THE SUMMARY FOR URBAN POLICYMAKERS OF THE IPCC'S SIXTH ASSESSMENT REPORT

CONSOLIDATED VOLUMES I, II & III

THE SUMMARY FOR URBAN POLICYMAKERS OF THE IPCC'S SIXTH ASSESSMENT REPORT

SUMMARY FOR URBAN POLICYMAKERS

The Summary for Urban Policymakers (SUP) Initiative is a series of three summary reports: *What the Latest Physical Science of Climate Change Means for Cities and Urban Areas*, distilled from the IPCC Working Group I report; *What the Latest Science on Impacts, Adaptation and Vulnerability means for Cities and Urban Areas*, distilled from the IPCC Working Group II report; and *What the Latest Science on Climate Change Mitigation Means For Cities and Urban Areas*, distilled from the IPCC Working Group III report.

This is a collection of the three volumes combined together.
For more information, visit: https://supforclimate.com

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This publication synthesizes the latest findings from the IPCC Sixth Assessment Reports in partnership with cities and businesses across the globe. It does not necessarily reflect the views of the IPCC and has not been subjected to IPCC review.

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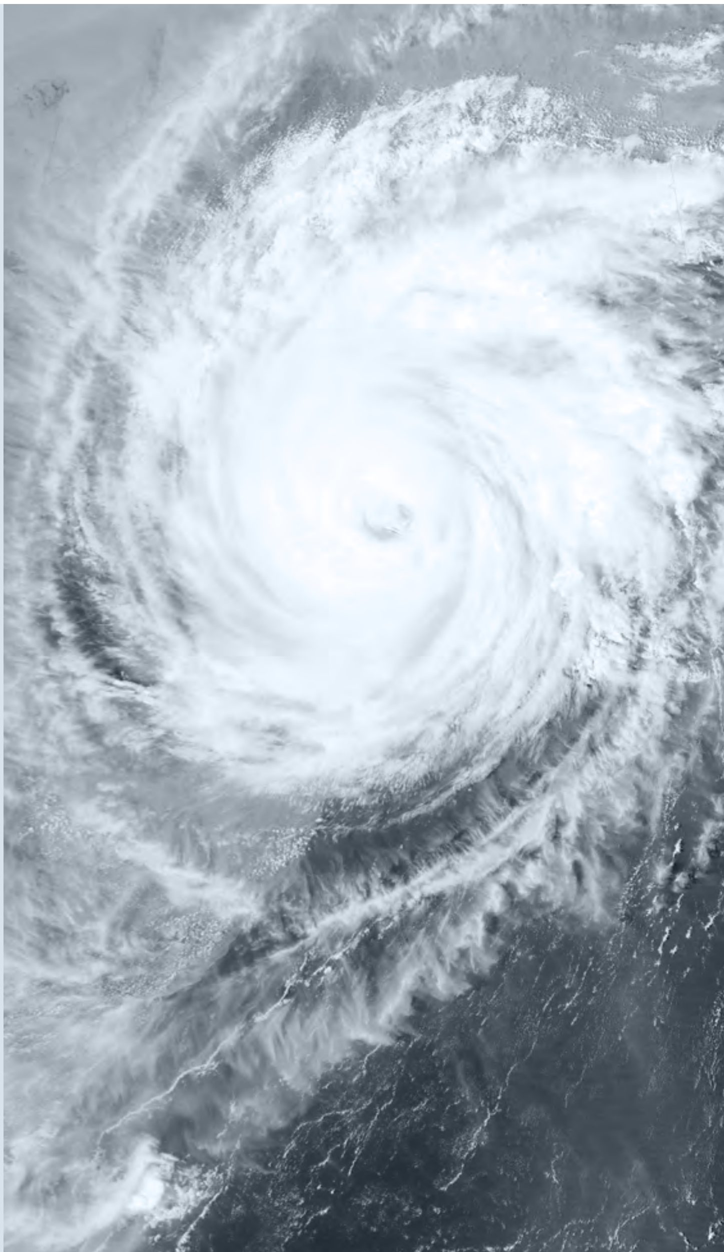


AUTHORS

Laura Gallardo (Chile)
Lead Author, Chapter 6, IPCC AR6 WGI
University of Chile

Rafiq Hamdi (Belgium)
Lead Author, Chapter 10, IPCC AR6 WGI
Meteorological Institute of Belgium

A.K.M. Saiful Islam (Bangladesh)
Lead Author, Chapter 12, IPCC AR6 WGI
Bangladesh University of Engineering and Technology

Ian Klaus (USA)
Series Editor of the SUP Series
Chicago Council of Global Affairs

Zbigniew Klimont (Austria/Poland)
Lead Author, Chapter 6, IPCC AR6 WGI
International Institute for Applied Systems Analysis

Jagdish Krishnaswamy (India)
Coordinating Lead Author, Chapter 7, IPCC Special Report on Climate Change and Land
Indian Institute for Human Settlements

Izidine Pinto (South Africa)
Lead Author, Chapter 11, IPCC AR6 WGI
University of Cape Town

Friederike Otto (United Kingdom)
Lead Author, Chapter 11, IPCC AR6 WGI
Imperial College London

Krishnan Raghavan (India)
Coordinating Lead Author, Chapter 8, IPCC AR6 WGI
Indian Institute of Tropical Meteorology

Aromar Revi (India)
Coordinating Lead Author, Chapter 18, IPCC AR6 WGII and Chapter 4, IPCC Special Report on 1.5°C
Indian Institute for Human Settlements

Anna A. Sörensson (Argentina)
Coordinating Lead Author, Chapter 10, IPCC AR6 WGI
University of Buenos Aires

Sophie Szopa (France)
Coordinating Lead Author, Chapter 6, IPCC AR6 WGI
Institut Pierre-Simon Laplace

REVIEW EDITORS

Valérie Masson-Delmotte (France)
Co-Chair, Working Group I, IPCC

Panmao Zhai (China)
Co-Chair, Working Group I, IPCC

CORE TEAM

Debra Roberts (South Africa)
Co-Chair, Working Group II,
IPCC

Seth Schultz (USA)
Lead Author, Chapter 4, IPCC Special Report on 1.5°C
Resilience Rising

Amanda Eichel (USA)
Lead for the SUP Initiative
Resilience Rising

Aromar Revi (India)
Coordinating Lead Author, Chapter 18, IPCC AR6 WGII and Chapter 4, IPCC Special Report on 1.5°C
Indian Institute for Human Settlements

Ian Klaus (USA)
Series Editor of the SUP Series
Chicago Council of Global Affairs

THE SUP SERIES

The 6th Assessment Report cycle (AR6) of the Intergovernmental Panel on Climate Change (IPCC) comes at a turning point in history. Human influence has warmed the planet, and widespread and rapid impacts are occurring to both natural and human systems in all regions of the world. In response, immediate action is needed if there is to be any hope of limiting global warming close to 1.5°C or well below 2°C below pre-industrial levels, as well as preparing for and adapting to current and future risks. AR6 is composed of three main reports: *The Physical Science Basis*; *Impacts, Adaptation and Vulnerability*; and *Mitigation of Climate Change*, as well as a synthesis report. It also includes three special reports: the *Special Report on Global Warming of 1.5°C*, the *Special Report on the Ocean and Cryosphere in a Changing Climate*, and the *Special Report on Climate Change and Land*. Together they offer the most current and comprehensive scientific understanding of the climate crisis.

The transformations needed in response to climate change will require decisive action in cities and urban areas. Cities and urban areas are a major source and driver of emissions; they are also crucial sites for system transitions in the near term and transformations over longer time frames. The Summary for Urban Policymakers (SUP) initiative provides a distillation of IPCC climate reports into accessible and targeted summaries that can help inform action at the city and regional scale. The latest three volumes of the SUP series are authored by IPCC AR6 cycle authors in conversation with city officials, national governments, and business communities in every region of the world. The first volume focuses on the physical science basis of climate change, the second on managing climate risks and adaptation, and the third on mitigation. Each volume is distilled from the official IPCC reports of the AR6 cycle. While focused on each discrete IPCC working group report, the individual volumes in the SUP series bring the findings into conversation with each other. In doing so, it provides accessible science for policymakers and supports preparation for the IPCC Special Report on Cities, due in 2025 as part of the 7th Assessment cycle.

This report, *What the Latest Physical Science of Climate Change Means for Cities*, distils IPCC AR6 Working Group I material for urban policymakers. Key findings on current and future changes in the climate and their implications for urban areas include:

- With global warming reaching 1.1°C over the last decade, human-induced climate change is affecting every region of the world, and even more the cities and urban areas therein.
- In the coming decades, warming will continue to worsen, as will associated effects on cities such as drought, heavy rainfall, floods, extreme heat, storm surges, and cyclones.
- Many cities and urban areas will also experience sea-level rise and associated coastal erosion, and more frequent coastal flooding.
- Looking out to 2050, without immediate and deep reductions in emissions, global warming would exceed 2.0°C, exposing even more cities and the people, infrastructure and ecosystems therein.

As this volume and the wider series make clear, the time for cities to act, and for stakeholders to enable such action, is now.

Gwangju, South Korea

1. THE PHYSICAL SCIENCE BASIS: HISTORICAL CONTEXT, LOCAL CONTENT

In Rio de Janeiro in 1992, UN member states – or parties – agreed to the United Nations Framework Convention on Climate Change (UNFCCC). The Paris Agreement, concluded twenty years later at the twenty-first Conference of Parties (COP 21), committed states to reducing warming to well below 2°C. The Paris Agreement included an opening for member states to increase their efforts – known as Nationally Determined Contributions – to reduce emissions beyond those contained in the Agreement. The commitment and means to do so have been the subject of negotiations at subsequent COPs.

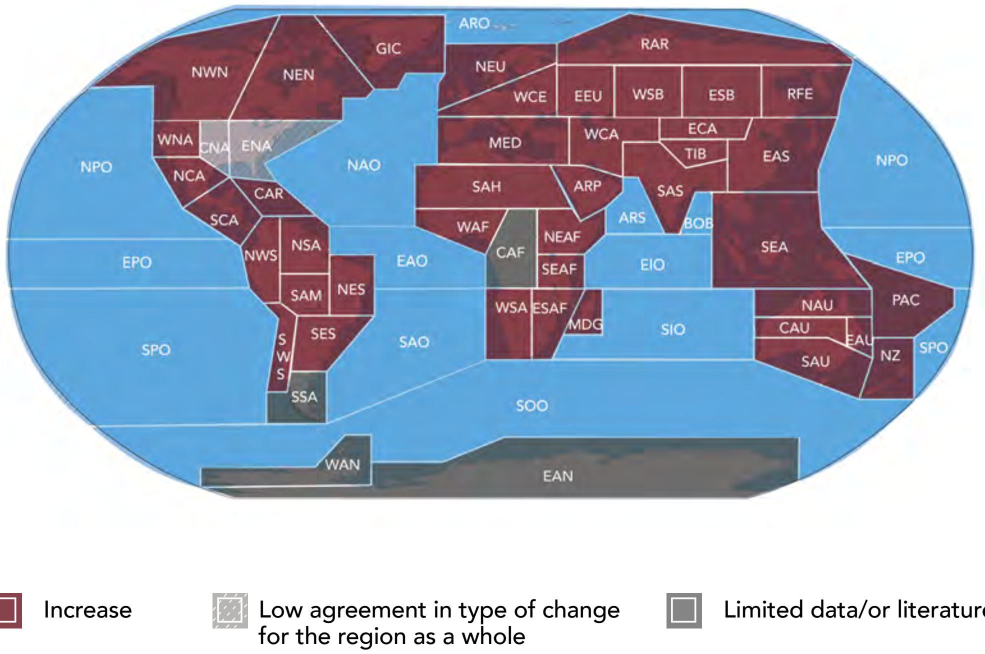
Paris, France

In addition to these commitments, COP 21 concluded with an invitation to the IPCC to deliver a special report on warming of 1.5°C.

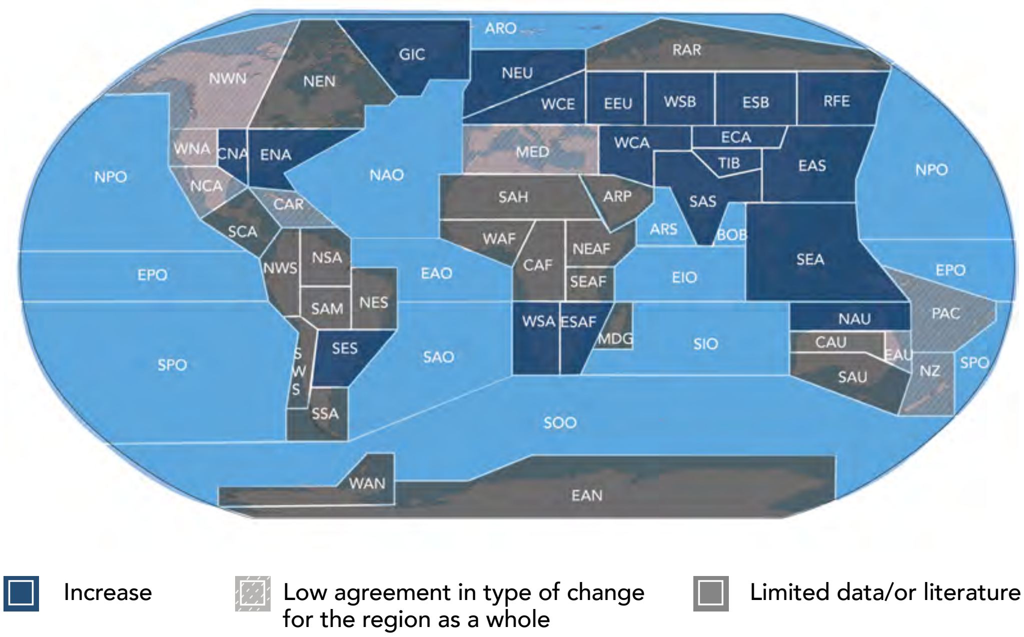
Published in 2018, the *IPCC Special Report Global on Warming of 1.5°C (SR1.5)* assessed the impacts at different levels of warming, particularly between 1.5°C and 2°C. It made clear the dramatically different potential impacts on human health, well-being and poverty, land and ocean ecosystems, and biodiversity as warming moves above 1.5°C. Every increment, every 0.1°C, of warming matters. Overshooting 1.5°C global warming, even if only temporarily, would lead to more catastrophic impacts in an increasingly uncertain world. SR1.5 also identified four simultaneous systems transitions needed to deliver the necessary emission reductions and adaptations, including a transition in the urban and infrastructure system, in addition to those in energy; land and ecosystems; and industry systems.[1] The 2019 *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* highlighted the cascading effects of changes occurring from the highest mountains to the deepest oceans, and from polar regions to tropical and temperate coastal areas. It noted the importance of cities in those regions as sites at the frontline of climate change.[2] The Special Report on *Climate Change and Land*, also published in 2019, did not explicitly focus on urban areas, though it discussed urbanisation as a key driver of land-use change, with tradeoffs for climate mitigation.[3]

The Physical Science Basis, published in 2021, updated these assessments, including findings related to the built environment, land, and sea level rise. Important new findings around impacts from heavy rainfall; extreme heat; air pollution; compound events; and low-likelihood, high-impact outcomes also featured in the report. Due to its global scope and perspective, there are limits to the urban evidence included in *The Physical Science Basis*. However, the interactive Regional Atlas – key elements of which are captured in Figure 1 – provides context for understanding climatic impact-drivers for cities in each region.[4]

Figure 1: Climate change is already affecting every inhabited region across the globe. Human influence contributes to many observed changes (since the 1950s) in weather and climate extremes.



(a) Observed change in **hot extremes**



(b) Observed change in **heavy precipitation**

Source: Derived from IPCC AR6 WGI Summary for Policymakers Figure SPM.3

IPCC AR6 WGI reference regions:

NORTH AMERICA:
NWN - North-Western North America
NEN - North-Eastern North America
WNA - Western North America
CNA - Central North America
ENA - Eastern North America

CENTRAL AMERICA
NCA - Northern Central America
SCA - Southern Central America
CAR - Caribbean

SOUTH AMERICA
NWS - North Western South America
NSA - Northern South America
NES - North-Eastern South America
SAM - South American Monsoon
SWS - South-Western South America
SES - South-Eastern South America
SSA - Southern South America

EUROPE
GIC - Greenland/Iceland
NEW - Northern Europe
WCE - Western and Central Europe
EEU - Eastern Europe
MED - Mediterranean

AFRICA
MED - Mediterranean
SAH - Sahara
WAF - Western Africa
CAF - Central Africa
NEAF - North Eastern Africa
SEAF - South Eastern Africa
WEAF - South Western Africa
ESAF - East Southern Africa
MDG - Madagascar

ASIA
WSB - Western Siberia
ESB - East Siberia
RFE - Russian Far East
WCA - West Central Asia
ECA - East Central Asia
TIB - Tibetan Plateau
EAS - East Asia
ARP - Arabian Peninsula
SAS - South Asia
SEA - South East Asia

AUSTRALASIA
NAU - Northern Australia
CAU - Central Australia
EAU - Eastern Australia
SAU - Southern Australia
NZ - New Zealand

SMALL ISLANDS
PAC - Pacific Small Islands
CAR - Caribbean

OCEANS
ARO - Arctic Ocean
NPO - North Pacific Ocean
EPO - Equatorial Pacific Ocean
SPO - South Pacific Ocean
NAO - North Atlantic Ocean
EAO - Equatorial Atlantic Ocean
SAO - South Atlantic Ocean
ARS - Arabian Sea
BOB - Bay of Bengal
EIO - Equatorial Indian-Ocean
SIO - South Indian-Ocean
SOO - Southern Ocean

POLES
RAR - Russian Arctic
WAN - West Antarctica
EAN - East Antarctica

The Physical Science Basis also builds on recent methodological advancements of particular value for urban practitioners and policymakers. Relevant and robust local information on climate change is increasingly needed and demanded for integrated adaptation and mitigation planning and action at the city scale, and to enable local decision making around the implementation of sustainable development. As Box 1 makes clear, for information to be both robust and reliable, multiple lines of evidence must be drawn upon, including different models and process understanding, observational data, and attribution.[5] Despite some identified knowledge gaps, there is significant material in *The Physical Science Basis* that can be useful for cities in the construction of their adaptation plans, including, for example, new urban modules developed to calculate the exchanges of heat and water between the urban fabric and its overlying atmosphere.[6] That material, and that which is relevant to mitigation, is covered below.

Localisation Methodology - constructing climate change information for cities

Fires, flooding, and tropical cyclones, among other extreme events, have struck cities around the world in recent years. For the risk assessment and adaptation action necessary to meet these challenges, policymakers need to understand the relationship between extreme conditions and climate change on the city scale. For regional climate change information to be robust and reliable, providing a well-grounded analytic foundation for policymakers, it should be based on multiple lines of evidence. These include: different types of observations, including local or indigenous knowledge; attribution of trends and events; different types of climate models; and expert knowledge on climatic processes.

Different types of observations are crucial to evaluate the past performance of diverse types of climate models that are used to project future climate impacts or to attribute specific and already experienced outcomes to the changing climate. Long-term observational records are crucial to assess if the types of extreme events of interest have become more common or intense over time. Diverse climate models can be more appropriate for different regions and to explore different types of questions about the future. In this sense it is important that the climate models employed to answer a specific question for a specific city represent the physical processes that are most relevant for that particular context.

For regional climate change information to be useful and relevant for integration in decision-making, co-production of information is a viable and efficient approach. In co-production the context and the values of the user and the scientists are taken into account in an explicit manner. Working together, data can be translated at a scale and with associated degrees of certainty to inform policymaking, while identifying the demand for specific new information that can be used to explore the future. City-scale climate monitoring networks, for example, enhance the understanding of the urban heat island and its interaction with climate change and provide key information for end users such as urban planners, policymakers, stakeholders, and the general public.[7] These approaches can increase use of data in urban policy decision-making and inform investments in improved climate modelling approaches.

Box 1.

Shenzhen, China

1. WHAT THE PHYSICAL ASPECTS OF CLIMATE CHANGE MEANS FOR CITIES

Based on an unprecedented volume of evidence, *The Physical Science Basis* presents the consequences of human influence on climate change, and hence the planet. Amid the rigorous science and nuanced findings contained in the report, a number of essential, and unequivocal, messages emerge.

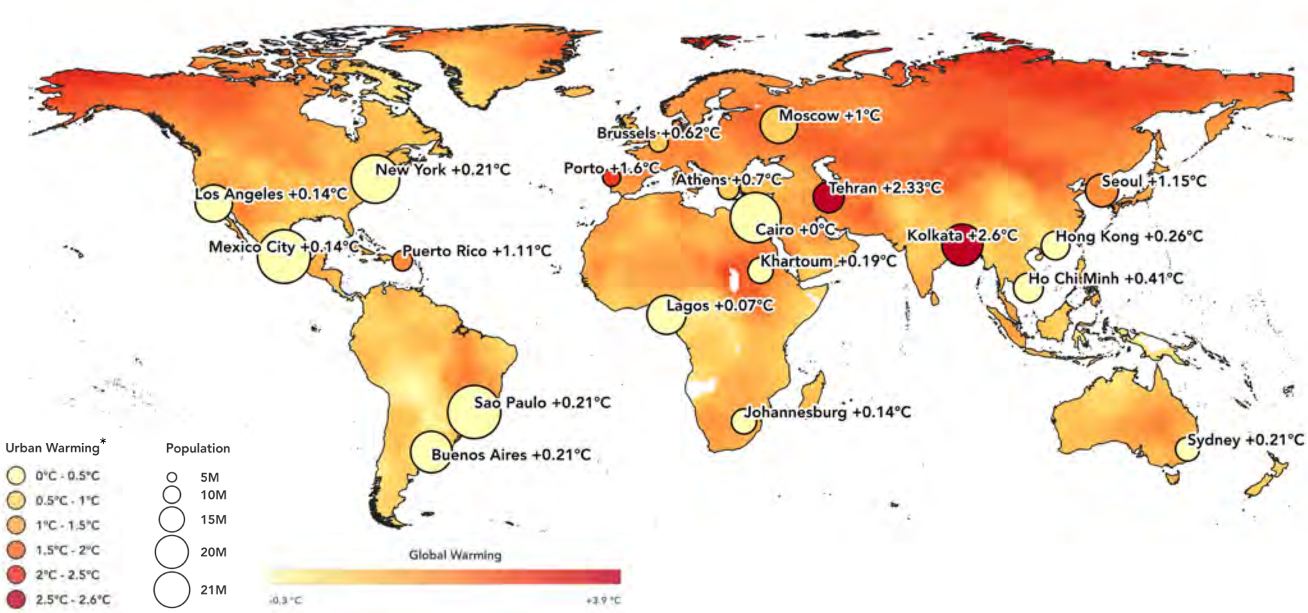
The climate change crisis is here. Human-induced climate change is increasingly affecting every region of the world, including through more intense weather and climate extremes. From a physical perspective, reducing human-caused global warming is possible by achieving net-zero CO_2 emissions combined with a sharp reduction of emissions from other greenhouse gases (GHG), in particular methane.

However, without immediate and deep reductions in GHG emissions, global warming will exceed 2°C by around 2050. Even with strong reduction of emissions the cumulative CO_2 emissions will increase and exceed 1.5°C in the next 20 years. The effects of historical GHG emissions will also be long lasting. Many of the changes, particularly with regards to the ocean, ice sheets, and global sea level rise, will last for centuries to millennia.

The rapidly changing climate, and climate-induced risks in particular, have profound implications for cities. Many of these track the key findings of *The Physical Science Basis*, only in more severe terms as the effects of climate change are often exacerbated in cities, particularly with regards to temperature increases. Observed warming is larger over land than the ocean, and therefore some large cities in West and South Asia and smaller cities in the Arctic have already exceeded 2°C (for 1.1°C of global warming). Even with strong reductions in emissions, many cities and urban areas will be increasingly exposed to more frequent drought, floods, extreme heatwaves and storm surge, as well as

Cairo, Egypt

Figure 2: Past trends in global surface air temperature (1958-2018) with cities reporting significant temperature increases.



*Urban Warming refers to the difference between local urban temperature change and surrounding warming.

Source: Change in the annual mean surface air temperature over the period 1958-2018 based on the local linear trend retrieved from CRU TS (°C per 68 years). This map has been amended from IPCC 2021, Climate Change 2021: The Physical Science Basis, Chapter 10: Linking Global to Regional Climate Change; United Nations, Department of Economic and Social Affairs, Population Division (2018); World Urbanization Prospects: The 2018 Revision, Online Edition.

more intense cyclones. Given the long life cycles of many urban and infrastructure systems, sea level rise will continue to have increasing implications even if warming is stabilised.

Climatic impact-drivers are climate-related means or events that impact societies and ecosystems. The temporal horizon of climatic impact-drivers runs on a continuum from rapid-onset events that may occur in hours or days to slow-onset events that evolve over many years as a result of an increased frequency and intensity of events. Climatic impact-drivers are increasing across all regions, and individual extreme events are increasing in frequency, intensity, and impact. Every region will experience concurrent and multiple changes in climatic impact-drivers at higher levels of global warming. In many places, these climatic impact-drivers are arriving simultaneously, in compound events, and overlapping with slow-onset drivers. A summary of key climatic impact-drivers in cities and urban areas is provided below.

Without immediate and deep reductions in GHG emissions, global warming will exceed 2°C by around 2050. Even with strong reduction of emissions the cumulative CO_2 emissions will increase and exceed 1.5°C in the next 20 years. Observed warming is larger over land than the ocean, and therefore some large cities in West and South Asia and smaller cities in the Arctic have already exceeded 2°C (for 1.1°C of global warming).

Precipitation and floods

Human-induced global warming is dramatically altering the global water cycle. Atmospheric moisture and precipitation intensity have increased, as has the transfer of water from soil to the atmosphere. Patterns of aridity have also been influenced by human-induced warming. Hydrological extremes – from water cycle variability to precipitation to tropical and extratropical cyclones – are going to continue and intensify.[8]

Studies at the regional scale, while not necessarily narrowed to the city level, offer specific insights into observed and anticipated changes in precipitation:

- Significant increasing trends in mean precipitation have been observed over some northern high-latitude regions. Meanwhile, decreasing trends have been observed over regions in tropical Africa, the Americas, and Southwest Asia.
- In high altitudes, total precipitation will increase, shifting from snowfall to rainfall except in the coldest regions and seasons. Meanwhile, total precipitation will decrease in a significant number of regions, including over the Mediterranean, Southern Africa, Amazonia, Central America, southwestern South America, southwestern Australia, and coastal West Africa.
- In mountains, in particular, surface and groundwater are likely to be impacted by the shift in precipitation from snow to rain. In South Asia and other regions where snowmelt is the primary source of runoff, this shift can lead to declines in streamflow and groundwater storage.
- Impacted areas include South America, and Northern North America, and the mountains of Asia.

Cities and urban areas are particularly vulnerable to floods owing to impervious surfaces and sealed soils that do not retain sufficient water. If impervious surfaces rise to 50-90% of the urban terrain, then 40-83% of rainfall becomes seasonal runoff. Heavy rain events can flood buildings, roadways, subway tunnels, and farmlands. Heavy precipitation may overwhelm metropolitan transportation and stormwater drainage systems, which are typically designed to withstand specific event intensity, duration, and frequency that can be exceeded by many climate-induced extreme events.[9]

Heavy rain events can flood buildings, roadways, subway tunnels, and farmlands. Heavy precipitation may overwhelm metropolitan transportation and stormwater drainage systems, which are typically designed to withstand specific event intensity, duration, and frequency that can be exceeded by many climate-induced extreme events.

New Orleans, USA

Monsoons and cyclones

A warmer climate will intensify very wet and very dry weather, as well as climate events and seasons, with implications for flooding or drought. However, the location and frequency of these events depend on changes in regional atmospheric circulation, including monsoons and mid-latitude storm tracks.

Monsoon precipitation, though complex, is projected to increase in the midterm to long term at the global scale, with a delayed onset over North America, South America, and West Africa and a delayed retreat over West Africa.[10] Monsoon precipitation will increase over South Asia, East Asia and central-eastern Sahel.[11]

Tropical cyclones bring intense winds, heavy rainfall, and flooding amplified by storm surges to cities and urban areas. There has been an increase in the proportion of the most intense tropical cyclones, and the average peak wind and heavy rainfall of tropical cyclones will also increase with further global warming.[12] Sea level rise, an increased proportion of the most intense cyclones, and increased heavy rainfall associated with coastal storms, will expose cities to compound wind, water, and coastal hazards with the potential for widespread human mortality and damage to housing, transportation, and energy infrastructure.[13]

Sea level rise, an increased proportion of the most intense cyclones, and increased heavy rainfall associated with coastal storms, will expose cities to compound wind, water, and coastal hazards with the potential for widespread human mortality and damage to housing, transportation, and energy infrastructure.

Puchong, Malaysia

Drought and aridity

As warming advances, droughts will become more frequent and severe, while impacting more total land area.[14] Droughts do differ in impact and response to GHG concentrations, and thus drought trends differ by region. For example:

- Over the last decade, the areas impacted by extreme meteorological drought in the Mediterranean, western North America, southwestern Australia, Southern Africa, and southwestern South America have increased.
- Regions that have shown increases in drought due to lack of rain are found in Africa and South America.
- In semi-arid areas with existing water availability constraints, drought is a major climatic impact-driver. On all continents, there are observed increases in agricultural and ecological drought.
- Soil moisture drought also increases water scarcity and damages to buildings.
- Looking forward, droughts in arid and semi-arid areas are likely to increase.[15]

Droughts, whether meteorological, hydrological, agricultural, or ecological, and while differing by region, significantly impact cities. Drought can lead to increased groundwater withdrawal and thus depletion. For coastal cities and urban areas, heat island effect worsens drought and aridity. A warming climate combined with human groundwater use, including in cities, will deplete groundwater resources in already dry regions.[16] Notably, ecological droughts can lead to disruption in food production, thus directly affecting cities.

Heat

Cities and urban areas are experiencing an increase in heatwaves. There are now more hot days, and they are hotter, and fewer cold days and nights. Heatwaves have increased in both duration and intensity, and these increases, along with a decrease in the intensity and frequency of cold extremes, will continue throughout the 21st century.

Cities and urban areas are experiencing an increase in heatwaves. There are now more hot days, and they are hotter, and fewer cold days and nights.

Istanbul, Turkey

Brighton, UK

Sea level and storm surges

Sea level and air temperature rises are projected in most coastal cities and urban areas. Changes in relative sea level, storm surges, and ocean waves meet with other drivers such as extreme precipitation and river flooding. Consequently, coastal flooding with increased recurrence and intensity of extreme sea levels will lead to increased erosion for cities in low-lying areas.[17]

There will be long-term impacts resulting from rising sea levels. The rise in sea level will continue beyond 2100 - and the impacts continue for centuries to millenia, but the pace of this rise will strongly depend on future emissions.[18] Increased warming will also lead to a decrease in seasonal snow cover and surface permafrost thaw. In high-latitude and mountain regions, thawing may destabilise settlements and critical infrastructure.

Air quality

Air quality has a significant impact on the health of local residents. However, the evidence linking climate change and air quality is mixed. In already heavily-polluted environments, some climate-driven changes in meteorological conditions can favour extreme air pollution episodes. Climate change induced disruptions, such as wildfires near cities, are likely to deteriorate air quality at local and regional scales, but remain difficult to project and quantify.[19] A warmer climate is expected to increase mean surface ozone over polluted regions, which could prove detrimental and significant to human health. This enhancement grows with the level of emissions of ozone precursors. For the most part, future air quality will be primarily driven by changes in precursor emissions as opposed to climate change.

Compound events

For cities and urban areas, it is important to consider equally discrete events; compound events; and low-probability, high-impact events.[20] When combined in close succession, or concurrently in different regions, non-extreme events can lead to extreme impacts that far exceed the impact of individual events.[21] In many cities and low-lying areas, concurrent storm surges and high river flows have led to compound flooding. Such events are projected to increase in frequency, as are wildfires from compound hot, dry, and windy events. Meanwhile, interactions between urban heat islands and extreme heat episodes make heatwaves more intense in urban than rural areas, particularly at night.

When combined in close succession, or concurrently in different regions, non-extreme events can lead to extreme impacts that far exceed the impact of individual events.

Jakarta, Indonesia

Canberra, Australia

2. WHAT HAPPENS IN CITIES MATTERS

As *The Physical Science Basis* lays out, cities, urban areas, and urbanisation processes are key drivers of how climate change manifests over and around urban areas.

Urbanisation can impact overall precipitation patterns in and near cities. This is true for average rainfall, and especially for heavy precipitation. Extreme precipitation, especially at high levels of global warming, will lead to the most serious impacts, including an increase in flood risks. Urbanisation also brings about changes to the water cycle that lead to increasing surface runoff intensity.[22] Finally, short-term solutions to reduce air pollution in urban centres that do not adequately consider associated emissions impacts can further exacerbate the impact of climate change both at the city scale and globally.

The impact of cities, urban areas, and urbanisation on the key drivers of climate change is perhaps nowhere more evident than when it comes to heat. The combination of future urbanisation and increasingly frequent extreme climate events, such as heatwaves, will have significant implications for heat stress in cities.[23] The urban heat island effect is caused by a number of factors, with

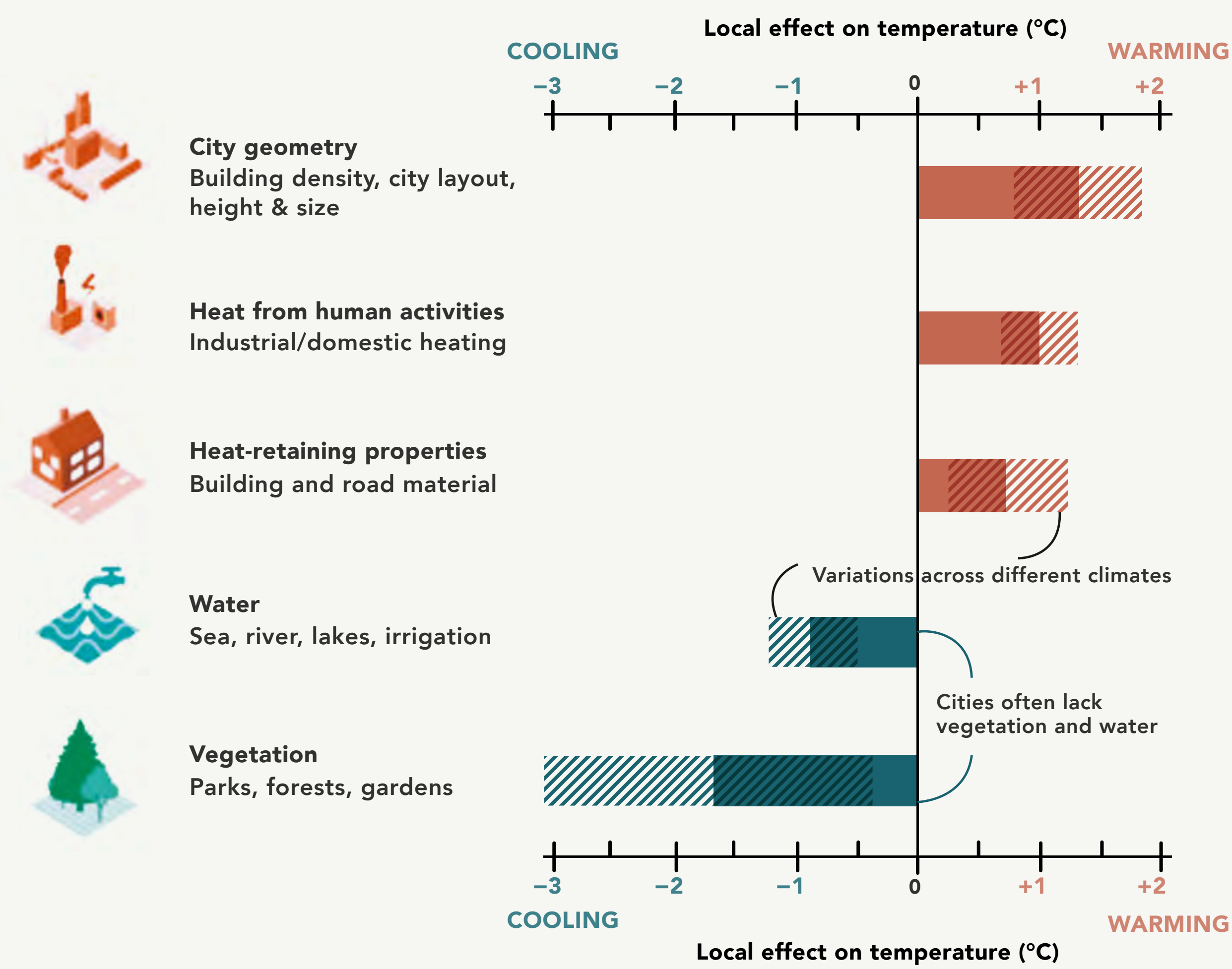
The combination of future urbanisation and increasingly frequent extreme climate events, such as heatwaves, will have significant implications for heat stress in cities.

Santiago, Chile

urban geometry being the strongest contributor. The number of buildings, and their size and their proximity, matters. Tall, proximate buildings absorb and store heat while reducing natural ventilation. The heat-retaining properties of the materials that make up concrete buildings, asphalt roadways, and dark rooftops – constituent parts of many cities – also adds to warming. These materials absorb and retain heat during the day, and re-emit that heat at night. Concentrated in cities and urban areas, human activities directly warm the local atmosphere through heat released from domestic and industrial heating or cooling systems, running engines, and other sources.

An absence of vegetation and water bodies, which can strongly contribute to local cooling, can further amplify the urban heat island effect. Looking forward, urbanisation will intensify urban heat island effects regardless of changes in the background climate.[24] However, sufficient integration of vegetation and water into the urban fabric can partially counterbalance the effect.[25] Urban greening, meanwhile, as well as urban and peri-urban agriculture, can potentially lessen the impacts of urban heat island and warming. Urbanisation can also induce the urban dryness island effect, when humidity in cities and urban areas drops below that of more rural areas.[26]

Figure 3: Cities are usually warmer than their surrounding areas due to factors that trap and release heat and a lack of natural cooling influences such as water and vegetation.



Source: Derived from IPCC AR6 WGI Chapter 10, FAQ10.2

CONCLUSION: LOOKING FORWARD

The Physical Science Basis offers the most current and comprehensive scientific understanding of changes to the physical world as a result of human activities. Even with drastic reductions in GHG emissions, global warming of 1.5°C will be exceeded in this century. Such warming increases both the frequency and severity of extreme weather and high-impact events whose effects are exacerbated in cities and urban areas. We must act now to adapt to those changes and mitigate the emissions driving them. The science makes strikingly clear that cities and urban areas are at once sources of climate forcers and important sites for innovation, adaptation, mitigation, and the implementation of sustainable development. With urban-related policies set not only by city officials, but also by policymakers at local, regional, and national levels, there is a considerable responsibility on, and opportunity for, urban policymakers at all levels of government to address the climate crisis.

Cities and urban areas face multiple, compounding risks and impacts that increase exponentially and disproportionately at higher warming levels. With an understanding of attribution and risks comes an imperative to act on opportunities and options for climate action. Systems transitions are needed to limit climate impact, including rapid and concurrent transitions in energy; land, ocean, coastal, and freshwater ecosystems; industry and society; as well as urban, rural and infrastructure systems.[27] The IPCC Working Group II report *Impacts, Adaptation and Vulnerability*, focuses on the risks climatic impact-drivers pose to lives, livelihoods, ecosystems, and biodiversity, arguing/showcasing how cities are frontrunners in adaptation action. Together with the IPCC's Working III report on *Mitigation of Climate Change*, the global community has a map of the solution space on climate change and sustainable development, with cities playing a central role in how we adapt and mitigate.

The global community has a map of the solution space on climate change and sustainable development, with cities playing a central role in how we adapt and mitigate.

Kolkata, India

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THE SUMMARY FOR URBAN POLICYMAKERS OF THE IPCC'S SIXTH ASSESSMENT REPORT

VOLUME I

WHAT THE LATEST PHYSICAL SCIENCE OF CLIMATE CHANGE MEANS FOR CITIES AND URBAN AREAS

SUMMARY FOR URBAN POLICYMAKERS

THE SUMMARY FOR URBAN POLICYMAKERS OF THE IPCC'S SIXTH ASSESSMENT REPORT

VOLUME II

WHAT THE LATEST SCIENCE ON IMPACTS, ADAPTATION AND VULNERABILITY MEANS FOR CITIES AND URBAN AREAS

SUMMARY FOR URBAN POLICYMAKERS

The Summary for Urban Policymakers (SUP) Initiative is a series of three summary reports: *What the Latest Physical Science of Climate Change Means for Cities and Urban Areas*, distilled from the IPCC Working Group I report; *What the Latest Science on Impacts, Adaptation and Vulnerability means for Cities and Urban Areas*, distilled from the IPCC Working Group II report; and *What the Latest Science on Climate Change Mitigation Means For Cities and Urban Areas*, distilled from the IPCC Working Group III report.

This is Volume II of the series and all three are available here: https://supforclimate.com

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SUP VOLUME I

What the Latest **Physical Science of Climate Change** Means for Cities and Urban Areas

SUP VOLUME II

What the Latest Science on **Impacts, Adaptation and Vulnerability** Means for Cities and Urban Areas

SUP VOLUME III

What the Latest Science on **Climate Change Mitigation** Means for Cities and Urban Areas

CONTENTS

AUTHORS

Ibidun Adelekan (Nigeria)
Coordinating Lead Author, Chapter 9, IPCC AR6 WGII
University of Ibadan

Anton Cartwright (South Africa)
Lead Author, Chapter 4, IPCC Special Report on 1.5°C
University of Cape Town

Winston Chow (Singapore)
Lead Author, Chapter 6 and Cross-Chapter Paper 2, IPCC AR6 WGII
Singapore Management University

Sarah Colenbrander (United Kingdom)
Contributing Author, Chapter 6, IPCC AR6 WGII
ODI

Richard Dawson (United Kingdom)
Lead Author, Chapter 6, IPCC AR6 WGII
Coordinating Lead Author, Cross-Chapter Paper 2, IPCC AR6 WGII
Newcastle University

Matthias Garschagen (Germany)
Lead Author, Chapter 16 and Cross-Chapter Paper 2, IPCC AR6 WGII
Ludwig Maximilian University of Munich

Marjolijn Haasnoot (Netherlands)
Lead Author, Chapter 13 and Cross-Chapter Paper 2, IPCC AR6 WGII
Utrecht University

Masahiro Hashizume (Japan)
Lead Author, Chapter 10, IPCC AR6 WGII
The University of Tokyo

Ian Klaus (USA)
Series Editor of the SUP Series
Chicago Council of Global Affairs

Jagdish Krishnaswamy (India)
Coordinating Lead Author, Chapter 7, IPCC Special Report on Climate Change and Land
Indian Institute for Human Settlements

Maria Fernanda Lemos (Brazil)
Coordinating Lead Author, Chapter 12, IPCC AR6 WGII
Pontifical Catholic University of Rio de Janeiro

Debbie Ley (Guatemala/Mexico)
Lead Author, Chapter 18, IPCC AR6 WGII
Lead Author, Chapter 4, IPCC Special Report on 1.5°C
Economic Commission for Latin America and the Caribbean

Timon McPhearson (USA)
Lead Author, Chapter 6, IPCC AR6 WGII
The New School

Mark Pelling (United Kingdom)
Coordinating Lead Author, Chapter 6, IPCC AR6 WGII
King's College London

Prathijna Poonacha Kodira (India)
Indian Institute for Human Settlements

Aromar Revi (India)
Coordinating Lead Author, Chapter 18, IPCC AR6 WGII
and Chapter 4, IPCC Special Report on 1.5°C
Indian Institute for Human Settlements

Liliana Miranda Sara (Peru)
Lead Author, Chapter 12, IPCC AR6 WGII
Cities for Life Forum

Nicholas P. Simpson (Zimbabwe/South Africa)
Lead Author, Chapter 9, IPCC AR6 WGII
University of Cape Town

Chandni Singh (India)
Lead Author, Chapter 10, IPCC AR6 WGII
Author, Cross-Chapter Paper 2, IPCC AR6 WGII
Indian Institute for Human Settlements

William Solecki (USA)
Lead Author, Chapter 17, IPCC AR6 WGII
Coordinating Lead Author, Chapter 1, IPCC Special Report on 1.5°C
City University of New York

Adelle Thomas (Bahamas)
Lead Author, Chapter 16 and Cross-Chapter Paper 2, IPCC AR6 WGII
Lead Author, Chapter 3, IPCC Special Report on 1.5°C
University of the Bahamas

Christopher Trisos (South Africa)
Coordinating Lead Author, Chapter 9, IPCC AR6 WGII
University of Cape Town

REVIEW EDITORS

Hans-Otto Pörtner (Germany)
Co-Chair, Working Group II
IPCC

Debra Roberts (South Africa)
Co-Chair, Working Group II
IPCC

CORE TEAM

Debra Roberts (South Africa)
Co-Chair, Working Group II
IPCC

Seth Schultz (USA)
Lead Author, Chapter 4, IPCC Special Report on 1.5°C
Resilience Rising

Amanda Eichel (USA)
Lead for the SUP Initiative
Resilience Rising

Aromar Revi (India)
Coordinating Lead Author, Chapter 18, IPCC AR6 WGII
and Chapter 4, IPCC Special Report on 1.5°C
Indian Institute for Human Settlements

Ian Klaus (USA)
Series Editor of the SUP Series
Chicago Council of Global Affairs

THE SUP SERIES

The 6th Assessment Report cycle (AR6) of the Intergovernmental Panel on Climate Change (IPCC) comes at a turning point in history. Human influence has warmed the planet, and widespread and rapid impacts are occurring to both human systems and ecosystems in all regions of the world. In response, immediate action is needed if there is to be any hope of limiting global warming close to 1.5°C or well below 2°C below pre-industrial levels, as well as adapting to and preparing for current and future risks. AR6 is composed of three main reports: *The Physical Science Basis*; *Impacts, Adaptation and Vulnerability*; and *Mitigation of Climate Change*, as well as a *Synthesis Report*. It also includes three additional publications: the *Special Report on Global Warming of 1.5°C*, the *Special Report on the Ocean and Cryosphere in a Changing Climate*, and the *Special Report on Climate Change and Land*. Together they offer the most current and comprehensive scientific understanding of the climate crisis and actions to address it.

The Summary for Urban Policymakers (SUP) series distils the IPCC reports into targeted summaries to inform action at the city and regional scale. Volume I in the series, *What the Latest Physical Science of Climate Change Means for Cities and Urban Areas*, identified the ways in which human-induced climate change is affecting every region of the world, and the cities and urban areas therein. In the coming years and decades, many cities and urban areas will be exposed to increased frequency and severity of extreme heat, an intensified water cycle including drought and heavy rainfall and floods, and an increased frequency of the most intense tropical cyclones and associated storm surge. More cities and urban areas will also increasingly experience the consequences of long-term sea-level rise, including coastal erosion and more frequent coastal flooding.

This second volume in the series, *What the Latest Science on Impacts, Adaptation and Vulnerability means for Cities and Urban Areas*, offers a concise and accessible urban-focused distillation of the IPCC Working Group II Report. The scale, reach, and complexity of contemporary urbanisation can compound the risks from climate change for cities.

Cities and urban areas have a critical role to play in delivering the climate resilient development needed to address these risks. This report assesses the feasibility and effectiveness, as well as the limitations, of different climate adaptation options. It explores the potential for maladaptation, or the triggering of unintended effects which may increase risk or greenhouse gas emissions (GHG). It synthesises the latest evidence on the need for urban-led transformation, the success of which will rely on activating five simultaneous systems transitions in: land, coastal, ocean, and freshwater ecosystems; urban, rural, and infrastructure systems; energy systems; industrial systems; and societal choices.[1] Finally, the report highlights opportunities for local governments to integrate urban adaptation and mitigation strategies to achieve sustainable development for all.


Gwangju, South Korea

1. INTRODUCTION

Between 2015 and 2050, an estimated 2.5 billion people will be added to the urban population with almost all this growth occurring in middle- and low-income countries.[2] This urban expansion will further concentrate climate change risks in the world's cities. Climate change exposes fault lines of inequality, poverty, poor governance, and inadequate infrastructure that undermine sustainable development in many cities.[3] Rapid urbanisation, and in particular, the rapid growth of unplanned and informal settlements in low- and middle-income nations and rapid urbanisation into hazard-prone areas, places large numbers of people beyond the reach of many formal climate policies and will require new approaches to climate resilient urban development.[4]

But cities and urban areas also sit at the center of the climate solution space. Global urbanisation is a 21st century megatrend, aggregating people, innovations, and investment, and enabling swifter action than is often possible at the national level. In this sense, urbanisation represents a crucial opportunity to accelerate climate responses required to limit warming to 1.5°C as well as work towards transformational adaptation and just, equitable, and climate resilient development (CRD).[5] The pursuit of CRD has the potential to deliver rapid, tangible benefits for marginalised urban dwellers, including cleaner air and water, reduced heat exposure and flooding, access to green space, and improved physical and mental health.[6]

Climate change exposes fault lines of inequality, poverty, fractured governance and inadequate infrastructure that undermine sustainable development in many cities. A 21st century megatrend, global urbanisation aggregates people, innovations and investment, enabling swifter action than is often possible at the national level.

Baguio, Philippines

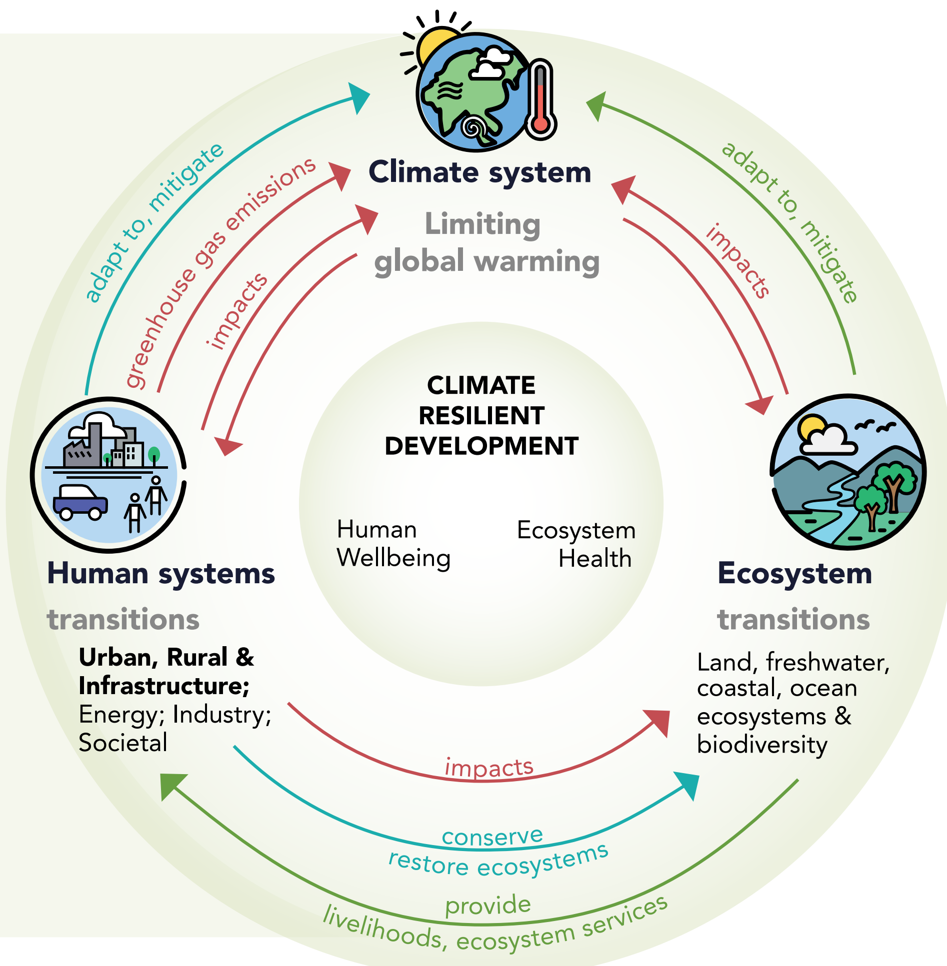
Published in August 2021, AR6 Volume I *The Physical Science Basis* offered the most current and comprehensive scientific understanding of changes to the physical world as a result of human activities. As volume 1 of the Summary for Urban Policymakers series, *What the Latest Physical Science of Climate Change Means for Cities and Urban Areas*, confirms, even with stringent $C0_2$ and other GHG emission reduction, decreased emissions will continue to add to the planet's cumulative CO_2 budget. This will lead to warming above 1.5°C in the next 20 years. However, without immediate deep reductions in GHG emissions, global warming will exceed 2°C by around 2050. Such warming increases the frequency, duration and severity of extreme weather and high-impact events whose effects are exacerbated in cities and urban areas.

While a range of climate change risks coalesce and aggregate in cities and urban areas, they have differing impacts across regions, sectors, and communities. Risks come from a dynamic interaction between climate-related hazards and the exposure and vulnerability of affected human or ecological systems.[7] Risks in urban areas are reduced by interventions aimed at decreasing vulnerability and exposure to hazards, as well as broader adaptation and mitigation responses to climate change.[8] Presented in a modified version in Figure 1, the AR6 risk framework examines the severe, interconnected, and sometimes irreversible impacts of emissions from urban areas on climate change and ecosystems, and in turn climate impacts on urban areas and linked economic and social systems, ecosystems, and biodiversity.

Figure 1: Climate Resilient Development through transitions in climate, ecosystems and human society

Human systems and ecosystems are interconnected. To move towards goals of human well-being and ecosystem health leading to overall CRD, system transitions are needed, of which the urban, rural, and infrastructure systems transition is vital. Key enablers for climate adaptation and CRD include inclusive governance and institutional capacity; finance; monitoring and evaluation; technology and innovation; lifestyle and behaviour change; and attention to culture and heritage.

Source: Derived from IPCC AR6 WGII, Summary for Policymakers, Figure SPM.1.



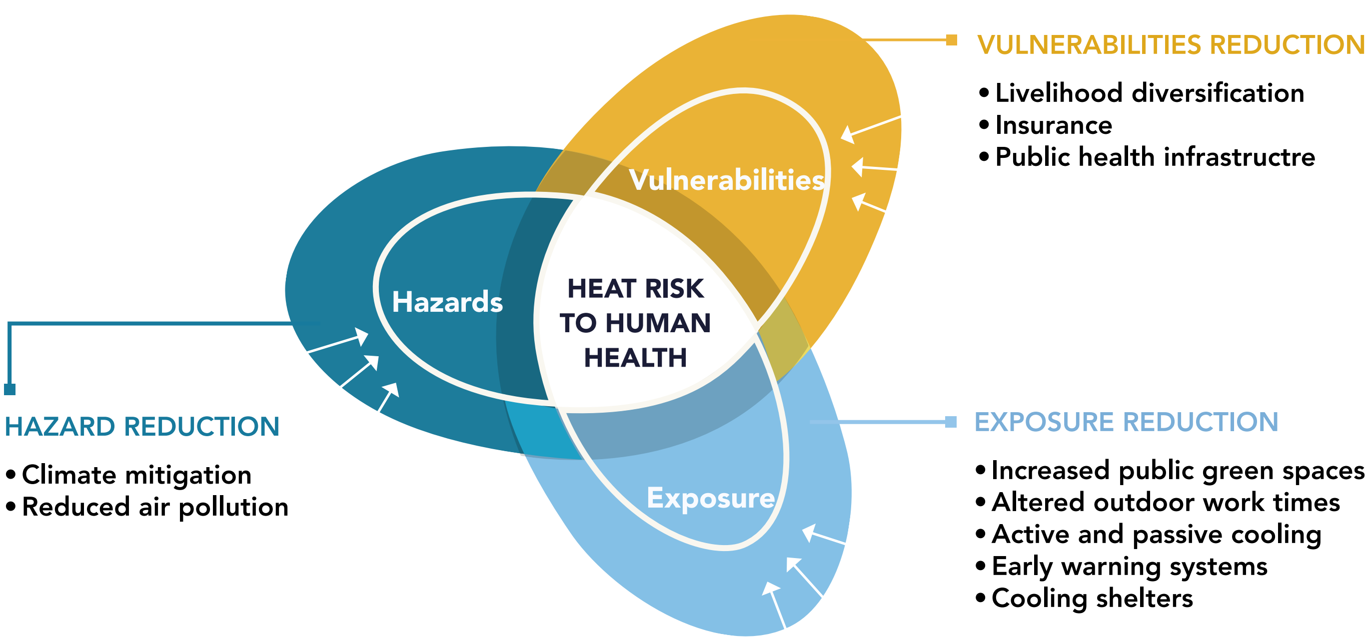
2. RISK CREATION AND CONCENTRATION IN CITIES AND URBAN AREAS

Understanding the need for, and feasibility of, urban-led transformations requires further exploration of the current and future hazards and exposure to them, as well as vulnerabilities in cities and urban areas.

The risk framework also provides insights on reducing adverse consequences for current and future generations by modifying hazards, and reducing vulnerabilities and/or exposure.[9] Exposure to hazards can be reduced by altering the physical form of urban areas, managing population and infrastructure growth, and modifying physical hazards along coasts and rivers.

Vulnerability can be reduced through efforts to promote inclusive development and to reduce inequality. The lack of or inappropriate responses can potentially increase vulnerability and overall risk. In addition, some adaptation responses can lead to maladaptive outcomes.[10] Responses that reduce risks can be enhanced by enabling conditions, including prudent and transparent multilevel governance, access to finance, improved institutional capacity, and behavioural change.[11]

Figure 2: Risk is a function of hazards, exposures, vulnerabilities, and adaptive capacities; all of which are mediated by mitigation and adaptation responses.



Risks from climate change result from dynamic interactions between hazards, exposures, and vulnerabilities; as well as from the adaptation and mitigation responses to modify hazards and reduce exposure and vulnerabilities. An illustrative example of one risk in cities and urban areas - heat risk to human health - is represented in the figure above.

Source: Derived from IPCC AR6 WGII, Chapter 1, Figure 1.5(d)

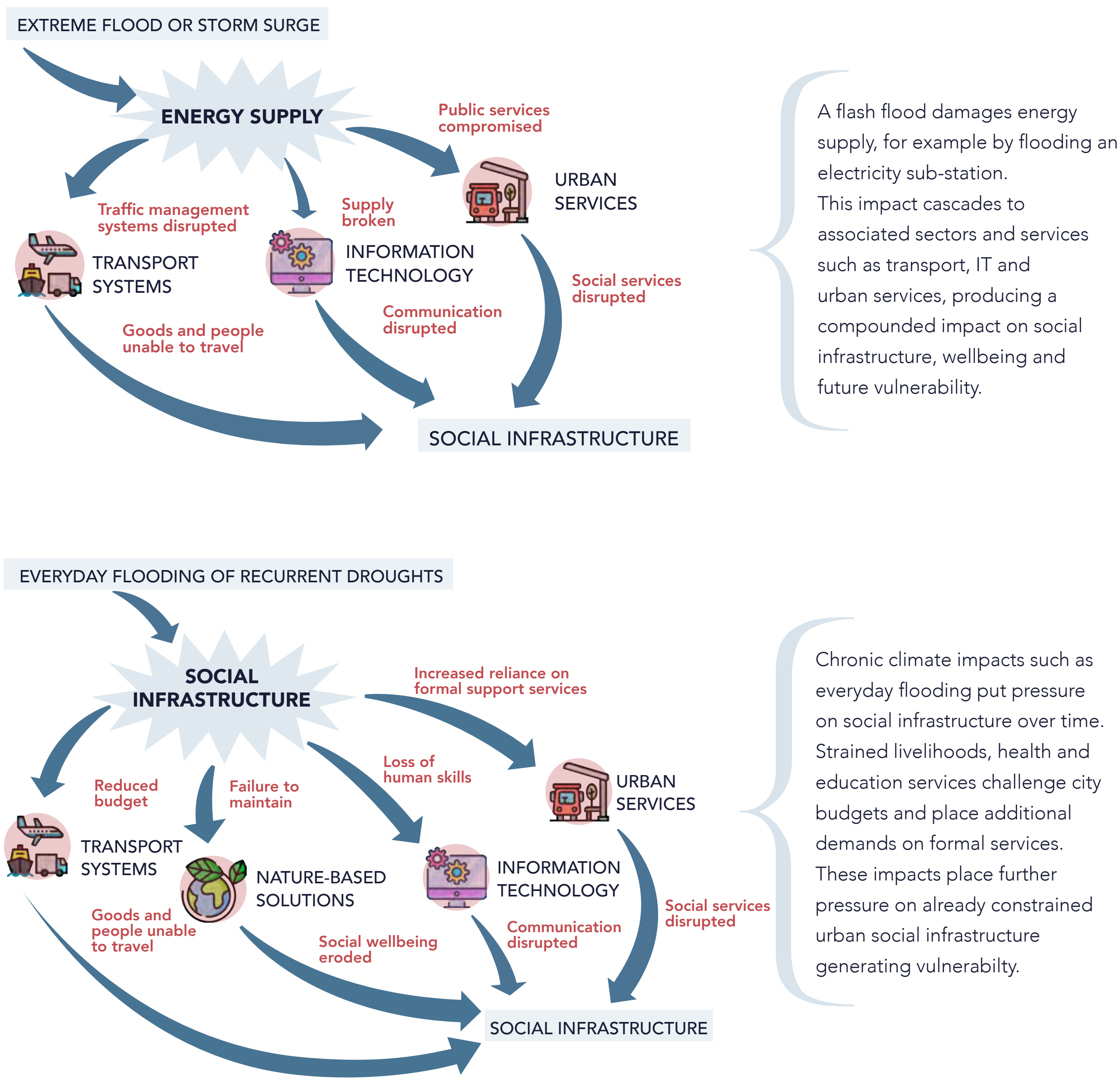
More than 4 billion people live in cities, and the global urban population has risen by more than 400 million between 2015–2020. If the global population moves from 8 to 11 billion by 2050, the urban population could double.[12] Much of this growth would be expected to occur in Asian and African cities and urban areas, particularly in informal settlements that house the most vulnerable and have greater exposure to climate hazards.[13]

- Asia, the world's second most urbanised region, with very high levels of poverty and informality, is home to seven of the eight megacities worldwide that are most vulnerable to disasters: Jakarta, Karachi, Kolkata, Manila, Osaka, Tianjin and Tokyo, which all have a population of over 10 million people.[14]
- In Africa, the world's most rapidly urbanising region, increasing climate risks in rapidly growing cities and urban areas are exacerbating pre-existing stresses related to poverty and socioeconomic exclusion. The number of days urban residents are exposed to extreme heat will increase dramatically with warming, with greatest exposure in West Africa. Relative to 2000, the amount of urban land exposed to high-frequency flooding and aridity across West, Central and East Africa is expected to rise by 2,600% and 700%, respectively, by 2030.
- Central and South America possess five megacities and over 100 secondary cities, many of which have very high levels of socioeconomic inequality, poor and unevenly distributed infrastructure, housing deficits, and the recurrent occupation of risk areas. Increasing temperatures and heatwaves are leading to higher water demand, damaging urban infrastructure, and accelerating tree ageing and death.[15]
- Nearly one-third of European cities show vulnerability to heatwaves, drought, and floods. In more than 10% of European cities at least one-quarter of the population lives within potential river floodplains.[16]
- North American cities are experiencing increasing severity and frequency of climate hazards and extreme events such as heatwaves, sea -level rise, storm surges and flooding, with particularly unequal outcomes for vulnerable groups based on income, ethnicity, and race.[17]

Dhaka, Bangladesh

Finally, as captured in Figure 3, urban risks stretch beyond urban areas, effectively linking rural and urban infrastructures, populations, and ecosystems, into interconnected and co-dependent systems, with implications for strategic investment in risk reduction and climate adaptation. Systemic risk, originating in urban risk, cascades into rural areas and regions as cities and urban areas host key sites for productive industries and employment with disruption impacting supply chains and flows of money, including through remittances from urban migrants.[18] Similarly, impacts and risks in more rural areas can impact cities and urban areas through, for example, food and water scarcity.

Figure 3: Climate impacts cascade through infrastructure across sectors



Source: Derived from IPCC AR6 WGII, Chapter 6, Figure 6.2

Future risks and vulnerability

At higher levels of warming, risks to cities and urban areas and their essential infrastructure will increase significantly. Global warming of 1.5°C in the near-term will increase unavoidable climate hazards and risks to ecosystems and humans.[19] At 1.5°C warming, without adaptation, an additional 350 million people living in cities and urban areas will experience the effects of severe drought, including water scarcity. At 2°C warming, that number grows to around 410 million.[20] Globally, 1 billion people live in areas at risk of coastal hazards by 2050. In that same year, 250,000 excess deaths per year are projected from climate change, with leading causes including heat, undernutrition, and diarrhoeal diseases.[21] Urban populations will experience increased exposure to heatwaves, and as well an increased burden of several climate-sensitive foodborne, waterborne, vector-borne, and non-communicable diseases.

By 2100, coastal flooding in cities from sea-level rise will affect between 158–510 million people, and expose USD 7.9–12.7 billion of infrastructural assets to flood damage. Risks to people, land, and infrastructure are highest in coastal areas of East and South-East Asia.[22] Urban infrastructure costs, including for maintenance and reconstruction of buildings and transportation hubs and networks, will increase with warming. Significant functional disruptions are projected for cities and urban areas located on coastlines and permafrost.[23] Progressive warming could lead to involuntary migration, especially from regions with high exposure and low adaptive capacity.[24] Intensification of precipitation, tropical cyclones, and drought, as well as increasing sea-level rise, is expected to increase displacement in the mid- to long-term. Meanwhile, even if warming stops, sea level rise is committed beyond 2050, escalating beyond 2100 and continuing for centuries to come, with direct impacts on urban areas along coastlines and cultural and natural heritage.[25]

Venice, Italy

Island of Seychelles

The increase in risks and impacts, while global, affect populations and regions differently. or example in the European Union, current annual damages to energy infrastructure of €0.5 billion yr^{-1} are projected to increase 1612% by the 2080s, in China, 34% of the population are vulnerable to electricity supply disruptions from a flood or drought, while in USA, higher temperatures are projected to increase power system costs by about USD 50 billion by 2050.[26] Exposure to climate hazards intersects with pre-existing, differential vulnerability based on gender, class, race, ethnicity, age, and resource access. It is also framed by cultural norms, diverse values, and practices.[27] Even if hazards associated with climate change were not projected to grow, increasing trends in urban inequality, precarious livelihoods, inadequate access to key infrastructure, and exclusionary decision-making processes indicate heightened vulnerability and therefore higher range and severity of risk to existing hazards. It is the combination of growing hazards associated with climate change, exposure to multiple climatic and non-climatic hazards, and worsening social and economic inequality and vulnerability, that drives an increase in climate change risks.

The evidence from urban and rural settlements is clear: climate impacts are felt disproportionately in communities that are most economically and socially marginalised. These effects are especially strong in smaller and medium-sized cities of Asia, sub-Saharan Africa and Central and South America.[28] In Central and South America and Africa, 22% and 59% of the urban population, respectively, live in informal settlements and are particularly vulnerable due to limited employment opportunities and infrastructure.[29]

With current policies, the world is on track for a temperature increase of 3°C or more by 2100. In the absence of stronger climate policy, warming above 4°C cannot be ruled out.[30]

At global warming levels of 1.1°C, cities and urban areas are experiencing significant and diverse impacts from climate change, especially related to health, livelihoods, and key infrastructure. And some major cities have already moved beyond 1.5°C of mean local warming. In short, urban policymakers should design adaptation policies and plans on the assumption that the average global temperature rise will exceed 1.5°C. The next section lays out the most recent science on adaptation gaps and limits.

With current policies, the world is on track for a temperature increase of 3°C or more by 2100. In the absence of stronger climate policy, warming above 4°C cannot be ruled out. Urban policymakers must design adaptation policies and plans on the assumption that the average global temperature rise will exceed 1.5°C, and potentially exceed 2.5°C for significant lengths of time over the century.

Espargos, Cape Verde

3. ADAPTATION GAPS AND LIMITS

Cities of varying sizes and locations have developed adaptation plans, and over 170 nations have included adaptation in their policies and planning processes.[31]

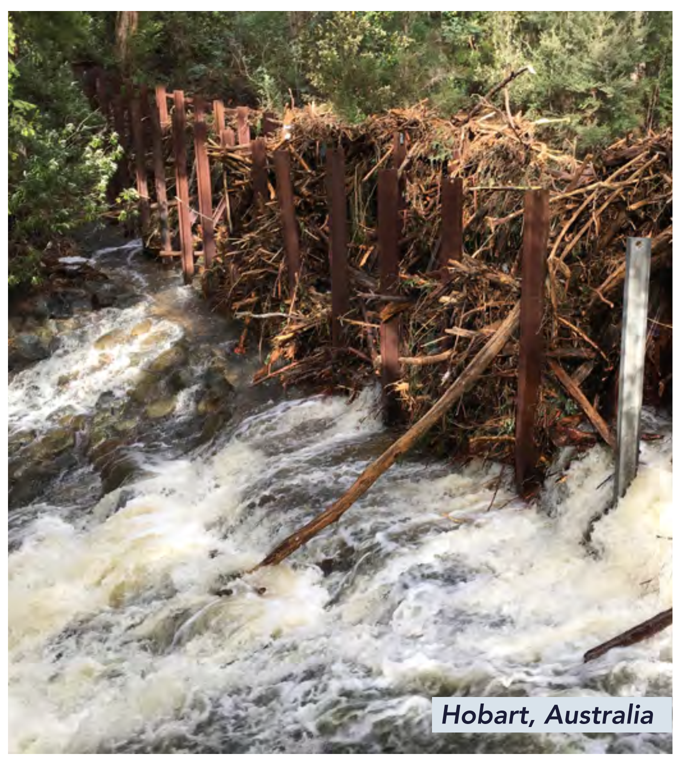
However, cities often face challenges when it comes to implementation, with only a limited number of city adaptation plans implemented to date. Further, many of these adaptation strategies focus narrowly on climate risk reduction, and while generally meant to be complementary to city-wide climate mitigation and/or sustainable development plans, a more integrated approach can create significant opportunities for co-benefits.[32] Near-term mitigation is essential to retain the space for such adaptation. Rapidly decreasing GHG emissions remains the most effective way to reduce future risks.[33]

Adaptation gaps

The development and implementation of adaptation plans and policies differ by region. As noted in the next section on knowledge gaps, there remains a significant gap in the peer-reviewed literature assessed for this report on city-level adaptation planning and implementation; however, the following observations can be made by region:

- Asian cities are undertaking adaptation actions but a majority of them focus on preparatory actions and capacity building for single hazards.[34] Even key port cities at high risk from climate impacts report that adaptation interventions constitute only a small proportion of cities' climate efforts.
- In North America, adaptation planning and implementation to address sea-level rise and coastal flooding have been initiated by many cities, though preparedness varies.[35]
- Adaptation progress across African cities has been slow, especially in West and Central Africa.[36] More than 80% of Africa's large coastal cities have no formally adopted adaptation policies, and planned adaptation initiatives in African cities have been predominantly determined at the national level with negligible participation of lower levels of government. While urban adaptation continues to be dominated

Cascais, Portugal

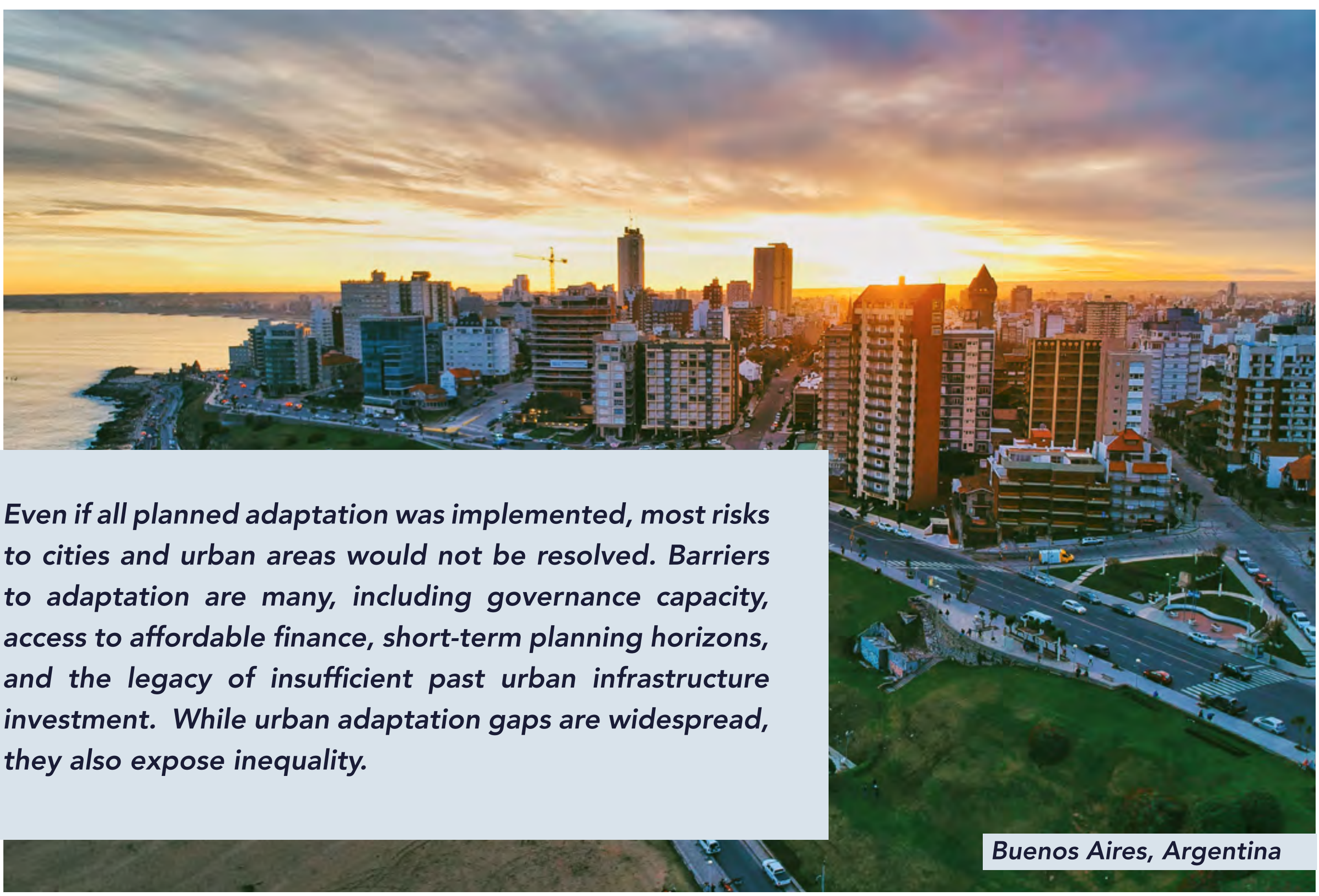


Hobart, Australia

by autonomous, informal responses by households, there are emerging examples of planned adaptation in cities such as in Durban, Cape Town and Lagos, and of community-led projects in cities such as Maputo. An increasing number of ecosystem-based adaptation projects such as restoration of mangrove, wetland, and riparian ecosystems have been initiated, with demonstrated long-term health, ecological, and social co-benefits, particularly addressing water-related climate risks and lengthening the life of existing built infrastructure.[37]

- Adaptation initiatives in Central and South America, meanwhile, have focused on regulation and planning, albeit still short-term, and urban water and housing management. Housing initiatives to improve informal and precarious settlements have been widely carried out in the region, but prioritising disaster reduction without incorporating resilient construction parameters or aligning policies of access to land and decent housing with community-based adaptation strategies. Comprehensive adaptation policies that include development and the reduction of poverty and inequality in the region will be necessary in order to engage diverse stakeholders for transformational adaptation.[38]
- Across Europe, adaptation planning in cities and urban areas, settlements and key infrastructures has increased. Many smaller cities and those with relatively lower GDP per capita still lack adaptation planning.[39] Gaps remain, on implemented adaptation, adaptation by private actors, and against sea level rise. While almost all large municipalities in Northern and Western Central Europe have implemented actions in at least one sector, nearly 40% of municipalities in Southern Europe have not yet done so. There are emerging examples of transformative urban adaptation, in Hamburg and Rotterdam , for example, but they remain pilots.

Critically, adaptation strategies already implemented or even just planned are insufficient to meet the current levels of risk associated with climate change. Put another way, even if all planned adaptation was implemented, most risks to cities and urban areas would not be resolved.[40] Urban adaptation gaps exist in all regions, as they do for all hazard types.



Even if all planned adaptation was implemented, most risks to cities and urban areas would not be resolved. Barriers to adaptation are many, including governance capacity, access to affordable finance, short-term planning horizons, and the legacy of insufficient past urban infrastructure investment. While urban adaptation gaps are widespread, they also expose inequality.

Buenos Aires, Argentina

Figure 4: The Urban Adaptation Gap

Source: Derived from IPCC AR6 WGII, Chapter 6, Figure 6.4

This is not simply a question of implementation. Barriers to adaptation are many, including governance capacity, access to affordable finance, short-term planning horizons, and the legacy of insufficient past urban infrastructure investment.[41] As Figure 4 illustrates, while urban adaptation gaps are widespread, they also expose inequality. In some regions, the gaps are higher for food insecurity and flooding than for heatwaves; but in all cases, poorer neighbourhoods, cities and urban areas, and regions face larger gaps than their wealthy counterparts.[42]

Adaptation limits

Even when fully implemented, there are limits to adaptation, particularly as warming increases. The greater the warming, the larger the impacts, and the more difficult it becomes to adapt, ultimately hitting hard limits, where no adaptive actions are possible to avoid intolerable risks.[43] Some coastal communities reliant on nature-based coastal protection will hit hard limits beginning at 1.5°C. The autonomous and evolutionary adaptation responses of terrestrial and aquatic species and ecosystems will also begin facing hard limits beginning at 1.5°C global warming.[44] Both hard limits, or conditions beyond which it is impossible to adapt, and soft limits, conditions that can limit adaptation because solutions are not available to certain people based on assets or capacities, are shaped by differences in levels of development, often leading to disproportionate impact on vulnerable groups. Geography is also an important factor, with coastal cities and urban areas, for example, likely to approach such limits before 2100 owing to risks related to sea-level rise and tropical cities and urban areas, in South and West Asia for example, approaching thermal limits due to high humid heat by 2060.[45]

Izmir, Türkiye

Knowledge gaps

While efforts to track urban adaptation have been improving dramatically, inconsistencies remain in methods, metrics, and data gathering.[46] Specifically, in major cities around the globe, peer-reviewed monitoring and evaluation of government-led urban adaptation is largely missing, even if it is captured and updated by global city networks or related NGOs.[47] Important gaps in instrumental knowledge include: event loss and damage data; city-relevant climate data; and data on adaptation experiments within and between governments, as well as including civil society and the private sector.[48] There are also key gaps in inclusive knowledge, or who's asking and who's answering. These include: Indigenous knowledge and local knowledge that brings together top-down and bottom-up capacities, as well as gender and child-sensitive planning.[49] Finally, key knowledge gaps remain concerning the systems transitions themselves, such as: understanding urban decision making support systems including the functioning of multi-level governance; monitoring and evaluation of adaptation projects, programmes, and spontaneous actions; and opportunities for peer-to-peer learning from local to international exchanges.[50]

Kathmandu, Nepal

4. ADAPTATION ACTION

Day-to-day decisions on the economy, nature, and infrastructure shape the adaptation options available to people living in cities and urban areas around the world. Avoiding lock-in of particular urban development trajectories that amplify climate risk or constrain the set of adaptation options is a central challenge for decision makers. While adaptation continues to focus overwhelmingly on interventions oriented around physical infrastructure, there are other measures and approaches through which greater urban resilience can be achieved. This growing range of urban adaptation options, detailed below, has been tested by experience.

Urban planning

The built environment and urban form mediates climate vulnerability, including, as Box 1 explores, in coastal cities and urban areas. A lack of open green spaces, for example, can exacerbate heat and flood risks. Planning that uses system-wide climate risk assessments and regulation, including climate-adapted land use and building performance, can help steer residents away from areas that are highly exposed to risks, and coordinate and foster effective private and public investments in adaptation and CRD.[51] Urban planning can also support coordinated and integrated adaptation and decarbonisation by mainstreaming climate concerns. For example, city plans can promote compact urban development with the co-location of jobs and housing to reduce the extent of land-use change and transport energy consumption. Such compact development patterns protect ecosystems that mitigate extreme heat, provide natural flood defences, offer habitats that improve biodiversity, and store carbon. Given lock-in, built environment adaptations should take care to avoid potential negative impacts on social equity and carbon-intensive construction.[52]

New York, USA

Adaptation Pathways for Sea-level Rise in Coastal Cities and Urban Areas

Combining and sequencing adaptation interventions can reduce risk, spread costs, and minimise lock-in. Breaking adaptation into manageable steps over time may help local policymakers explore alternative adaptation pathways. This flexible approach can accelerate adaptation action by allowing policymakers to prioritise between near-term and future options, and to manage uncertainty through monitoring, learning, and subsequently updating their strategy.

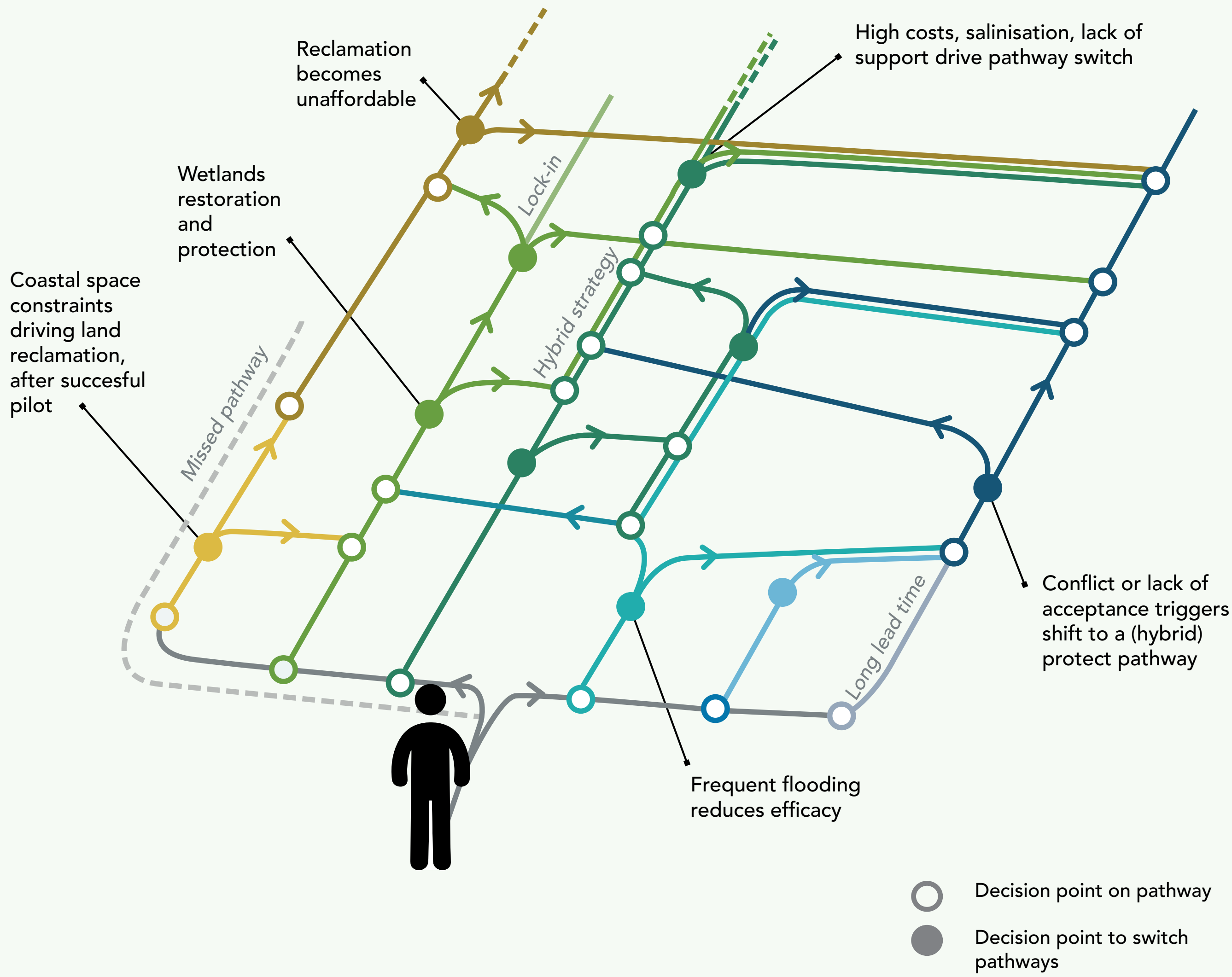
For cities in particular—as illustrated in Figure 5 on adaptation pathways for coastal cities and settlements to sea level rise—considering the full sequence of adaptation options allows policy makers to anticipate critical decision points, identify triggers and avoid decisions that block certain options in future.[53] Identifying and exploring such pathways is especially important for coastal cities given the immediacy and intensity of impact under high-warming scenarios, the long-term certainty of continued sea-level rise, and the long time horizon to plan and deliver effective adaptation responses.

The impacts of sea-level rise can be somewhat mitigated by preventing new developments in vulnerable and exposed areas. Meanwhile, a range of adaptation options are available for existing developments. Many megacities have elected to invest in “hard” protection pathways for water adaptation infrastructure, such as sea walls. However, such hard protection pathways can become increasingly costly, institutionally challenging, and do not reduce the risk of salinisation of coastal land. A hybrid strategy that integrates nature-based solutions, such as retaining retaining and restoring mangroves and marshes, can reduce further risk, reduce cost, and provide additional livelihood and biodiversity benefits. While maintaining a hard protection pathway may be preferred because of costs associated with switching to an alternative pathway, transitioning away to softer adaptation options can prove less costly in the long-term. Finally, retreating from the coast through planned relocation or migration can effectively reduce risk and provide opportunity for re-establishing coastal ecosystems, but requires careful and inclusive planning in source and destination settlements.[54]

Box 1.

Cape Town, South Africa

Figure 5: Coastal Cities & Settlements: Indicative Adaptation Pathways for Sea Level Rise



Strategies	Examples of Adaptation Options	Strategies	Examples of Adaptation Options
Advance	New seawards land reclamation above sea level	Accommodate	Wet and dry proofing built environment Floating cities (experimental, not shown)
Protect	Sea walls, levees, storm barriers Wetlands, mangroves, coral reefs	Retreat	No build zones Planned relocation

Source: Derived from IPCC AR6 WGII, Cross-Chapter Paper 2, Figure CCP2.4

Infrastructure

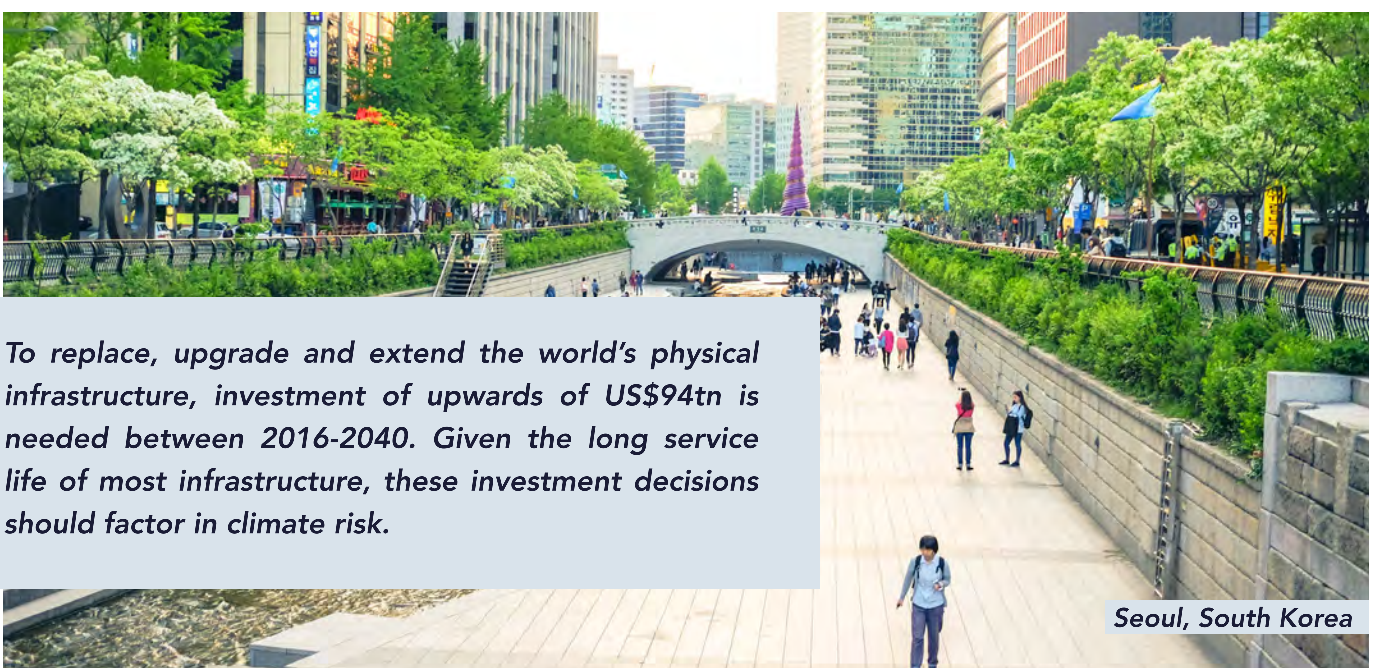
Investment in low-carbon and resilient infrastructure can meet pressing human and economic needs today while providing an opportunity for medium- to long-term climate resilient development. To replace, upgrade, and extend the world's physical infrastructure, investment of upwards of USD 94 trillion is needed between 2016 and 2040. Given the long service life of most infrastructure, these investment decisions should factor in climate risk.[55]

An increasing number of adaptation options exist for key infrastructure sectors and for all stages of the infrastructure life cycle from planning, design, and delivery to operation and maintenance. The suitability of these options depends on existing infrastructure systems, location, governance capacities, and access to finance.[56] Engineered climate resilience-building measures are being implemented in urban centres, but high construction and maintenance costs make many of these interventions less accessible in low- and middle-income countries. Further, high material and operations energy intensity of these measures can conflict with decarbonisation efforts.[57]

Many cities and urban areas lack sufficient infrastructure relating to water supply, sanitation, electricity, transport, and housing, with the shortfalls concentrated in informal settlements.[58] These development deficits interact with climate hazards to increase vulnerability.[59] As such, addressing these basic deficits while improving climate-adapted performance and integrated long-term planning creates significant opportunities for adaptation in less wealthy cities. Upgrading informal settlements—including through investment in climate resilient infrastructure—can improve living standards, while enhancing resilience to climate impacts as well as other hazards.[60] Despite the importance of achieving the SDGs and advancing adaptation, there is limited evidence of resilient infrastructure investment in informal settlements.[61]

Nature-based solutions including Ecosystem-based adaptation

Solutions that engage nature, explored further in Box 2, are increasingly employed in cities to protect, sustainably manage, and restore natural or modified ecosystems for disaster risk reduction and effective adaptation. When focussed on adaptation, these are called ecosystem-based adaptation (EbA) measures. EbA measures use ecosystem management to increase resilience and reduce vulnerability of people and ecosystems to climate change.[62] Nature-based solutions (NbS) pertain to a wider range of actions expected to have adaptation and mitigation co-benefits, including the protection and restoration of forests and other high-carbon ecosystems.[63] There is growing evidence that these solutions can contribute to climate adaptation and mitigation and hold co-benefits for human health



To replace, upgrade and extend the world's physical infrastructure, investment of upwards of US$94tn is needed between 2016-2040. Given the long service life of most infrastructure, these investment decisions should factor in climate risk.

Seoul, South Korea

Leveraging Nature for Urban Adaptation

Street trees, green roofs, green walls, and other urban vegetation can provide low-cost means to reduce air temperature and the impacts of heat waves by cooling private and public spaces through shading and evapotranspiration.[64] Vegetated barriers along streets or in urban forests can also reduce particulate matter, the ambient air pollutant with the largest global health burden.[65] Blue infrastructure, including rivers, streams, ponds, lakes, and wetlands, provide cooling in addition to other ecological and hydrological functions critical to sustainable urban water management. Grassland, riparian buffers, and forested watersheds can enhance water filtration into the soil, protecting against urban flood and drought while mangroves and coastal wetlands reduce storm surges and coastal flooding.[66]

Well-designed green and blue infrastructure can have significant advantages over grey physical infrastructure: they are often cheaper to construct and maintain, while safeguarding biodiversity and human health. By comparison, grey infrastructure can seal off soil or bury streams, thereby increasing flood risk and altering the hydrology necessary to sustain ecosystems and livelihoods. NbS may yield co-benefits such as contributing to food supply, providing recreational spaces, or improving mental health.[67] Carbon-rich ecosystems in urban areas, such as wetlands and forests, also store and sequester carbon, thus linking adaptation and mitigation.

Political commitment and swift, persistent, and consistent action to scale up investments in NbS are needed to close the climate adaptation gap.[68] NbS have huge potential to advance CRD in cities but do not typically receive sufficient recognition or investment. NbS can be implemented in combination with hard protection measures to create a hybrid strategy that can enable large-scale impacts by, for example, combining stormwater drains, sewers, and urban wetlands to manage and filter run-off. Successful NbS require site-specific knowledge and science-based design, pilot monitoring, adaptive upscaling, and understanding of long-term performance, maintenance, and costs.[69] Inequitable access to NbS can be addressed by prioritising investments in risk and vulnerability hotspots, such as in communities exposed to high heat or lacking urban tree canopy or accessibility to parks.[70]

Such solutions can also be maladaptive. For example, urban greening projects can privilege wealthy urban residents, drive up property prices, and change neighbourhoods. Local, inclusive community planning is important to ensure benefits are equitably distributed and protects the most vulnerable.[71] Still, there is clear evidence that carefully planned and locally relevant NbS implemented as part of a city's suite of climate responses can reduce risk, mitigate GHGs, and deliver multiple health and development benefits.

Box 2.

and well-being, and local biodiversity across household, neighborhood, municipal, and regional scales. Yet, these solutions that engage nature, EbA and NbS, are vulnerable to climate change impacts. Hence, they may have limited feasibility at higher degrees of warming if deep cuts in GHG emissions are not implemented.[72]

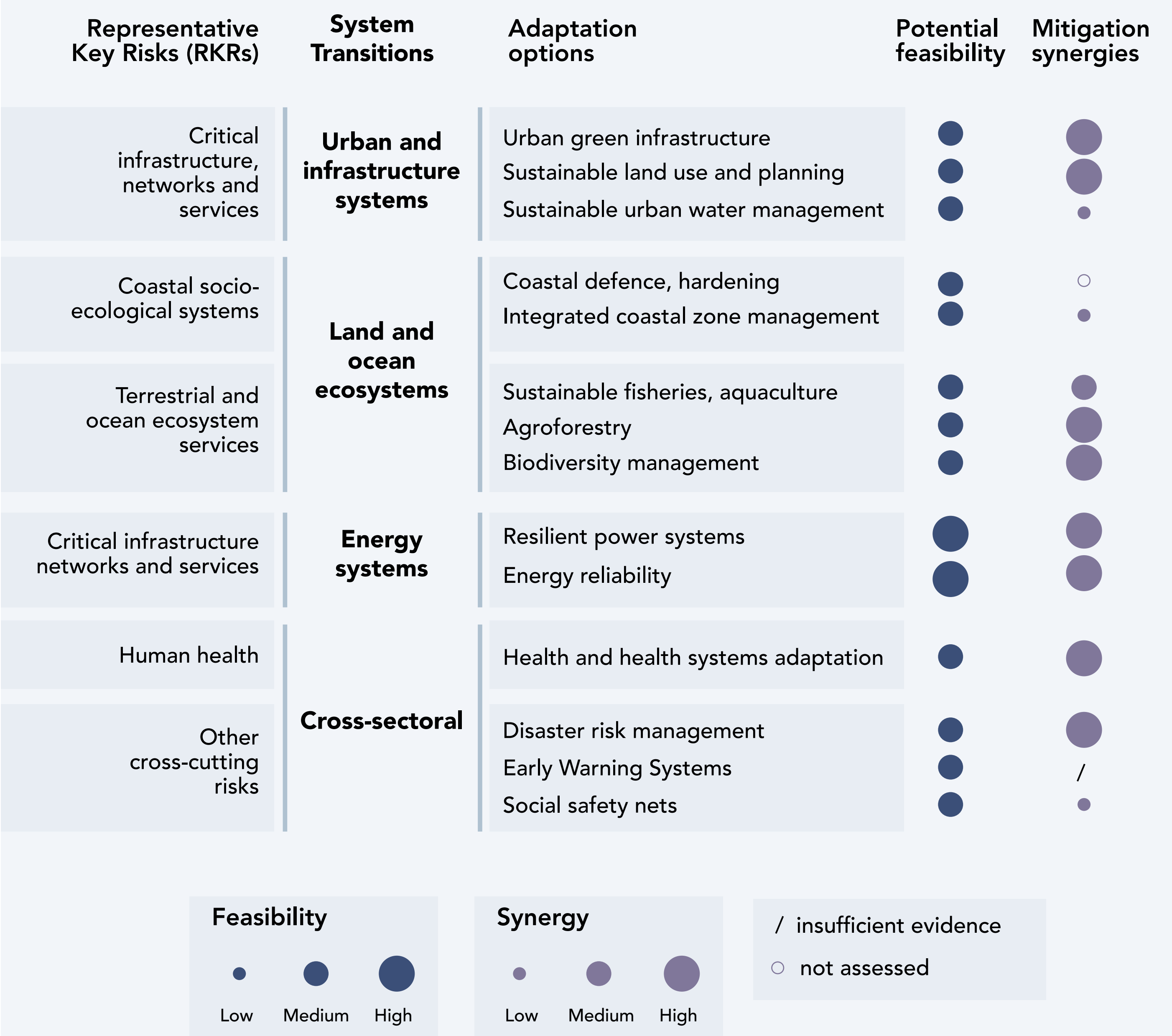
Social infrastructure and systems

Development of social infrastructure and systems is integral to adaptation planning and implementation. These include healthcare, education, social safety nets, inequality reduction programmes, and disaster risk management tools including insurance,. Strong and equitable healthcare systems can protect the health of populations in the face of known and unexpected stressors.[73] Disaster risk management is highly feasible when supported by strong institutions, inclusive governance, local engagement, and trust across actors. Integration of worldviews, belief systems and Indigenous knowledge and local knowledge into disaster risk management can facilitate successful, disability-inclusive, and gender-focused adaptation.[74]

As Figure 6 illustrates, climate services, such as early warning systems and seasonal forecasts, build adaptation capacity and enable short- and longer-term risk management decisions.[75]

Efforts to adapt may have to speed up and can be accelerated by closer collaboration between the diverse actors deploying adaptation. Establishing linkages between multiple levels of government and with the private sector and civil society can help deliver coordinated action across the range of adaptation options and processes of strategic visioning, planning, experimentation, capacity building, construction of coalitions, and communications. Local authority capacities and willingness are important enablers.[76] Growing awareness of how drivers of urban change and vulnerability interact has motivated an interest in transformational approaches to adaptation that can link incremental adaptation actions to accelerated or alternative development efforts, taking care to ensure greater inclusion in urban decision-making and equity in the distribution of outcomes.[77]

Figure 6: Multidimensional feasibility of select climate responses and adaptation options organized by System Transitions and Representative Key Risks (RKRs)



Source: Derived from IPCC AR6 WGII Summary for Policymakers, Figure SPM.4A

5. CLIMATE RESILIENT DEVELOPMENT AND TRANSFORMATION IN CITIES AND URBAN AREAS

Climate resilient development (CRD) presents a framework and process that allows cities and urban areas to undertake activities that simultaneously promote climate adaptation, mitigation and sustainable development, while highlighting the role of equity, inclusion, and justice in pursuing necessary actions.[78]

As interest in CRD as an approach to urban planning, design, and development has accelerated in recent years, the assessed knowledge on what conditions can promote or hinder CRD has also begun to build. This section offers an overview of the state-of-the-art knowledge around CRD and explores how cities can promote emerging and established best practices.

CRD: what we know

In terms of both actions and timeframes, CRD extends beyond previously explored adaptation approaches. Climate adaptation often is associated with specific projects or discrete actions, and is typically short-term in its time horizon. Adaptation expands into CRD when it explicitly connects to sustainable development and mitigation, taking a longer time horizon, involving a broader array of stakeholders, making active choices to accelerate deep transformational change, and recognising multiple pathways with different synergies and trade-offs attached to specific actions and decisions. Adaptation and mitigation action, as well as sustainable development, are interdependent processes. Pursuing climate and development goals in an integrated manner increases their effectiveness in enhancing human, ecosystem and planetary health.

Opportunities for CRD are diminishing and not equitably distributed around the world. CRD prospects are increasingly limited if GHG emissions do not peak and net-zero targets, both global and regional, are not met. Globally, climate actions that advance the synergies of mitigation, adaptation, and sustainable development have occurred slowly and unevenly. Climate impacts and risks increase ongoing and acute

Vancouver, Canada

development challenges. This is especially the case in developing regions and sub-regions, as well as on coasts and small islands, and in deserts, mountains, and polar regions. The increase in vulnerability and economic and social inequalities associated with such impacts and risks undermines efforts to achieve sustainable development in urban areas.

Cities and urban areas offer critical spaces to realise adaptation and mitigation simultaneously with significant potential co-benefits, while also pre-empting potential trade-offs. Renewable-energy based electrification, for example, can improve indoor and outdoor air quality, thus resulting in better respiratory health for urban dwellers. Green and blue urban infrastructure has the potential to sequester or store carbon, as well as to reduce urban heat island effects and flooding associated with stormwater run-off.[79]

Given projected rapid changes in the built environment, opportunities for enhanced use of sustainable materials, and promotion and mainstreaming of land-efficient low-carbon urban development, the next decade and beyond will be critical. Much of the new urban development in the short and medium term future will be self-built and informal, requiring new modes of governance and planning.[80]

Effective adaptation requires focus on inequity in climate vulnerability and responses. CRD efforts will be most effective when linked with conditions that promote social and environmental justice; and, conversely, conditions of inequity and exclusion are understood to limit CRD efforts. Sustainable development, when linked with a rights-based approach, can advance prosperity, human well-being, equity, and climate justice. A balance of power and participation across stakeholders are needed for effective climate action, including: prioritising investments to reduce climate risk for low-income and marginalised residents; participatory planning of urbanisation, infrastructure, and risk management; and monitoring climate action for climate justice.

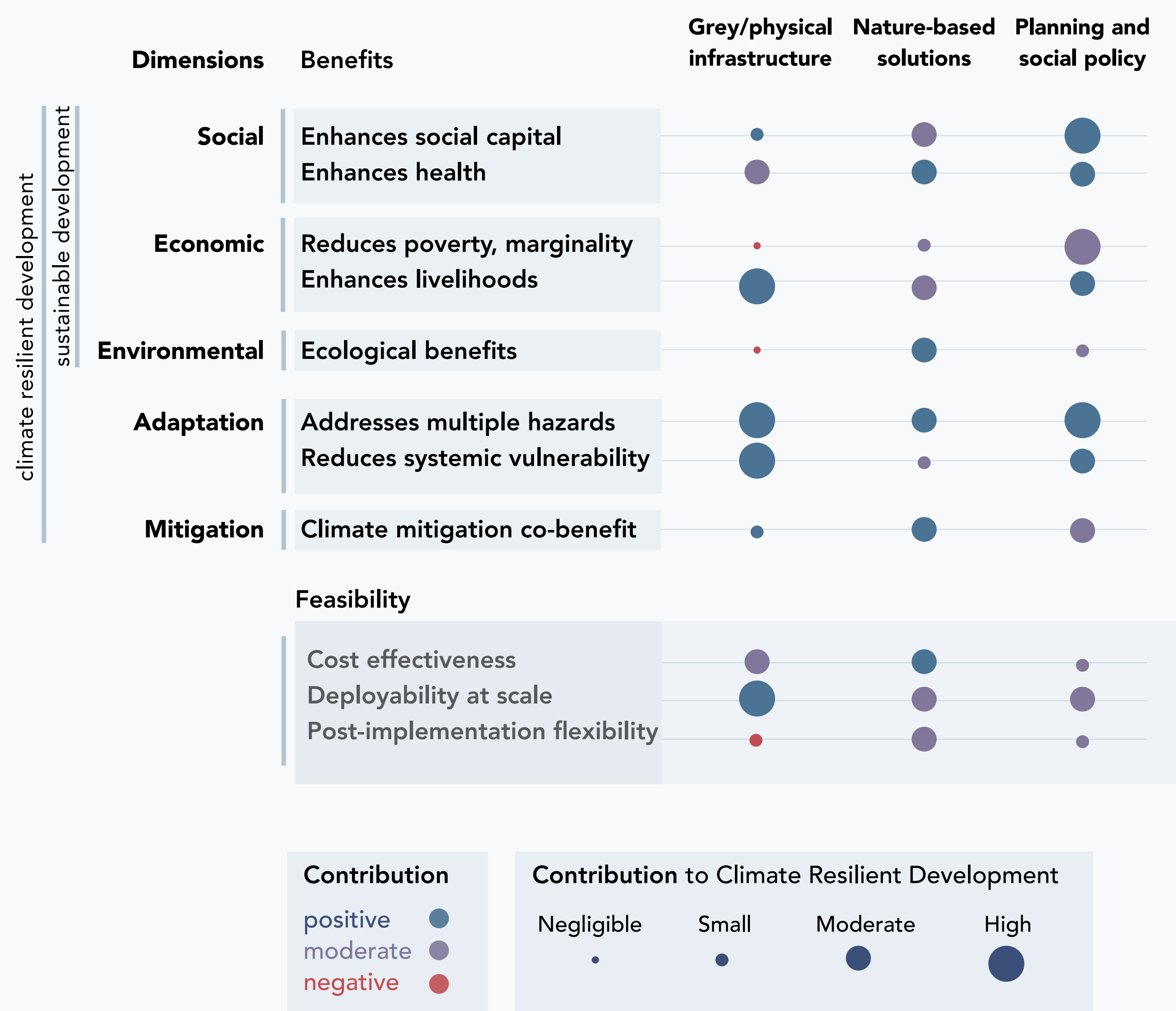
Figure 7 shows potential benefits of adaptation options fundamental to CRD. Physical infrastructure can provide resilience to a range of climate hazards, while providing notable co-benefits to livelihoods. However, notable challenges can limit the benefits of physical infrastructure: a lack of flexibility post-deployment; the transfer of risk to other people and places; and negative ecological impacts.

The integration of research, policy, and action to support CRD efforts remains the exception in most regions. Community-based adaptation planning and actions, with the potential to enhance well-being and advance the Sustainable Development Goals, provide one area of notable ongoing efforts. Complex trade-offs and gaps persist, including in the alignment of mitigation and adaptation efforts across geographic scale and policy areas.[81]

Cities and urban areas offer critical spaces to realize adaptation and mitigation simultaneously with significant potential co-benefits, while also pre-empting potential trade-offs.

Sarajevo, Bosnia-Herzegovina

Figure 7: Contributions of urban adaptation options to Climate Resilient Development and their feasibility



Grey/physical Infrastructure — Dikes, seawalls; water storage, greywater use; slope revetments; air conditioning; passive cooling; upgrading trasnport, energy, water & sanitation infrastructure; information & communication technologies; urban design & building regulations

Nature-based solutions — Urban agriculture; street trees; green roofs; parks and open spaces; community gardens; rain gardens; bioswales; retention ponds; riverbanks; floodplains and watershed restorations

Planning and social policy — Land use planning; social safety nets; emergency and disaster risk management; health services; climate education; heritage conservation

Source: Derived from IPCC AR6 WGII Chapter 6, Figure TS.9(d)

6. ENABLING CONDITIONS FOR URBAN CLIMATE ACTION

Enabling conditions play a critical role in determining the scalability and efficacy of climate responses. Such conditions promote or advance the adaptation process and are positively associated with the likelihood that strategies will be properly planned and put into practice. Crossover and connection exists between enabling conditions for climate adaptation and those for CRD, and for that matter, mitigation, as explored in SUP Volume 3.

Urban climate resilient development is enabled when governments, civil society, and the private sector, supported by science and the media, make inclusive development choices that prioritise risk reduction, equity, inclusion, and justice, and when decision-making processes, finance, and actions are integrated across governance levels, systems, and timeframes. This section identifies a set of enablers that are applicable to both climate adaptation and CRD, including: inclusive governance and institutional capacity, and political commitment; finance; monitoring and evaluation; technology and innovation; lifestyle and behaviour change including building climate literacy; and attention to culture and heritage.


Singapore

Inclusive governance and institutional capacity

Inclusive governance of urban systems can improve opportunities for incremental adaptation and transformative change. Inclusive processes strengthen the ability of city governments and other stakeholders to jointly consider factors such as the rate and magnitude of change and uncertainties, associated impacts, and timescales of different pathways. Climate responses in all cities and urban areas can be enhanced by multi-level, multi-scalar, and multi-actor governance, with particular attention to the participation of the most vulnerable and marginalised groups. This is particularly true in many low-income countries where urban populations are expanding rapidly and city-scale governance is not yet well established.[82] A number of principles and lessons have been identified to address governance challenges and strengthen enablers. These include using an adaptation pathways approach to make short-term decisions consistent with long-term goals, and using inclusive planning processes that give voice to vulnerable people.[83] Urban governance for CRD is most effective when supported by formal and informal institutional capacities that are well-aligned across scales, sectors, policy domains and timeframes.

Finance

Provided by national and subnational governments, finance is essential for many adaptation and mitigation interventions, as many such measures do not generate the direct returns on investment necessary to attract private finance. Considerable variation is present among national and city governments in terms of their public budgets and commensurate capacity to fund climate action. Looking beyond public expenditure to public revenues, a critical challenge for many city governments will be to climate-proof their budgets. Cities and urban areas that can demonstrate coherence in climate risk management across private and public actors may attract preferential access to finance.

Private finance for adaptation may be sourced from households' and firms' own resources, or from financial institutions such as commercial banks, investment companies, and pension funds.[84] Private finance from financial institutions can be directed towards CRD through, for example, spatial plans that encourage the construction of housing and infrastructure in areas that are less exposed to climate hazards as well as building regulations and codes that take account of future climate risks.[85] Private finance from the latter can be mobilised through dedicated financing instruments such as bank loans, bond issuance, public-private partnerships, and land value capture. In many cases, deploying these instruments will require the

Climate responses in all cities can be enhanced by multi-level, multi-scalar and multi-actor governance, with particular attention to the participation of the most vulnerable, and marginalised groups.

London, UK

use of public resources to ensure satisfactory risk-return ratios for private financiers, who rarely provide finance for adaptation on easier or cheaper terms than for other purposes. Many city governments do not have the authority to deploy all of these instruments, so mobilising private finance depends on effective multi-level governance.[86] Mobilising finance for the points of greatest social and ecological need, rather than to the points of greatest financial return, remains a challenge for the private sector.

Forging greater consensus on the financial implications associated with climate change risk remains an under-explored component of urban adaptation. Alignment of the capital allocations of cities, national governments, utilities, and the private sector can support risk avoidance in cities and urban areas where the finance and insurance sector have a presence. Where the insurance sector refuses to underwrite new developments within city-demarcated setback lines, or which vehicle insurance aligns with the phasing out of specific vehicle types, for example, rapid change becomes possible.

With higher warming comes greater risks and adaptation costs: the costs of adapting to 1.5°C is a fraction of the cost of adapting to 3°C. International, concessional climate finance is not keeping pace with rising adaptation costs, nor was it ever intended to cover the total financing needs for CRD. Urban policymakers therefore need to think holistically about possible financial resources from all public and private actors and from global to local scales.[87]

Monitoring and evaluation

Monitoring and evaluation (M&E) of past adaptation and ongoing adaptation and CRD implementation can advance knowledge and enhance decision-making strategies by providing cities with knowledge regarding the progress and effectiveness of climate adaptation and mitigation action. Roughly one-third of countries have undertaken steps to develop national adaptation M&E systems, but fewer than half of these are reporting on implementation. Efforts to establish a single set of metrics and common and consistent reporting of local risk and adaptation implementation are increasingly sophisticated at the local level, particularly through global city networks tracking city-level commitments. Meaningful and continuous monitoring and evaluation can help provide insights into the role of local context in risk reduction and system-level transitions. Monitoring is critical to derive early warning signals on climatic hazards to assess when and where accelerated or adjusted action is needed. Data and information produced by monitoring and evaluation is especially important for policy makers and practitioners when arguing for or promoting new and aggressive action.[88]

Technology and innovation

Technology and innovation, coupled with access to emerging actionable data, information, and enhanced decision-making capacity, are also critical to enhancing adaptation and CRD. New technologies and design innovations in urban transportation systems, for example, can enhance adaptation by strengthening

Hangzhou, China

capacity of existing road, rail, ports, and airports to withstand more extreme weather, while simultaneously delivering mitigation goals via reduced GHG emissions from the adoption of electric vehicles, car-sharing, and increased public transport use.[89] Other examples of existing technologies for adaptation in cities and urban areas include smart meters to monitor water use, technology-based service delivery, and embedded smart waste management.[90] In terms of climate mitigation, new decarbonisation technologies applied in energy, infrastructure, and industrial systems can facilitate and enable system transitions within cities and urban areas.[91]

Lifestyle and behaviour change

Lifestyle and behaviour change is key to preparing for, and responding to, climate change.[92] Tools to incentivise adaptation behavior include: better information on climate impacts and risks to shape individual risk beliefs; zoning restrictions; building codes to guide climate resilient infrastructure development, and improving climate literacy.[93] Regulatory instruments, including tax and fiscal incentives for business and individuals, can support city-wide behavior change towards low-carbon and risk reducing choices.[94] Access to information is critical for adapting to climate risk and reducing vulnerability to hazards, yet access to this information is often not equally available. For example, low literacy can hamper ability to respond to early warning information.[95]

Overall, behavioural interventions are more readily taken up if they are aligned with cultural practices, norms, and beliefs; on temporal scales within peoples' planning horizons; and built upon relationships of trust and legitimacy.[96] The feasibility of adaptation strategies and interventions, especially those entailing changing behaviour and practices, is increased by recognising and incorporating peoples' values and beliefs and indigenous knowledge and local knowledge systems, as well as the voices of women and vulnerable groups.[97]

Culture and heritage

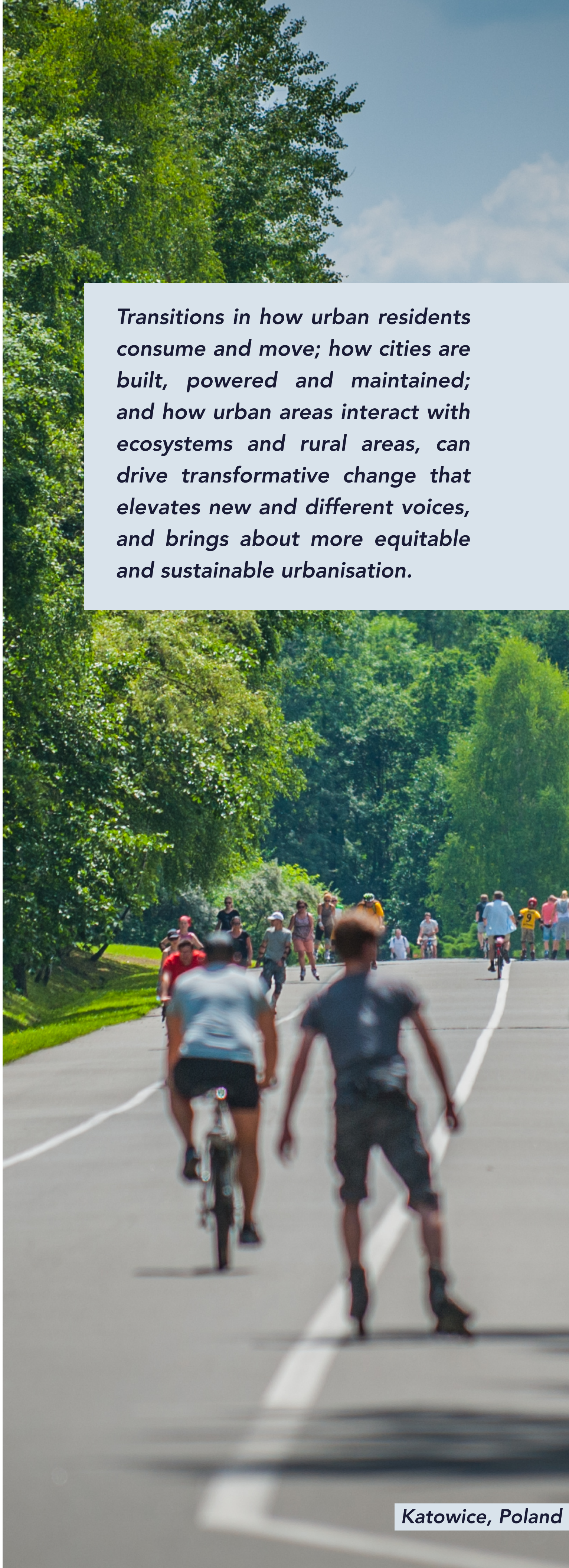
Culture and heritage can offer sources of aspiration and ambition to respond to climate change amidst feelings of discomfort, loss of sense of place, displacement, and anxiety. The manner in which urban leaders engage and articulate climate risks and opportunities influence societies' capacity for change. Specific cultural and natural heritage sites can serve as physical, social, and psychological refuges for communities during and after climate impacts. Culture and heritage can be drivers for urban areas to undergo ecological transition, supported by ecosystem-based adaptation. This action can be strengthened by cultural practices that promote a circular economy, focus on multi-generational time horizons, imbue an ethic of stewardship and conservation, and encourage broader transformative changes associated with CRD.[98]


Amsterdam, Netherlands

CONCLUSION: FROM TRANSITIONS TO TRANSFORMATION

The current opportunity to advance prosperity, human well-being, equity, and climate justice is significant. The continued warming of the planet, as well as associated extreme heat, drought, heavy rainfall, floods, storm surges, and cyclones, require immediate and extensive adaptation actions to make cities and urban areas more resilient. Yet the risks associated with climatic change are not borne evenly. They fall disproportionately on marginalised and vulnerable communities, exposing and deepening existing inequalities. Cities and urban areas have a central role to play in the systems transitions needed to adapt and mitigate, and, at the same time, to pursue climate resilient development that addresses inequality and promotes human well-being and ecosystem health. Some adaptation actions are needed immediately, while simultaneous system transitions and climate resilient development pathways offer a larger and long-term opportunity to move towards transformational action. Mitigation remains an essential precondition for the success of such effort, and a rapid reduction in GHG emissions remains the most effective way to reduce future risks.

Transitions in how urban residents consume and move; how cities are built, powered, and maintained; and interactions of urban areas with ecosystems and rural areas can power transformative change that elevates new and different voices while bringing about more equitable and sustainable political settlement. Such a renegotiation of the relationships between groups of people, between people and nature, and between people and the material world is required to meet the crises at hand.



Transitions in how urban residents consume and move; how cities are built, powered and maintained; and how urban areas interact with ecosystems and rural areas, can drive transformative change that elevates new and different voices, and brings about more equitable and sustainable urbanisation.

Katowice, Poland

ANNEX

Essential Principles and Concepts

Clarity in some essential principles can further the understanding of current climate science and the development and implementation of associated policies.This annex provides IPCC definitions from Working Group II on concepts central to understanding, and taking action around, cities and climate change. So as to maintain consistency, these definitions, while shortened at times, are drawn directly from AR6 WGII.[99]

Adaptation in human systems is the process of adjustment to actual or expected climate and its effects to moderate harm or take advantage of beneficial opportunities. In natural systems, it is the process of adjustment to actual climate and its effects; potentially facilitated by human intervention.

Adaptation limits are the point at which a system's needs or an actor's objectives cannot be secured from intolerable risks through adaptation actions.

Climate justice links sustainable development and human rights to achieve a rights-based approach to addressing climate change.

Climate Resilient Development refers to the process of implementing GHG mitigation and adaptation measures to support sustainable development for all.

Exposure is the presence of people; livelihoods; ecosystems, species, environmental functions, services, and resources; infrastructure; and economic, social, or cultural assets in places that could be adversely affected.

Hazard is the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.

Impacts are the consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. Impacts generally refer to effects on lives; livelihoods; health and well-being; ecosystems and species; economic, social, and cultural assets; services (including ecosystem services); and infrastructure. Impacts may be referred to as consequences or outcomes, and can be adverse or beneficial.

Losses and damages: Lowercase letters (losses and damages) refer broadly to harm from (observed) impacts and (projected) risks and can be economic or noneconomic; Loss and Damage (capitalised letters) to refer to political debate under the United Nations Framework Convention on Climate Change (UNFCCC) following the establishment of the Warsaw Mechanism on Loss and Damage in 2013.

Maladaptation is actions that lead to increased risk of adverse climate-related outcomes, including via increased GHG emissions, increased or shifted climate vulnerability, more inequitable outcomes, or diminished welfare, now or in the future. Maladaptation is most often an unintended consequence.

Mitigation is a human intervention to reduce emissions or enhance the sinks of GHGs.

Resilience is the capacity of social, economic, and ecological systems to cope with a hazardous event, trend, or disturbance, responding or reorganising in ways that maintain their essential function, identity, structure, and capacity for adaptation, learning, and transformation.

Risk is the potential for adverse consequences for human or ecological systems, recognising a diversity of values and objectives associated with such systems. **Key risks** have severe consequences for humans and social-ecological systems from the interaction of climate related hazards with the vulnerabilities of societies and systems exposed.

Social infrastructure is the social, cultural and financial activities and institutions as well as associated property, buildings and artefacts and policy domains such as social protection, health and education that support well-being and public life

Transformational adaptation is adaptation that changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts.

Vulnerability is the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

ENDNOTES

[1] As the AR6 cycle moved from the Special Reports and Working Group I to Working Groups II and III, a fifth systems transition,societal transition, was added to the four originally described in the Special report on 1.5oC of global warming.
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[4] Ibid., Technical Summary, TS.B.8.1
[5] Ibid., Chapter 6, Executive Summary; Summary for Policymakers, Section D
[6] Ibid., Chapter 6, 6.3.2, 6.3.3, 6.3.4
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[8] Ibid., Technical Summary, Figure TS.13; Chapter 1, 1.3.1
[9] Ibid., Summary for Policymakers, Section A
[10] Ibid., Summary for Policymakers, B.5.4
[11] Ibid., Cross-Chapter Paper 2, CCP2.2
[12] Ibid., Chapter 6, Executive Summary
[13] Ibid., Chapter 6, 6.1.4
[14] Ibid., Chapter 10, 10.4.6
[15] Ibid., Chapter 12, 12.3.7
[16] Ibid., Chapter 13, 13.6.1
[17] Ibid., Chapter 14, 14.5.5
[18] Ibid., Chapter 6, 6.2; Chapter 16, 16.5.2
[19] Ibid., Summary for Policymakers, B.3
[20] Ibid., Chapter 6, Executive Summary
[21] Ibid., Chapter 7, Executive Summary, 7.3.1
[22] Ibid., Cross-Chapter Paper 2, Figure CCP2.3
[23] Ibid., Summary for Policymakers, B.4.5
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[27] Ibid., Chapter 6, Executive Summary; Chapter 9, Box 9.1; Chapter 10, Executive Summary; Chapter 12, 12.5.7; Chapter 18, Cross-Chapter Box GENDER | Gender, Climate Justice and Transformative Pathways
[28] Ibid., Chapter 8, 8.4.5; Chapter 9, 9.9.3; Chapter 10, 10.4.6; Chapter 11, 11.3.5; Chapter 12, Fig. 12.7, 12.3.2; Chapter 13, 13.6; Chapter 14, 14.5.3
[29] Ibid., Chapter 8, 8.3.4, Box 8.5, Box 8.6; Chapter 9, 9.9.4, 9.9.5; Chapter 10, 10.4.6; Chapter 12, 12.5.7
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[31] IPCC, 2022. ***Climate Change 2022: Impacts, Adaptation and Vulnerability***, Summary for Policymakers
[32] Ibid., Chapter 6, Executive Summary; Chapter 10, 10.4.6; Chapter 12, 12.5.5
[33] Ibid., Chapter 18, 18.4
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[35] Ibid., Chapter 14, Box 14.4, 14.5.5
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[39] Ibid., Chapter 13, 13.6.2
[40] Ibid., Chapter 6, 6.3.2
[41] Ibid., Chapter 6, 6.4.2, Table 6.7
[42] Ibid., Chapter 12, 12.5.5 and 12.5.7
[43] Ibid., Summary for Policymakers, C.2, C.3
[44] Ibid., Chapter 16, 16.4.3
[45] Ibid., Cross-Chapter Paper 2, CCP2.3; Ibid., Chapter 10, 10.4.6
[46] Ibid., Chapter 6, 6.4.4
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[48] Ibid., Chapter 6, 6.4.1
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[51] Ibid., Chapter 12, 12.5.5
[52] IPCC, 2022. ***Climate Change 2022: Mitigation of Climate Change***, Technical Summary TS5.2; Chapter 8, Executive Summary; IPCC, 2022. ***Climate Change 2022: Impacts, Adaptation and Vulnerability***, Chapter 6, 6.3.5
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[67] Ibid., Chapter 2, Cross-Chapter Box NATURAL | Nature-Based Solutions for Climate Change Mitigation and Adaptation; Chapter 6, 6.3.4; Chapter 10, FAQ 10.4; Chapter 13, Executive Summary
[68] Ibid., Chapter 13, Executive Summary
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THE SUMMARY FOR URBAN POLICYMAKERS OF THE IPCC'S SIXTH ASSESSMENT REPORT

VOLUME II

WHAT THE LATEST SCIENCE ONIMPACTS, ADAPTATION AND VULNERABILITY MEANS FOR CITIES AND URBAN AREAS

SUMMARY FOR
URBAN
POLICYMAKERS

WHAT THE LATEST SCIENCE ON CLIMATE CHANGE MITIGATION MEANS FOR CITIES AND URBAN AREAS

The Summary for Urban Policymakers (SUP) Initiative is a series of three summary reports: *What the Latest Physical Science of Climate Change Means for Cities and Urban Areas*, distilled from the IPCC Working Group I report; *What the Latest Science on Impacts, Adaptation and Vulnerability means for Cities and Urban Areas*, distilled from the IPCC Working Group II report; and *What the Latest Science on Climate Change Mitigation Means For Cities and Urban Areas*, distilled from the IPCC Working Group III report.

This is Volume III of the series and all three are available here: https://supforclimate.com

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SUP VOLUME I

What the Latest Physical Science of **Climate Change** Means for Cities and Urban Areas

SUP VOLUME II

What the Latest Science on **Impacts, Adaptation and Vulnerability** Means for Cities and Urban Areas

SUP VOLUME III

What the Latest Science on **Climate Change Mitigation** Means for Cities and Urban areas

CONTENTS

AUTHORS

Mustafa Babiker (Saudi Arabia)
Coordinating Lead Author, Chapter 12, IPCC AR6 WGIII
Lead Author, Chapter 4, IPCC Special Report on 1.5°C
Saudi Aramco

Amir Bazaz (India)
Contributing Author, Chapter 4, IPCC Special Report on 1.5°C
Indian Institute for Human Settlements

Paolo Bertoldi (Italy)
Lead Author, Chapter 9, IPCC AR6 WGIII
Lead Author, Chapter 4, IPCC Special Report on 1.5°C
European Commission

Felix Creutzig (Germany)
Coordinating Lead Author, Chapter 5, IPCC AR6 WGIII
Mercator Research Institute on Global Commons and Climate Change

Heleen De Coninck (Netherlands)
Coordinating Lead Author, Chapter 16, IPCC AR6 WGIII
Coordinating Lead Author, Chapter 4, IPCC Special Report on 1.5°C
Eindhoven University of Technology

Kiane De Kleijne (Netherlands)
Chapter Scientist, Chapter 12, IPCC AR6 WGIII
Contributing Author, Chapter 4, IPCC Special Report on 1.5°C
Radboud University

Shobhakar Dhakal (Thailand)
Coordinating Lead Author, Chapter 2, IPCC AR6 WGIII
Asian Institute of Technology

Stuti Haldar (India)
Indian Institute for Human Settlements

Kejun Jiang (China)
Lead Author, Chapter 3, IPCC AR6 WGIII
Coordinating Lead Author, Chapter 2, IPCC Special Report on 1.5°C
Energy Research Institute

Şiir Kılkış (Turkey)
Lead Author, Chapter 8, IPCC AR6 WGIII
The Scientific and Technological Research Council of Turkey

Ian Klaus (USA)
Series Editor of the SUP Series
Chicago Council of Global Affairs

Jagdish Krishnaswamy (India)
Coordinating Lead Author, Chapter 7, IPCC Special Report on Climate Change and Land
Indian Institute for Human Settlements

Shuaib Lwasa (Uganda)
Coordinating Lead Author, Chapter 8, IPCC AR6 WGIII
Lead Author, Chapter 6, IPCC Special Report on Climate Change and Land
Global Center on Adaptation

Leila Niamir (Iran/Austria)
Chapter Scientist and Contributing Author, Chapter 5, IPCC AR6 WGIII Report
International Institute for Applied Systems Analysis

Minal Pathak (India)
Scientist, IPCC WGIII Technical Support Unit
Ahmedabad University

Joana Portugal Pereira (Brazil)
Lead Author, Chapter 4, IPCC AR6 WGIII
Coordinating Lead Author, Annex C, IPCC AR6 WGIII
Universidade Federal do Rio de Janeiro

Aromar Revi (India)
Coordinating Lead Author, Chapter 18, IPCC AR6 WGII
and Chapter 4, IPCC Special Report on 1.5°C
Indian Institute for Human Settlements

Joyashree Roy (India/Thailand)
Coordinating Lead Author, Chapter 5, IPCC AR6 WGIII
and Chapter 5, IPCC Special Report on 1.5°C
Asian Institute of Technology

Karen C. Seto (USA)
Coordinating Lead Author, Chapter 8, IPCC AR6 WGIII
Yale University

Chandni Singh (India)
Lead Author, Chapter 10, IPCC AR6 WGII
Author, Cross-Chapter Paper 2, IPCC AR6 WGII
Indian Institute for Human Settlements

Shreya Some (India)
Contributing Author Chapter 17, IPCC AR6 WGIII Report
and Chapter 5, IPCC Special Report on 1.5°C
Scientist, IPCC WGIII Technical Support Unit
Asian Institute of Technology

Linda Steg (Netherlands)
Lead Author, Chapter 6, IPCC AR6 WGIII
Lead Author, Chapter 4, IPCC Special Report on 1.5°C
University of Groningen

Diana Ürge-Vorsatz (Hungary)
Vice-Chair, Working Group III, IPCC
Central European University

REVIEW EDITORS

Priyadarshi R. Shukla (India)
Co-Chair, Working Group III
IPCC

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IPCC

Seth Schultz (USA)
Lead Author, Chapter 4, IPCC Special Report on 1.5°C
Resilience Rising

Amanda Eichel (USA)
Lead for the SUP Initiative
Resilience Rising

Aromar Revi (India)
Coordinating Lead Author, Chapter 18, IPCC AR6 WGII
and Chapter 4, IPCC Special Report on 1.5°C
Indian Institute for Human Settlements

Ian Klaus (USA)
Series Editor of the SUP Series
Chicago Council of Global Affairs

THE SUP SERIES

The 6th Assessment Report cycle (AR6) of the Intergovernmental Panel on Climate Change (IPCC) comes at a turning point in history. Human influence has warmed the planet, and widespread and rapid impacts are occurring to both natural and human systems in all regions of the world. In response, immediate action is needed if there is to be any hope of limiting global warming close to 1.5°C or well below 2°C below pre-industrial levels, as well as preparing for and adapting to current and future risks. AR6 is composed of the three main reports: *The Physical Science Basis*; *Impacts, Adaptation and Vulnerability*; and *Mitigation of Climate Change*, as well as a *Synthesis Report*. It also includes three additional publications: the *Special Report on Global Warming of 1.5°C*, the *Special Report on the Ocean and Cryosphere in a Changing Climate*, and the *Special Report on Climate Change and Land*. Together they offer the most current and comprehensive scientific understanding of the climate crisis.

The Summary for Urban Policymakers (SUP) series distils the IPCC reports into targeted summaries to inform action at the city and regional scale. Volume I in the series, *What the Latest Physical Science of Climate Change Means for Cities and Urban Areas*, identified the ways in which human-induced climate change is affecting every region of the world, and the cities and urban areas therein. Volume II, *What the Latest Science on Impacts, Adaptation and Vulnerability means for Cities and Urban Areas*, assessed the feasibility and effectiveness of different adaptation options. To achieve climate resilient development, synergies between policies and actions for climate change adaptation, mitigation, and other development goals are needed.

This third volume in the series, *What the Latest Science on Climate Change Mitigation Means for Cities and Urban Areas* offers a concise and accessible distillation of the IPCC Working Group III Report for urban policymakers. The 21st century is characterised by a rapidly growing urban population, urban land expansion and associated rise in demand for resources, infrastructure, and services. These trends are expected to drive the growth in emissions from urban consumption and production through 2100, although the rate of urban emissions growth will depend on the type of urbanisation and the speed and scale of mitigation action implemented. Aggressive and ambitious policies for transition towards net zero greenhouse gas (GHG) emissions can be implemented in cities and urban areas, while contributing to sustainable development. Ultimately, mitigation action and adaptation are interdependent processes, and pursuing these actions together can promote sustainable development.

Gwangju, South Korea

1. THE SCALE OF THE PROBLEM, AND SOLVING IT

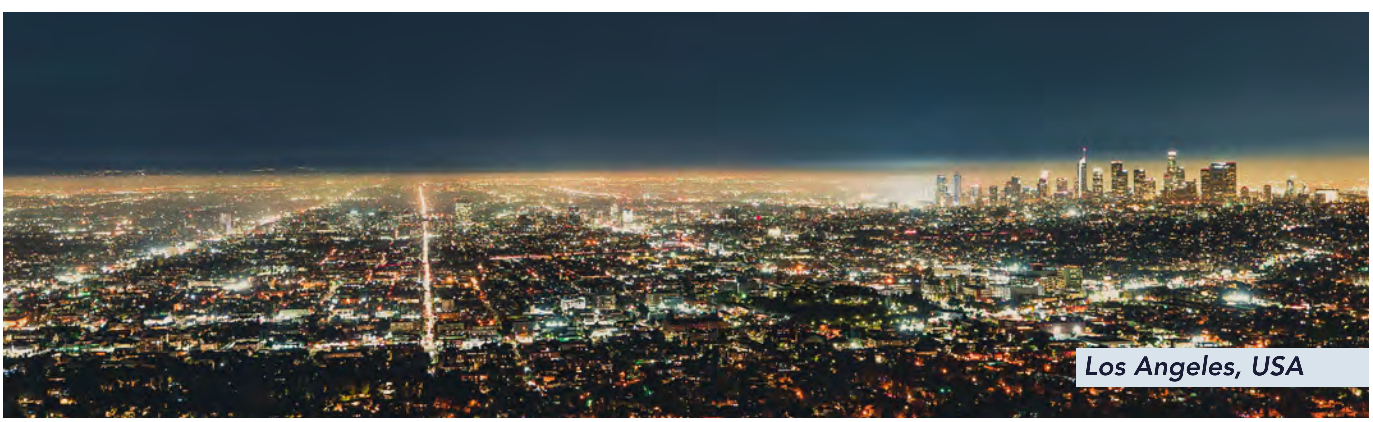
The urban share of global GHG emissions, including those linked to the consumption of goods and services, is high and continues to increase. In 2015, the urban share of global emissions was about 62%. By 2020, just five years later, the urban share of emissions had increased to between 67-72% of global emissions. These emissions are not equally distributed across urban areas: about 100 of the largest emitting cities account for about 18% of the global carbon footprint. [1]

While the drivers of urban GHG emissions are complex and vary across geography, income levels and economies, there are opportunities for all cities and urban areas to reduce emissions and further develop without significant emissions growth. Population size, state of urbanisation, and city form all play a part in defining options for cities. Developing countries, in particular, present opportunities to shift development pathways toward sustainability and implement climate resilient development.

A substantial share of the population in low-emitting countries lack access to modern energy and mobility services. Eradicating energy poverty and providing decent living standards in the context of achieving sustainable development objectives can be achieved while simultaneously reducing global energy demand and without significant global emissions growth.[2] Low-emission urbanisation can improve well-being; however, such urbanisation can still result in increased global GHG emissions through increased emissions outside of city boundaries.

Within the larger story of urbanisation in the 21st century, a number of global trends will shape our ability to limit global warming:

- The size of the global urban population is large and growing, currently totalling 4.5 billion and projected to be 7 billion by 2050;
- With ongoing urbanisation in the Global South, cities in those regions currently at early stages of urban development will require significant new infrastructure build-up, whereas established cities will need to replace or rebuild ageing infrastructure. In all cases, the associated demand for materials comes with potentially high levels of embodied emissions, heightening the need to decarbonise and dematerialise such work;
- There are a large number of cities with inadequate institutional, financial, and technical capacities to plan, enact, and implement local climate change actions;
- The growing preponderance of megacities and extended metropolitan areas present unique challenges for governance as well as energy and carbon efficiency; and
- Reinforcing interactions among urban infrastructures and technologies, institutions, and individual and collective behaviours could create inertia and path dependency, also known as carbon lock-in.[3]



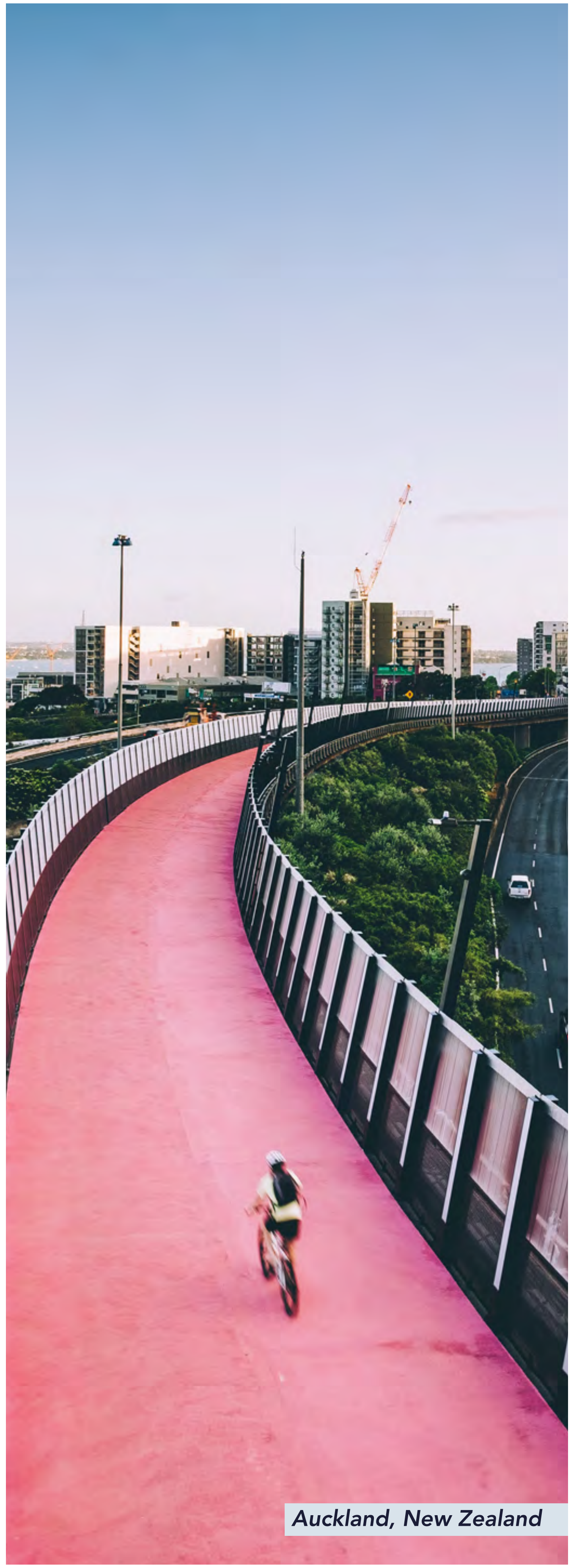
Los Angeles, USA

Mitigation of climate change in cities and urban areas has a crucial role in determining the future of the global climate. Cities and urban areas are often more energy efficient than non-urban areas, but the manner in which cities are designed, built, retrofitted, and powered will greatly impact current and future emissions.

Under scenarios with stringent mitigation efforts, peak emissions may be reached as soon as possible. Even with immediate stringent CO_2 emissions reductions, decreased emissions will continue to add to the planet's cumulative CO_2 budget. This will lead to warming above 1.5°C in the next 20 years. However, without immediate deep reductions in GHG emissions, global warming will exceed 2°C by around 2050. The stark differences between possible outcomes will rely on widespread and sustained mitigation efforts that surpass any sector-by-sector approach alone, tackling the mitigation opportunities in the urban system as a whole while providing other co-benefits.

If cities and urban areas are to aggressively pursue low- and net-zero pathways, they will need to integrate an Avoid-Shift-Improve (ASI) framework into their actions and choices. An ASI framework can support climate mitigation strategies and actions within sectors but also across urban and other systems, emphasizing demand-side climate mitigation. The ASI framing includes actions that help in avoiding emissions by behavioural and lifestyle changes, and redesigning service provisioning systems; shifting choices to already existing competitive low-carbon technologies and service-provisioning systems; and improving efficiency of technologies in end-use sectors.

Continuing with sectoral-based approaches and along existing development pathways will not achieve rapid and deep emissions reductions. Instead, shifting development pathways towards sustainability offers opportunities to broaden the range of enablers, policies, and instruments that a society can use to accelerate mitigation, while increasing the likelihood of making progress on development goals.[4] For example, promoting walkable urban areas, when combined with electrification using clean renewable energy as well as green and blue urban infrastructure that limits local warming, can deliver several co-benefits to human health and well-being as well as climate change mitigation and adaptation.[5] While the appropriate set of policies to shift development pathways depends on national and local circumstances and capacities, cities and urban areas will be focal points for mitigation actions and systemic transitions.


Auckland, New Zealand

2. GOALS AND POTENTIAL FOR MITIGATION

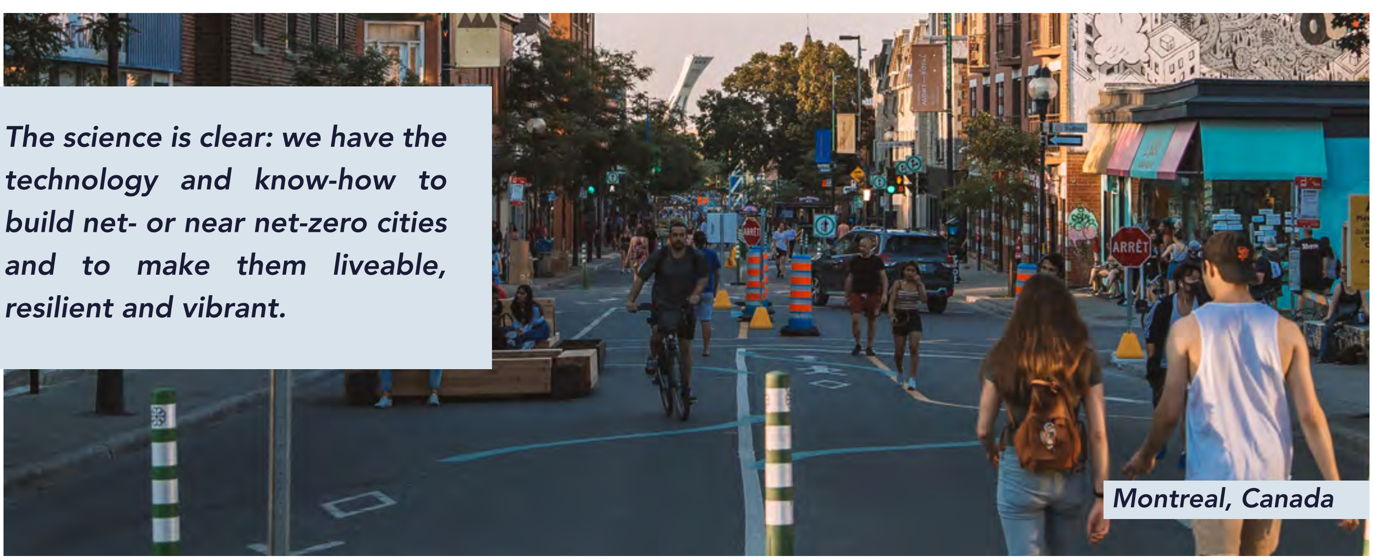
The magnitude, pace and patterns of urbanisation in the coming decades will significantly impact emissions while offering a window of opportunity to decarbonise and dematerialise.[6] The science is clear: we have the technology and know-how to build net- or near net-zero cities and to make them livable, resilient and vibrant.[7] Furthermore, mitigation actions within cities affect GHG emissions outside of urban boundaries through urban consumption, production and supply chains. Therefore, urban climate action can have positive cascading effects in other sectors and regions, including beyond administrative boundaries of cities.[8] The biggest challenges to delivering on such opportunities are in the areas of governance, finance, technology, planning and consumption. Territorial strategies to deliver net-zero cities must embed mitigation targets and approaches within a broader context of social, economic and human well-being that includes connections between rural and urban.

The energy, transportation, housing and food requirements of urban residents offer significant demand-side mitigation options, and can have cascading effects on other sectors, such as land use, and thereby reduces GHG emissions within cities as well as beyond urban territorial boundaries. Such options can be developed and delivered through low-carbon infrastructures, granular and efficient end-use technologies and strategies that avoid higher demand for materials and energy. Many of the tactical steps to such reduction are explicitly urban, including the use of electric vehicles (EVs), active transportation like walking and cycling, and shared pool mobility. In the built environment, they also include the development of compact urban planning, energy efficiency measures, passive design, active measures like heat pumps, and low-energy intensity and consumption buildings.[9]

An integrated approach to urban mitigation must bring together strategies to:

- Reduce or change energy and material use towards more sustainable production and consumption, including through urban planning for more accessible and walkable urban areas with more compact urban form;
- Increase adoption of electrification of urban energy systems while switching to low-emission energy sources and renewable energy; and
- Enhance carbon uptake and storage in urban environments.

There are multiple ways that these broad mitigation strategies can be integrated across established, rapidly growing and emerging cities.



The science is clear: we have the technology and know-how to build net- or near net-zero cities and to make them liveable, resilient and vibrant.

Montreal, Canada

Mitigation and urban typologies

The characteristics of cities vary greatly. They have different geographies, climates, economies, demographics, resource endowments, and dependencies on ecosystems and regions. As a result, effective and feasible mitigation strategies also vary across cities. One immediate way to consider diverse mitigation strategies is by using urban typology. Typologies are classifications based on a shared feature or characteristic. Examples of features or characteristics which may be used to establish city typologies include population size, urban form, and geography.

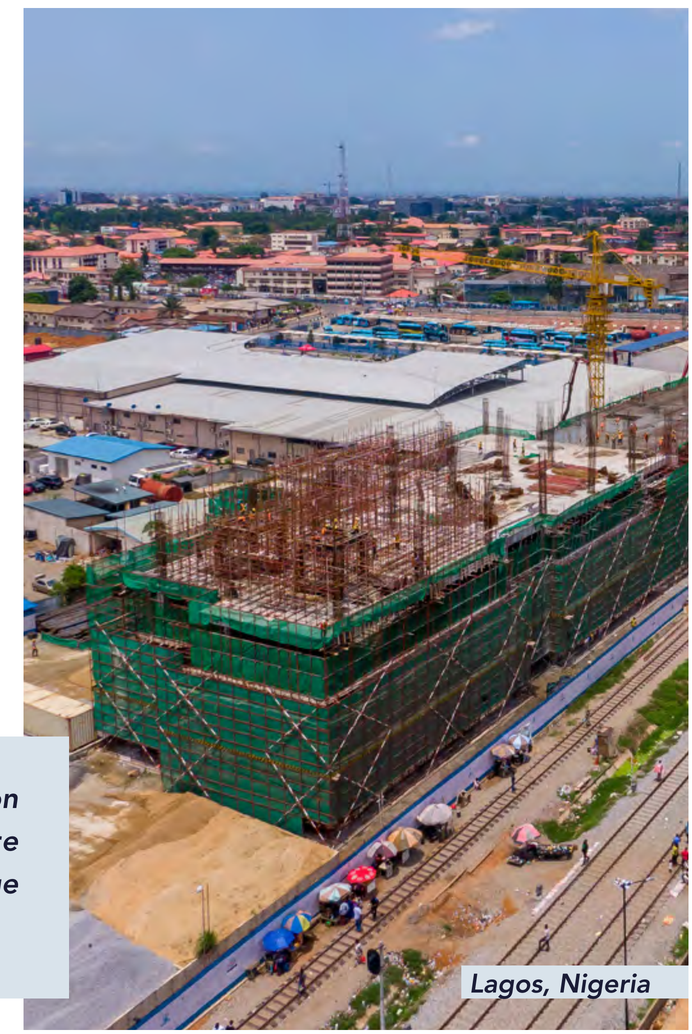
It is possible to bundle urban mitigation strategies according two key urban characteristics, both of which are also important emissions drivers: urban form and stage of urban development. Completed in 2014, the IPCC Fifth Assessment Report (AR5) established that the spatial form of cities is a major driver of urban emissions. Compact and walkable cities where destinations and origins are in close proximity are generally correlated with low per capita GHG emissions.[10] In contrast, cities with dispersed and automobile-centric urban form, characterised by low densities of housing and employment as well as separation of uses, generally have higher per capita GHG emissions.

The AR6 completed in 2022 and covered in the SUP series built on this work and further assessed that the stage of urban development affects the demand for infrastructure and carbon lock-in. Settlements that are in early stages of urbanisation with relatively low levels of infrastructure deployment have large opportunities to pursue low- or net-zero urbanisation pathways, whereas established cities with mature infrastructure generally have more locked-in energy behaviours. A key innovation in AR6 is the conceptualisation of three key city typologies as entry points for urban mitigation: an established city, a rapidly growing city, and an emerging city. These three general typologies occur along a continuum across a national or territorial urban system, made up of many interconnected urban areas and cities of various sizes and types. A single city can have neighbourhoods that are established, other districts that are rapidly developing, and an emerging periphery.

All cities have significant opportunities to implement mitigation strategies; the city typologies provide a roadmap for the approaches that are most feasible and effective for each type of city. With the city typologies as the frame, urban mitigation strategies are clustered into four categories:

- Reducing energy and material consumption through spatial planning;
- Decarbonising the urban energy system through electrification while simultaneously switching to net-zero emissions sources;
- Sequestering and storing carbon in cities; and,
- Changing urban demand and energy behaviours.[11]

Settlements that are in early stages of urbanisation with relatively low levels of infrastructure deployment have large opportunities to pursue low- or net-zero urbanisation pathways.



Lagos, Nigeria

Accelerating demand-side mitigation actions through Avoid-Shift-Improve strategies

The acceleration and scaling up of mitigation actions in urban areas requires a focus on the demand side. Demand-side actions may reach beyond the choice of an individual to include broader choices in infrastructure and technologies. Individual action, while important, must be supported by large structural changes.

Demand-side actions can be broadly understood through the ASI frame introduced in section 1. Within the ASI frame, it is helpful to think of actions in three domains: the socio-behavioural, especially important for avoid strategies, where social norms, culture, and individual choices play an important role; infrastructure, which provides underlying cost-benefit justification and is particularly relevant for shift options; and the technological, which is especially important for improve options.

Avoiding energy use and related emissions is possible through behavioural changes reflected in altered product consumption choices or through more efficient product designs. Teleworking is another important opportunity with significant mitigation potential, particularly if one ongoing impact of the COVID-19 pandemic includes a structural shift toward more remote work. Enhanced electrification of certain key sectors can contribute to demand-side mitigation by avoiding incremental electricity demand, which reduces the decarbonisation burden on the electricity supply side.

Shift measures are most relevant for transport and food, including: modal shift to shared pooled mobility; safe, comfortable public transport systems; and a shift towards balanced, less water-intensive, sustainable, and healthy diets. These options would need to be underpinned by adequate low-carbon physical infrastructure and other mechanisms that support shifting individual and societal choices towards low-carbon and less water-consuming profiles, such as safe and convenient transit corridors and desirable and affordable plant-based diets.

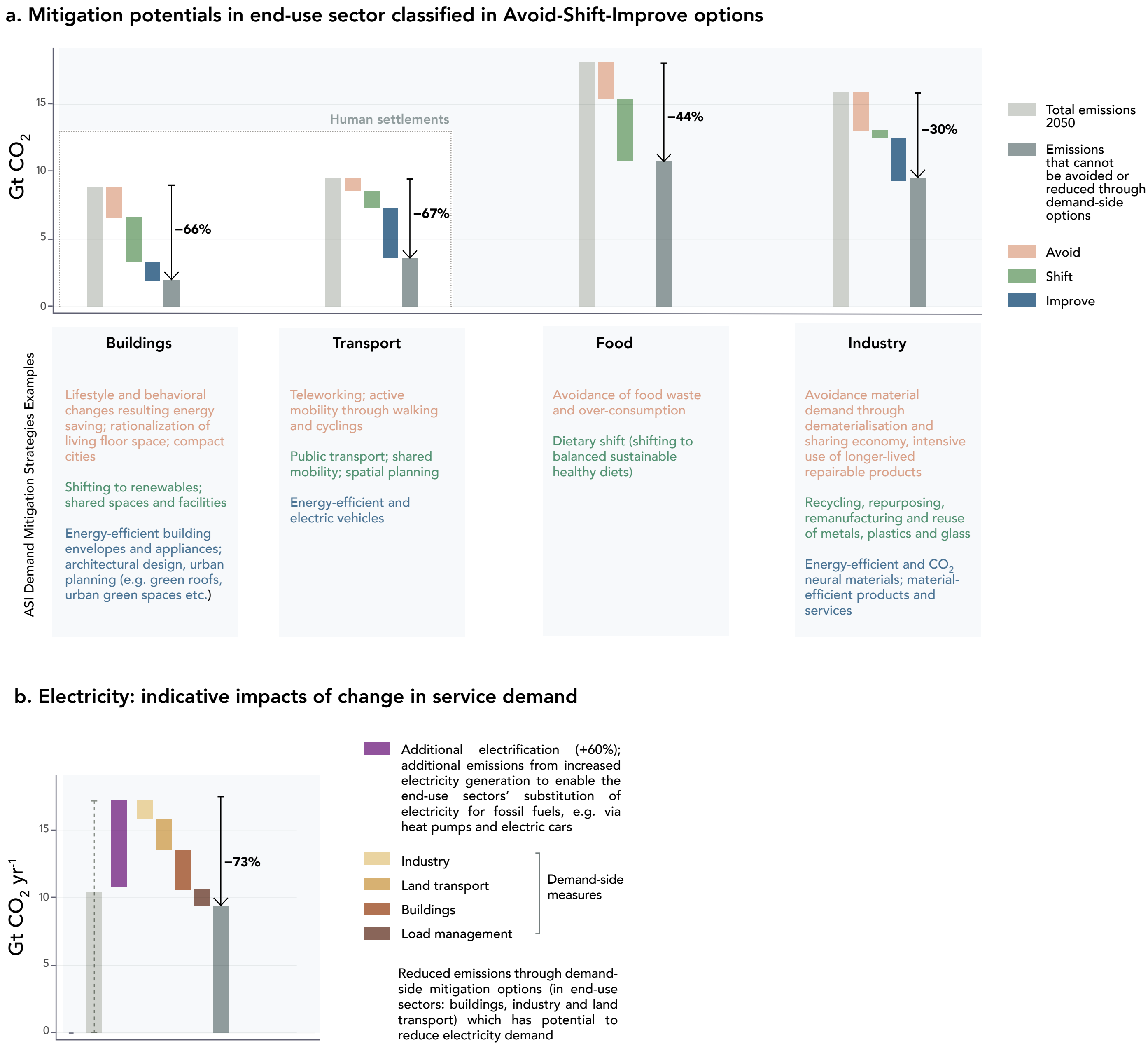
Improvements provide significant impact on the building, transport, and industrial sectors. Notable examples here include: the design of energy efficient building envelopes, improved household appliances, wider use of electric cars, and more efficient material and energy use in industrial production.

Importantly, ASI strategies are found to be consistent with high levels of well-being most notable in health due to improved air quality and enhanced energy use. In some cases, the co-benefits of a reduction strategy can even go beyond the associated mitigation benefits.[12] Food, mobility, and water are additional categories where well-being is improved. For example, mobility-linked enhanced well-being outcomes are found in compact cities that emphasise teleworking and have a system (or cross-sectoral) orientation towards mitigation approaches.

Box 1.

Hangzhou, China

Figure 1: Mitigation potential of demand-side options by 2050.



Source: A re-interpretation of data underlying the Figure SPM.6, Summary for Policymakers, IPCC AR6 WGIII

Deep and accelerated emissions reductions across urban systems, regardless of city type, require a territorial approach that integrates mitigation and sustainable development strategies across space. It will be very difficult for a city to achieve deep emissions reductions without accounting for its peripheral, regional, and global reach and influence.[13] A territorial orientation towards emissions reductions is thus crucial. A large number of cities have adopted net-zero emissions targets. In some cases, the scope of these targets extends beyond the boundary of the city to include upstream and downstream emissions. In most cases, realising these stringent emissions reduction targets would involve some form of carbon offsetting for residual emissions through enhancing carbon uptake. In the case of established cities, for example, investments in urban green and blue infrastructure could offset residual emissions that cannot be reduced.[14]

3. SYSTEMS TRANSITIONS

Although much of the scientific literature on mitigation focuses on individual sectors, cities offer the opportunity for systemic responses. As such, urban mitigation actions have the potential to reach across sectors and beyond urban boundaries concurrently. This section outlines elements of the five key interconnected systems: urban, rural, and infrastructure systems; energy; land and food systems; industry; and societal transitions.[15] To the degree that it is possible and relevant, each transition pathway integrates ASI options as well as city typology analysis.

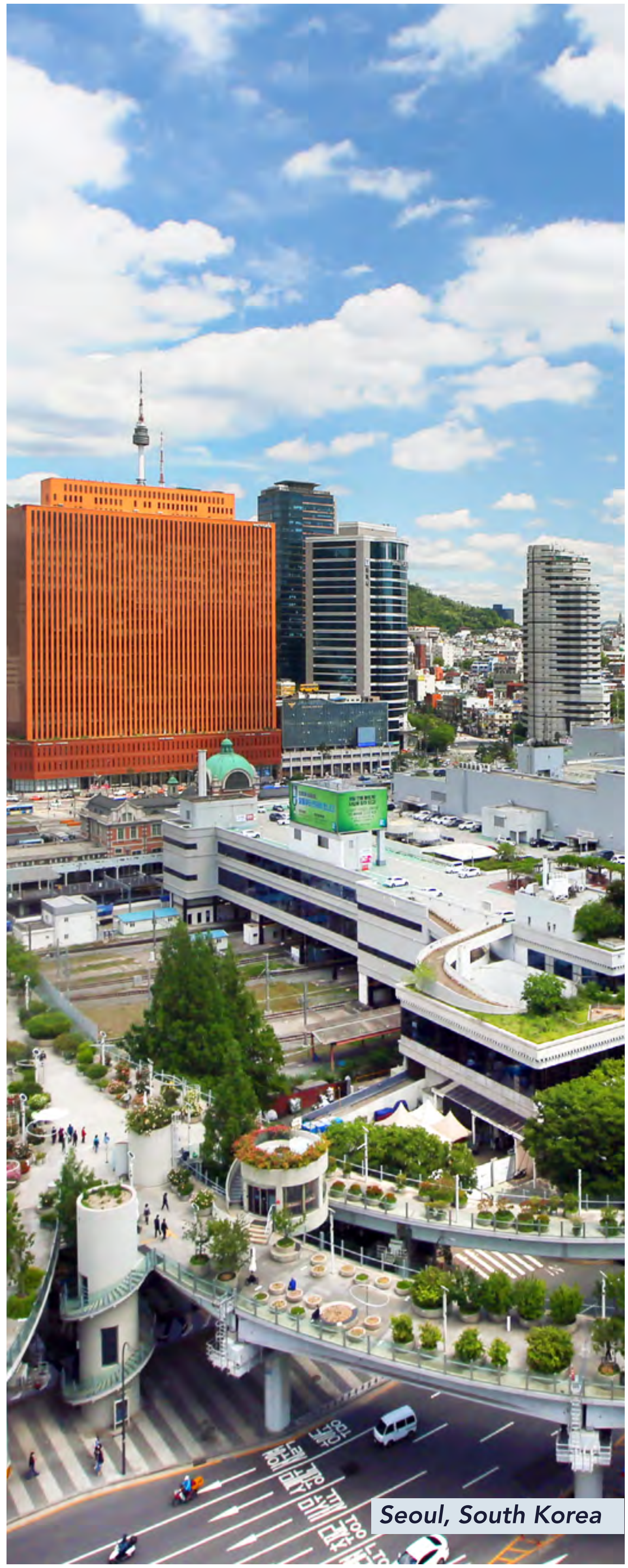
A number of mitigation options can be acted upon, with significant impact, in the near term. Many of these actions can be implemented in buildings and mobility, including; thermostat adjustments, direct feedback of energy uses in buildings, reduced speed limits, teleconferencing, and rapid street space reallocation. Importantly, short-term actions can be a starting point for setting up and enabling system transitions. A change in choice architecture or decision-making ability aimed at reducing energy and material input, for example, can be a starting point towards more energy efficient mobility via an increase in use of shared pooled mobility that can reduce the need for highly-resource and energy-intensive automobile production.

The Systems transitions

The *urban and infrastructure systems* transition brings together energy, buildings, transportation, and land-use options within cities and urban areas.[16]

For the energy sector, options focusing on ASI strategies (Box 1 and Figure 1) can reduce the demand for energy and materials, while on-site renewable energy can meet the remaining energy demand with low- or zero-carbon energy. Cities can retrofit existing buildings, in particular in developed countries with limited population growth and largely established cities as well as construct new buildings according to building codes that mandate net-zero energy at the building or district level and, gradually, the use of low-emission construction materials.[17]

For the building sector, particular attention is needed to maintain human comfort without dramatically increasing the demand for cooling, owing in part


Seoul, South Korea

to urban heat island effect. In addition to efficient mechanical cooling systems with climate-friendly refrigerants, passive and traditional cooling techniques such as natural ventilation, shading and evaporative cooling should be promoted.

For the transportation sector, changes in urban form, behaviour change programs, the circular economy, the shared economy, energy sufficiency and efficiency, and digitalisation can support systemic changes that lead to reductions in demand for transport services or the use of more efficient transport modes. For example, cities can reduce their transport-related fuel consumption by around 25% through combinations of compact land use and the provision of less car-dependent transport infrastructure.[18] Disruptive, hybrid, largely non-networked technologies have significant potential for low-emissions development in urban areas of developing countries.[19] Ultimately, the best strategies for pursuing urban and infrastructure system transition will depend on a given city's typology, including its current and future land use, spatial form, and state of urbanisation.

Energy systems transitions

Urban areas must play a key role in the energy systems transition on both the demand side as well as the supply side. A city that is walkable and designed around people rather than cars, for example, can reduce energy demands, while demand management and demand response can increase the flexibility of energy systems to accommodate larger shares of variable renewable energy sources.[20] Electrification at the urban scale, including large-scale options based on electrified public transport, heat pumps, and renewable-energy-based district heating and cooling networks, provide entry points to realise the energy systems transitions.[21]

On the supply side, roofs, walls, and balconies in cities and urban areas offer a large potential area for solar photovoltaic (PV) installations. Despite falling PV prices, there is still the need for policy to enable this potential.[22] Local energy communities at urban or district scale are important sites for promoting renewable energy systems and fostering citizens' participation and engagement. Urban residents can become active prosumers[23] by offering demand flexibility, energy storage, and renewable energy generation.[24] Coupling energy planning and citizen engagement can boost the share of renewable energy.

Istanbul, Türkiye

Land and food systems transitions

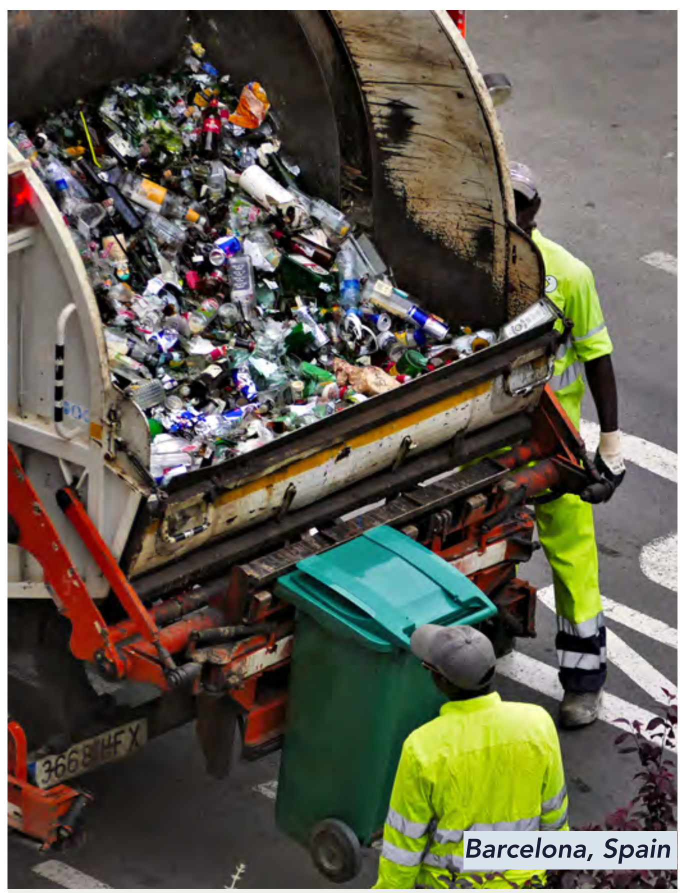
Land-based demand-side measures are relevant in the urban context. The land and food systems transition, sustainably implemented, offers an essential opportunity to reduce emissions as land-use change accounts for about 13-21% of total GHG emissions. Cities are major users of land- and water-based resources, and urban residents can significantly reduce overall emissions by shifting to sustainable healthy diets, reducing water use and food waste, recycling wastewater, conserving green areas that serve as water catchments, and building with wood and biochemicals.[25] Enhancing carbon uptake and storage in the urban environment, including through nature-based solutions such as permeable surfaces, green spaces, trees, rivers, ponds, and lakes would be equally important to facilitate emissions reductions.[26] Most of these measures can be implemented in the short term, do not require additional land, and can potentially support sustainable development. However, if poorly implemented and governed, land-based measures can result in trade-offs with livelihoods and ecosystem services.

In the context of national or local net-zero GHG emissions targets, carbon dioxide removal may be necessary to neutralise residual GHG emissions from hard-to-abate sectors, such as those from some industrial activities, long-distance transport, or methane and nitrous oxide from agriculture and polluted water bodies.[27] Finally, the land use sector can also be a carbon sink if properly managed. In city environments, urban green and blue infrastructure, including retained local ecosystems, green areas, parks, and urban farming, can play a significant role in GHG emissions reductions while also delivering ecosystem services co-benefits.[28]

Industrial systems transition

Buildings, infrastructure, and transport all require materials such as cement and concrete, iron and steel, glass, bricks, plastics, and other chemicals. Increased basic materials extraction and production have caused industrial emissions to grow faster than emissions in other sectors over the last decades.[29] Modelling suggests that in developed countries, per capita material stocks are levelling off, while in developing countries the construction of new infrastructure and growing demand for products still drives global material demand. Climate action may also spur material demand, like steel for windmills, building insulation materials for heating/cooling systems, and EVs.[30]


Mandaue City, Philippines


Barcelona, Spain

Historically, mitigation efforts in industry have focussed on incrementally improving existing manufacturing processes, for example by increasing efficiency to limit energy demand and material inputs, therefore limiting direct and indirect emissions associated with the extraction of resources. While important, incremental changes alone are insufficient to realise net-zero emissions from the industrial sector. Additional transformational changes are needed, such as low- to zero-GHG intensity production processes in the longer term, switching to alternative energy carriers and feedstocks, and capturing and storing remaining CO_2. Reducing primary production is also key, and can be achieved through a lowered demand for materials, increased material efficiency, and circularity.[31]

Cities can play an important role to facilitate the industrial systems transition through: spatial planning that limits material demand, implementation of improved design standards, and building codes. Additional strategies include: promoting circularity through dedicated policies for recycling and waste and developing urban-industrial symbiosis to use waste from cities as fuel, feedstock, and construction material, including creating a demand for bio-based building materials.[32] In every case, coordinated action throughout value chains to promote all mitigation options is a prerequisite for reaching net-zero CO_2 emissions in industry.[33]

In addition to incentivising the industrial system transition, cities may also be affected by it. Some industrial sectors are growing while others are shrinking. Furthermore, the potential for generating wind and solar power is not distributed evenly across the world, neither are geological formations suitable for storing CO_2. Energy-intensive industries requiring renewable electricity, hydrogen produced through electrolysis, or captured CO_2 storage sites to reduce emissions may relocate to those regions where this is available.[34] Such changes in global supply chains will have global distributional effects on employment and economic structure, and would require socially inclusive emissions phase-out plans within the context of just transitions.[35]

Mannheim, Germany

Societal systems transition

Finally, one of the important developments of the AR6 cycle is the emphasis on societal transitions encompassing demand, services, and social aspects of mitigation. Demand-side strategies, spread across all sectors, offer the potential to reduce emissions by 40-70% by 2050. Within the ASI framework, the greatest 'Avoid' potential comes from reducing long-haul aviation and providing short-distance, low-carbon urban infrastructure alternatives.[36] Demand for passenger and freight services can be reduced through combinations of teleworking, digitalisation, dematerialisation, supply chain management, and smart and shared mobility.[37] Transport demand management incentives are likely necessary to support such systemic changes.

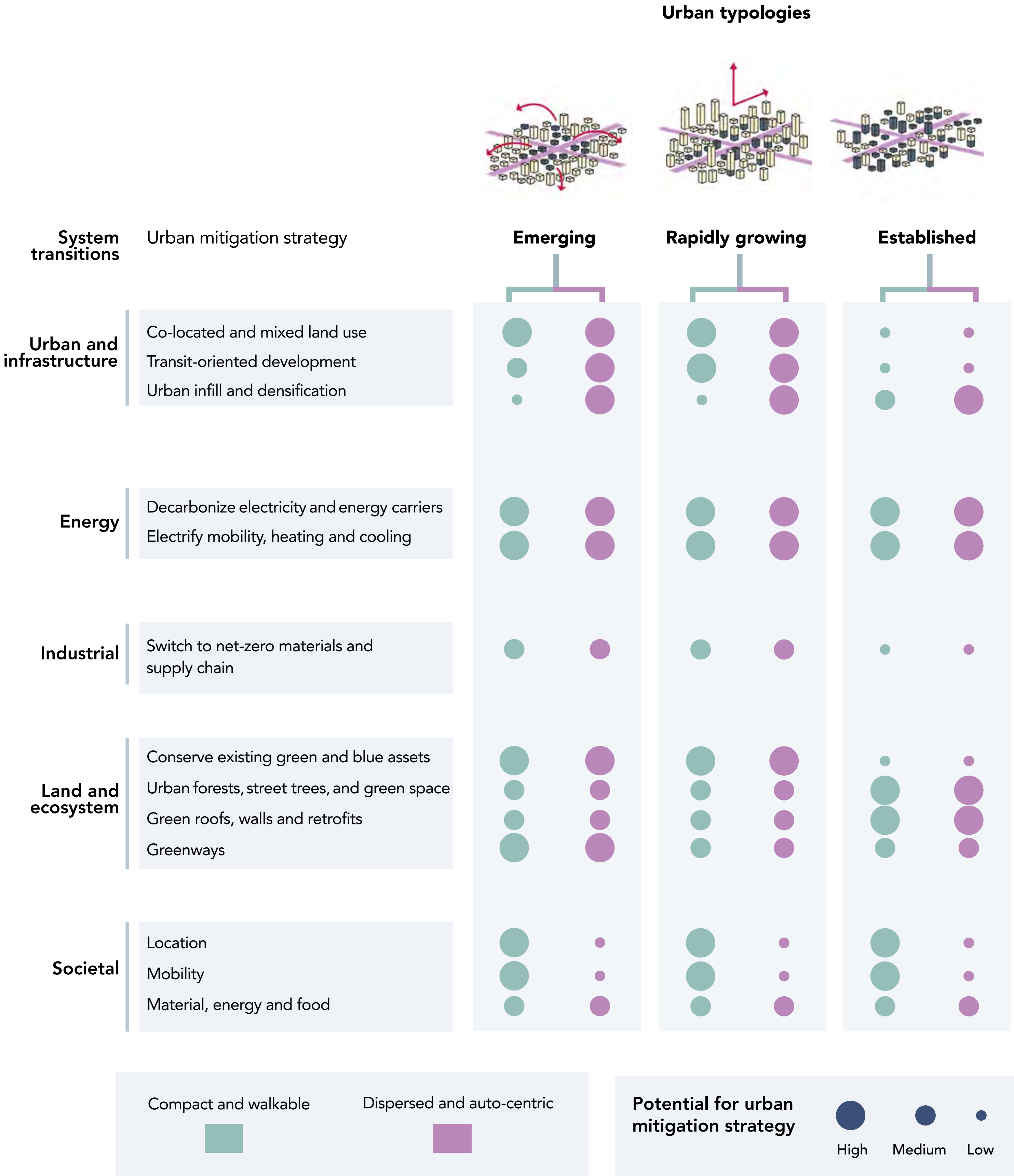
Collective social change over the longer term, including towards less resource-intensive lifestyles, depends on building a social mandate through public participation and deliberation, as well as effective communications campaigns that adequately explain and incentivise alternative options. Individuals are capable of reducing their GHG emissions and may become role models in a broader, collective effort to normalise and prioritise low-carbon lifestyles, invest in low-carbon businesses, and advocate for strong climate policies.[38]

Finally, urban consumption patterns and supply chains have regional and global implications. As such, the full potential for reduction of consumption-based urban emissions will be achieved only when emissions beyond cities' administrative boundaries are also reduced. Such a territorial approach requires cooperation and coordination between national and sub-national governments, as well as with industry and civil society.[39]

Mitigation interventions, which are by design large and complex and cut across multiple urban scales, are often beyond local budgetary and institutional capacity. Innovative partnerships are needed across multiple local, regional, national, and international institutions and stakeholders, particularly to mobilise financial resources and identify innovative governance structures, processes, and mechanisms.[40]

Turin, Italy

Figure 2: : Potential of urban mitigation strategies across urban typologies (growth x form) and systems transitions.



Source: Derived from IPCC AR6 WGIII, Chapter 8, Figure 8.20, Figure 8.21.

Feasibility

The feasibility of mitigation options depends on a wide array of factors, including the geophysical, environmental-ecological, technological, economic, socio-cultural, political, and institutional. As Figure 2 illustrates, these factors are key to accelerated implementation.[41] Almost all mitigation options face institutional barriers that must be addressed to enable their application at scale.

Feasibility also differs across regions. The institutional capacity to support deployment of options, for example, varies across countries, while spatial planning has a higher potential of impact at early stages of urban development. The feasibility of demand side responses, meanwhile, depends on capacities as well as socio-cultural and local conditions. The speed and scale of implementation also affects feasibility: most options face barriers when they are implemented rapidly at a large scale. The feasibility of mitigation options can increase when synergies with adaptation options are leveraged.[42]

Options, synergies and trade-offs

Mitigation options in urban areas can have synergies across a range of SDGs, and in some cases can result in both complementarity and trade-offs within the urban application as well as through dependencies on other ecosystems and regions elsewhere. These interactions vary depending on the scale and the development context.


Athens, Greece

Figure 3: Overall feasibility of mitigation options and synergies and trade-offs between sectoral mitigation options and the SDGs.

Sector	Mitigation Response Options	Overall Feasibility	1	2	3	4	5	6	7	8	9	10	11	12	14	15
Energy	Solar Energy	High	+	★	+			★	+	+	+		+	★		★
Energy	Wind energy	Medium	+	★	+			+	+	+	+		+	★	★	★
Energy	Geothermal	Low	+		★			★	+		+		+			
Energy	Energy storage for low-carbon grids	Low														
Energy	Demand side mitigation	Medium	+	+	+		+	+	★	★	+	+	+			
Energy	System integration	Medium														
Urban	Urban land use and spatial planning	Medium	+	★	+	+	+	+	+	+	+	★	+	★	★	★
Urban	Electrification of the urban energy system	High	+	★	+	+	+	+	+	+	+	+	+	★	+	★
Urban	District heating and cooling networks	Medium	+	−	+				+	+	+		+	+		+
Urban	Urban green and blue infrastructure	High	+	+	+	+		+	+	+	+	★	+	+	+	+
Urban	Waste prevention, minimization and management	Medium	+	+	★			+		★	+					+
Urban	Integrating sectors, strategies and innovations	Medium	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Building	Building design and performance	Low	+	+	+			+	+	★		+	+	+		+
Building	Change in construction methods and circular economy	Medium			+			★	+	★	+		+	+		
Building	Envelope improvement	Low	★	+	★	+		+	+	★	★	★	+	+		
Building	Heating, ventilation and air conditioning (HVAC)	Low	★	+	+			+	+		★	★	+	+		
Building	Efficient Appliances	Medium	★	+	+	+	+	+	+	★	−	★	+	★		+
Building	Change in construction materials	Low			+			★	+	★	+			+	+	
Building	Demand Side management (active management operation, digitalization and flexible comfort requirements)	Low	★	★	+	+	+	★	★	★	★	★	+	+		+
Building	Renewable energy production	Low	+		★	+	+		+	+	+	+	+	+		
Transport	Demand reduction and mode shift	Medium	+		+	+	+		+	+	★	+	+	+		
Transport	Biofuels for land transport, aviation, and shipping	Low		★	★				+	+	+		+		★	★
Transport	Electric vehicles for land transport	Low				★				★	+	+	★	+	★	

Related Sustainable Development Goals:

- 1 No poverty
- 2 Zero hunger
- 3 Good health and wellbeing
- 4 Quality education
- 5 Gender equality
- 6 Clean water and sanitation
- 7 Affordable and clean energy
- 8 Decent work and economic growth
- 9 Industry, innovation and infrastrcuture
- 10 Reduced inequalities
- 11 Sustainable cities and communities
- 12 Responsible consumption and production
- 13 Climate action
- 14 Life below water
- 15 Life on land
- 16 Peace, justice and strong institutions
- 17 Partnership for the goals

\+ Synergies
− Trade-offs
★ Synergies and trade-offs
Blanks represent no assessment

Overall Feasibility: High, Medium, Low

Source: Derived from IPCC AR6 WGIII, Summary for Policymakers, SPM.8

As Figure 3 illustrates, there are multiple near-term sustainable development benefits that result from mitigation actions. There are synergies between sustainable development and mitigation actions that promote, among other benefits: energy efficiency and renewable energy; urban planning with more green spaces; reduced air pollution; and demand-side mitigation strategies such as shifts to balanced, sustainable healthy diets. Zero- or low-emission electrification and shifts to public transport can enhance health and employment benefits, enhance energy security goals, and improve equity. In industry, low- or zero-emission electrification can contribute to reduced environmental pressures, as well as increased economic activity and employment. Notably, enhanced mitigation and broader actions to shift development pathways towards sustainability can have distributional consequences within and between countries, potentially shifting income and employment profiles and generating new employment opportunities.[43]

Mitigation actions can also contribute towards adaptation and community resilience; indeed, mitigation remains essential to effective adaptation and climate resilient development. Opportunities for synergies between mitigation actions and adaptation needs exist in sustainable urban planning and infrastructure design, including green roofs and facades, permeable urban surfaces, urban agriculture, and water-sensitive design. These options can reduce flood risks and pressure on urban drainage systems, improve infiltration and ground-water recharge, alleviate urban heat island effects, enhance urban biodiversity, and enhance health and well-being benefits from reduced air pollution and improved aesthetics. In general, measures promoting walkable urban areas that are combined with low- or zero-emission electrification can create health co-benefits from cleaner air.

In certain instances, mitigation options also come with trade-offs. Increasing urban density to reduce travel, for example, can also increase vulnerability to heat waves and flooding. Air pollution control techniques can involve trade-offs with waste management strategies, especially if incineration is involved. Trade-offs can also arise if food systems are coupled with bioenergy, electricity, and heat. Electrification of urban energy systems can negatively impact freshwater aquatic, coastal, and marine ecosystems if delivered through enhanced hydropower development and biofuel cultivation. Material demand due to enhanced electrification may increase, so appropriate policy design becomes especially important.[44] Many of the potential trade-offs between mitigation and sustainable development could be minimised through appropriate policies, as well as enhanced attention to social equity, particularly through participatory processes of decision-making.


Queenstown, Singapore

4. ENABLING CONDITIONS FOR SYSTEMS TRANSITIONS AND TRANSFORMATION

Enabling conditions are the policies, investments, and engagement strategies that must be in place in order to realise, promote, or advance systems transitions and ultimately transformation. They play a critical role in determining the scalability and efficacy of mitigation efforts by both creating the legal frameworks for action, but also engaging the specific actors that must ultimately implement change. These enabling conditions relate to urban policy and planning, governance, finance, lifestyle and behaviour change, innovation, and technology. Crucial elements of each are outlined below:

Urban policy and planning

Urban policies and spatial planning are necessary to establish targets and guidelines for the key attributes of cities that drive urban emissions through interventions at multiple geographic scales. For instance, metropolitan policies and integrated strategic spatial planning can facilitate compact urban areas, restructure urban regions, and shape and reduce energy demand and transportation patterns. Similarly, cities can facilitate a shift to sustainable healthy diets through food procurement policies that promote local production and reduce vehicle use. Through building codes, cities can regulate material and construction standards for buildings, including requirements for efficient heating and cooling techniques and appliances.

Some interventions involve decisions beyond the administrative boundaries of cities and require cooperation with other levels of government. For instance, upscaling EVs involves a range of policies, incentives, and regulations complemented across local, state, and national levels. Coordination mechanisms for urban policy within a nested governance framework can join fragmented policymaking and enable the implementation of cross-sector policies beyond a single-sector focus, teaming up multiple institutions to increase capacity for low-carbon transitions.[45]

Although spatial planning provides a unique opportunity to envision low- or net-zero cities, especially through the integration of land use and transport planning, the implementation of such visions requires a broad approach to urban policy that includes a range of policies and investment approaches across administrative and territorial boundaries, partnerships between public and private sectors, and vertical integration of local, regional, and national policies that affect urban space.

Governance and institutions

While many cities have set ambitious goals, and in many cases achieved significant outcomes for carbon reduction to date, none are capable of realising the necessary impact alone: implementing ambitious climate action in cities requires the involvement of governance at multiple levels. Further, regional, national, and international climate goals are most impactful when local governments are involved alongside higher levels as partners, rendering urban areas key foci of climate governance more broadly. Cities will also need to create engagement avenues with multiple local stakeholders and actors, including the private sector and civil society, particularly grassroots and front-line organisations that capture indigenous and locally-lived expertise and experience.[46] Climate mitigation responses that integrate considerations of all relevant communities from a perspective of justice and equity can cultivate widespread support for expanding the scope and scale of action.[47]

Ensuring focus on governance creates a legal basis to respond systemically to the mitigation agenda.[48] Cities have the ability to implement policies across a range of sectors, but such an ability is contingent upon their institutional capacities to develop, coordinate, and integrate sectoral mitigation strategies within their context and with intentional involvement from the local community. These institutional capacities are influenced by incumbent political context, governance and regulatory regimes, and budgetary considerations. Such institutional constraints are more pronounced in the developing world.[49]

Ultimately, a transformative reimagination across governance and institutional frameworks is needed to enable climate mitigation in cities and regions. The reimagined configuration must be responsive to the stage of development, city size and typologies, and incumbent institutional capacities.[50]

Financing urban mitigation

Availability and access to finance is a crucial dimension of urban climate mitigation action and also a substantive barrier, mostly due to limited financial capacity and lack of creditworthiness among city governments, particularly for intermediate cities in emerging markets. Current mitigation finance across all sources, sectors, and regions is in the range of 16-33% of the average need up to 2030 for scenarios that limit temperature rise to 2°C. Crucially, mitigation investment gaps are the highest for developing countries.[51] Policy action is effective when matched by long-term and consistent financial support for implementation.[52] Yet at an aggregate level, progress on aligning climate finance with low-emission pathways has been slow, reflecting a serious and persistent misallocation of financial resources.[53] Cities, along with international institutions, national government, and local stakeholders, will play an important role in mobilising climate finance across key sectors and, increasingly, by aligning cross-sectoral considerations to enable upscaled financial flows.[54] For example, the mobilisation of financial resources to leverage cross-sectoral mitigation opportunities requires both a combination of public and private capital as well as new business models, including community-led bottom-up mitigation action.[55] For example, green municipal bonds offer significant potential to expand sources of finance but more importantly, enable cross-sector collaboration and cooperation.[56] In addition to new business models, it is crucial to ensure sustainable and predictable intergovernmental transfers to city governments that enable financing of mitigation action. Predictable transfers can help facilitate, for example, access to low-concession large infrastructure finance. Large low-carbon infrastructure projects are often beyond the capacity of local municipal budgets, jurisdictions, and institutions and thus, calls for innovative partnerships across a range of actors, such as international institutions, national and regional governments, transnational networks, and local stakeholders.[57]

Current mitigation finance across all sources, sectors, and regions is in the range of 16-33 percent of the average need up to 2030 for scenarios that limit temperature rise to 2°C.

Austin, USA

Lifestyle and behavioural change

Behavioural change is an important and underutilised driver that can be cultivated to rapidly mitigate climate change.[58] Such change can be encouraged and supported by policy and system changes, including energy pricing policies, providing sustainable technology, and making the low-carbon choice the default option.[59] Urban infrastructure investments can also enable low-carbon lifestyles through, for example, compact urban layouts and accessible electric transit systems. The numbers with regards to the built environment are striking. Between 5-30% of global annual GHG emissions by 2050 can be limited by a combination of new and repurposed infrastructure and compact cities, co-location of jobs and housing, more efficient use of floor space and energy in buildings, and the reallocation of space for active mobility.[60] Finally, the process of policy development and implementation matters. Public support for policy and implementation, including system changes, improves when benefits and costs are shared, and when decision-making processes encourage trust.[61]

São Paulo, Brazil

Innovation and technology

Significant progress has been made in climate change mitigation technologies and innovation in recent years. Innovation, together with other enabling conditions, has the potential to support system transitions and to shift development pathways to limit warming. For instance, widespread technological innovation in combination with public policy can advance the implementation of clean energy options, such as feed-in tariffs. Additionally, innovation can enhance human wellbeing through developing new and improved ways of service delivery. Mobility apps, for example, that offer mobility-as-service can also encourage active and healthy lifestyles.[62] However, innovation can also result in negative externalities, such as rebound effects leading to lower net emissions reductions and increased dependence on foreign knowledge and technology, especially in developing countries. Effective policy and governance can minimise negative externalities and avoid trade-offs between innovation and sustainable development.[63] Regulatory and economic instruments can stimulate innovation and support emission reductions. Gaps in innovation cooperation remain, which need to be addressed through improved financial support for international technology cooperation and enhanced capacities in developing countries across innovation value chains.[64]

Paris, France

CONCLUSION

Addressing warming in an urban world requires urgent and ambitious action. Yet importantly, the ambitious actions cities and urban areas must take to continue the transition towards net-zero GHG emissions do not exist outside of geography and history. Instead, mitigation strategies must be intertwined with climate resilient development, with policymakers pursuing synergies with adaptation options. While cities and urban areas may differ in essential ways—from populations, to the built environment, to level of adaptation preparedness, to the onset of climatic impact drivers—the underlying fact remains: emissions must be reduced in all cities, urban areas, and linked peripheral regions, and this must happen now. The necessary steps and strategies needed to advance systems transition, and the urban and infrastructure transition in particular, can provide the beginning of a wider transformation, one in which people reconsider their relationship with each other, with nature, and with the material world.

Mumbai, India

ANNEX

Essential Principles and Concepts

Clarity in some essential principles can further the understanding of current climate science and the development and implementation of associated policies. This annex provides IPCC definitions from Working Group II and Working Group III on concepts central to understanding, and taking action around, cities and climate change. So as to maintain consistency, these definitions, while shortened at times, are drawn directly from AR6 WGII and WGIII.[65]

Adaptation in human systems is the process of adjustment to actual or expected climate and its effects to moderate harm or take advantage of beneficial opportunities. In natural systems, it is the process of adjustment to actual climate and its effects; potentially facilitated by human intervention.

Choice architecture describes the presentation of choices to consumers, and the impact that presentation has on consumer decision-making.

Climate Resilient Development refers to the process of implementing GHG mitigation and adaptation measures to support sustainable development for all.

Co-benefits are positive effects that a policy or measure aimed at one objective has on another objective, thereby increasing the total benefit to society or the environment. Co-benefits are also referred to as ancillary benefits.

Dematerialise refers to the reduction in the quantity of the materials used in the production of one unit of output. It is a circular economy principle that can affect the operations and emissions of the transport sector, as reductions in the quantities of materials used reduces transport needs, while reductions in the weight of products improves the efficiency of transporting them. Dematerialisation can occur through more efficient production processes but also when a new product is developed to provide the same functionality as multiple products. e.g. smart phone, which provides the service of at least 22 other former devices.

Impacts are the consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. Impacts generally refer to effects on lives; livelihoods; health and well-being; ecosystems and species; economic, social, and cultural assets; services (including ecosystem services); and infrastructure. Impacts may be referred to as consequences or outcomes, and can be adverse or beneficial.

Mitigation is a human intervention to reduce emissions or enhance the sinks of GHGes.

Prosumer is a consumer that also produces energy and inputs energy to the system, for which it is an active agent in the energy system and market.

Rebound effects are phenomena whereby the reduction in energy consumption or emissions (relative to a baseline) associated with the implementation of mitigation measures in a jurisdiction is offset to some degree through induced changes in consumption, production, and prices within the same jurisdiction. The rebound effect is most typically ascribed to technological energy efficiency improvements.

Resilience is the capacity of social, economic, and ecological systems to cope with a hazardous event, trend, or disturbance, responding or reorganising in ways that maintain their essential function, identity, structure, and capacity for adaptation, learning, and transformation.

Risk is the potential for adverse consequences for human or ecological systems, recognising a diversity of values and objectives associated with such systems. Key risks have severe consequences for humans and social-ecological systems from the interaction of climate related hazards with the vulnerabilities of societies and systems exposed.

Transformational adaptation is adaptation that changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts.

Urban share refers to total urban emissions based on consumption-based accounting.

Vulnerability is the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

ENDNOTES

[1] IPCC, 2022. ***Climate Change 2022: Mitigation of Climate Change***, Technical Summary, TS. 5.2; Chapter 8, 8.1.6, 8.3.3; Carbon footprint refers to combined global CO_2 and CH4 emissions through the production and consumption of goods and services
[2] Ibid., Summary for Policymakers, Figure SPM.2; Chapter 1, Figure 1.2; Chapter 2, 2.2, 2.4, 2.6; Chapter 3, 3.7; Chapter 4, 4.2; Chapter 6, 6.7; Technical Summary, Figure TS.4, Figure TS.5
[3] Ibid., Chapter 8, 8.1.4, 8.1.5, 8.1.6
[4] Ibid., Technical Summary, Box TS.3; Chapter 4, 4.3,Figure 4.7, Cross-Chapter Box 5 | Shifting development pathways to increase sustainability and broaden mitigation options
[5] Ibid., Chapter 8, 8.2, 8.4; Chapter 4, 4.4.1
[6] Ibid., Chapter 8, Cross-Working Group Box 2 | Cities and Climate Change; Chapter 5, 5.3; Chapter 10, 10.2, 10.8
[7] Refers to GHG emissions. These estimates include all CO2 and CH4 emission categories except for aviation and marine bunker fuels, land-use change, forestry and agriculture.
[8] Ibid., Summary for Policymakers, C.6; Chapter 8, 8.2, 8.3, 8.4, 8.5, 8.6, Figure 8.21; Chapter 13, 13.2
[9] Ibid., Summary for Policymakers, Figure SPM.6, C.8.2; Chapter 11, Table 11.4, Box 11.2, 11.3, 11.4; Chapter 5.3, Chapter 10, 10.2, 10.8
[10] Ibid., Chapter 8, 8.2, 8.3.4, 8.4, 8.6
[11] Ibid., Chapter 5, 5.1, 5.3, Table 5.1, Figure 5.6, Figure 5.7, Figure 5.8, Figure 5.10 , 5.6.2, Table 5.5, Table 5.7; Technical Summary, Box TS.12, TS. 5.8, TS. 6.3
[12] Ibid., Chapter 5, 5.2.3
[13] Ibid., Technical Summary, TS.5.2
[14] Ibid., Chapter 8, 8.6.1, Box 8.4
[15] As the AR6 cycle moved from the Special Reports and Working Group I to Working Groups II and III, a fifth systems transition, societal transition, was added to the four originally described in the Special Report on Global Warming of 1.5ºC.
[16] Ibid., Chapter 8, Fig 8.4.7
[17] Ibid., Chapter 9, 9.6, 9.9; Chapter 8, 8.4, Box 8.4, 8.5; Chapter 13, 13.5, 13.9
[18] Ibid., Chapter 10, Executive Summary
[19] Ibid., Chapter 8, 8.3.2
[20] Ibid., Chapter 8, 8.4.3
[21] Ibid., Chapter 8, 8.4.3
[22] Ibid., Chapter 9, 9.9
[23] IPCC, 2022: Annex I: Glossary [van Diemen, et al. (eds)]. In IPCC, 2022: ***Climate Change 2022: Mitigation of Climate Change***. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.020
[24] IPCC, 2022. ***Climate Change 2022: Mitigation of Climate Change***, Chapter 9, 9.9.5
[25] Ibid., Chapter 7; Chapter 5, 5.3.6.1; IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, et al. (eds.)]. In press.
[26] IPCC, 2022. ***Climate Change 2022: Mitigation of Climate Change***, Summary for Policymakers, C.6.2
[27] Ibid., Chapter 12, 12.3
[28] Olsson, L., et al., 2019: Land Degradation, 4.9.1. In: ***Climate Change and Land***: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, et al. (eds.)]. In press
[29] IPCC, 2022. ***Climate Change 2022: Mitigation of Climate Change***, Chapter 11, 11.2.2
[30] Ibid., Chapter 11, 11.3.1
[31] Ibid., Chapter 11, 11.3
[32] IPCC, 2022. ***Climate Change 2022: Mitigation of Climate Change***, Summary for Policymakers, C.6.2; Chapter 5, 5.3, Figure 5.7; Chapter 8, 8.2, 8.4, 8.6, Figure 8.21; Chapter 9, 9.4, 9.6, 10.2
[33] Ibid., Chapter 11, 11.3.1, 11.3.2, 11.3.3, 11.4.3
[34] Ibid., Chapter 11, Box 11.1, 11.2.3
[35] Ibid., Chapter 11, 11.6
[36] Ibid., Technical Summary, Figure TS.20, Figure TS.21; Chapter 5, 5.3.1, 5.3.2, Figure 5.7, Figure 5.8, Table 5.1
[37] Ibid., Chapter 5, 5.3; Chapter 10, 10.2, 10.8
[38] Ibid., Chapter 5, 5.4.1, 5.4.3, 5.4.4, Figure 5.14
[39] Ibid., Chapter 8, 8.4, Box 8.4, 8.5; Chapter 9, 9.6, 9.9; Chapter 13, 13.5, 13.9
[40] Ibid., Technical Summary, TS.5.2; Chapter 8, 8.4, 8.5
[41] Ibid., Technical Summary, Figure TS.31, Box TS.15; IPCC, 2022: Annex II: Definitions, Units and Conventions [Al Khourdajie, et al. (eds)]. In IPCC, 2022: ***Climate Change 2022: Mitigation of Climate Change***. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.021
[42] IPCC, 2022. ***Climate Change 2022: Mitigation of Climate Change***, Chapter 6, 6.4; Chapter 7, 7.4; Chapter 8, 8.5; Chapter 9, 9.10; Chapter 10, 10.8
[43] Ibid., Summary for Policymakers, D.3.2; Chapter1, 1.4, 1.6; Chapter3, 3.6; Chapter 4, 4.2; Chapter 5, 5.2; Chapter 11, Box 11.1; Chapter 14, 14.3; Chapter 15, 15.2, 15.5, 15.6
[44] Ibid., Chapter 8, Figure 8.4, Supplementary Material SM8.1; Chapter 17, Figure 17.1
[45] Ibid., Chapter 8, 8.5.1, Box 8.3; Chapter 13, 13.7; Cross-Chapter Box 9 | Case studies of integrated policymaking for sector transitions

[46] Ibid., Chapter 8, 8.5.1
[47] Ibid., Chapter 13, 13.2, 13.6, 13.8, 13.9
[48] Ibid., Chapter 13, 13.2, 13.5, 13.7, 13.9
[49] Ibid., Chapter 8, 8.4, 8.5, 8.6; Chapter 13, 13.3, 13.4
[50] Ibid., Technical Summary, Box TS.13; Chapter 13, 13.6; Chapter 9, 9.9
[51] Ibid., Summary for Policymakers, Figure SPM.9; Chapter 14, 14.4; Chapter 15, 15.1, 15.2, 15.3, 15.4
[52] Ibid., Chapter 7, 7.6
[53] Ibid., Chapter 15, 15.2, 15.3
[54] Ibid., Chapter 12, 12.6.4
[55] Ibid., Chapter 12, 12.6.4; Chapter 15, 15.2, 15.3, 15.4; Chapter 9, 9.9
[56] Ibid., Chapter 8, 8.5.4
[57] Ibid., Chapter 8, 8.4, 8.5
[58] Ibid., Chapter 4, 4.4; Chapter 5, Figure 5.14; Chapter 13, 13.9; Chapter 14, 14.5; Chapter 15, 15.6; Chapter 16, 16.3, 16.4, 16.5, Cross-Chapter Box 12 | Transition Dynamics
[59] Ibid., Summary for Policymakers, Figure SPM.6; Chapter 2, 2.4.3, 2.6.2; Chapter 4, 4.2.5; Chapter 5, 5.1, 5.2, 5.3, 5.4, Figure 5.4, Figure 5.10, Table 5.2, Table 5.2; Chapter 7, 7.4.5; Chapter 8, 8.2, 8.4; Chapter 9, 9.4; Chapter 10, 10.2; Chapter 12, 12.4; Technical Summary, Figure TS.20
[60] Ibid., Summary for Policymakers, Figure SPM.6; Chapter 5, 5.3.1, 5.3.3, 5.4, Figure 5.7, Figure 5.13, Table 5.1, Table 5.5, Table 5.2; Chapter 8, 8.4; Chapter 9, 9.5; Chapter 10, 10.2; Chapter 11, 11.3, 11.4, Table 11.6; Technical Summary, Box TS.12
[61] Ibid., Chapter 6, 6.7.6
[62] Ibid., Chapter 9, 9.9; Chapter 16, 16.1, 16.3, 16.4, 16.6; Chapter 16, Cross-Chapter Box 11 | Digitalization: efficiency potentials and governance considerations
[63] Ibid., Chapter 16, 16.2, 16.3, 16.4, 16.5, 16.6
[64] Ibid., Chapter 4, 4.4; Chapter 14, 14.2; Chapter 16, 16.5.3
[65] Ibid., Summary for Policymakers, C.10.4; IPCC, 2022: Annex I: Glossary [van Diemen, R., et al. (eds)]. In IPCC, 2022: ***Climate Change 2022: Mitigation of Climate Change***. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.020; IPCC, 2022: Annex II: Glossary [Möller, V., et al. (eds.)]. In: ***Climate Change 2022: Impacts, Adaptation and Vulnerability***. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2897–2930, doi:10.1017/9781009325844.029

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VOLUME III

WHAT THE LATEST SCIENCE ON CLIMATE CHANGE MITIGATION MEANS FOR CITIES AND URBAN AREAS

SUMMARY FOR URBAN POLICYMAKERS

ADVISORS: CITY OFFICIALS

Hamidou Baguian
City of Bobo-Dioulasso, Burkina Faso

Zach Baumer
City of Austin, USA

Lia Cairone
City of New York, USA

Yoonjin Cho
City of Seoul, Republic of Korea

Leticia Clemente
City of Baguio, Philippines

Ricardo Cofré
City of Peñalolén, Chile

Tiffany Crawford
City of Melbourne, Australia

Nisreen Daoud
Municipality of Greater Amman, Jordan

Manuel de Araújo
City of Quelimane, Mozambique

Johan De Herdt
City of Antwerp, Belgium

Gillian Dick
City of Glasgow, United Kingdom'

Sharon Dijksma
City of Utrecht, The Netherlands

João Dinis
City of Cascais, Portugal

Roshanie Dissanayake
City of Colombo, Sri Lanka

Tamsin Faragher
City of Cape Town, South Africa

Yann Françoise
City of Paris, France

Erika Alejandra Fregoso Cuenca
City of Guadalajara, Mexico

Natalia Garay
Metropolitan Region of Santiago, Chile

Katrina Graham
City of Hobart, Australia

Solape Hammond
State of Lagos, Nigeria

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City of Canelones, Uruguay

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City of Asheville, USA

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City of Buenos Aires, Argentina

Bryan Ho-Yan
City of Guelph, Canada

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City of Zagreb, Croatia

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City of Malmö, Sweden

Kunal Khemnar
City of Pune, India

Sonia Knauer
City of Belo Horizonte, Brazil

Felipe Mandarino
City of Rio de Janeiro, Brazil

Carolina Manriquez
Metropolitan Region of Santiago, Chile

Sri Maryati
City of Palembang, Indonesia

Daniela Mastrángelo
City of Rosario, Argentina

Anna Mitchell
City of Sydney, Australia

Ahmad Zabri bin Mohamed Sarajudin
City of Seberang Perai, Malaysia

Rosli Nordin
City of Kuala Lumpur, Malaysia

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City of Kisumu, Kenya

Herman Padonou
National Association of Municipalities of Benin

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City of Lima, Peru

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City of Malmö, Sweden

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Irma Ventayol i Ceferino
City of Barcelona, Spain

Anthony Xenon Walde
City of Makati, Philippines

Fernand Yapi Cocody
City of Abidjan, Cote d'Ivoire

ADVISORS: BUSINESS LEADERS

Per Boesgaar
Arup

Brodie Boland
McKinsey & Company

John Carstensen
Mott MacDonald

Carlo Castelli
Jacobs

Bruce Chong
Arup

Henning Diederichs
Institute of Chartered Accountants in England and Wales

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Wood

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Arup

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WSP

Amanda May
National Grid

Dhiren Naidoo
Wood

Emily Ojoo-Massawa
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Diego Padilla-Philipps
WSP

Kirtiman Pathak
McKinsey & Company

Graeme Riddell
Marsh

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Arup

Kaitlin Shilling
Arup

Ben Smith
Arup

Stephanie Tseng
Mott MacDonald

Stephane Villemain
Ivanhoé Cambridge

Christine Wissink
Wood

David Wright
National Grid

Daniela Zuloaga
Arup

ENDORSEMENTS

TEAM

Madhurya Balan
Indian Institute for Human Settlements

Amir Bashir Bazaz
Indian Institute for Human Settlements

Beena Chester
Resilience First

Gemma Cowan
Resilience Rising

Andy Deacon
Global Covenant of Mayors

Sarah Grumulaitis
Arup

Nicola Iezza
ICLEI – Europe

Amy Leitch
Arup

Marni McGregor
Global Covenant of Mayors

Malavika Navale
Indian Institute for Human Settlements

Prathijna Poonacha Kodira
Indian Institute for Human Settlements

Giorgia Rambelli
Global Covenant of Mayors

Chandni Singh
Indian Institute for Human Settlements

Debabrat Sukla
Indian Institute for Human Settlements

Swati Surampally
Indian Institute for Human Settlements

Padma Venkatraman
Indian Institute for Human Settlements

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CONSOLIDATED VOLUMES I, II & III

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