Book Review

Climate Change 2022 Mitigation of Climate Change: Urban System

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change 2042pp.

Reviewed by

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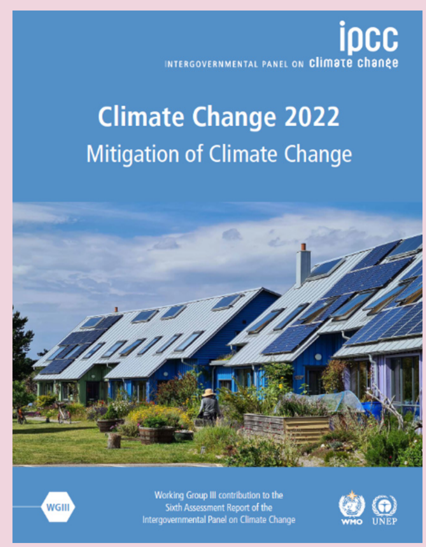
Received: 5 Nov 2023 ; Revised from: 26 Mar 2023 ; Accepted: 27 Mar 2023

Print-ISSN: 2228-9135, Electronic-ISSN: 2258-9194, https://doi.org.10.56261/built.v21.251630

Summary

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR6) assesses literature on the scientific, technological, environmental, economic, and social aspects of mitigation of climate change. The IPCC-AR6 integrates factors of developments in the UN Framework Convention on Climate Change (UNFCCC) process. It includes the Kyoto Protocol and the Paris Agreement, and the UN 2030 Agenda for Sustainable Development including the Sustainable Development Goals (SDGs). This paper reviews the urban system and its pathways in transition to the net zero emissions. The key messages of urban mitigation in the IPCC-AR6 are presented. It is found that the urban green and blue infrastructure can contribute to climate resilience through carbon sequestration, emissions reduction, and energy and material efficiency. It also contributes multiple co-benefits. To achieve urban transformational changes, it requires climate finance and engagement of multiple scales of governance. This includes governments and non-state actors. A knowledge gap to achieve net-zero-emissions cities is highlighted, and a case study of climate resilient development in Thailand's building sectors towards a low carbon society is discussed.



Keywords: Urban climate change mitigation, IPCC, net zero emissions, co-benefits, synergy, and trade-off.

Introduction

This paper reviews the critical findings of IPCC-AR6 for urban systems, which are useful to policy makers, administrators, people involved in construction including city/building designers to achieve zero carbon cities or buildings. Urbanization is associated with higher incomes and higher energy and material consumption. Urban population growth in future will happen in developing countries. Its per capita emissions are low but expected to rapidly increase. Changes in incomes and lifestyles result in increasing construction of infrastructure and the built environment. New cities when designed and constructed, it will lock-in future urban greenhouse gas (GHG) emissions. Thus, they must be properly designed. GHG emissions in urban are only carbon dioxide (CO_2) and methane (CH_4).

Its emissions share in global emissions is increasing. The IPCC-AR6 reported that urban emissions were estimated at 29 $GtCO_2$-eq in 2020. Urban emission share in national emissions globally increased from 56% in 2000 to 62% in 2015. From 2000 to 2015, global urban emissions per capita increased from 5.5 to 6.2 tCO_2-eq per person. Africa increased from 1.3 to 1.5 tCO_2-eq per person (22.6%). Asia-Pacific region increased from 3.0 to 5.1 tCO_2-eq per person. Eastern Europe and West-Central Asia regions increased from 6.9 to 9.8 tCO_2-eq per person. Latin America and Caribbean regions increased from 2.7 to 3.7 tCO_2-eq per person. Middle East region increased from 7.4 to 9.6 tCO_2-eq per person.

The future share of urban emissions is expected to increase. Global urban emissions are projected to increase from 29 $GtCO_2$-eq (2020) to 34 $GtCO_2$-eq (2050). To limit global warming to 1.5-degree Celsius, high electrification, high energy and material efficiency, high renewable energy share, and behavior changes are key measures of near zero emissions at 3 $GtCO_2$-eq in 2050. Under an aggressive scenario to limit global warming to 2-degree Celsius, urban emissions in 2050 will be 17 $GtCO_2$-eq in 2050.

The construction of new infrastructure using conventional technologies will increase emission, ranging from 8.5 $GtCO_2$ to 14 $GtCO_2$ per year by 2030. Thus, there is an urgent action to integrate mitigation and adaptation measures to cope with urban climate resilience. Urban mitigation actions have benefits on employment and economic competitiveness including multiple co-benefits to achieve net zero emissions in urban system.

The integrated spatial planning for compact city and resource efficiency includes co-location of housing and jobs, shared space, and transit-oriented development (TOD). These measures could mitigate up to 26% of urban emissions in 2050 compared to the business-as-usual (BAU). Compact cities typically have shortened distances between housing and jobs, and modal shift (towards walking, cycling, and low emissions public transportation), utilize passive cooling/heating in buildings, and urban green infrastructure. Finally, urban transformational change requires engagement of multiple scales of governance. It includes governments and non-state actors. Partnerships between cities and institutions (international, and governments), networks, and local stakeholders play a key role in mobilizing climate finance for urban transformational change.

Sections in the review are organized as follows: trends in urbanization, co-benefits and trade-offs of urban mitigation actions, urban systems and related emissions, urban mitigation options, a roadmap for integrating mitigation strategies, knowledge gaps and research needs, governance, institutions, and finance, and conclusions.

Trends in Urbanization

In the IPCC-AR6, six trends in urbanization are found important. First, the size and relative proportion of the population continues to increase. Second, urban population growth in developing countries and least-developed countries is increasing. Third, small and medium cities are a main type of urban system. Fourth, there is a trend of megacities and extended metropolitan regions. Fifth, decreasing population is found in several cities across the world. Thus, shrinking urban populations could offer retrofitting opportunities. Sixth, urbanization in emerging economies is characterized by informality and an informal economy. Figure 1 shows the population of the world by area and size in 2018. Currently urban areas are a net source of CO_2 emissions because emissions from sources are higher than negative emissions from sink.

Co-benefits and Trade-offs of Urban Mitigation Actions

In urban mitigation measures, co-benefits are the primary concerns. Co-benefits are defined as "the positive effects that a policy or measure aimed at one objective might have on other objectives, thereby increasing the total benefits to the society or environment." The IPCC-AR5 (2008-2014) presented co-benefits of urban mitigation options. For example, local air quality and public health are improved. It is found that productivity increases in urban centers. The long-term effects of sustainable development (SD) are related to climate resilience. Figure 2 summarizes synergies and tradeoffs related to UN SDGs for the mitigation options in urban areas. The IPCC-AR6 (2015-2023) shows that mitigation options for urban systems have synergies linked to UN

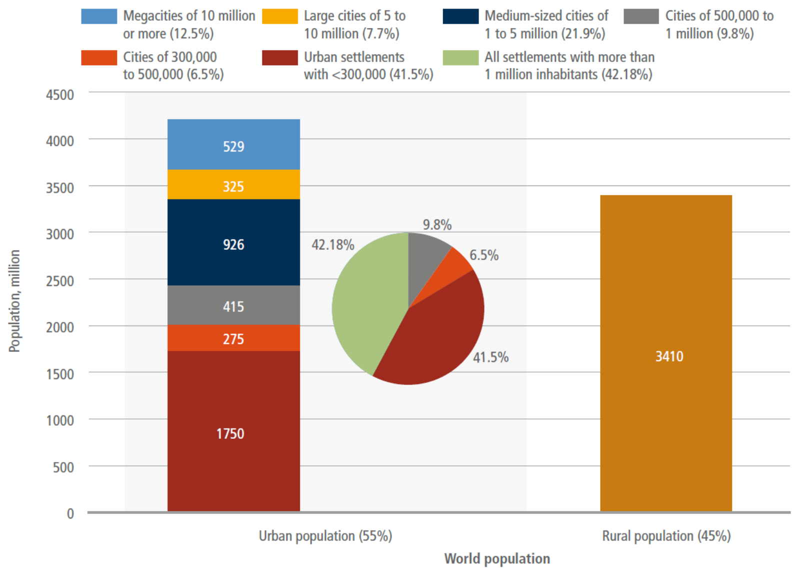


Figure 1. World population by class of urban in 2018.

SDGs. However, some measures produce both synergies and trade-offs, which need further investigation.

Mixed-use compact development has benefits on improving productivity while urban spatial structures with more walking distances and vehicles reliance have trade-offs. Urban climate resilience measures can mitigate health impacts to low-income people. Electrification with renewable electricity can reduce outdoor air pollution and improve indoor air quality by electric heating and cooking devices.

Coupling Mitigation and Adaptation

The IPCC-AR6 shows several studies assessing the synergies and co-benefits of mitigation and adaptation actions. Co-benefits happen when the mitigation actions result in increasing adaptation targets. In contrast, the trade-offs happen when mitigation measures reduce

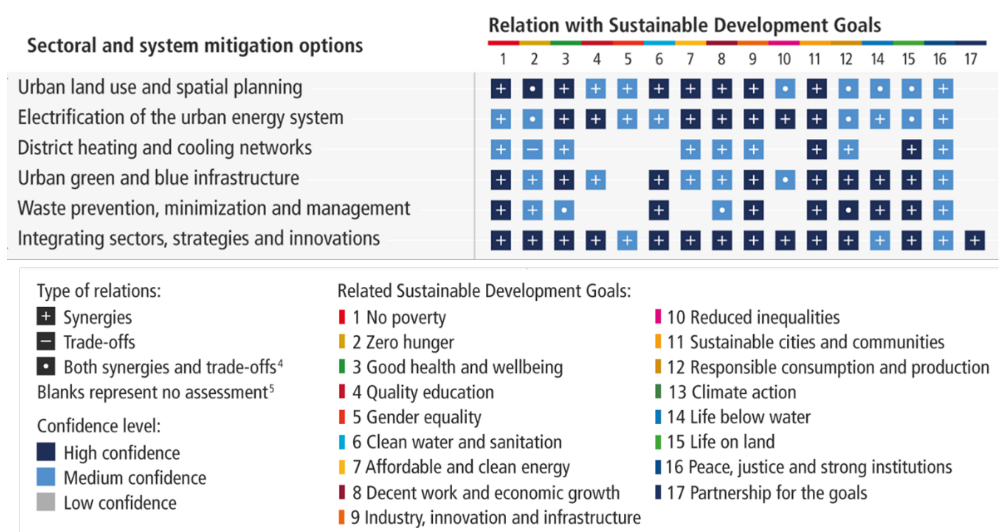


Figure 2. Co-benefits, synergies, and trade-offs of mitigation actions in urban areas.

adaptation targets. The magnitudes of co-benefits and trade-offs vary depending on several factors. These factors are urban planning, buildings, energy, green and blue infrastructure, transportation, behavior, governance, waste, and water. High-density areas with less green and open spaces can increase urban heat island (UHI) effect. Some mitigation measures may increase costs to poor people and marginalized groups; therefore, it reduces adaptive capacity of those people. For instance, the phasing out old cars policy may affect poor people. Urban green infrastructure such as trees and greenspaces reduce energy demand as well as sequester carbon. It also provides a benefit of reducing heat island effect.

Urban Systems and Related Emissions

The IPCC-AR6 investigates how urban land use, the built environment and infrastructure reduce emissions through energy and material efficiency. The structure of the built environment for transport and building energy use affects the emissions. Figure 3 shows urban population density by decade (1970–2010). It is found that urban population densities are declining while the global urban areas expand double. The decrease in urban densities happens simultaneously with an increase in urban sprawl. (see Figure 3). Figure 4 shows the percentage of total urban land expansion. The nature in Figure 4 includes forest, grassland, shrubland, water, and bare soil.

Trends in Urban Greenhouse Gas Emissions

The IPCC-AR6 estimates urban GHG emissions towards 2100, based on a consumption-based approach by using multiple datasets together with the scenarios of selected Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathway (RCP). Figure 5 presents emissions per capita in 2015. Figure 6 presents key emission metrics and trends for both 2000 and 2015. Details of SSP-RCP scenarios are described in the IPCC-AR6.

The IPCC-AR6 summarized four key trends of urban emissions. (i) Total urban CO_2-eq emissions (CO_2 and CH_4) were estimated to be 25 $GtCO_2$-eq, accounting for 62% of the global total in 2015, and those emissions increased to 29 $GtCO_2$-eq in 2020, accounting for 67–72% of global emissions. (see Figure 6) (ii) The increase of emissions is driven by increases in area and per capita emissions. (iii) The share of urban CO_2-eq emissions and national emissions in global total between 2000 and 2015 increased in the Asia and Pacific countries. In contrast, the share decreased for developed countries. (iv) In terms of capita emissions, developed countries produce nearly seven times higher than Africa.

Scenarios of Future Urban Greenhouse Gas Emissions

When the key trends of urban emissions are identified, future urban emissions are estimated. The IPCC-AR6 estimates urban land areas expanding as much as 211% in 2050 under SSP5, known as “fossil fuel-intensive development”. The smallest estimated urban extents happen in SSP3, known as “regional rivalry”. However, these estimates still have large uncertainties and variations such as the rate of urban expansion, the level of economic development and the estimated population growth. Under SSP1, known as “sustainability”, global urban extents could reach one million km^2 in 2050. Details of projection of global urban land in 2050 are presented in the IPCC-AR6. Then, this information is used in estimation of global urban areas and global emissions.

Emissions from Global Urban Areas

In the IPCC-AR6, only seven SSP-RCP scenarios are selected. The GHG emissions in selected SSP-RCP climate storylines are shown in Figure 7. The SSP1-RCP1.9 scenario is based on green growth. Urban GHG emissions are projected to rise to 34.0 $GtCO_2$-eq (SSP2-RCP4.5) or 40.2 $GtCO_2$-eq (SSP3-RCP7.0) in 2050 under moderate to low mitigation efforts. The SSP5-RCP8.5 emissions pathway, which is without any decarbonization, shows the most carbon lock-in. The remaining five SSP-RCP emissions pathways are in between the SSP1-RCP1.9 and the SSP5-RCP8.5 emissions pathways. Urban land expansion in future is estimated to increase heat island effects and increasing night-time extreme temperatures.

Urban Mitigation Options

The IPCC-AR6 highlights urban mitigation options into three main strategies: (i) decreasing urban energy demand and material use, (ii) electrification and switching to zero carbon energy, and (iii) increasing urban carbon uptake/sink by green and blue infrastructures. However, barriers in the urban systems are hard to remove.

The lifespans of urban infrastructures and the built environment are long. It can highly lock in carbon not only during construction but also during operations and demolition after operation. Urban structures can lock in carbon in the design, lay out, and construction processes by several forms. Multiple interactions in the urban systems can create inertia and path dependency that are difficult to break. (see Figure 8). To avoid carbon lock-in, it involves decision/authority beyond the administrative boundaries of cities. However, urban building codes are found to be the most effective measure of energy and material efficiency for buildings.

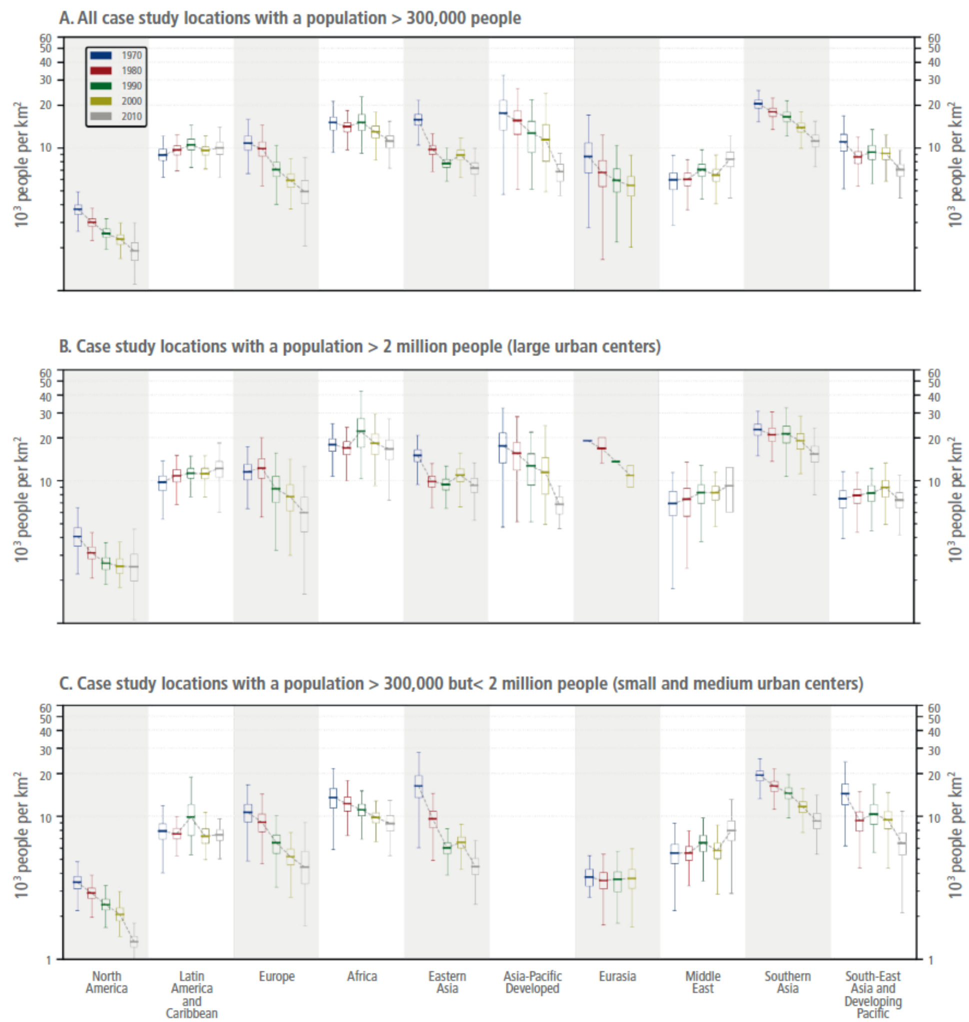


Figure 3. Urban population density by decade (1970–2010), grouped by IPCC.

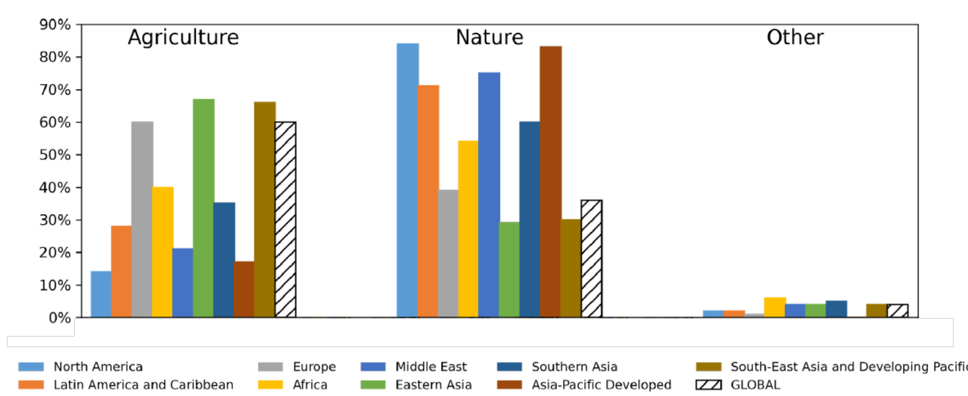


Figure 4. Percent of total urban land expansion from other land covers, sorted by IPCC.

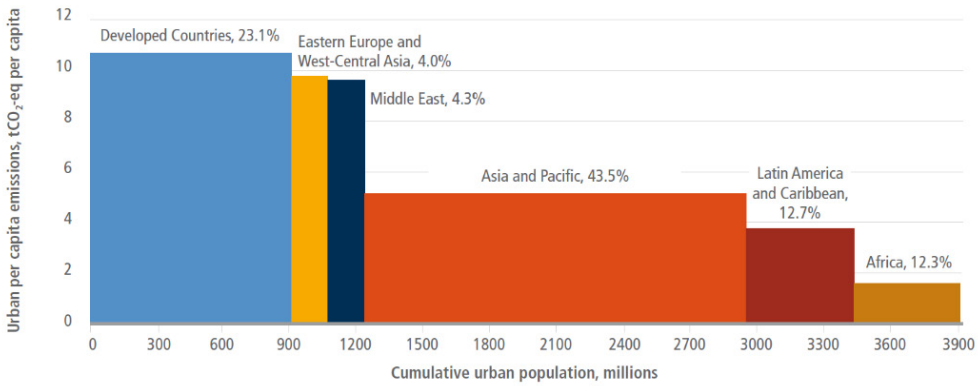


Figure 5. Average urban emissions per capita in 2015.

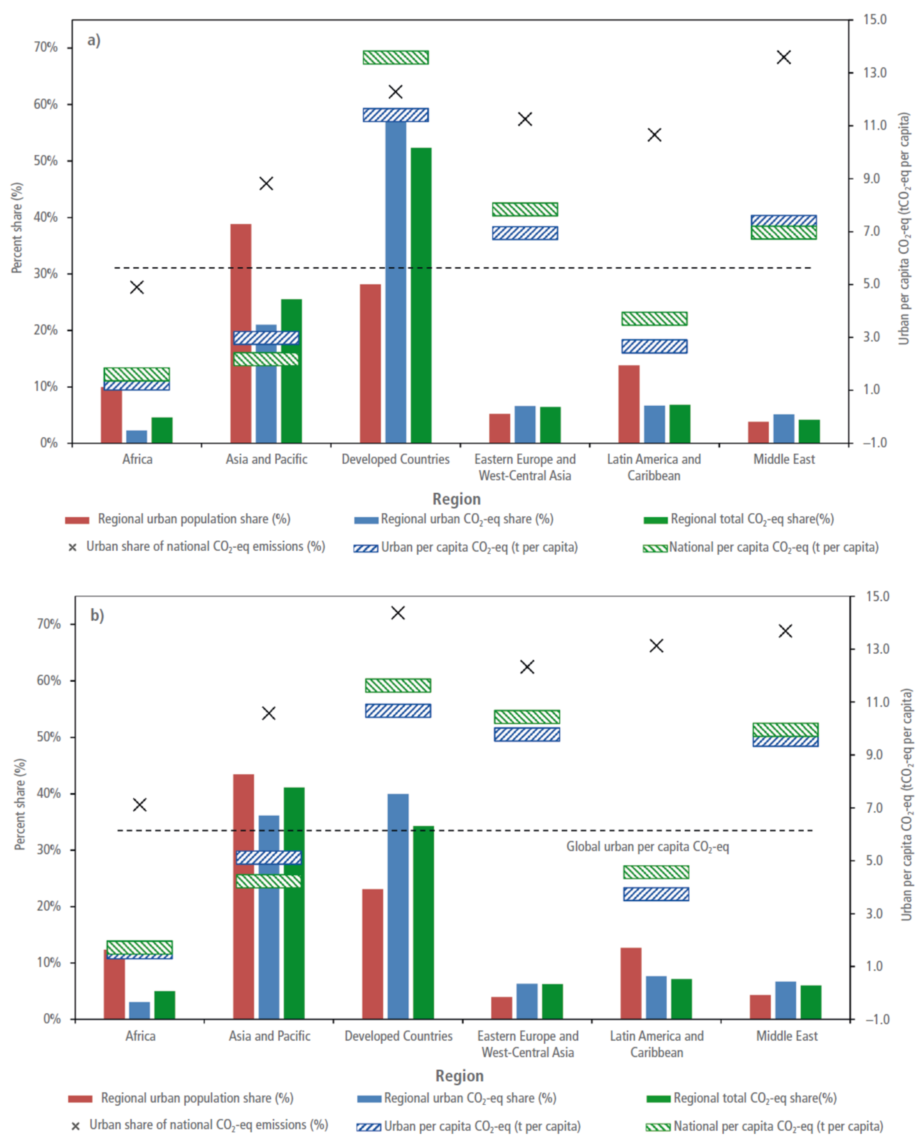


Figure 6. Key urban emission metrics and trends for six regions (a) 2000 and (b) 2015.

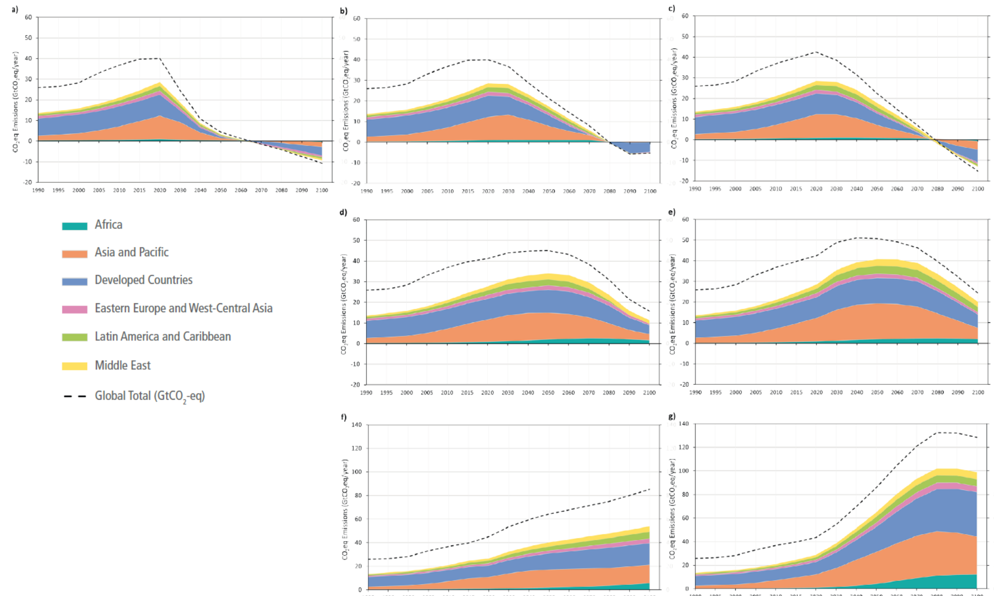


Figure 7. Emissions from global urban areas in seven SSP-RCP scenarios.
Notes:
(a) SSP1-RCP1.9,
(b) SSP1-RCP2.6,
(c) SSP4-RCP3.4,
(d) SSP2-RCP4.5,
(e) SSP4-RCP6.0,
(f) SSP3-RCP7.0,
(g) SSP5-RCP8.5.

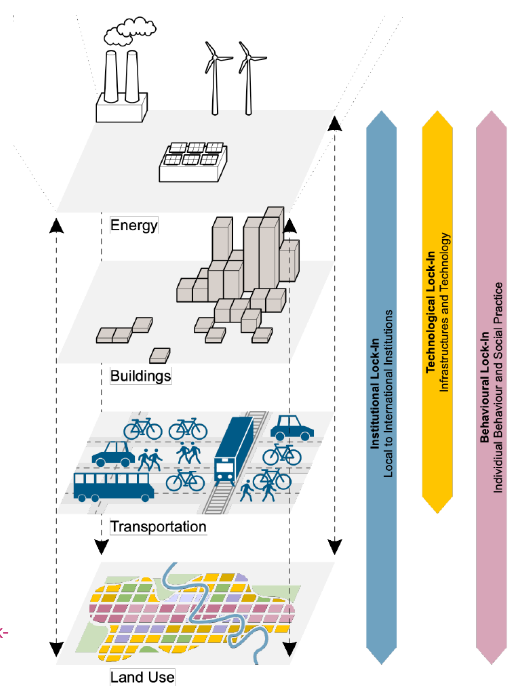


Figure 8. Cascade of urban lock-in from multiple interactions.

The urban green infrastructure (UGI) has been highlighted in the IPCC-AR5 as a key mitigation option. It includes several options such as street trees, parks, and sustainable urban drainage system to building green roofs or green facades, green walls, and vertical forests. These options offer multiple co-benefits.
The IPCC-AR6 recommends that the compact and walkable infrastructures contribute to emissions mitigation while the dispersed urban form can result in high emissions. Four dimensions of urban form are found important: density, land-use mix, connectivity, and accessibility. A low-carbon city may have these features: (i) co-located high densities of housing, jobs; (ii) high mixed land uses; (iii) high connectivity; and (iv) high accessibility by short distances and less times using transport modes.

A Roadmap for Integrating Mitigation Strategies

Urban mitigation strategies vary depending on land use, spatial form, development level, and state of urbanization. GHG emissions mitigation for established cities can be achieved by repurposing, or retrofitting existing buildings, encouragement of modal shift, urban electrification and increasing urban densities. For rapidly growing cities, new developing infrastructures can avoid higher future emissions by co-located jobs and housing, effective transportation using low-carbon technologies, and urban electrification. The electrified actions include transportation, cooling, heating, cooking, and so on. Increasing green and blue assets can contribute to urban mitigation. New and emerging cities, when properly designed, can achieve net zero emissions.

Effective policies and measures of urban mitigation strategies vary depending on urban factors. Mitigation strategies in urban are effective when multiple interventions are implemented simultaneously.

Knowledge Gaps and Research Needs

The IPCC-AR6 identifies knowledge gaps and research needs. Understanding city level and its data is a gap. There is a gap on how to integrate urban mitigation actions into planning and design processes of cities that have yet to be built. Urban transformational changes to climate resilience remain the key gap. Thus, research needs are (i) drivers for emissions and understanding how sectors interact in cities, (ii) the relationship between climate and urban processes, and (iii) urban transformation towards climate resilience.

Governance, Institutions, and Finance

Climate governance at multiple levels is mandatory to green cities and emissions targets. The non-state actors such as businesses and private could contribute to global net-zero emissions. As of 2019, it is reported that more than 10,000 cities, regional governments, states and provinces showed emission reduction by developing climate action plans and reporting corresponding emissions. Financing urban mitigation is another important measure. It can avoid lock-in emissions in infrastructures and the built environments. However, it requires multi-level governance responses. The transformational changes are influenced by outside factors. These factors are lack of authorities, high costs, lack of funding for mitigation, conflict-of-interest policy objectives, silence to climate actions. etc.

A Case Study of Climate Resilient Development in Thailand's Building Sector

Building design and urban planning play crucial roles in reducing the impact of climate change and adapting to future challenges in Thailand, as outlined in various national development plans such as the 20-Year National Strategy, the 13th National Economic and Social Development Plan, the National Reform Plan, the Environmental Quality Management Plan, and the Thailand's National Climate Change Act. Moreover, Thailand has set a target for net zero emissions by 2065. It has enforced Building Energy Code for obtaining construction permits for buildings of 2,000 square meters or more as specified in the regulations of Ministry of Energy.

The building and construction industry in Thailand can contribute to urban climate resilience, which will slow down and limit the severity of climate change impacts. The green building standards, low-carbon buildings, and passive heating/cooling designs, such as TREES by the Thai Green Building Institute (TGBI), have been widely adopted. One of the main objectives of these standards is to reduce energy consumption and other resources in buildings, which will help reducing GHG emissions. The design and renovation of buildings to be green buildings aims to minimize environmental impact as much as possible, covering efficient energy use and harmful impact reduction while yielding positive effects on climate and the natural environment. This improves the quality of life for occupants. Such operations must consider the long-term impacts throughout the building's lifecycle, from site selection, design, construction, usage, maintenance, and modifications to demolition. Continuous development is necessary to enhance sustainable, environmentally friendly building design and construction quality.

In terms of adaptation, designing buildings and built environments is to reduce the long-term occurrence of urban heat islands, requiring cooperation from all stakeholders, especially for large-scale projects such as urban planning revisions, increasing green spaces within cities, installing biofiltration planter boxes in urban areas to reduce stormwater runoff and filter pollutants, as well as constructing flood barriers. These endeavors must primarily be undertaken by government bodies or organizations capable of investment. Meanwhile, businesses and citizens will participate in considering investments in buildings to help reduce energy costs, thereby reducing environmental impacts and enhancing their resilience to prepare for living in a warming world, which is already occurring and likely to intensify.

Examples of adaptation projects to cope with a warming world include establishment of a provincial-level greenhouse gas reduction guideline by the Thailand Greenhouse Gas Management Organization (TGO). Additionally, there has been an analysis of suitable and feasible measures to reduce greenhouse gas emissions in line with province's context, along with the development of comprehensive greenhouse gas reduction plans of the province. TGO has been implementing these projects since 2016, covering a total of seventeen provinces in Thailand. These initiatives aim to support Thailand's transition towards a low carbon society, fostering sustainable development.

Conclusions

Urban systems and settlements are important to climate resilience. The most important urban mitigation plans include consideration of long lifespan of layout and infrastructures. City plans, including planning of land use, modes of transport, and the built environment, are found to be the most impactful emissions reduction and priorities. Options to reduce emissions in all cities include sustainable production and consumption, electrification, and improving carbon uptake and carbon sink. In established cities, options include improving or retrofitting buildings, supporting walking, cycling, and public transport. Options in rapidly growing cities include avoiding future emissions by co-locating jobs and housing and transformational changes to low emission technologies. New cities need to design space for energy-efficiency infrastructure and services. The long lifespan of urban infrastructures will lock in behavior and corresponding emissions. Co-benefits, synergies and trade-offs of urban mitigation options need to be carefully investigated. Finally, key future research needs are highlighted, and a cast study of climate resilient development in the building sector in Thailand towards a low carbon society is discussed.

CRediT Authorship Contribution Statement

Bundit Limmeechokchai, Chompoonut Kongphunphin, Pornphimol Winyuchakrit, Piti Pita, Pemika Misila: Conceptualization, Methodology / Study design, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing –original draft, Writing –review and editing, Visualization, Supervision, Project administration, Funding acquisition.

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