CLIMATE OPPORTUNITY: MORE JOBS; BETTER HEALTH; LIVEABLE CITIES

QUANTIFYING THE BENEFITS OF CLIMATE CHANGE MITIGATION MEASURES IN BUILDINGS, TRANSPORT AND ENERGY SUPPLY

METHODOLOGIES

GLOBAL COVENANT of MAYORS for CLIMATE & ENERGY
NEW CLIMATE INSTITUTE
C40 CITIES

Climate Opportunity: More jobs; better health; liveable cities

Methodologies

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1 Table of Contents

2 Introduction

This document presents the detailed methodological approaches for the Opportunity 2030 report, which seeks to quantify the impacts and benefits of city-level climate action measures in buildings, transport and energy supply.

New impact assessment methodologies for the analysis of the impacts of climate action through **energy efficiency retrofit in residential buildings, enhanced bus networks, and district-scale renewable energy** in major global regions, are presented in the chapters of this report.

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.

3 Methodology overview / general approach, assumptions

3.1 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.

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 sometimes variable between the sectors analysed in this report, depending on the data 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.

The following approach was taken for the identification of the enhanced action scenario (EAS). Three options were considered:

1. The preferred option was to use scenarios from the scientific literature which are explicitly found to be compatible with a 2 °C, a 1.5 °C scenario, or found generally to be Paris-Agreement-compatible.
2. For sectors and actions where scenarios from option 1 are not available, it was preferred to use scenarios from the scientific literature which are described as enhanced or high ambition scenarios, or likewise. These scenarios were checked for Paris Agreement compatibility by comparing the emissions outcomes to the emission trends of the enhanced actions in the Deadline 2020 report, and by confirming that the emissions outcomes are not out of line with a trend towards full decarbonisation of the sectors in the second half of the century, as required by the Paris Agreement.
3. For sectors and actions where scenarios from option 1 and 2 were not available and could not be constructed with the existing available scientific literature, the analysis considers multiple scenario options which are intended to illustrate the scale of impacts that could be expected from different roll-outs of actions. The mitigation implications of these actions are presented for information purposes.

4 Energy efficiency retrofit for existing residential buildings

The study analysis the impacts of energy efficiency retrofit scenarios in the urban residential building sector, focusing on *job creation* and *household savings and wealth*. The analysis of this study considers measures that are applied to all residential buildings in urban areas and which are 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. The methodologies are not confined to specific technologies but rather are based on outcomes for reducing energy demand; as such, all energy demand reduction measures are included in the scope, including for example, weatherisation of windows and doors, wall insulation, renovation and insulation of roofing, installation of building elements to manage solar heat gains, structural adjustments to optimise thermal flows, and building automation and control, amongst others, Calculations consider both the existing building stock in 2015, as well as future retrofit for anticipated new building constructions. For new buildings, their construction is considered a separate activity which occurs in both scenarios; only the impact of retrofitting activities on pre-existing buildings is assessed. All scenarios modelled include assumptions for the rate of decommissioning of the existing building stock and the rate at which new residential buildings will be constructed; the subsequent impact on average household PEC is also built into the baseline scenario.

4.1 Overview of impacts assessed

The following terms 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 all household occupants combined, after taxes.
- **Household saving rate**: financial resources households have available each year after all expenditure from essential needs for use towards increasing assets and making investments.

Job creation impacts

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. Indirect jobs are subsequently created in various stages of the supply chain. Secondly, money saved from lower energy bills, and earned by the newly employed workers, is re-spent in the broader economy, creating induced jobs in a wide variety of service and retail industries (Bell, 2011).

For the most part, these jobs are local in nature but affecting all areas; measures to improve energy efficiency have to take place at the site where the buildings stand, in all regions of the EU (Janssen and Staniaszek, 2012). Measures are typically implemented through engineering, construction and installation companies from the local or semi-local economy (Torregrossa, no date).

Several types of methodologies could be used to analyse job creation outcomes:

- Macroeconomic studies;

- Sector-specific studies: a wide variety of approaches to quantitative modelling are used at the sector level. They usually begin with a qualitative analysis to identify the main factors likely to drive employment in a certain direction in the future;
- Analyses of occupations, skills, training and education: methodologies to research occupations, skills involve quantitative modelling or qualitative research.

Ürge-Vorsatz (2010) calculated the positive effect on jobs by taking into account of:

- *Direct effects* through the creation of new jobs in the construction industry;
- *Indirectly*, on all the sectors that supply materials and services to the construction industry itself;
- The savings caused by the reduction in energy consumption, plus the additional consumption fuelled by the wages of the additional jobs created, will increase the disposal income of the families; income that, when spent, will generate additional induced benefits to employment. These are referred to as *induced effects* (Ürge-Vorsatz *et al.*, 2010).

Many comparable studies (UNEP, 2008; Ürge-Vorsatz *et al.*, 2010; see for example ACEEE, 2011; BPIE, 2011; Janssen and Staniaszek, 2012; Meijer *et al.*, 2012), attribute job creation mainly to investments, relating the possible growth in employment to the investment that is needed to realise the depth and rate of retrofit envisaged. This study uses the same approach, relating job creation to the total amount of investment in energy efficiency retrofit.

Household savings and wealth

Energy bills play a significant role in households' regular expenditures. Further, expenditure on energy includes household's final consumption expenditure devoted to electricity, gas and other housing fuels. The energy spending for the average household ranges depending 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.

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. 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).

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

4.2 Overview of measures considered

Building retrofit needs and starting points are vary widely across cities and regions. As such, the scenario parameters for the assessment of the benefits of energy efficiency retrofits for existing residential buildings are not always absolute. Instead, most of them are relative parameters (e.g. presented as percentage increase in the renovation rate rather than an absolute number of buildings being retrofitted every year). When modelling the impacts of relative parameters, it is possible to obtain a more direct indication of what can be expected under marginal or significant changes from the existing situation, which is relevant for cities with diverse starting situations and needs.

In line with other major studies (see, for example, BPIE, 2011), scenarios for energy efficiency retrofit are defined based on two characteristics: **renovation rate**, and **renovation depth**. Further, the **cost of the renovation measures** and the **scope of the building stock** are two other important parameters we took into account and to which our assessment is quite sensitive.

Renovation rate

The rate of retrofit indicates the proportion of the building stock which is retrofitted each year, as a percentage. For example, a retrofit rate of 2% indicates that 2% of the building stock is retrofitted in a single year, meaning that it would take at least 50 years for the entire existing building stock to be retrofitted.

Depth of renovation

The efficiency improvements or “depth of renovation” refers to the scale of work that takes place at the buildings which are retrofitted, represented as the proportion of energy saved in those buildings after the retrofitting measures are completed, compared to the status before the renovation.

4.3 Calculation logic

Figure 1 provides 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 beneath the figure for some steps that require a more thorough description.

Methodological logic overview

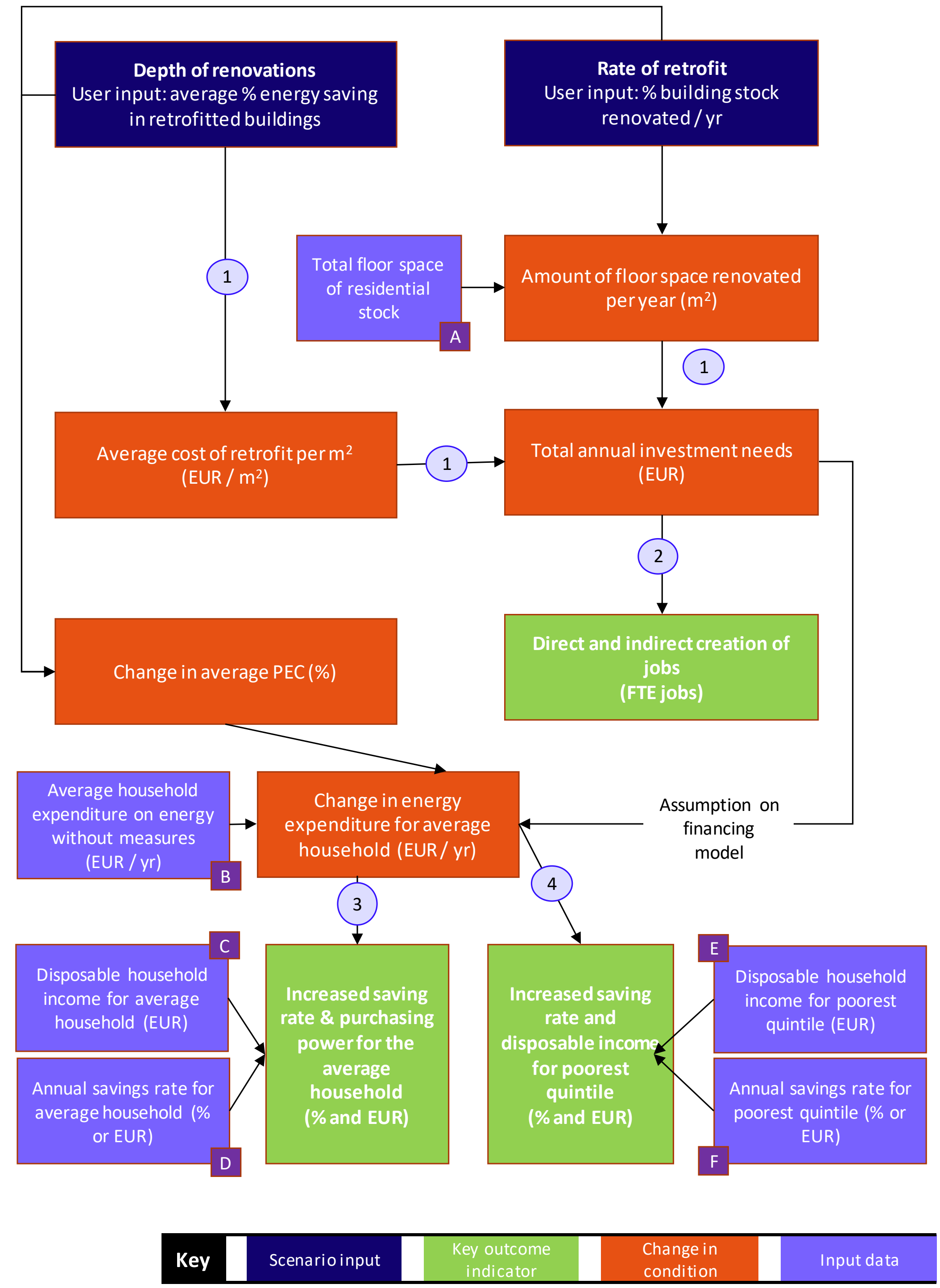


Figure 1: Calculation logic for impacts of residential building retrofit

Description of steps

(1) The average cost of renovation measures per m² is determined based on the proportion of minor, moderate, deep and near-zero energy (nZEB) measures carried out, and the average costs of these different measures per m². For this analysis, the cost forecasts of BPIE (2011) are used as the basis for analysis for the European Union and adapted for the other regions of this study based on

calculated cost multiplier factors for construction works between regions. The costs are based on the depth of the renovation measures, in line with the BPIE analysis (2011). Figure 2 shows how the forecast costs from the BPIE analysis decrease over time: in 2015, deeper renovation measures were considerably more expensive per m² than more shallow measures, but the costs converge considerably up to 2050 due to the learning rates of the technologies, which lead to cost reductions due to technological advancements, enhanced economies of scale, more efficient supply chains and more experience amongst workers.

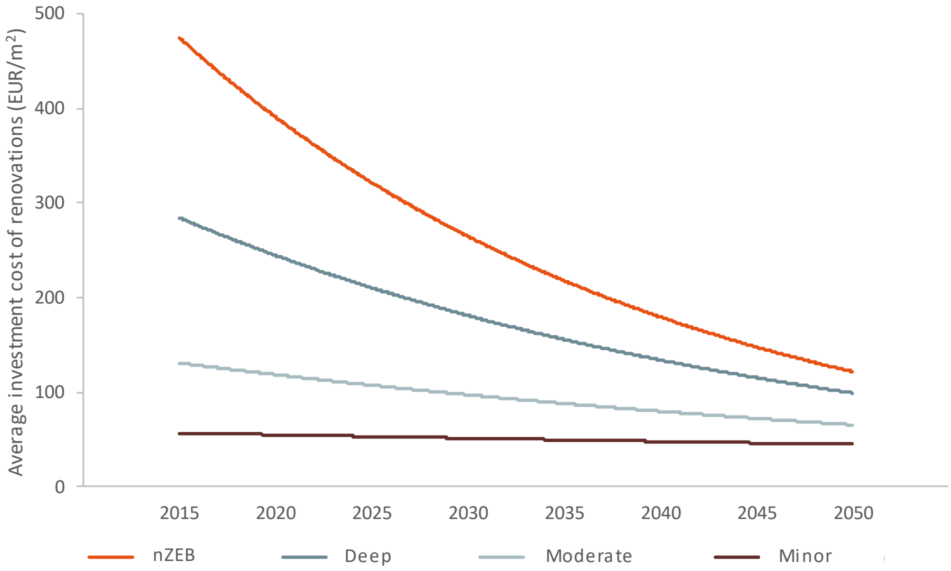


Figure 2: Forecast development of renovation costs for different renovation depths under current renovation pathways. Extracted from BPIE (2011)

The cost forecasts shown in Figure 2 were only available for a continuation of the current situation in retrofits, which features relatively low rates of retrofit, and a relatively shallow renovation depth pathway. Realistically, the cost of renovation measures may be expected to decrease at an even faster rate in the case that the rate of retrofit increases and the renovation depth pathway becomes steeper, since a higher level of activity would accelerate the learning rate of the technologies and practices. In the enhanced retrofit scenario, it is assumed that the learning rate and the rate at which the costs decrease between 2015 and 2030 will double, as the rate of retrofit increases by slightly more than double over this period. This assumes a linear correlation between the rate of renovation and the rate of cost decrease. This assumption entails limitations: on the one hand, the costs will be affected by technological developments across the economy outside of the construction sector; on the other hand, the rapidly increased use of high depth renovation measures over minor measures in the enhanced retrofit scenario (in addition to the higher rate of retrofit) may cause the costs of these measures to decrease by an even greater rate.

2 The total number of jobs generated through the energy efficiency measures is estimated through multiplying the total annual investment requirements by an employment factor. Determining job creation through an employment factor is a common approach (see Table 1). In line with the literature review, we take an employment factor of 17 FTE jobs per EUR 1 million investment in energy efficiency measures for the European union and one of 17.1 FTE jobs per EUR 1 million investment in North America.

The selected job creation factor for this study includes a net impact of job creation and job losses in different sectors. The estimation of the breakdown of the job creation according to job creation and losses per sector, as well as the types of jobs created (professional, skilled, unskilled) is based on the models conducted in a study by Urge-Vorsatz (2010).

Table 1: Overview of employment factors used in various comparable studies

Study	Region	Employment factor
BPIE (2011)	European Union	17 jobs per €m
(ILO, 2011)	European Union	15.7 jobs per €m
Janssen and Staniaszek (2012)	European Union	19 jobs per €m
Meijer *et al.* (2012)	European Union	17 jobs per €m (based on BPIE 2011)
Ürge-Vorsatz (2010)	Hungary	17 jobs per €m
Deutsche Bank (2012)	United States	11.9 jobs per $m
Cambridge Econometrics (2015)	United States	17.3 jobs per $m
Supple (2010)	United States	20 jobs per $m
Renner (2009)	United States	21.5 jobs per $m
U.S. Green Building Council (2011)	United States	13.6 jobs per $m
Duffy (2016)	United States	15.7 jobs per $m

3 The effective reduction in energy expenditure of the average household is based on the % primary energy consumption (PEC) savings across the entire urban residential building stock, multiplied by the average household's expenditures on energy. The potential effect of energy efficiency improvements on household saving rates and purchasing power is determined by assuming that the full value of the reduced energy expenditure will be available to the household, thus increasing its potential savings.

4 To assess the impact for the lowest and highest income quintile households specifically, the same calculations in step 3 are followed, using household expenditure data specific for each of the quintile groups. The results are presented in terms of impact on the savings rate and also in comparison to the household's total disposable income.

4.4 Definition of scenarios

The analysis of impacts for enhanced energy efficiency retrofits for residential buildings in this study focuses on two regions: European Union and North America. The study compares enhanced scenarios to a reference scenario, which is defined as a continuation of the prevailing practice regarding the rate and depth of retrofit activity.

A few studies are available which estimate what could be the contribution of energy efficiency retrofits for space heating and cooling in existing residential buildings, for deep decarbonisation of the building sector:

- Data from the Energy Performance of Buildings (Erhorn and Erhorn-Kluttig, 2015) indicates that the average rate of retrofit of the existing building stock each year was around 1% across the EU in 2013, ranging from 1.6% in Austria to around 0.1% in Spain and Poland. Alternate literature sources for previous years present similar findings: Jensen (2009) finds an ongoing rate of retrofit in the EU of approximately 1.2-1.4%, whilst Lechtenböhmer (2011) estimates a rate of 1%.
- Ürge-Vorsatz *et al.*, (2015) developed a "frozen efficiency scenario" which tries to represent a baseline or business as usual scenario. The Frozen Efficiency scenario assumes that the energy performance of new and retrofit buildings do not improve as compared to their 2005 levels and retrofit buildings consume around 10% less than standard existing buildings for space heating and cooling, while most of new buildings have higher level of energy performance.

Renovation rates are assumed to be constant throughout the analysed period at the level of 1.4%.

- According to the same study of the Central European University (Ürge-Vorsatz et al., 2015), their "deep efficiency scenario" demonstrates how far today's state-of-the-art construction and retrofit know-how and technologies can take the building sector in reducing energy use and CO2 emissions, while also providing full thermal comfort in buildings. In their model, the retrofit rate assumed for all regions, grows linearly from 1.4% in 2005 to 3.0% in 2020. After 2020 it stays at a constant level.
- Passive House Institute (2017) reports that passive houses have been successfully built across the world in multiple climate zones, reaching energy intensities of 15 kWh/m2 for heating and cooling in both new and renovated buildings. Deep retrofits have been shown to reach these levels (BMUB, 2016).

In line with the findings of the aforementioned studies, a scenario was constructed for enhanced retrofit action which would result, according to the model, in improving efficiency and achieving energy savings of up to 80% in Europe and 68% in North America, compared to the reference scenario. Table 2 gives an overview of these parameters.

Table 2: Situation of building retrofits in the European Union, North America and China

Reference scenario (2015-2030)			
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**	**China**
Renovation rate (%)	1.4% per year	1.4% per year	1.4% per year
Efficiency improvement through renovation in the target year (%)	10% (final energy consumption of 93 kWh/m² by 2020)	10% (final energy consumption of 61 kWh/m² by 2020)	10% (final energy consumption of 31 kWh/m² by 2023)
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 (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 for the European Union and North America and between 2015 and 2023 for China, whilst the rate of retrofit increases from the current to the target levels between 2020 and 2025 for the European Union and China and between 2020 and 2028 for China, to be sustained thereafter up to 2030.			
	European Union	**North America**	**China**
Target renovation rate (%)	3.0% per year by 2025	3.0% per year by 2025	3.0% per year by 2028
Target efficiency improvement through renovation in the target year (%)	80% (final energy consumption of 22 kWh/m² by 2020)	68% (final energy consumption of 22 kWh/m² by 2020)	26% (final energy consumption of 22 kWh/m² by 2023)

4.5 Data sources

Table 3 provides details on the data sources used for required inputs. Their input code can be compared to the calculation logic chart in Figure 1.

Table 3: Data sources for inputs to bus network enhancement impact calculations

Code	Indicator	Unit	Source*		
			European Union	North America	China
A	Total floor space of residential stock	m2	(IEA, 2013)		
B	Average household expenditure on energy without measures	EUR/year	(Eurostat, 2017)	(Government of Canada, 2017; United States Department of Labor, 2017)	(National Bureau of Statistics of China, 2017)
C	Disposable household income for average household	EUR	(Eurostat, 2017)	(Government of Canada, 2017; United States Department of Labor, 2017)	(National Bureau of Statistics of China, 2017)
D	Annual savings rate for average household	% and EUR	(OECD, 2017b)		
E	Disposable household income for highest and poorest quintile	EUR	(Eurostat, 2017)	(Government of Canada, 2017; United States Department of Labor, 2017)	(National Bureau of Statistics of China, 2017)
F	Annual savings rate for highest and poorest quintile	% and EUR	(Eurostat, 2017)	(Government of Canada, 2017; United States Department of Labor, 2017)	(National Bureau of Statistics of China, 2017)

4.6 Assumptions used in this study

In addition to the information provided in the previous sections, the following assumptions were made for the completion of the analysis for the European Union, North America and China in this study:

- It is assumed that approximately half of the learning rate for retrofit costs is based on activity within the industry and the remaining half on external influences, and the future cost forecasts are adjusted accordingly. For example, in the case that the rate of retrofit would increase by a factor of 5 (e.g. from approximately 1% of the building stock per year to 5% of the building stock), the rate at which the costs decrease would be assumed to increase by a factor of about 2.5.
- When analysing the impact of the rate of retrofit on the building stock, the simplified assumption is taken that each building is renovated before any building is renovated a second time, such that a retrofit rate of 5% will ensure complete retrofit of the building stock in twenty years.
- This study takes information for average buildings from the region, whilst it is noted that such parameters will vary in reality across different types of buildings, in different areas. This simplification should be considered especially when scaling down the results to the scale of specific cities.
- Annual demolition rate of 2.0% (in OECD regions) and 1.0% (in non-OECD regions) are assumed in the calculations to estimate the increase in building stock every year. This is in line with IEA projections (Global Buildings Performance Network, 2013; BPIE, 2016; IEA, 2016c).

5 Bus network and service enhancement in urban areas

The study focuses on the impacts of scenarios for enhanced bus networks in urban passenger transportation systems on indicators for *air pollution and related health impacts* and *road fatalities*.

5.1 Overview of impacts assessed

Air pollution and related health impacts

The World Health Organization (WHO, 2014) reports that in 2012 one in eight of total global deaths - around 7 million people - died prematurely as a result of air pollution exposure. This makes air pollution the world's largest single environmental health risk.

This study considers the health impacts associated with reduced ambient atmospheric concentration of $PM_{2.5}$ in urban populations, based upon reduced emissions of primary particulate matter (PM), sulphur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3), due to changes in activity for urban passenger transportation.

$PM_{2.5}$ refers to particulate matter with a diameter less than 2.5 μm. $PM_{2.5}$ is the most lethal outdoor air pollutant in urban areas (OECD, 2011). Its atmospheric concentration is derived from the emissions of primary particulate matter from fossil fuel combustion processes, as well as from atmospheric reactions between other pollutant gases (secondary particulate matter), namely SO_2, NO_x, and NH_3.

Concentrations of $PM_{2.5}$ in any given location can be derived from five distinct sources: natural sources of particulate matter including dust and sea salt; secondary PM from international transboundary emissions; primary and secondary PM from national emissions; primary and secondary PM from urban emissions; and primary PM from local street emissions. Natural sources of PM cannot be affected by urban policies and interventions, nor can PM be derived from activities in other locations within or outside of the region. As such, the calculation methodology focuses only on changes to the proportion of air pollution concentrations that can be attributed to urban transport. The urban system is analysed as a whole as an average, with emissions and $PM_{2.5}$ concentrations assumed to be constant across all urban areas; variations in exposure levels between more and less polluted districts and streets are not addressed.

The indicator assessed with this methodology will only reflect the number of all-cause premature deaths per year, and as such it considerably underestimates the 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.

Road 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 vehicle 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 3.6) to reduce global road fatalities by half by 2020 compared to 2015.

Several characteristics of traffic and transport infrastructure contribute to increasing the risk of collisions and fatal accidents in urban areas. These factors include traffic volumes, vehicle speeds, condition of roadways, provisions for segregation of transport modes, road user training and behaviour, amongst other factors (WHO, 2015). In this study, it is assumed that enhancement in bus network infrastructure will change urban passenger activity and segregation of transport modes, consequently reducing the volume of vehicle traffic on public roadways (i.e. including private vehicles and buses travelling on non-segregated lanes). The changes in fatalities associated with accidents on these public roadways are assessed.

This outcome indicator includes all fatalities that are linked to traffic accidents, including amongst vehicle passengers, other road users and pedestrians.

Potential time savings for commuters

Traffic congestion is a significant burden for commuters in all regions of the world. In 2015, the average urban commuter across the global cities studied was assessed to have lost around 40 hours per year to congestion during their commutes (INRIX, 2017). In some cities, including cities in the focus regions of this research (North America and Latin America), the average commuter lost over 80 hours during 2015, equivalent to 2 full working works. 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 and lifestyle choices also play an important role.

In this study, it is assessed 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, which in some regions is likely to include a high proportion of disadvantaged communities.

This calculated impact is intended to indicate *potential* time savings as a measure of increased economic flexibility. In reality, there are multiple feedback loops associated with this outcome which may mean that the potential time savings are not observed: for example, there is evidence to indicate that commuters may "optimise" their journeys and their lifestyles 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. The actual response of each commuter based on these potential feedback effects cannot be estimated with any degree of confidence, so the indicator assessed here is the *potential* time saving, whilst it should be recognised that there are different ways in which this potential can be utilised, and it may not be that average observed commute times decrease by the same amount as the estimated potential.

5.2 Overview of measures considered

Specific public transportation needs are different between cities, and starting points are even more variable. As such, the scenario parameters for the assessment of the benefits of public transportation enhancements in this study are not always absolute (e.g. a specific transport network density per population would be an absolute indicator), but rather most of them are relative (e.g. a percentage increase in transport network density compared to the existing situation). Modelling the impacts of these relative parameters offers a more direct indication of what impacts could be expected for marginal or significant changes from the existing situation, which is relevant for cities with diverse starting situations and needs.

The following parameters are included in the scenarios. These key parameters were selected for inclusion based on their importance for affecting modal shift (GIZ, 2004; Broaddus, Litman and Menon, 2009; refer to IEA, 2009, 2016b; ITDP, 2015; ERC, 2016) and for the modernisation of energy systems.

Network length of bus system

The network length of the system is defined as the total kilometres of bus route length in the urban area. 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. The parameter is levered in terms of relative increases, such that a scenario input might be a 100% increase by a certain date, or effectively a doubling of the total kilometres of bus route length.

Frequency of bus service

The frequency of service is defined based on the time interval between bus services running on a given route. Increases in the frequency of service facilitate an increase in the hourly ridership capacity, and also improve the convenience of public transport and the attractiveness of its use. The parameter is also levered in terms of relative increases, such that a scenario input of a 100% increase in the frequency of service by a certain date effectively means halving the interval time between services.

Usage of dedicated bus lanes / bus rapid transit

The parameter is used in this analysis to assess the proportion of the existing network length that is converted to dedicated bus lanes. As such, the maximum value is 100%. BRT lines are also included within this category on the basis that they operate with dedicated lanes.

Penetration of low carbon buses in the vehicle stock

Low carbon buses are defined as those with fuel cell or electric drive technologies. The simplified assumption is made for the analysis that electric buses are powered by renewable energy technologies and that the tank to wheel emissions equivalent is zero.

5.3 Calculation logic

Figure 3 provides 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 beneath the figure for some steps that require a more thorough description.

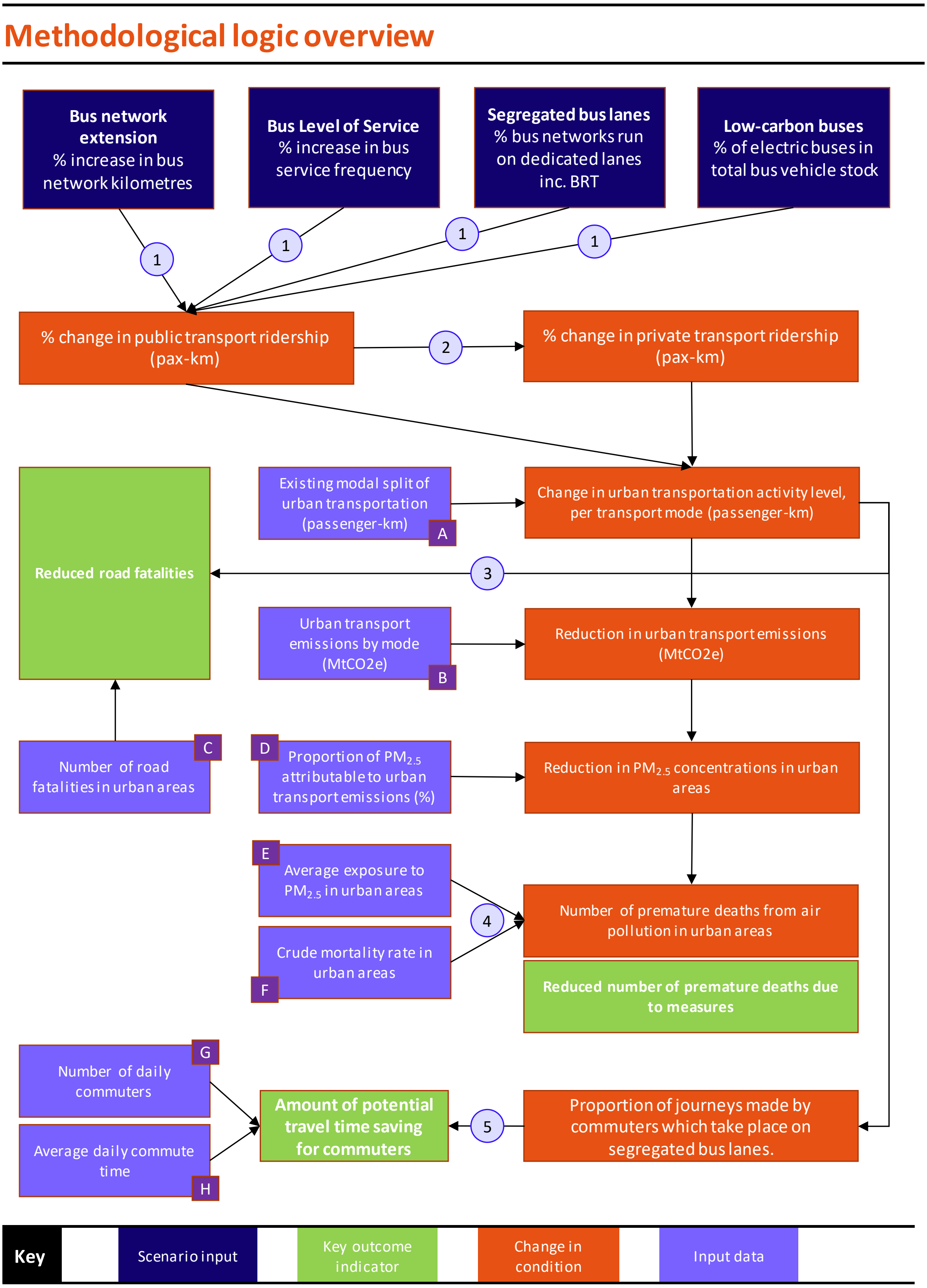


Figure 3: Calculation logic for impacts of enhanced bus networks

Description of steps

1 The urban public transportation activity ($PubT$) resulting from the measures is calculated based upon the initial urban public transportation activity before the interventions ($PubT_0$), adjusted by the change in the scenario parameter conditions (Δc_{PUB-n}) and the proportional elasticities which determine the relationships between changes in the conditions and impacts on transportation activity (f_{PUB-n}). Changes in the scenario parameter conditions are modelled inputs, and include percentage change in the total length of the urban bus network, percentage change in frequency of bus service, percentage change in the proportion of dedicated bus lanes, and percentage change in the cost of private vehicle use. The elasticities that determine the impacts of these parameters on public transportation ridership are taken from the literature, and are specific to the regions' studies as far as possible. These elasticities indicate the rate to which a change in the parameter affects the ridership. For example, an elasticity for frequency of service of 0.7 would indicate that for every 1% increase in the frequency of the bus services, the ridership would increase by 0.7%. For most parameters, multiple elasticities are available from the literature, covering either regions, countries or specific cities. Elasticities from the literature were collected and assigned to the regions of this study, and the average of the literature estimates was taken for the calculations unless there was reason to believe that specific values were more accurate or representative than others. The elasticities used in the analysis are presented in Table 4 alongside the ranges available from the analysis.

2 The urban private transportation activity ($PrivT$) resulting from the measures is calculated based upon the initial urban private transportation activity before the interventions ($PrivT_0$), adjusted by the change in the urban public transportation activity ($\Delta PubT$) and the absolute elasticity which determines the relationship between changes in these two indicators ($f_{PUB-PRIV}$). For example, an absolute elasticity of 0.8 indicates that for every additional unit of public transportation activity (1 passenger km), there are 0.8 fewer passenger-kilometres travelled in private cars. As per the proportional elasticities determining changes in public transportation ridership, multiple elasticities are available from the literature and the average of the literature estimates was taken for the calculations from each region, unless there was reason to believe that specific values were more accurate or representative than others.

Table 4: Urban transportation elasticities used for the analysis

Relationship (f_{PUB-n})	Elasticities used in the analysis: North America	Elasticities used in the analysis: Latin America
Bus network length change on ridership numbers	+0.79 (range 0.71 – 0.89)	+0.77 (range 0.71 – 0.89)
Frequency of service change on ridership numbers	+0.69 (range 0.5 – 1.05)	+0.68 (range 0.5 – 1.05)
Provision of dedicated bus lanes on ridership numbers	+0.2	
Increase in transit ridership on reduced LDV use	-0.78 (range -0.72 to -0.83)	
Changes in transport activity and changes in accident rates (f_{FAT})	+1.3 (range +1.0 to +1.80)	

Sources: (TRB, 2004; VTPI, 2015; Litman, 2017a, 2017c, 2017b)

3 The resulting level of road accident fatalities is determined by adjusting the number of fatalities before the interventions by the change in the volume of private transportation activity ($\Delta PrivT$) and the elasticity factor that determined the relationship between changes in transport activity and changes in accident rates and fatalities (f_{FAT}) (see Table 4).

4 Estimated emissions of SO_2 and NOx are used as a proxy for the emissions of all the major air pollutants under consideration: primary PM, SO_2, NO_x, and NH_3. This simplification recognises that emissions of SO_2 and NOx are highly influential to the production of secondary particulate matter, and assumes that the emissions of other air pollutants are reduced proportionally to SO_2 and NOx. A number of studies have applied such simplifications that assume uniform reductions of all these gases for the calculation of local outdoor air pollution, most notably the OECD 2050 Environmental Outlook (OECD 2011). Detailed data for SO_2 and NOx emissions is not available under all scenarios. Instead, the relationships between CO_2 emission projections and SO_2/NOx projections were analysed for each region to produce an indicative factor that allows for the estimation of air pollutant emissions based upon CO_2 emissions, the data for which is readily available. The **reduction of premature mortality** can be calculated depending on the change of atmospheric concentration of $PM_{2.5}$ between scenarios (Bollen, 2009; Fang *et al.*, 2013; Public Health England, 2014):

$$\text{Premature deaths from particulate air pollution} = \text{Attributable factor (AF)} \times \text{Crude death rate (DR)} \times \text{Population } (P_{>30})$$

$$\text{Attributable factor (AF)} = \frac{\beta^{G} - 1}{\beta^{G}}$$

The attributable factor (AF) calculates the percentage of deaths which may be attributed to excessive $PM_{2.5}$ concentrations. In this equation, G is the concentration of the pollutant, given in units of 10 µg/m³. β refers to the estimated factor of the log-linear relationship between the concentration of any given pollutant and the resulting mortality rate (concentration-response factor). Krewski et al. (2009) finds a 5.9% risk increase of premature mortality from all causes for every $PM_{2.5}$ concentration increase of 10 µg/m³. Therefore, the value 1.059 is used for the concentration response factor β, as per Fang et al. (Fang *et al.*, 2013) and Bollen (Bollen, 2009). It is common practice when calculating premature deaths from $PM_{2.5}$ concentrations to consider only the population over 30 years of age (Public Health England, 2014).

This study does not apply a low concentration threshold (LCT). The use of an LCT assumes that below a certain level of $PM_{2.5}$ concentrations, there is no effect on mortality. There is no general consensus on whether the use of an LCT is appropriate or not, due to the lack of empirical evidence that such a threshold does or does not exist. The use of an LCT of 5.8 µg/m³ in this study would have no impact on the results, since the reductions from the measures do not result in concentrations below 5.8 µg/m³ in the analysed regions.

5 Average journey times are adjusted to find time savings by considering the portion of the average journey time that is spent actively in transit vehicles and the distance travelled, the portion of the network length that is served by dedicated bus lanes, and the average time saving per km for bus routes shifted from non-segregated to segregated lanes.

5.4 Definition of scenarios

The analysis of impacts for enhanced bus networks in this study focuses on two regions: North America and Latin America.

A handful of studies exist which estimate what could be the contribution of urban public transport system development, for deep decarbonisation of the transport sector:

- The ITF Transport Outlook (OECD, 2017a) includes a Robust Governance scenario specifically for urban areas in North America and Latin America, which the scenarios in this analysis are based on. This results in a 21% reduction of LDV traffic in North America, a 32% reduction in Latin America, and a 40% reduction in South Asian cities in 2050 compared to the reference scenario.

- ARUP & C40 Cities (2016) *urban action scenario* includes the target for the modal share of private vehicles to decline from 64% in 2015 to 53% in 2050, in contrast to an increase to 72% under a reference scenario, through rapid expansion of public transport. This entails a 26% reduction in private vehicle activity compared to the reference scenario.
- IEA (2009) estimate in their *BLUE shifts scenario* that the introduction of strong and effective policies could cut the global use of private vehicles by 25% in 2050 compared to the reference case, resulting in a 50% increase over the 2005 level, rather than an 80% increase under the reference scenario. (50% compared to high baseline). The 25% reduction in private vehicle use from the reference case in 2050 is valid for both OECD urban areas and non-OECD urban areas. For OECD urban areas this translates to a 20% reduction compared to 2005 levels, whilst in non-OECD areas this would entail approximately a 300% increase in private vehicle activity compared to 2005.
- The 2016 Energy Technologies Perspectives (IEA, 2016b) finds that by 2050, a 2°C scenario would require the use of private cars for urban transportation to be reduced by 18-26% compared to a business-as-usual scenario.

In line with the findings of the aforementioned studies, a scenario was constructed for enhanced bus networks through an iterative process. Scenario parameters for which there was no specific input from the literature were sought, based on those which would result, according to the model, in reducing urban private vehicle usage in North America by approximately 21% compared to the reference case in 2050, by 32% in Latin America and by 40% in South Asia. Table 5 gives an overview of these parameters.

Table 5: Scenarios for analysis of impacts of enhanced bus networks

<table>
<tr><th colspan="4">Reference scenario (2015-2030)</th></tr>
<tr><td colspan="4">For all regions, total transportation activity is projected to increase up to 2030, under a reference scenario (ICCT, 2017; IEA, 2017; OECD, 2017a). 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 remains insignificant in all regions, in line with the baseline projections of the 2017 ICCT Roadmap Model baseline (ICCT, 2017).</td></tr>
<tr><th></th><th>North America</th><th>Latin America</th><th>South Asia</th></tr>
<tr><td>Network length of bus system</td><td>~6% increase</td><td>~10% increase</td><td>~50% increase</td></tr>
<tr><td>Frequency of bus service</td><td>~6% increase</td><td>~10% increase</td><td>~50% increase</td></tr>
<tr><td>Usage of dedicated bus lanes</td><td>Remaining constant (~1% of total network length)</td><td>Remaining constant (~10% of total network length)</td><td>Remaining constant (~4% of total network length)</td></tr>
<tr><td>Share of zero-carbon buses</td><td>Remaining constant at ~1%</td><td>Remaining constant at ~1%</td><td>Remaining constant at ~1%</td></tr>
<tr><td>(Growth of transport activity)</td><td>13% increase</td><td>20% increase</td><td>~75% increase</td></tr>
<tr><td>(Share of public transport)</td><td>Remaining constant (19-20%)</td><td>31% (2015) to 29% (2030)</td><td>Remaining constant (66%)</td></tr>
<tr><th colspan="4">Enhanced bus networks scenario (2015-2030)</th></tr>
<tr><td colspan="4">In the enhanced bus networks scenario, major network improvements are implemented by 2030 for increasing bus network length and service frequency as far as required as estimated by the model in order 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</td></tr>
</table>

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	South Asia
Network length of bus system (2030 compared to 2015)	~50% increase	~65% increase	70% increase
Frequency of bus service (2030 compared to 2015)	~50% increase	~65% increase	70% increase
Usage of dedicated bus lanes (2030)	Increase to 22%	Increase to 27%	Increase to 24%
Share of zero-carbon buses (2030)	Increase to 100%	Increase to 100%	Increase to 100%

5.5 Data sources

Table 6 provides details on the data sources used for required inputs. They input code can be compared to the calculation logic chart in Figure 3.

Table 6: Data sources for inputs to bus network enhancement impact calculations

Code	Indicator	Unit	Source*	
			North America	Latin America
A	Transportation activity / modal split in urban areas before interventions	Pax-km	ICCT Roadmap 1.0 Model (ICCT, 2012) adjusted for urban areas by factor from IEA (2009); 2017 Baseline adjustment to ICCT Roadmap Model; ITF Transport Outlook (OECD, 2017a).	
B	Total transport CO_2 emissions from urban areas, by mode, before measures	MtCO2e	ICCT Roadmap 1.0 Model (ICCT, 2012) adjusted for urban areas by factor from the Energy Technology Perspectives (IEA, 2016b).	
C	Number of road fatalities in urban areas, before measures	-	(WHO, 2017a)	
D	Proportion of $PM_{2.5}$ attributed to urban transportation	%	Karagulian (2015)	
E	Mean annual exposure to $PM_{2.5}$ concentrations in urban areas before interventions	µg/m³	Ambient Air Pollution Database (WHO, 2016)	
F	Crude death rate	Deaths / population	World Population Prospects (UN, 2015)	
G	Number of daily commuters	-	Author assumption based on urban population figures from World Population Prospects (UN, 2015)	
H	Average daily commute time	Minutes	49.2 minutes per journey (based on average values from 2015 American Community Survey Data)	69.4 minutes per journey (author estimation based on multiple sources)

5.6 Assumptions used in this study

In addition to the information provided in the previous sections, the following assumptions were made for the completion of the analysis for North America and Latin America in this study:

- The simple assumption is made for the analysis that electric buses are powered by renewable energy technologies and that the tank to wheel emissions equivalent is zero.
- When data was not available on transport activity at the urban level, the proportion of passenger transport activity that takes place in urban areas is assumed based on factors from the IEA (2009), which estimates that 80% of bus travel and 50% of LDV activity take place in urban areas in OECD North America, 90% of bus travel and 40% of LDV activity in the OECD Europe and OECD Pacific regions, and 70% of bus travel and 60% of LDV activity in the rest of the world.
- It was assumed that despite the severity of the input scenario levers, the share of private vehicle use would not fall lower than that of the lowest currently existing modal split share in a major city: the IEA (2009) report that the modal share of private vehicle use in Hong Kong was as low as 20% in 2009; this is taken as the assumed minimum share. This assumption did however not affect the results for the scenarios elaborated in this study.
- For the assessment of fatalities from road traffic accidents, the reference scenario does not include any significant advances in safety due to ongoing technological or regulatory improvements. Although there has been a general improvement in road safety observed in recent decades, such improvement trends appear to have levelled out over the past 5 years; the rollout and potential impact of new technologies is rather unpredictable and not included in this reference.

6 District-scale renewable energy

The study focuses on the impacts of scenarios for enhanced district heating and cooling on indicators for *air pollution and related health impacts*, *jobs, fuel expenditures and energy security* in China, Africa and the European Union.

6.1 Overview of impacts assessed

Job creation impacts

The assessment considers jobs resulting from investments in heating technologies and pipelines, as well as O&M jobs. It also includes potential reductions in jobs for certain technologies, e.g. as a result of decreasing demand for conventional heating technologies. Jobs are estimated based on monetary expenditures, and – where possible – specified per technology.

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.

Fuel expenditures and import dependency

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.

Air pollution and related health impacts

The World Health Organization (WHO, 2014) reports that in 2012 one in eight of total global deaths - around 7 million people - died prematurely as a result of air pollution exposure. This makes air pollution the world's largest single environmental health risk.

This study considers the health impacts associated with reduced ambient atmospheric concentration of $PM_{2.5}$ in urban populations, based upon reduced emissions of primary particulate matter (PM), sulphur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3), due to changes in urban heating.

$PM_{2.5}$ refers to particulate matter with a diameter less than 2.5 µm. $PM_{2.5}$ is the most lethal outdoor air pollutant in urban areas (OECD, 2011). Its atmospheric concentration is derived from the emissions of primary particulate matter from fossil fuel combustion processes, as well as from atmospheric reactions between other pollutant gases (secondary particulate matter), namely SO_2, NO_x, and NH_3.

Concentrations of $PM_{2.5}$ in any given location can be derived from five distinct sources: natural sources of particulate matter including dust and sea salt; secondary PM from international transboundary emissions; primary and secondary PM from national emissions; primary and secondary PM from urban emissions; and primary PM from local street emissions. Natural sources of PM cannot be affected by urban policies and interventions, nor can PM be derived from activities in other locations within or outside of the region. As such, the calculation methodology focuses only on changes to the proportion of air pollution concentrations that can be attributed to urban transport. The urban system is analysed as a whole as an average, with emissions and $PM_{2.5}$ concentrations assumed to be constant across all urban areas; variations in exposure levels between more and less polluted districts and streets are not addressed.

The indicator assessed with this methodology will only reflect the number of all-cause premature deaths per year, and as such it considerably underestimates the 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.

6.2 Overview of measures considered

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 with heat from district systems instead of individual boilers in buildings. Fuel savings are achieved through efficiency improvements associated with district heating as well as electricity demand reductions through decreased use of electric boilers. This results in fuel demand reductions, lowering emissions and air pollution.

Use of recovered industrial waste heat:

Given as the proportion to which it contributes to the total district heating energy supply. This is based on estimations of the potential for waste heat in urban areas. The advantage of this option is that it doesn't require fuel input, which means no additional fossil fuel combustion leading to air pollution, and no requirements for additional fossil fuel imports.

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. This has an impact on greenhouse gas emissions as well as jobs and energy security.

Use of combined heat and power (CHP) plants instead of dedicated heat plants:

Given as the proportion to which it contributes to the total district heating energy supply. An increase in CHP capacity requires the availability of suited thermal power plants in urban areas. This increases efficiency of heat generation, inducing fuel demand reductions, emissions reductions and reduced air pollution.

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. Given the fact that district cooling has a higher coefficient of performance (COP), the replacement of individual cooling appliances with district cooling reduces electricity demand. This triggers fuel demand reductions and associated emissions and air pollution reductions. Next to this it impacts investments in pipelines which has an impact on job creation.

A detailed breakdown of supply technologies for cooling scenarios is not given since the feasibility and comparative advantages of different technologies in specific areas of different regions is uncertain. Rather, the assumption is made that all district cooling is supplied by a combination of renewable energy generation technologies, and trigeneration from thermal plants where the potential is available without significantly affecting output for electricity or heat from these plants. As such, the results of the analysis are relevant whichever energy supply technology is determined preferable.

6.3 Calculation logic

Figure 4 provides 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 beneath the figure for some steps that require a more thorough description.

Methodological logic overview

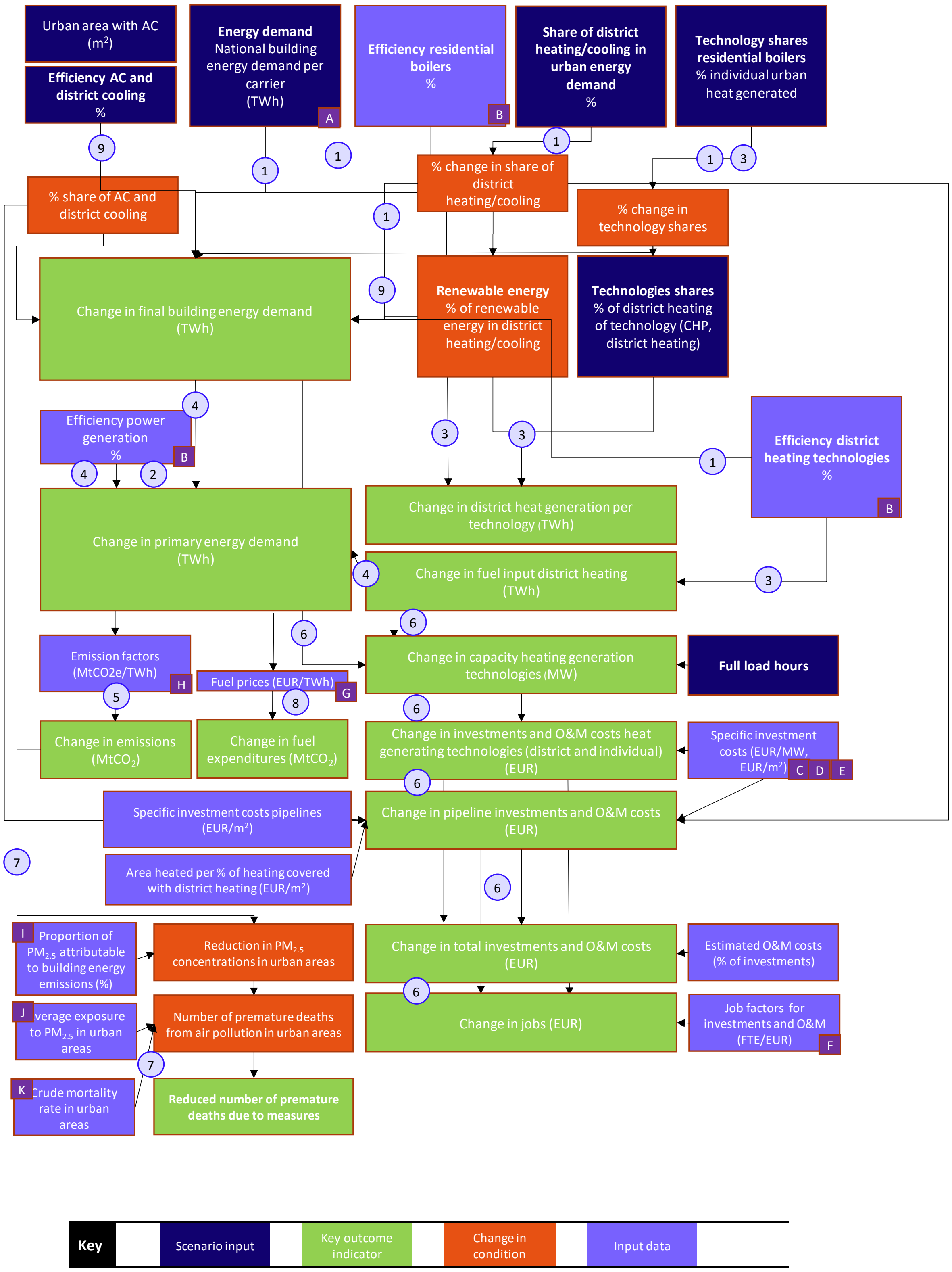


Figure 4 Calculation logic for impacts of increased district-scale renewable energy

Description of steps

1 To model changes final energy demand in urban buildings, we combine the following data and assumptions:

- IEA World Energy Outlook 2016 scenario data for 2014 and the New Policies Scenario in 2030 on:
  - Energy demand in the building sector.
  - Power sector generation mix and generation efficiencies.
- Efficiency of residential boilers (from Xiong et al, 2015), current and future (applied to 2030).
- Share of district heating in urban heating demand, current and scenario input for 2030 (from Xiong et al, 2015).
- Mix of boiler-types used in urban individual heating, currently and scenario input for 2030 (from Xiong et al, 2015).
- Conversion efficiencies of boilers, currently and estimated for 2030.

The changes in energy demand, relative to the reference scenario are induced by a change in district heat generation and a change in energy mix in heat generation.

First, urban heat demand in the reference scenario and the District Heating scenario for China and the European Union is established using 2030 district heat generation from the NPS scenario and the estimated share of district heating in urban heat generation from Xiong et al (2015).

$$UHD_{2030} = \frac{DH_{\mathrm{BAU}}}{\%DH_{\mathrm{BAU}}}$$

Where:

UHD_{2030} = Total urban heating demand in 2030 (in the reference and Enhanced district heating scenario).

DH_{BAU} = District heat generation in 2030 in the reference scenario.

$\% DH_{\mathrm{BAU}}$ = Share of district heating in total urban heating demand in the BAU scenario.

By multiplying the UHD_{2030} by the assumed share in district heating in the Enhanced district heating scenario, the district heating generation is calculated.

The remaining heat is assumed to be generated with individual boilers. Multiplying the heat generated with boilers with the shares of boiler technologies (coal, oil, gas, electricity, biomass, other renewables) and dividing by the conversion efficiencies of each technology yields the final energy demand in urban buildings per energy carrier in the reference and Enhanced district heating scenario:

$$\Delta FEC_{carrier\ x} = UHD_{2030} * ((1 - \%DH_{\mathrm{BAU}}) * \frac{\%B_{carrier\ x,\mathrm{BAU}}}{\eta_{Bcarrier\ x}} - (1 - \%DH_{DHS}) * \frac{\%B_{carrier\ x,DHS}}{\eta_{Bcarrier\ x}})$$

Where:

$\Delta FED_{fuel\ x}$ = Change in final energy consumption of energy carrier x (coal, oil, gas, electricity, bio energy or other renewables).

$\%DH_{DHS}$ = Share of urban heat generated with district heating in the Enhanced district heating scenario

$\%B_{\mathrm{carrier\ x,\ ref/DHS}}$ = Share of heat generation of a boiler with energy carrier x in the reference or Enhanced district heating scenario.

$\eta_{Bcarrier\ x}$ = Conversion efficiency of a boiler with energy carrier x.

For China, the share of urban heating generated with district heating is based on Xiong et al (2015) and for the European Union is based on Heat Roadmap Europe and IEA Energy Technology Perspectives (Connolly *et al.*, 2014; IEA, 2017).

2 Because electric boilers are considered, fuel input for power generation is also impacted by changes in heating. We assumed that the reduction in electricity consumption (due to increased use of district heating and reduced use of AC – discussed below) reduces power produced from fossil thermal power generation only. The electricity generation per fossil energy carrier is reduced proportional to the individual shares in fossil power generation in the reference scenario. Dividing the change in electricity generation per energy carrier by the thermal power generation efficiencies results in the change in primary energy consumption (PEC).

3 Next, the district heat generation is distributed over different district heating technologies (both dedicated heat boilers and CHP). The mix in the reference scenario is based on Xiong et al (2015). By applying conversion efficiencies of each technology, the fuel input for district heating is calculated. For CHP we assumed that heat generation is a by-product of electricity production and the efficiency is estimated using a power loss factor. This means that only the additional fuel required to compensate for the reduced power production due to the use of CHP is allocated to heat generation.

4 The change in total PEC is then calculated by aggregating changes in energy use for individual boilers, district heating and electricity generation.

5 Changes in emissions are calculated by multiplying default emissions factors (IPCC, 2006) with the changes in PEC. Emissions are expressed in CO_2-equivalent and includes CO_2, CH_4 and N_2O. Global Warming Potentials from IPCC AR4 with a 100-yr. horizon are applied (IPCC, 2006).

6 The total number of jobs generated through district heating and cooling implementation is estimated from investments and O&M expenditures, based on the estimated changes in generation capacities. The capacities are calculated by dividing energy generation per heating technology by the estimated full load hours per technology. Specific investments costs (in EUR/MW) are then multiplied with the change in capacities, resulting in the change in investments. For CHP, only the additional investments costs are considered, so only the costs difference between CHP capacity and comparable dedicated power capacity.

Investments in pipelines are estimated from specific investments costs expressed per area of heated or cooled floorspace that is covered by district heating (or cooling). The area covered with district heating and the total district heating demand in the reference scenario are required inputs. This results in an estimate of the district heat generated per square meter, which is multiplied by the district heat generated in the Enhanced district heating scenario. The resulting estimation of the area covered with district heating is then multiplied with the estimated investments costs per square meter. Costs and areas covered per unit of heat are sensitive to the location of the district heating, as it depends on the climate and the density of buildings.

Pipelines are not only used for heating, but also for district cooling. The floorspace area for cooling is calculated by multiplying the share of households with cooling, the share of cooling demand that is met with district cooling and the total urban floor area. For district cooling, the same specific costs as for district heating. For China, these are based on Xiong et al. (2015).

Due to a lack of data for district cooling pipeline construction costs in Africa, the authors apply an average factor of construction cost differences between African countries and China to the pipeline construction costs data input for China. This factor is calculated based on estimates for public sector construction cost per square meter of administrative buildings in China, South Africa, Nigeria, Ghana, Kenya, Morocco, Angola, Egypt and Equatorial Guinea in 2016 (CIDB, 2017). To obtain an average value for Africa, the construction costs estimates for all eight African countries have been weighted with respective population sizes provided in the UN Population Prospects report (UN, 2017). This results in an assumed African average of 670 USD/m^2. With construction costs per square meter in China being 502 USD/m^2, the ratio of construction cost differences between Africa and China is 1.33.

O&M expenditures are estimated by applying O&M cost factors as a share of investment volumes.

China

A factor for the number of jobs created in the construction, energy and manufacturing sectors per unit of investment is given in the 2012 Chinese Population and Labour Yearbook This factor, valid for the year 2007, was adjusted for 2014 based on information on annual salary increases for specific sectors between 2007 and 2015 from the 2016 China Statistical Yearbook (National Bureau of Statistics of China, 2016).

European Union

A factor for the number of jobs created in the construction, energy and manufacturing sectors per unit of investment is given by Eurostat. This factor is calculated calculating the number of jobs created in less than three months in each quarter from 2012 until 2015 divided by the total gross investment in tangible goods within each sector (European Commission, 2017).

Africa

The data input for number of 'jobs created per USD 1 million investments' stems from estimates for the employment-loan ratio achieved by public project finance activities of the African Development Bank (AfDB) between 1990-2010 (Simpasa, Shimeles and Salami, 2015). The estimate for infrastructure financing is based on 14 projects with a total investment volume of USD 353.8 million and 20,312 jobs created, thus resulting in an employment-loan ratio of 57.4 jobs per USD 1 million investment (see Table 3 in the study). The study accounts for both direct and indirect job creation through infrastructure investment. Other studies on employment effects of investments identify similar job factor effects (Estache *et al.*, 2013; IFC, 2013), however, job factors vary to a high degree between different African countries and regions.

The job factor estimate has furthermore been adjusted with the annual average real wage growth in Africa. As Simpasa, Shimeles and Salami (2015) do not provide the specific timeframe for implementation of infrastructure projects between 1990 and 2010, we assume an equal distribution across the entire time period and thus assume that the values represents a good estimate for 2000. For this reason, we apply the average real wage growth in Africa to the job factor estimate for 2000 to obtain an adjusted estimate for 2014. The average real wage growth of 3.0% is based on data provision in the ILO's Global Wage Report 2016/2017 for 2006-2015 (ILO, 2016). This results in job factor of 37.32 jobs per USD 1 million investment.

7 PM concentrations and impacts of air pollution on health are based on estimated CO_2 emissions calculated in step 5. Estimated emissions of SO_2 and NOx are used as a proxy for the emissions of all the major air pollutants which lead to adverse health impacts. This simplification recognises that emissions of SO_2 and NOx are highly influential to the production of secondary particulate matter, and assumes that the emissions of other air pollutants are reduced proportionally to SO_2 and NOx. A number of studies have applied such simplifications that assume uniform reductions of all these gases for the calculation of local outdoor air pollution, most notably the OECD 2050 Environmental Outlook (OECD 2011). Detailed data for SO_2 and NOx emissions is not available under all scenarios. Instead, the relationships between CO_2 emission projections and SO_2/NOx projections were analysed for each region to produce an indicative factor that allows for the estimation of air pollutant emissions based upon changes in CO_2 emissions, the data for which is more readily available. These relationships are based on the comparison of the projections for air pollutant emissions up to 2030 under different scenarios conducted by IIASA (2012); the projections are intended to correspond to the World Energy Outlook scenarios (IEA, 2012), so these two sources were compared to derive a factor with which the emissions of air pollutants for a given change in CO2 emissions in the region could be estimated. It is assumed that the ambient PM2.5 concentrations will change at a uniform rate in line with changes in the emissions

of SO_2 and NOx air pollutants, while current concentrations were taken from the WHO Ambient Air Pollution database (WHO, 2017b).

T*he* **reduction of premature mortality** can be calculated depending on the change of atmospheric concentration of $PM_{2.5}$ between scenarios (Bollen, 2009; Fang *et al.*, 2013; Public Health England, 2014):

$$\text{Premature deaths from particulate air pollution} = \text{Attributable factor (AF)} \times \text{Crude death rate (DR)} \times \text{Population } (P_{>30})$$

$$\text{Attributable factor (AF)} = \frac{\beta^{G} - 1}{\beta^{G}}$$

The attributable factor calculates the percentage of deaths which may be attributed to excessive $PM_{2.5}$ concentrations. In this equation, G is the concentration of the pollutant, given in units of 10 µg/m³. β refers to the estimated factor of the log-linear relationship between the concentration of any given pollutant and the resulting mortality rate (concentration-response factor). Krewski et al. (2009) finds a 5.9% risk increase of premature mortality from all causes for every $PM_{2.5}$ concentration increase of 10 µg/m³. Therefore, the value 1.059 is used for the concentration response factor β, as per Fang et al. (Fang *et al.*, 2013) and Bollen (Bollen, 2009). It is common practice when calculating premature deaths from $PM_{2.5}$ concentrations to consider only the population over 30 years of age (Public Health England, 2014).

This study does not use of a low concentration threshold (LCT). The use of an LCT assumes that below a certain level of $PM_{2.5}$ concentrations, there is no effect on mortality. There is no general consensus on whether the use of an LCT is appropriate or not, due to the lack of empirical evidence that such a threshold does or does not exist. The use of an LCT of 5.8 µg/m³ in this study would have no impact on the results, since the reductions from the measures do not result in concentrations below 5.8 µg/m³ in the analysed regions.

8 To calculate the impact on fuel expenditures, changes in PEC are multiplied with estimated fuel prices. The costs are based on spot prices, so they exclude taxes and other end-use cost factors. For China, costs are based on the assumptions for China/Asia in the World Energy Outlook 2016 (IEA, 2016). For Africa, fuel costs for coal, natural gas and oil are based on average commodity prices in 2014 provided by the African Development Bank (AFDB, 2016).

9 Next to heating demand, cooling demand is estimated, and scenarios include district cooling. However, there is limited experience with district cooling and information on air-conditioning (AC) use (installed capacity, average size of AC units in households) is very limited. This means that there is uncertainty in the data and we decided not to include cost estimates for the replacement of AC with district cooling. However, we will estimate savings in electricity consumption, and thus emissions. The electricity savings are calculated with the following steps:

$$\Delta El_C = (\%EL_{C,BAU} * \left(1 - \%AC_{BAU} * \%DC_{DHCS} * \frac{COP_{AC}}{COP_{DC}} \%RE_{DC}\right)) * EL_{BAU}$$

Where:

ΔEL_C	=	Change in electricity use for cooling (TWh).
$\%AC_{BAU}$	=	Share of households that use an AC.
$\%El_{C,BAU}$	=	Share of electricity consumption used for AC in the reference scenario.

$\%DC_{DHCS}$ = Share of AC that is replaced by district cooling in the Enhanced district heating and cooling scenario.

$COP_{AC,DC}$ = Coefficient of performance of AC, respectively district cooling

$\%RE_{DC}$ = Share of renewable district cooling generation.

EL_{BAU} = Electricity consumption in the reference scenario.

The change in electricity is then used to calculated total change in primary energy consumption (step 4), assuming electricity demand reductions impacts fossil thermal power generation only. The changed PEC impacts greenhouse gas emissions (step 5) and air pollution.

6.3.1 Estimating current and future energy demand for cooling in China

For China, we found estimates of the share of AC in building electricity consumption in IEA (2016). In 2014 this was estimated to be 17% and it is projected to increase to 21% by 2030. We couldn't find statistics on the number of households or buildings with AC and we estimated that currently 50% of the buildings is equipped with AC, which will rise to 60% by 2030.

6.3.2 Estimating current and future energy demand for cooling in Africa

To estimate the feasibility of considering the potential implementation of district cooling systems in several African cities, an estimate of the cooling demand—current and future—is required.

Data sources on current cooling demand that can be applied to Africa are scarce and show significant discrepancies:

- The study from (Ürge-Vorsatz *et al.*, 2015) gives aggregated final energy demand for space heating and cooling for a number of regions worldwide, including Sub-Saharan Africa, but does not show the split between heating and cooling per region.
- Final energy demand for cooling in Africa is given by (Petrichenko, 2016), but the values given there are inconsistent with those for overall electricity demand in e.g. (IEA, 2016a).
- The IEA ETP scenarios (IEA, 2017) contain current and projected values for cooling electricity demand, but do not include Africa as separate region.
- The IEA Energy Balances (IEA, 2016a) contain total electricity demand separately for residential and commercial/public buildings for most countries in the world, enabling an estimation of Africa's electricity demand in buildings, but do not specify the end-use.

It is thus problematic to rely on these studies for estimating Africa's cooling energy demand without making additional assumptions. We have proceeded to make a first-order estimate of the current (2014) cooling energy demand in North Africa ("NAF") and Sub-Saharan Africa ("SSA") by assuming that the share of cooling demand in total electricity demand in buildings would be similar to that in India, obtained from (IEA, 2017).

This results in the levels of total and per-capita cooling demand as shown in Table 7. As can be seen, North Africa's estimated per-capita demand would be roughly 2.5 times as high as that of India, whereas that in Sub-Saharan Africa would be about half that of India.

Table 7: Cooling demand (absolute and per-capita) estimated by assuming the same share of cooling in total buildings electricity demand in North Africa and Sub-Saharan Africa as in India according to (IEA, 2017). Population data from (UN, 2017).

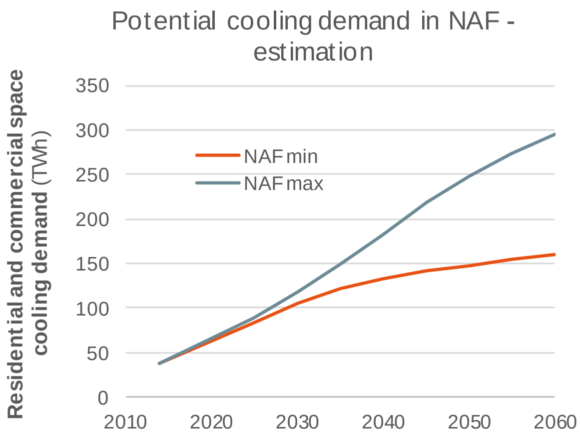
Region	Total cooling demand (TWh)	Per capita (kWh / cap)
North Africa	38	171

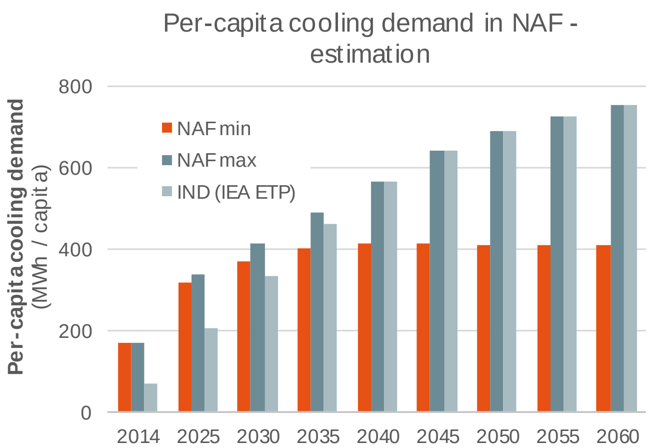
Sub-Saharan Africa	35	37
India (for comparison)	90	70

In order to estimate the potential future range of development of cooling demand in Africa, we make two assumptions for the lower and upper bound for North Africa and Sub-Saharan Africa, respectively:

- **North Africa** (currently estimated higher than India):
  - **Lower bound**: Assuming that the total cooling demand in North Africa will exhibit the same growth rate as that in India until 2060 according to (IEA, 2017), but with a *10-year lead*.
  - **Upper bound**: Assuming that the per-capita cooling demand in North Africa will reach the same value in 2040 as projected for India by 2040 according to (IEA, 2017), and stay at the same level as projected for India afterwards.
- **Sub-Saharan Africa** (currently estimated lower than India):
  - **Lower bound**: Assuming that the cooling demand in Sub-Saharan Africa will exhibit the same growth rate as that in India until 2060 according to (IEA, 2017), but with a *10-year delay*.
  - **Upper bound**: Assuming that the per-capita cooling demand in Sub-Saharan Africa will reach the same value in 2060 as projected for India by 2060 according to (IEA, 2017) and follow a 2014-2060 trajectory scaled to that of India.

This results in the lower and upper bounds of estimated future potential cooling demand in North Africa and Sub-Saharan Africa as shown in Figure 5.





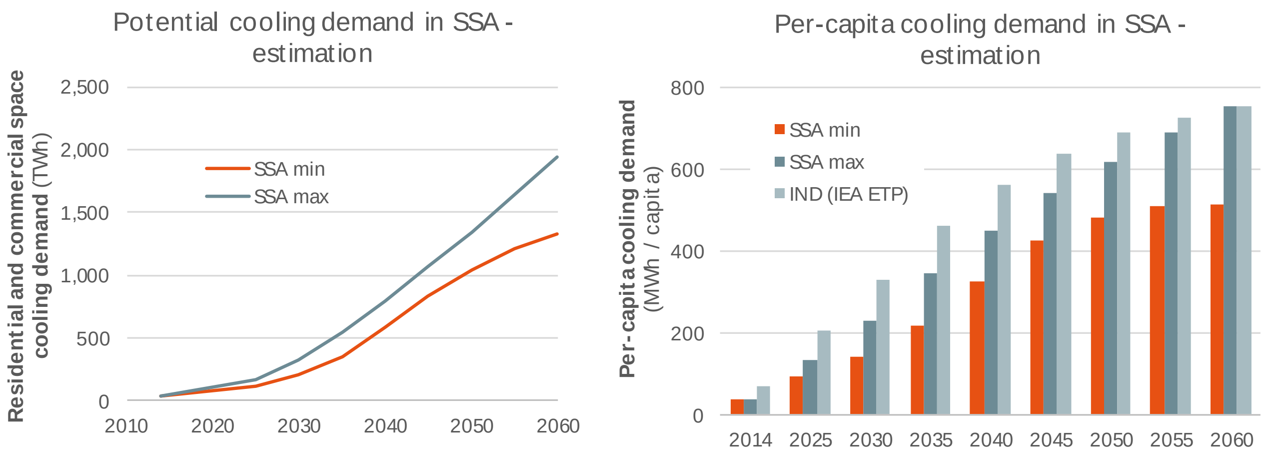


Figure 5: The estimated upper and lower bounds of future cooling demand in North Africa and Sub-Saharan Africa. Lower and upper bounds are determined as described in the text above.

The sum of these two scenarios then determines the lower and upper bound for the continent of Africa, which is shown in Figure 6.

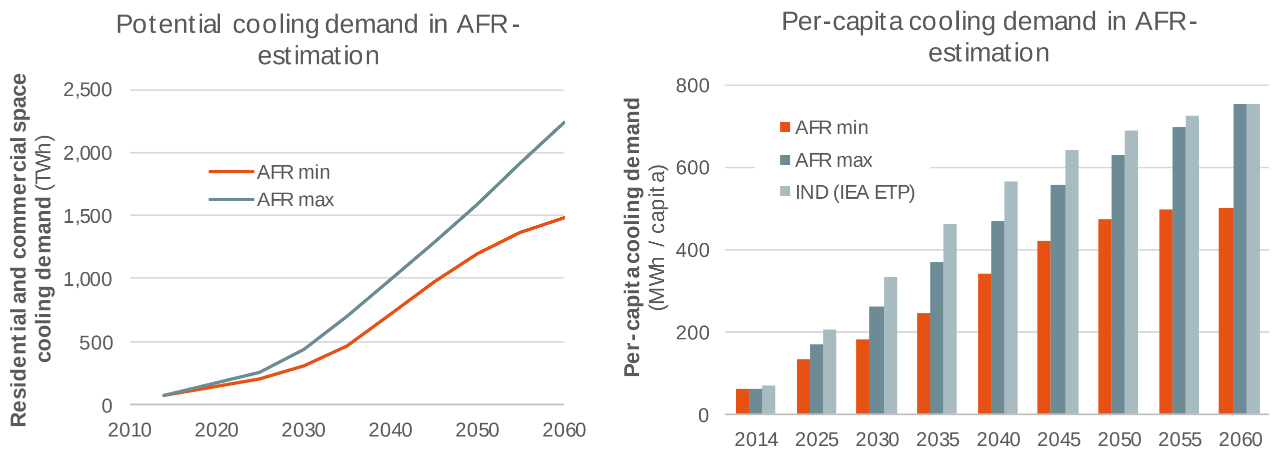


Figure 6: The estimated upper and lower bounds of future cooling demand in Africa. Lower and upper bounds are determined by summing up those of North Africa and Sub-Saharan Africa shown in Figure 5.

We thus see that the cooling demand in Africa around the halfway turn of the century could reach the order of 1,500–2,300 TWh, or 500–800 kWh/capita. Note that these numbers should be treated with extreme caution as already the baseline value for 2014 is an uncertain estimation (see above).

The comparison with India used throughout is cautiously considered reasonable based on the following notions:

- The total amount of cooling degree-days is relatively similar in the two regions, and among the highest in the world along with the Middle East; the future dependence of this amount on global warming is positive and comparable for both India and North/Sub-Saharan Africa (Labriet *et al.*, 2013).
- Both Africa and Asia (with India the largest contributor) are expected to urbanize much faster than other regions in the world until 2050 (UNDESA, 2014), supporting the assumption that growth rate patterns of cooling demand in Africa and India may be to some degree comparable in the future.
- Further, the urbanization rate in India (33% in 2016) is similar to that of Sub-Saharan Africa (36%) (World Bank, 2017), in both cases significantly lower than the worldwide average which is above 50%, and much of the increase in cooling demand in both India and Sub-Saharan

Africa would be expected in cities, among other reasons because of typically much higher electrification rates prevalent in urban areas as compared to rural regions. This supports the assumption that per-capita cooling demand may converge in the future between India and Sub-Saharan Africa.

- GDP growth rates in India and several major African countries, including major economies such as Kenya, Tanzania, Ethiopia, Côte d'Ivoire and Senegal, are in the order of 6%-8% (IMF, 2017), numbers which are not recorded across other regions in the world with similar cooling degree-days, with the exception of South-East Asia. This supports the assumption that Sub-Saharan Africa cooling demand per capita may exhibit similar strong growth rates currently projected for India. Since this does not apply to North Africa, we have assumed that growth rates there will be lower than in India. Definition of scenarios

Table 8 introduces the scenarios which are analysed for China and Africa in this study.

The reference scenario is based on the IEA World Energy Outlook 2016 and Energy Technology Perspectives 2017. For China and the European Union, further details from Xiong et al. (2015) are used on e.g. the technology mix and efficiencies of heating technologies. Furthemore, IRENA's REMAP is also used as a reference for technology shares (IRENA, 2017a).

Very little information is available to inform a reliable and realistic estimate for the potential role that district cooling systems can play in the supply of energy for future cooling demand in China and Africa. District cooling has so far only managed to reach a foothold in a few Gulf countries, where it is estimated that it has the potential to deliver 50% of cooling demand in the UAE by 2030, 42% in Qatar, and 25% in Saudi Arabia, which would "prevent the region from having to build 20 GW in new electricity-generating capacity" (Fayad *et al.*, 2015). In other regions of the world, the technology has played only a marginal role, to date.

The potential for district cooling hinges on a number of factors, which will have to be considered for any plans on implementation of such systems in urban areas in China, Africa and the European Union as well:

- Total cooling demand in terms of cooling degree-days. As mentioned above, this is very high in Africa, among the highest in the world along with the Middle Eastern region and South and South-East Asia (Labriet *et al.*, 2013).
- The density of buildings. As mentioned by (Fayad *et al.*, 2015), district cooling can be an economic solution for cooling (instead of using air conditioning units) in areas where the cooling demand is "sufficiently dense", measured in e.g. refrigeration tonnes per square meter. Conventional cooling technologies do not depend on the cooling demand density.
- A well-planned and regulated local real estate market in areas where the above criteria are met, as district cooling is considerably less localized than air-conditioning units for individual dwellings, or central cooling systems operating on the level of individual buildings. As advised by (Fayad *et al.*, 2015), district cooling may also require government intervention in the (a) designation of appropriate zones, (b) regulation of tariffs, and (c) performance standards and codes.

For the European Union a market saturation of 18% is taken from an ambitious scenario that assumes the Swedish uptake of district cooling for the rest of Europe from (RESCUE partners, 2014). In the absence of better information for China or the African continent, this study analyses a scenario in China in which 42% of cooling demand can be supplied by district cooling systems, which is roughly the average of the calculated potential for three Gulf countries analysed by Fayed et al. (2015). In Africa, two scenarios are assessed: one in which district cooling supplies 25% of cooling demand and the other, 50%. 25-50% is roughly equal to the range of the potential between the gulf countries analysed in Fayed et al.

These scenarios for district cooling are only for illustrative purposes, since an evaluation is not made on how realistic such scenarios may be for urban areas of China and Africa. Here, a major gap in the availability of information on this important mitigation potential is highlighted.

Table 8: 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%

European Union				
In the European Union, as in China, 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 scenarios for both heating and cooling are based on information from RESCUE (2014) and IRENA (2017b). The prospects for district cooling are uncertain, so these measures are analysed in a separate scenario.				
	2014	**Reference (2030)**	**Enhanced DH scenario (2030)**	**Enhanced DHC scenario (2030)**
Use of district energy for urban heating demand	9%	9%	30%	30%
Use of recovered industrial waste heat for district energy	2%	1%	22%	22%
Use of renewable energy technologies for district heating	28%	49%	59%	59%
Use of CHP for district heating	70%	52%	24%	24%
Use of district energy for cooling demand	Negligible	Negligible	Negligible	19%

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)**	**25% DC scenario (2030)**	**50% DC 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.

6.4 Data sources

Table 9 provides details on the data sources used for required inputs. Their input code can be compared to the calculation logic chart in Figure 1.

Table 9: Data sources for inputs to bus network enhancement impact calculations

Code	Indicator	Unit	Source*		
			China	Africa	European Union
A	Building final energy consumption, power generation and primary energy input in power generation in 2014 and 2030 in the New Policies Scenario.	TWh	IEA, 2016. World Energy Outlook 2016. International Energy Agency (IEA), Paris		
B	Efficiency boilers (coal, oil, gas, electricity for district heating, CHP and individual boilers). Biofuel: assumed to have same efficiency as gas.	%	Xiong et. al (2015)	n.a.	Xiong et. al (2015)
C	Investments costs individual boilers	EUR/MW	Coal, gas, oil: Xiong et. al (2015) Bio-energy: DEA (2016)[1]	n.a.	(European Commission, 2016)

[1] https://ens.dk/sites/ens.dk/files/Analyser/old_technology_data_for_individual_heating_plants_and_energy_transport_aug2016.pdf

D	Investment costs CHP:	EUR/MW	IEA (2014)[2] Based on cost difference in IEA WEO2014 between CCGT CHP en CCGT	n.a.	IEA (2014)[3] Based on cost difference in IEA WEO2014 between CCGT CHP en CCGT
E	Investment costs district heat boilers:	EUR/MW	EC (2016)[4] Based on European cost, a cost fact expressing the typical cost difference between investments costs in China and Europe of power plant is applied to district heating plants	n.a.	(European Commission, 2016)
F	Job factors		2012 Chinese Population and Labour Yearbook	Simpasa et al. 2015 Estache et al. 2013; IFC 2013,	(European Commission, 2017)
G	Fuel costs	EUR/TWh	IEA (2016)		
H	Emissions factors	$MtCO_2/TWh$	[5]IPCC (2006)		
I	Proportion of $PM_{2.5}$ attributed to urban transportation	%	Karagulian (2015)		
J	Mean annual exposure to $PM_{2.5}$ concentrations in urban areas before interventions	$\mu g/m^3$	Ambient Air Pollution Database (WHO, 2016)		
K	Crude death rate	Deaths / population	World Population Prospects (UN, 2015)		

6.5 Assumptions used in this study

In addition to the information provided in the previous sections, the following assumptions were made for the completion of the analysis for China, Africa and the European Union in this study:

- Coal boilers (individual boilers) are first displaced by district heating.
- Biomass, solar thermal and geothermal district heating grow to nearly 19% at the expense of coal.

[2] IEA (2014), World Energy Outlook 2014
[3] IEA (2014), World Energy Outlook 2014
[4] https://ec.europa.eu/energy/sites/ener/files/documents/Report%20WP2.pdf
[5] 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 Energy http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

- Electricity savings are assumed to be at the expense of fossil thermal power generation.
- Pipelines for district cooling are assumed to have the same investment costs as pipelines for heating.
- District cooling is assumed to be electricity driven, unless it is renewable. Although there are thermal options to cool, this is not considered given the fact that investments in district heating are not calculated. Because we only study energy and emissions, electricity is a good proxy to calculated emissions reductions.
- Heat plants and CHP are assumed to have a lifetime of 30 years
- Individual boilers are assumed to have a lifetime of 20 years.
- Annual O&M costs of district heating and CHP installations are assumed to be 4% of the total investment costs.
- Annual O&M costs of individual boilers are assumed to be 5% of the total investment costs.
- Annual O&M pipelines are assumed to be 1% of the total investment costs.
- Full load hours of district heating and CHP plants are assumed to be 2000
- Full load hours of waste heat recovery plants are assumed to be 4000
- Full load hours of individual boilers are assumed to be 1600

7 Scaling results to the global and city level

The results from each action and region are downscaled and upscaled to consider the impact of each action on cities and in the world.

7.1.1 Downscaling approach

The population is the main indicator to scale down results for the city level. Indicators from all scenarios are adjusted to reflect the population of the cities in the regions analysed. This assumes that all major cities in the region have the same characteristics or responds in the similar way to enhanced retrofit activity.

Also, the methodology does not aim to extrapolate the results to other regions but to downscale the impact to cities located in the specific regions included in the analysis. Therefore, scaled down results are indicative approximations based on population and not bottom up evaluation of specific cities. The results are scaled down to cities with 1 million inhabitants and the C40 network. The impact is scaled down using the following expression:

$$Impact\ in\ cities = Impact\ in\ region \cdot \frac{Population\ city}{Urban\ population\ region}$$

7.1.2 Upscaling approach

For most of the actions and benefits analysed, a similar approach to the downscaling is used to scale up results to the world, the urban population is the scaling factor. Nonetheless, to assess impact in a global level, there is need to understand how regions outside the previous scope of the analysis will respond to the action. It is assumed that regions with similar activity levels and economic indicators will respond in a similar way. As such, all countries worldwide were mapped to the specific regions included in the study, through following these four steps:

1. Identify which countries still need to be mapped to other regions;
2. Choose indicators that reflect demand for retrofit in analysed region;
3. Determine the region to which a country should be mapped;
4. Calculate scaling factors;

These steps are described in more detail in the following sections.

1. Identify which countries still need to be mapped to other regions

Three regions were analysed in detail for each of the actions included in the analysis. The countries belonging to these regions are already included within the regional data and do not need to be re-mapped to a region. For all other countries, this first step looks at whether the actions and the scenarios are appropriate for inclusion in the global aggregation.

For **enhanced bus networks**, all countries are included in the upscaling analysis for the global aggregation.

Enhanced residential building energy efficiency retrofit activity would not have the same level of impact in all regions of the world, due to heating requirements and the differing situations of the building stock. For the global aggregation, we include only countries with a significant demand for heating, either alone or in combination with a significant demand for cooling.

To determine the heating demand of countries, the heating-degree days (HDD) indicator is used. (KAPSARC, 2015). This indicator contains information on for how many hours a year and by how many degrees a country's temperature differs from a comfortable temperature, usually taken as 15°C. By taking the HDD values from 1948 and 2013 and creating clusters that aim to group countries with the same HDD profile, one can create three categories:

- Countries that generally only have a significant demand for cooling only
- Countries that generally only have a significant demand for heating only
- Countries that have high demand for both heating and cooling.

The results can be seen in the map below.

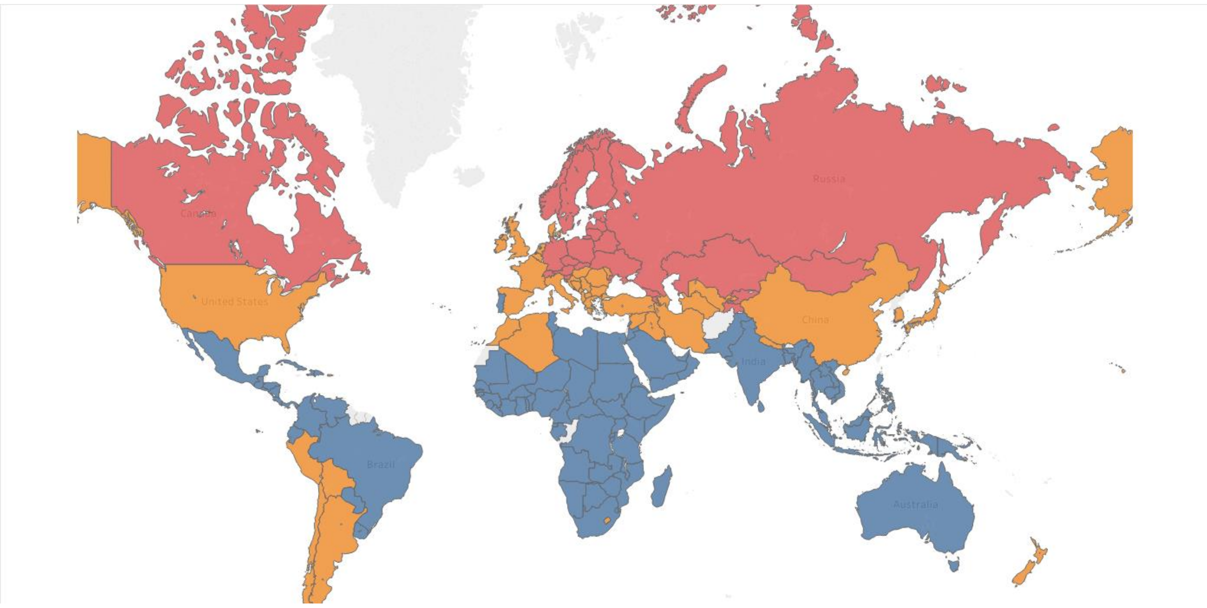


Figure 7 Country clustering based on heating-degree days data. Countries with demand for cooling are presented in blue, both heating and cooling in orange and only heating in red.

For **enhanced district energy**, different scenarios are defined for the development of district cooling (DC), district heating (DH) or scenarios with both heating a cooling (DHC). The results from distinct scenarios are scaled up considering only the countries where it is reasonable to assume the expansion of that type of district scale option. All countries are included in the global aggregation, but only for the scenarios that are most applicable. All countries with significant demand for cooling exclusively are mapped to Africa, and only included in the global aggregation for the district cooling scenario. Countries with a significant demand for heating exclusively are included in the global aggregation of scenarios for district heating only. All other countries are included in the global aggregation for all scenarios

2. Choose main indicators that reflect demand for retrofit in analysed region;

Indicators were selected which were considered to best represent the conditions in countries and how they may relate to the specific regions included in the analysis. This includes a combination of economic indicators, activity indicators, and indicators of the sector characteristics. The indicators for each action are presented in **Error! Reference source not found.**:

Table 10 Indicators used to map countries to regions for the different actions

Type	Indicator	Definition	Building retrofit	Bus networks	District energy
Economic	GDP growth per capita	Average 2014-2016	✓	✓	✓
Economic	GDP per capita	Average 2014-2016	✓	✓	✓
Activity/demand	Heating and cooling demand per capita	HDD + CDD avg last 10 years	✓		✓
Sector characteristics	Floor space per capita	Urban Area/Urban Population in 2010	✓		
Sector characteristics	Exposure to ambient air pollution (PM2.5)	Average 2014-2016		✓	

Type	Indicator	Definition	Building retrofit	Bus networks	District energy
Sector characteristics	Incidence of road fatalities per capita	Average 2014-2016		✓	

A check mark (✓) indicates that the indicator was used for the mapping exercise for the specific action

3. Determine the region to which a country should be mapped

The indicators are collected for all countries that still need to be mapped and compared to the average values of the same indicators for the focus regions of the study. The region that best matches the country for each indicator is the one where the difference between indicators between the country and the region is the minimum. Based on this first calculation the country can be mapped to a different region for each indicator. Therefore, a stage-like process is also applied to identify to which region the country should be mapped considering multiple region one-on-one matches. This classification follows the procedure that in the first stage the country is mapped to a region if it matches the region for 3 or 4 indicators; in the second the remaining countries are mapped to a region if they match it for 2 indicators, and do not match any other region for two indicators. Thereon, for the remaining countries, specific mapping approaches are determined for each action depending on the indicators considered most relevant and the indicators statistically shown to be the most influential in determining the mapping exercise for the countries that were successfully mapped in stages 1 and 2.

4. Calculate scaling factors

The urban population in 2030 is summed up for the countries mapped to each region. These numbers are finally used to scale up the results from each region and then added to obtain worldwide results. The scaling factors are calculated by adding this extra urban population to the respective region and dividing the result by the original region urban population.

$$Impact\ in\ world = \sum_{i=1}^{3} Impact\ in\ region_i \cdot Scaling\ factor_i$$

The global aggregation is determined through this approach for following indicators in this analysis:

- Job creation from residential building retrofit;
- Road fatalities reduction from enhanced bus networks;
- Economic benefits of time savings from enhanced bus networks;
- Job creation from enhanced district energy.

For air pollution and health related to enhanced bus networks and enhanced district energy, an upscaling approach through the use of a scaling factor is considered to be too inaccurate, due to the widely ranging conditions related to exposure to particulate matter in specific countries, and the importance of this indicator for the health outcomes. Since these indicators required to estimate the health impact of pollution, as defined in sections 4.3 and 6.3, are accessible for nearly all countries, the global aggregate is the sum of the individually calculated impact for each country, assuming that the underlying conditions and indicators related to pollution trends for each individual country between 2015 and 2030 change in line with the change assessed for the region to which the countries are mapped.

8 References

ACEEE (2011) *How does energy efficiency create jobs*. Available at: http://aceee.org/files/pdf/fact-sheet/ee-job-creation.pdf.

AFDB (2016) *AFDB Commodity Prices, 2016*. Available at: http://dataportal.opendataforafrica.org/ahpsoie/afdb-commodity-prices-2016 [accessed on 29 September 2017].

ARUP and 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. doi: 10.1080/01441640903020251.

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

BMUB (2016) *Sanierte Vorkriegsbauten erreichen erstmals Effizienzhaus Plus Standard*. The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety. Available at: http://www.bmub.bund.de/pressemitteilung/sanierte-vorkriegsbauten-erreichen-erstmals-effizienzhaus-plus-standard/?tx_ttnews%5BbackPid%5D=3420 (Accessed: 30 June 2017).

Bollen, J. (2009) *Co-benefits of Climate Policy*, *International Energy Workshop 2009*.

BPIE (2011) *Europe 's buildings under the microscope*. Available at: http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf.

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.

Broaddus, A., Litman, T. and Menon, G. (2009) 'Transportation Demand Management: Training Document', (April).

Cambridge Econometrics (2015) *Assessing the Employment and Social Impact of Energy Efficiency*. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/CE_EE_Jobs_main 18Nov2015.pdf.

CIDB (2017) *The drivers of the cost of public sector construction - Assessment and recommendations*. Available at: http://www.cidb.org.za/publications/Documents/Drivers of Cost of Construction Assessment and Recommendations.pdf [accessed on 29 September 2017].

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. doi: 10.1016/j.enpol.2013.10.035.

Deutsche Bank (2012) *United States Building Energy Efficiency Retrofits*. Available at: https://assets.rockefellerfoundation.org/app/uploads/20120301221532/United-States-Building-Energy-Efficiency-Retrofits.pdf.

Duffy, R. (2016) *This green house II: Building momentum on green jobs and climate action through energy retrofits across Canada*. Available at: http://www.columbiainstitute.ca/sites/default/files/resources/ColumbiaInstitute_This_Green_House_II_FINAL.pdf.

EC-Energy (2017) *EU Buildings Datamapper*.

ERC (2016) 'Building Sustainable Transport Today , Clean Transport Tomorrow', in Presentation by Ethiopian Railway Corporation made during COP 22, T. D. (ed.). Presentation by Ethiopian Railway Corporation made during COP 22, Transport Day. Available at: http://www.ppmc-transport.org/wp-content/uploads/2016/10/3.-Shewangizaw-Kifle.pdf.

Erhorn, H. and Erhorn-Kluttig, H. (2015) 'Overview of national applications of the Nearly ZeroEnergy Building (NZEB) definition Detailed report', (April). Available at: http://www.epbd-ca.eu/wp-content/uploads/2016/01/Overview_of_NZEB_definitions.pdf.

Estache, A. *et al.* (2013) *Infrastructure and Employment Creation in the Middle East and North Africa*. doi: 10.1596/9780821396650.

European Commission (2016) 'Mapping and analyses of the current and future (2020-2030) heating/cooling fuel deployment (fossil/renewables)', (March), p. 222. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/Report WP2.pdf.

European Commission (2017) *Eurostat*. Available at: http://ec.europa.eu/eurostat (Accessed: 21 June 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.

Fang, Y. *et al.* (2013) *Impacts of 21st century climate change on global air pollution-related premature mortality*, *Climatic Change*. doi: 10.1007/s10584-013-0847-8.

Fayad, W. *et al.* (2015) *District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy*. Available at: https://www.strategyand.pwc.com/media/file/Unlocking-the-potential-of-district-cooling.pdf.

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 Buildings Performance Network (2013) *Tool for Building Energy Performance Scenarios - Methodology*. Available at: http://www.gbpn.org/databases-tools/mrv-tool/methodology (Accessed: 26 May 2017).

Government of Canada (2017) *Statistics Canda*.

ICCT (2012) *Global Transportation Roadmap Model Version 1.0*. Available at: http://www.theicct.org/global-transportation-roadmap-model.

ICCT (2017) *Transportation roadmap 2017 baseline results update*. Available at: http://www.theicct.org/transportation-roadmap (Accessed: 12 December 2017).

IEA (2009) *Transport Energy and CO2 : Moving towards Sustainability - Books - OECD iLibrary*, *Energy*. doi: 10.1787/9789264073173-en.

IEA (2012) *World Energy Outlook 2012*.

IEA (2013) *Transition to Sustainable Buildings - Strategies and opportunities to 2050*. Paris, France: International Energy Agency. doi: 10.1787/9789264202955-en.

IEA (2016a) *Energy Statistics and Balances*. Paris, France.

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 (2017) *Energy Technology Perspectives 2017. Catalysing Energy Technology Transformations*. Paris, France: International Energy Agency. Available at: http://www.iea.org/etp2017/.

IFC (2013) *IFC Jobs Study - Assessing Private Sector Contributions to Job Creation and Poverty Reduction*. Available at: http://finnfund-new.navigo.fi/ajankohtaista/en_GB/job-creation/_files/89760896104071948/default/IFC Jobs Study January 2013.pdf.

IIASA (2012) *Emissions of Air Pollutants for the World Energy Outlook 2012 Energy Scenarios*. Available at: http://www.worldenergyoutlook.org/media/weowebsite/energymodel/documentation/IIASA_WEO2012_air_pollution.pdf.

ILO (2011) *Comparative Analysis of Methods of Identifi cation of Skill Needs on the Labour Market in Transition to the Low Carbon Economy*.

ILO (2016) *Global Wage Report 2016/17: Wage inequality in the workplace*. Available at: http://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_537846.pdf [accessed on 29 September 2017].

IMF (2017) *World Economic Outlook Database*. Available at: https://www.imf.org/external/pubs/ft/weo/2017/01/weodata/index.aspx (Accessed: 21 September 2017).

INRIX (2017) *INRIX Global Traffic Scorecard*.

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 (2015) *A Global High Shift Scenario*, *International Journal for Sustainable Transportation*. Available at: https://www.itdp.org/wp-content/uploads/2015/11/A-Global-High-Shift-Cycling-Scenario_Nov-2015.pdf.

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

Jensen, O. M., Wittchen, K. B. and Thomsen, K. E. (2009) *Towards very low energy buildings: Energy saving and CO2 emission reduction by changing European building regulations to very low energy standards*.

KAPSARC (2015) *Global Degree-Days Database | KAPSARC*. Available at: https://www.kapsarc.org/research/projects/global-degree-days-database/ (Accessed: 20 July 2018).

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. doi: 10.1016/j.atmosenv.2015.08.087.

Krewski, D. *et al.* (2009) *p*, *Research report (Health Effects Institute)*.

Labriet, M. *et al.* (2013) 'Impacts of climate change on heating and cooling: a worldwide estimate from energy and macro-economic perspectives', *Mitigation and Adaption Strategies for Global Change*, online. doi: 10.1007/s11027- 013-9522-7.

Lechtenböhmer, S. and Schüring, A. (2011) 'The potential for large-scale savings from insulating residential buildings in the EU', *Energy Efficiency*, 4(2), pp. 257–270. doi: 10.1007/s12053-010-9090-6.

Litman, T. (2017a) *Evaluating Public Transit Benefits and Costs: Best Practices Guidebook*. Available at: http://www.vtpi.org/tranben.pdf.

Litman, T. (2017b) *Transit price elasticities and cross-elasticities*. Available at: https://www.vtpi.org/tranelas.pdf.

Litman, T. (2017c) *Understanding transport demands and activities: How Prices and Other Factors Affect Travel Behavior*. Available at: http://www.vtpi.org/elasticities.pdf.

Marchetti, C. (1994) 'Anthropological invariants in travel behavior', *Technological Forecasting and Social Change*, 47(1), pp. 75–88. doi: 10.1016/0040-1625(94)90041-8.

Meijer, F. *et al.* (2012) *Jobs Creation Through Energy Renovation of the Housing Stock*.

National Bureau of Statistics of China (2016) 'China Statistical Yearbook 2016'.

National Bureau of Statistics of China (2017) *Statistical Communiqué of the People's Republic of China on the 2016 National Economic and Social Development*. Available at: http://www.stats.gov.cn/english/PressRelease/201702/t20170228_1467503.html (Accessed: 31 March 2017).

OECD (2011) *OECD Environmental Outlook to 2050*. Available at: http://www.keepeek.com/Digital-Asset-Management/oecd/environment/oecd-environmental-outlook-to-2050_9789264122246-en#page9.

OECD (2017a) *ITF Transport Outlook 2017*. OECD Publishing. doi: 10.1787/9789282108000-en.

OECD (2017b) *OECD data - online database*. Available at: https://data.oecd.org/.

Passive House Institute (2017) *Passive House Database*. Available at: http://passivehouse-database.org/index.php?lang=en#information.

Petrichenko, K. (2016) *Energy demand for space cooling in the context of SE4All objectives*. Available at: http://www.energyefficiencycentre.org/-/media/Sites/energyefficiencycentre/Workshop Presentations/Various-workshop-presentations/26-IEA-Cooling_Petrichenko.ashx?la=da.

Public Health England (2014) *Estimating local mortality burdens associated with particulate air pollution*. London. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332854/PHE_CRCE_010.pdf.

Renner, M. (2009) *Green Jobs: Working for People and the Environment*. Available at: http://sustainability.wfu.edu/wp-content/uploads/2010/02/Worldwatch_Green-Jobs-Working-for-People-and-Environment-Report-2009.pdf.

RESCUE partners (2014) ‘RESCUE - Renewable Smart Cooling for Urban Europe - WORK PACKAGE 2’, *Rescue*. Available at: http://www.rescue-project.eu/fileadmin/user_files/WP2_Reports/RESCUE_WP_2.3_EU_COOLING_MARKET.pdf.

Simpasa, A., Shimeles, A. and Salami, A. O. (2015) ‘Employment Effects of Multilateral Development Bank Support: The Case of the African Development Bank’, *African Development Review*, 27, pp. 31–43. doi: 10.1111/1467-8268.12137.

Supple (2010) *Unlocking the Building Retrofit Market: Commercial PACE Financing*. Available at: http://www.buildingefficiencyinitiative.org/sites/default/files/legacy/InstituteBE/media/Library/Resources/Financing-Clean-Energy/Issue-Brief-Unlocking-the-Building-Retrofit-Market-PACE-Financing.pdf.

Torregrossa, M. (no date) *Energy-efficiency investment with special regard to the retrofitting of buildings in Europe*.

TRB (2004) *Traveler Response to Transportation System Changes Handbook, Third Edition: Chapter 10, Bus Routing and Coverage*. Washington, D.C.: Transportation Research Board. doi: 10.17226/23330.

U.S. Green Building Council (2011) *A new retrofit industry*. Available at: http://www.gbcsa.org.za/wp-content/uploads/2013/06/USGBC-Report-A-New-Retrofit-Industry-An-analysis-of-the-job-creation-potential-of-tax-incentives-for-energy-efficiency-13-June-2011-Copy.pdf.

UN (2015) *World Population Prospects: the 2015 revision*. Available at: https://esa.un.org/unpd/wpp/DataQuery/ (Accessed: 24 April 2017).

UN (2017) *World Population Prospects 2017*. Available at: https://esa.un.org/unpd/wpp/ (Accessed: 28 July 2017).

UNDESA (2014) *World Urbanization Prospects*, *Undesa*. doi: 10.4054/DemRes.2005.12.9.

UNEP (2008) *Green Jobs : Towards decent work in a sustainable, low-carbon world*. Available at: http://www.unep.org/PDF/UNEPGreenjobs_report08.pdf.

United States Department of Labor (2017) *Bureau of Labor Statistics*.

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. *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.* (2015) ‘Heating and cooling energy trends and drivers in buildings’, *Renewable and Sustainable Energy Reviews*. Elsevier, 41, pp. 85–98. doi: 10.1016/j.rser.2014.08.039.

VTPI (2015) *Transport Demand Management Encyclopedia*.

WHO (2014) *7 million premature deaths annually linked to air pollution*.

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

WHO (2016) ‘Ambient Air Pollution Database’. Available at: http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/.

WHO (2017a) ‘Global Health Observatory data repository: Road traffic deaths’. World Health Organization. Available at: http://apps.who.int/gho/data/node.main.A997.

WHO (2017b) ‘Global Urban Ambient Air Pollution Database (update 2016)’, *WHO*. World Health Organization. Available at: http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/ (Accessed: 29 September 2017).

World Bank (2014) ‘Transport for Health: The Global Burden of Disease from Motorized Road Transport’, p. 39. doi: 10.1016/B978-012373960-5.00335-X.

World Bank (2017) *Urban population (% of total)*. Available at: http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS/countries/CN?display=default.

Xiong, W. *et al.* (2015) ‘Heat roadmap china: New heat strategy to reduce energy consumption towards 2030’, *Energy*. Elsevier Ltd, 81, pp. 274–285. doi: 10.1016/j.energy.2014.12.039.

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