action scenario (EAS), including net job gains and losses in the construction and energy supply sectors, as well as induced impacts. Figure 5 shows that while a reference scenario pathway could be expected to yield a total of approximately 200,000 full-time equivalent (FTE) jobs sustained over the period 2015-2030 in urban areas of the European Union, and approximately 330,000 in North America; jobs in the sector would increase almost five times under the enhanced action scenario (EAS), creating close to 1 million FTE jobs in the European Union and 1.3 million in North America. This difference in the net employment impact of the two scenarios is highly significant in the context of national unemployment rates: the gain is equivalent to approximately 4% of unemployed persons in the European Union, and 12% in the United States in 2017 (18.5 million and 7.7 million people were unemployed in the European Union and North America, respectively, in 2017) (Eurostat, 2017; Trading Economics, 2017).

Figure 5. Full-time equivalent jobs generated through retrofitting (2015-2030).



[13] It is noted that the increased personal incomes of newly employed workers could have a rebound effect for increasing emissions if increased incomes are re-spent on emission intensive activities. Although various studies acknowledge this rebound effect (e.g. IEA 2014), increased personal consumption need not necessarily equate to increased emissions, depending on trends for consumer behaviour.

Analysis of the types of jobs created by a deep renovation scenario, compared to a shallow renovation scenario, in Hungary (Ürge-Vorsatz et al. 2010), gives an indication of how the employment impact of the enhanced action scenario may be split between sectors and skillsets. The majority of the positive employment impact in the enhanced retrofit scenario would likely come from job creation in the construction and supply industries, which far offsets potential job losses in the energy industries stemming from reduced energy demand, as demonstrated in Figure 6. A smaller but still significant share of this employment impact comes from the induced effect that increased employment may have for increased spending and demand for services in the broader economy. Of the jobs that are created through direct employment in the construction sector, Figure 6 shows that retrofitting will generate employment opportunities for professionals, skilled workers and unskilled workers. A key difference between the scenarios is the increase in the demand for skilled and professional workers, driving incentives for improved education and staff training opportunities. The number of professional level staff employed in the enhanced action scenario is approximately 30 times greater than in the reference scenario, in both regions.

Despite the potential job creation from investments in building retrofits, it should also be considered that these investments may entail an opportunity cost, depending on the source of finance and whether or not the finances are diverted from other potential investments in the local economy which could also lead to job creation. However, depending on the source of the resources, and the incentives for private sector investment, action could lead to additional resources being diverted away from investments that may otherwise have occurred outside of the region, resulting in job creation elsewhere.

Figure 6. Breakdown of net employment impacts in the enhanced retrofit scenario. Indicative based on employment split from deep renovation scenario in Urge-Vorsatz (2010).

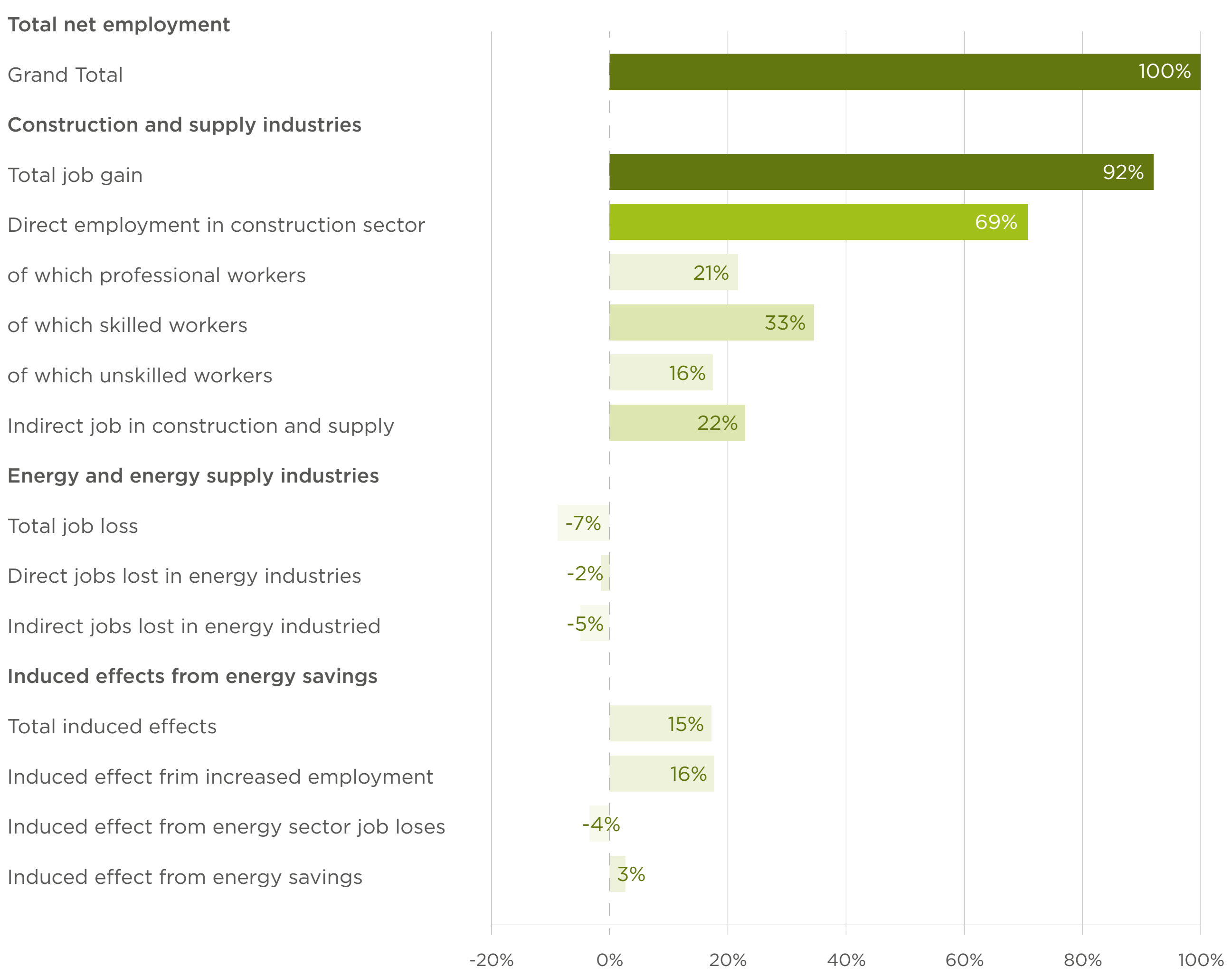


Table 7. Scaling down the results to cities (1 million inhabitants) and the C40 cities in the region.

SCALING DOWN THE RESULTS				
Average annual investment needs (2015-2030)	European Union	1-million city	Reference	~ EUR 30 million
			EAS	~ EUR 140 million
		C40 network cities	Reference	~ EUR 920 million
			EAS	~ EUR 4.4 bn
	North America	1-million city	Reference	~ EUR 60 million
			EAS	~ EUR 240 million
		C40 network cities	Reference	~ EUR 2.1 bn
			EAS	~ EUR 8.4 bn
Average annual job creation (2015-2030)	European Union	1-million city	Reference	~ 500 jobs
			EAS	~ 2,400 jobs
		C40 network cities	Reference	~ 15,500 jobs
			EAS	~ 74,000 jobs
	North America	1-million city	Reference	~ 1,050 jobs
			EAS	~ 4,100 jobs
		C40 network cities	Reference	~ 37,000 jobs
			EAS	~ 145,000 jobs
GHG emission reductions of enhanced action scenario (2030)	European Union	1-million city	330 $ktCO_2e$	
		C40 network cities	10.2 $MtCO_2e$	
	North America	1-million city	280 $ktCO_2e$	
		C40 network cities	9.9 $MtCO_2e$	

Scaled down results are indicative approximations based on population and not bottom up evaluation of specific cities.

4.5.3 Household cost savings and wealth

Energy bills play a significant role in households' regular expenditures. In 2014, expenditure on energy, which includes household's final consumption expenditure devoted to electricity, gas and other housing fuels represented 4.3% of total household expenditure in the European Union and 2.3% in North America (Eurostat, 2017; Government of Canada, 2017; United States Department of Labor, 2017). The total energy spending for the average household depends on the countries' existing infrastructure, climate conditions and energy prices (EC-Energy 2017). More than half of this expenditure can usually be attributed to energy consumption for spatial heating and cooling (IEA 2016c).

The burdens of energy related expenditure are particularly relevant for lower-income households, for whom such expenditures usually account for a far greater proportion of disposable income. For example, low-income households in the EU spent about 8.5% of their disposable income on energy in 2014, around double the proportion spent by the average household (European Commission DG-Energy 2015). Many lower-income households under-heat their homes, reduce consumption on other essential goods or are forced into debt to meet their energy needs (European Commission DG-Energy 2015). Around 125 million people in the EU, or roughly a quarter of the population, cannot afford suitable indoor thermal comfort (Csiba et al. 2016), whilst just over 50 million people, or about one 7th of the population in North America, struggle to meet energy expenditures (Fraser Institute 2016); (Gridmates 2016).

A significant improvement in household energy efficiency, through higher renovation rates and deeper renovation pathways can have a substantial impact in lowering energy bills, which can effectively supplement the amount of money that households are typically able to save each year for asset accumulation, including savings or potential investments (for this study, we will refer to it as the annual household saving rate). Although it broadly differs between solvent households and lower income ones, the annual household savings rate is considered a key factor for development outcomes, since the ability for households to improve their future economic situation depends to an extent on the ability to accumulate assets and make investments.
As such, enhanced building retrofit can play a role in the alleviation of not only energy poverty but also general economic poverty in lower-income households.

The impacts of retrofit measures in the urban residential building sector are assessed in this section with regards to the impact on the household's final expenditure on energy related to spatial heating and cooling, and the potential effects on annual household saving rates.

Reduction of household primary energy consumption

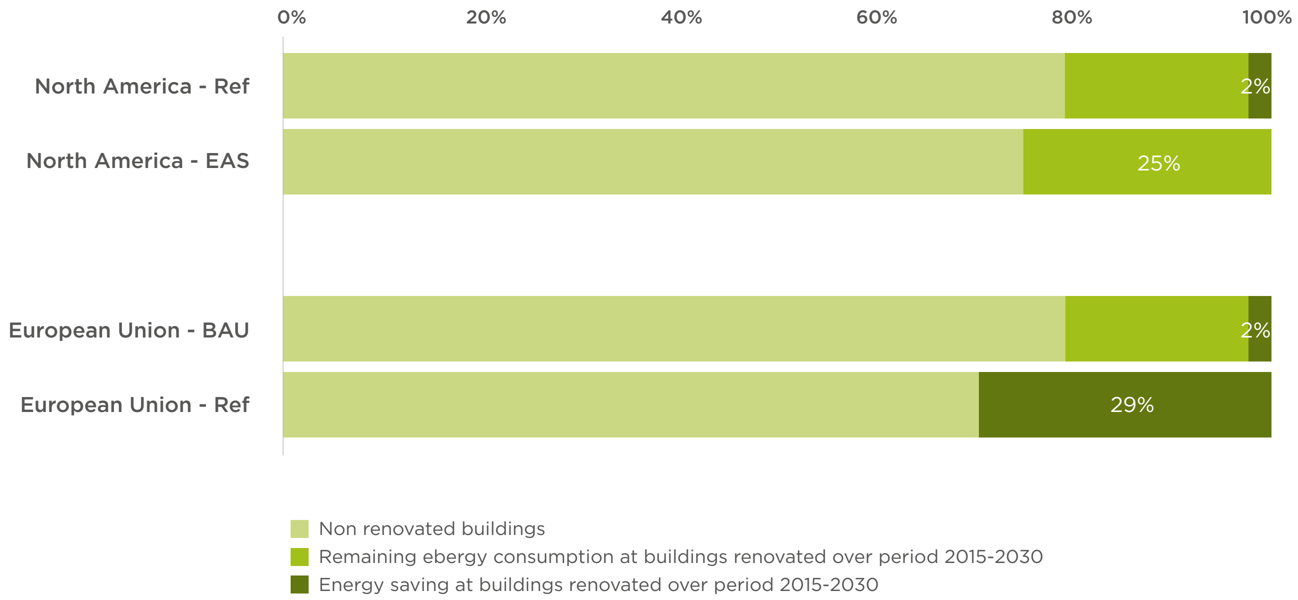
While retrofit activity under the reference scenario in both the European Union and North America may reduce energy demand by an average of 10%, best practice examples have shown that existing buildings can be retrofitted to meet the energy characteristics of new residential buildings (BPIE 2016) (see scenarios in section in 4.3). As such, the average energy efficiency improvements for retrofitted buildings over the entire period of analysis between 2015 and 2030 under this scenario will be of 64% in cities of the European Union and 55% in North America cities[14].

These energy efficiency improvements apply to the specific individual buildings where retrofit measures take place during the period, independent of the rate of retrofit. The difference between the scenarios for the overall urban residential building stock in 2030, considering the rates of retrofit, is more profound. Figure 7 shows that the average annual energy demand for spatial heating and cooling of households in both regions may be 25-29% lower in 2030 under the enhanced action scenario, compared to the current demand. The reduction under the reference scenario would be just 2%.

THE BURDENS OF ENERGY RELATED EXPENDITURE ARE PARTICULARLY RELEVANT FOR LOWER-INCOME HOUSEHOLDS, FOR WHOM SUCH EXPENDITURES USUALLY ACCOUNT FOR A FAR GREATER PROPORTION OF DISPOSABLE INCOME.

[14] Part of the 2015-2020 action considered under these scenarios is no longer possible, as it assumes action to start in 2015. These scenarios are illustrative of what could be achieved if implementation was to start right away, which is needed in order to enhance adaptive capacity, strengthen resilience and reduce vulnerability to climate change (ARUP & C40 Cities 2016).

Figure 7. Reduction of energy demand for spatial heating and cooling in the urban residential building stock in 2030.



Household savings and wealth

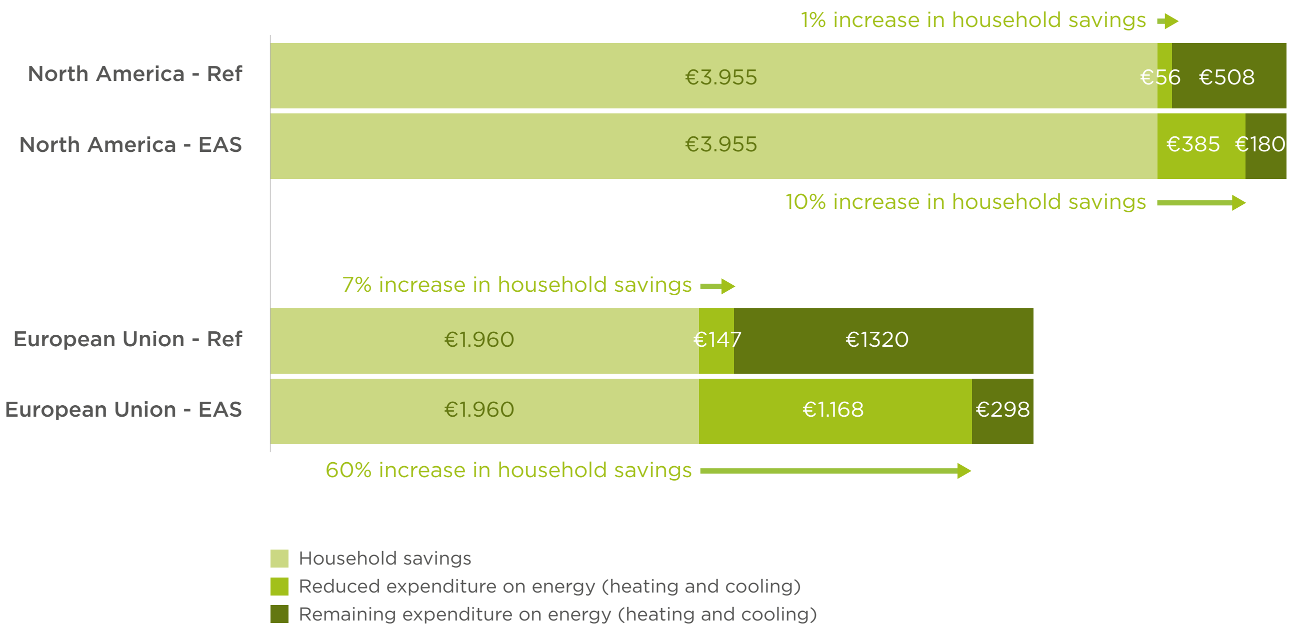
Household savings and wealth are assessed based on the impacts of reduced household energy expenditure on annual household cash flows, disposable incomes and typical household annual saving rates. The analysis considers the individual average household. The annual household saving rate refers to the financial resources households have available each year after all expenditure from essential needs for use towards increasing assets and making investments; while the household's disposable income refers to the household's total income, after taxes.

For both the reference scenario and enhanced retrofit scenarios, the actual impacts for the individual households' financial flows will depend on the financing model, For the purpose of focusing on the analysis the theoretical impacts of the measures, this study's estimated payback period for investments assumes that the household occupants cover the full costs of renovations. In reality, the financing mechanisms would vary widely depending on the policy options, ownership structures and instruments for implementation of the measures[15].

Annual expenditure on energy for spatial heating and cooling for the average household in 2030 is projected to be approximately EUR 1,320 in the European Union, and EUR 508 in North America, under a reference scenario. The significant difference between the regions is owing to the considerably lower prices of energy in North America, which are projected to prevail. Under the enhanced action scenario, this energy expenditure will decrease by about EUR 1,170 for the average retrofitted household in the EU and by around EUR 385 for the average household in North America after the payback of the investment, compared to savings of approximately EUR 147 and EUR 56, respectively, which would have happened under the reference scenario.

For this study, we assume a yearly saving rate of 4.2% for EU and 5.4% for North America, throughout the period between 2015 and 2030. The difference between these saving rates can be partially attributed to the fact that social security contributions are significantly higher in the EU than in North America (Alberto Alesina 2001). Figure 8 shows the reduction in energy expenditure for each region next to the annual household savings, showing the impact that this reduced expenditure could have on increasing household's savings: through reduced expenditure **for spatial heating and cooling in the enhanced action scenario, households could effectively increase their annual household savings after the payback period by approximately 60% (or close to 1,170 EUR annually) in the European Union and 10% (or about 385 EUR annually) in North America**.

Figure 8. Reduced expenditure on energy and potential impact on household annual savings compared to 2030 cashflows, after completion of project cost payback period.



[15] For more details on this study's calculation of the payback period, please refer to the separate Technical Note document.

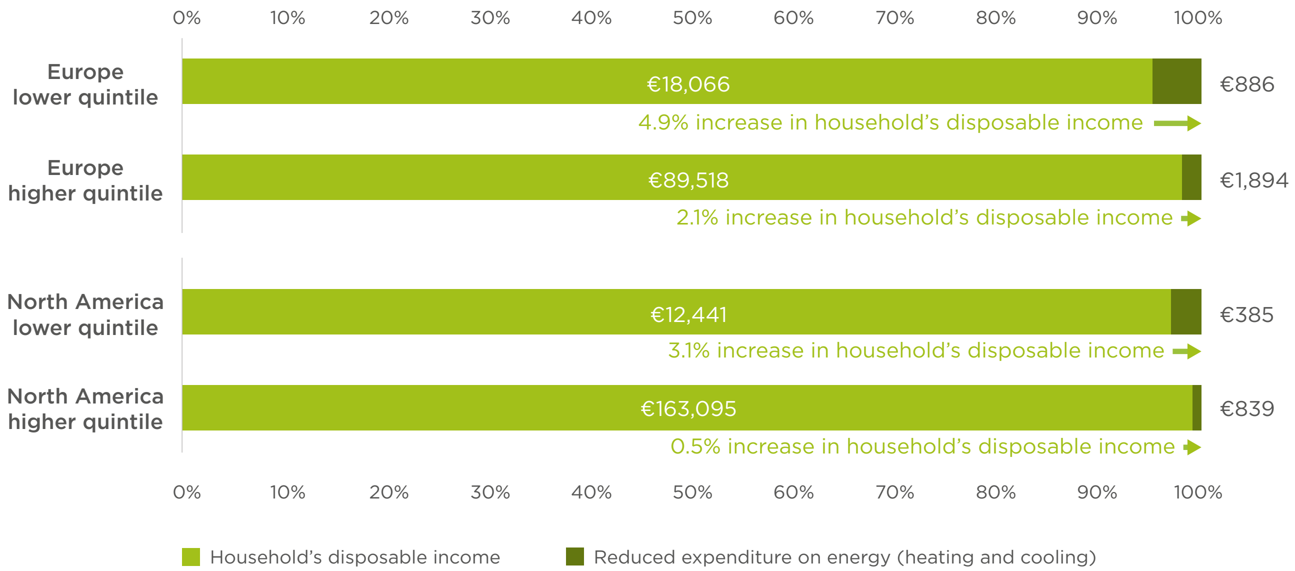
Implications for the lowest income quintile

Annual household saving rates are significantly lower for low-income households. In 2015, the average nation-wide household[16] savings for households in the lowest-income quintile of the European Union was EUR 120, compared to an average savings of over EUR 21,000 for households in the highest-income quintile. In a more extreme case, the average North American household in the lowest-income quintile currently has negative savings rates, spending approximately EUR 10,000 per year more than their disposable income; while households in the highest-income quintile are saving about EUR 30,000 per year (Eurostat 2017; Government of Canada 2017; United States Department of Labor 2017). In addition, energy expenditures of lower income households usually form a larger relative proportion of their overall expenditures. As such, reduced expenditures for energy consumption makes a far higher proportional difference to disposable incomes and saving rates for lower income households.

Figure 9 shows that while a financial benefit of retrofit activities exists for households in lowest and highest quintiles, the relative benefit for lower income households is higher: **disposable income of a European household in the lowest quintile could increase by about 4.9%** with the economic benefits of reducing energy through retrofits, **compared to 2.1% increase of disposable income in a household in the highest quintile.** Similarly, for **North America, a household in the lowest quintile could potentially increase its disposable income by 3.1%, compared to a 0.5% increase of a household in the highest quintile.**

The disparity between quintiles for the impacts of reduced energy expenditure on household annual saving rates are even greater than the impacts on disposable income: the lowest quintile household in the **European Union could increase its saving rate about 6 times (600%) through energy reductions from retrofits in 2030, while saving rates of higher income quintiles could increase around 7.4% for the same year.** For North American households, lower income groups currently have a negative savings rates, meaning they spend more than what they receive as income, this limits their opportunities to save money, increase their assets or make investments. Our calculations show that the **negative savings rates of the households in the lowest income quintiles could be alleviated and reduced by 3% until 2030 by reducing energy use -and thus, expenditure- through building retrofits.** Higher income quintiles could increase their savings by 2.3% until 2030 by implementing these retrofit measures[17].

Figure 9. Potential increase in household's disposable income due to reduced energy expenditure in the lower and higher income quintiles in 2030 under the enhanced action scenario. Results for the European Union and North America.



These projections demonstrate how residential building retrofit is a particularly pro-poor measure, whilst not incurring any disadvantages to other groups. The calculations assume that retrofit activity shows no prejudice to lower and upper income groups, and that retrofit activity is spread equally amongst the building stock, regardless of the economic situation of household occupants. Whether this assumption can hold in reality is dependent on the design of the specific policies and instruments with which the measures are implemented. This highlights the importance of policy design considerations and financial mechanisms available, especially taking into account that costs of capital are much higher and access to credit is much more difficult for those households in the lowest income quintiles.

[16] The household statistics presented here refer to the average household (including urban and rural households).

[17] It is likely that a proportion of the savings coming from energy retrofits will be used for new expenditures, rather than only contributing to increase household's saving rates. As such, the figures given are maximum potentials which may contribute to increased saving rates and/or increased expenditures, both of which may contribute to enhanced economic welfare.

4.6 CASE STUDY

Case studies from London and Toronto illustrate, at the local level, how residential energy efficiency retrofit is delivering GHG emission reductions while also addressing multiple benefits to the population.

4.6.1 London

Background

Emissions from buildings account for 77% of London's total emissions (Mayor of London 2017 b)[18]. Homes account for 35%. Retrofitting homes across the city is an essential strategy, given that at least 80% of London's existing buildings will still be standing by 2050, and considering that 10.1% of households in London, including those within the social sector are deemed to be fuel poor (Mayor of London, 2016)[19].

Actions

The aim of the RE:NEW programme is to reduce carbon emissions and energy bills in London's homes. RE:NEW helps organisations such as London boroughs, housing associations, and universities to implement retrofit projects and alleviate fuel poverty, as well as supporting the city to achieve the ambitious target of being a zero carbon city by 2050. RE:NEW offers free technical support to social landlords and mixed tenure schemes at every stage of the retrofit process, from initial stock review to retrofit strategy and project development through to funding and procurement support. It includes a framework of retrofit suppliers.

Benefits

Since 2009 RE:NEW has helped improve over 130,205 of London's homes, saving around 46,000 tons of carbon dioxide a year and approximately £8.85m in annual energy bill savings (Mayor of London 2018).

Programme data suggests that retrofitting homes has led to over 2,100 person years of employment being supported[20]. Based on the gross number of households supported, it is estimated that a total of over 2,500 households are expected to have been lifted out of fuel poverty through interventions backed by RE:NEW (Mayor of London 2016). And tackling fuel poverty not only saves money, but also improves health. In London, it is estimated that 82,000 privately rented properties are associated with excess cold, with the cost to the NHS (National Health Service) as a result of not improving them being £18.9m per year (Mayor of London 2017c).

Figure 10. A housing estate in London

"The Mayor is committed to making London a zero carbon city by 2050 and programmes like RE:NEW are key to helping us meet this ambition and reduce fuel poverty. Over 130,000 London homes have benefited from the RE:NEW retrofitting programme, saving £8.85m in annual energy bills and lowering emissions. Moreover, evidence suggests that the benefits of improving our homes go beyond bills and emissions , including sustaining jobs in the retrofit sector and improving health outcomes for residents in London."

Shirley Rodrigues
Deputy Mayor for Environment and Energy

4.6.2 Toronto

Background

Homes and buildings generate about half of the greenhouse gas emissions in Toronto. As many of these residential dwellings were built prior to the advent of energy efficiency standards in the Ontario building code (1986), the City of Toronto recognized this as an opportunity to address climate change. The municipality identified energy efficiency retrofits of homes and multi-residential buildings as a strategic priority to reduce GHG emissions by 80% by 2050 as outlined in TransformTO - Climate Action Program for a Healthy, Equitable, and Prosperous Toronto (City of Toronto 2017b).

Action

The City has established a goal to retrofit all existing buildings by 2050 to the highest emission reduction technically feasible, on average achieving a 40% energy performance improvement over 2017 levels, while limiting affordability impacts to residents.

Launched in 2014, the Residential Energy Retrofit Pilot Program operates as two streams – the Home Energy Loan Program (HELP) and the High-rise Retrofit Improvement Support Program (HI-RIS) – which apply to eligible single-family houses and multi-residential buildings in Toronto, respectively (City of Toronto 2017 a). Through a 'one-window' service delivery model, property owners gain access to financing, utility rebates and incentives and support services including energy assessment and project development support.

Benefits

Initial findings (from January 2014 to December 2017)[27] demonstrate the wide benefits of the deep energy retrofits of Toronto housing and encourage its continue and development to address the full untapped potential of the sector.

Table 8. Program Overview and Main Impacts

	HELP	HI-RIS
Retrofit projects completed/committed	125 homes	8 buildings (9 projects)
Average operating cost savings	$560/year	$40,600/years
Types of energy efficient retrofit measures undertaken	Windows and doors, heating system, insulation, air sealing	Windows and balcony doors, roof, boiler, elevator motor, water conservation
Average total energy reduction (natural gas and electricity)	30%	26%
Average greenhouse gas emission reductions	33% per home	26% reduction per project
Jobs created[21]	30 jobs	60 jobs

[18] Considering Scopes 1 and 2 only.
[19] A household is considered to be fuel poor if: a) they have required fuel costs that are above average (the national median level); and b) were they to spend that amount, they would be left with a residual income below the official poverty line.
[20] Using the approach of this report, it can be expressed as 300 full-time equivalent (FTE) jobs sustained for seven years over the period (2009-2016).

[21] Source: Email exchange with the City of Toronto, Environment and Energy Division. All values are measured.

“Improving the energy performance of residential buildings, through programs such as HELP and Hi-RIS, also improves housing affordability and creates jobs. Our efforts to retrofit buildings need to be dramatically accelerated to achieve Toronto’s low-carbon goals as envisioned by TransformTO.”

Mike Layton
Toronto City Councillor

Figure 11. 6061 Young Street Windows Comparison.

Old, single-pane windows

New double-glazed Low-E windows

Figure 12. 6061 Young Street, whole building. Photo Credit: City of Toronto.

Figure 13. Before and After the retrofit intervention in the Junction neighbourhood. Photo Credit: City of Toronto.

4.7 OPPORTUNITIES FOR RESIDENTIAL ENERGY EFFICIENCY RETROFIT

Energy efficiency is the most cost-effective measure for securing the reliability of the energy system reducing greenhouse gas emissions from the energy sector, while delivering outcomes for the economy, prosperity, social inclusion and other development agendas.

Despite the vast potential for energy and cost savings through deep retrofit of residential buildings, energy efficiency in the building sector remains one of the least exploited cost-effective mitigation measures available. This is caused by short-sighted investment planning, split incentives between building owners and renters, lack of ability for communal action in multi-family buildings, and lack of policy support, amongst diverse other factors.

The findings from this report present evidence base for accelerated actions for deep energy efficiency retrofits in the residential building sector. It equips city, national governments, private sector and citizens with several reasons for a joint collaborative effort toward this goal. Case studies from London and Toronto illustrate, at the local level, how this action is delivering GHG emission reduction while also addressing multiple benefits to the population. Deeper retrofit results in a far greater volume of job creation, including local jobs for unskilled, skilled and professionals. Depending on the financing structure and the duration of the payback period, the eventual annual cost savings can be great enough to effectively increase the annual savings rate of households by significant volumes.

Building retrofit, if implementation is carefully planned, can be a particularly pro-poor measure. The benefits analysed in this study are particularly relevant for lower-income populations. The scale of potential job creation in the European Union and North America is equivalent to 4-12% of the unemployed populations in these regions. Reduced energy expenditures can boost household disposable incomes of the lowest income quintile in North America by a rate that is six times greater than the impact for the highest income quintile. For lower-income households who spend a highly significant portion of their income on energy bills, energy efficiency retrofits have the potential to alleviate not only energy poverty but also general economic poverty.

Additional measures for optimizing energy use in residential buildings, that were not within the scope of this research report, have the potential to further enhance the impacts of the measure. Additional measures for optimizing energy use in residential buildings, that were not within the scope of this research report, have the potential to further enhance the impacts of the measure. Additional measures found by McKinsey & C40 Cities (2017) to have considerable emission reduction potential in cities include standards for new buildings, technological improvements to energy supply systems including HVAC appliances and water heating and modernisation of lighting technologies.

ENERGY EFFICIENCY IS THE MOST COST-EFFECTIVE MEASURE FOR SECURING THE RELIABILITY OF THE ENERGY SYSTEM REDUCING GREENHOUSE GAS EMISSIONS FROM THE ENERGY SECTOR, WHILE DELIVERING OUTCOMES FOR THE ECONOMY, PROSPERITY, SOCIAL INCLUSION AND OTHER DEVELOPMENT AGENDAS.

05 ENHANCED BUS NETWORKS AND BUS SERVICES

>>>>>>>>>>>>>>>>>>>>>>>>>>

SUMMARY OF RESULTS FOR ENHANCED BUS NETWORKS

Under the *reference scenario*, bus network infrastructure will continue to develop at a moderate rate in all regions up to 2030, whilst overall urban transport activity increases by approximately 20% and 35% in North America and Latin America, respectively. These projections may cause premature mortality associated with air pollution to increase to over 250,000 annual deaths in cities across the two regions, whilst road traffic fatalities in these cities will also increase to over 180,000 per year.

An *enhanced bus networks scenario*, where bus network lengths and service frequency are increased up to 2030 by 100% in Latin America and 300% in North America, the proportion of bus routes that operated on dedicated lanes is increased to 22-24%, and the share of low- and zero-carbon bus technologies reaches a 100% share of the bus vehicle stock by 2030, is estimated to result in the following outcomes and impacts:

- The share of private light duty vehicles (LDV) in the urban transport mix may reduce by 22% in North America and by 35% in Latin America, compared to the reference scenario.
- The reduction of vehicle traffic in cities will cause a reduction in annual GHG emissions in 2030 by approximately 80 $MtCO_2e$ in North America and 40 $MtCO_2e$ in Latin America.
- The reduction of vehicle emissions in cities will also cause a reduction in exposures to excessive ambient air pollution, leading to the prevention of over 6,000 premature deaths per year in North America and over 30,000 premature deaths per year in Latin America, compared to the reference scenario.
- The reduction of traffic volumes will reduce the frequency of road traffic accidents, leading to the prevention of over 6,000 fatalities per year in North America and over 50,000 fatalities per year in Latin America, compared to the reference scenario.
- The introduction of dedicated private bus lanes could reduce the commute times of the average public transport user by 9-10%, equivalent to a total potential annual time saving of 1.8 billion hours for commuters in North America and 7.5 billion hours in Latin America.

Cities around the world are working towards improving the efficiency and sustainability of urban transport systems for the enhanced mobility of urban populations. Private car ownership is not only a source of mounting traffic congestion, but also an important cause of local air pollution, and mounting social disparities (ITDP 2017). Countries and subnational governments have identified modal shift to public transport, as well as measures to avoid unnecessary journeys and improve the efficiency of travel (see ASI Avoid-Shift-Improve concept, GIZ 2004), as a key strategy for reducing emissions whilst increasing equity in urban mobility and accessibility.

Several cities have developed passenger transport systems that result in rather progressive rates of public transport usage: for example, the share of private vehicle travel for urban passenger transport in 2011 was just 11% in Hong Kong, 12% in Tokyo, 15% in Bogotá and 7% in Paris (LTA, 2011; Omnil, 2012). Sustainable transport modes also accounted for more than 70% of passenger transport activity in Barcelona, Vienna and Prague in 2015 (UITP 2015). While these cities provide positive examples of urban transport systems that are moving in a sustainable direction, this does not mean that a shift to sustainable transport will be an easy undertaking: in many cities in regions across the world, there is considerable lock-in to infrastructure and urban planning decisions that favour less sustainable modes of transport, particularly private vehicle use. Achieving the targets identified in the literature for modal shift and transport demand management will require carefully planned policies and a high level of ambition to implement sustainable systems. A broader appreciation of the cross-sectoral impacts and benefits of sustainable transport could play a key role in catalysing the required ambition.

This chapter looks at some of the impacts of specific measures for improvement of bus networks and incentivising the use of public transport, including enhancements to the density of the bus network, the frequency of bus services, the usage of dedicated segregated bus lanes or fully-fledged bus rapid transit (BRT), and the uptake of zero carbon technologies in the vehicle stock.

> “An advanced city is not one where even the poor use cars, but rather one where even the rich use public transport.”
>
> **Enrique Peñalosa**
> Mayor of Bogotá, Colombia (2013)

>>>>>>>>>>>>>>>>>>>>>>>>>>

5.1 IMPORTANCE OF ENHANCED BUS NETWORKS AND BUS SERVICES IN CITIES

Urban vehicle traffic is a significant contributor to greenhouse gas emissions globally. Global greenhouse gas emissions from the transport sector excluding aviation and shipping grew more than from any other sector in previous decades, increasing from approximately 2.8 $GtCO_2e$ in 1970, to approximately 7.6 $GtCO_2e$ in 2014 (Sims et al. 2014; IEA/OECD 2017). Urban areas account for approximately 50% of these emissions (IEA 2016b). Despite its rapid growth in previous decades, emissions from the sector look to continue to grow at a considerable rate, in particular due to anticipated growth of transport demand and activity in developing countries. Under current policy projections, global transport sector emissions excluding shipping and aviation are projected to increase from 7.6 $GtCO_2e$ in 2014 to approximately 10-11 $GtCO_2e$ in 2050. In contrast, compatibility of the sector with the goals of the Paris Agreement would require transport emissions to significantly reduce to 2-3 $GtCO_2e$ by 2050 (IEA/OECD 2017).

Achieving the major slashes in emissions in the transport sector requires going beyond technological improvements for enhanced energy- and emissions-intensity of transport activity, to the broader transformation of the transport sector; the Avoid-Shift-Improve paradigm currently pursued by many policy makers includes travel demand reduction and mass modal shift to public transportation, as well as technological efficiency improvements (GIZ 2004). The urban action scenario of ARUP & C40 Cities (2016) indicates a mitigation potential by 2050 of approximately 300 $MtCO_2e$/year from enhanced bus services and bus rapid transit in cities of the C40 network worldwide, identifying this as the most important measure for reducing emissions in urban transport in these cities.

The provision of enhanced bus networks to shift private vehicle users to public transport networks is a key priority for many cities. Problems associated with excessive volumes of single occupancy private vehicles manifest themselves as major everyday issues for productivity and quality of life for most city dwellers: time lost to rush hour congestion, accessibility disadvantages and health-endangering local air pollution are examples of major issues that most city dwellers accept and deal with on a daily basis.

Measures to improve these conditions through bus network enhancement are tangible and have high visibility within a relatively short period of time, which should make such measures highly attractive to politicians at the subnational level. Since subnational governance usually exercise strong power over urban public transport, often through direct ownership or influence in investments and operational of public transport assets, enhanced bus networks are a feasible and attractive option.

> “Air pollution caused by petrol and diesel vehicles is killing millions of people in cities around the world. Working with citizens, businesses and mayors of these great cities[22], we will create green and healthy streets for future generations to enjoy.”
>
> **Anne Hidalgo**
> Anne Hidalgo Mayor of Paris and C40 Chair

[22] “The mayors of London, Paris, Los Angeles, Copenhagen, Barcelona, Quito, Vancouver, Mexico City, Milan, Seattle, Auckland & Cape Town committed to a series of ambitious targets, including procuring zero-emission buses from 2025 to make their cities greener, healthier and more prosperous by signing the C40 Fossil-Fuel-Free Streets Declaration in October 2017. http://www.c40.org/other/fossil-fuel-free-streets-declaration

5.2 POTENTIAL IMPACTS OF ENHANCED BUS NETWORKS AND BUS SERVICES

Transport systems are so deeply integrated in urban planning and urban lifestyles, that the impacts of improvements in public bus transportation networks are felt beyond the users of the networks, also extending to businesses, city dwellers and the wider economy. Table 8 gives an overview of some of the key potential impacts from the improvement of bus networks and services including considerations on equity. Both positive ("+") and negative ("–") impacts are listed.

Table 9. Overview of some potential direct and indirect outcomes and impacts from improvement of bus networks.

TYPE OF IMPACTS	EXAMPLES OF OUTCOMES AND SPECIFIC IMPACTS	EQUITY CONSIDERATIONS
Social impacts (Health and safety impacts)	+ Health benefits from improved air quality due to reduced traffic (reduced emissions of local air pollutants from vehicles) + Reduced fatal and non-fatal injuries (due to reduced congestion and improved transport safety) + Stress reduction due to enhanced quality of environment + Health impact from increased exercise in between public transport journeys	Lower income communities are often in areas of greater exposure to pollution and risk of road fatalities.
Social impacts (Quality of Life and Urban Liveability, Culture and Institutions)	+ Reduced community fragmentation caused by wide, high-speed roads by private vehicles + Available personal time (reduced travel time due to reduced congestion	Such community fragmentation normally occurs in lower-income communities.
Economic impacts (Individuals)	+ Higher disposable income for households (cost savings from reduced of car ownership and maintenance) + Improved employment opportunities due to improved mobility: better access to jobs and services due to reduced congestion, reduced journey times, and enhanced public transport links + Potential reduced price of public transport for users due to reduced marginal cost of service from the increase in ridership – Alternatively, price of public transport could increase to users if expensive investments are to be recouped, depending on implementation model	Lower income groups are often the most marginalised and the most restricted in terms of mobility and accessibility to jobs and urban services. These groups have the most to gain from enhancements.
Economic impacts (Wider economy)	+ Cost savings and enhanced energy security through reduced dependence on fossil fuels + Increased productivity through reduced travel time + Energy conservation for use in other economic activities + Technology spill-overs and enhanced development of markets for advanced technologies – Potential loss of jobs in car manufacturing industries – Opportunity costs of investments in expensive public infrastructure, unless private finance is leveraged	The loss of jobs in car manufacturing industries could negatively affect local skilled and unskilled workers unless adequate retraining programmes are put in place for jobs in new industries related to bus infrastructure.
Environmental impacts	+ Improved air quality + Noise reduction + Reduced greenhouse gas emissions + Improved water quality from reduced polluting emissions and fluid leaks + Reduced habitat fragmentation when linked with strategic land-use planning objectives	

Source: Authors' elaboration based on VTPI (VTPI 2015), Broaddus et. al. (Broaddus et al. 2009), Sims et. al. (Sims et al. 2014).

>>>>>>>>>>>>>>>>>>>>>>>>

5.3 SCOPE OF ANALYSIS

Regions

The analysis of benefits and impacts for enhanced bus networks is presented in this report for cities within **North America** and **Latin America**[23]. These regions were selected for analysis due to the differences between the structure of urban transport sector at present, and differences in projected activity trends for the future. Enhancement of bus networks and services is a key issue in the cities of both regions, with great opportunities for GHG emission reduction. A summary of the present situation of urban transportation in these regions is presented in Table 10. The information shows that the regions are very different from one another with regards to the starting situation for urban passenger transportation; whilst urban planning and infrastructure investments in many North American cities were based around optimal compatibility with private light duty vehicles (LDVs), leading to a major reliance on this mode of transport, modes of transport in Latin American cities are far more variable, infrastructure developments without a detailed urban planning in some cities causing a significant lock-in as infrastructure is young, while others remain fairly underdeveloped. Another key difference between the two regions is that whilst Latin America will still have to make significant investments in new transportation infrastructure for substantial projected increases in travel demand over the coming decades, offering the option to plan for more sustainable transport trajectories, significant modal shift in North America will require the re-design and replacement of existing infrastructure for which there is a considerable degree of perceived lock-in. These different starting positions, combined with behavioural differences and perceptions of the bus systems, may have implications for the extent to which measures for enhanced bus networks can affect modal shift away from private to public transport.

Table 10. Situation of urban transportation in North America and Latin America in 2015.

	NORTH AMERICA	LATIN AMERICA
Urban population[1]	292 million	506 million
Daily commuters[2]	115 million	203 million
Total urban passenger transportation activity for all modes[3]	2.7 trillion passenger-kilometres; 1.8 trillion vehicle-kilometres (projected growth of 20% up to 2050)	1.3 trillion passenger-kilometres; 440 million vehicle-kilometres (projected growth of 35% up to 2030)
Urban bus passenger transportation activity[3]	207 billion passenger-kilometres	413 billion passenger-kilometres
Transportation activity per capita[4]	9 km per capita per day	<3 km per capita per day
Modal split of urban transport[3]	91% light duty vehicles; 8% bus; 1% other.	59% light duty vehicles; 32% bus; 9% other. Public transport usage varies from 23% in Guatemala to 73% in Ecuador.
Cities with BRT[5]	16 cities, with network length of 448 km (<10% of all BRT systems in cities globally); 810,000 passengers per day	54 cities, with network length of 1,757 km (33% of all BRT systems in cities globally); 19.4 million passengers per day
Average speed of bus transport[6]	20.6 km/h	15.1 km/h

Sources: 1 – World Development Indicators (World Bank 2017); 2 – OECD (2017b); 3 – OECD (2017a); 4 – Authors' calculations; 5 – BRT Data (BRT Centre of Excellence et al. 2017); 6 - Hertz (Hertz 2015), Muñoz et al (2013).

[23] For this analysis, North America includes Canada and the United States of America; Mexico is analysed within the Latin America group. The Latin America group also includes the Caribbean.

Scenario parameters

While many measures are available to improve the transport networks of a country or region, in this study we focus only on those related to bus networks and bus services, leaving out measures related to light rail systems or mass rapid transit (MRT) systems which might include on-street or underground trains. The analysis for the potential of enhanced bus networks considers the impacts of the following measures:

- **Increasing network length of bus system:** Increases in the total network length increase the network density, which increases the feasibility and convenience of access to the public transport network for the population.
- **Increased frequency of bus service:** Increases in the frequency of service, through the provision of more buses, facilitate an increase in the hourly ridership capacity, and also improve the convenience of public transport and the attractiveness of its use.
- **Usage of dedicated bus lanes / bus rapid transit:** Cities can demarcate lanes of existing roads for use as dedicated bus lanes with limited or no access to other vehicles. Lanes or busways can also be constructed specifically for buses. A further extension on this concept is the introduction of complete bus rapid transit (BRT) systems. Dedicated lanes are the key feature of BRT systems, which also often feature prioritisation of bus traffic at intersections, and features to maximise the efficiency of the boarding and offboarding process, for example through sophisticated stations with raised platforms and ticket machines. Well planned and enforced dedicated bus lanes and BRT systems can increase the speed and reliability of conventional bus systems, increasing the attractiveness of their use.
- **Penetration of low carbon buses in the vehicle stock:** A variation of definitions on low carbon emission buses exist. Some consider buses to be low carbon technology if they run on any fuel but achieve specific emission reductions compared to current efficiency standards. In other sources only low or zero emission technologies are included, such as fuel cell or electric drive technologies[24]. The analysis in this study considers primarily the latter under the category of low carbon buses. The rate at which low- and zero-carbon buses can be introduced to the public transport fleet may depend upon the age of the existing fleet and the options available for de-commissioning older vehicles.

Section 5.4 provides details on the scenarios assessed in this analysis.

Impacts

This study focuses on the outcomes and impacts of enhanced bus networks in cities for **premature mortality from outdoor air pollution, reduced road fatalities and available personal time**, measured through **potential commuter time savings**[25].

- Change in **premature mortality from outdoor air pollution** is assessed based on the impact of transport system changes on the emissions of air pollutants, and the consequent changes in the concentration of fine particulate matter ($PM_{2.5}$) in urban areas. This includes all-cause mortality from $PM_{2.5}$.
- The assessment of **road fatalities** is associated with changes in the volumes of traffic on public roadways and the consequent changes in the number of accidents. This includes all fatalities that are linked to traffic accidents on public roadways, including amongst vehicle passengers, other road users and pedestrians.
- The analysis **available personal time**, measured through **potential time savings for commuters** assesses the extent to which the segregation of bus lanes through the use of modern BRT or conventional private bus lanes may reduce commute times for public transport users, and the extent to which the reduced commute times may increase mobility and accessibility to economic opportunities for peri-urban populations[26].
- These impacts were selected for analysis based upon analysis from C40 and input from C40 cities on the most relevant issues for decision makers, as well as feasibility of the quantitative analysis.

[24] Assuming a decarbonised power sector

[25] Annex I includes a flow chart summary of the methodological steps for the quantitative assessment of these impacts, whilst full details are included in the separate technical methodological document.

[26] Considering feedback loops associated with commuters "optimising" their lifestyles based on a willingness to travel for a certain amount of time, which could result in them moving to areas further away from the city centre and maintaining the original commute time.

5.4 SCENARIOS FOR ENHANCED ACTION

Table 11 introduces the scenarios which are analysed for North America and Latin America in this study. The enhanced bus networks scenario parameters would result, according to the model, in reducing private vehicle usage in North America by approximately 22%, compared to the reference scenario case, and by 35% compared to the reference case in Latin America. This is in line with the potential identified in the robust governance scenario of the ITF Transportation outlook 2017 (OECD 2017a). This outcome would also be in line with the identified potential from ARUP & C40 Cities' urban action scenario (ARUP & C40 Cities 2016), the IEA's BLUE Shifts scenario (IEA 2009b), and the 2DS scenario from IEA's ETP (IEA 2016b)[27].

Table 11. Scenarios for analysis of impacts of enhanced bus networks.

REFERENCE SCENARIO (2015-2030)

For all regions, total transportation activity is projected to increase up to 2030, under a reference scenario (OECD 2017a; IEA/OECD 2017; ICCT 2017). Projections for bus network measures are estimated by the model based on the anticipate needs for the network to cope with the increase in passenger public transport which is forecast under current policy projections (OECD 2017a). The share of electric buses increases to approximately 25% in North America, and 5% in Latin America, in line with emission intensity projections of the 2017 ICCT Roadmap Model baseline (ICCT 2017).

	NORTH AMERICA	LATIN AMERICA
Network length of bus system	~25% increase	~21% increase
Frequency of bus service	~28% increase	~25% increase
Usage of dedicated bus lanes	Remaining constant (~1% of total network length)	Remaining constant (~4% of total network length)
Share of zero-carbon buses	Increase from ~1% to ~25%	Increase from <1% to ~5%
Growth of transport activity	20% increase	47% increase
Share of public transport	Remaining constant (8-9%)	34% (2015) to 31% (2030)

[27] See the separate Technical Note document for further information on the construction of the methodologies.

ENHANCED BUS NETWORKS SCENARIO (2015-2030)

In the enhanced bus networks scenario, major network improvements are implemented by 2030 for increasing bus network length and service frequency by 300% in North America, and 100% in Latin America, to increase passenger numbers in line with the Robust Governance scenario of ITF 2017 (OECD 2017a). Dedicated bus lanes or BRT corridors are introduced to cover 50% of the bus network by 2050; it is assumed that these measures will require gradual investments which will be complete by 2050, with partial progress by 2030, as indicated in the table below. The share of zero-carbon buses reaches 100% by 2030.

	NORTH AMERICA	LATIN AMERICA
Network length of bus system	~300% increase	~100% increase
Frequency of bus service	~300% increase	~100% increase
Usage of dedicated bus lanes	Increase to 22%	Increase to 24%
Share of zero-carbon buses	Increase to 100%	Increase to 100%

Figure 14 shows how North America and Latin America have very different starting situations when it comes to transportation activity and modal split. Transportation activity in urban areas added up to approximately 9 km per capita per day in North America in 2015, of which private vehicle use accounted for 91%. By contrast, urban transportation activity in Latin America was less than 3 km per capita per day in 2015, with private light duty vehicles (LDV) accounting for 59% of this activity. Whilst the United States accounted for the largest volume of private motorised urban transportation in the world in 2015, major Latin American cities have positioned themselves as world leaders in the piloting and further development of BRT systems. 61% of BRT transportation activity worldwide is in Latin America, where these networks transport approximately 19.4 million passengers per day (BRT Centre of Excellence et al. 2017).

The high share of LDVs use in North America is projected to further increase in the coming decades under a reference scenario, along with total passenger transportation activity, as Figure 10 shows. Just two modes of motorised transport carried major significance in the region in 2015, with private vehicles and buses accounting for approximately 99% of urban journeys collectively, and activity within both of these modes is projected to increase by approximately 20% up to 2030, maintaining the current modal split shares. This projection represents a feasible, yet conservative estimate; whilst the reference scenario for North America in this analysis is in line with estimates from most studies (e.g. OECD 2015; OECD 2017a). Other models (e.g. ICCT 2012) project a far higher increase in activity of private vehicles, which would push the modal split share of private vehicles even higher.

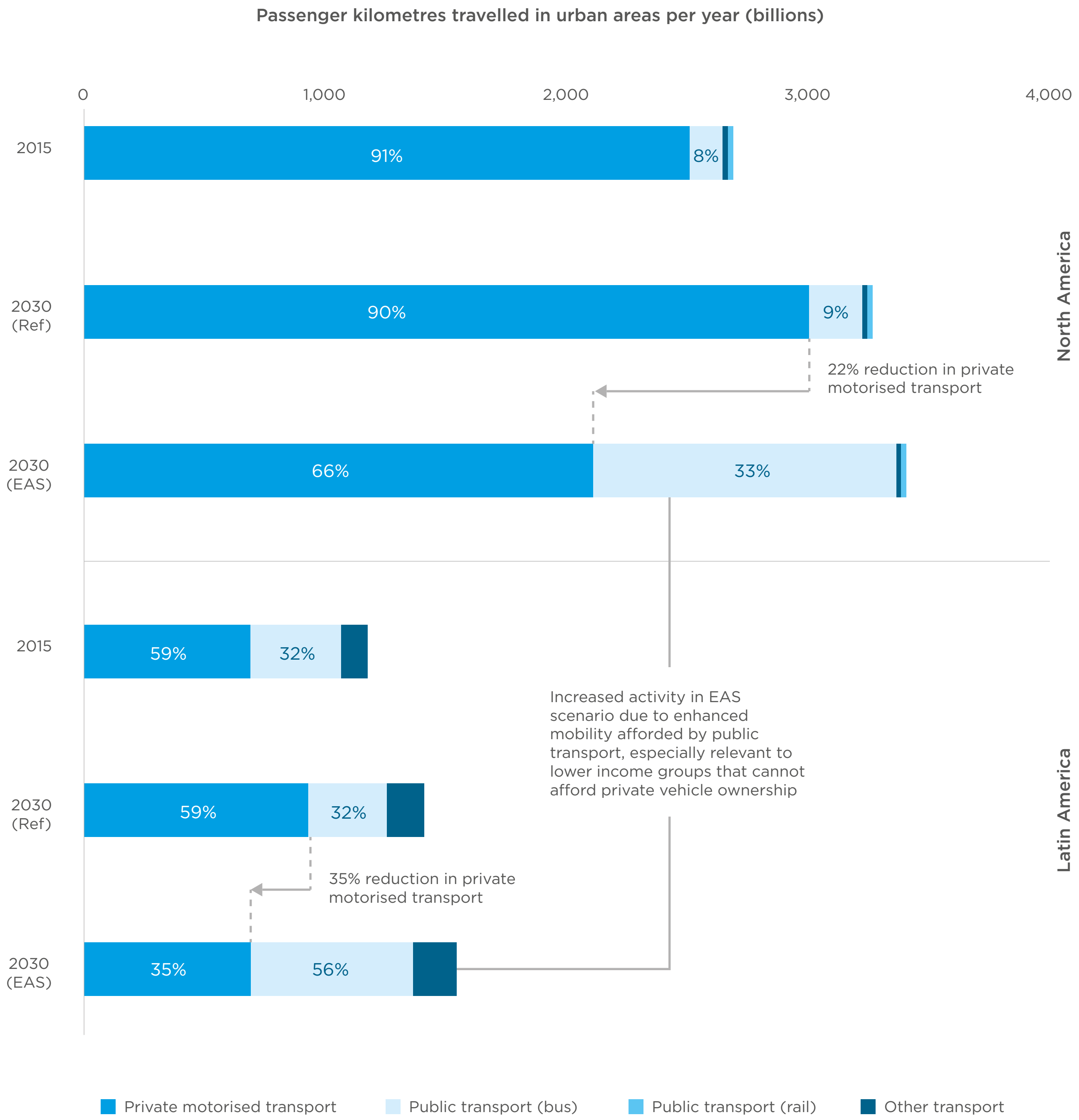
A significant increase in urban passenger transportation activity is projected for Latin America, where urban population growth, economic development and increased mobility for disadvantaged groups will provide an upwards driving force on transport demand. Accounting for growth in overall transport activity, this entails roughly a 35% increase of LDV activity between 2015 and 2030. This scenario could cause significant problems for Latin American cities, many of which already face considerable struggles with current levels of urban congestion, and the negative implications that it incurs; the rapid increase in urban population in recent decades alongside a relative lack of urban planning interventions has led to a diverse, yet underdeveloped and fractured urban transportation system (Jirón 2013), and the absorption capacity for increased traffic volumes is particularly limited in many cities.

The implementation of measures to enhance bus networks can have a significant impact on reducing private vehicle activity in 2030. Figure 14 shows that measures could achieve a 22% reduction in LDV activity in North American cities by 2030, and as much as a 35% reduction in Latin America[28]. In North America, the enhanced bus network scenario would see LDV activity fall to nearly 10% below its 2015 level, with total vehicle-kilometres travelled and road congestion also falling. These shifts would be initiated by rapid increases in the number of bus riders under the enhanced bus networks scenario, with bus passenger activity more than doubling in Latin America and increasing by a factor of five in North America between 2015 and 2030. An overall increase in the passenger kilometres travelled can be observed in both regions under the enhanced action scenario, compared to the reference scenario; this is due to the enhanced mobility options that improved public transport may entail for those who previously had a lack of access to private or public transport for some journeys.

[28] See Annex I for information on calculation methodology.

The enhanced action scenarios would reduce GHG emissions by approximately 80 $MtCO_2e$ in North America and 40 $MtCO_2e$ in Latin America in 2030, compared to the reference scenario. The implications of the scenarios for GHG emission reductions are explored in more detail in section 5.5.1.

Figure 14. Modal shift from enhanced bus networks in North America and South America.



Source: Results from authors' modelled analysis.

5.5 QUANTIFIED IMPACTS OF ENHANCED BUS NETWORKS

5.5.1 Premature deaths from outdoor air pollution

One in eight of total global deaths in 2012 - around 7 million people – was related to excessive exposure to air pollution (WHO, 2014). Previous research from NewClimate Institute found that enhanced climate change mitigation contributions, in line with trajectories for 100% renewable energy (including the transport sector) by 2050, could result in the reduction of over 2.5 million premature deaths annually by 2030 in India, China, the EU and the US combined (Day et al. 2015).

Urban transport is a major contributor to the health risks of air pollutants: pollutants from vehicles are emitted directly into the streets on which the majority of the population move, work and live. Congested areas in inner-cities are the places with both the highest density of local air pollutant emissions from vehicles and the highest density of human activity. Enhanced bus networks and measures to affect modal shift can reduce the emissions of air pollutants in cities, and the associated health impacts, by reducing the number of polluting vehicles on the street, by reducing the emission of pollutants from public transportation vehicles, and by reducing the amount of congestion which leads to higher emissions per kilometre travelled.

In this section, several measures for enhanced urban public transportation are assessed for their impacts on shifts in passenger transportation activity and emissions from urban transportation, with consequent impacts for outdoor concentrations of fine particulate matter ($PM_{2.5}$)[29] and its effect on premature mortality. The analysis includes all-cause mortality from air pollution exposure, but does not include other significant impacts on human health and the related economic and social costs from non-lethal conditions such as chronic and acute bronchitis, or asthma.

Figure 15 shows that the average exposure to concentrations of $PM_{2.5}$ in exceeded the WHO's guidelines of 10 ug/m^3 by more than two times in Latin America in 2015. Pollution levels are considerably worse in Latin American cities, although North American cities have far higher emissions, both from the transport sector as shown in Figure 15, but also from other sectors. There are several reasons for this apparent mismatch: firstly, local climatic conditions are a major factor influencing the propensity of air pollutants to remain in the local ambient area; secondly, emissions of pollutants from less compact cities – such as the typically sprawled cities of North America – are diffused across a larger area resulting in lower concentrations; thirdly, developed county regions are more likely to have greater penetration of modern technologies for efficient combustion and cleaner emission exhausts, causing some of the most harmful air pollutants to be partially filtered of emissions; finally, the political framework in terms of environmental quality standards, as well as its enforcement, have proven to be more robust and strict in developed county regions, limiting the concentration of harmful air pollutants that can be released into the ambient.

Despite improvements in reducing the emissions of air pollutants from vehicles in recent decades in North America, outdoor air pollution remains a significant strain on public health in the region. It was estimated that outdoor air pollution of all causes led to the premature deaths of over 100,000 people in United States and Canada in 2012 (Day et al. 2015). The transport sector is the greatest single contributor to this significant health burden (MIT 2013), accounting for over a quarter of $PM_{2.5}$ concentrations in 2015, with urban populations at particularly high threat.

Levels of outdoor air pollution and subsequent health impacts are generally projected to improve in North America between 2015 and 2030, under a reference scenario, despite the growth in vehicle traffic, due to a combination of factors. Improvements in energy efficiency, ongoing reductions in the emissions intensity of power generation and industry, and technological improvements that prioritise the reduction of harmful air pollutants from emissions will lead to a general decline in the emissions of air pollutants from power and industry. The consequent reduction in the concentration of $PM_{2.5}$ in urban areas under the reference scenario may not lead to a significant reduction in the number of air pollution related premature deaths between 2015 and 2030, as shown in Figure 15, since urban population growth and an ageing population will increase the number of people exposed; outdoor air pollution is projected to account for approximately 65,000 premature deaths per year in North America between 2015 and 2030. By 2030, urban transport will be attributable to an increasingly large share of remaining outdoor air pollution: whilst the emissions of air pollutants from other sectors will decrease between 2015 and 2030 under current policy scenarios, the same trend is not projected for the urban transport sector in North America, where technological and efficiency improvements are not projected to adequately compensate for increased activity. Figure 15 shows that the enhanced action scenario for bus networks could lead to an approximately 24% reduction in the emission of air pollutants from the urban passenger transport sector in North America in 2030, compared to the reference scenario, resulting in approximately 6,000 prevented deaths each year from air pollution related disease.

[29] Particulate matter (PM) includes all solid and liquid articles suspended in the air. PM2.5 refers to particles that are less than 2.5 micrometers in diameter. PM2.5 concentrations are often the major focus of air pollution analysis, since these small particles have the most significant health impacts since their fine size causes them to be drawn deeper into the lungs, compared to larger particles which may be more easily filtered by the body.

The impact of the enhanced scenario in Latin America is projected to be even greater. In Latin American cities, transport activity is a main source of direct and indirect pollution. On average, urban transport emission are attributed as the source of 31% of fine particulate matter in urban areas in 2015 (Karagulian et al. 2015). The burden of air pollution in the region has been equated to a welfare loss equivalent to 2% of annual GDP (Sanchez et al. 2016). Figure 15 shows that exposure to fine particulate matter in cities will decrease by more than a quarter under a reference scenario up to 2030, despite considerable increases in activity and emissions from transport. This is due to the anticipated increased uptake of cleaner emitting technologies across all sectors. Nevertheless, large increases in the urban population and the ageing of the urban population mean that the number of annual premature deaths related to air pollution is projected to rise to nearly 200,000 by 2030. In Latin American cities, the enhanced bus networks scenario could lead to a 32% reduction in the emission of air pollutants from urban passenger transport, compared to the reference scenario, resulting in the prevention of approximately 30,000 premature deaths per year. This scenario would also entail an absolute reduction in the emissions from the sector between 2015 and 2030.

The distributional spread of the significant health benefits from the enhanced action scenario across different population groups is mixed. These benefits will be most concentrated in areas of high traffic density, typically in inner-cities and/or areas of cities with low development of public transport. Inner city areas may include higher- or lower-income groups, depending on the city structures. Likewise, areas of public transport blackspots could be caused by low demand due to high car ownership in higher-income areas or by the underdevelopment of infrastructure in underserved low-income areas.

Figure 15. GHG emissions from urban passenger transport, average $PM_{2.5}$ exposure and annual premature deaths from air pollution in cities of North America and Latin America.

Source: Results from authors' modelled analysis

Table 12. GHG emissions from urban passenger transport, average $PM_{2.5}$ exposure and annual premature deaths from air pollution in cities of North America and Latin America.

SCALING DOWN THE RESULTS			
Prevented premature deaths in 2030 (compared to reference scenario)	North America	1-million city	20 prevented premature deaths
		C40 network cities	640 prevented premature deaths
	Latin America	1-million city	45 prevented premature deaths
		C40 network cities	3,800 prevented premature deaths s
Emission reductions in 2030 of enhanced action scenario (compared to reference scenario)	North America	1-million city	270 $ktCO_2e$
		C40 network cities	9.4 $MtCO_2e$
	Latin America	1-million city	54 $ktCO_2e$
		C40 network cities	4.6 $MtCO_2e$

Scaled down results are indicative approximations based on population and not bottom up evaluation of specific cities.

5.5.2 Road traffic accident fatalities

Motor vehicle crashes is the leading cause of death amongst 15-29 year olds globally, and within the 10 top causes of death for all other segments of the global population (World Bank 2014). Motor crashes were responsible for 1.25 million deaths in 2013 and it is estimated that road traffic fatalities and injuries account for economic losses equivalent for approximately 3% of GDP globally and 5% of GDP in low- and middle-income countries (WHO 2015). It is a target of the Sustainable Development Goals (SDG 6.3) to reduce global road fatalities by half by 2020.

Implementing improved bus systems can contribute to reductions in traffic accidents and fatalities in different ways. A shift in transportation activity from private vehicle to public transport results in fewer vehicle-kilometres travelled, fewer drivers on the road and consequently a safer transport environment for drivers, pedestrians and cyclists alike. Dedicated bus lanes also reduce interaction between buses and other vehicles, minimising the risk for traffic crashes between these modes. Latin America reports statistics an average 40% reduction in fatalities and injuries in streets where a BRT system is in place. The expansion of bus services can also be easily delivered alongside improved driver training, since new jobs for drivers will be created by the service expansion.

This section analyses projections for all road fatalities that are linked to traffic accidents on public roadways, including amongst vehicle passengers, other road users and pedestrians.

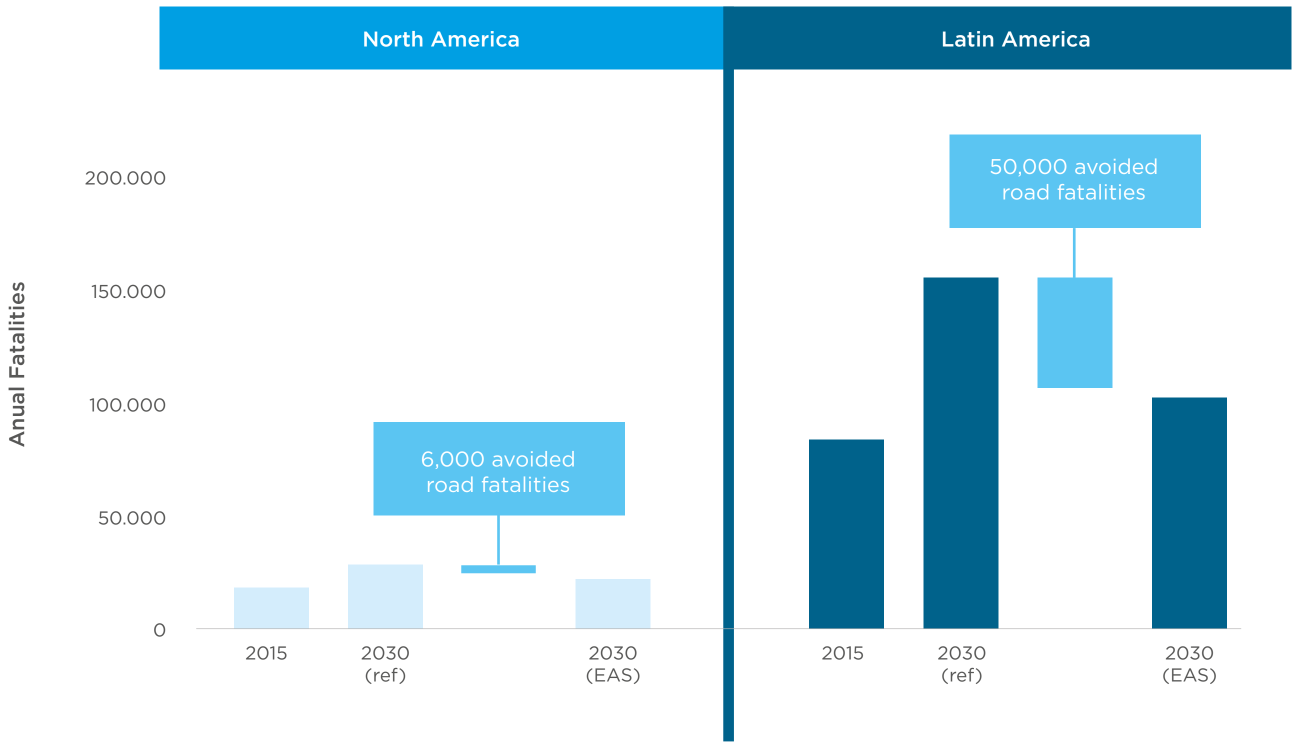
Figure 16 shows a stark contrast between current rates of fatality between North America and Latin America. More than 80,000 road traffic fatalities were recorded in Latin American cities in 2015 (WHO 2017; NHTSA 2013), equating to a rate of 16 deaths per 100,000 capita. This is more than double the rate of 6 deaths per 100,000 capita in North America, although road fatalities are one of the major causes of death in the North American region, with over 17,000 deaths in cities in 2015 (WHO 2017; IADB 2015).

In contrast to the goal of SDG 6.3 to reduce global road fatalities by half by 2020, Figure 16 shows fatalities are projected to increase under a reference scenario in both regions up to 2030 due to further projected increases in urban transport activity and congestion, taking annual fatalities in the two regions combined to approximately 180,000.

The measures levered in the enhanced bus networks scenario could lead to a reduction of approximately 56,000 road traffic fatalities per year in the two regions combined, compared to the reference scenario. The vast majority of this decline is projected from Latin America, where approximately 50,000 deaths could be prevented. Nearly 6,000 deaths could be avoided in 2030 under the enhanced scenario in North America. The large disparity in the potential impact between the regions is due to the significant difference in the starting situation between the two regions, and also differences in the extent to which the measures are projected to be able to reduce LDV activity and reduce congestion in urban areas.

The benefits of the enhanced action scenario for reducing fatalities is relevant for all regular road users in the urban area, which includes all population groups across society. Lower-income groups may be slightly more affected by these benefits since higher-income groups generally have a lower exposure to road traffic accidents per km travelled, due to ownership of modern and safer cars, and residence in safer and well-policed areas.

Figure 16. Road traffic accident fatalities in urban areas of North America and Latin America.



Source: Results from authors' modelled analysis.

Table 13. Scaling down the results to cities and the C40 city network.

SCALING DOWN THE RESULTS			
Annual traffic accident fatalities in urban areas (2030)	North America	1-million city	20 prevented premature deaths
		C40 network	600 prevented premature deaths
	Latin America	1-million city	70 prevented premature deaths
		C40 network	6,000 prevented premature deaths

Scaled down results are indicative approximations based on population and not bottom up evaluation of specific cities.

5.5.3 Potential commuter time savings

Traffic congestion is a significant burden for commuters in all regions of the world. In 2015, the commuter in the average city was assessed to have lost around 40 hours per year to congestion during their commutes (INRIX 2017). In some cities, including cities in North America, Latin America and Europe, the average commuter lost over 80 hours during 2015, equivalent to 2 full working weeks. Several countries have estimated the annual costs of congestion for commuters into the billions; in the United States, for example, it is estimated that congestion cost commuters approximately USD 300 billion in 2016 (INRIX 2017).

Congestion is a major cause of excessive commute times, exacerbated by deficiencies in public transport infrastructure in many cities. Other socioeconomic factors such as housing costs also play an important role in determining commute times, since high inner-city housing prices may force or encourage people to move further away from their workplaces. The segregation of buses from public roadways to dedicated lanes can make a considerable impact on travel time reduction for commuters using public transport; bypassing congested roads with dedicated bus lanes may save on average up to 2 minutes per kilometre travelled (Levinson et al. 2003).

This section analyses the extent to which the segregation of bus lanes, through the use of modern BRT or conventional private bus lanes, may reduce commute times for public transport users. We also evaluate the extent to which the reduced commute times may increase mobility and accessibility to economic opportunities for peri-urban populations, which in some regions is likely to include a high proportion of disadvantaged communities. It should be noted that alongside this benefit, that there may be a temporary negative impact caused by additional congestion for other road users during the time of construction and introduction of segregated lanes.

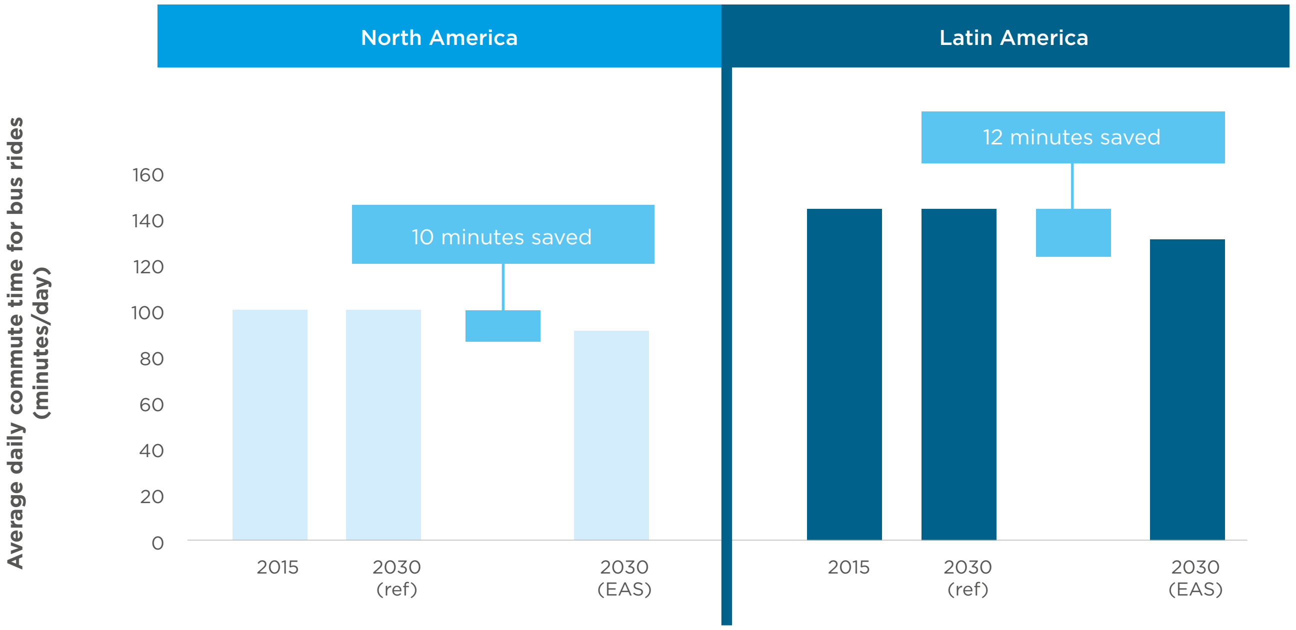
Average commute times in North America and Latin America in 2015, including two daily journeys, were around 100 minutes, and 140 minutes, respectively. Figure 17 shows that commuting times up to 2030 under the reference scenario will likely remain relatively constant, whilst the segregation of bus lanes under the enhanced bus networks could lead to time savings of approximately 10% and 9% in North America and Latin America, respectively, or approximately 10-12 minutes per day[30]. For the average commuter with a 48-week working year, this potential time savings adds up to a significant 40-48 hours per year, equivalent to a week's full-time work, which could otherwise also be leisure time. This time saving is an average across all commuters using bus networks, assuming that bus lane segregation is implemented in equal measures across all routes. For example, in the scenario that 22% of the bus network uses segregated lanes by 2030, the average bus riders will benefit from segregated bus lanes for 22% of their journey length. This average is unlikely to be an accurate representation, since some lines may be preferred for segregated lane development; therefore, some commuters may not benefit from the measures at all whilst others benefit from this for the entire duration of their route. For commuters where 100% of their route is segregated from other road traffic, commuting times may be reduced by more than 45% in North America, and 35% in Latin America.

Under the enhanced bus networks scenario, we estimate an average potential time saving of 10-12 minutes per day for a commuting population of 45 million daily bus riders in North America and 155 million daily commuters in Latin America. This translates into a total of 1.8 billion hours and 7.5 billion hours saved across public transport commuters in North America and Latin America, respectively. For the economy as a whole, this time is comparable to that spent by over 940,000 full time equivalent workers in North America and 3.9 million full time equivalent workers in Latin America. The economic value of this time could be worth approximately USD 11.9 billion in North America and USD 7-10 billion in Latin America by 2030. The effective time reduced per journey may be greater still if one considers separately the time spent in walking to the nearest entry point for public transport; walking occupies a greater portion of the journey for public transit users than it does for those with private transport. This increase in physical activity contributes to a healthy lifestyle, which according to the World Health Organization, should include at least 150 minutes of moderate-intensity aerobic physical activity throughout the week.

This calculated impact is only a potential. In reality, there are multiple feedback loops associated with this outcome which may mean that the potential time savings are not realised: for example, there is evidence to indicate that commuters may "optimise" their lifestyles and the distance of their journeys based on a willingness to travel for a certain amount of time (Marchetti 1994; Axhausen 2010). As such, commuters may respond to time savings by moving to areas further from the city centre, which may incur an economic advantage for the commuter. Alternatively, if sufficient incentives are in place to avoid this spread, the time savings may be utilised for increased economic productivity, or for a multitude of purposes that may increase quality of life. For example, the average commuter with a potential 10% time saving in North America and 9% in Latin America could choose to move up to a further 3.7 km and 2.5 km away from their commuting destination, respectively, to optimise their economic situation, if they are content with their commuting time. Whilst this may entail an economic benefit for individuals, it may also entail negative connotations associated with potential urban expansion and sprawl; urban planners should consider carefully how to address potential feedbacks, in the design of such measures. On the other hand, this increase in the acceptable commute distance may increase mobility and accessibility to city centre services and employment opportunities for marginalised communities on the peripheries of cities. This is particularly relevant in developing countries where informal settlements on city peripheries are often poorly connected to urban opportunities.

[30] See Annex I for information on calculation methodology.

Figure 17. Potential commuter time savings from enhanced bus networks in North America and Latin America.



	NORTH AMERICA	LATIN AMERICA
Commuters using bus networks in 2030 (ES)	45,302,907	155,882,905
Impact for average commuter using bus networks under enhanced scenario		
Commute time saved	10%	9%
Minutes per day saved	10	12
Hours per year saved	40	48
Combined impact across population under enhanced scenario		
Million hours commuting time saved per year	1,806	7,482
Equivalent additional full-time workers*	940,541	3,896,629
Estimated annual economic value**	ca. USD 11.9 bn	ca. USD 7–10 bn
Combined impact for average 1-million city under enhanced scenario		
Million hours commuting time saved per year	6.2	10.7
Equivalent additional full-time workers*	3,220	5,575
Estimated annual economic value**	ca. USD 41 million	ca. USD 10-14 million
Combined impact for C40 Cities network under enhanced scenario		
Million hours commuting time saved per year	204	910
Equivalent additional full-time workers*	106,000	474,100
Estimated annual economic value**	ca. USD 1.35 bn	ca. USD 0.85-1.2 bn

*Source: Results from author developed quantitative analysis models. *The number of equivalent full-time workers is included as a demonstrative reference point. It may not be that the impact on the economy is equivalent to this additional workforce, since potential time savings will not only be used for productive purposes. **The estimated annual economic value is a preliminary estimate, which will be further analysed for future outputs of the project.*

>>>>>>>>>>>>>>>>>>>>>>>>>

5.6 CASE STUDY

Case studies from Seattle and Rio de Janeiro illustrate, at the local level, how this action is delivering GHG emission reductions while also addressing multiple benefits to the population.

5.6.1. Seatle

Background

Road transportation is the largest single source of climate and air pollution in the city, representing two thirds of Seattle's greenhouse gas emissions. It disproportionately impacts communities of color and lower income residents (Seattle Office of Sustainability & Environment 2017). The challenge is amplified as the population is expected to grow almost 20% in the next 20 years.

Action

Seattle has been developing a wide transportation program largely focused on smart growth policies combined with the enhancement of bus and light rail networks and services to help achieve the goal of carbon neutrality by 2050, while transforming the city into a greener, healthier, and more prosperous place to live. Seattle's urban village strategy provides the foundation for their climate-friendly transportation policies (Seattle Office of Sustainability & Environment 2017).The RapiRide System, a premier bus service with dedicated corridors, will be expanded from 3 lines to an integrated bus network with 10 lines and the city committed to transition to Fossil-Fuel-Free Streets by only procuring zero-emission buses from 2025 (C40 Cities 2015).

Benefits

Seattleites are spending less time in traffic, riding more in public transit, driving cleaner cars, and putting less miles on them. The reduction of vehicle miles travelled is a key enabler to support achieving the goal to end serious and fatal crashes by 2030 (City of Seattle 2017). Recent commute trip data show nearly half of commuters rely on transit and overall decrease of 4500 drive-alone commuters – despite employment growth of 60,000 jobs since 2010 (City of Seattle, 2017b). The expansion of the RapidRide System is expected to speed up travel time during the busiest commute hours by around 10 – 15% and improve to 85% the number of trips coming on time. The decarbonisation of the bus fleet will further enhance the air quality minimizing public health impacts.

Figure 18. Electric bus being tested in Seattle (Puget Sound Business Journal 2015).

Source: https://www.bizjournals.com/seattle/blog/techflash/2015/11/king-county-metro-starts-testing-100-electric.html

"As one of the fastest growing cities in the U.S., Seattle is a leader nationwide in cutting our emissions and building a climate friendly city. Cities don't have the luxury of climate denial and cannot wait for federal leaders to embrace science. The effect of inaction is already at our doorstep. Our bold and transformative investments in our green economy, resilient infrastructure and transportation provide a strong foundation on which to build the next generation of climate actions."

Mayor Durkan
City of Seattle

5.6.2. Rio de Janeiro

Background

Over the past 15 years, the lack of long term integrated planning (land use and transport) and low quality offerings of public transportation, associated with national government subsidies of gasoline prices and incentives for private vehicle acquisition, generated a steep increase in the use of private vehicles in the city of Rio de Janeiro (a 55% increase in the use of cars and 272% of motorcycles) despite modest population growth (9%) (Government of Rio de Janeiro 2018; Data.Rio 2018).

Action

Between 2009 and 2017, in order to mitigate and revert the increased trend of greenhouse gas emissions and reduce traffic congestion, which mostly affects the poor, the city increased its high-capacity public transport systems, including the implementation of 120 km of Bus Rapid Transit (BRT). The share of trips made by high-capacity transport has increased from 18% to 63%. The city of Rio has also been exploring opportunities to decarbonize the bus fleets through the use of low carbon technologies (hybrid and full electric buses) and biofuels (City of Rio de Janeiro 2011 and 2017; Globo 2014).

Benefits

The example of the TransOeste BRT, the first one to be implemented (56 kilometres of exclusive lanes and 58 stations), demonstrates how enhanced bus networks can provide a high-capacity solution for a city, crucial for shifting Rio onto a more sustainable path, with cleaner air, healthier people, shorter travel times and improved access for lower travel cost (ITDP 2014).

The TransOeste corridor has reduced an inner-city trip by 55%, from 1 hour and 40 minutes to around 45 minutes, directly benefiting 185,000 passengers which are being transported per day. It is also expected to save an estimated 107,000 tons of CO_2 per year over a 20-year period, thanks to fuel-efficient buses, rationalized bus routes and the attraction of new users for the high quality public transport system (ITDP 2014; C40 Cities 2016). With the implementation of the system, a 20% reduction in traffic fatalities has also been observed[31].

The decarbonisation of the bus fleets have the potential to further enhance the quality of air, reducing by more than 50% the exposure of fine particulate matter ($PM_{2.5}$) and the effects on premature mortality (ISSRC 2013).

> “Investments in the capacity of public transportation in Rio de Janeiro not only led to a reduction of greenhouse gas emissions and traffic related problems, but also contributed to the reduction of inequality between citizens, since it offered more transport options to low-income and vulnerable user groups, while building a more livable and sustainable city.”
>
> **Mayor Crivella**
> City of Rio de Janeiro

Figure 19: BRT in Rio de Janeiro.

Photo credit: Marcos Tognozzi (Technical Coordinator, Secretary of Transportation, City of Rio)

[31] Source: Assessment of the Secretary of Transportation of the City of Rio

5.7 OPPORTUNITIES FROM ENHANCED TRANSPORTATION ACTION

This chapter has demonstrated the significant potential and attractiveness of city level action for enhanced bus networks and bus services, including zero-emission buses.

Investments in enhanced bus networks and services constitutes one of the best options for the reduction of greenhouse gas emissions in cities, and in the transport sector overall, while delivering positive impacts for the economy, quality of living, social inclusion and other development agendas. This is critical, in a sector where compatibility with the goals of the Paris Agreement will require a sector transformation that entails a complete reversal of the current trend for the increase in emissions under current policies.

The findings from this report present an evidence base for accelerated actions for enhanced bus networks and bus services. It equips city, national governments, private sector and citizens with several reasons for a joint collaborative effort toward this goal. Case studies from Seattle and Rio de Janeiro illustrate, at the local level, how this action is delivering GHG emission reductions while also addressing multiple benefits to the population.

Fatalities from road traffic accidents and from premature mortality associated with outdoor air pollution are two of the leading causes of premature death in cities worldwide. Action for enhanced bus networks and services in line with the scenarios analysed in this report would lead to a significant shift in the modal split of passenger transport, and the amount of transport activity in private light duty vehicles, which could prevent the premature deaths of more than 90,000 people each year by 2030, in North America and Latin America combined. The impacts would be greater still, if the economic and social costs of non-lethal health conditions would be considered in addition.

These major benefits for human health and safety also come along with other benefits for daily convenience and economic gain: the measures of the enhanced action scenario for bus networks will save travel time for approximately 200 million commuters in the Americas on a daily basis, saving a total of over 9 billion hours per year, equivalent to nearly 5 million additional full-time employees over the period of a year. Furthermore, the enhanced bus scenario results indicate that the measures could result in improved mobility and accessibility to city services for lower-income groups, whose potential travel demand may have been curtailed in the past due to lack of access to public transport and inability to afford private transportation.

Additional measures for modern urban mobility systems, that were not within the scope of this research report, have the potential to further enhance the impacts of the measure. Additional measures found by McKinsey & C40 Cities (2017) to have considerable emission reduction potential in cities include transit oriented development, measures to enhance conditions for non-motorised transport (including cycling and walking), next generation vehicle technologies (including shared mobility concepts and electric vehicles), and modern approaches to urban commercial freight.

06
DISTRICT-SCALE RENEWABLE ENERGY

SUMMARY OF RESULTS FOR DISTRICT-SCALE RENEWABLE ENERGY

Under a *reference scenario*, district heating capacities will increase significantly in China to cover the majority of urban heat demand, although it will remain powered by inefficient coal heat plants, and the use of district cooling will remain negligible. No significant development of district heating or cooling is expected for Africa under the reference scenario.

An *enhanced action scenario* for district heating in China could see the district heating network further expanded and transitioned to the increased use of waste heat recovery, renewable energy and CHP, with the following impacts:

- The reduction in combustion of fossil fuels for heat in cities will cause a reduction in GHG emissions of approximately 600 $MtCO_2e$ in 2030.
- Exposures to excessive ambient air pollution will also be reduced, leading to the prevention of over 100,000 premature deaths per year in 2030, compared to the reference scenario.
- Further expansion of district heating generation capacity and pipeline installation will employ more than 715,000 more people in 2030, than those working in the sector in 2014. This is more than 235,000 additional jobs in 2030 compared to the reference scenario.

The prospects for the penetration of district cooling remain highly uncertain; this is an area where there is a major need for further research efforts, if the development of such systems is to become feasible. The use of renewable energy powered district cooling systems to supply a moderate portion of urban cooling demand in 2030 may have the following impacts:

- The reduction of electricity consumption may reduce emissions by over 200 $MtCO_2e$ and by 21-42 $MtCO_2e$ in Africa, in 2030.
- The reduction of air pollutant emissions may lead to the prevention of 15,000 premature deaths per year China and 11,000-21,000 premature deaths per year in Africa, compared to the reference scenario.
- Installation and maintenance of pipelines for district heating could lead to an estimated 150,000 jobs in China, and 41,000-82,000 jobs in Africa, in 2030.

The status of district energy systems is highly variable across different regions, based on differences in climatic conditions and feasibility of district scale systems, but also differences between countries in the historical structure of the energy supply industry and markets. District energy systems have been a mature technology option for several decades already in some countries, notably in northern Europe and several Former Soviet Union countries, whilst the installation of these systems is a relatively new and emerging phenomenon in some countries, and an entirely unexploited potential in others. Worldwide, district heating – which up to now is the most mature of district energy applications – accounted for approximately 13% of energy demand for spatial heating in buildings in 2014 (IEA/OECD 2017). District heating systems remain more common in non-OECD countries where they account for 29% of spatial heating demand, compared to 7% in OECD countries. The vast difference in the adoption of these systems between countries can be seen in that district heating accounts for 72% of spatial heating in Russia, where urban energy systems were traditionally very centrally managed, compared to less than 1% in the United States, where district energy systems are technically feasible in many areas, yet the historical structure of the energy sector was never highly conducive to their implementation.

District energy systems typically consist of a network of insulated pipes that distribute hot or cold water produced in central plants to multiple buildings in a district, neighbourhood or city' (IRENA 2017a). Hence, spatial heating and cooling can be delivered without buildings having to operate individual boilers, furnaces, electric heaters or air conditioning units. Supplying energy collectively at the district level entails potential efficiency gains, and means that thermal energy can be transported from where it has little or no value – such as in industrial waste heat or cold ocean water – to places where it is needed and highly valued. Although renewable energies accounted for only 5% of district energy worldwide in 2014 (IRENA 2017a), district energy systems have the necessary flexibility to integrate high levels of variable renewable energies by means of heat storage, smart systems and flexible supply (UNEP 2015). District energy systems are one form of decentralised urban energy: other forms of urban decentralised energy such as building scale renewables are not included in the scope of this analysis. District energy systems were singled out for analysis in this report due to their current under-representation in energy sector planning, their considerable potential, and the proven maturity of technologies.

The significant variation in the adoption of district energy systems across countries worldwide is indicative that significant district energy requires proactive and deliberate planning. Since the feasibility of systems depends not only on technical feasibility but also support from energy industries and the participation of all or most residential and commercial units in the district area, such systems are unlikely to grow organically without significant centralised planning. This indicates an important role for city governance structures in supporting the adoption of district energy systems.

This chapter assesses some of the impacts increased uptake of district renewable energy systems for spatial heating and cooling in cities. This includes the replacement of building-scale heating systems, electric heating and appliance-scale air conditioning units with district heating and cooling systems, powered by renewable energies, industrial waste heat and combined heat and power (CHP).

6.1 IMPORTANCE OF DISTRICT SCALE RENEWABLE ENERGY IN CITIES

The effort to reduce global greenhouse gas emissions implies a radical transformation of energy systems and patterns of energy consumption in end-use sectors. Households in many regions of the world still predominantly rely on the direct combustion of fossil fuels to generate heating and or significant use of electricity for cooling for buildings. Space heating and cooling as well as hot water supply are estimated to account for almost half of global energy consumption in buildings (IEA 2011), making this a highly significant source of global emissions.

In this context, the promotion of energy-efficient and affordable district energy systems represents one of the most-efficient ways to reduce emissions and primary energy demand. A transition to district energy systems, coupled with energy efficiency measures could contribute to a significant degree to CO_2 emission reductions required in the energy and buildings sectors by 2050 to keep the global temperature rise in line with the Paris Agreement goals (UNEP 2015). It has been estimated that deployment of district scale clean energy could achieve emissions savings of 0.7 $GtCO_2e$ by 2050 (ARUP & C40 Cities 2016).

District scale heating and cooling systems can often achieve significant improvements compared to conventional individual household systems such as boilers or AC units in areas with where energy demand intensities are sufficient (see for example Shimoda et al. 2008; Connolly et al. 2014; Möller & Lund 2010; Sperling & Möller 2012). Such conventional technologies might improve system efficiency in fuel consumption, increase the resilience of urban heating and cooling supply, lower the vulnerability to different supply chain shocks and disruptions, and decrease indoor pollution due to centralised generation. Currently, about 95% of energy used worldwide for district scale heating systems stems from fossil fuel based generation (IRENA 2017a).

Apart from the general switch to district scale heating and cooling systems, such systems can achieve even more substantial improvements in reducing emissions and air pollution by using recovered waste heat from industry and renewable energy carriers for generating the energy at the district level plants. The current use of renewables in district scale systems is limited. Heat is available in abundance as a waste by product of industries in many countries and may offer the most attractive source of input for district heating in the case that the proximity of facilities makes the recovery of heat feasible; this is common practice in some Northern European countries and despite minimal use to date, could supply approximately half of national district heat supply in China (Xiong et al. 2015). As of 2014, renewable district heat only represented about 1% of renewable energy use worldwide while the contribution of renewable district cooling was insignificant (IRENA 2016). This share might increase to up to 3% for district heating by 2030 due to developments in China and the European Union (IRENA 2017a), only tapping into some of potential for using district scale renewable energy in cities globally. Some countries already rely on renewable energy generation from waste, biofuels, geothermal and solar PV for their district heating systems with countries such as such as Denmark or Switzerland already reaching about 40% of renewable energy use (IRENA 2017a). Recent studies foresee a significantly increasing trend to utilise district scale renewable energy for heating around the world. Technological development for 4th generation district energy[32] (Lund et al. 2014) will help drive the further integration of renewable energy sources into district systems.

Market developments for district scale cooling fuelled by renewable energy remain comparatively slow, with mostly conventional fossil fuel generation used in district cooling systems installed as of today (ADB 2017). Driven by the expected increase in energy demand for cooling in several regions in the coming decades, renewable-based district cooling technologies might offer great potential to achieve reliable cooling supply alongside low emission development pathways in the cooling sector. For instance, the energy demand for cooling on the African continent may increase between 2015 and 2030 by about four times and even by about ten times by 2040 (author's own calculations[33]). District-scale cooling technologies, such as sea water air conditioning (SWAC) currently installed in the city of Port Louis, Mauritius with expected reduction of fossil fuel-based energy generation of 26 MW (UNEP 2015), might offer great potential for sustainable solutions to meet these demands in sustainable ways in urban areas.

[32] 4th generation district energy is defined as a technological and institutional concept. Through use of smart thermal grids and smart energy systems, 4G district energy systems can supply modernised low-energy buildings with low grid losses using low-temperature heat sources. Since it can operate with lower temperatures, the concept is particularly suited to use of renewable energy technologies.

[33] Refer to separate methodology document for further information.

Apart from the advantages of district-scale renewable energy systems in cities, the expensive investments in public heating and cooling infrastructure might face some risk that urban heating and cooling demand from district-scale systems might not develop as expected. The increase of efficiency standards in urban building stocks due to necessary policy action and advances in technology might significantly reduce the need for urban heating and cooling. Such potential risks of unused or insufficient district-scale infrastructure should be accounted for in long-term policy and investment planning in cities. This is an important consideration for the installation of new district energy systems, but has less relevance for the feasibility of transitioning existing district scale systems to renewable forms of energy. Another relevant consideration for renewable district energy systems is that more efficient buildings may also increase the potential for lower temperature heat networks, which may make use of renewable or waste heat more easily.

6.2 POTENTIAL IMPACTS OF DISTRICT ENERGY SYSTEMS

Table 14 shows that the switch to district energy systems in the urban environment can entail a broad range of outcomes and impacts for equity considerations, for urban populations who continuously depend on heating or cooling for prolonged periods of the year. Both positive ("+") and negative ("–") impacts are listed.

Table 14. Overview of some potential direct and indirect impacts from district energy systems in cities.

TYPE OF IMPACTS	EXAMPLES OF OUTCOMES AND SPECIFIC IMPACTS	EQUITY CONSIDERATIONS
Social impacts (Health and safety impacts)	+ Health benefits from improved air quality due to reduced indoor and outdoor emissions of local air pollutants + Health benefits from greater use of affordable heating and/or cooling (lower incidence of 'sick-building' syndrome')	Low income households usually have the greatest vulnerability to air pollution and sick-building syndrome.
Social impacts (Quality of Life and Urban Liveability, Culture and Institutions)	+ Better access households to heating and cooling – Construction work to install district energy systems can result in temporary discomfort for residents	Improved equity in reliable and affordable heating and cooling in urban areas (especially for low-income households)
Economic impacts (Individuals)	+ Reduced exposure of households to energy price fluctuation + Lower expenditure for heating and cooling and decreased risk to face fuel poverty for low-income households + Increase in property value for buildings connected to modern district energy systems + Insulation from energy price spikes and greater long-term certainty on heating and cooling bills	Reduced energy consumption results in a proportionally greater increase in household purchasing power for lower income households Lower-income households are the least resilient to energy price spikes which can have a significant impact on energy poverty and associated burdens.
Economic impacts (Wider economy)	+ Job creation through installation, operation and maintenance of district energy systems and increased reliance on local energy sources for district scale renewable energy + Increase in local prosperity from greater use of local resources, reduced fossil fuel imports, and a more-efficient primary energy consumption + Potential source for additional local government revenue if district energy systems are publicly owned + Reduction in public health spending due to improvements in air quality + Technology spill-overs and enhanced development of markets for advanced technologies + Reduced fuel import dependency and cost savings + More-reliable energy source that can provide power and heat/cooling at times of disruption (e.g. extreme weather) and overall increase in network stability – Opportunity costs of investments in expensive public infrastructure, unless private finance is leveraged – Potential loss of jobs in sectors related to sales, instalment and maintenance of conventional energy systems, as well as fossil fuel production (might be compensated by job growth in district energy system sector) – Increased risk of unused or insufficient infrastructure, if demand for district energy does not develop as expected	District heating systems can result in the creation of many jobs for local workers, but can also lead to the loss of jobs for local and unskilled staff in conventional energy industries. Measures to implement district energy should be implemented with sufficient considerations to maximise opportunities for local and unskilled staff and avoid adverse outcomes. Additional resources available for local governments and public health can result in additional pro-poor investments.
Environmental impacts	+ Improved indoor and outdoor air quality + Reduced GHG emissions and ozone depleting substances + Reduced consumption of water resources in urban areas with district cooling systems compared to conventional cooling systems + Improved water quality from reduced polluting emissions + Reduction of heat-island effects in urban areas	Water availability and quality is usually a more critical issue for lower-income areas where infrastructure and supply is more frequently disrupted.

Source: Authors' elaboration based on IEA (2009a), UNDP (UNEP 2015) and IRENA (IRENA 2017a).

>>>>>>>>>>>>>>>>>>>>>>>>>

6.3 SCOPE OF ANALYSIS

Regions

The analysis of benefits and impacts for district scale renewable energy is presented in this report for cities within **China** and the region of **Africa**. These regions were selected due to the potential and the insights from the contrasting regional characteristics. China is presented as an example of a region with high potential demand for heating and cooling, and where district energy systems are rather mature but requiring a shift to renewable forms of energy supply. The Africa region is presented as an illustrative example of a region with almost no district energy infrastructure in the present, yet with high demand for cooling in the future, especially concentrated within cities that are undergoing rapid transformation.

Table 15 shows that the situation and prospects for district energy systems in China and the African region is very different. In China, the use of district heating is dominant in urban areas (78% of spatial heating demand in buildings in urban areas), and the potential for enhancing district energy is in the transition to the use of waste heat recovery and renewable energy sources, along with the increased uptake of district cooling, which is so far negligible. In Africa, district heating systems are not feasible in the vast majority of the areas due to the relatively low heating-degree-days across the most populated areas of the continent; for this reason, scenarios for heating in Africa are not assessed. The potential for district cooling remains largely uncertain, but energy demand for cooling will increase substantially in the coming decades, and early experiences in the gulf states indicate that a significant portion of this cooling demand could be met through district energy systems.

The estimated average figures for the Africa region in Table 15 obscures considerable differences in conditions within the region. We estimate that energy demand for spatial cooling per capita is more than four times greater in North Africa than in Sub-Saharan Africa, although it is reasonable to consider that there will be a degree of convergence in per capita cooling demand in the coming decades, due to higher rates of projected economic growth in Sub-Saharan Africa.

Table 15. Situation of heating and cooling energy demand in China and and in Africa in 2014.

	CHINA	AFRICA REGION
Urban population	780 million	470 million
Energy demand for spatial heating in urban areas	Approximately 170 kWh per capita. Spatial cooling accounted for an estimated 17% of electricity demand in buildings.	Estimated 60 kWh per capita (~40 kWh/cap. in Sub-Saharan Africa/cap. and 170 kWh in North Africa). Spatial cooling accounted for an estimated 21% of electricity demand in buildings.
Energy demand for spatial cooling	Approximately 170 kWh per capita. Spatial cooling accounted for an estimated 17% of electricity demand in buildings.	Estimated 60 kWh per capita (~40 kWh/cap. in Sub-Saharan Africa/cap. and 170 kWh in North Africa). Spatial cooling accounted for an estimated 21% of electricity demand in buildings.
Status of district energy systems	Approximately 170 kWh per capita. Spatial cooling accounted for an estimated 17% of electricity demand in buildings.	Estimated 60 kWh per capita (~40 kWh/cap. in Sub-Saharan Africa/cap. and 170 kWh in North Africa). Spatial cooling accounted for an estimated 21% of electricity demand in buildings.
Technologies for district energy generation	Heat for district heating is generated by dedicated thermal heat plants (55%) and CHP (45%). The use of recovered industrial waste heat is negligible.	District scale energy currently has no significant penetration in Africa.
Technologies for non-district energy heating and cooling	Approximately 40% of non-district-scale energy for heating in urban buildings comes from electric heaters, with individual boilers and electric systems accounting for the remaining 60%.	Electric AC systems account for the majority of existing spatial cooling in Africa.

Sources: Based on outputs of authors' model. See sources in technical note for information.

Scenario parameters

The analysis for the potential of district-scale renewable energy systems considers the impacts of the following measures.

Measures for district heating:

- Use of district scale systems for building heating: the scenarios consider the proportion of the urban area's heating demand that is supplied by heat from district systems.
- Use of recovered industrial waste heat: given as the proportion to which it contributes to the total district heating energy supply.
- Use of renewable energy generation technologies for district scale heating: given as the proportion to which it contributes to the total district heating energy supply.
- Use of combined heat and power plants instead of dedicated heat plants: given as the proportion to which it contributes to the total district heating energy supply.

Measures for district cooling:

- Use of district scale systems for building cooling: the scenarios consider the proportion of the urban area's cooling demand that is supplied by energy from district systems. District cooling is assumed to be supplied by a combination of renewable energy generation technologies and trigeneration from thermal plants where the potential is available.

Section 6.4 provides details on the scenarios assessed in this analysis.

Impacts

This study focuses on the impacts of district scale renewable energy systems in cities for premature mortality from outdoor air pollution, reduced fossil fuel imports and job creation.

- Change in premature mortality from outdoor air pollution is assessed based on the impact of energy system changes on the emissions of air pollutants, and the consequent changes in the concentration of fine particulate matter ($PM_{2.5}$) in urban areas. This includes all-cause mortality from $PM_{2.5}$.
- Job creation is assessed with regards to the direct net employment impact for the installation and maintenance of energy generation and distribution infrastructure, based on the volume of upfront capital investments.
- Reduced fossil fuel imports are assessed in terms of the potential reduction in imports (or exports) based on changes in the energy mix that arise from the use of district scale energy solutions and renewable technologies.

These impacts were selected for analysis based upon analysis from C40 and input from C40 cities on the most relevant issues for decision makers, as well as feasibility of the quantitative analysis.

>>>>>>>>>>>>>>>>>>>>>>>>>

6.4 SCENARIOS FOR ENHANCED ACTION

Table 16 gives an overview of the scenarios which are analysed for China and Africa in this study.

Table 16. Scenarios for analysis of impacts of district scale renewable energy systems.

CHINA

As a country with a relatively mature district heating network, there remains high potential for further increasing the coverage of district heating, and switching to cleaner sources of energy for district systems. The enhanced district scenario is based on information from the high ambition scenarios of Xiong et al (2015) and IRENA (2017b). The prospects for district cooling in China are uncertain, so these measures are analysed in a separate scenario. The proportion of cooling supplied by district scale systems in this scenario is based on the average technical potential found for three Gulf states, and should be considered only an illustrative indication of the potential impacts of the measure.

	2014	REFERENCE (2030)	ENHANCED DH SCENARIO (2030)	ENHANCED DHC SCENARIO (2030)
Use of district energy for urban heating demand	78%	78%	85%	85%
Use of recovered industrial waste heat for district energy	Negligible	Negligible	11%	11%
Use of renewable energy technologies for district heating	Negligible	Negligible	22%	22%
Use of CHP for district heating	45%	41%	57%	57%
Use of district energy for cooling demand	Negligible	Negligible	Negligible	42%

AFRICA REGION (2030)

District heating scenarios for Africa are not assessed, since the prospects for district heating are very low due to low heating demand in the most populated areas. Prospects for district cooling are considerably under-researched, to the extent that no specific feasible scenarios could be identified for inclusion in this analysis. Instead, two exemplary scenarios are presented in which district systems are used to supply 25% and 50% of urban cooling demand on the continent. Of the few examples where such analysis exists, estimates for the potential of district cooling in Gulf states range from approximately 25-50%. This range is an exemplary illustration for the Africa region analysis and does not imply that the outcomes are determined by the authors to be desirable or practically feasible, since the state of knowledge on this topic is not sufficient to draw such conclusions*.

	2014	REFERENCE (2030)	ENHANCED DH SCENARIO (2030)	ENHANCED DHC SCENARIO (2030)
Use of district energy for urban heating demand	District heating feasibility is negligible and heating scenarios are not assessed for Africa			
Use of recovered industrial waste heat for district energy				
Use of renewable energy technologies for district heating				
Use of CHP for district heating				
Use of district energy for cooling demand	Negligible	Negligible	25%	50%

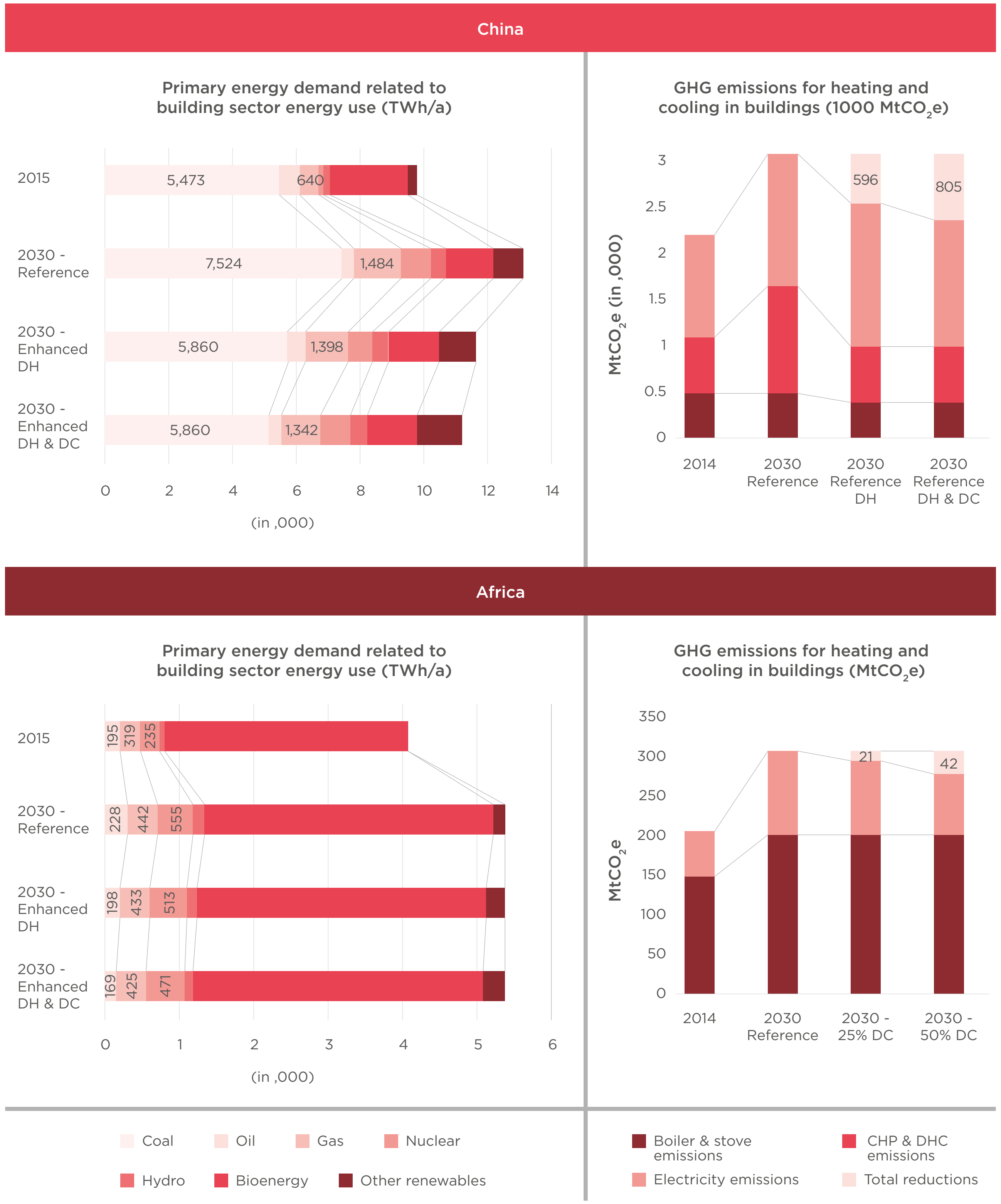
** The range assessed is for exemplary illustration only. The potential for DC in Africa could be limited by the sophistication of new buildings built up to 2030. Whilst DC is likely to be an efficient means of cooling in many growing cities in Africa, most city growth is driven by rural-urban migration, typically from lower income households, and new residential constructions often include only basic technologies and structures; considerable interventions would be needed to ensure that new building structures were compatible with DC systems, should this be deemed a desirable action in some areas of the region.*

Due to the limited availability of information on Paris Agreement compatible scenarios for district-scale heating and cooling in the literature, these scenarios are based partially on higher-ambition potentials identified in the literature and partially on artificial constructions for exemplary illustration of potential impacts.

Figure 20 gives an overview of the implications of the scenarios identified for primary energy demand and emissions from heating and cooling in buildings. The enhanced district heating scenario in China results in an emission reduction of approximately 600 $MtCO_2e$ in 2030, compared to the reference scenario in 2030. This is due mostly to a reduction in primary energy demand for coal the reduction in coal-fuelled electricity demand due to district heat, replacement of household coal stoves (amongst others) with district heat, and through more efficient use of existing coal plants for CHP. Further reduction in coal demand, through the replacement of coal fired electric appliances for cooling with district cooling under the enhanced district heating and cooling scenario, would further reduce emissions in 2030 by approximately 200 $MtCO_2e$. These potential emission reductions equate to approximately 0.6-0.8 tCO_2e per capita for the urban population in 2030. This is in line with the Paris Agreement compatible scenarios of the *Deadline 2020* report (ARUP & C40 Cities 2016), which report an average per capita emission reduction of 0.61 tCO_2e for eight major cities in China in 2030. The district heating and cooling scenario would result in an absolute reduction of coal consumption related to building sector energy compared to 2014. Combined with complementary measures for energy efficiency improvements and the decarbonisation of the electricity supply sector, as required for compatibility of the Paris Agreement objectives, this could reduce primary demand for coal and other fossil fuels further and lead to a considerable absolute reduction in emissions compared to 2014.

The district cooling scenarios for Africa would result in emission reductions for spatial cooling in buildings of approximately 20 $MtCO_2e$ in 2030 under the 25% district cooling scenario, and approximately 40 $MtCO_2e$ in 2030 under the 50% district cooling scenario. Figure 20 indicates that this reduction would largely be due to a reduction in coal and gas consumption for electricity to power individual cooling appliances, which are replaced by district cooling plants powered by renewable energy sources and trigeneration, where possible. These potential emission reductions equate to approximately 0.025-0.05 tCO_2e per capita for the urban population in 2030.

Figure 20. Primary energy demand for building sector energy use and GHG emissions for heating and cooling, under different scenarios.



>>>>>>>>>>>>>>>>>>>>>>>>>

6.5 QUANTIFIED IMPACTS OF DISTRICT SCALE RENEWABLE ENERGY

6.5.1 Premature mortality from outdoor air pollution

District scale renewable energy systems may contribute to significant reductions in outdoor air pollution from the energy sector in urban areas in several ways:

- District heat and cooling plants are often more efficient than individual building-scale technologies, requiring less primary energy and subsequently fewer emissions to deliver the same heating and cooling supply.
- District scale generation offers more potential for the integration of renewable technologies and the use of recovered waste heat in the supply of heating and cooling, thereby further reducing the need for the combustion of fossil fuels and air pollutant emissions usually associated with electricity generation or individual building-scale boilers.

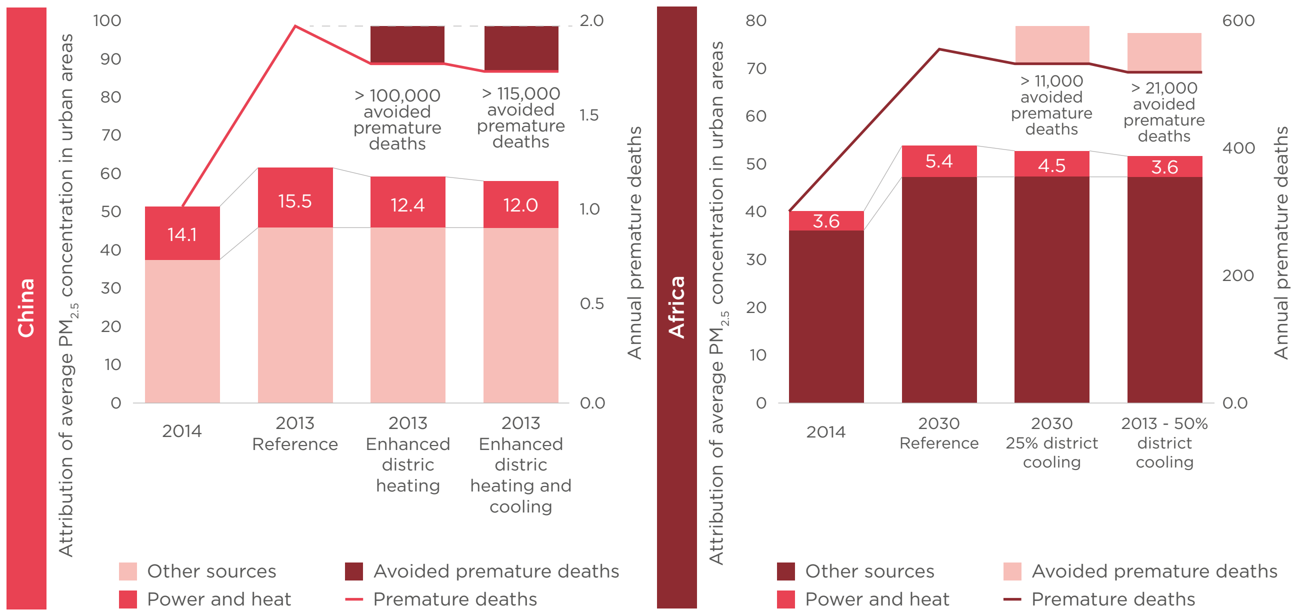
The potential for district heating to impact air pollution and associated premature mortality in China is particularly large: approximately a quarter of outdoor particulate matter concentrations in urban areas of China could be attributed to emissions for heating (authors' estimation based on Liu et al. 2016).

District cooling systems could reduce demand for electricity and subsequently the emissions associated with power generation in both China and the Africa region. The potential gains from district cooling in Africa are particularly due to the considerable forecast increase in cooling demand and the increased emissions related to electricity generation in the coming years.

The social and economic burden of air pollution is presently one of the most critical issues facing many cities in developing countries. Figure 15 shows that the number of premature deaths from air pollution in China's and Africa's urban areas is estimated to increase significantly up to 2030, under the reference scenario. The very large increases in the health burden associated with pollution is due to a combination of factors: emissions of air pollutants from other sectors outside of urban power and heat are expected to grow, whilst urban population growth and population ageing will push the death rate higher still.

Figure 21 shows that the enhanced district heating scenario may prevent more than 100,000 annual premature deaths in 2030, compared to the reference scenario, by reducing emissions from power and heat used in buildings. Including renewable energy powered district cooling technologies may lead to the prevention of a total of over 115,000 deaths per year by reducing emissions from electricity generation. District cooling could also have a major impact on reducing premature deaths in Africa. The use of renewable energy powered district cooling technologies to supply 25% of cooling demand in 2030 could prevent more than 15,000 premature deaths, with a 50% supply scenario preventing more than 30,000 premature deaths.

Figure 21. Impact of district scale energy for preventing premature deaths from outdoor air pollution in China and Africa.



6.5.2 Job creation

The implementation of enhanced district scale energy systems may entail a significant shift in investment patterns which may lead to changes in the level of employment within the sector and beyond. District scale systems will reduce investments and jobs in sectors associated with the installation and maintenance of building-scale heaters and coolers, but will increase investments and jobs in the construction, operation and maintenance of centralised generation capacity, as well as the construction and maintenance of district pipeline networks and building scale connectivity and metering. Investments in district scale energy systems are likely to be higher than alternative systems, usually leading the larger volumes of job creation during the construction period as well as for maintenance and operation; this does not necessarily mean that these technologies are more expensive in the long term, since reduced fuel consumption considerably reduces the total costs of these technologies when considered over their project lifetimes. Jobs may also be more likely to be local, depending on the circumstances for manufacturing individual boilers.

DISTRICT SCALE SYSTEMS WILL INCREASE INVESTMENTS AND JOBS IN THE CONSTRUCTION, OPERATION AND MAINTENANCE OF CENTRALISED GENERATION CAPACITY, AS WELL AS THE CONSTRUCTION AND MAINTENANCE OF DISTRICT PIPELINE NETWORKS AND BUILDING SCALE CONNECTIVITY AND METERING.

This section analyses the impact of measures for district scale renewable energy systems for the creation and losses of direct jobs in these industries, and indirect job creation from the supply chain. Due to efficiency gains, such systems are likely to reduce the total amount of primary energy supply required to meet demand; the impact of this effect on employment in the energy sector is included in this analysis, although potential impacts on employment for fossil fuel production (where relevant) are not assessed, since pathways for fossil fuel production activity and the consequent level of employment in the sector may not necessarily be depending on domestic energy demand.

For district heating, we assess the extent to which measures will affect employment for the construction, installation, operation and maintenance of centralised energy generation plants, distribution network infrastructure and building-scale boiler systems. For district cooling, the available information on investments associated with centralised energy supply capacities and individual air conditioning units is not deemed to be reliable, so only the investment and employment impacts of the distribution network for district cooling is assessed for this indicator. From the available information, it is assumed that the positive impacts for employment from new centralised energy generation capacity for district cooling will be similar to the scale of job losses in the building-scale air conditioning unit production and installation industries. As such, the employment impact from the distribution infrastructure is assumed to be the net employment gain from the measures. This is believed to be a conservative assumption since the analysis of district heating indicates that investments and employment for centralised energy generation capacity may be greater than that for individual building scale units.

Significant expansions of China's urban energy infrastructure are expected between 2015 and 2030, due to continued urban population growth and rising per capita energy demand, associated with economic growth. This is reflected in Figure 22 and Figure 23, which show that accumulated investments of more than EUR 200 billion in the installation of new infrastructure for heating will be required between 2015 and 2030 to meet projected demand. A great deal of this investment is for the installation of new pipelines for expanded district heating, which is forecast under the reference scenario. In the enhanced district heating scenario, the investment costs for pipelines increase slightly, whilst the investment volume for district scale heat generation capacity increases by more than double. This significant increase in the enhanced district heating scenario is due to a moderate increase in the penetration of district heating systems, as well as the increased use of waste heat recovery and renewable energy technologies, which have a higher upfront capital cost. In the scenario that includes district cooling, the required investments for pipelines increases further yet, with total accumulated investments for the 2015-2030 period reaching nearly EUR 300 billion.

Figure 22. Accumulated capital investments of district scale energy scenarios in China.

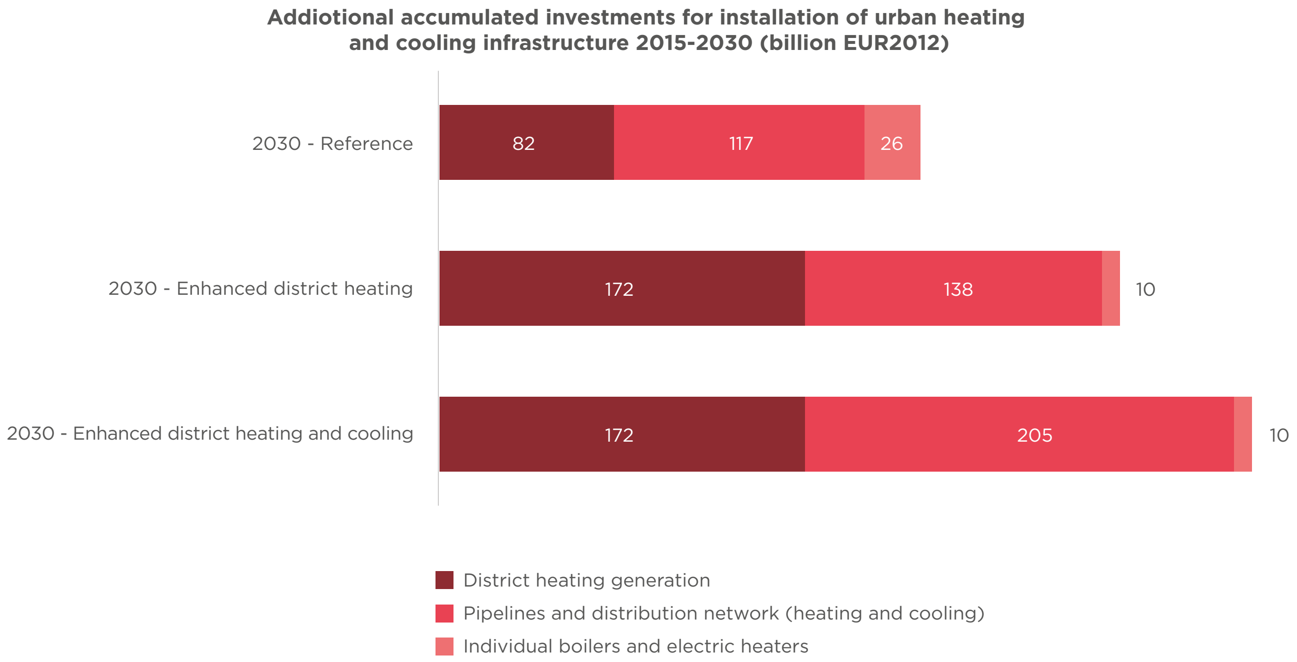
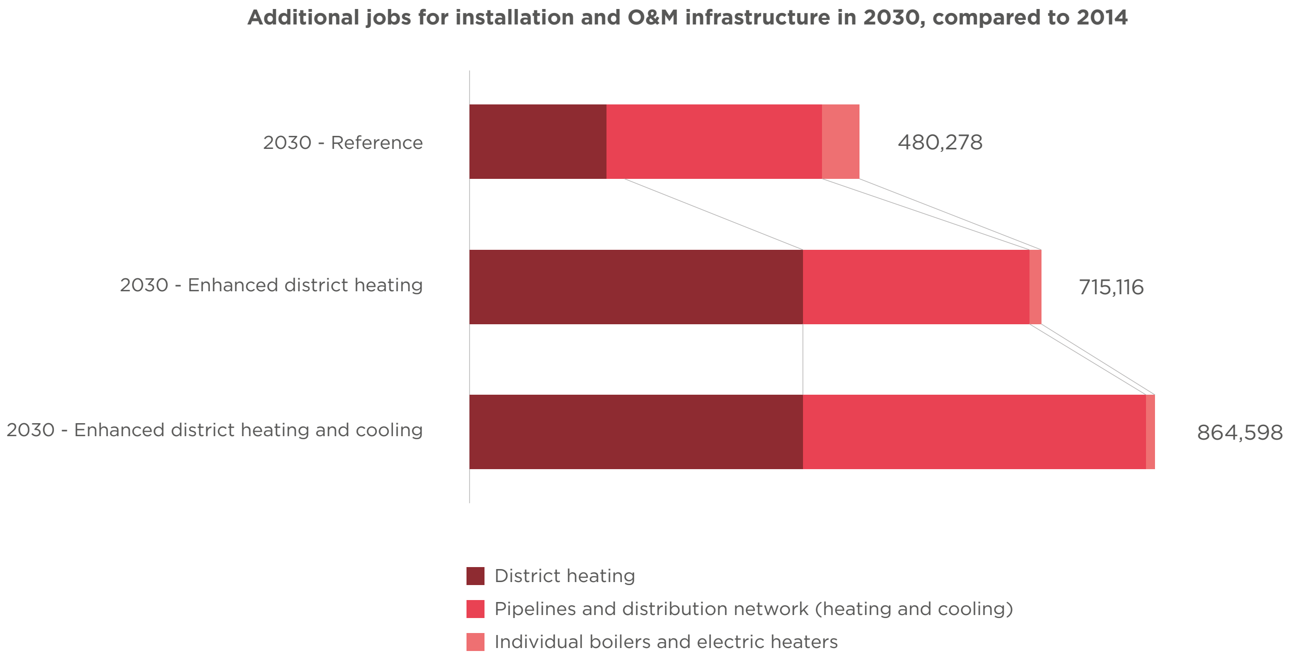


Figure 23. Employment impacts of district scale energy scenarios in China.



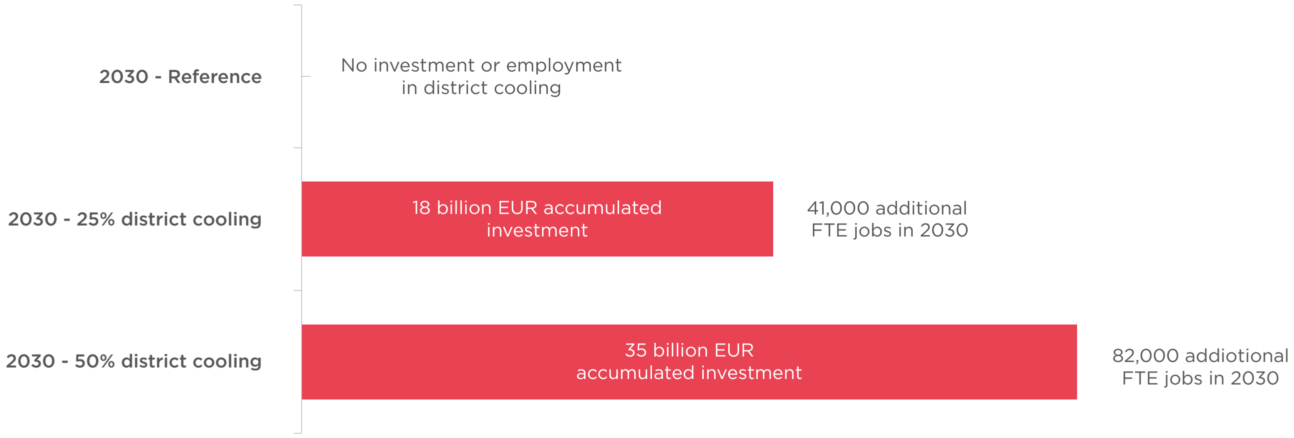
The realisation of these scenarios will also require highly significant increases in the number of workers within the energy and construction industries, as indicated in Figure 23. Whilst the reference scenario will require an additional 480,000 workers by 2030, compared to 2014, the enhanced district heating scenario will employ 235,000 more people in addition, mostly due to increased employment for installation and O&M of clean technologies for district heat generation. These figures show the net impact for direct and indirect job creation in the sector accounting for the replacement of jobs on individual boilers. The construction and maintenance of distribution network for district cooling in the third scenario would employ a further 160,000 people still, by 2030.

The additional jobs created in the enhanced action scenario include a mixture of jobs for unskilled, skilled and professional workers. Although the upfront investments in district heating networks are large, most of the technologies and materials (such as large pipelines) are mature and expertise could usually be expected to be locally available, so the proportion of jobs which are local is likely to be high. The enhanced scenarios may entail job losses within some energy generation sub-sectors, including coal heat plants and coal stoves for buildings, and could also result in job losses for fossil fuel production. Whether these job losses occur depends on national circumstances and strategic decisions related to fossil fuel production; in the case that job losses in these industries do occur, these are more than offset by new jobs created in cleaner energy industries, and any negative impacts from these job losses can be mitigated through programmes for re-training and reallocation.

Scenarios for ambitious penetration of district cooling systems could also have a major impact for employment in the Africa region. Figure 24 shows that the use of renewable energy powered district cooling for 25% of cooling demand in Africa in 2030 will require accumulated investments of approximately EUR 18 billion between 2015 and 2030, with more than 40,000 people employed in pipeline installation and maintenance in 2030. In the scenario where district cooling supplies 50% of cooling demand, these investments and employment rates double.

The employment impact for district cooling systems is a net additional impact, since the results relate to job creations from the pipeline investments, whilst it is estimated that the loss of jobs from the production and installation of individual cooling appliances is offset by the jobs in centralised cooling supply facilities, either through trigeneration or renewable energy technologies. However, it is important to recognise that suitable retraining and reallocation programmes will be necessary to mitigate any negative impacts of the transfer of jobs from one energy sector sub-sector to another. For the additional jobs for pipeline installation, these will contain a mix of unskilled, skilled and professional jobs, and can be largely due to the generally widespread maturity and available expertise for pipeline installation.

Figure 24. Investments and employment impacts for district cooling pipeline installation and maintenance in Africa.



6.5.3 Fossil fuel import dependency and import cost savings for imports

Through increased efficiency and the relative ease of integrating renewable energy technologies, district energy systems may offer the ability to enhance energy security through reducing reliance on imports of fossil fuels, thereby also accruing cost savings at the national level.

For the regions studied in this analysis, the district energy scenarios do not make a hugely significant impact on import dependency. Across the Africa region, the reduction in the primary demand for coal and gas through the measures for district cooling in 2030 (compared to the reference scenario) is estimated to be equal to less than 1% of fossil fuel imports in 2014. For China, the greatest impact in the reduction of fossil fuel consumption is in coal, but this has a limited impact for energy security in China from an import dependency perspective, due to the scale of coal production in China. This indicator might have greater relevance in other regions where there is a greater reliance on fossil fuel imports for the supply of heat.

DISTRICT ENERGY SYSTEMS MAY OFFER THE ABILITY TO ENHANCE ENERGY SECURITY THROUGH REDUCING RELIANCE ON IMPORTS OF FOSSIL FUELS.

>>>>>>>>>>>>>>>>>>>>>>>>>>

6.6 CASE STUDY

Case studies from Qingdao and Port Louis illustrate, at the local level, how this action is delivering GHG emission reductions while also addressing multiple benefits to the population.

6.6.1. Qingdao, China

Background

Qingdao is a fast-growing city in China with a high proportion of manufacturing seeking to pursue further economic growth. It is one of China's low-carbon pilot cities, leading the transition towards low-carbon development. It has established a close connection between its economic development target and mitigation and adaptation targets (C40 Cities & Sustainia 2017). Before 2020, one of the its main focus is improving energy efficiency and rationalization of industrial structure (Sustainia 2017).

Actions

The city of Qingdao aims to adopt a non-coal-based energy system with a low-temperature heat distribution network. Instead of coal, Qingdao will use natural gas, solar thermal, shallow ground geothermal and excess heat recovered from industrial plants to power its district heating, cooling and power production and distribution systems. It will provide a population of more than 400,000 in eight locations in the City with access to clean and highly efficient district energy including 18.3 million m² of heating area, 1.7 million m² of cooling area, and 107.9 MWh of electricity.

Benefits

When compared to the equivalent production of energy through traditional coal-fired sources, which is a business-as-usual scenario, once operational (by 2020) the project will: (i) result in annual energy savings equivalent to 537,900 tons of standard coal, thereby providing a global public good by avoiding the annual emission of 1,398,455 tons of CO_2, a greenhouse gas; (ii) improve local air quality through the estimated annual reduction of emissions of sulfur dioxide by 12,909 tons, nitrogen oxides by 3,765 tons, and particulate matter by 5,379 tons; and (iii) eliminate the negative impacts of coal transportation through urban areas by truck or train (C40 Cities & Sustainia 2017; ADB 2015). This is expected to have significant impact preventing respiratory and heart diseases.

Figure 25. Heat pump in Uni Town, photo credit: City of Qingdao.

Detail of a heat pump located beneath Uni Town, one of the production areas, inaugurated in July 2017. During winter, "free heating" from sewage (domestic wastewater) is recovered and supplied through the heating system network to various consumers and during summer, indoor heat from consumers is removed and transferred to the system.

Figure 26. Uni Town, a commercial street, is one of the communities served by the heating and cooling network. Photo credit: City of Qingdao

6.6.2. Port Louis

Background

The first district cooling system in Africa, using sea water for air- conditioning (SWAC), is being developed in Port Louis, the capital city of Mauritius island.

Port Louis Central Business District, the targeted area for the first phase of the project, is one of the hottest places on the island combining the subtropical climate with the natural urban heat island effect created by the concentration of buildings and human activities. Air conditioning is an essential year-round requirement for any business in the capital (Urban Cooling 2018a). And this is particularly key since electricity is the main source of greenhouse gases emission (45%) due to the island's high dependence on imported fossil fuel for its electricity generation (Stats Maritius 2016).

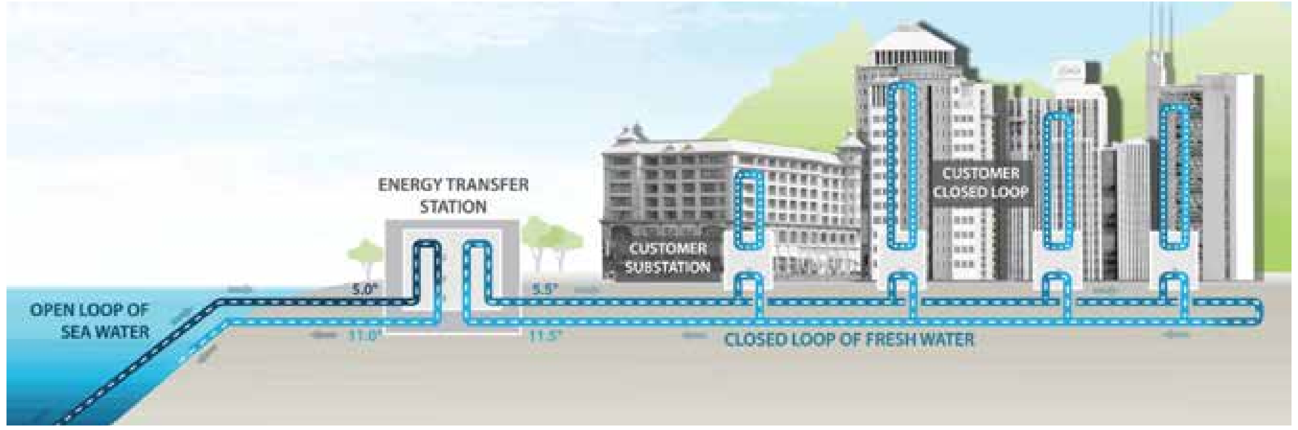
Action

Very cold seawater (5˚C) from the Indian Ocean will be pumped from about 1100 m deep at a distance of 6 km from the shoreline to cool buildings in Port Louis central business district and nearby locations (UNEP 2017; Urban Cooling 2018c).

Benefits

When completed, the project will replace traditional air conditioning systems in buildings currently powered through fossil fuel-based plants, enabling to reduce the power supply by about 26 MW. The project is expected to create 40 direct green jobs for skilled local engineers and technicians, and potentially create many more indirect jobs in downstream businesses such as aquaculture and pharmaceutical (AfDB 2014; AfDB 2016). It will increase energy security, enhancing the reliability of power supply while providing savings of around US$5 million per year on fossil imports, as well as reduce CO_2 emissions by around 40,000 tons per year (Urban Cooling 2018b).

Figure 27. Urban cooling process (Urban Cooling 2018c).



Source: http://www.urbancooling.mu/seawater-and-conditioning/the-process.html

>>>>>>>>>>>>>>>>>>>>>>>>>

6.7 OPPORTUNITIES FROM DISTRICT-SCALE RENEWABLE ENERGY

Considering its potential importance as a measure to mitigate climate change and deliver on multiple development related objectives, district-scale renewable energy projects are somewhat under-represented in research literature and planning for the energy sector; consequently, action for the implementation of these systems could be significantly increased. District-scale renewable energy systems have not only one of the greatest potentials for emission reductions from the energy sector in cities, but also a relatively high degree of technological maturity in some applications; the opportunities for the upscaling and optimisation of these technologies is considerable. Case studies from Qingdao and Port Louis illustrate, at the local level, how this action is delivering GHG emission reduction while also addressing multiple benefits to the population.

One application of district-scale energy where there is presently less technological maturity and a need for much more research and action in particular, is for cooling. Very little information exists on the status and prospects of district cooling, and the implementation of this measure is far below its current potential, often not even existing in the form of demonstration projects in countries of potential feasibility. District cooling could be a highly important technology in many warmer regions in the future, where continued economic development is projected to result in enormous increases in energy demand for cooling.

Part of the reason that district-scale energy systems are often overlooked in research and implementation is that energy sector investments are often centralised at the national level, where the planning of district-scale projects faces many barriers. The findings of this report demonstrate clear incentives for devolving resources for energy supply, for the achievement of local and national development objectives. Investments in district-scale renewable energy systems can create jobs for local workers, and may result in significant improvements in air quality and prevention of related premature mortality. The impacts would be greater still, if the economic and social costs of non-lethal health conditions would be considered in addition. Impacts for energy security from fossil fuel imports depend entirely on the energy sources of the specific country, but can result in major economic gain for countries with high fossil fuel imports for their energy sectors.

The findings also indicate that the full opportunity of the benefits rely on careful planning and supporting interventions to avoid adverse impacts. For example, the net job gains will include job losses in some sectors, such as for the manufacture and installation of individual household heating and cooling appliances, and programmes may be needed to retrain people appropriately. Implementation of enhanced district-scale renewable energy programmes should also be planned carefully and with foresight to minimise the potential costs and asset stranding risk associated with the decommissioning of individual heating and cooling units that are not near the end of their technological lifetime.

Additional measures for modern urban energy systems, that were not within the scope of this research report, have the potential to further enhance the impacts of the measure. Whilst this report has focused on decentralised energy generation, McKinsey & C40 Cities (2017) find considerable emission reduction potential in cities from the further penetration of renewable technologies in centralised electricity generation to decarbonise the electricity grid.

>>>>>>>>>>>>>>>>>>>>>>>>

07

FINDINGS AND CONCLUSIONS FOR FURTHER WORK

Climate action can be action for health, quality of life and prosperity. This report has quantitatively assessed some of the major links between the climate and development agenda. The analysis of measures for energy efficiency retrofit in the residential building sector, district-scale renewable energy, and enhanced bus networks for modal shift of urban transportation has found positive impacts for various regions and countries in different stages of economic development.

- **Residential energy efficiency retrofit** can lead to net job creation of over **2 million jobs in the EU and the US**, equivalent to 4-12% of the unemployed population in 2017, and can **increase household annual saving rates by 10-60%**, with the lowest-income households benefiting the most.
- **Enhanced bus networks and bus services** could **prevent the premature deaths of nearly 100,000 people per year** from air pollution related mortality and road traffic fatalities in the Americas, **saving nearly 10 billion hours of commuter travel time each year** by 2030, equivalent to nearly 5 million additional full-time workers.
- **District-scale renewable energy** in China and Africa can **prevent over 100,000 premature air pollution related deaths per year** by 2030, whilst also creating **jobs for nearly 1 million people**, approximately 500,000 more than in the reference scenario.

Climate action can be a pro-poor investment. The findings of the analysis indicate that climate change action may incur equal or even greater benefits in cities of developing countries, where populations often have the most to gain from the introduction of modern technologies and practices. Likewise, lower-income groups in all regions were found to be likely to accrue the greatest benefits from most of the measures assessed. This finding further strengthens the observed link between climate action and the development agenda.

Exploiting the full extent of the opportunities available to cities requires a fundamental shift away from the business as usual. In all of the action assessed in this report, the scale of the benefits was usually substantially greater in the case of the Paris Agreement compatible pathways than under the reference scenario. Likewise, the Paris Agreement compatible pathways deviate substantially from the reference case in terms of the scale of action and investments needed in the sectors. The climate, health and prosperity opportunities available to cities depends on focused, deliberate action to introduce appropriate policy interventions and invest in the most cost-effective actions for multi-objective impact.

The opportunities available to cities depends on careful planning to avoid adverse outcomes. Since enhanced action in the sectors analysed requires a significant shift in investment patterns and policy signals, it is inevitable that the shift of investments away from some older industries will result in job displacement, which could threaten the positive impacts of net job creation in the case that programmes are not designed to retrain and channel affected workers into the new, decent job opportunities. As with most large infrastructure investments, there are several other potential negative impacts which could be incurred by the measures, unless sufficient planning is taken to mitigate these adverse outcomes. This is particularly relevant for lower-income and marginalised groups, who, despite having the most to gain from the benefits associated with the measures, are also often most vulnerable to the adverse impacts if not sufficiently controlled for.

Further research is vital to continue to build the evidence case and to make it more accessible to city-level decision makers. The results presented in this report are an awareness raising teaser for particular scenario analysis in specific regions, but these results are based on new methodology development and analysis which also has broader utility moving forwards:

- **Better understanding of causal relationships:** The new methodological tools for the three sectors covered combine the scientific literature on several causal relationships in the chain between policy stimulus and impact indicators, into a tool for universal application. Further research on specific causal relationships could help to further improve these methodologies in the future, improving their accuracy and the breadth of the applicability. This especially true to approaches that can be generally applied to a range of circumstances with reasonable accuracy, which have an important role to play in making information on benefits accessible, alongside more precise case specific analysis approaches.
- **Improved data from cities for inputs and ex-poste assessment:** The methodological approaches could also be significantly enhanced by improved availability of data on cities, both related to input data for activities in sectors, but also on ex-poste measurement of actually observed impacts, which can serve to validate and strengthen theoretical ex-ante methodologies.

Increased collaboration can accelerate climate action. This report provides exemplary evidence on how cities can make the case to accelerate action for the three measures assessed. Further work is needed to deepen the evidence base for these measures, and for the many other measures that are vital to achieving the necessary emission reductions in cities in the short term, including but not only for decarbonisation of the electricity grid, enabling next generation mobility, and improving waste management, which are also measures with considerable potential in cities (McKinsey & C40 Cities 2017). A great deal of fragmented research and information relevant for these objectives exists, from research institutions, civil society organisations and information collected by city-level and national governments. Enhanced collaboration between these groups to share information and better understand estimated and observed impacts can help to accelerate the developing case for action, empowering cities to make the necessary moves towards a climate safe, healthy and prosperous future.

REFERENCES

ADB, 2017. *District Cooling in the People's Republic of China: Status and Development Potential*, Alberto Alesina, 2001. Why doesn't the US have a European-style welfare state? *Harvard Institute of Economic Research*. Available at: https://scholar.harvard.edu/files/glaeser/files/why_doesnt_the_u.s._have_a_european-style_welfare_state.pdf

Anil, M. et al., 2016. *The True Cost of Fossil Fuels : Saving on the Externalities of Air*, Available at: http://www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=36&CatID=141&SubcatID=2726

ARUP & C40 Cities, 2016. *Deadline 2020: How cities will get the job done*, Available at: http://www.c40.org/researches/deadline-2020

Axhausen, K.W., 2010. The Limits to Travel: How Far Will You Go? *Transport Reviews*, 30(2), pp.271–273.

Becqué, R. et al., 2016. *Accelerating Building Efficiency: Eight Actions for Urban Leaders*, Available at: http://publications.wri.org/buildingefficiency/#sec2 [accessed on 21 December 2016].

Bell, C.J., 2011. Understanding the True Benefits of Both Energy Efficiency and Job Creation., pp.109–116.

BPIE, 2016. *Nearly zero-energy buildings. Definitions across Europe*, Brussels, Belgium: Buildings Performance Institute Europe. Available at: http://bpie.eu/uploads/lib/document/attachment/128/BPIE_factsheet_nZEB_definitions_across_Europe.pdf

BRT Centre of Excellence et al., 2017. Global BRT Data. Available at: http://brtdata.org/ [Accessed August 23, 2017].

City of Seattle, 2017b. 2017 Center City Commuter Mode Split Survey. Department of Transportation https://commuteseattle.com/wp-content/uploads/2018/02/2017-Commuter-Mode-Split-Survey-Report.pdf

City of Toronto, 2017 a. Home Energy Loan Program and High-rise Retrofit Improvement Support Program Evaluation. Available at https://www.toronto.ca/legdocs/mmis/2017/pe/bgrd/backgroundfile-102272.pdf

City of Toronto, 2017 b. TransformTO: Climate Action for a Healthy, Equitable and Prosperous Toronto - Report #2 - The Pathway to a Low Carbon Future https://www.toronto.ca/wp-content/uploads/2017/10/99b9-TransformTO-Climate-Action-for-a-Healthy-Equitable-and-Prosperous-Toronto-Report-2-The-Pathway-to-a-Low-Carbon-Future-Staff-Report-April-2017.pdf

Climate Action Tracker, 2016. Climate Action Tracker Data Portal. Available at: http://climateactiontracker.org/decarbonization/intro

Connolly, D. et al., 2014. Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system. *Energy Policy*, 65, pp.475–489. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421513010574

Copenhagen Economics, 2012. Multiple benefits of investing in energy efficient renovation of buildings: Impact on Public Finances., (October), pp.1–80. Available at: http://renovate-europe.eu/wp-content/uploads/2015/10/Multiple-benefits-of-EE-renovations-in-buildings-Full-report-and-appendix.pdf [accessed on 13 December 2016].

Csiba, K., Bajomi, A. & Gosztonyi, Á., 2016. *Energy Poverty*, Available at: www.iea.org/topics/energypoverty/

Day, T., Höhne, N. & Gonzales, S., 2015. *Assessing the missed benefits of countries' national contributions*, NewClimate Institute, Cologne. Available at: http://newclimate.org/2015/03/27/indc-cobenefits/

Dubash, N.K. et al., 2014. Measuring the Co-Benefits of Climate Change Mitigation. *Annual Review of Environment and Resources*, 39(1), pp.549–582.

EC-Energy, 2017. EU Buildings Datamapper.

EEFIG, 2015. *Energy Efficiency – the first fuel for the EU Economy*, Available at: http://www.unepfi.org/fileadmin/documents/EnergyEfficiency-Buildings_Industry_SMEs.pdf

Enrique Peñalosa, 2013. Enrique Peñalosa: Why buses represent democracy in action | TED Talk. Available at: https://www.ted.com/talks/enrique_penalosa_why_buses_represent_democracy_in_action [Accessed August 24, 2017].

Erickson, P. & Tempest, K., 2015. Keeping cities green: Avoiding carbon lock-in due to urban development. Available at: http://www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-WP-2015-11-C40-Cities-carbon-lock-in.pdf

European Commission, 2016. EU Building Stock Observatory. Available at: https://ec.europa.eu/energy/en/eu-buildings-factsheets [Accessed February 8, 2017].

European Commission DG-Energy, 2015. Vulnerable Consumer Working Group: Working Paper on Energy Poverty., (November).

Eurostat, 2017. Eurostat online database, Available at: http://ec.europa.eu/eurostat/data/database

Ferreira, M. & Almeida, M., 2015. Benefits from energy related building renovation beyond costs, energy and emissions. *Energy Procedia*, 78, pp.2397–2402.

Fraser Institute, 2016. *Energy costs and Canadian households: How much are we spending?*, GIZ, 2004. Sustainable Urban Transport: Avoid-Shift-Improve (A-S-I)., p.2. Available at: http://www.sutp.org/files/contents/documents/resources/E_Fact-Sheets-and-Policy-Briefs/SUTP_GIZ_FS_Avoid-Shift-Improve_EN.pdf

Global Opportunity Explorer, 2017. Mexico City: Green Bonds for Climate Action. Available at: http://www.globalopportunityexplorer.org/cities/mexico-city-green-bonds-for-climate-action [Accessed December 14, 2017].

Government of Canada, 2017. Statistics Canada.

Gridmates, 2016. Energy Poverty in the U.S.

Heffner, G. & Campbell, N., 2011. *Evaluating the co-benefits of low-income energy-efficiency programmes*, Available at: https://www.iea.org/publications/freepublications/publication/low_income_energy_efficiency.pdf [accessed on 15 December 2016].

Hertz, D., 2015. Urban buses are slowing down. *City Commentary*. Available at: http://cityobservatory.org/urban-buses-are-slowing-down/

Hoornweg, D., Sugar, L. & Gómez, C.L.T., 2011. Cities and greenhouse gas emissions: moving forward. *Environment and Urbanization*, 23(1), pp.207–227. Available at: www.sagepublications.com [Accessed August 24, 2017].

IADB, 2015. ROAD SAFETY STRATEGY - IDB Closing the Gap: Reducing road traffic deaths in Latin America. Available at: https://publications.iadb.org/bitstream/handle/11319/7310/PlanDeAccion_ING.pdf?sequence=4&isAllowed=y

IASS, 2017. *Mobilizing the co-benefits of climate change mitigation*, Potsdam. Available at: http://www.iass-potsdam.de/sites/default/files/files/iass_2017_mobilizing_cobenefits_climate-change.pdf

ICCT, 2012. *Model Documentation and User Guide: ICCT Roadmap Model Version 1-0*, Washington DC, USA: The International Council on Clean Transportation.

ICCT, 2017. Transportation roadmap 2017 baseline results update. Available at: http://www.theicct.org/transportation-roadmap [Accessed December 12, 2017].

IEA, 2014. *Capturing the multiple benefits of energy efficiency*, Available at: http://www.iea.org/Textbase/npsum/MultipleBenefits2014SUM.pdf

IEA, 2009a. Cogeneration and District Energy. *IEA Report*, p.60. Available at: https://www.iea.org/publications/freepublications/publication/CHPbrochure09.pdf [accessed on 28 September 2017].

IEA, 2016a. Decoupling of global emissions and economic growth confirmed.

IEA, 2016b. *Energy Technology Perspectives 2016. Towards Sustainable Urban Energy Systems*, Paris, France: International Energy Agency.

IEA, 2016c. *Energy Technology Perspectives 2016 - Annex E: Buildings Sector Model*, Paris, France: International Energy Agency. Available at: https://www.iea.org/media/etp/etp2016/AnnexE_UrbanBuildingsEnergyEstimationMethodology_web.pdf

IEA, 2011. *Technology Roadmap - Energy-efficient Buildings: Heating and Cooling Equipment*, Available at: https://www.iea.org/publications/freepublications/publication/buildings_roadmap.pdf [accessed on 29 September 2017].

IEA, 2013. *Transition to Sustainable Buildings - Strategies and opportunities to 2050*, Paris, France: International Energy Agency. Available at: www.iea.org/etp/buildings

IEA, 2009b. *Transport Energy and CO_2: Moving towards Sustainability - Books - OECD iLibrary*, Available at: http://ida.lib.uidaho.edu:2891/energy/transport-energy-and-co2-moving-towards-sustainability_9789264073173-en

IEA/OECD, 2017. *Energy Technology Perspectives 2017. Catalysing Energy Technology Transformations*, Available at: http://www.iea.org/etp2017/

INRIX, 2017. INRIX Global Traffic Scorecard.

IRENA, 2016. *REmap:Roadmap for Renewable Energy Future 2016 Edition*, Abu Dhabi. Available at: http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_2016_edition_report.pdf

IRENA, 2017a. *Renewable Energy in District Heating and Cooling - A sector roadmap for REmap*, Available at: http://www.irena.org/remap/IRENA_REmap_DHC_Report_2017.pdf [accessed on 28 September 2017].

IRENA, 2017b. *Renewable Energy in District Heating and Cooling - A sector roadmap for REmap*, Available at: http://www.irena.org/remap/IRENA_REmap_DHC_Report_2017.pdf

ITDP, 2014. Impact Analysis of Transoeste Bus Rapid Transit System in Rio de Janeiro. Available at https://www.itdp.org/wp-content/uploads/2014/07/Transoeste_Analysis_FINAL.pdf

ITDP, 2017. Public Transport.

Janssen, R. & Staniaszek, D., 2012. How Many Jobs? A Survey of the Employment Effects of Investment in Energy Efficiency of Buildings., (May).

Jirón, P., 2013. *Sustainable Urban Mobility in Latin America and the Caribbean*, Available at: https://unhabitat.org/wp-content/uploads/2013/06/GRHS.2013.Regional.Latin_.America.and_.Caribbean.pdf

Karagulian, F. et al., 2015. Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level. *Atmospheric Environment*, 120, pp.475–483. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1352231015303320

Kennedy, C. et al., 2009. Greenhouse Gas Emissions from Global Cities. *Environ. Sci. Technol.*, 43, pp.7297–7302. Available at: http://pubs.acs.org/doi/pdf/10.1021/es900213p [Accessed August 24, 2017].

Levinson, H. et al., 2003. Bus Rapid Transit: Synthesis of Case Studies. *Transportation Research Record: Journal of the Transportation Research Board*, 1841, pp.1–11.

Liu, J. et al., 2016. Air pollutant emissions from Chinese households: A major and underappreciated ambient pollution source. *Proceedings of the National Academy of Sciences*, 113(28), pp.7756–7761. Available at: http://www.pnas.org/lookup/doi/10.1073/pnas.1604537113

LTA, 2011. Passenger Transport Mode Shares in World Cities. *Journeys*, (November), pp.60–70. Available at: http://www.ltaacademy.gov.sg/doc/JOURNEYS_Nov2011 Revised.pdf

Lucon, O. et al., 2014. *Chapter 9 - Buildings. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge UK and New York USA*. Available at: https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter9.pdf [Accessed December 21, 2016].

Lund, H. et al., 2014. 4th Generation District Heating (4GDH). *Energy*, 68, pp.1–11.

Marchetti, C., 1994. Anthropological invariants in travel behavior. *Technological Forecasting and Social Change*, 47(1), pp.75–88.

Mayor of London, 2016. Positive Energy – the Business Case for Retrofit. Available at https://www.london.gov.uk/sites/default/files/renew_positive_energy_-_the_business_case_for_retrofit-_online_0.pdf

Mayor of London, 2017. How we're cleaning up London's air | London City Hall. Available at: https://www.london.gov.uk/what-we-do/environment/pollution-and-air-quality/how-were-cleaning-londons-air [Accessed December 14, 2017].

Mayor of London, 2017 b. London Environment Strategy. Draft for Public Consultation. August 2017. Available at https://www.london.gov.uk/sites/default/files/london_environment_strategy-_draft_for_public_consultation.pdf

Mayor of London, 2017 c Draft Fuel Poverty Action Plan for London. August 2017. Available at https://www.london.gov.uk/sites/default/files/draft_fuel_poverty_action_plan.pdf

Mayor of London, 2017 d. RE:NEW – Helping to Make London's home more energy efficient. Available at https://www.london.gov.uk/sites/default/files/renew_brochure_-_february_2017.pdf

McKinsey & C40 Cities, 2017. *Focused acceleration: A strategic approach to climate action in cities to 2030*, Available at: http://www.c40.org/researches/mckinsey-center-for-business-and-environment

MIT, 2013. Study: Air pollution causes 200,000 early deaths each year in the U.S. Available at: http://news.mit.edu/2013/study-air-pollution-causes-200000-early-deaths-each-year-in-the-us-0829 [Accessed May 11, 2017].

Möller, B. & Lund, H., 2010. Conversion of individual natural gas to district heating: Geographical studies of supply costs and consequences for the Danish energy system. *Applied Energy*, 87(6), pp.1846–1857. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0306261909005248

NHTSA, 2013. Trafic Safety Facts: Rural/urban composition. Available at: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812181%0A

NYC City Government, 2016. Program Progress | NYC Clean Heat. Available at: https://www.nyccleanheat.org/content/program-progress [Accessed December 14, 2017].

OECD, 2015. *ITF Transport Outlook 2015*, OECD Publishing. Available at: http://www.oecd-ilibrary.org/transport/itf-transport-outlook-2015_9789282107782-en

OECD, 2017a. *ITF Transport Outlook 2017*, OECD Publishing. Available at: http://www.oecd-ilibrary.org/transport/itf-transport-outlook-2017_9789282108000-en

OECD, 2017b. *OECD Labour Force Statistics 2016*, OECD Publishing. Available at: http://www.oecd-ilibrary.org/employment/oecd-labour-force-statistics-2016_oecd_lfs-2016-en

Olivier, J.G.J., Muntean, M. & Peters, J.A.H.W., 2016. Trends in Global CO_2 Emissions 2016 Report. *PBL Netherlands Environmental Assessment Agency & European Commission's Joint Research Centre (JRC)*, pp.6–86.

Omnil, 2012. *Enquête globale transport*.

PAGE, 2016. Integrated Planning & Sustainable Development: Challenges and Opportunities.

Rogelj, J. et al., 2015. Energy system transformations for limiting end-of-century warming to below 1.5 °C. *Nature Climate Change*, 5(6), pp.519–527. Available at: http://www.nature.com/doifinder/10.1038/nclimate2572 [Accessed October 19, 2016].

Sanchez, S. et al., 2016. Air Pollution and Health in Latin America and the Caribbean : An Overview. Available at: https://science.gsfc.nasa.gov/610/applied-sciences/air_quality_health_showcase/Sanchez_AQ_Health_Showcase.pdf

Seattle Office of Sustainability & Environment 2017. Drive Clean, Implementation Strategy. Available at https://www.seattle.gov/Documents/Departments/OSE/Reports/Drive%20Clean%20Seattle%202017%20Report.pdf

Shimoda, Y. et al., 2008. Verification of energy efficiency of district heating and cooling system by simulation considering design and operation parameters. *Building and Environment*, 43(4), pp.569–577. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360132306003301

Sims, R. et al., 2014. *IPCC Fifth Assessment Report (AR5)* - Chapter 8: Transport,

Sperling, K. & Möller, B., 2012. End-use energy savings and district heating expansion in a local renewable energy system – A short-term perspective. *Applied Energy*, 92, pp.831–842. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0306261911005502

Stats Mauritius, 2016. Environment Statistics – 2016. Available at http://statsmauritius.govmu.org/English/Publications/Documents/EI1331/Env_Stats_Yr2016.pdf

van Staden, M. & Musco, F., 2010. *Local governments and climate change: sustainable energy planning and implementation in small and medium sized communities*, Springer.

Sudmant, A. et al., 2016. Low carbon cities: is ambitious action affordable? *Climatic Change*, 138(3–4), pp.681–688.

Torregrossa, M., *Energy-efficiency investment with special regard to the retrofitting of buildings in Europe.*

Trading Economics, 2017. Trading Economics.

UITP, 2015. *Mobility in Cities Database*., Available at: http://www.uitp.org/sites/default/files/cck-focus-papers-files/MCD_2015_synthesis_web_0.pdf

UN, 2015. World Population Prospects: the 2015 revision. Available at: https://esa.un.org/unpd/wpp/DataQuery/ [Accessed April 24, 2017].

UNDESA, 2014. *World Urbanization Prospects*, Available at: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf

UNEP, 2009. Buildings and Climate Change: Summary for Decision Makers. ... *Programme, Sustainable Buildings and Climate* ..., pp.1–62. Available at: http://www.unep.org/sbci/pdfs/SBCI-BCCSummary.pdf [21 May 2015].

UNEP, 2015. *District Energy In Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy*, Available at: http://districtenergyinitiative.org/report/DistrictEnergyReportBook.pdf [accessed on 28 September 2017].

United States Department of Labor, 2017. Bureau of Labor Statistics.

Ürge-Vorsatz, D. et al., 2012. *Best Practice Policies for Low Energy and Carbon Buildings: A Scenario Analysis*, Budapest, Hungary: Center for Climate Change and Sustainable Policy (3CSEP) for the Global Buildings Performance Network. Available at: http://www.gbpn.org/sites/default/files/08.CEU Technical Report copy_0.pdf

Ürge-Vorsatz, D. et al., 2010. Employment Impacts of a Large-Scale Deep Building Energy Retrofit Programme in Hungary., p.158. Available at: http://zbr.kormany.hu/download/8/82/00000/Study Deep Building Energy Retrofit Prog.pdf

Ürge-Vorsatz, D., Novikova, A. & Sharmina, M., 2009. *Counting good: quantifying the cobenefits of improved efficiency in buildings*, Available at: http://psb.vermont.gov/sites/psb/files/projects/EEU/screening/Urge-Vorsatz__Counting_Good.pdf [accessed on 13 December 2016].

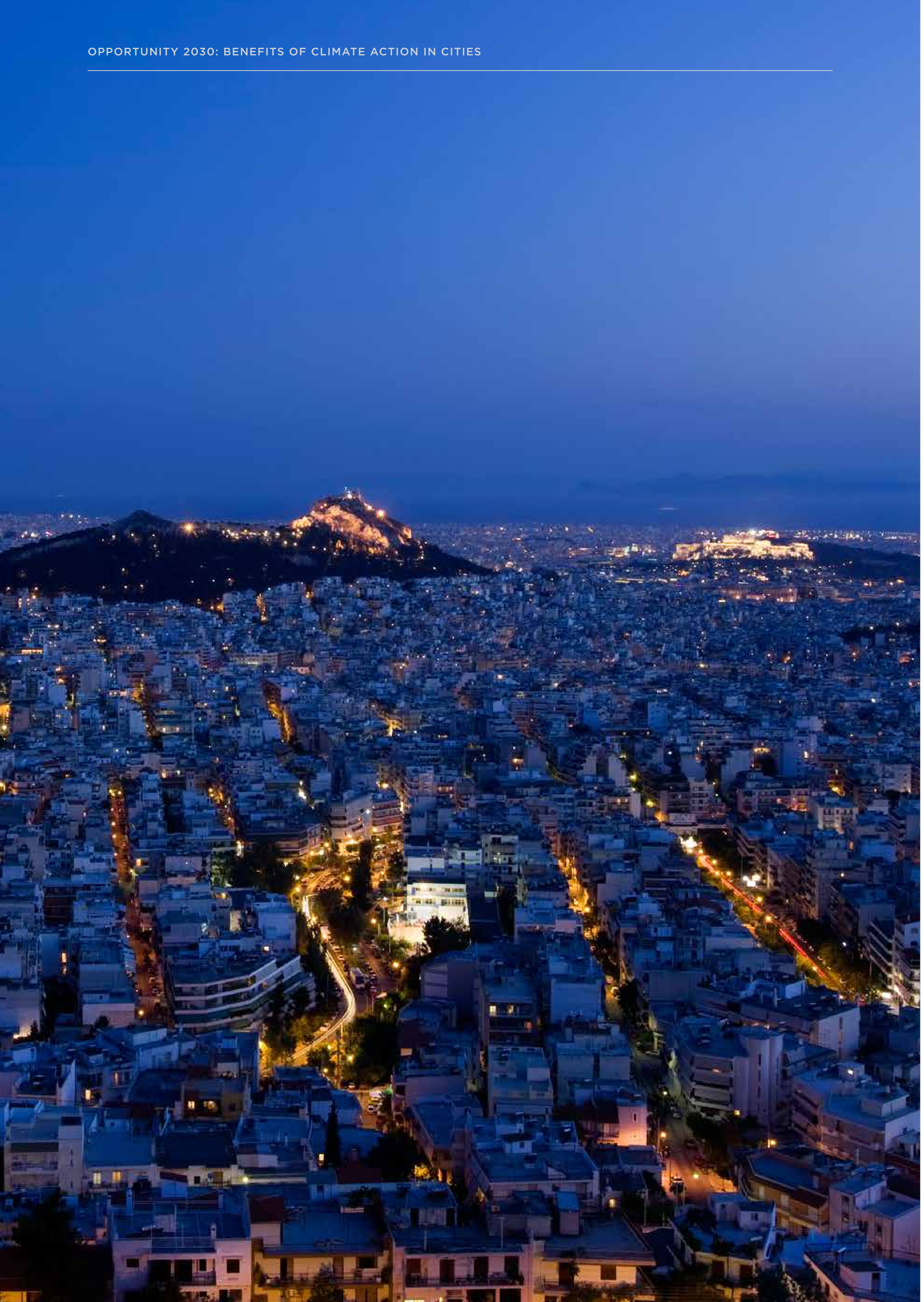
WHO, 2015. *Global Status Report on Road Safety 2015*, Available at: http://www.who.int/violence_injury_prevention/road_safety_status/2015/en/

WHO, 2017. Road traffic deaths - data by country. *Global Health Observatory data repository*. Available at: http://apps.who.int/gho/data/node.main.A997%0A [Accessed August 23, 2017].

World Bank, 2014. Transport for Health: The Global Burden of Disease from Motorized Road Transport., p.39.

World Bank, 2017. *World Development Indicators*, The World Bank Group.

Xiong, W. et al., 2015. Heat roadmap china: New heat strategy to reduce energy consumption towards 2030. Energy, 81, pp.274–285.

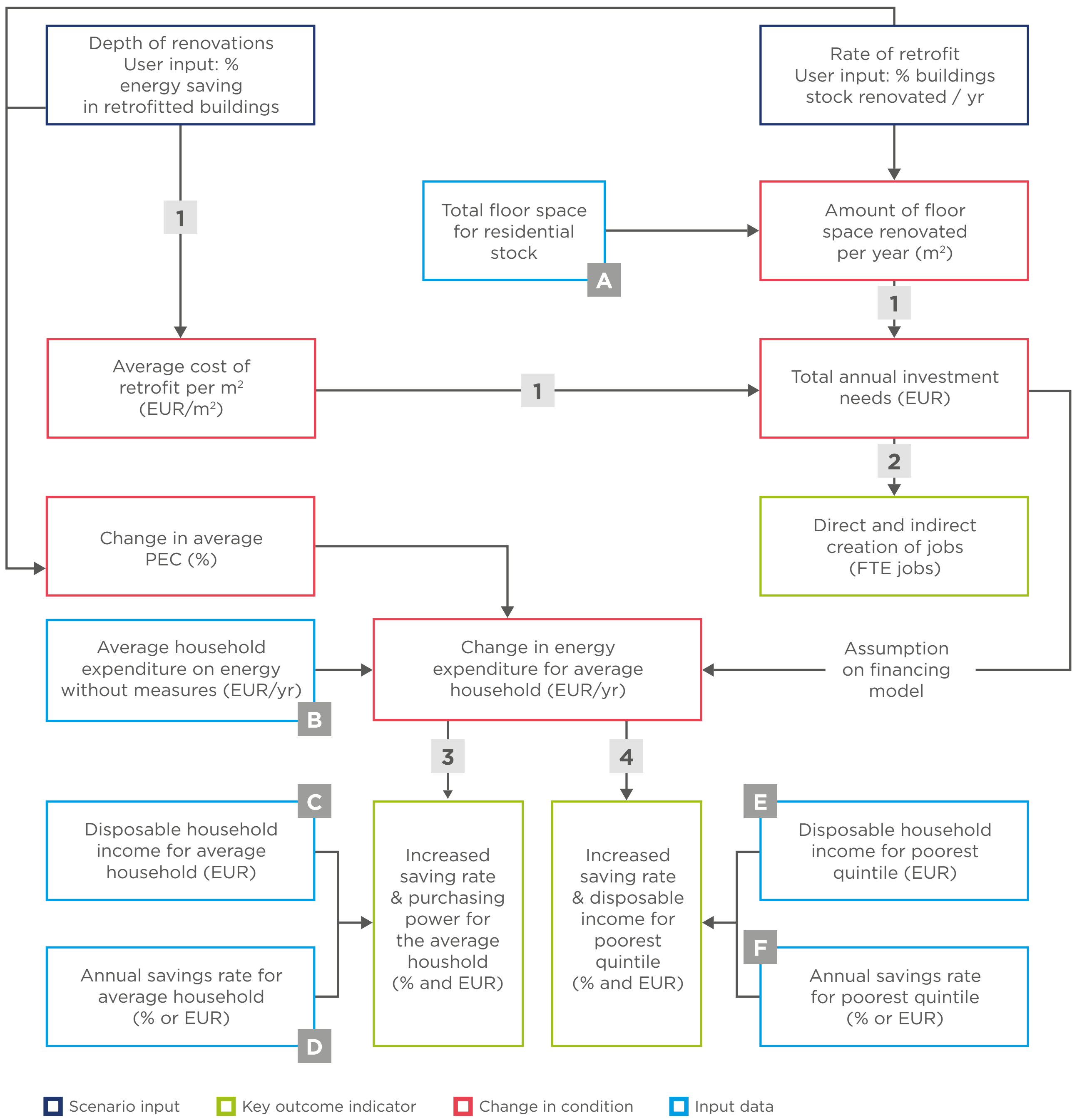


ANNEX I

The flow charts below provide a graphical overview of the calculation logic, demonstrating how data sources and model inputs are used to complete the steps required for the calculation. Further explanations are given in the technical methodology document.

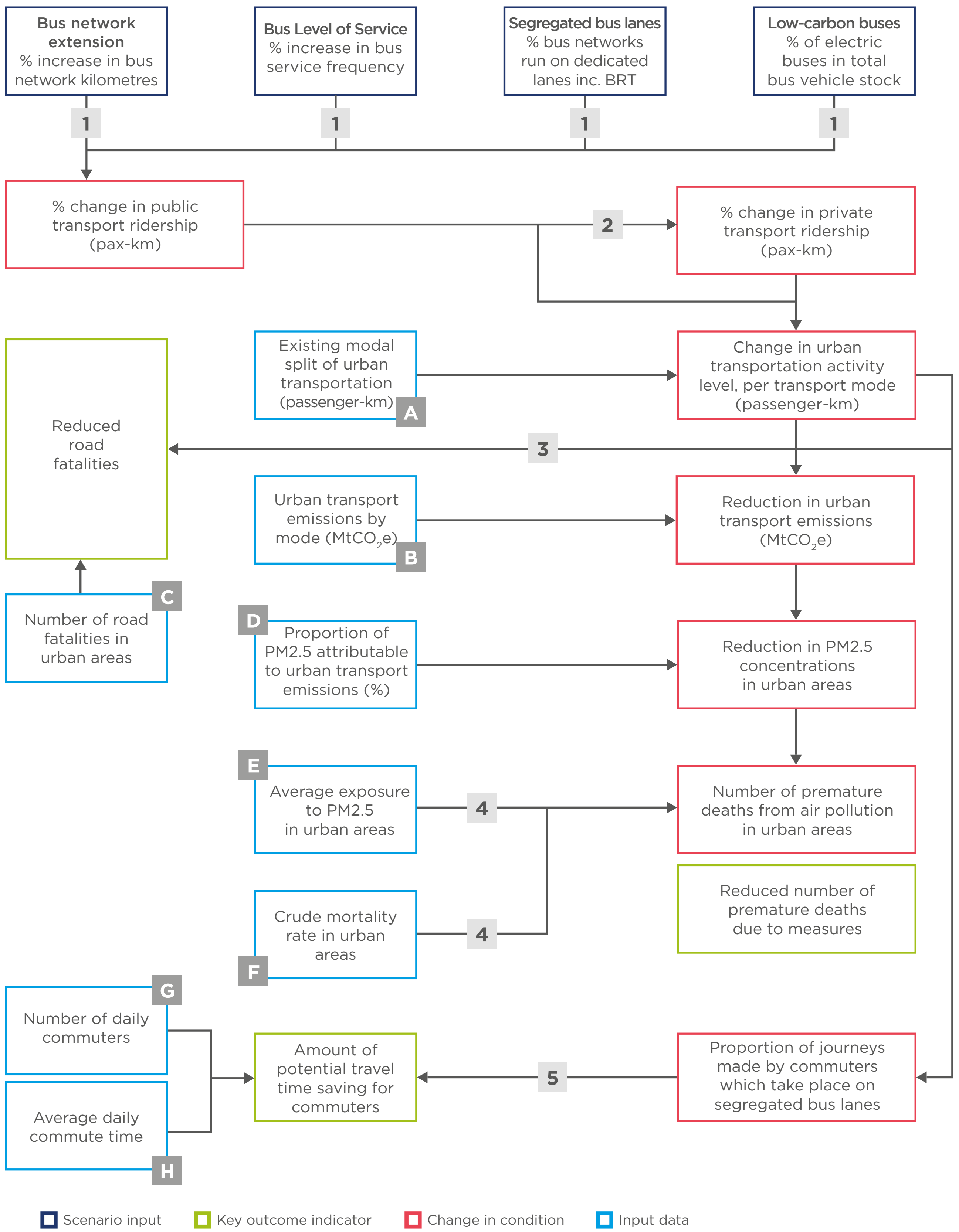
7.1.1 Calculation logic for energy efficiency retrofits in residential buildings

METHODOLOGICAL LOGIC OVERVIEW



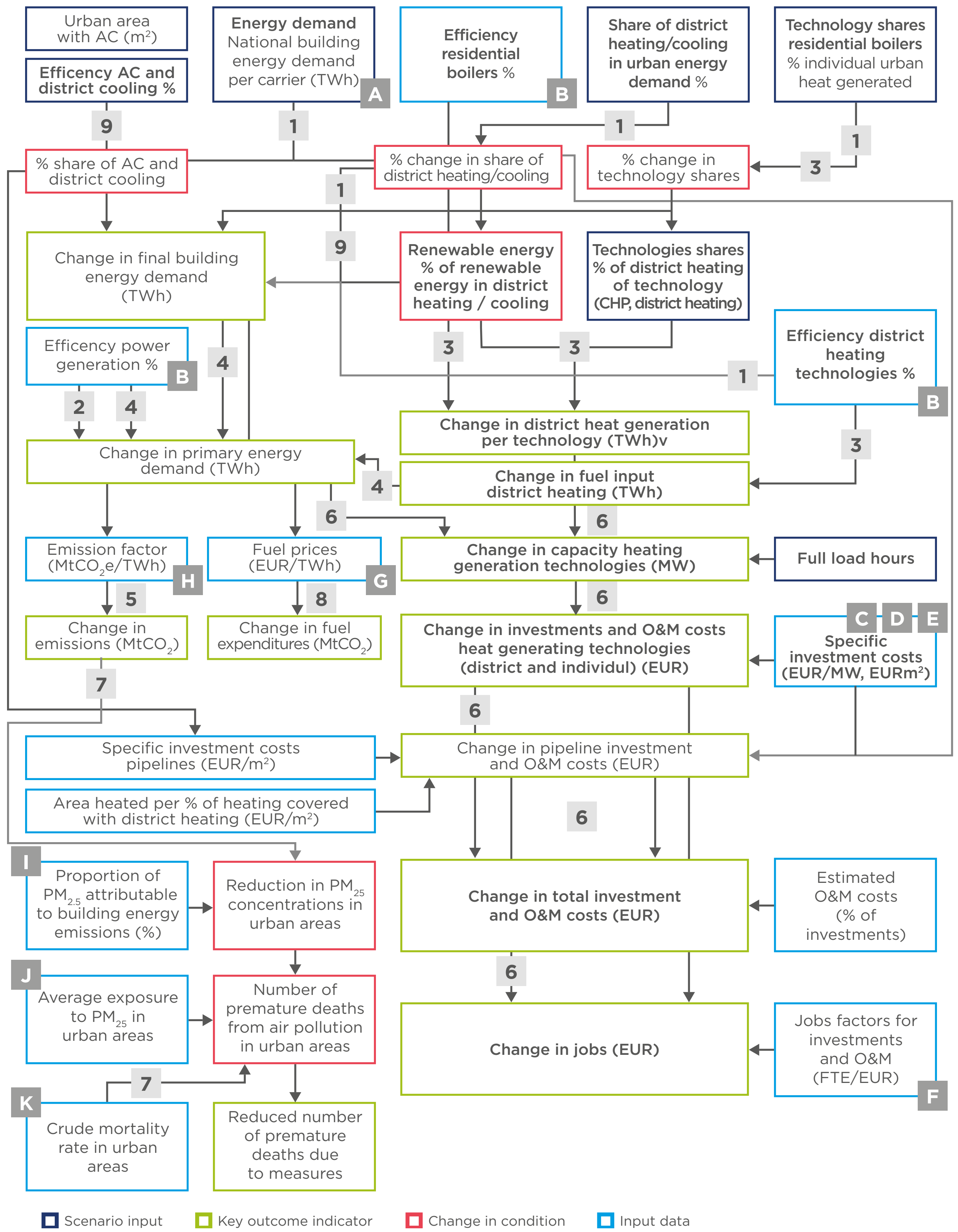
7.1.2 Calculation logic for enhanced bus networks

METHODOLOGICAL LOGIC OVERVIEW



7.1.3 Calculation logic for quantified impacts of district scale renewable energy

METHODOLOGICAL LOGIC OVERVIEW



NewClimate – Institute for Climate Policy and Global Sustainability gGmbH

Cologne Office
Am Hof 20-26
50667 Cologne
Germany

Berlin Office
Brunnenstraße 195
10119 Berlin
Germany

T +49 (0) 221 999833-00
E info@newclimate.org

F +49 (0) 221 999833-19
www.newclimate.org

C40 Cities Climate Leadership Group

3 Queen Victoria Street, City
London EC4N 4TQ
United Kingdom

www.c40.org