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The Climate Technology Progress Report 2023

Speed and Scale for Urban Systems Transformation

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GLOSSARY

The entries in this glossary are primarily taken or modified from definitions provided by reports published by the Intergovernmental Panel on Climate Change (IPCC).

Climate technology	Climate technologies are those that help us reduce greenhouse gases and adapt to the adverse effects of climate change. (See definition of technology below).
City	An urban centre is defined by a density of at least 1,500 inhabitants per km2 and a total population of at least 50,000, (UN Habitat 2020)
Deployment	The act of bringing technology into effective application, involving a set of actors and activities to initiate, facilitate and/or support its implementation (IPCC 2022).
Diffusion	The spread of a technology across different groups, users or markets over time (IPCC 2022).
Enabling environment	The set of resources and conditions within which the technology and the target beneficiaries operate. The resources and conditions that are generated by structures and institutions that are beyond the immediate control of the beneficiaries should support and improve the quality and efficacy of the transfer and diffusion of technologies (Nygaard and Hansen 2015).
Feasibility	The potential for a mitigation or adaptation technology to be implemented. Factors influencing feasibility are context-dependent, temporally dynamic and may vary between different groups and actors. Feasibility depends on geophysical, environmental-ecological, technological, economic, sociocultural and institutional factors that enable or constrain the implementation of an option. The feasibility of options may change when different options are combined and increase when enabling conditions are strengthened (IPCC 2022).
Governance	A comprehensive and inclusive concept of the full range of means for deciding, managing, implementing and monitoring policies and measures. Whereas government is defined strictly in terms of the nation State, the more inclusive concept of governance recognizes the contributions of various levels of government (global, international, regional, subnational and local) and the contributing roles of the private sector, of non-governmental actors and of civil society in addressing the many types of issues facing the global community (IPCC 2018).
Innovation	Both the processes of research and development and the commercialization of the technology, including its social acceptance and adoption (IPCC 2000). Furthermore, innovation is seen as the process of generation, acceptance and implementation of new ideas, processes, products or services (Thompson 1965) as well as an outcome – any thought, behaviour or thing that is new (Barnett 1953).
Innovation system	All important economic, social, political, organizational and other factors that influence the development, diffusion and use of innovations (IPCC 2000).
Institution	Rules, norms and conventions that guide, constrain or enable human behaviours and practices. Institutions can be formally established, for instance through laws and regulations, or informally established, for instance by traditions or customs. Institutions may spur, hinder, strengthen, weaken or distort the emergence, adoption and implementation of climate action and climate governance (IPCC 2022).
Technology	Technology is "a piece of equipment, technique, practical knowledge or skills for performing a particular activity" (IPCC 2000). It is common practice to distinguish between three different components of technology (Müller 2003): • Hardware: the tangible component, such as equipment and products • Software: the processes associated with the production and use of the hardware • Orgware: the institutional framework, or organization, involved in the adoption and diffusion process of a technology These three components are all part of a specific technology, but the relative importance of each component may vary from one technology to another.
Technology transfer	The exchange of knowledge, hardware and associated software, money and goods among stakeholders, which leads to the spread of technology for adaptation or mitigation. The term encompasses both the diffusion of technologies and technological cooperation across and within countries (IPCC 2022a).
Transformative change	A system-wide change that requires the consideration of social and economic factors which, together with technology, can bring about rapid change at scale (IPCC 2018).
Transition	The process of changing from one state or condition to another in a given period of time. Transition can occur in individuals, firms, cities, regions and nations, and can be based on incremental or transformative change (IPCC 2022; IPCC 2022a).

CONTENTS

FOREWORD

This year is set to conclude the first Global Stocktake, which was established as a process to allow nations and other stakeholders to evaluate collective progress in meeting the goals of the Paris Agreement. It not only evaluates where we are at, but identifies areas that need more consideration, and which efforts should be targeted to accelerate climate action to create the urgently needed transformational changes.

It is clear that the current pace and scale of global action is insufficient to tackle climate change. Even though global commitment to the Paris Agreement is strong, there is an urgent need to accelerate our actions. To strengthen the global response to the threat of climate change, governments need to support system transformations that mainstream climate resilience and low greenhouse-gas emission development. We need to ensure not only a rapid scaling up of the implementation and use of climate technologies, but that these technologies, in addition to addressing the climate objectives, also have significant co-benefits for our systems as a whole and are informed by the local context.

More effective and strategic international cooperation on technology development and transfer is essential to enable the rapid system transformations that are required. Cost reductions and increased funding for key technologies can enable greater deployment in all geographic areas, particularly in developing countries. Understanding how these transformations can be accelerated, the mechanisms, gaps, and context-specific conditions is crucial.

The focus of the 2023 edition of the 'Climate Technology Progress Report' is on climate technologies for the urban and infrastructure system, zooming in on case studies from Asia, where strong synergies exist for mitigation, adaptation, and high co-benefits for socio-economic development. More than half of the world's population lives in cities and towns, and it is projected that by 2050, 6.6 billion people, accounting for 68 per cent of the global population, will be living in urban areas. The report highlights that progress of climate technology in an Asian urban setting is deeply contingent on the presence of robust urban infrastructure such as transport systems, water supply and energy distribution networks. Climate technology champions and local governments are essential for integrating climate technology transfer priorities into long-term urban development setting ambitious targets. Finally, the report highlights the necessity to embrace a new paradigm for urban infrastructure investment such as aggregation, green and climate bonds, impact and innovation funds and gender lens investments.

This year's report is produced and published as a collaboration between the UNEP Copenhagen Climate Centre and the UNFCCC Technology Mechanism, comprising the Technology Executive Committee and the Climate Technology Centre and Network. The report aims to enhance our understanding of the progress being made on technology development and transfer, progress enablement, and the need for gap filling, to assist decision makers in their choices for strategic and catalytic actions and investments, and for Parties to use the report's findings in discussions of technology development and transfer under the UN Climate Convention and the Paris Agreement.

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EXECUTIVE SUMMARY

The world is at a critical turning point in the battle against the triple planetary crisis of climate change, biodiversity loss and pollution, a crisis that knows no boundaries and has cross-generational impacts. The number of extreme weather events over the last 30 years has been staggering, and 2023 has been no exception. It is evident, though, that current levels of climate technology implementation are inadequate to address this challenge. Meeting national and international climate targets requires efficient and rapid scaling up of the implementation and use of climate technologies, which, in addition to climate objectives, also have significant co-benefits.

2023 not only falls within a period of transformation to a low-carbon, more resilient future with reduced emissions while adapting to the climate impacts, but also marks the conclusion of the first Global Stocktake. The Global Stocktake was established under the United Nations Framework Convention on Climate Change (UNFCCC) process to assess and take stock of the global response regarding the extent and type of progress made towards meeting the goals of the Paris Agreement. The Global Stocktake Synthesis Report reveals that much needs to be done to meet the ambitions of the Paris Agreement. As part of the Global Stocktake process, a Technical Dialogue has provided an assessment of collective progress towards achieving the purpose and long-term goals of the Paris Agreement and informing the Parties about potential areas for updating and enhancing their action and support, as well as for strengthening international cooperation for climate action. One of the key findings of the Technical Dialogue was that in order to strengthen the global response to the threat of climate change, governments need to support system transformations that mainstream climate resilience and low greenhouse gas emissions development. The importance of system transitions is further informed by the fact that more than 56 per cent of the world's population lives in cities and towns. It is projected that by 2050, 6.6 billion people, accounting for 68 per cent of the global population, will be living in urban areas.

Last year, the Climate Technology Progress Report (CTPR), set out a framework and approach for tracking and exploring trends in technology progress. While the 2022 edition applied the approach using data and cases from the Africa region, the 2023 CTPR continues to explore progress and sets out analyses and case studies focused on urban transitions in the context of Asia. Asia houses one of the fastest-growing urban populations and is highly vulnerable to extreme weather and climate change impacts. As the share of population living in urban areas is significantly correlated with per capita income levels, the cases included in the report are selected to represent a variety of different types of cities, representing developed, emerging, and developing countries in Asia.

1.

Technology inclusive system transitions can generate benefits across different sectors and regions, provided they are supported by appropriate enabling conditions, including effective multi-level governance and institutional capacity, policy design and implementation, innovation, and climate and development finance.
By adopting a system transitions framework, it leads to a more holistic view of a group of technologies that can support transition and as a result, is consistent with the understanding that there is no "one-size-fits-all" technological solution or transition. Evaluating synergies and trade-offs of urban technologies through a systems transition framework helps create a better understanding of equity and justice and their roles in paving climate resilient development pathways.

Many technologies, such as cooling technologies in the building sector, show high economic feasibility and large potential to reduce greenhouse gas emissions and/or to reduce climate vulnerability. However, sociocultural, and institutional challenges hinder further upscaling the implementation and use of these technologies. Identifying synergies between and co-benefits of technologies could increase perceptions of desirability and increase opportunities for economic benefits and enhanced equity.

The feasibility assessment undertaken in the report, reveals strong evidence for highly feasible technologies for urban systems. It also reveals gaps between the desirability of technologies, such as nature-based solutions, which have high synergies on mitigation and adaptation, and the need to strengthen institutional dimensions, as well as highlighting more specific features such as the need for gender-responsive approaches. In this way, the work here could serve both to inform the immediate needs of decision makers and as a call for future assessments.

2.

To drive a systemic and transformative urban transition, it is imperative to prioritize comprehensive technological innovations in critical domains, such as urban building, transportation, energy supply, water systems and urban planning.
The progress of climate technology is not exclusively reliant on research and development; instead, it is deeply contingent on the presence of robust urban infrastructure encompassing vital components such as transport systems, water supply and sanitation networks, energy distribution, communication networks, public spaces and buildings.

Recognizing the synergistic benefits of applying innovative climate technologies can help incentivize governments to further enhance the adoption of such technologies. These synergistic benefits include, but are not limited to, improving energy independence and flexibility, addressing local environmental pollution, fostering economic development, and inspiring innovation.

Region-specific climate technologies can play a significant role in facilitating the transition to low-carbon and sustainable practices in local areas, whether they are emerging or mature cities. Cases from the Global South highlight this fact.

3.

Transforming urban systems to mitigate and adapt to the impacts of climate change has become a central matter for municipalities and regional authorities.

Future governance systems should prioritise being flexible, adaptable, and anticipatory to the ever-increasing complexity and uncertainty. This entails, a combination of both hard and soft governance tools to inform policy, as well as creating spaces for open dialogue, building trust, plurality of perspectives, new narratives, and spaces for reflexivity. Thus, future governance inevitably requires new kinds of capacities to steer, coordinate, build partnerships amongst multi stakeholders in various spatial scales, and across sectors.

While implementing climate technology solutions is critical in pursuing low-carbon, climate-resilient development pathways, this depends to a great extent on good governance, adequate resource mobilization and allocation, and institutional capacity-building to attract and finance them effectively. Governance arrangements should include better interlinkages between existing institutions and emerging actors to catalyse sufficient access to public and private resources and nurture partnerships for climate technology implementation, commercialization and scale-up at the city level.

Local leadership and stewardship play a key function in enabling the establishment of comprehensive policies that foster climate technology action as a key component of cities' sustainability agendas. The work of climate technology champions, for example a mayor or chief minister, is essential for supporting the process of integrating climate technology transfer priorities into long-term urban development and climate action plans, leading on clear target setting and milestones to measure progress and keeping systemic changes monitored and accountable for stakeholders, including public and private-sector financiers and international donors.

4.

Successful technology-inclusive initiatives at most times involve a range of policies and instruments at the national and sub-national level, which together with incentives spur replicability across cities.

It is evident that governments at all levels have a key role to play in technology development and transfer during the initial stages through clear policies, investments in research and development and through funding subsidies and other mechanisms. Both climate and development challenges can be addressed simultaneously, to maximize synergies and minimize tradeoffs. However, implementing integrated policies and approaches is challenging in practice and there is still too much of sectoral or supply-side actions to facilitate climate technology development and transfer, more is needed in terms of mainstreaming initiatives in overall city strategies. Moreover, urban development has led to the loss of green and blue spaces. A focus on nature-based solutions in urban planning and policies can address climate change and deliver a range of benefits. Besides technology development, behaviour and lifestyle changes, and urban planning are important interrelated issues, which can facilitate avoiding carbon lock in especially in small and medium-sized cities.

Cities have limited control over development and transfer of many climate technologies, which are handled at the national level. However, local governments have an important role to play, for example by managing land and infrastructure required for technology adoption; allocating parking spaces for charging and making rooftops and land available for solar photovoltaic; demonstrating technologies and taking a lead, for example, by purchasing electric cars for their own use or being the first sites for solar photovoltaic; and by setting ambitious targets and regulations in line with national policies.

Careful attention should be given to consequences from policies to facilitate technology development and transfer, on vulnerable groups, given the high degree of informality of the population, that make up a sizeable portion in Asian cities.

5.

Project-to-project approaches, that are determined by business models and risks assessments, still dominate actions on technology development and transfer. Thus, the business-as-usual mindset prevails, and numerous challenges persist.

New kinds of coordination mechanisms and decision making are needed in both horizontal (among various stakeholders and across different departments and different functional areas) and vertical (at national, regional, and municipal levels). However, these add complexity to a project and overhead costs for investors, which are challenging to allocate, but are necessary in obtaining better overall economic outcomes and an increase in social and economic returns.

Several new approaches are emerging, such as bundling and aggregation, green and climate bonds, impact investment funds, blended finance, and gender lens investment. These ensure that finance is directed where it is needed most, and where it has the most impact.

Given the increasing complexity in investment approaches, project preparation and transaction management are even more important. This will provide critical support services for structuring deals and channelling finance flows. Project development and preparation facilities can play an important role in originating, developing and curating investor-ready pipelines and pushing the investor envelope by helping potential investors to understand and relate to urban development in the climate context.

1.
Introduction

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1.1 CONTEXT

The world is at a critical turning point in the battle against the triple planetary crisis of climate change, biodiversity loss and pollution, a crisis that knows no boundaries and has cross-generational impacts. The number of extreme weather events over the last 30 years has been staggering, and 2023 has been no exception. It is evident, though, that current levels of climate technology implementation are inadequate to address this challenge (IPCC 2022). Meeting national and international climate targets requires efficient and rapid scaling up of the implementation and use of climate technologies, which, in addition to climate objectives, also have significant co-benefits.

2023 not only falls within a period of transformation to a low-carbon, more resilient future and reduce emissions while adapting to the climate impacts but also marks the conclusion of the first Global Stocktake. The Global Stocktake was established under the United Nations Framework Convention on Climate Change (UNFCCC) process to assess and take stock of the global response regarding the extent and type of progress made towards meeting the goals of the Paris Agreement. The Global Stocktake synthesis report (UNFCCC 2023) reveals that much needs to be done to meet the ambitions of the Paris Agreement. As part of the Global Stocktake process, a Technical Dialogue has provided an assessment of collective progress towards achieving the purpose and long-term goals of the Paris Agreement and informing the Parties about potential areas for updating and enhancing their action and support, as well as for strengthening international cooperation for climate action[1]. One of the key findings of the Technical Dialogue was that in order to strengthen the global response to the threat of climate change, governments need to support system transformations that mainstream climate resilience and low greenhouse gas emissions development (UNFCCC 2023).

Further to this, more than 100 developing countries have by now assessed their climate technology needs[2], showing clearly that major gaps remain in the implementation of climate technologies and access to them. The Technology Needs Assessments underline the fact that intensive efforts to support cooperation and innovation are essential throughout the technology cycle and across all sectors and geographies. A better understanding of the status and nature of technology development and transfer globally is needed to enhance climate technology efforts and to enable rapid system transformations, both under the UNFCCC Technology Mechanism and beyond it.

It needs to be said, however, that, although system transformations open up many opportunities, rapid change can be disruptive and therefore a focus on inclusion and equity can increase ambition in climate action and support and ensure a just transition.

Given this backdrop, the 28th UN Climate Conference, or the Conference of the Parties (COP), is a pivotal opportunity for the international community to scale up climate action. Climate finance, along with technology transfer and capacity-building, will be key issues and the COP Presidency has called for private and public-sector stakeholders to commit funding and technology for system transformations, in particular for food and agriculture systems. Such systems transformations will also enable mitigation pathways consistent with the Paris temperature goals by underpinning the phase out of existing high-carbon-emission systems and technologies, while scaling up low-carbon and zero-emission alternatives, and implementing both supply and demand-side measures. At the same time, we also need implementation of technologies that support adaptation and resilience to the projected risks.

The importance of system transitions is further informed by the fact that more than 56 per cent of the world's population lives in cities and towns. It is projected that by 2050, 6.6 billion people, accounting for 68 per cent of the global population, will be living in urban areas (Kundu *et al.* 2023). In Asia, particularly, this is expected to have a drastic effect on the changing dynamics of urbanization, where the urban population is expected to rise to 3.5 billion by 2050 (from 2.4 billion in 2020). This will involve multiple transformations, not just of the urban landscape, but also in associated services, such as transport, energy provision, and water and waste management.

Several mega trends – including rapid urbanization, digitalization, the impacts of climate change and demographic changes among others, have consequences for the current and future realities. System transformations to address climate change must operate against a context of these evolving and dynamic complexities and uncertainties and have a large degree of unpredictability. Notwithstanding this, IPCC (2018) has identified several factors that, when strengthened for climate change mitigation and adaptation, can enable the required system transformations. They include innovation, institutions, policy, governance, and finance.

1 Synthesis report available at https://unfccc.int/documents/632292

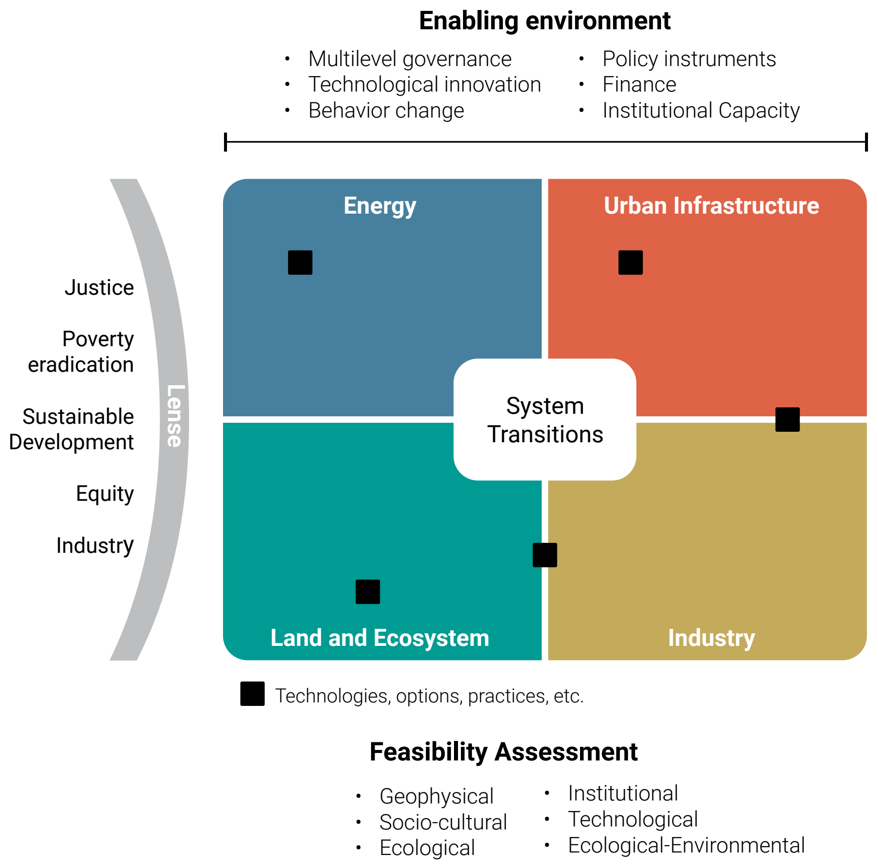
2 Find more information at www.tech-action.org

To reach transformational change there is a need for system transitions, being the process of changing from one state or condition to another in a given period of time. The IPCC Sixth Assessment Cycle highlighted various key system transitions. These include energy, industry, urban and infrastructure, land, and ecosystems (including oceans) and societal systems. Collectively, and if appropriately guided, these transitions can enable faster and deeper adaptation and mitigation actions, while also advancing broader sustainable development. By bringing together mitigation, adaptation and sustainable development, system transitions can be key drivers for achieving low-carbon, climate-resilient, and sustainable development.

Box 1: System transitions

To achieve system transitions, technology development and transfer is one of the indispensable enabling conditions. It is hence essential to understand better the processes that shape technology development and transfer in general, and thereby to understand the factors that lead to successful outcomes as well as barriers that hinder such outcomes. An enabling environment for enhanced technology development and transfer consists of resources and conditions that are generated by different structures and institutions. In addition to focusing on enabling environments, this report also focuses on feasibility. 'Feasibility' indicates how likely it is that a mitigation or adaptation technology is implemented, based on how many barriers and enablers are in place. The feasibility for a technology, and enabling conditions for the same, are interlinked, such that feasibility increases when enabling conditions are strengthened.

Figure 1.1 illustrates the enabling conditions needed for system transitions as a dynamic environment that enables change, and examples of lenses through which this can be approached. Technologies are embedded within or across systems.



1.2 FOCUS

The focus in this report is on climate technologies and how to enhance their development and transfer. 'Technology' is understood as not only a piece of hardware, but a concept that includes the skills, knowledge and techniques to operate it (IPCC 2000). For simplicity, 'technology development and transfer' is referred to as a concept that comprises development, demonstration, deployment, diffusion, transfer and uptake.

Understanding the feasibility of technology development and transfer and their enabling conditions has a significant impact on the potential for the different climate technologies to be implemented. This report therefore aims to fill a space where it provides systematic and annual assessments of the current state of feasibility and requisite enabling conditions for technology development and transfer at the sectoral and regional levels.

In 2022, the CTPR set out a framework and approach for tracking and exploring trends in technology progress. While the 2022 edition applied the approach using data and cases from the Africa region, the 2023 CTPR continues to explore progress and sets out analyses and case studies focused on urban transitions in the context of Asia. Asia houses one of the fastest-growing urban populations and is highly vulnerable to extreme weather and climate change impacts (IPCC Working Group II 2022). As the share of population living in urban areas is significantly correlated with per capita income levels, the cases included in the chapters are selected to represent a variety of different types of cities, representing developed, emerging and developing countries in Asia.

The report continues to ask the following questions, all within the context of enhancing technology development and transfer:

1. What progress is being made?
2. What has enabled it?
3. Where are the gaps?
4. Building on this understanding, how do we better enhance climate technology development and transfer?

The focus aligns with the work of the two bodies of the UNFCCC Technology Mechanism, namely the Technology Executive Committee (TEC) and the Climate Technology Centre and Network (CTCN), and their joint work programme. The TEC strives to promote science-based and systemic approaches, bolstering transformative technology solutions, and focusing on high-impact, high-potential sectors and actions. The CTCN seeks to enhance transformational impact and scale across various areas and does so through using national systems of innovation and digitalization as key enablers. The purpose of the Technology Mechanism's first joint work programme[3] is to accelerate efforts on transformative climate technology development and transfer in order to support countries to achieve the goals of the Paris Agreement and those of the UNFCCC, and to implement their national climate plans. While urban and infrastructure system transitions are not a direct focus area for the Technology Mechanism, they capture cross-cutting elements from its focus areas.

The report focuses particularly on technologies for the urban and infrastructure system that have very strong synergies for mitigation, adaptation and sustainable development, and is structured in two parts:

Part A continues to use the global feasibility assessment as set out in the 2022 scoping report, and supplement it with regional data for Asia. The feasibility assessment builds on the work done for the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6).

Part B investigates the enabling conditions that influence the feasibility and progress of technology development and transfer. Chapters 3, 4, 5, and 6 are thus focused on technology, innovation and supporting infrastructure; institutional settings and governance; the policy and regulatory framework; and investment and finance, respectively.

3 https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TEC_Documents_doc/6e7cae499c2b418e93d2d2a1bcca1a20/e9a1b6ffadbe47bcb3f2634881df13f5.pdf

Informal settlements on the shores of Mumbai, India ©Shutterstock

Part A

2.

Feasibility Assessment

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2.1 INTRODUCTION

This chapter assesses the feasibility of adaptation and mitigation technologies[4] that form part of the urban system transition. Specifically, this chapter assesses five technology groupings, which for simplicity are referred to as technologies, within the urban system: public transport, building cooling, water management, social housing, and energy distribution and generation. These technologies are selected as they have very strong synergies among mitigation, adaptation and the UN Sustainable Development Goals (SDGs) or high co-benefits for adaptation (as in the case for public transport) as well as promoting equity and justice, or are especially targeted to marginalized populations within an urban context. Keeping with the theme of the Climate Technology Progress Report (CTPR) 2023, the focus is on cities in an Asian context, addressing the following questions:

1. What are key technologies for adaptation and mitigation for urban system transitions with an emphasis on the Asia region?
2. What is the state of feasibility for these key technologies and specifically, what has changed since the IPCC Sixth Assessment Reports from Working Group II and Working Group III? What are the main changes in the indicators and the overall feasibility, and why?
3. How can the selection of a portfolio of technologies facilitate the urban system transition and how does this interact with and support other system transitions?
4. What is the potential role of the four key enablers (policy and regulatory frameworks; institutional settings; governance, investment and finance; and innovation, technology development and technology transfer) in overcoming barriers and improving the feasibility of these options?

The technologies are evaluated using the well-established "feasibility assessment" methodology originating in the IPCC Special Report on Global Warming of 1.5°C and further developed in IPCC Sixth Assessment Report Working Groups II and III, which developed a multidimensional approach to assess "the degree to which the response options are considered possible" with literature to support feasibility up to a 1.5°C level of global warming (IPCC 2018).

In this approach, "feasibility" is operationalized by first identifying the critical dimensions of feasibility and secondly, evaluating the performance of the technologies on indicators that capture key elements of these dimensions (Singh *et al.* 2020). The feasibility assessment provides information about which technologies are currently feasible, allowing for a prioritization of options for funding and implementation. The assessment also gives a clear indication of where the barriers or knowledge gaps exist for technologies that may be less feasible and thus provides a signal for where to deploy enablers that could improve the feasibility of these technologies.

The system transition framework is adopted for this assessment. The society-wide transformations that enable mitigation pathways that are consistent with the Paris Agreement temperature goals and support adaptation and resilience to the projected risks entail sociotechnical transitions and social-ecological resilience, respectively, across multiple global systems. The reports of the IPCC Sixth Assessment Cycle employed this framing to highlight five system transitions: (1) energy, (2) industry, (3) urban and infrastructure, (4) land, coastal and open ocean ecosystems and (5) societal. In each system transition, this framing facilitates the evaluation of how to maximize synergies and identify and minimize trade-offs between technologies within a system transition and between other systems. Importantly, by bringing together mitigation, adaptation and sustainable development, system transitions are a key enabler for achieving climate-resilient development.

Unlike a sectoral approach, a system transitions framework shifts the focus from evaluating single mitigation or adaptation technologies to emphasizing the relationship between technologies. Taking the urban transport system as an example, the more discrete, sectoral approach would focus on single policies such as new parking restrictions. The more integrated perspective provided by system transitions would emphasize clean public transport options that have more synergies and multiple co-benefits, which can support more comprehensive transformations towards sustainable mobility. System transitions can also highlight the importance of transitions in the built environment and other infrastructure to supporting the transition of urban transport.

4 In this report, the understanding of what a technology is follows the definition laid out by the IPCC (2000), where a technology is "a piece of equipment, technique, practical knowledge or skills for performing a particular activity". At times in this chapter, technology and options are understood to be synonymous. Responses, especially those that would relate to 'coping', are not evaluated as technologies for the purposes of this report.

2.2 FEASIBILITY ASSESSMENT ACROSS URBAN SYSTEM TRANSITIONS

2.2.1 Identification of technologies within the urban system transition framework

Table 2.1 shows the discrete technologies that comprise each technology group. The five technology groups selected for this assessment were determined by first reviewing the technologies included for adaptation and mitigation from the IPCC's Sixth Assessment Reports for Working Group II and Working Group III. The technologies were narrowed down to those that are more specific to responses in Asian urban systems and those that contribute to equity and justice, based on the regional chapter for Asia from Working Group II (Shaw *et al.* 2023) and content related to Asia in Working Group III. Secondly, these discrete technologies were situated within the urban system transition. According to the IPCC Sixth Assessment Report (AR6) cycle, the urban system transition consists of sustainable land use and urban planning, sustainable urban water management, green and blue infrastructure and ecosystem services, the electrification of the urban energy system, district heating and cooling networks, and waste prevention, minimization and management. Finally, the technologies were reviewed for evidence of strong synergies between adaptation and mitigation.

This process identified three of the technology groups – building cooling, water management and energy distribution and generation – along with the discrete technologies associated with each group (discrete technologies are viewed not independently but as related to each other, especially when implemented). The feasibility of these technologies is evaluated in this chapter within the context of water management and building cooling, in recognition of the critical importance of green and nature-based infrastructure.

Table 2.1 Discrete technologies within the technology groups.

Technology group	Subtechnology	Discrete options considered for feasibility assessment
Water management	Green infrastructure	Green roofs and walls, green and bio swales and the urban canopy
	Blue infrastructure	Construction/restoration of wetlands, retention ponds and roof ponds
	Other	Permeable pavements, rainwater harvesting, decentralized water management, water reuse and early warning systems
Public transport	Mass transit	Mass transit systems, such as buses, trams, subways and light rail transit (LRT)
Building cooling	Passive cooling strategies	Overhangs, louvres, insulated walls and windows, diode roofs, textured walls, cool roofs (high albedo surfaces), modelling of building orientation and prevailing winds, new materials and earth-air tunnels
	Enhanced ventilation	Wind towers, wooden lattice openings and solar chimneys
	Green/blue infrastructure	Green roofs, green walls/green facades and roof ponds
	Heating, Ventilation and Air Conditioning (HVAC)	Evaporative cooling and heat pumps
Social housing	Resettlements	Housing resettlement (post-disaster resettlement and preventive resettlement of the population in risk areas)
	Improvements	Informal settlement improvements, slum upgrading, community-led adaptation (with technical and economic government support) and nearly zero-energy buildings (NZEB)
	Regulations	Climate-resilient housing regulations (urban and building codes, and zones with environmental restrictions on occupation), monitoring and control systems and sustainable buildings
Energy distribution and generation	Energy reliability and infrastructure resilience	Microgrids, smart grids and defensive islanding
	On-site generation of renewables	Photovoltaic solar and wind

This approach also revealed the importance of urban planning as well as the need to disaggregate the grouping, since not all features are equally feasible and there are significant implications for equity and justice. Examining the issue from an equity perspective reveals two key technologies/options (public transport and social housing) as playing a key role. In many cases, more marginalized residents live primarily in various forms of informal settlement. This points to social housing as an option with substantial opportunities for mitigation and adaptation that would also foster a more inclusive urban system. Similarly, public transport fosters more equitable urban mobility and has important mitigation potential, since it would displace private vehicles powered by fossil fuels. Public transport is not generally implemented as a means of adaptation and there is no feasibility assessment for adaptation, but has been retained in light of the substantial co-benefits of adaptation, which are discussed separately in the report.

2.2.2 Approach to assessment for this chapter

This feasibility assessment builds on the work done for the IPCC AR6 with updates from the literature between the literature cut-off dates of Working Group II and Working Group III of August 2023. This section discusses only those details that are specific to the findings presented in this chapter. See Annex 1A for full details of the feasibility assessment approach.

Scores were produced for each of the technologies identified above, based on an overview of the peer-reviewed literature. Unlike the full systematic reviews that were conducted for the AR6 feasibility assessment, which examined all the literature, this effort focused on identifying any major updates, with an emphasis on existing published systematic reviews. As a result, a score that is the same as the one in AR6 cannot be interpreted as a clear indication of any major changes in the scoring beyond the comprehensive assessment completed in that report. However, as the technology groups in this chapter are focused on urban applications, many scores are not directly comparable to the IPCC AR6 assessments. For social housing, the feasibility assessment in AR6 is substantially different, such that the effort outlined here represents a new contribution.

Where possible, the scoring was derived from literature focused on Asia. However, in many cases, the feasibility score was derived from the global literature as there is often insufficient literature at the regional level. So, while a feasibility assessment can be used at different levels and scales, literature constraints can arise when adopting a regional lens. Additionally, Asia is a large and diverse region, geographically, economically and culturally. To highlight this diversity, the feasibility assessment is illustrated with examples of technologies applied in different countries and socioeconomic and institutional contexts in the Asian region.

The indicators and dimensions from AR6 were retained for this chapter. These indicators are those most identified in the overall literature and can be applied to the Asia region as a whole because of the diversity of settings represented by this region. However, if this exercise were to be repeated for a specific country or subregion, this indicator list should be reviewed for its applicability and relevance to the important dimensions in that location.

Additionally, since this feasibility assessment builds on AR6, technology groups are evaluated separately for mitigation and adaptation, although mitigation scores were recoded to follow the Working Group II assessment approach for adaptation to improve the ability to compare across applications. However, different scores can emerge for the same technology group depending on whether it is being applied to mitigation or adaptation, especially for institutional and sociocultural dimensions. In these cases, a decision maker implementing the technology may need to address the lower feasibility scores to ensure benefits for both mitigation and adaptation. As many decision makers continue to look at mitigation and adaptation in isolation, these divergent scores underscore the need to integrate the feasibility assessment for mitigation and adaptation.

2.3 FEASIBILITY ASSESSMENT RESULTS

The results for the feasibility assessment are shown in Fig. 2.1. This shows the feasibility scores for adaptation and mitigation for each of the five technology groups of water management, energy generation and distribution, social housing and public transport (in Panel a) and building cooling, both without and with the contribution of green and nature-based technologies (in Panel b). The feasibility assessment on the technologies evaluated in Fig. 2.1 are assessed as having at least medium confidence. Tables for all the references and scores that support these results are shown in Annex 1B. Any modifications to the scores found in AR6 are clearly identified and evaluated in these tables.

Overall, water management, including water-use efficiency and water-resource management, has a high level of technological feasibility. For the technological dimension, the scoring remains the same as in previous assessments, although new literature focuses on the role of artificial intelligence to support sustainable water management, which makes these findings more robust (see, for example, Aivazidou *et al.* 2021). Economic feasibility has improved since AR6 due to water and energy cost savings, although some implementation costs can vary widely. Water management and use efficiency is currently constrained by governance and institutional factors, such as inadequate institutional capacity for preparing for the changing availability of water, especially in the long term, along with unsustainable and unequal water use and sharing practices. The small number of articles that focus specifically on Asia have been documented (Adem Esmail and Suleiman 2020), which may be in part explained by a lack of consideration of transitions for water infrastructure in a Global South context. Nonetheless, notable efforts related to flooding prevention highlight the medium feasibility of water management in Asia for adaptation. In Working Group II's AR6, policy and infrastructure – when combined with a cross-cutting synergy on early warning systems – generated effective adaptation in Shanghai (China) and Ho Chi Minh City (Vietnam) to reduce flood risks (Scussolini *et al.* 2017; Yu, Zhai and Chen 2018).

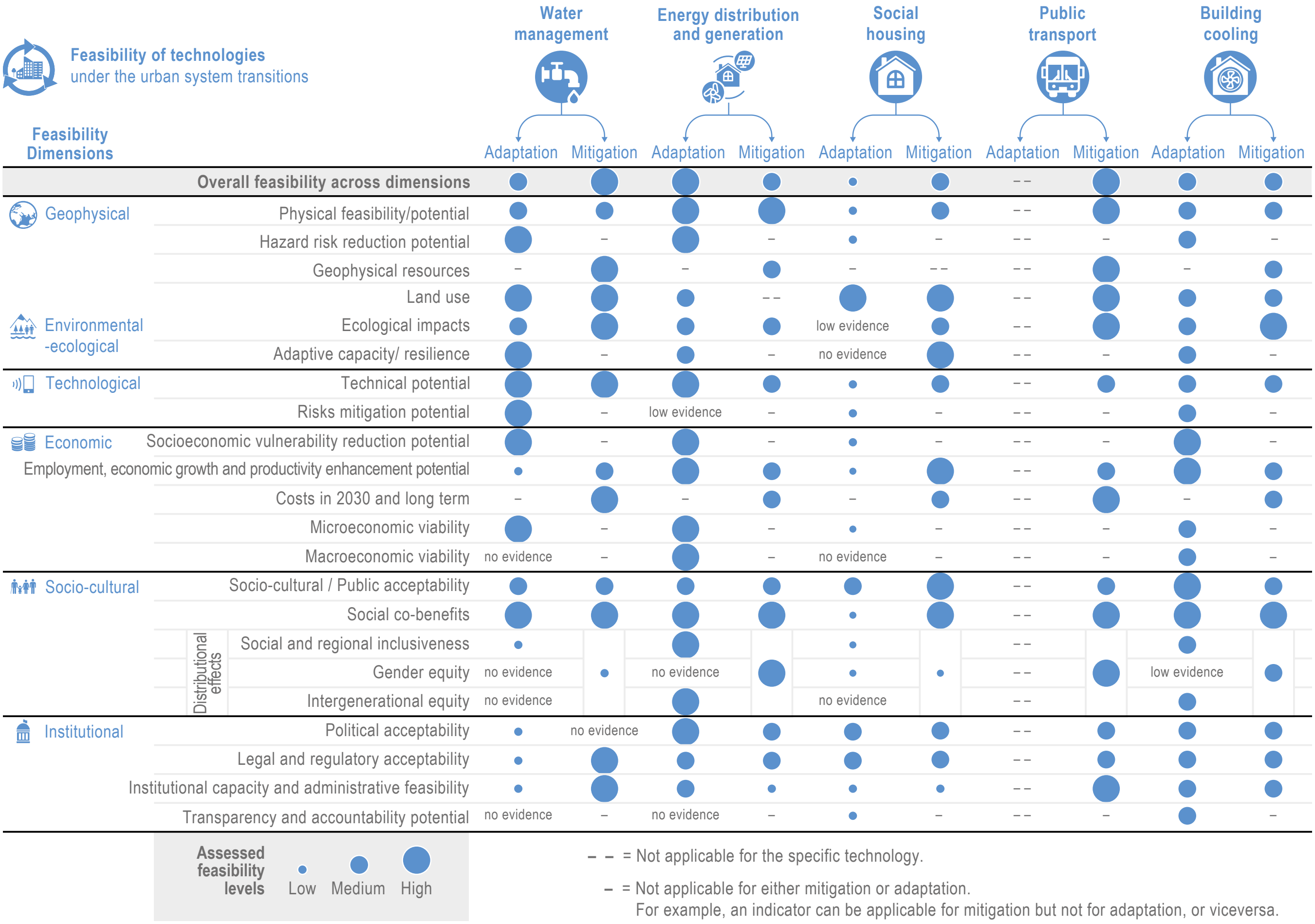
This feasibility assessment also highlights the potential for adaptation and mitigation through energy generation and distribution in urban settings with a high and medium feasibility, respectively. The high feasibility was previously documented for electricity systems that can be adapted to climate risks with strong synergies for mitigation (Shaw *et al.* 2023). Adaptation feasibility is also supported through the major gains in adaptive capacity and other socioeconomic conditions in the Global South from climate-resilient power systems (Banerjee, Mishra and Maruta 2021). By contrast, social housing is assigned a low feasibility for adaptation and a medium feasibility for mitigation. The low feasibility score for social housing is due in large part to its low scoring on the sociocultural dimension. This can be illustrated by considering the resettlement component of many social housing programmes and the resulting distributional impacts and livelihood outcomes. It is common that while these programmes result in some risk-reduction benefit, inequalities within and beyond communities are often amplified due to distributional issues (see, for example, See and Wilmsen 2020). However, these feasibility scores need not remain low with substantial evidence for participatory and rights-based approaches improving outcomes when resettlement is desired. This includes associating social housing with social inclusion processes and policies (including employment and income generation, education, access to information, equipment and public services) and property legal tenure programmes to counter maladaptation through the reproduction of pre-existing or creation of new inequalities (see, for example, See and Wilmsen 2020; Nagle Alverio *et al.* 2021).

Public transport as a mitigation option has a high feasibility score. This high feasibility across multiple dimensions is highlighted by the improvements in environmental attributes (for example, reducing air pollution) and the potential for enhanced mobility (see, for example, Ceder 2021). Public transport is not widely evaluated as an adaptation, as reflected in Fig. 2.1, as it is not considered as an adaptation option; however, there are substantial co-benefits for adaptation, as identified in the mitigation feasibility assessment and other linkages to sustainable development. Public transport can improve livelihoods, adaptive capacities and equity (Sharifi 2021). The capacity to combine land use and urban planning with public transport also highlights the high institutional feasibility, especially in settings where there is already integrated governance across these activities. For example, high feasibility was observed in Singapore, where the government has strong implementation capacity and over three-quarters of the land is owned by the State (Diao 2019).

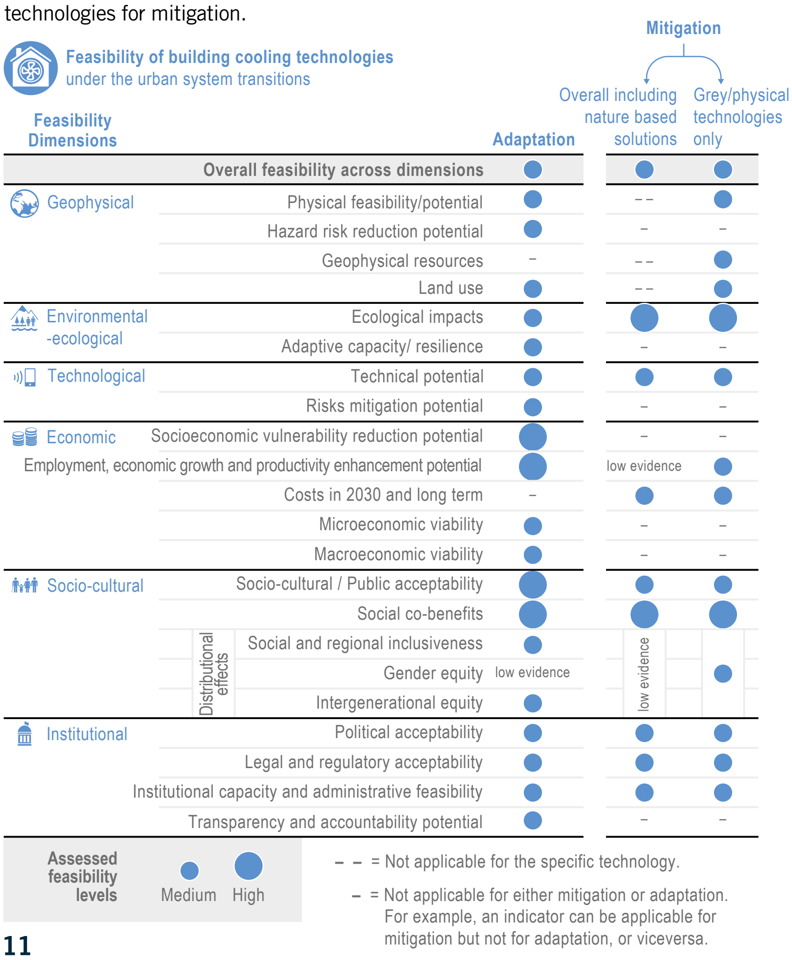
Reflecting the already warmer climate, energy demand for cooling in Asia is much higher than in other regions, which brings into focus the importance of building cooling technologies for both adaptation and mitigation (Shaw *et al.* 2023). In light of this, the medium feasibility scores for these technologies could suggest a closer look to investigate where feasibility issues exist, especially along economic, sociocultural and institutional lines. Looking more specifically at the contribution of green and nature-based infrastructure reveals that adding these technologies improves the ability to assess opportunities for economic benefits and enhancing equity. While these are currently low feasibility, the quality of the evidence may point to the potential for gains on these indicators, whereas there was little potential for grey infrastructure. The increase in the use of green measures across Asia is encouraging, since there is the potential for mitigation and adaptation gains beyond what can be achieved with "hard" infrastructure (see, for example, Brink *et al.* 2016). However, efforts to improve feasibility from an institutional perspective are needed to fulfil this potential.

Figure 2.1 Feasibility of technologies for urban system transitions.

Panel A - Feasibility scores for water management, energy generation and distribution, social housing and public transport.



Panel B - Feasibility scores for building cooling. Technology groups were evaluated without and with the contribution of green and nature-based technologies for mitigation.



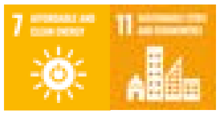
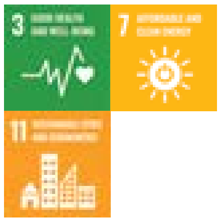
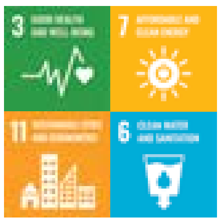
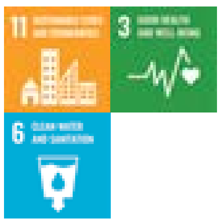
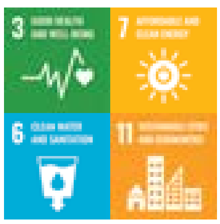
Panel A shows feasibility scores for adaptation and mitigation for the four technology groups of water management, energy generation and distribution, social housing and public transport. Public transport was not assessed for adaptation as there is no literature on public transport as an adaptation option.

Panel B shows feasibility scores for building cooling, both without and with the contribution of green and nature-based technologies. Where a square has hatched lines, it indicates that this indicator does not apply to mitigation and/or adaptation. A solid grey square indicates that this indicator is not applicable for the given technology. The overall feasibility scores for these technologies are evaluated as having medium confidence or higher. More details are available in Annex B.

2.4 LINKS BETWEEN MITIGATION, ADAPTATION AND SUSTAINABLE DEVELOPMENT

Climate-resilient development has been recognized as central to achieving mitigation, adaptation and the SDGs. In Table 2.2, the technology groups are evaluated for their synergies for mitigation and adaptation. Only the SDGs that have strong, direct, positive effects are shown. Some of the benefits are evident in the feasibility assessment, with additional support provided here with relevant references. This list, however, is not exhaustive and there may be impacts on other SDGs. All technologies are strongly synergistic with SDG13 – Climate action. Although trade-offs may exist, these were not specifically assessed.

Table 2.2 Links between mitigation, adaptation and sustainable development. For mitigation, there are no trade-offs with the SDGs. For adaptation, these are the strongest synergies, and no strong trade-offs were identified.

Technology	Mitigation	Adaptation	SDGs (strong positive effects)	References
Public Transport	Reduces emissions if people take public transport rather than driving their own cars	Increases resilience of populations in case of evacuations, for example, for people seeking shelter, and providing mobility to people who do not have other means of transport		Giles-Corti, Lowe and Arundel 2020; Nieuwenhuijsen 2020; Abduljabbar, Liyanage and Dia 2021
Building cooling	Reduces energy as demand for cooling decreases	Improves thermal comfort		Piselli *et al.* 2020; Prabhakar *et al.* 2020; Nematchoua, Sadeghi and Reiter 2021
Water management	Reduces energy demand as demand for water pumping decreases if appropriate water management technologies are used	Creates long-term benefits as well as ensuring adequate supply that also reduces systemic vulnerabilities, for example, when providing water to underserved populations		Capodaglio and Olsson 2020; Francis Mutua Dimuthu Daluwatte and Sivakumar 2020; Oral *et al.* 2020; Sørup *et al.* 2020
Social housing	Reduces both energy consumption and embedded emissions	Reduces 1) structural risks to the buildings and local infrastructure in floods and landslides; 2) risks to water supply; 3) health risks due to inadequate sanitation and density; 4) heat island effect; 5) risks from marginalization and exclusion in the territory and in the decision-making arena		Adabre and Chan 2019; Chang, Jou and Chung 2021; Helble, Ok Lee and Gia Arbo 2021
Energy distribution and generation	Reduces emissions if using renewable energy	Provides electricity to vulnerable populations, who might otherwise not be able to access it from reliable sources, and to health centres and shelters; lighting for shelters, early warning systems and communication systems		Ahad *et al.* 2020; Guerrero *et al.* 2020

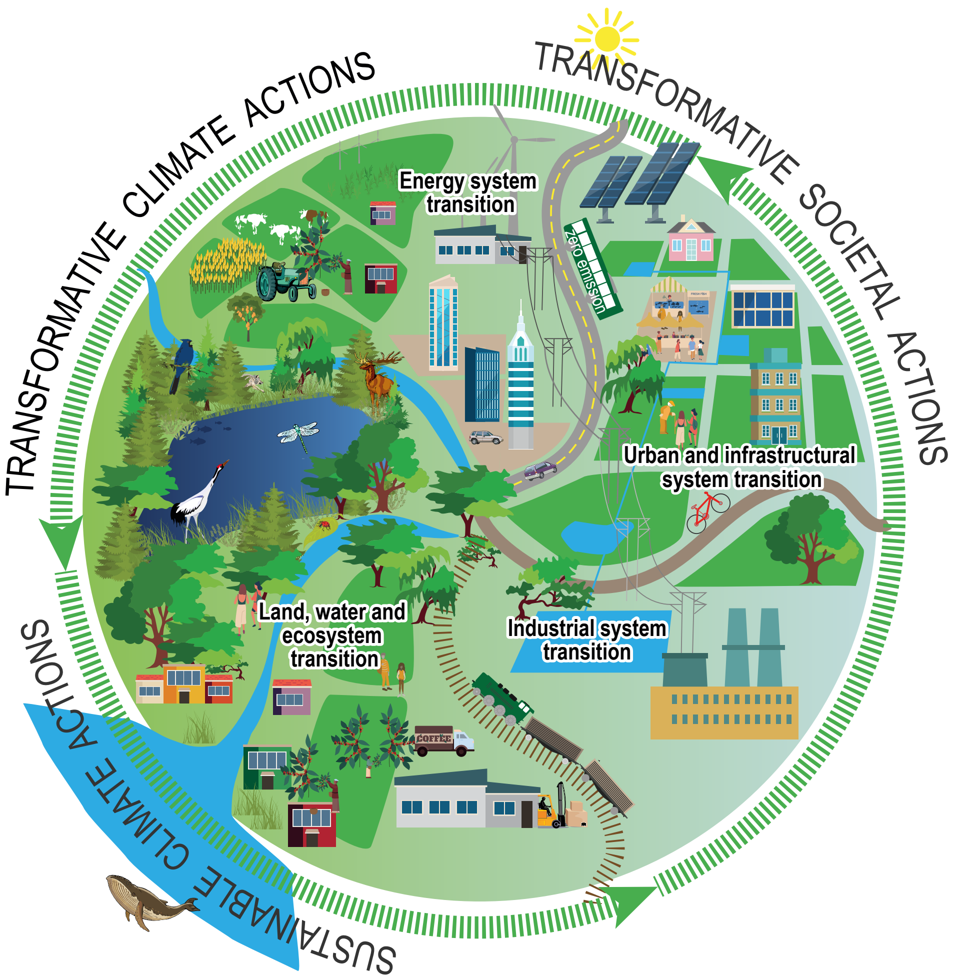
2.5 SYNERGIES AND TRADE-OFFS OF URBAN SYSTEM TECHNOLOGIES EVALUATED THROUGH A SYSTEM TRANSITION FRAMEWORK

The system transitions framework allows for an evaluation of how the five technology groups that comprise the urban system transition can produce positive and negative effects within other system transitions. For example, land and water use in the urban system affects land and water use in other systems (such as the industrial or land ecosystem system). This can also highlight rural-urban linkages, such as how agricultural practices can affect energy usage in urban centres through water and land.

The framework also emphasizes the importance of societal system transitions through the role that the whole of society and individuals within societies play in shaping the decisions that take place when choosing technologies. Evaluating societal transitions allows for a detailed examination of other societal dimensions that facilitate system transitions, such as behaviours and norms that may support the increased use of new technologies. Societal transitions also emphasize greater inclusion of minorities and participation in decision-making, highlighting equity and justice in using and sharing resources, urban land and basic urban services, and the centre of climate action.

In Fig. 2.2, the five technology groups are related to the urban system transition and to other relevant system transitions. This highlights some of the key relationships and interactions between system transitions and climate-resilient development.

Figure 2.2 Societal Transition: The five technologies within the transitions and how they relate to each other across relevant system transitions. Transformative actions through system transitions characterize climate-resilient development. This figure shows the five technologies within the five system transitions (energy, industry, urban and infrastructure, and land, water and ecosystem system transitions with societal transitions encompassing all of them). The figure shows the linkages between system transitions and therefore the technologies, and highlights the need for integrating the assessment of mitigation, adaptation and sustainable development. Climate-resilient development seeks climate actions that are both sustainable (interconnecting economic, social and ecological processes and considerations) and transformative (where there is a fundamental change in systems with impacts that shift and accelerate the trajectory of progress towards climate-neutral, inclusive, resilient and sustainable development pathways), which are shaped by societal transitions in which all of society plays a role. Fig. 2.2 is derived from Schipper *et al.* (2023).



The technologies assessed in the feasibility assessment have a clear impact on urban system transitions and have direct or indirect effects on other system transitions, as follows:

1. Public transport: transport systems help provide connectivity within cities and beyond. The means of transport are important as they relate to emissions and particles, and thus improved health (for example, through using sustainable public transport instead of private vehicles, particularly those powered by fossil fuels) but also to decreased vulnerability by providing transport resources to those who do not have access to or cannot afford a private vehicle. Public transport also reduces the space required for parking and roads, thus allowing for more green spaces in cities (for example, planting trees where there used to be vehicle lanes will help with cooling cities subject to an urban heat island effect and offer public space for recreation, sport and cultural activities). In addition, a public transport system that is clean, fairly distributed throughout the territory, intermodal, cheap and safe is crucial to improving the quality of poor and informal settlements, which are generally precarious and marginalized due to the enormous difficulty of accessing and connecting to distant work areas.

2. Building cooling: technologies such as natural cooling link to the energy system transition insofar as they help reduce emissions through reduced electricity use, as well as decreasing vulnerability through thermal comfort. Under warming scenarios where more building cooling will be needed, energy demand for cooling will be reduced by using natural cooling compared to other approaches.

3. Water management: water links all system transitions as water use in one system transition will necessarily impact water availability and use in another system transition. Sustainable and resilient water management, although considered more as an adaptation option, can also help reduce emissions in some cases (for example, only pumping the necessary amount of water when water-use management technologies are used). If the overall energy consumption for water management can be reduced, there can be mitigation benefits.

4. Social housing: this group of technologies has strong synergies with mitigation and adaptation, as well as with sustainable development. Sustainable building solutions applied to social housing and informal settlements (for example, efficient and local choices of construction materials and technologies; waste and emissions-efficient construction processes; provision of public transport infrastructure and clean, high quality sanitation, among others) can reduce energy demand and decrease vulnerability through increased comfort and reliability of services and infrastructure. Strong synergies with sustainable development and territorial justice can be achieved in robust participatory and inclusive family resettlement processes, as well as in informal settlement improvement and upgrading projects that reduce local climate vulnerability.

5. Energy distribution and generation: this technology mainly highlights the link with energy system transitions as cities can also generate electricity, for example, through solar systems or community systems that are used both for consumption and sale back to the grid. Distributed generation through renewable energy in cities will decrease emissions as well as serving as a redundant electricity source in the case of grid failure during extreme weather events, therefore also having reliability benefits.

2.6 FROM A FEASIBILITY ASSESSMENT TO ENABLING CONDITIONS

System transitions can generate benefits across different sectors and regions, provided they are supported by appropriate enabling conditions, including effective multi-level governance and institutional capacity, policy design and implementation, innovation, and climate and development finance. Comparing the feasibility assessment to the available enablers highlights a key element of a feasibility assessment – it can help distinguish between dimensions where there are opportunities to improve feasibility and dimensions where there are soft or hard constraints.

Mitigation options in energy and buildings have high economic feasibility; however, feasibility issues have been identified for sociocultural and institutional dimensions. Looking at enablers that are available to improve sociocultural and political indicators shows opportunities to improve overall feasibility, such as identifying synergies and co-benefits to increase perceptions of desirability (see, for example, He *et al.* 2019). The feasibility assessment also can help focus attention on where the availability of and access to finance is especially key. In this analysis, finance could be prioritized for public transport, where the economic feasibility is lower due to barrier of substantial initial costs even though the benefits for the environment and economic growth can be high over the longer term.

This evaluation can also provide guidance on where policy approaches could be implemented, as well as highlighting more specific features, such as where there may be a need for gender-responsive approaches (for example, low feasibility for gender equity). It can also reveal gaps between the desirability of options, such as nature-based solutions, which have high synergies on mitigation and adaptation and the need to increase feasibility for institutional dimensions (Mukherjee *et al.* 2022). Specifically, this could point to the need for evaluation of how to integrate development goals at all scales in cities and the need for urban system transitions to improve political acceptance and reduce trade-offs (see, for example, Mah 2019).

The diversity that characterizes cities, especially in the Asia region, can also provide a test bed for feasible adaptation and mitigation technologies that can facilitate learning and innovation. In this way, indicators with low feasibility in one location could be evaluated against another location where higher feasibility has been observed for transferable approaches. This could be especially beneficial in building up a literature base that is more specific to sociocultural indicators in Asia (see, for example, Wimbadi, Djalante and Mori 2021). Much of the literature on this aspect comes from high-income countries. Documenting innovative approaches and engaging communities in planning and implementation may draw out learnings where there is more limited evidence.

2.7 DISCUSSION AND CONCLUSIONS

The results of this feasibility assessment reveal strong evidence for highly feasible options for urban systems. By highlighting this potential, this chapter points to the need – and could serve as a starting point – for understanding the full range of technologies for urban transitions in both a global and regional context. In this way, the work here could serve both to inform the immediate needs of decision makers and as a call for future assessments.

By adopting a system transitions framework, this analysis takes a more holistic view of a group of technologies that can support transition and as a result, is consistent with the understanding that there is no "one-size-fits-all" technological solution or transition. Collectively, these system transitions widen the solution space and accelerate and deepen the implementation of sustainable development, adaptation and mitigation actions by equipping actors and decision makers with more effective options that lead to climate-resilient development. However, any given technology may differ in its feasibility and effectiveness alongside relevant features such as urban growth typologies (such as established, rapidly growing and emerging established cities) and urban dimension and structure (for example, metropolitan, city, urban net). Specific technologies can then be assessed in more detail as embedded within specific local socio-=political, economic and institutional contexts as well as geographical location, cultural norms, attitudes and assumptions. A specific regional focus can also place even more emphasis on prioritizing attention to adaptation options, which contribute to the expansion of urban social and territorial justice and the inclusion of vulnerable and marginalized groups in the policy arena of decision-making, particularly in sensitive urban sectors such as housing, transport and water supply.

The system transitions framework and feasibility assessment, especially through the sociocultural and institutional dimensions, help create a better understanding of equity and justice and their roles in creating climate-resilient development pathways. Climate-resilient development integrates mitigation, adaptation and sustainable development, underpinning equity and justice. Therefore, the implementation of system transitions and the feasibility assessment, together with the right set of enabling conditions, can provide solid recommendations, at different levels, to achieve climate-resilient development.

The Hive Nanyang Technological University in Singapore uses Nature-based Solutions to keep temperatures low ©Shutterstock

Part B

3.

Technology, innovation and supporting infrastructure

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3.1 INTRODUCTION

While certain climate technologies have already demonstrated their economic viability and require rapid, substantial scaling, there remains an urgent imperative for integrated innovations in pivotal domains to facilitate systemic transformation. The journey toward establishing a low-carbon, resilient urban environment also necessitates the creation of complementary urban infrastructure and enabling technologies.

In the context of technological innovation and supporting infrastructure, this chapter will summarize the progress of urban climate technology from the perspectives of technological innovation and supporting infrastructure, emphasizing the importance of synergy benefits and regional strategies. Section 3.2 offers an extensive examination of current technological advancements and prospective innovations across various critical sectors. Section 3.3 shifts the focus towards the pivotal role played by infrastructure and delineates various categories of urban infrastructure geared towards effectively combatting climate change. Moreover, Section 3.4 delves into the indispensable comprehension of the synergistic advantages that urban climate technologies and infrastructure can provide in terms of both mitigation and adaptation, alongside other environmental and economic co-benefits. Section 3.5 concentrates on region-specific strategies aimed at mitigating carbon emissions lock-in within established cities while concurrently striving to avert carbon lock-in within emerging urban centres.

3.2 CURRENT TECHNOLOGICAL PROGRESS AND INNOVATION REQUIREMENTS

The transition towards a climate-focused urban paradigm necessitates concerted efforts in urban building systems, transport systems, energy supply systems, water systems and urban planning (Institute for Carbon Neutrality, Tsinghua University 2023). The subsequent sections will primarily offer a condensed overview of current advances within these critical technologies, as well as setting out the prerequisites for their continued evolution, which is essential for catalysing sustainable urban development.

Figure 3.1 Key areas for the transition towards a climate-focused urban paradigm.

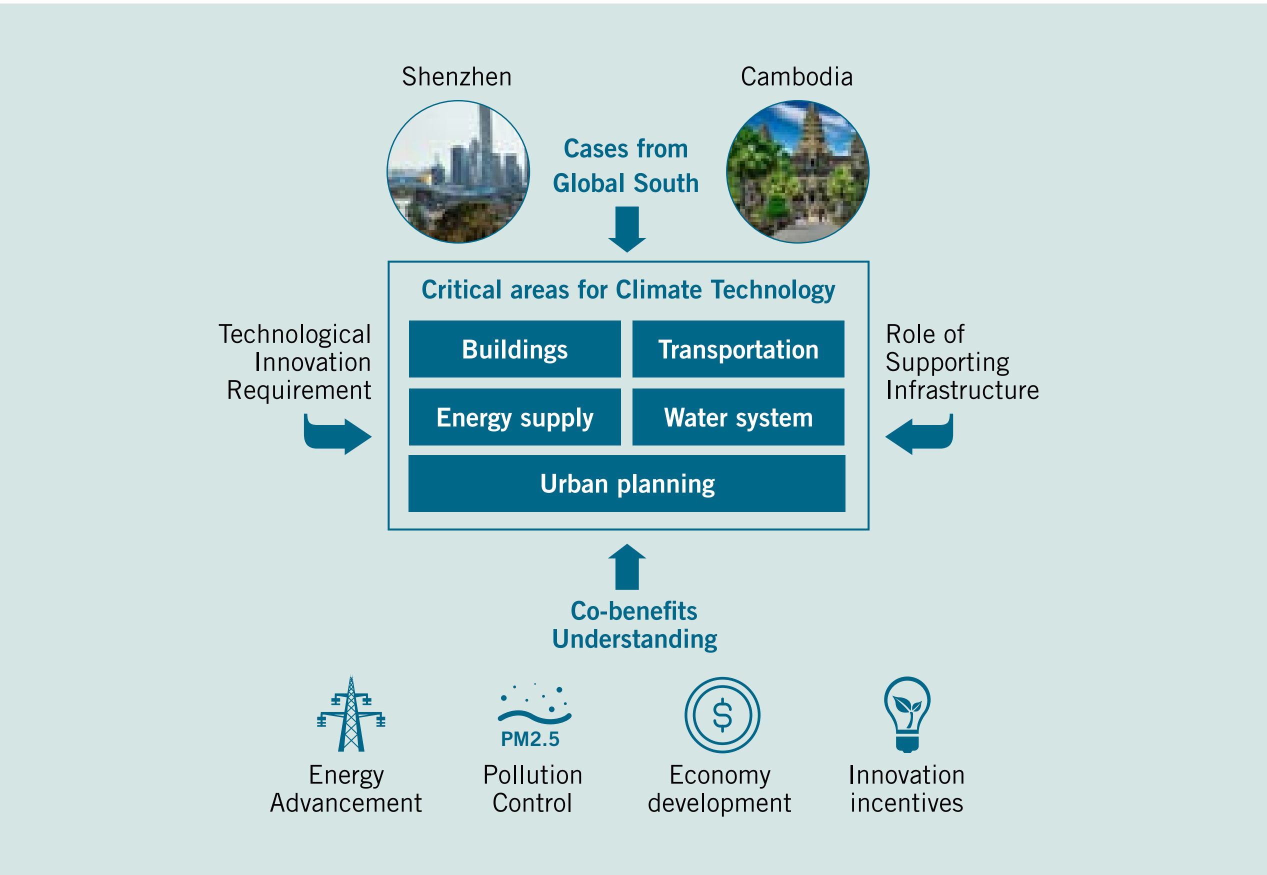

Table 3.1 Technological progress, innovation requirements and contribution to urban mitigation and/or adaptation.

Key area	Technology categories	Innovation requirement		Urban mitigation	Urban adaptation
Urban building system	Low-carbon and resilient construction material	Material performance	Alternative technologies	X	X
	Renewable energy integration	Energy conversion efficiency	Self-sustaining structures	X	
	Energy-efficiency technologies	System connectivity	Heat pump performance	X	
Urban transport system	Vehicle electrification	Next-generation batteries	Fast-charging stations	X	
	Intelligent transport system	Seamless integration	Interoperability	X	
Urban energy supply system	Urban energy management and optimization	Internet of Things technologies	Big data	X	X
	Smart grid and energy storage	Grid stability	Resilient supply	X	
Urban water system	Smart water management	Real-time data processing	Multi-parameter sensors	X	X
	Water recycling and reuse system	Energy efficiency	Energy recovery	X	X
	Stormwater management solutions	Optimal stormwater retention	Nature-based solution	X	X
Urban planning	Climate mitigation urban planning	Advanced modelling software	Participatory planning	X	
	Climate-adaptive urban planning	Durability	Predictive modelling		X
	Urban modelling and simulation	Climate projection	Virtual reality technology	X	X

3.2.1 Urban building

The building sector is the core area of urban climate mitigation and adaptation, since it plays a pivotal role in shaping the sustainability and resilience of urban environments. Building operations account for 30 per cent of global final energy consumption and 26 per cent of global energy-related emissions (International Energy Agency [IEA] 2022a).

Sustainable construction materials

Sustainable construction materials play a pivotal role in improving both energy and material efficiency. Careful selection of sustainable materials, such as recycled steel, reclaimed wood, bamboo, recycled plastic, cob and hempcrete contributes to the reduction of natural resource consumption and waste generation (Olivetti *et al.* 2018). Additionally, climate-resilient construction materials are designed to withstand the challenges posed by a changing climate, which can include more frequent extreme weather events, temperature fluctuations, increased moisture and other environmental stressors.

It is imperative to continuously invest in research and development to improve material performance, find new alternatives and enhance the scalability and cost-effectiveness of sustainable materials (Pásztory 2021). The focus of innovation should centre around bolstering material strength and thermal resistance. Vacuum-insulated panels (VIPs) and aerogels, for instance, offer superior thermal resistance, enabling buildings to maintain comfortable indoor temperatures while minimizing energy usage. Moreover, there is a pressing need to explore and adopt new eco-friendly alternatives that seamlessly replace conventional materials without compromising the structural integrity of the structures (Orhon and Altin 2020).

Integration of renewable energy

By harnessing clean and renewable sources, such as solar, wind and geothermal power, buildings can significantly lower their carbon footprint. The integration of renewable energy technologies into buildings aims to create energy-efficient and self-sustaining structures (Jaysawal *et al.* 2022). For instance, building-integrated photovoltaics (BIPV), solar roof tiles and solar windows enable buildings to harness electricity directly from sunlight.

The quest for more efficient and cost-effective renewable energy solutions has become a driving force for continuous research and development. Innovations in solar panel efficiency, wind energy technologies and battery storage systems have been sparked by the ever-increasing demand for sustainable building solutions. Taking photovoltaic (PV) technology as an example, technological advancements in PV panels are of utmost importance for enhancing energy conversion efficiency and driving down the cost of solar energy systems (Lewis 2016). Innovations in thin-film solar cells (Sivaraj *et al.* 2022), bifacial panels (Rasheed *et al.* 2022), and tandem solar cells (Rasheed *et al.* 2022) are particularly promising, since they can significantly bolster the performance of PV systems. Advancements in battery technologies, such as lithium-ion, flow, and solid-state batteries, hold great potential in enabling improved energy storage and management within buildings (Kim *et al.* 2019).

Energy-saving technologies in buildings

As cities worldwide continue to prioritize the urgent fight against climate change and its environmental impact, the significance of energy-saving solutions is escalating. In this quest for sustainability, Building Energy Management Systems (BEMS), heat pumps and waste heat recovery have emerged as pivotal technologies driving the paradigm shift toward sustainable urban living.

By harnessing the power of smart sensors and automation, BEMS optimize energy usage based on real-time data, leading to substantial energy savings and cost reductions for building owners and occupants alike. Future innovations should focus on enhancing the connectivity of BEMS with other building systems and integrating them seamlessly into smart grids which drive to the innovation of Positive Energy District (PED) concept. This implies an integrated approach for designing urban areas, districts or groups of connected buildings that produce net zero greenhouse gas emissions, managing an annual local/regional overflow production of renewable energy. The PED approach emphasizes the flexibility dimension of urban districts in the regional energy system based on renewable energy and addresses the ecological and energy footprints of goods and services. (Clerici Maestosi *et al.* 2021)

Heat pumps have garnered widespread recognition and adoption due to their impressive energy efficiency in both heating and cooling buildings (Belussi *et al.* 2019). Directing research and development efforts toward enhancing heat pump performance in extreme climates is of utmost importance. Waste heat recovery technologies have witnessed considerable advancements in recent years, offering a sustainable approach to harnessing untapped energy potential (Gholamian *et al.* 2020). Research should centre on enhancing the efficiency of heat exchangers and thermal conversion processes. Incorporating waste heat recovery technologies into the very fabric of urban infrastructure, such as district heating systems, can multiply their impact across entire urban landscapes.

3.2.2 Urban transport

Urban transport plays a pivotal role in both climate mitigation and climate adaptation efforts due to its significant influence on greenhouse gas emissions and its impact on the resilience of cities in the face of climate change. As the adaptation technology of urban transport is primarily addressed in urban planning, this section specifically emphasizes mitigation technology, with the content on adaptation introduced in section 3.2.5 Urban Planning.

Vehicle electrification

Major global carmakers have made substantial investments in electric vehicle (EV) technology, resulting in a diverse and expansive range of electric car models available in the market today. Innovation is required to lower the manufacturing costs to make EVs more affordable to a broader range of consumers. Battery technology, a crucial component limiting the performance of electric vehicles, has seen remarkable improvements. Ongoing research and development in next-generation batteries, such as solid-state batteries, show great promise in revolutionizing the electric vehicle industry (Sun 2020). Sustained efforts in battery research are essential to enhance energy storage capacity, charging speed and overall battery lifespan.

At the same time, the development of charging infrastructure has been advancing at a rapid pace, in tandem with the growing popularity of electric vehicles. Notably, the prevalence of fast charging stations has significantly reduced charging times, alleviating concerns about the inconvenience of charging an electric vehicle (Wang *et al.* 2021). Further expansion and enhancement of the charging infrastructure involves strategically placing fast charging stations in urban areas and along motorways to ensure convenient and reliable charging options (see Chapter 5).

Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) have emerged as a transformative force, reshaping modern transport and propelling us into an era of unprecedented urban mobility. By harnessing the power of big data analytics and machine learning algorithms, transport authorities can derive invaluable insights from the vast troves of information generated by various transport systems. This wealth of data offers a deeper understanding of travel patterns, traffic trends and peak hours, empowering decision makers to make informed choices in infrastructure planning, transport route planning and operational adjustments.

Traffic information management- and self driving system, Chongqing, China @Shutterstock

Ongoing technological innovation remains essential to tackle the challenges that lie ahead. A pressing requirement is ensuring the seamless integration and interoperability of various ITS components (Costin and Eastman 2019). With cities and transportation agencies implementing diverse ITS systems, compatibility and smooth communication are paramount to unlocking the full potential of these innovations. Advancements in data analytics and artificial intelligence will play a pivotal role in further optimizing ITS capabilities. By refining predictive algorithms and fully harnessing real-time data, transport authorities can anticipate traffic incidents, identify congestion hotspots and pinpoint potential chokepoints.

3.2.3 Urban energy supply system

A low-carbon and resilient urban energy supply system is essential for cities to address the challenges posed by climate change and ensure sustainable, reliable and resilient energy infrastructure.

Urban energy management and optimization

Urban energy management and optimization are key components of smart urban energy systems that focus on maximizing energy efficiency, minimizing waste and enhancing reliability across the city. These strategies involve the integration of advanced technologies and data-driven approaches to optimize energy consumption, distribution, and utilization.

One of the central pillars of urban energy management is demand-side management (DSM). DSM employs various techniques to balance energy supply and demand by encouraging users to modify their energy consumption patterns (Kanakadhurga and Prabaharan 2022) enabling creation of energy communities. In recent years, with the accommodation and control of increasing renewable energy, the power system has undergone a paradigm shift, leading to more Distributed Energy Resources (DERs) in the grid. Consequently, Energy Communities are a cooperative strategy of novel sharing renewable energy DERs, aligned with consumption minimization and flexible utilization of energy by active consumers to ease the high energy loads of the power grid (Weckesser *et al.* 2021) DSM technical tools can also help cities balance energy supply and demand, thus alleviating energy pressures during extreme weather conditions such as heatwaves, cold spells or other climate-related events. The future of DSM systems hinges on technological innovations, necessitating advancements in leveraging Internet of Things (IoT) technologies for personalized energy management. The future of innovation in this field lies in developing standardized protocols and communication interfaces that facilitate seamless data exchange between different energy systems and components. Moreover, innovative energy analytics and artificial intelligence play a crucial role in urban energy management (Farzaneh *et al.* 2021). These technologies process vast amounts of data from various sources, such as weather conditions, building occupancy and energy consumption patterns. By analysing this data, urban planners and energy managers can identify opportunities for energy savings, predict peak demand periods and implement proactive measures.

Smart grids and energy storage

Integrating smart grid technologies and energy storage solutions is vital for the effective implementation of electrification. Smart grids enable real-time monitoring, demand-response management and seamless integration of renewable energy sources. Advanced energy storage technologies include advanced metering infrastructure (AMI), battery energy storage systems (BESS) and DERs.

AMI is a key component of a smart grid that enables two-way communication between utility companies and consumers (Ghosal and Conti 2019). One important technological innovation requirement for AMI is to develop smart meters that can efficiently and securely communicate with utility companies and the devices in homes or businesses. In addition, BESS play a crucial role in storing excess energy generated during periods of low demand and supplying it during peak demand or when renewable energy sources are not readily available. BESS can smooth out fluctuations in power supply, improve grid stability and enhance the integration of renewable energy sources into the grid. Moreover, DERs encompass a wide range of small-scale, localized energy technologies, including solar panels, wind turbines, small-scale natural gas generators and microgrids. Smart grid technologies enable efficient integration and management of DERs, allowing them to contribute to overall grid stability and balance supply and demand in real time.

3.2.4 Urban water system

The urban water system plays a critical role in both mitigating and adapting to the impacts of climate change. On the one hand, the urban water system can contribute to climate change mitigation by implementing various strategies to reduce greenhouse gas emissions. On the other hand, as climate change leads to more frequent and severe extreme weather events, such as floods and droughts, the urban water system must adapt to ensure water security and resilience (see Chapter 4 for an urban water management case study in Thai cities).

Smart water management

Smart water management is crucial for sustainable water use and efficient resource allocation, especially in the face of climate change. Several key technologies, including IoT sensors and devices, AMI and Data Analytics and Decision Support Systems play a vital role in carbon reduction efforts.

IoT sensors and devices provide real-time data on water consumption, quality, leaks, pressure and weather conditions (Radhakrishnan and Wu 2018). To further contribute to carbon reduction, innovations are required in developing multi-parameter sensors that can measure both water-related parameters and gas emissions. AMI enables utility companies to remotely monitor and manage water consumption patterns, leading to improved billing accuracy, leak detection, and water conservation efforts. Advancements are needed in creating energy-aware AMI systems, allowing utilities to track and manage energy consumption effectively. Data Analytics and Decision Support Systems play a pivotal role in processing the vast amount of data collected. By analysing data on water consumption, distribution network inefficiencies and energy usage, decision makers can identify opportunities for carbon emission reductions.

Water recycling and reuse systems
Water recycling and reuse systems are essential components of sustainable water management and are instrumental in mitigating the impact of climate change by reducing greenhouse gas emissions and strengthening water availability in the face of growing water scarcity.

Membrane filtration technologies, such as reverse osmosis, have made significant progress in water recycling, reuse systems and desalination. Future research and development efforts should focus on improving the energy efficiency of membrane filtration and reverse osmosis systems. Another critical technology in water recycling and reuse is advanced biological treatment and nutrient removal (Deng *et al.* 2016). Continuous research and optimization of biological treatment processes are essential to further reduce greenhouse gas emissions. Decentralized water recycling and reuse systems offer an innovative approach to water management. Exploring the concept of hybrid decentralized systems that combine different water treatment technologies and approaches can offer a more efficient and versatile approach to water recycling and reuse, further reducing environmental impact.

Stormwater management solutions
Urban areas are increasingly grappling with the adverse effects of climate change, resulting in intensified stormwater runoff that poses significant challenges, such as frequent flooding and pollution of bodies of water. Implementing innovative stormwater management solutions has become crucial to combat these issues.

Permeable pavements are an advanced stormwater management solution that allow water to permeate the surface, rather than creating runoff (Sambito *et al.* 2021). The current technological progress in permeable pavements has demonstrated their efficacy in managing moderate rainfall events. There is a need for further technological innovation to enhance their performance during heavy storms. Green roofs, also known as vegetated or living roofs, are another innovative stormwater management technique that is gaining popularity in urban environments. Future technological innovation should focus on optimizing plant selection and irrigation systems to ensure optimal stormwater retention and long-term vegetation health. Rain gardens and retention basins are nature-based solutions that utilize landscaping and engineering techniques to manage stormwater (Kasprzyk *et al.* 2022). While these techniques have proven effective in mitigating flooding and improving water quality, future technological innovation should focus on optimizing their design and maintenance.

3.2.5 Urban planning

Urban land use planning plays a pivotal and indispensable role, since it provides a crucial framework for guiding the sustainable development and management of cities and their surrounding areas. This essential realm of urban planning involves climate-responsive urban design and the use of urban modelling and simulation.

Climate-adaptive urban planning
Climate-adaptive urban planning is an integrated approach that incorporates climate considerations into the design and development of urban areas. The primary objective is to establish resilient and sustainable cities capable of effectively mitigating and adapting to the effects of climate change.

One of the key strategies for climate-adaptive urban planning is the implementation of green infrastructure. Ongoing technological innovation is necessary to further improve the efficiency and effectiveness of green infrastructure. This involves developing more durable and sustainable green roofing materials and optimizing irrigation systems with smart sensors and automated controls. Additionally, flood-resilient infrastructure designs have utilized advanced modelling and simulation tools to evaluate flood risks and develop appropriate measures (Van, Cheng and Le 2020). Future innovation should focus on enhancing predictive modelling and early warning systems to better anticipate and respond to flood events. Ongoing research and development in sustainable farming practices are essential to further enhance climate-smart urban agriculture. This includes optimizing vertical farming systems (Mir *et al.* 2022) with advanced LED lighting and automation.

Climate-mitigation urban planning
Technological innovation plays a crucial role in low-carbon urban land use planning and transport network planning, helping cities to reduce carbon emissions, improve efficiency and create more sustainable urban environments.

Geographic Information Systems (GIS) and geospatial analysis tools allow urban planners to visualize and analyse data related to land use, transport and environmental factors. This enables them to make informed decisions about where to locate infrastructure, green spaces and mixed-use developments to minimize carbon emissions and enhance sustainability. Advanced modelling software allows urban planners to simulate different land use scenarios and their potential carbon impacts. These models can predict the environmental consequences of various development choices, helping cities make more sustainable decisions. Technologies such as cool roofing materials and reflective pavements can help mitigate the urban heat island effect, reducing energy demand for cooling in buildings and lowering carbon emissions.

Urban modelling: simulation and energy system optimization
Urban modelling and simulation encompass the creation of virtual representations of urban environments and the use of computational techniques to simulate various scenarios and interactions within these models. These tools play a vital role in assessing how climate change impacts cities and their inhabitants.

Current urban modelling and simulation tools have benefited significantly from the availability of higher spatial resolution data and the integration of diverse datasets from various sources. Integrating climate data, such as temperature, precipitation and wind patterns, into urban models enhances their accuracy in assessing climate change impacts. Continued advancements in remote sensing technologies and data integration methods are essential to further improve the accuracy and granularity of urban models. Moreover, modern urban models are beginning to incorporate climate projections to assess the long-term impacts of climate change on urban areas (Lucas *et al.* 2021). Additionally, virtual reality, digital twinning and advanced visualization techniques have become invaluable tools in helping stakeholders, policymakers and the public comprehend the implications of urban planning decisions. Advancements in virtual reality technology have the potential to improve the level of immersion and realism in urban simulations, making them more accessible and engaging for a broader audience.

3.3 THE ROLE OF URBAN INFRASTRUCTURE

Technological advance depends not only on the technology's research and development but also on the support provided by urban infrastructure. Urban infrastructure encompasses physical and organizational structures, facilities and systems that are crucial for the functioning and development of cities and urban areas. This includes transport systems (roads, bridges and public transport), water supply and sanitation networks, energy distribution systems, public lighting, communication networks, public spaces and buildings. The significance of urban infrastructure lies in its role in fostering the deployment of climate technology, solutions and innovative practices.

Table 3.2 Typical urban infrastructure for urban facilities and services.

Urban facilities and services	Type of urban infrastructure			
Transport	Sustainable public transport	Charging facilities	Non-motorized transport infrastructure	Carpooling and ride-sharing initiatives
Building	Green buildings	Energy-efficient systems	Waste management facilities	-
Energy	Renewable energy sources	Smart grid	Energy storage	-
Wastewater	Water treatment plants	Purification facilities	Interconnected pipelines	Reservoirs
Street lighting	Smart lighting	Lighting networks	Lamp posts	Security cameras

The transport system's vital infrastructure comprises sustainable public transport, charging facilities for electric vehicles, non-motorized transport infrastructure and carpooling and ride-sharing initiatives. Sustainable public transport involves implementing and expanding efficient, low-emission options, such as buses, trams and trains, aiming to decrease reliance on private cars. Developing and enhancing infrastructure for non-motorized transport, including pedestrian walkways, cycling lanes and bike-sharing systems, can also encourage people to opt for cycling and walking.

The building system's vital infrastructure revolves around establishing sustainable and eco-friendly frameworks that promote resource-efficient construction and minimize environmental impact. Green building materials form the foundation of sustainable construction infrastructure, with the use of recycled and locally sourced materials also reducing transport-related emissions. Energy-efficient systems are integral to the infrastructure of sustainable buildings, encompassing advanced HVAC systems, as well as smart lighting and energy management controls. Waste management facilities are crucial components of a sustainable building system, with the infrastructure supporting efficient waste separation, recycling and responsible disposal practices.

The energy system's crucial infrastructure encompasses a variety of sustainable initiatives aimed at reducing carbon emissions and promoting efficient energy use. At its core, the energy system focuses on transitioning away from fossil fuels and embracing renewable energy sources. This entails investing in renewable energy infrastructure such as solar panels, wind farms, hydroelectric power plants and geothermal energy systems. Additionally, smart-grid technologies are being deployed to optimize energy distribution and consumption. Smart grids enable better integration of renewable energy sources and improve the overall reliability and stability of the energy system.

The water system's vital infrastructure comprises a network of well-maintained water treatment plants and purification facilities, interconnected pipelines, reservoirs and storage tanks. These elements form the backbone of the water supply system, ensuring the delivery of clean and safe water to homes, businesses and industries. Water treatment plants play a pivotal role in purifying water from various sources, such as rivers, lakes and groundwater, to make it suitable for consumption and other purposes. These facilities employ advanced technologies and processes to remove contaminants and pathogens, ensuring that the water meets rigorous quality standards. Interconnected pipelines serve as the arteries of the water system, efficiently transporting treated water from the treatment plants to distribution centres and ultimately, to consumers.

Most cities have infrastructure networks that provide their citizens with energy, communication, transport, public lighting and other services. When this ageing infrastructure is replaced or updated, it is often done independently for each network, even though there is a large and untapped potential in integrating and advancing them. Modern technology could allow this integration, offering safer city environments, better connectivity and more services to cities and their citizens.

Public lighting infrastructure is particularly well placed to take up the role of a connectivity platform that offers not only smart lighting but also a series of other functions and benefits to cities. Lampposts are omnipresent in cities, offering great potential for standardization, and could integrate the various sensors and telecommunication technologies that are necessary in smart cities, as well as offering access to charging. (Colclough *et al.* 2020)

Table 3.3 Categories of co-benefits of adopting urban climate technologies.

Categories	Related technologies	Co-benefits
Energy	Energy efficiency and renewable energy technologies	Lower energy bills and energy independence improvement
Pollution control	Sustainable transport	Air and water quality improvement
Economic development	Emerging sustainable technologies	Green job creation and economic growth
Innovation incentives	High-tech climate technologies	Innovation and research motivation

One synergistic benefit in relation to energy arises from the potential for energy independence and security. Embracing renewable energy sources and enhancing energy efficiency can decrease a region's reliance on imported fossil fuels, mitigating the impacts of fluctuating fuel prices and geopolitical tensions. By developing a diversified and locally sourced energy mix, local governments can create more stable and resilient energy infrastructure, ensuring a consistent energy supply for their communities.

In terms of pollution control and reduction, local governments can significantly reduce greenhouse gas emissions while improving air and water quality by embracing climate technologies (Karlsson, Alfredsson and Westling 2020). For example, promoting and expanding sustainable transport options such as public transport, cycling lanes and pedestrian walkways can bring about a reduction in emissions from vehicles, providing climate-resilient alternatives to cope with potential disruptions in traditional transport systems during extreme weather events. Furthermore, efforts to plant trees and create urban forests offer multiple advantages. Not only do they sequester carbon, thereby contributing to mitigation efforts, but they also provide shade, enhance air quality and lower the risk of heat-related illnesses during heatwaves, making them vital for urban adaptation.

As for economic development, the potential of climate technologies to create green jobs and stimulate economic growth is another key synergistic benefit. As local governments invest in and promote the adoption of climate-friendly technologies, they create new opportunities in renewable energy industries, energy-efficient manufacturing, sustainable transport and other related sectors. This, in turn, boosts employment rates, fosters skill development and enhances the overall economic resilience of the region.

Regarding innovation incentives, high-tech climate technologies also offer opportunities for innovation and research and development (R&D). As local governments prioritize the adoption of cutting-edge technologies, they foster an environment that encourages private-sector investment in R&D, attracting skilled professionals and innovative companies to the area. This fosters a culture of technological advance and expertise, positioning the region as a hub for climate solutions and attracting further investments in sustainable development.

Furthermore, understanding the synergistic benefits arising from urban climate technologies can also serve as a powerful motivation for local governments to proactively promote their adoption. Climate technologies encompass a wide range of innovative solutions designed to combat climate change and its adverse effects. These technologies not only address climate challenges but also offer numerous additional advantages that can positively impact local communities, environment and economies.

3.4 LOCALIZED STRATEGIES IN THE GLOBAL SOUTH: CASE STUDIES

Considering the varying stages of development observed across cities, it is crucial to adopt a region-specific approach to urban transformation. This entails implementing specific strategies that cater to the distinct challenges faced by established cities, particularly those related to carbon emissions lock-in, while at the same time, focusing on preventing carbon lock-in in emerging cities.

In established cities with high levels of carbon emissions lock-in, strategic approaches may involve retrofitting existing infrastructure with energy-efficient technologies, promoting the adoption of renewable energy sources and implementing robust transportation systems that prioritize public and non-motorized modes of transport. Examples include Ha Giang (Vietnam) and Shenzhen (China), with the former focusing on an integrated approach that led to a transition to a low-impact, low-carbon society, and the latter focusing on sustainable development in a megacity. The case of Shenzhen is described in detail here (Box 2).

Box 2: Shenzhen: innovation driving the sustainable development of a megacity

Building on the United Nations' 2030 Agenda for Sustainable Development, China is exploring specialized regional solutions for implementing the SDGs. A plan to build "Agenda for Sustainable Development innovation demonstration areas" has been in place since 2016. This initiative is intended to demonstrate on sustainable development within the country and offer China's experiences to other nations striving to implement the 2030 Agenda for Sustainable Development.

As of August 2023, a total of 11 regions have been approved by the State Council to become innovation demonstration areas. These include Taiyuan in Shanxi, Guilin in Guangxi and Shenzhen in Guangdong (first cohort, 2018); Chenzhou in Hunan, Lincang in Yunnan and Chengde in Hebei (second cohort, 2019); Ordos in Inner Mongolia, Xuzhou in Jiangsu, Huzhou in Zhejiang, Zaozhuang in Shandong and Hainan Tibetan Autonomous Prefecture in Qinghai (third cohort, 2022) (The Administrative Center for China's Agenda 21 2022).

Each of these regions has a specific focus for their development theme (China, Ministry of Science and Technology 2022). Centred around these themes, each demonstration area has made significant progress in various aspects, such as urban renewal, low-carbon development, environmental protection and social governance. For example, Shenzhen, which is guided by the theme "Innovation Driving the Sustainable Development of Megacities", prioritizes addressing challenges such as limited resource and environmental carrying capacities, as well as insufficient social governance support through systematic solutions.

Shenzhen has made significant progress in various areas, including low-carbon transport, green construction, energy conservation, water conservation and sponge city development. According to the latest data available up to the end of 2021, Shenzhen has a total of 544,000 new energy vehicles, ranking it among the leading cities globally. The city has also added 18.87 million square metres of green building area and received 162 new green building certification labels. Water usage per 10,000 RMB of GDP in the entire city is 7.09 cubic metres, with a recycling rate of 73 per cent; the cumulative built-up area meeting the requirements of a sponge city now covers 353.5 square kilometres, accounting for 37 per cent of the total urban built-up area. The government has demonstrated significant support. Shenzhen has allocated a considerable sum of 13.4 billion yuan in fiscal resources toward R&D, contributing to a total societal R&D investment in excess of 150 billion yuan. Impressively, R&D expenditure corresponded to 5.46 per cent of the region's GDP (China, Ministry of Science and Technology 2022).

The ascent in GDP growth rates in the demonstration areas showed a distinct improvement compared with previous periods. There is a noticeable trend of green recovery, with ongoing enhancements in energy and resource efficiency. The renewable energy sector is growing rapidly and efforts to address water, soil, and air pollution have been strengthened, leading to positive socioeconomic and environmental results.

Emerging cities have the advantage of being able to proactively prevent carbon lock-in by implementing forward-thinking strategies from the early stages of development. Examples of region-specific approaches for emerging cities include incorporating green building principles into urban planning, establishing sustainable transport networks from the outset and integrating renewable energy systems into the urban fabric. Examples include Jakarta (Indonesia) and Cambodia, with the former focusing on smart infrastructure upgrading and the latter on sustainable mobility development. The case shown in Box 3 describes sustainable mobility in Cambodia in more detail.

Box 3: Sustainable mobility in Cambodia: e-mobility

Traffic congestion is a problem in most cities in South-East Asia. Transport is a major contributor to greenhouse gas emissions, particularly as most transport is based on fossil fuels. Sustainable transport is needed to reduce greenhouse gas emissions, for example, by switching to low-carbon fuels.

In Cambodia, reliance on road transport has increased as the country's economy has developed. Cambodia relies mainly on fossil fuel vehicles, most of which are second-hand. With the increase in the number of vehicles on the road and the fuel composition of Cambodia's energy mix, concerns have been raised about emissions and deteriorating air quality in the country's urban areas.

In 2019, Cambodia requested technical assistance for the Climate Technology Centre and Network (CTCN) under the United Nations Framework Convention on Climate Change (UNFCCC) to help accelerate the transition to cleaner and more efficient mobility systems and contribute significantly to Cambodia's efforts to meet its Nationally Determined Contributions (NDC) targets. Throughout the period of technical assistance, the Policy Action Plan for the development of low-emission mobility policies was developed to support the implementation of Cambodia's Intended Nationally Determined Contributions (INDC) targets for the transport sector. The support was achieved through a review of Cambodia's INDC, relevant policies and regulations; the transport sector growth, emissions and business-as-usual scenario; an impact analysis of two alternative e-mobility scenarios, and barriers to e-mobility and e-mobility policies. Based on the technical, social, environmental and gender analysis and the barriers/gaps, action areas and enabling conditions identified, a recommendation was made to implement e-mobility in Cambodia. This recommendation will help ministerial policymakers in Cambodia to develop e-mobility policies in order to achieve the INDC target for the transport sector. A proposal for a Green Climate Fund (GCF) readiness project has also been developed for further action.

In 2022, based on the proposal developed above, the GCF readiness project entitled "Climate Technology Deployment Roadmap for an E-mobility Ecosystem in Cambodia" was successfully launched to support the deployment of e-mobility. Based on the roadmap, the country will focus on establishing the long-term strategy for the deployment of e-mobility technology in Cambodia by strengthening its readiness in terms of policies and regulations, institutions, its means of implementation such as technology, finance and infrastructure to create an enabling environment that will support the fulfilment of its NDC in the transport sector. The aim is to mitigate GHG emissions in the transport sector through policy instruments to promote low-emission modes of transport.


Phnom Peng, Cambodia ©Shutterstock

3.5 CONCLUSIONS

The key messages of this chapter are as follows:

- To drive a systemic and transformative urban transition, it is imperative to prioritize comprehensive technological innovations in critical domains, such as urban building, transportation, energy supply, water systems and urban planning.
- The progress of climate technology is not exclusively reliant on research and development; instead, it is deeply contingent on the presence of robust urban infrastructure encompassing vital components such as transport systems, water supply and sanitation networks, energy distribution, communication networks, public spaces and buildings.
- Recognizing the synergistic benefits of applying innovative climate technologies can help incentivize governments to further enhance the adoption of such technologies. These synergistic benefits include but are not limited to improving energy independence and flexibility, addressing local environmental pollution, fostering economic development and inspiring innovation.
- Region-specific climate technologies can play a significant role in facilitating the transition to low-carbon and sustainable practices in local areas, whether they are emerging or mature cities. Cases from the Global South highlight this fact.

Integrating renewable energy technologies into buildings such as these solar glass windows is crucial when planning cities of the future ©Shutterstock

4.

Institutional settings and govenance

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4.1 INTRODUCTION

Understanding institutional settings and governance processes is critical to the effective delivery of climate technology solutions for low-carbon and climate-resilient development in Asian cities. Creating the appropriate enabling environment for the development and transfer of climate technologies becomes imperative in this context. This requires unpacking the complex social, political, institutional, regulatory and financial dimensions that play a defining role in shaping the ability of national actors to successfully govern processes of technological change (TEC 2022; CTPR 2022). Sustainability transition is an interdisciplinary field, aimed at understanding long- term, non-linear socio-technical changes (Kovacic and Benini 2022). This lens is used to guide the analysis in this chapter on institutional aspects and governance in the context of climate technologies in Asian cities, because it enables an analysis of the deep structural and systemic shifts that are required for cities to better anticipate and adapt to increasingly dynamic and complex challenges posed by climate change and development needs.

4.2 GOVERNANCE OF SUSTAINABILITY TRANSITIONS IN URBAN SYSTEMS

Transforming urban systems around energy, mobility, food and housing to mitigate and adapt to the impacts of climate change has become a central matter for municipalities and regional authorities (McCormick *et al.* 2013; Frantzeskaki and Kabisch 2016; Elmqvist *et al.* 2019). Urban systems can fundamentally change towards more sustainable modes of production and consumption when appropriate innovations and nature-based solutions emerge and become mainstreamed in the market and wider economic system (for example, Kabisch *et al.* 2016; Loorbach, Frantzeskaki and Avelino 2017). Innovations include climate-compatible technologies but can also take the form of new social practices, business model governance mechanisms and regulatory structures. New social practices include the incorporation of social principles for implementing urban eco system-based adaptation to achieve climate justice for nature and people (Vidal Merino *et al.* 2021). They also include innovations such as nature-based solutions for flood-risk management, circumventing the entrenched urban planning and development patterns of growing cities from the Global South (Gajjar *et al.* 2021).

However, innovations often face multiple barriers to their development and diffusion. For example, they often struggle against established technologies that may have benefited from decades of accumulated efficiency gains (for example, Kivimaa *et al.* 2021), are well integrated into established habits and lifestyles (Shove and Walker 2010; Klitkou *et al.* 2015), and may be actively defended by established industries with vested interests in preserving the status quo (Geels 2014; Turnheim and Sovacool 2020; Ting and Byrne 2020; Mauw, Smith and Torrens 2023). Kern and Rogge (2016) indicate that future low-carbon transitions are different from the past because there is more emphasis on deliberate planning and governance aimed at shaping the selection environment towards adopting climate technologies. One example is the German *Energiewende*, a comprehensive national programme that targets several sectors and technologies in the economy, enabling bottom-up innovation, experimentation and learning. Based on the strategic objectives of addressing climate change, phasing out nuclear power and improving energy security by substituting imported fossil fuel with renewable sources, the *Energiewende* is providing a direction to innovation and economic growth across different sectors through targeted transformations in production, distribution and consumption (for example, David 2017; Rogge and Johnstone 2017).[5]

Other examples include the cities of South Africa, where innovative approaches occur in the cooperative space where government, the private sector, knowledge institutions and civil society role players meet – the “quadruple helix” (South African Cities Network [SACN] 2016: 287). The cooperative space creates an enabling environment for the necessary systemic changes to happen so that the productivity, inclusivity and sustainability of cities is improved (Fig. 4.1). However, “this requires a commitment from all role-players to collaborate, as well as strong intergovernmental coordination among the various role-players that influence city form and space” (ibid.).

5 Targeted, measurable, and time-bound missions also set a clear direction for research and innovation in the new Horizon Europe programme and reinforce the two main pillars of the European Green Deal around climate action and digitalization. The promise of missions is that bottom-up experimentation involving a broader and more diverse set of stakeholders leads to more effective solutions that can be scaled up, thereby contributing to the meeting long-term environmental objectives and targets (Mazzucato 2018).

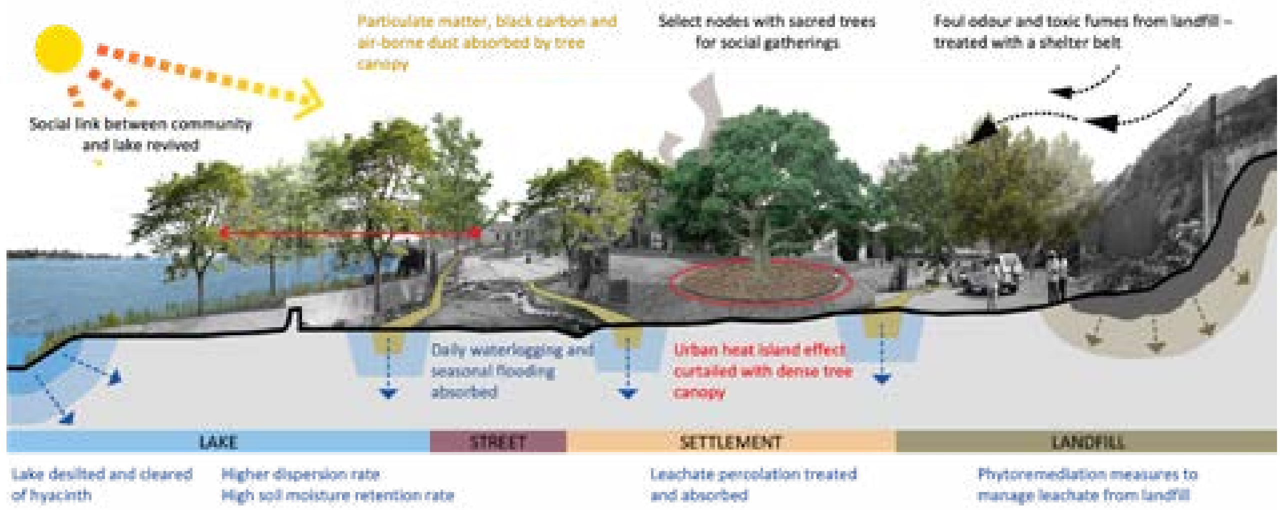
Figure 4.1 An illustration of the Quadruple helix (SACN, 2016).

Furthermore, sustainability transitions research emphasizes the participation and influence of a much broader and diverse set of stakeholders including civil society, non-governmental organizations and grass-roots institutions (Fressoli *et al.* 2014; Seyfang and Longhurst 2015; Smith and Stirling 2016). Thus, urban climate action that actively includes local actors is more likely to avoid unintended, negative maladaptive impacts and mobilize a wide range of local capacities (UN-Habitat 2022).

Supporters of transformation in the context of climate change strongly articulate the challenges associated with switching from current, potentially maladaptive development trajectories, onto future pathways that are climate responsive. Although scholarship on maladaptation highlights the dangers of path dependency, the concept is under-applied for understanding the potential outcomes of development trajectories that result in what we call an *adaptation-constrained space*. (Gajjar et al. 2019) For example, the current form of urbanization in Bangalore city has decreased its capacity to respond to concurrent risks of urban flooding. What is required instead is the recognition and integration at an urban scale, of socially just and adaptive community spaces. Community commons provide the opportunity to implement a range of nature-based solutions, to mitigate environmental and climate-related hazards, enhance natural assets in cohort with social ownership and enterprise and foster female-led socio-ecological innovations.

'Community commons' (Mohan and Muraleedharan 2022) are shared spaces within settlements and constitute critical spaces that provide environmental, social and economic support for the urban poor (Figure 4.2 uses an example of potential solutions in Churmuri Bhatti, Dharwad, India, where potential solutions could use buffer vegetation along a lake edge to provide shaded areas for domestic activities, green covers to alleviate urban heat island effect, and permeable pavements to allow recharge of run-off water an reduce dust pollution). Environmentally, these hold the potential to regulate and mitigate heat stresses and manage flood and drought conditions. Socially, they facilitate common interactions and periodic celebrations and festivals. Economically, community commons support income-generating activities that extend from within the household. Yet these are often neglected and are therefore at the receiving end of climate change and haphazard urbanization induced risks. Comprehending the myriad ways in which these spaces accommodate individual and community living emerges as a starting point to initiate these as critical spaces for instituting adaptation and mitigation strategies in poor urban settlements. Collaborative governance between municipal stakeholders and decision-makers is required for the benefits of such community spaces to be realized.

Figure 4.2 Illustrative solutions in Churmuri Bhatti, Dharwad, India (Mohan and Muraleedharan 2022).



According to Foxon (2011) and Geels and Schot (2010) sustainability transitions occur through the co-development of technologies with socioeconomic and institutional changes. Hence, the development of technologies and their diffusion in society determines the pace at which sustainability transitions are achieved (Bento and Wilson 2016; Gross *et al.* 2018). Cities can make distinct contributions to the development and diffusion of innovations, providing spaces for experimentation, learning and upscaling of climate technologies, as well as nature-based solutions for mitigation and adaptation (Gajjar *et al.* 2021; Gajjar *et al.* 2019; Bulkeley and Broto 2013; Raymond *et al.* 2017; von Wirth *et al.* 2019). From the testing of mobility-as-a-service concepts, data collection and analysis of innovative housing models, to the design of participatory tools directly engaging citizens in urban planning and the development of sustainable city districts, cities provide testing grounds to experiment with and learn from innovations in real time that respond to growing pressures from climate change (e.g. International Council for Local Environmental Initiatives [ICLEI] Africa 2021; Bulkeley *et al.* 2016; Voytenko *et al.* 2016). However, transitions research shows that innovations will drive systemic change under particular circumstances (for example, Coenen, Hansen and Rekers 2015; Frantzeskaki 2019). Initially, innovations are typically not competitive in terms of costs and performance and emerge in protected spaces or 'niches' where they are shielded from normal market forces and consumer preferences (Smith and Raven, 2012). To this end, R&D labs, incubators to run experiments or subsidized demonstration projects offer protected spaces where new ideas can be developed, tested and improved before they can be fully scalable and commercialized.

4.3 UPSCALING OF TECHNOLOGIES

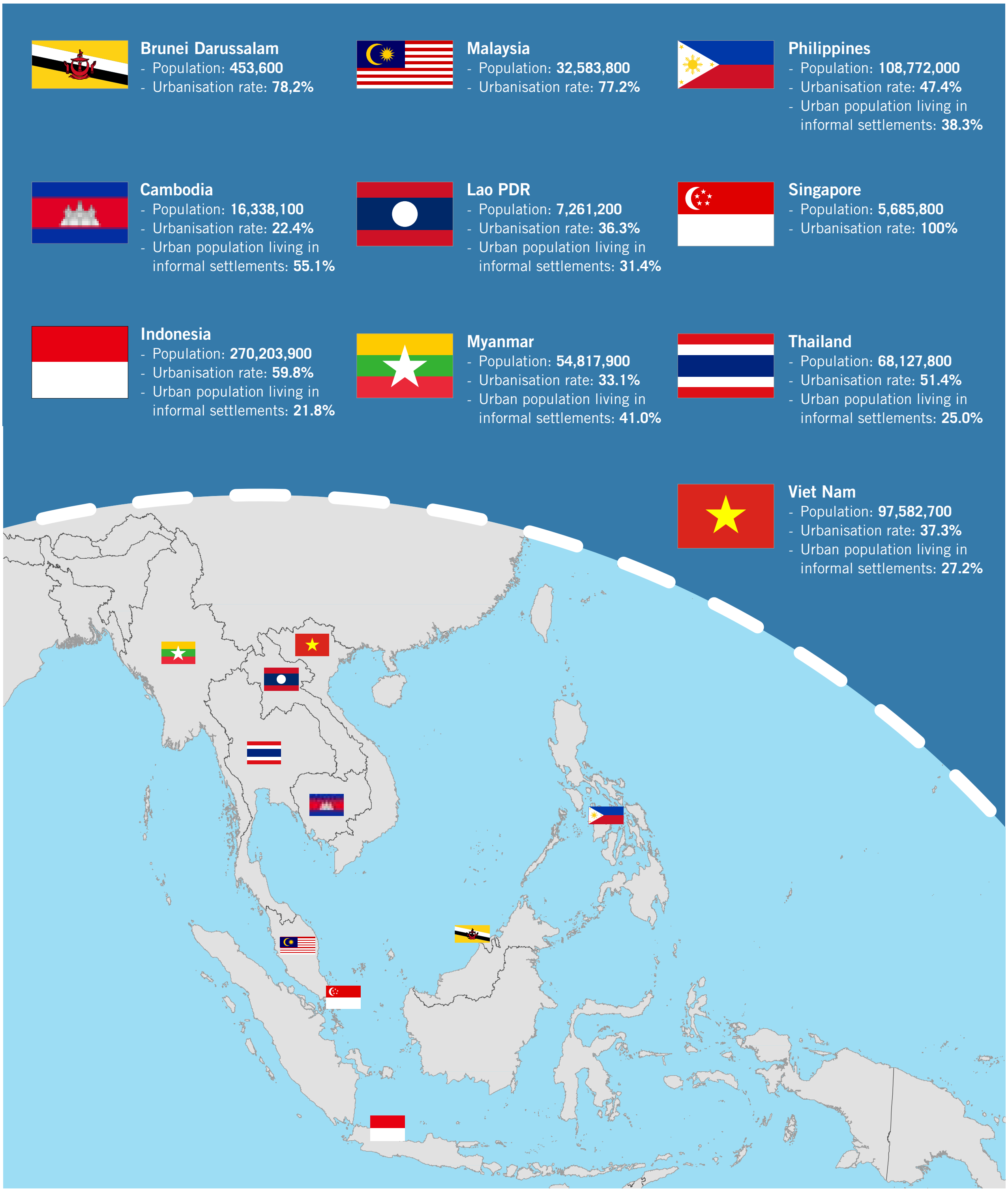
Experimentation has great potential to generate novel ideas and solutions that can support urban system transformation. Place-based experimentation at the city level can potentially turn the diversity of knowledge and innovation systems into an asset (McCann and Soete 2020). For this chapter, however, the question is how to govern the upscaling of innovations within and across cities (Coenen, Raven and Verbong 2010). The wider diffusion of innovation typically occurs through the formation of institutional networks that connect initiatives by sharing ideas, objects and activities across local contexts (Loorbach *et al.* 2020), the outcomes of which can be considered at different levels. The impact and influence of experimentation with potentially transformative innovations are enhanced by existing platforms for networking and communication, arising from activities by international city networks such as ICLEI, C40 Cities Climate Leadership Group (C40) and the Global Covenant of Mayors for Climate and Energy, among others (Davidson, Coenen and Gleeson 2019; Diercks, Larsen and Steward 2019). Such networks can facilitate the sharing of ideas and best practices across space and scale, which allow innovations to be shared, replicated, and adapted into new contexts (Nguyen, Davidson and Coenen 2020). As an example, the Global Environment Facility (GEF) has the sustainable cities impact programme, which support 23 cities in nine countries, by bringing together city officials, urban actors and national governments to create innovative models for implementation of integrated sustainability solutions and providing city-to-city exchanges, learning and sharing of best practices (GEF 2021). Networks of this nature often benefit from coordinated institutional support, adequate resources and infrastructure that enable local city administrations, civil society actors and businesses to interact and co-produce long-term governance objectives. The emergence of international city networks addressing sustainability and climate change represents a successful mode of transnational network governance.

In the next section, cases are used to demonstrate how mutually reinforcing dynamics at different levels of governance influence the upscaling of innovations within and across cities.

4.4 CASE STUDIES ON ASEAN CITIES

Asia houses one of the fastest-growing urban populations and is highly vulnerable to extreme weather and climate change impacts (IPCC Working Group II 2022; World Meteorological Organization [WMO], 2023). As an example, South-East Asia has an average urban population growth of around 2.21 per cent, while the rural population is declining at a rate of -1.3 per cent (United Nations Development Programme [UNDP] 2015). Moreover, while urbanization is taking place across the urban-rural divide, as well as in megacities, there is also an increase in growth in so called secondary cities such as those found in Association of Southeast Asian Nations [ASEAN] countries (Fig. 4.3). Accounting for almost 40 per cent in GDP growth by 2030 in the ASEAN region, secondary cities are considered fast-paced urban growth, usually consisting of a population of 200,000 to 2 million people (ASEAN 2022). As depicted in Fig. 4.3, ASEAN countries have varying urbanization rates, with some, such as Vietnam and Thailand, seen to have accelerated growth in the next few years.

Figure 4.3 ASEAN member states, population sizes, urbanization rates and percentages of informal settlements (ASEAN 2022).

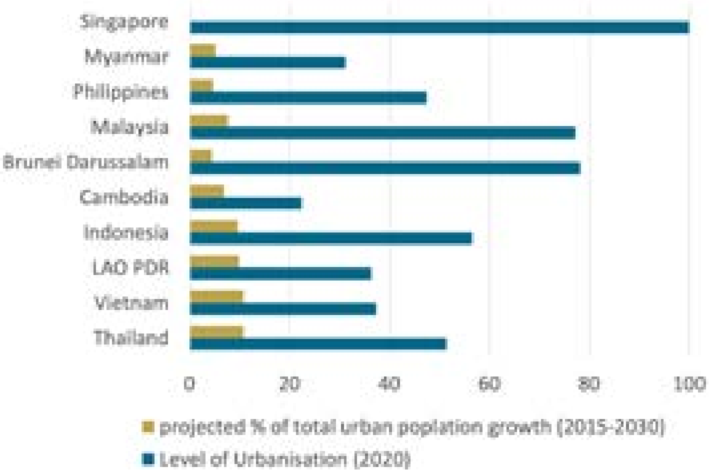


While urbanization has provided economic opportunities and raised the standard of living for millions of people, there are also social and environmental costs. These include (ASEAN 2017):

- an increase in urban sprawl[6]
- local governments being unable to provide adequate infrastructure that matches the rapid need for housing and public services, leading to informal settlements
- increased water consumption, which is causing shrinking aquifers
- problems with traffic congestion due to a rise in the ownership of cars and motorcycles, leading to air pollution and greenhouse gas emissions
- a large amount of waste, with significant impacts on land, rivers and lakes.

6 Urban areas may expand in an incoherent, fragmented fashion that serves to increase segregation and inefficient land use.

Figure 4.4 ASEAN member states' level of urbanization in 2020 and projected total urban population growth by 2030 (ASEAN 2022).



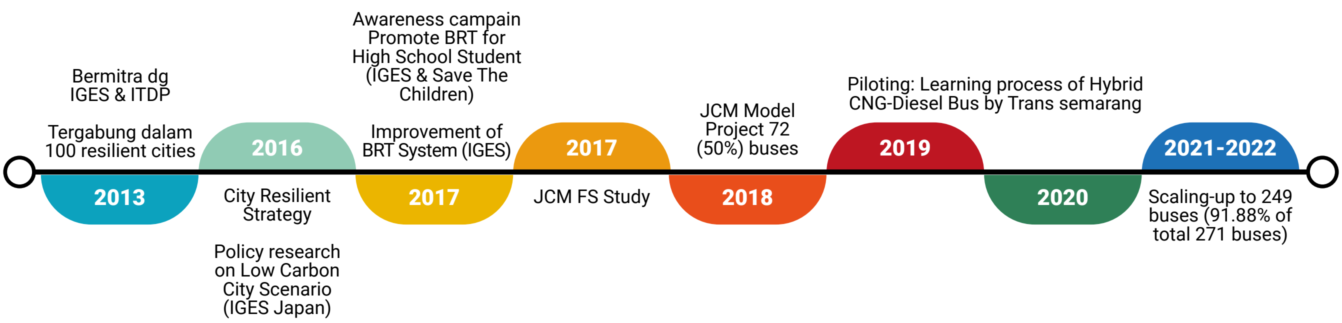
To refine the analysis, this chapter focuses on cities located in ASEAN member states (Fig. 4.4). They range from the medium-sized Melaka City in Malaysia to the rapidly urbanizing Semarang City in Indonesia and water management issues in cities in Thailand. The intention in choosing these cases was to represent the varying levels of urbanization shown in Fig. 4.4 and the thematic areas of transport, water management issues and integrated green action plans.

4.4.1 Scaling-up processes of CNG buses in Semarang, Indonesia

An initiative to transition from diesel to hybrid compressed natural gas (CNG)-diesel buses in the mass transit system was implemented in Semarang between 2013 and 2022. While the use of CNG has been criticized for continued reliance on fossil fuels, the pilot case typifies the city's incremental transition towards lowering its greenhouse gas emissions. This case study demonstrates the role of buses as a more efficient form of traffic regulation compared to other car-heavy cities. Semarang is the capital of Central Java Province and is Indonesia's fifth-largest city, with a population of over 1.6 million people. It is growing in a way that is beginning to sprawl, making it challenging for some parts of society to reach places efficiently. Furthermore, the city faces various challenges as a coastal city, specifically tidal flooding, erosion, land subsidence and rising sea levels. In 2014, the local government of Semarang launched a resilience strategy to improve management and quality services. The city resilience strategy forms part of the Rockefeller 100 Resilient Cities initiative. The governance of the strategy development involved a chief resilience officer, who formed a steering committee that included the city secretary, acting as the committee advisor, the head of Semarang's Bappeda (Regional Development Planning Agency), urban decision makers, representatives from the business sector and the community, and academics. Various initiatives were identified in collaboration with city stakeholders, one of which was the bus rapid transit improvement and fuel conversion programme. The aims of these initiatives were addressing climate change issues, improving air quality and enhancing acces to public transport in the city.

The programme had undertaken research into low-carbon technologies in public buses, followed by a feasibility study as part of a city-to-city programme between Semarang and Toyama, Japan. This study benefited from the support of the Joint Crediting Mechanisms funded by the Japanese Ministry of Environment. Over a four-year pilot period (from 2016 to 2019), 72 retrofitted Hybrid CNG-diesel buses were deployed, equivalent to 50 per cent of the city's total public fleet. Given the success of this initiative, a scaling-up process was initiated in 2020-2022 and increased the fleet to 249 buses or 92 per cent of the total city's fleet (Fig. 4.5).

Figure 4.5 Scaling-up process for Trans Semarang CNG Buses (Nugroho, 2023).



Several factors facilitated the deployment of hybrid CNG-diesel buses. First, capacity and knowledge accumulation through the pilot project took around two years from early 2019 until the end of 2020. These included a comprehensive technical analysis of low-carbon technologies for CNG buses in the city in the initial stage. The research included: 1) developing an emissions inventory in the transport sector; 2) ensuring alignment with local policies and measures to reduce air pollution and greenhouse gases based on existing plans; 3) quantifying the impacts of priority policies and estimating the effects on selected policies; 4) building a consensus across relevant stakeholders on follow-up actions; 5) translating policy recommendations into practical actions. The quantitative analysis gave stakeholders and policymakers insights into the benefits of simultaneously mitigating climate change and air pollution. The results were also useful in helping local decision makers to move from evidence-based research to practical actions at the city level. In this case, a science-based policy decision-making process involved local stakeholders and ownership of the project by many parties was important.

Secondly, as part of stakeholder engagement, a policy dialogue was instigated to introduce the low-carbon technology bus fleets, with a focus on student ridership, since this is the largest group of users. Continuous engagement was important insofar as it increased the chances that policymakers would follow through with implementing activities after the project concluded. Additionally, in 2017, the Institute for Global Environment Strategies (IGES) began collaborating with several partners, including Diponegoro University and the Institute for Transportation Development Policy, on the development of guidelines for reforming the city's bus rapid transit system. These guidelines were centred on sustainable urban planning and included 1) mixed land use; 2) multiple transport options; 3) public space; 4) preservation of historic structures; 5) community engagement; 6) arts, culture and creativity and 7) recreation. Guidelines are important, because they provide easy-to-understand information for policymakers. Furthermore, the IGES worked with local and international NGOs to focus on behavioural and attitudinal changes, particularly the preferential switch to using public transport instead of private vehicles. This is an example of learning beyond technocratic approaches, since it entails a reflection on personal preferences and values, such as aspirational ownership of private vehicles.

Thirdly, Semarang City was able to leverage multiple partnerships and combine resources, to create an enabling environment for sustainable transport (UN 2019). The pilot project, which involved retrofitting 72 buses to convert them to hybrid CNG buses, was 50 per cent funded by the city authorities, with the remaining 50 per cent from the carbon market, a Joint Crediting Mechanism, and bilateral cooperation between Indonesia and the Japanese government. With the support of the Ministry of Transport, the project has now encouraged 23 other cities in the country to follow Semarang's example as a means of progressing towards sustainable transport.

- Engagement with regional and international networks and platforms that specialize in providing climate technology solutions was essential to keep expertise up to date and informed on the latest developments, as well as creating opportunities for resource mobilization, collaboration and partnerships. The project is an example of engaging with various actors, including the business sector, from the outset. It is through engagement that the early stage of the decision-making process fostered participation and overcame barriers to address existing risks.
- Learning that goes beyond technocratic approaches also entails reflection on personal preferences and values, such as aspirational ownership of private vehicles, as was evident in this case.

4.4.2 Melaka, Malaysia, Green Climate Action Plan (GCAP)

Malaysia has one of the highest energy demands per capita in South-East Asia and has voluntarily committed to reducing its greenhouse gas emissions by 45 per cent based on 2005 levels by 2030 (ASEAN 2022) Given that Malaysia has one of the more advanced economies in the region, its climate change plans could set an example for its larger, fast-growing neighbouring countries (Indonesia, Thailand and Vietnam) (Gouldson *et al.* 2016). There are some instances where the country has been reluctant to take a stance in international climate change negotiations, partly because fossil fuels such as oil and gas provide significant revenues for its tax base. Nevertheless, there are a few climate change initiatives that provide exemplars for other cities to follow. One of these is in Melaka City, which is located 130 km away from the capital of Kuala Lumpur, and has a rapidly increasing population, which currently stands at 579,000 inhabitants.[7]

Melaka is considered a world heritage city, with a strong manufacturing and service base, and is a popular tourist destination. A large part of the city is viewed as environmentally sensitive due to its rich biodiversity. There are several environmental qualities and challenges around economic competitiveness, including ongoing coastal development without due consideration of climate-change related impacts, the continuous expansion of the urban periphery and rapid urbanization which,

7 Smart Melaka Blueprint

among other things, has resulted in a growing traffic congestion problem. In terms of transport, Melaka has an average of 1.9 motorcycles and 1.4 cars per household respectively. This is considered a high level of private ownership, leading to worsening air and environmental quality in the city (Zen *et al.* 2019).

Melaka's path towards urban sustainability is a result of sequential steps over many years. One of the first steps was to establish a Green Technology Council, chaired by the Chief Minister of Melaka, as a high-level body that was tasked with coordinating the implementation of climate change mitigation and adaptation policies at the state and city level, as well as coordinating cross-sector green city initiatives. This was followed by a Green Technology Blueprint in 2011, and shortly afterwards, in 2012, Melaka signed up to the United Nations Urban Environmental Accords, providing support at the global level. Around the same time, sub-regional economic cooperation, called the Indonesia-Malaysia-Thailand Growth Triangle (IMT-GT) wanted to pursue green cities initiatives, specifically in Melaka (Malaysia), Songkhla and Hat Yai (Thailand), and Medan and Batam (Indonesia). Melaka was chosen as a flagship project for the IMT-GT, working closely with the Centre for IMT-GT (CIMT), the Asian Development Bank (ADB) and the Prime Minister's Planning Unit, to develop the Green Climate Action Plan (GCAP). Consequently, in 2014, Melaka's GCAP was developed with the assistance of the ADB. (ADB 2014)

Melaka's GCAP had provided an integrated urban approach, emphasizing the 3Es namely Environment (natural resources and low-carbon technology), Economic competitiveness (service delivery efficiency, financial innovation, revenue generation and job creation) and Equity (inclusive, accessible and affordable) (ADB 2014). The GCAP had specific outputs, which included developing a baseline and targets, and establishing indicators and associated indexes to track progress not only within Melaka, but also as a basis for intercity comparison. Other outputs included capacity-building programmes related to integrated urban development among heads of department, as well as a long-term public awareness forum to support the green city action plan. As part of implementing the GCAP, the Melaka Green Technology Corporation collaborated with the Malaysia Industry Government Group for High Technology (MIGHT), resulting in six projects, which are: (i) energy-efficient buildings; (ii) city infrastructure; (iii) green tourism; (iv) smart grid; (v) wastewater eco-park, and (vi) solar industry eco-park. More specific implementation efforts underway include a pilot energy efficiency project to upgrade streetlights and selected public buildings, electric vehicle charging stations, development of the Hang Tuah Jaya Green City, conversion of diesel buses into electric buses and initiation of the Melaka Green Seal for building certification (ADB 2022).

The Malaysian case study had shown the importance of the role of the sub-economic regional body, the IMT-GT and the partnerships with the ADB in supporting and funding the GCAP in Melaka. These international organizations also provided international best practices or frameworks to implement local projects, such as integrated urban planning. They also encouraged city twinning to share lessons during the implementation stages. As a result, multiple partnerships with international organizations, donors and various levels of government were essential.

4.4.3 Institutional challenges in water-related management in Thai cities in the context of urbanization and climate change

Water-related management challenges in Thai cities are increasingly complex, arising from compounded multi-scalar issues of institutional structure, urban and water governance, and drastic changes in ecological and hydrological landscapes (Friend and Thinphanga 2018). Existing water-related problems are intensified by the unpredictability of climate change and extreme weather events. The 2011 flood disaster in Central Thailand is an example of the interlinked problems of land use change, excessive rainfall, weak institutional capacity in decision-making and ineffective governance in coordinating across multi-stakeholders (Anukularmphai 2011; Pahl-Wostl *et al* 2012; Suhardiman et al 2017).

In the past decades, rapid urbanization in Thai secondary cities, such as Hat Yai, Udon Thani and Khon Kaen, has driven drastic land use changes, transforming rural, agricultural and green spaces into built urbanized areas. Most cities are growing without effective enforcement of comprehensive land use plans, which are often 10 to 15 years out of date. Unregulated expansion of urbanized areas into naturally low-lying floodplains and filling in waterways, such as canals and wetlands, are increasing the exposure and sensitivity of local communities to hazard risks and climate impacts (Friend and Hutanwatr 2021). City administrations and local communities in urban areas are faced with regular flash floods, water contamination and poor quality of water supplies. Existing water infrastructure and systems in most cities are outdated. With rapid urbanization, the development of new water infrastructure, such as piped water and drainage, is inadequate and cannot keep up with increasing demand.

Institutional structures and arrangements create tensions and conflicts in the planning and implementation of water-related management and disaster risk reduction at both city and watershed scales. Multiple government agencies under different ministries are responsible for water-related management, including the development, management, operation and maintenance of water, flood, and irrigation infrastructure, while local administrations have limited remits within their administrative boundaries. In most Thai cities, urbanized areas cover several administrative units. Political tensions and conflicts arise from flood protection and diversion schemes and competition over limited water resources.

For example, urbanized areas of Hat Yai City in southern Thailand extend over five medium-sized administrative units beyond the Hat Yai City Municipality. Located in the downstream area of the Khlong U-Tapao River Basin, Hat Yai City is naturally low-lying and flood-prone and experiences regular floods. Water diversion methods using irrigation canals as drainage, water pumps and sluice gates are a common approach to protecting the urban centres of Thai cities, including Hat Yai, from flooding. Decisions to operate infrastructure for flood diversion, such as opening or closing sluice gates, become institutional and governance challenges. Ill-informed decisions lead to the subsequent issues of prolonged flooding in downstream areas or water shortages due to excessive drainage, further impacting local livelihoods and environments. The flood diversion approach using hard infrastructure also creates new socioeconomic and environmental problems, since climate change is not incorporated into the design of water and flood infrastructure development. In Hat Yai, the response to the 2010 flood disaster was to construct new drainage canals, completed in 2022, but based on rainfall data from 2010 (Hat Yai Today 2017). In the face of climate change and urbanization, newly constructed water and flood infrastructure is costly and becomes ineffective as flood patterns change due to alterations in rainfall patterns and land use.

At the watershed scale, multiple government agencies responsible for water resource management, disaster risk reduction and the operation of water and flood infrastructure are faced with unpredictable weather conditions, contributing to ineffective implementation of existing plans. With the oscillating pattern of floods and droughts, the role of networked irrigation infrastructure, such as dams and canals, also changes, serving as both storage and drainage. Operational plans and decisions on storing or discharging water become ineffective under climate uncertainties, leading to worsening flood disasters and water supply shortage crises (Friend and Thinphanga 2018). Cities such as Khon Kaen and Ubon Ratchathani, in the Chi-Mun River Basin, a subsidiary of the Mekong River, have repeated experiences of flood and drought disasters. While extreme rainfall events contributed to the flood disasters in 2017, 2019 and 2022, decisions to discharge water from upstream dams led to worsening floods in the downstream area of Ubon Ratchathani (Nathanri 2017a; Nathanri 2017b; Wipatayotin 2022; Bangkok Post 2021). Discharging too much water or discharging it too early without significant rainfall to refill the dams could lead to water supply shortages.

Despite the establishment of the Office of National Water Resources, a centralized, single command centre for water resource management in 2017, coordination across the different agencies at national and local scales for implementation still poses major institutional challenges. The development and application of climate technologies that support the coordination of cross-sectoral government agencies and collaboration of non-state actors to generate both scientific data, such as changing hydrological patterns in urban areas, and community-level information, particularly marginalized and vulnerable groups, will be critical for improving inclusive governance in the decision-making process. Moreover, climate technologies need to be easily accessible and applicable to the local context.

Solutions and approaches to address complex water-related management challenges in the face of climate uncertainties and urbanization require not only scientific and technical methods but also improving governance and institutional capacity at multiple scales. Strengthening the knowledge capacity of local administrations to better understand the linkages between climate change, land use and water-related issues is critical to influencing local development planning and implementation. However, in practice, understanding and incorporating climate uncertainties, future risks and urban spatial dynamics into planning and decision-making processes will require rethinking the knowledge-policy-practice interface. New forms of knowledge production based on inclusive engagement of multi-stakeholders will be necessary to respond to the complexity of social, environmental, and economic concerns in climate-integrated urban land use, water and disaster management planning. Participatory research, engagement and learning tools, such as Citizen Science and Shared Learning Dialogue approaches, together with technologies such as data platforms, will play a critical role in enabling knowledge co-production (Reed *et al.* 2013, Albali and Iwama 2022).

The case study of water management in Thai cities has shown that water resources and water-related disaster risk management are increasingly complex with the challenge of climate uncertainty and urban dynamics. Approaches and solutions need to move beyond a technical and scientific problem to be fixed by experts. Decision-making roles need to involve non-state actors, including formal and informal organizations. Moreover, the case study has shown that urbanized spaces can cover several jurisdictions, which is significant for the capacity to provide integrated and holistic solutions such as urban planning, climate change and water management.

4.5 DISCUSSION AND CONCLUSION

The cities analysed in this chapter represent some of the challenges and opportunities encountered when deploying climate technology solutions for climate change mitigation and adaptation in Asian cities. Each of these cities has varying characteristics that provide lessons and insights for best practices of governance and institutional dimensions required to develop and implement climate technology solutions in Asian cities. This section sets out key messages and policy recommendations to improve city governance arrangements to generate enabling environments for innovation and increase the effectiveness of climate technology transfer. Urbanization is intricately linked with other global challenges, which include biodiversity loss, widening inequality – making communities vulnerable to future climate change impacts – and emerging threats and opportunities that include digitalization, among other mega trends. In this chapter, our aim has been to recommend that future governance systems prioritize flexibility, adaptability and the ability to anticipate ever-increasing complexity and uncertainty. This entails a combination of both hard and soft governance tools and can include technocratic approaches to inform policy, as well as creating spaces for open dialogue, building trust, a plurality of perspectives, new narratives and spaces for reflection. Accordingly, governance in these settings will inevitably require new kinds of capacities to steer, coordinate and build partnerships among multi-stakeholders on various spatial scales and across sectors.

Network building through coordination and collaboration. The implementation of climate technology solutions requires coordination among different government agencies, departments and stakeholders. Ensuring effective collaboration and communication between these entities can be challenging, especially when formal and informal structures are complex and overly bureaucratic. Managing interactions, coordination and collaboration between vertical and horizontal components of government efficiently is often termed multilevel governance. This describes a whole government approach and includes both vertical and horizontal components of government that are fit to deliver services efficiently (UN-Habitat 2022).[8] This is important because there are multiple policy levers that need to be pulled to access opportunities, which may exist at different scales and in different sectors. Often, there are power dynamics between vertical levels of government and horizontally across quasi-government and non-governmental organizations and actors (UN-Habitat 2022). These play out in a balance between decentralization and central control, across sectors, between actors and along interdependent dimensions, which include political, administrative and fiscal resources. All three case studies show the significance of partnerships that include multiple stakeholders (for example, non-state actors), such as the private sector, government and communities, at various scales (regional, national and city levels).

Stakeholder engagement and inclusive governance. In terms of urban governance, engaging all actors, which includes local government, the business sector, civil society, and communities was essential in all the case studies. It is through engagement that decision-making processes can foster participation and overcome traditional barriers to address existing risks and prevent new ones. For example, there are informal institutions, such as lack of trust, which can hinder effective public participation, engagement, and buy-in.

Capacity building and knowldge sharing. Building the capacity of government officials, policymakers and other stakeholders to understand and manage climate technologies was essential. Addressing knowledge gaps, technical skills and institutional capacity can be challenging, particularly when power dynamics influence decisions. Capacity development can also entail training city officials on the topic of integrated urban planning, and familiarity with data acquisition, as part of evidence-based decision-making. Cities that collect and analyse data related to energy consumption, emissions and environmental impacts can make informed decisions about the implementation of climate technologies. This data-driven approach enables cities to identify priority areas, set realistic targets and monitor progress towards sustainability goals.

8 Multi-level climate governance simultaneously involves both top-down processes (related to the translation of federal policy decisions into lower-level plans) and bottom-up processes (related to the translation of policy decisions from the local level to a higher level) (Gornitzka et al. 2005; Cerna 2013). Accordingly, multi-level climate governance involves inter-sectoral, multi-actor and multidimensional processes related to climate change adaptation/mitigation policy and a variety of factors at various levels of action.

Capacity to mobilize and finance resources. Implementing climate technologies often requires significant financial resources. Securing funding, allocating resources and ensuring equitable distribution of investments across different areas of the city can be challenging, particularly when informal practices, such as corruption or patronage, influence the decision-making process (UN-Habitat 2022). While implementing climate technology solutions is critical in pursuing low-carbon, climate-resilient development pathways in Asian cities, these largely depend on good governance, adequate resource mobilization and allocation, and institutional capacity-building to attract and finance them effectively (see Chapter 6). Governance arrangements should include better interlinkages between existing institutions and emerging actors to catalyse sufficient access to public and private resources and nurture partnerships for climate technology implementation, commercialization and scale-up at the city level.

Leadership, especially local champions. Both case studies in Semarang and Melaka show the importance of vision and leadership, especially commitment and buy-in at the local level. Melaka appointed its Chief Minster to chair its Green Technology Council, acting as an intermediary between various levels of government. Leadership at the city level also plays a role in terms of cooperation between cities, such as sharing lessons learned, multi-stakeholder relationships, and providing political will between the regional, national, and local levels. Furthermore, good governance and leadership play a crucial role in facilitating climate technology transfer in Asian cities. The transfer of climate technologies involved the exchange of environmentally sound technologies, as well as practices from one context to another, require harmonization between policy frameworks and emergent institutional set-ups. The capacity to pull multiple policy levers that are needed in order to access opportunities, which may exist at different scales and in different sectors, can be challenging. This can be compounded by power dynamics between actors and along interdependent dimensions, which include political, administrative, and fiscal resources. In this regard, local leadership and stewardship play a key function in enabling the establishment of comprehensive policies that foster climate technology action as a key component of cities' sustainability agendas. The work of climate technology champions, for example a mayor or chief minister as shown in the case studies, were essential for supporting the process of integrating climate technology transfer priorities into long-term urban development and climate action plans, leading on clear target setting and milestones to measure progress and keeping systemic changes monitored and accountable for stakeholders, including public and private-sector financiers and international donors.

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5.

Policies and regulatory frameworks

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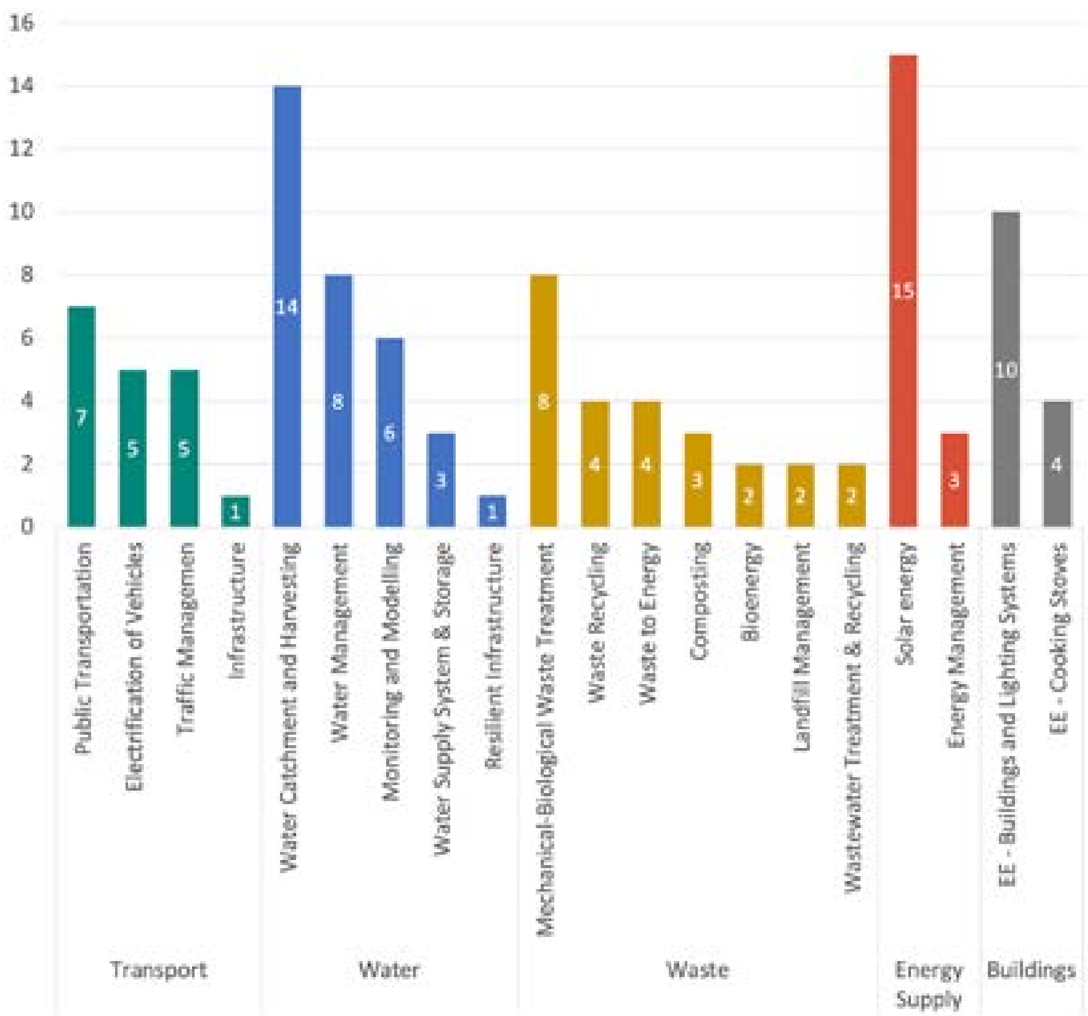
5.1 INTRODUCTION

The role of policy is crucial for supporting both emerging and innovative climate technologies and solutions that enhance the quality of life. Key areas that urban policy can influence are decisions around land use and urban planning, local transportation, biodiversity, buildings and the water and waste sectors. Policies and regulatory initiatives include carbon pricing instruments, funding for R&D and deployment and energy efficiency or emissions standards, capital subsidies or incentives to encourage the shift to sustainable choices, information in the form of awareness programmes or labelling and government procurement (Rissman *et al.* 2020). For urban areas, these may include, for example, efficiency standards for buildings, vehicles and appliances, incentives to encourage the shift from private transport to electric vehicles or public transport, mandates for rainwater harvesting in buildings and where relevant, bans or phase-out incentives for older and more polluting vehicles. An analysis of climate technology priorities in Transport, Water, Waste, Energy Supply, Building and Industry sectors for 20 countries in the Asia region is reflected in Fig. 5.1 This shows the various actions prioritized by countries under the GEF-funded Technology Needs Assessment project. The length of the bar indicates the number of countries that identified a given technology as a national priority.

These priorities relate well with the recent IPCC report that identifies the following key strategies for climate change mitigation and adaptation: energy efficiency or shift options (efficient buildings, appliances and public transport); improvement options such as cleaner technologies (electric vehicles); avoidance options (waste management, circularity and non-motorized transport (NMT)) and resilience and resource conservation (nature-based solutions and water management) (Pathak *et al.* 2022) (IPCC 2022).

Figure 5.1 Sector-wise Asia Specific Technology Priorities.



Source: own analysis of country Technology Needs Assessment reports available at www.tech-action.org

This chapter explores the policies and combinations of policies that facilitate a transformation of these sectors. It aims to address the question: "What types of policy measures or combinations thereof enable success and upscaling of climate technologies in Asian cities?" The subsequent sections focus on selected technology solutions for different sectors, highlighting country and city examples from Asia: advancing rooftop solar, electric vehicles, public transport, building and nature-based solutions. The last section sets out the key findings and highlights a few discussion points.

5.2 POLICY FRAMEWORKS FOR SECTOR TRANSFORMATIONS

5.2.1 Advancing rooftop solar in cities

Energy systems, including production, distribution and consumption systems, play a critical role in ensuring the sustainability and resilience of urban communities, as well as achieving national net zero goals. Renewable sources, such as solar and wind power, can improve cost efficiency and provide a buffer against volatile fossil fuel prices, easing financial burdens (International Renewable Energy Agency [IRENA] 2022). Transitioning to clean, renewable energy sources, improving energy efficiency and reducing energy demand are key mitigation strategies for the urban energy system. This section examines the policies and initiatives towards advancing rooftop photovoltaics.

At a global scale, there is a significant potential of 27 PWh yr−1 for rooftop solar photovoltaic systems, achievable at costs ranging from USD 40 to USD 280 per MWh. Asia has the highest potential (10 PWh yr−1) with India and China demonstrating the lowest cost of attaining the potential (Joshi *et al.* 2021). Solar and wind power installations are rapidly expanding, enabling cities to shift away from fossil fuels and achieve cleaner, more sustainable energy sources, thus enhancing resilience against energy supply disruptions (Irfan *et al.* 2019; IEA 2022b; Asian Development Bank 2023; Maguire 2023; Mathews *et al.* 2023). Innovative policies and business models drive the adoption of small-scale rooftop solar and solar photovoltaic systems in Asian cities (Azhgaliyeva *et al.* 2023). Initially, these included R&D support for development and deployment. Subsequently, ambitious national and state solar programmes were announced in many countries, which included national, state and in some cases city-wide targets, mandatory renewable energy purchase obligations, capital subsidies and market-based incentives such as feed-in tariffs and net metering to incentivize generation (Kiseleva *et al.* 2015; IEA 2022b; International Solar Alliance 2022; International Solar Alliance 2023; Govindarajan *et al.* 2023).

Feed-in tariffs are acknowledged as significant policies for stimulating the growth of renewable energy (ASEAN Centre for Energy [ACE] and China Renewable Energy Engineering Institute [CREEI] 2018; Polzin *et al.* 2019; Do *et al.* 2021; Roslan *et al.* 2022; Sreenath *et al.* 2022; Azhgaliyeva *et al.* 2023). A number of studies in Asia, including from Indonesia, Malaysia, Thailand and Vietnam, indicate their success in encouraging investments, particularly in solar, and observe how increased returns on investment from feed-in tariffs can impact photovoltaic capacity (Tongsopit *et al.* 2017; Sreenath *et al.* 2022; Azhgaliyeva *et al.* 2023). Feed-in tariffs were combined with additional incentives, such as favourable loans and tax benefits, to contribute to enhancing the overall feasibility of projects at different stages (Tongsopit *et al.* 2017).

Net metering policies have encouraged the deployment of distributed renewable energy technologies in Asian urban areas, allowing individuals and businesses with renewable energy systems to sell excess electricity back to the grid (Rehman *et al.* 2020). The city of Kitakyushu first offered USD 200-500 per kilowatt to encourage residents to install solar systems in their homes (Su *et al.* 2022). In Japan, ambitious actions by local mayors were effective in driving the energy transition from centralized to decentralized energy systems in cities (Takao 2020). Evidence from Foshan, China and Seoul, South Korea suggests that community energy initiatives can contribute to urban energy transitions, but successful deployment requires identifying relevant technologies and addressing complex interactions between critical processes[9], along with sufficient policy attention and political will (Mah 2019). China's Residential Plot B45 integrates solar systems into planning processes and architectural design in cities (Lobaccaro *et al.* 2019).

An assessment of successful rooftop solar programmes in Asia shows the highest uptake when multiple actions at different levels are implemented simultaneously. Despite the successful case studies, technical and financial barriers are an obstacle to achieving the desired scale of adoption in many developing Asian countries. Typical challenges include high upfront costs, technological challenges integrating a large share of variable energy into the grid and institutional barriers (see Chapter 6).

9 Five critical processes influencing the speed and scale of community energy development includes visioning, leadership, networking, institutionalization and reconfiguration of relationships between incumbents and newcomers, involving regulatory changes and market restructuring.

Box 4: Urban actions for upscaling rooftop solar: Seoul and New Delhi

Seoul, South Korea, has implemented a range of initiatives for promoting solar energy. The Solar City Seoul project, launched in 2017, aimed to cover 1 million households and all municipal sites to achieve 1000 MW of installed solar photovoltaic capacity by 2022 (C40 2019; Renewable Energy Policy Network for the 21st Century [REN21] 2019). The project has achieved remarkable results, surpassing its intermediate goals by installing 357 MW of solar panels across 285,000 households (C40 2019). Nonetheless, the solar drive was discontinued after a change of party at the mayor's office in 2021. Within the initiatives, Seoul supported its citizens by providing subsidies, low-interest loans and leasing options to make solar systems more affordable. Municipal land was allocated for larger-scale solar power generation. Public buildings are mandated to install solar photovoltaic systems. These collective efforts underlined Seoul's commitment to addressing climate change and building a sustainable, greener future (Broom 2019; BreatheLife: Seoul 2020; Kim and Gim 2021), while it also shows that the pursuit of such long-term policies is a challenge in itself in the polarized political context.

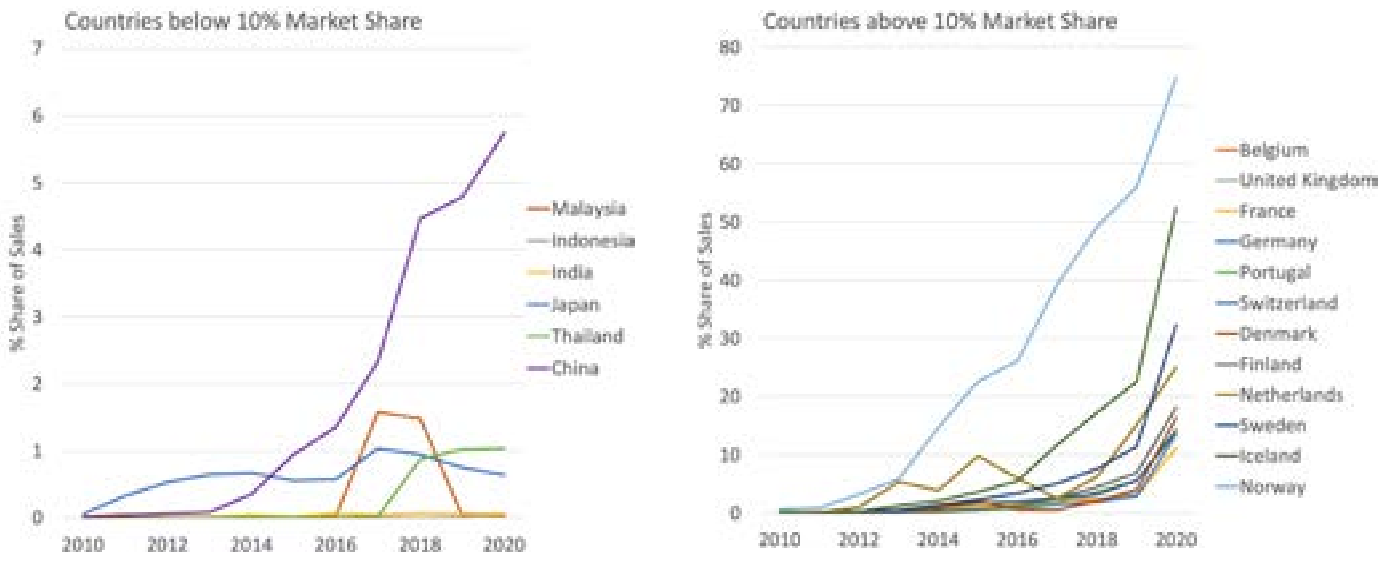
Delhi's approach involves offering generation-based incentives, capital subsidies and renewable energy mandates specifically targeting government buildings (Gillard *et al.* 2018; Kuldeep *et al.* 2018). The key barriers to the adoption of rooftop solar in Delhi were lack of awareness, financing, subsidy processes and bidding prices (Dutt 2020). In recent years, the adoption of rooftop solar in Delhi has been gradually increasing, but customized policy solutions are required for different residential consumer segments, including reducing risk perception for Co-operative Group Housing Societies, implementing awareness campaigns for high and middle-income homeowners and developing innovative approaches for the low and lower-middle-income section (Dutt and Ranjan 2022).

5.2.2 Electric vehicles

Electrification will play a significant role in decarbonizing light-duty vehicles (IPCC 2022) that usually run on petrol or diesel fuel. Several developed countries have already achieved more than a 10 per cent market share in electric vehicle sales for light-duty vehicles. The strong growth in market share in developed country markets has been due to tightening CO2 emissions regulations in some countries and continued policy support in terms of purchase subsidies and tax incentives (IEA 2022c). However, in Asia, except China, the market share has remained below 2 per cent (Fig. 5.2a & 5.2b), and in the case of Malaysia, they have even declined. In the case of many Asian countries, the higher upfront cost of electric vehicles compared to internal combustion engine vehicles and the lack of many electric vehicle models are seen as a key barrier (Muzir *et al.* 2022). Two and three-wheelers will continue to occupy a large share of the urban transport mix in several Asian cities, given their efficiency and affordability for first and last-mile connectivity (Kanuri *et al.* 2019; Huu and Ngoc 2021). While Asian countries still have a large population of petrol-driven two-wheelers , electric vehicles are increasingly making an entry into this market, and market shares have rapidly increased in ASEAN countries where some countries, such as Vietnam, had already achieved a market share of 8.5 per cent in 2020 (Le *et al.* 2022). In China, scooter-type electrified two-wheelers are the dominant market player (Li *et al.* 2023). The market share of electric vehicles for other road transport vehicles, such as heavy-duty vehicles, will depend on improvements in energy density, specific energy (energy stored per unit weight) and costs (Cano *et al.* 2018).

Figure 5.2 Market share of electric vehicles in light duty vehicles a) Market share for electric vehicles in Asia; b) Countries where market share is more than 10 per cent.

a b



Source: (IEA 2022).

Cities in Asia have high concentrations of air pollutants (particulate matter (PM) $PM_{2.5}$, PM_{10}) and, in many cases, well beyond the World Health Organization (WHO) recommended levels (WHO 2023). A significant proportion of these pollutants is related to the combustion of fossil fuels in internal combustion engines of two, three and four-wheelers, buses and trucks (Guttikunda *et al.* 2019). There is no air pollution associated with electric vehicles at the point of use, which is why they are a good solution for cities in Asia that are trying to improve their air quality. There can be air pollution if electricity is produced using fossil fuels. However, since increasing the share of renewables is central to most NDCs for countries in Asia, it is safe to assume reduced air pollution and decarbonization of the transport sector from the adoption of electric vehicles in the region. Electric vehicles have also made rapid inroads into the two-wheeler and three-wheeler space in Asia, in addition to light-duty vehicles (Dhar and Munshi 2023).

The costs of lithium-ion batteries have declined continuously over the last decade and were around USD 137 per kWh in 2020 (Frith 2021). A total cost of ownership analysis for cars in the US market shows that despite higher purchase prices, battery electric vehicles can recoup the initial price premium faster. However, though the decline has made electric vehicles competitive, the up-front costs continue to be a significant barrier to their uptake in developing countries (Goel *et al.* 2021). Therefore, countries where electric vehicles have witnessed significant growth in market share have provided purchase subsidies to reduce their upfront cost. The high upfront cost is a more significant barrier for private electric vehicles than public vehicles, since the annual mileage is lower (Box 5).

The perception of lower driving range is another significant barrier for electric vehicles (Goel *et al.* 2021) and is also called range anxiety. Typically, the driving range of vehicles can be increased by having a larger battery, however, since batteries are expensive, there is a trade-off. Range anxiety can be reduced by increasing the availability and reliability of charging points (She *et al.* 2017) and reducing the time required for charging. Charging for private vehicles happens primarily at home (varying between 75 and 90 per cent of the total) and less at public charging stations (Wenig *et al.* 2019) However, public charging, despite having a smaller percentage of overall charging demand, plays a significant role in alleviating the range anxiety of users (Wenig *et al.* 2019) and in many cases can be the only option for charging where users cannot provide their own charging points (for example, for an individual living in an apartment). Therefore, public charging should be provided in office areas, commercial areas and transit stations. Public charging requires collaboration between utility companies (for power supply and grid access), city authorities (planning for parking spaces) and the private sector (actual provision of charging points and end-user interface) and policy support for planning, building regulations and tariff setting for electricity.

Box 5: EV Policy in Thailand

Thailand is one of the countries that has been achieving success in the electrification of the road transport sector. The market share of electric vehicles in light-duty vehicles has increased steadily and exceeded 1 per cent in 2019 (Fig. 11), increasing to 3 per cent in 2022 (IEA 2023). Thailand has attracted investment from leading manufacturers for the production of electric vehicles in the country and can therefore emerge as a hub for electric vehicle production in the region.

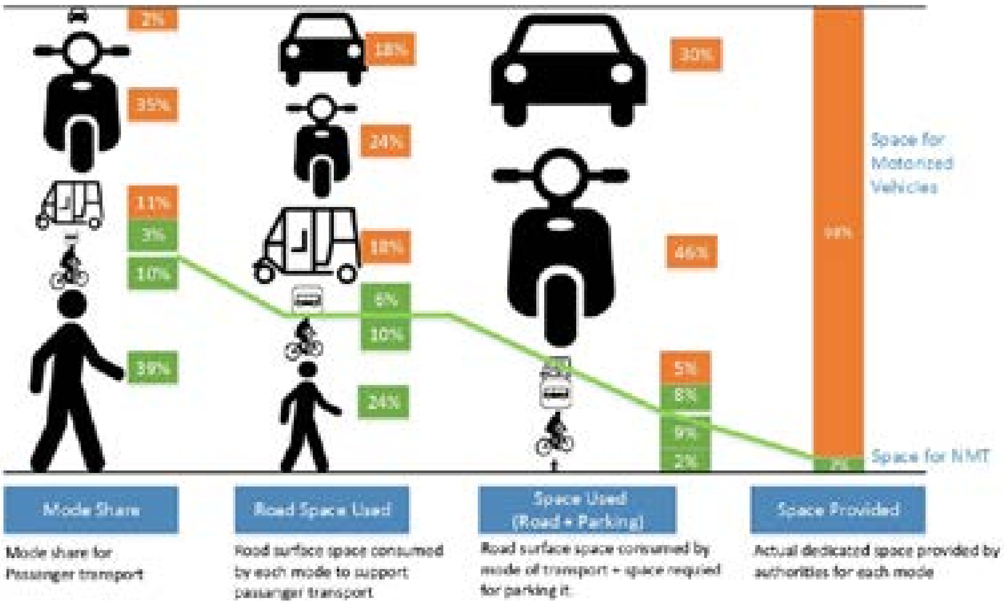
The success that Thailand has achieved in electric vehicles can be linked to multiple factors. On the manufacturing side, it is primarily because Thailand has been a hub for producing Japanese-origin light-duty vehicles based on internal combustion engines and therefore has the infrastructure, supplier base and skills for vehicle production. This innovation capability is being exploited by Chinese manufacturers to create a production base for electric vehicles in Thailand. It has also created a roadmap for electric vehicles that aims to position the country as a hub for electric vehicle manufacturing and has a target of having 1.2 million such vehicles domestically by 2036 (Wattana and Wattana 2022). The roadmap has been complemented by several policy measures, such as providing lower tariffs on imports of components for electric vehicles to encourage local assembly and manufacturing, incentives to stimulate the domestic market, national electric vehicle standards, etc. (Wattana and Wattana 2022). To promote charging infrastructure, the government has subsidized charging station equipment and introduced a special tariff for electric vehicle charging; by 2021, there were 693 public charging stations (Wattana and Wattana 2022) To make the policy intent clearer, the government announced in 2021 that Thailand would only sell zero-emission vehicles from 2035.

5.2.3 Public transport system

Public transport supported by a network of non-motorized transport (NMT) infrastructure is vital for sustainable transport, especially from an energy efficiency, reducing air pollution and climate change perspective (Wimdadi *et al.*, 2021). Public transport has very low per-passenger kilometre fuel consumption, and NMT modes typically require no fossil energy. Therefore, any shift from cars to public transport and NMT improves the system's overall energy efficiency. A wide range of non-motorized modes can be used, such as walking, bicycles, skateboards, push scooters, etc., for access to and from the public transport system.

Historically, the core city is designed to favour pedestrian and non-motorized movements, since no cars were available from the pre-industrial period. Therefore, cities in Brazil, Columbia, China and many cities in Europe are restoring the core city to NMT modes (Salter 2011), with public transport modes used for long-distance travel beyond the core city. NMT modes are also essential for providing first and last-mile connectivity for public transport outside core city areas (Madapur *et al.* 2020). A system that efficiently combines a well-connected public transport network and NMT modes uses little space compared to private cars and provides mobility to a large section of the population, especially those who do not have access to their own vehicle (children, elderly, women, the poor, etc.). For example, in a study done for a typical medium-sized city, Rajkot in India, it was found that public transport and NMT modes account for 52 per cent of the total trips made in the city; however, only 19 per cent of space is used for public transport and NMT modes (Fig. 11).

Figure 5.3 Road space used in Rajkot, India.



Source: (Munshi et al. 2014)

Rapid urbanization poses challenges to mobility in Asia (Wimbadi *et al.* 2021). However, investments in good public transport systems, for example, Bus Rapid Transit System in Ahmedabad, and the Metro in Delhi, have allowed cities to go for poly-centric (multiple centres of activities in the city with good connectivity) expansion of cities (Munshi *et al.* 2018) to achieve mobility needs at a reasonable cost. The proportion of public transport usage in Asian cities is notably substantial when compared worldwide (Newman and Kenworthy 2012), even with lower or less extensive public transport network coverage. This holds significant implications for policymakers, as it underscores the necessity of methods to retain existing public transport when planning and designing urban transportation systems in Asian cities. From the policy perspective, Asia also has a variety of para-transit modes, such as motorcycle taxis in Ho Chi Minh City, shared auto-rickshaws in Indian cities, jeepneys in Manila, etc., which have compensated for the lack of public transport infrastructure and also provided first and last mile connectivity (Hasselwander *et al.* 2023). However, their lack of integration into the system results in redundant and overlapping routes and adds a new dimension to public transport policy in Asia. If the para-transit modes can be integrated using IT-based solutions such as Mobility as a Service, they can improve accessibility for users and simultaneously improve overall efficiency and sustainability for the end users (Hasselwander *et al.* 2023).

5.2.4 Buildings

The building sector is significant for mitigation and adaptation due to direct and indirect emissions associated with building construction and operations and for the benefits of thermal comfort and in building resilience to climate extremes. With a growing emphasis on environmental responsibility and resource conservation, buildings constructed now and in future will require innovative and ambitious technologies in their design, construction and operation. Existing buildings will also need to consider retrofits and upgrading technologies to reduce energy consumption. Building level technologies include energy-efficient building construction, efficient appliances, integration of renewable energy, the use of low-emissions and climate-friendly materials, green rating systems and passive design for climate adaptation.

Several different terms are used to describe sustainability initiatives in buildings. These include green buildings, eco-friendly buildings, climate-resilient buildings, net-zero/zero-carbon buildings, grid-interactive buildings, zero-energy buildings, energy star buildings, energy-efficient buildings and carbon smart buildings, (collectively referred to below as green buildings). The different labels imply the type of initiative the strategy focuses on. Energy star ratings, for example, would imply a specific energy performance standard, while net-zero buildings might focus on achieving net-zero emissions through a mix of strategies, including on-site renewables and strategies to reduce the emissions embodied in construction materials. Integrating sustainability in the building sector can reduce operational as well as embodied energy, reduce emissions and generate a range of benefits, including the mental and physical health and well-being of residents. This section discusses the diverse approaches adopted in Asian countries and cities for the building sector.

Singapore has implemented a number of strategic policies and provided incentives to advance green building systems towards achieving the goal of greening 80 per cent of buildings by 2030 (Han 2019; Jain *et al.* 2020; UNEP 2021; Lai *et al.* 2023). The Green Mark Incentive Scheme offers cash or floor area incentives to encourage the adoption of eco-friendly building technologies and design practices (Singapore BCA 2020). The scheme was complemented by legislation mandating that new buildings and major retrofit projects meet minimum environmental sustainability standards (Singapore Building and Construction Authority [BCA] 2023a). The "Super Low Energy" programme, launched in 2018, promotes cost-effective buildings that are 60 percent more energy efficient relative to the 2005 building codes (Yale University 2013; Singapore BCA 2018; Han 2019). Incentives include the "Building Retrofit Energy Efficiency Financing Scheme", "Skyrise Greenery Incentive Scheme" and the "Quieter Construction Innovation Fund" (Green Future 2020). Research and development are also emphasized, leading to the establishment of a Green Buildings Innovation Cluster to advance energy-efficient solutions and practices in Singapore's buildings (Singapore BCA 2023b).

In South-East Asia, green building technologies[10] such as the building envelope; building equipment; renewable energy utilization; water saving and greenery systems have been a focus, particularly considering the region's hot and humid tropical climate. The challenge lies in finding a balance between energy conservation and cost-effective building performance *(Cao et al. 2016; Lai et al.* 2023). Enhancing the thermal performance of building envelopes is critical for energy savings, though there is an ongoing debate about the most effective approach.

India's Long-Term Low Carbon Development Strategy emphasizes the promotion of adaptation in urban design, energy and material efficiency in buildings and sustainable urbanization (Ministry of Environment, Forest and Climate Change [MoEFCC] 2022). India's National Building Code 2016 and Model Building Byelaw 2015 also include provisions for sustainable buildings (International Finance Corporation [IFC] 2021).

The Bureau of Energy Efficiency has formulated the Energy Conservation Building Code (ECBC) with the aim of promoting energy efficiency in commercial buildings. The code sets minimum energy performance standards and emphasizes passive design and renewable energy. Implementation of the ECBC and advanced Energy Efficiency Measures can deliver significant energy savings in both residential and commercial buildings (Tulsyan *et al.* 2013; Chedwal *et al.* 2015; Rajan *et al.* 2018). While most states have adopted the ECBC, widespread implementation is lacking (National Resources Defense Council [NRDC] 2023). Limited capacity means a few individuals are responsible for managing all energy-efficiency activities at the state level, leading to low implementation (Chandel *et al.* 2016; Alliance for an Energy Efficient Economy [AEEE] 2017; Yu *et al.* 2017). Effective implementation would require capacity building and institutional strengthening, enhancing coordination and focusing on energy efficiency across most states, and leveraging interdependence between different levels and contexts of policymaking. This understanding can be valuable for implementing the ECBC policy at the municipal level as well, considering the different priorities and governance tools available to municipalities (Goyal 2022).

The demand for green buildings in India is increasing, with 7.6 million square metres of floor space certified as green in 2020 (IFC 2021). Real estate developers are adopting voluntary green ratings systems, while governments at national and sub-national levels are offering incentives such as fast-track clearances, additional Floor Area Ratio benefits, certification fee reimbursements and tax benefits to promote eco-friendly construction practices (EDGE 2022; National Institute of Urban Affairs [NIUA] 2022; Green Rating for Integrated Habitat Assessment [GRIHA 2023]; Indian Green Building Council [IGBC] 2023).

The success of these initiatives requires understanding the roles of primary actors (government, developers, citizens and NGOs) in both technological and non-technological aspects, and the interactions between them (Zhang and He 2022). The government plays a central role in leading the transition, while non-state actors including NGOs, developers and citizens support these efforts. Synergies from multi-actor interactions and the interplay of technical and non-technical development are essential for a successful green building transition (Siva *et al.* 2017; Zhang and He 2022).

Learning lessons from successfully adopted initiatives could help upscale initiatives for cities in less developed countries within the region and other medium and smaller cities within the country.

10 Green building technologies encompass actions and strategies aimed at mitigating the environmental impact and energy consumption of buildings while optimizing resource utilization (Lai *et al.* 2023).

Box 6: Near-zero energy buildings in China

China has taken ambitious steps to scale up zero-energy buildings. National policies and targets with funding for the demonstration of pilot projects have been effectively supported by local design guidelines and incentives (Liu et al. 2019; Nascimento et al. 2022). These include the Near Zero-emission Buildings Standard China (2019), the Green and High-Efficiency Cooling Action Plan, 2019; the National Energy Conservation Law (amendment) China (2016); the Energy Efficiency Leader Scheme China (2015); the Strategic Action Plan for Energy Development China (2014); the Fuel Excise Tax China (2012); Demand-Side Management Implementation Measures China (2010); the Building Energy Efficiency Labelling Scheme (2008) and Energy Conservation in Buildings China (2006) (NewClimate Institute 2022).

China's Green Building Action Plan (2013) required 20 per cent of newly constructed buildings from 2015 to adhere to green standards, including public buildings and affordable housing funded by the government. Buildings achieving 2-star and 3-star green certifications will qualify for financial support from the state and will be given preference in the local urban planning process. Local governments must establish their own strategies to align with the overarching national plan (Nascimento et al. 2022; NewClimate Institute 2022).

A study reviewing 254 central and 1,175 local Green Building Plans in China between 2004 and 2021 showed that central policy had a key role in providing direction for investments and action. Local governments responded by improving their green buildings performance framework. Over time, targets became more efficient and generated better compliance and upscaling. The five key elements of China's green building policies were 1) reducing economic inequality and enhancing regional cooperation; 2) improving legal and regulatory systems, 3) policy innovation 4) information disclosure and 5) developing market-oriented green finance systems (Hu et al. 2023).

A multi-level inspection system ensures the enforcement of building energy codes and improves energy efficiency in the rapidly growing construction sector. Results show high compliance rates, yet these rates require careful interpretation due to factors such as limited sample size and potential data gaps, suggesting the need for refined criteria, better data access and a national information platform, but overall, China's unique approach demonstrates the efficacy of a well-designed compliance framework in advancing building energy code enforcement (Evans et al. 2010; Bin and Nadel 2012)

5.2.4 Nature based Solutions

Nature-based solutions (NbS), which include urban forests, green roofs, urban parks and bodies of water, among others, are a promising solution for Asian cities due to their multiple benefits of reducing the urban heat island effect, reducing energy demand and emissions, improving air quality, delivering health benefits, water recharge and reducing stormwater runoff (Lwasa *et al.* 2022). There are ongoing efforts to reverse the loss of natural blue and green space in many Asian cities (Mohd Noor *et al.* 2013). These include policy efforts targeted towards the use of NbS for better water management such as recharging lakes, bodies of water, rainwater harvesting and other water-sensitive design features. Nature-based solutions have been referenced in a few NDCs submitted by countries in the Asia-Pacific region, however, some NDCs refer to international finance as an enabler (United Nations Economic and Social Commission for Asia and the Pacific [UNESCAP] 2022). This section discusses policy initiatives towards NbS and includes a discussion on water conservation.

Many Asian cities face severe water deficits resulting from large-scale groundwater withdrawal far exceeding the rate of natural recharge, which has further led to shrinking groundwater tables and impacts on both water quality and availability, putting billions at risk (Ray and Shaw 2019). Simultaneously, cities face a dramatic loss of green cover resulting from rapid and poorly managed growth. Future challenges include risks to water availability from a changing climate, rising demand, increased concrete surfaces and reduced green spaces. Several traditional practices, including urban ponds and stepwells in India and waterspouts in Nepal, have been lost in the process of urban development (Bandarin and Van Oers 2014).

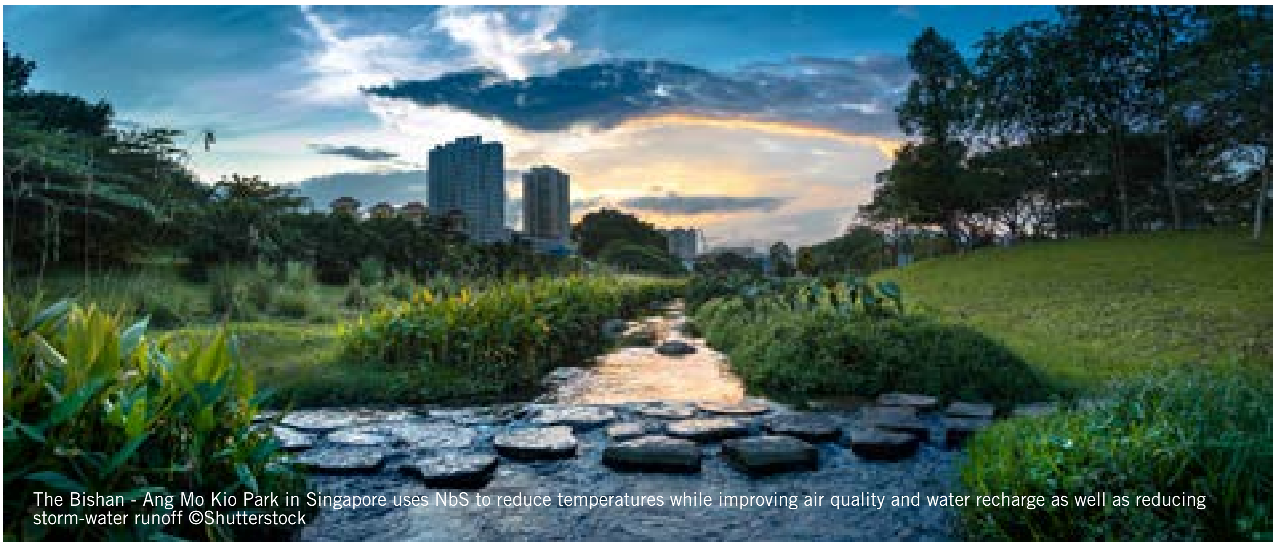
The Chinese "Sponge City Programme", initiated in 2013 and adopted by 30 pilot cities, involves developing solutions to manage urban flood risk, purify stormwater and provide water storage opportunities for future usage. Urban flooding is also an issue in other Asian countries, such as India and Bangladesh, and Indian cities such as Chennai, Mumbai and Kochi are currently developing roadmaps to develop sponge cities to tackle urban flooding. In Vietnam, several cities have implemented water-sensitive urban design measures (Asian Development Bank 2019). In Laos, these include restoration of wetland habitats in four cities along the Mekong River (Sales 2019).

India's Ministry of Housing and Urban Affairs (MoHUA) has set up the Climate Centre for Cities (C-Cube), which has established collaborations with 100 cities to build resilience among individuals, communities, institutions, businesses and systems in response to climate-induced events through a range of initiatives including capacity building, infrastructure provision and improved service delivery (MoHUA 2023). In Barishal, Bangladesh, converting a canal using community participation to make it navigable has delivered benefits to ecosystems and improved water quality (Mukherjee *et al.* 2022). Several cities have made efforts to capture rainwater by integrating rainwater harvesting into building codes, providing incentives and in some cases, mandating rainwater harvesting for all new buildings (Lee *et al.* 2010; Cook *et al.* 2019; Siriwardane-de Zoysa *et al.* 2021; Lai *et al.* 2023).

The city of Gurgam in India has introduced some NbS including green belts along roads, biodiversity parks and an eco-corridor to enhance "natural elements" in the city and address urban environmental risks. Ten 'Miyawaki Urban Forests' have been planned to increase green cover (Mukherjee *et al.* 2022). Biodiversity parks have been developed in Delhi (Panwar and Dhote 2022) and Delhi is also the first city in India to include a blue-green policy focus in its 2041 master plan. In addition, a blue-green master plan is also being developed for Bhopal under the Smart Cities Mission; similarly, there is a rejuvenation of lakes under the Udaipur Smart City programme and the development of parks and gardens as part of the Nashik Smart City Mission (Udas-Mankikar and Driver 2021).

Despite instances of successful implementation, the use of NbS in Asia is generally limited. Some of the constraints encountered in this context are environmental, while others are planning or regulatory restrictions that limit the implementation of novel techniques (Home *et al.* 2010). Challenges to water management include the high upfront costs of installing rainwater harvesting systems, poor awareness, lack of incentives and a low level of ambition in building codes. As a consequence, rainwater harvesting, despite its significant potential as a win-win solution, has achieved limited adoption. Mandating rainwater harvesting for all new buildings and finding innovative financial models for retrofitting existing buildings is necessary. Introducing water metering in cities can help in water conservation, however, ensuring the urban poor are not adversely impacted is important (Sathre *et al.* 2022).

Compared to other global regions, there is limited scholarly literature on the promotion of NbS and ecosystem-based adaptation for Asian cities (Wolff *et al.* 2023), particularly on the limitations associated with the implementation of NbS. While these solutions have gained traction in South-East Asia in the last decade, nature-based solutions designed for urban contexts in advanced economies might not be directly applicable to informal, laisser-faire type development in the Asian context and will need research and empirical work (Wolff *et al.* 2023). However, there are several instances, such as in China, where the national government has taken initiatives to adapt urban development policies to implement NbS. A few countries, such as India, are on the path to developing integrated urban development policies with nature-based solutions, which are developing in a positive direction. The NDCs of numerous Asian nations also explicitly include references to NbS, which indicates that there is also a reasonable pipeline of NbS projects in Asia (Seddon *et al.* 2019). These examples will need documentation, research and support for upscaling in other similar urban contexts in Asia.



The Bishan - Ang Mo Kio Park in Singapore uses NbS to reduce temperatures while improving air quality and water recharge as well as reducing storm-water runoff ©Shutterstock

5.3 DISCUSSION AND CONCLUSION

Several climate technologies, for both mitigation and adaptation, have achieved success in Asia. These span all sectors – energy, buildings, transport, water and urban planning. For example, most Asian countries have adopted policies or initiatives to encourage the adoption of electric vehicles. Several Asian countries have adopted minimum appliance efficiency standards and appliance labelling. A number of countries have included water conservation measures as part of building and development guidelines. In line with global technological developments, several cities have rooftop solar policies and initiatives including capital subsidies, generation-based incentives and city-wide targets.

Successful initiatives have often involved a range of policies and instruments at the national and sub-national level, which together with incentives have spurred replicability across cities. Compared with cities in the advanced economies, there is limited literature on cities in the Global South, in particular on evaluating the impacts of urban policies.

It is evident that governments at all levels have a key role to play in technology development and adoption during the initial stages through clear policies, investments in R&D and funding through subsidies and other mechanisms. China's national building policies and India's electric vehicle roadmap are examples of such policies. Regulations, for example building byelaws, can specify standards for efficiency and clean energy. Incentives and awareness building programmes can support greater deployment.
Many of the initiatives are often limited to sectoral or supply-side actions and often not mainstreamed within an overall city strategy. Supply-side actions need to be complemented with policies that can reduce demand. For example, clean technologies need to be complemented by energy efficiency and measures to reduce demand for floor space, cars, etc.

Developing Asian countries are faced with simultaneous climate and development challenges and undertaking climate action can offer multiple benefits for adaptation, mitigation and achieving the SDGs. Cities can work on identifying key policy actions that can maximize synergies and reduce or avoid trade-offs. This is challenging in practice, as it would require a careful evaluation of urban interventions for co-benefits and trade-offs and many of these are not easy to measure. Efforts need to be made to ensure solutions do not leave out the most vulnerable populations, who make up a sizeable share of the population in Asian cities.

While this chapter focuses on technology interventions, there are also other potential solutions, for example, urban planning and behavioural and lifestyle change, and many of these are interrelated. Technologies supported by urban planning and infrastructure can enable behaviour change (Creutzig *et al.* 2022) and avoid lock-ins, especially in small and medium-sized cities. Asian cities differ in terms of their development status, size (megacities to medium and small cities), level of infrastructure, cultural diversity and presence of informality. In many large Asian cities, a significant share of the population still resides in informal settlements. For local governments, particularly in the Global South, the priorities of providing housing and basic infrastructure have greater significance than climate actions. This is a critical time: missing the window of opportunity to take urgent action would lock these cities into high-carbon pathways with a large number of people increasingly vulnerable to climate risk.

The following key messages can be taken from this chapter:

- Several climate technologies are cost competitive and widely deployed in Asian cities. Successful initiatives have most often involved a combination of instruments, namely coordinated policies, ambitious targets, incentives and awareness programmes.
- Key technologies such as renewables and electric vehicles, though already cost competitive, require subsidies and incentives to address financial barriers to private-sector participation.
- Cities have limited control over several climate technologies such as fuel standards and energy prices, which are handled at the national level. However, local governments play an important role in technology adoption by 1) managing land and infrastructure required for technology adoption, for example, allocating parking spaces for charging and making rooftops and land available for solar photovoltaic; 2) in demonstrating technologies and taking a lead, for example, by purchasing electric cars for their own use or being the first sites for solar photovoltaic; 3) setting ambitious targets and regulations in line with national policies.
- Barriers to wider technology adoption in Asian cities include high upfront costs, limited awareness and understanding of benefits, weak institutions and a lack of autonomy for raising revenue and financing investments.
- Asian cities have a variety of public transport and para-transit modes, such as motorcycle taxis and shared auto-rickshaws, and their integration into the public transport system gives transport policy a new dimension.
- Urban development has led to the loss of green and blue spaces. A focus on nature-based solutions in urban planning and policies can address climate change and deliver a range of benefits.
- Sustainable development is a key priority for all cities, especially for rapidly growing cities in Asia that have a high degree of informality. Policy implementation must carefully evaluate trade-offs with development priorities.

6.

Climate finance for urban technologies

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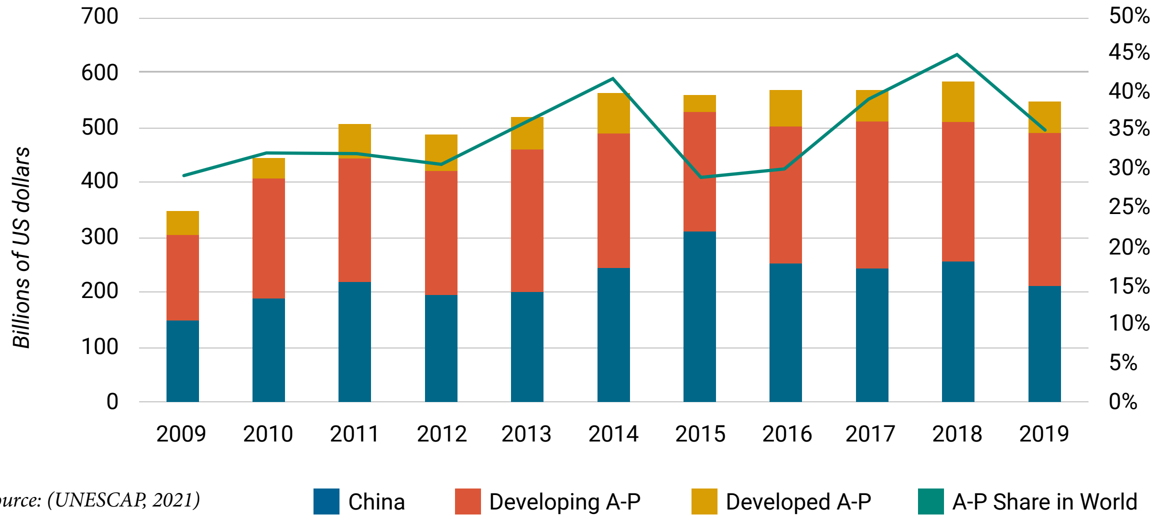
6.1 INTRODUCTION

As a response to managing the rapid growth of population and resource demand (for example, energy and water), smart city initiatives and related urban development are proliferating across Asia. Governments are increasingly developing investment frameworks and seeking partnerships with the private sector to close the investment gap.

From 2009 to 2019, foreign direct investment inflows into Asia and the Pacific grew gradually from about USD 350 billion to just under USD 600 billion annually. In 2019, about 40 per cent of foreign direct investment was in China, with most of the balance to developing countries in Asia and the Pacific (see Fig. 6.1). Infrastructure investment initiatives related to urban development in 2020 were USD 260 billion (Frost and Sullivan 2017a).

Figure 6.1 Foreign direct investment inflows to Asia and the Pacific and their global share, 2009 to 2019.



Source: (UNESCAP, 2021)

Note: ***China*** *includes Hong Kong, China and Macao, China;* ***A-P*** *stands for Asia and the Pasific;* ***Developing A-P*** *excludes China, Hong Kong China and Macao, China.*

Unfortunately, these levels of investment fall short of requirements: the Asian Development Bank estimated in 2017 that developing Asian countries need about USD 1.7 trillion in annual infrastructure investments until 2030, in order to maintain growth, improve essential services and develop climate resilience (Asian Development Bank 2017). While the effort to increase investment into sustainable urban initiatives is laudable, how will this investment be mobilized in practice? It is important for urban planners and political leaders to recognize that the problem is not so much a question of the supply in absolute terms, since there is ample investment capacity in the global system. Rather, the problem lies in the ability to move large volumes of money and deploy it where it is most needed and where the social, environmental and economic returns on investment are the highest.

This chapter explores the challenges facing project developers and investors in sustainable urban technologies and infrastructure. The case studies included relate to urban design and function including e-mobility, public and private transport, electrification (particularly rooftop solar), energy efficiency and cooling (including solutions driven by Internet connectivity and the Internet of Things, smart grids, green buildings, waste management and recovery, and logistics.

6.2 THE CHALLENGES OF FINANCING SUSTAINABLE DEVELOPMENT IN THE URBAN CONTEXT

Financing the implementation of climate technologies in the context of sustainable cities and urban systems is a complex endeavour that involves addressing challenges such as the level of development, the economic context, governance structures, the potential for public-private partnerships and regional differences. Financing challenges cut across sectors and technologies, meaning that the same or similar sets of challenges face almost every project in the clean energy and climate sectors and indeed across almost the whole range of sustainable development. In the urban development context, however, the familiar broad challenges are often exacerbated by specific issues:

Access to Finance: While the availability of climate finance[11] has increased dramatically in recent years, with unprecedented supplies coming on stream from both the public and private sectors, the supply remains uneven. Some economies that face the greatest climate impacts struggle to mobilize the funding required to achieve their NDCs and the UN's Sustainable Development Goals (SDGs). The supply of early-stage and risk capital for climate technology-inclusive development projects is especially scarce, and local economic conditions and market deficiencies (for example, lack of regulation, capital controls, collateral requirements, low creditworthiness and relative inexperience) compound fundraising challenges. In many fast-growing cities in developing Asia, these issues are exacerbated because resource allocation barely keeps up with the rate of growth and the demand for "new" infrastructure. Funding is still not reaching the most challenging market segments and, in particular, many local small and medium enterprises (SMEs) face challenges attracting investment, which in turn constrains innovation, job creation and growth.

Mismatch between developers and investors: There continues to be a considerable investment gap, with many commercially and environmentally sound projects not yet meeting required investment standards, due to institutional and governance deficiencies, lack of data for reliable valuation, documentation gaps, absence of standard operating procedures and limited management capacity. The same is true for much-needed public investments in climate technologies, with even less capacity on the demand side (public sector proponents) for formulating and managing investment projects. For their part, investors often have limited familiarity with many of the climate and clean energy technologies and business models and they typically do not have well-established channels or sufficient resources to originate and prepare projects for investment. In the urban development segment, and even more so in the SME space, investors are also concerned about the limited number of exit opportunities, and this increases the perceived investment risks. As a result, there is a divergence of expectation and assessment around project maturity and readiness, valuation and risk levels, which frustrates the ability of developers and investors to engage constructively.

Risk management: the major risks that developers and investors of sustainable urban development initiatives routinely face include market risks, tariff and related regulatory risks, usage and related market risks (for example, the number of people using their product or service), technology and development risks (because the technology may be unproven in that setting), liquidity risks, operational risks and finally, commercial and economic risks. Additionally, climate risk is an under-appreciated factor for many projects, for example, for companies operating in the heating and cooling sectors, upstream and downstream logistics, market aggregation, food processing and distribution, cold chain and storage (to name only a few).

Higher upfront costs: significant upfront investments are generally needed to develop and implement sustainable technologies and infrastructure. For example, green buildings, renewable energy installations, smart public transportation systems, recycling and circular waste management facilities can have higher initial capital costs compared to traditional alternatives.

Jabodebek IRT train in south jakarta, Indonesia ©Shutterstock

Long payback periods and uncertain returns: while sustainable infrastructure may lead to cost savings over the long term, the payback period for these investments can be lengthy and it can be challenging to value the financial benefits. This can deter private investors who are seeking quicker returns on their investments and may require a bigger role for a public sector co-investor with a longer investment horizon. At the city level, there is often a mismatch between municipalities' annual budgets and the long-term nature of sustainable investments, which often makes it difficult for cities to commit to or meet long-term planning objectives.

Complexity and fragmentation: urban sustainability involves multiple interconnected systems, including transportation, energy, water, waste and housing. Coordinating and integrating these systems can be complex and financing them often requires both vertical and horizontal coordination among various stakeholders at the national, regional and municipal levels. This can lead to increased complexity and overhead costs, which are not easy for investors to allocate.

Policy and regulatory barriers: inconsistent or unclear regulations and policies can create barriers for sustainable investment. A lack of supportive policies and conflicting or changing regulations can undermine project economics and deter investment.

11 In this chapter, climate finance refers to financing for initiatives that reduce greenhouse gas emissions, improve the capacity for adaptation to climate change or improve resilience to climate-related impacts.

Revenue generation: sustainable infrastructure development projects (especially in public-private partnership structures) often rely on user fees, taxes or other revenue streams to defray capital investment and cover operational and maintenance costs. From the perspective of both the government and the investor, it is often difficult to ensure that these revenue streams are predictable and sustainable over the project's lifespan while remaining reasonable for consumers.

Behavioural challenges: it can be challenging to encourage behavioural changes in urban residents, such as adopting public transport or reducing energy consumption. While behavioural shifts are often essential for the success of sustainable infrastructure initiatives, they require widespread education and awareness campaigns. There is also often a lack of political leadership in many cities, which is an essential factor for driving investments and creating an enabling environment for policy and behaviour changes.

In short, addressing these myriad challenges requires a combination of supportive policies, capacity building and stakeholder engagement, innovative financing mechanisms and a long-term vision for sustainable urban development. To make this happen, it is an essential precondition to have a strong framework for collaboration between governments, the private sector, non-profit organizations and communities. This is where project development and preparation facilities can play a critical role in originating and preparing projects for investment, reducing business development costs, derisking financing structures, convening and coordinating among the various stakeholders and accelerating the time to financial close.

6.3 APPROACHES AND INSTRUMENTS FOR FINANCING INNOVATIVE TECHNOLOGIES AND BUSINESS MODELS THAT CAN MAKE CITIES MORE SUSTAINABLE

Increasingly, a range of more innovative, evolving financial instruments are being developed and refined to address the challenges outlined above. These instruments can help close the investment gap between investors and project developers, while also addressing the problem of the lack of data and information asymmetry, which enables better pricing and management of risk and more equitable investment valuation. These instruments can include approaches such public-private partnerships, project (i.e. limited recourse) finance, blended finance, bundling, green and climate bonds, gender lens investment, crowd funding, carbon finance and innovation funds. Successful sustainable urban development often requires a mix of these financing mechanisms, along with effective governance, policy frameworks and stakeholder engagement.

This section explores some of the key financing techniques and mechanisms that are being successfully deployed, while illustrating some of the challenges and opportunities in the different technology areas and sectors. Table 6.1 summarizes case studies across eight different technology and sector areas. Details of the case studies can be found in Annex 2.

Table 6.1 Summary of case studies for the financing of urban climate technologies and systems.

No.	Company	Country	Description
Sector: E-Mobility			
1	Selex	Vietnam	electric motorbikes
Sector: Green Buildings			
2	Thailand National Housing Authority (NHA)	Thailand	green, affordable housing
Sector: Cooling			
3	PAC	Thailand	air conditioning and water heating
Sector: IoT			
4	Brainbox AI	TBD	AI-enhanced cooling
Sector: Solar Rooftop			
5	Fourth Partner	India	distributed and rooftop solar
Sector: Circular Economy			
6	Binbag	India	recycling hubs for e-waste
Sector: Water			
7	TapEffect	Cambodia	piped systems for potable water
Sector: Industrial Logistics			
8	WorldBridge Industrial Developments[12]	Cambodia	eco-friendly industrial clusters

12 Fundraising for this company was supported through a Cambodia-focused venture-building platform called Platform Impact (platform-impact.com).

Bundling and aggregation: Bundling refers to the process of aggregating the assets of projects, and in some cases companies (as whole companies or parts), into a portfolio to create efficiencies and economies of scale. The benefits include reduced costs, risk mitigation and achieving a "ticket size" investment that is more attractive to investors. The portfolios need to consist of similar types of assets underpinned by similar contractual terms and risk profiles.

Renewable energy and, particularly, rooftop solar photovoltaic lend themselves well to this bundling approach. Particularly in the urban context, there is huge growth in demand for rooftop solar, and especially on commercial and industrial facilities. Companies are mainly developing solar commercial and industrial facilities using the operating expenditure (or utility model, in which a solar contractor retains and operates the solar assets and provides a utility service to captive customers, often in the framework of a net metering regime and in connection with the introduction of smart grid technology. Once a portfolio reaches a critical mass (typically >10 MW), it is possible to further aggregate the assets either through a sale to a financial investor or using securitization techniques. This frees up the balance sheets of the commercial and industrial operators to write more new business and scale up investment more aggressively. Companies such as Fourth Partner are using these techniques to scale up rapidly and have had several rounds of raising capital to expand their geographic scope (see case study in Annex 2: Solar Rooftop).

One of the challenges facing aggregation, however, is that each asset forming part of the portfolio still needs to be "closed" as a separate transaction, involving acquisition, preparation, due diligence and approval processes. Through standardization of procedures and development of uniform documentation, this approach still offers considerable economies of scale in comparison with traditional standalone / piecemeal financing.

Green and climate bonds: green, climate-themed and so called ESG (Environment-Sustainability-Governance) bonds have started to gain traction among issuers of large corporate and public (or sovereign) bonds. Some financial institutions and intermediaries are now also structuring these green and climate bonds to aggregate the assets of cities and municipalities and also smaller SME companies into bond issues, using them principally as a route for refinancing companies and projects that are already in operation at some scale. PFAN is seeing an increasing use of green or climate-themed bonds, as a way of financing green building infrastructure. For example, with assistance from the Asian Development Bank, Thailand's National Housing Authority issued its first social bond in 2020 and subsequently issued a sustainability bond in 2021, based on the certification of a substantial share of the asset pool being certified as green buildings (see case study in Annex 2: Cooling; Green Buildings).

One of the challenges around the issue of green and climate-themed bonds revolves around certification and verification, especially related to clarifying the use of proceeds. While there is little consensus, it appears that the new EU Taxonomy may provide a *de facto* standard for the industry. In the medium term, PFAN sees green or climate-themed bonds as becoming an important tool to be able to tap into larger pools of capital for financing cities and SME / project developers of climate and clean energy projects in the urban context.

Impact investment funds: impact funds seek to achieve both financial returns as well as measurable social and environmental benefits. In the urban development context, they can be structured to address decarbonization, energy access, poverty alleviation, health care improvement, access to education, gender equality and multiple other aspects. Usually such funds recognize a trade-off between financial metrics (for example, return on investment) and environmental or social targets and indicators (for example, reduced carbon emissions, improved health outcomes, increased access to clean transport, etc). Impact funds are often structured using blending techniques, with donors and development banks assuming higher risks and longer-term coverage by providing first-loss and junior tranches of investment.

One of the drawbacks to the deployment of impact finance is that its supply, while increasing quickly, is still limited, and impact funds tend to be relatively small and highly specialized. Due diligence tends also to be onerous, resource intensive and lengthy. Still, there is great potential for impact funds to support SME development in the urban context and particularly for e-mobility start-ups, cooling and energy efficiency enterprises, waste management and logistics companies. Among the case studies examined here, Binbag, Atomberg, Worldbridge, Selex and TapEffect have all raised or are seeking to raise finance from impact funds (see case studies in Annex 2: E-Mobility; Tap Effect; Circular Economy;).

Electric mobility: Electric vehicles, including electric cars, buses, two-wheelers and three-wheelers, contribute to lower emissions and improved air quality. The expansion of charging infrastructure and incentives for electric vehicle adoption are important components of decarbonizing urban transportation. Selex Motors is a Vietnamese company that leverages data insights and cutting-edge technologies such as IoT, artificial intelligence (AI) and big data in its development of electric motorcycles (see case study in Annex 2: E-Mobility). The challenges in an emerging and rapidly evolving sector such as e-mobility are enormous, given the typically high upfront capital investments and diversity of options and choices around fundamental issues such as charging, battery swapping, allocation of costs and benefits (for example, across transport and the power system) and the need for some public support or participation.

Cooling and cold chain: Air conditioning and refrigeration services are increasing rapidly in developing countries due to improvements in living standards, especially in concentrated urban areas. The cooling services industry (which includes space cooling and refrigeration) is currently responsible for more than 10 per cent of global greenhouse gas emissions (Dong *et al*. 2021). PAC Corporation is a woman-led company based in Bangkok that specializes in creating innovative energy-saving cooling and heating products. The e-mobility company Selex provides a cold box that can be attached to Selex's electric motorbikes used for food delivery (see case studies in Annex 2: E-Mobility; Cooling). In 2019 to 2021, PFAN partnered with the Kigali Cooling Efficiency Program (to help develop and facilitate investment in more than 20 efficient cooling and cold-chain businesses across Asia and Africa, with a range of business models and financing approaches (PFAN 2021).

Smart technologies and controls (IoT): a recent trend is seen in the development of IoT-based smart energy management systems, which are revolutionizing building and facility management and control. Indeed, the deployment of sensors, data analytics and IoT devices enables cities to monitor and manage resources more efficiently, optimizing energy use, waste management, traffic flow and more. One of the case studies in this chapter, BrainBox AI, utilizes advanced HVAC technology enhanced by AI to create smarter and more eco-friendly cooling systems for buildings (see case study in Annex 2: Internet of Things; Cooling). While many of the IoT solutions leverage the power of AI through deep learning, cloud computing and custom algorithms, and result in significant savings, they are often difficult for customers to understand, which can be a challenge in scaling up their entry in new markets.

Integrated development and logistics: logistics technologies and systems are integrated into business models and products and are often implemented in combination to achieve synergistic effects in reducing carbon emissions, enhancing environmental quality and making cities more liveable and resilient in the face of climate change. Successful implementation requires collaboration among governments, urban planners, industries, communities and technology providers. World Bridge Industrial Developments in Cambodia provides resilient, eco-friendly industrial / commercial infrastructure at affordable rates along with access to state-of-the-art digital IoT, R&D and logistics services (see case study in Annex 2: Industrial logistics). While the opportunity for smart logistics platforms and services provides SMEs with several key advantages, the higher cost and complexity can be challenging for many SMEs to accept and adopt.

Circular economy: embracing circular economy principles involves reducing waste generation and maximizing the reuse, recycling and refurbishment of materials. This reduces the need for new resource extraction and production. Binbag in India aims to develop a network of decentralized recycling hubs dedicated to e-waste throughout the country (see case study in Annex 2). Circular economy approaches span a wide range, making it extremely hard to generalize. One common challenge is that climate tech investors in circular economy start-ups tend to view investments through the same lens as software or software as a service (SaaS) companies and they often do not understand the operations and dynamics of circular economy businesses.

Gender lens investment: bringing a gender lens to sustainable urban development projects and a climate lens to gender projects may unlock new investment opportunities in public and private markets. Gender lens investing is a rapidly growing movement and a growing body of research clearly links gender diversity in leadership and the workforce to increased financial returns, lower risk and sustainable growth. Many women innovators and entrepreneurs are creating disruptive solutions to the climate crisis and are addressing gender in product or service design in ways that are more responsive to market needs in the urban context. Women in distribution channels, marketing or sales may be the key to a competitive edge for a company or service. As consumers, women make 80 per cent of household buying decisions worldwide and often constitute key market segments that deliver green growth and impact, including at the city level. Case studies in the Annex 2 exemplify how a gender lens investment approach has helped to unlock funds for TapEffect in Cambodia and PAC Corporation in Thailand.

Clean water supply and management: sustainable water management includes technologies for rainwater harvesting, grey water reuse, reducing leakage losses and efficient irrigation systems to reduce water waste and ensure water availability. In many cases, the challenge is simply to provide clean potable water. Indeed, the lack of access to potable water is a pressing concern in underserved urban centres in many developing countries and it can be extremely challenging for water providers to navigate the legal and regulatory landscape and to raise the financing required for capital investments in systems that can cover tens of thousands of people with limited ability to pay. TapEffect plans to launch at least 10 piped water systems in Cambodia in the next two years, with an ambition to expand to at least 180 systems by 2030 (see case study in Annex 2: Clean Water).

6.4 CONCLUSIONS

Based on an observation and interpretation of the case studies as elaborated above, this chapter draws the following broad conclusions:

- Asia's cities are growing rapidly and financing is being deployed to support a range of innovative and entrepreneurial solutions, as illustrated by the new business models presented in this chapter. Such approaches are driving the transition to decarbonization and smart infrastructure, led by sectors such as e-mobility energy efficiency, cooling, green buildings, the IoT and the circular economy.

- While there are clear benefits to a top-down, holistic planning approach for smart city investment and development, financing often remains hostage to a bottom-up, project-by-project approach, in which the importance of the individual business model and risk assessment are the main factors determining financing structure and outcomes. Raising finance for smart city initiatives and urban developments is not fundamentally different.

- Financing flows for urban infrastructure are hampered by a business-as-usual mindset. It is critical for entrepreneurs, investors, civil society and city officials to embrace a new paradigm for urban infrastructure investment. Fortunately, there are a number of new approaches –namely aggregation, green and climate bonds, impact and innovation funds (deploying blended finance) and gender lens investment – that are breaking down barriers and channelling funding to where it is needed most and where it has the most impact.

- These new investment approaches require increased coordination and decision-making, both horizontal (among various stakeholders and across different departments and different functional areas) and vertical (at national, regional and municipal levels). This leads to increased complexity and overhead costs for investors, which are not easy to allocate, but ultimately results in better overall economic outcomes and an increase in social and economic returns.

- In relation to this, project preparation and transaction management are critical support services for structuring deals and channelling finance flows, including but not limited to SMEs in the private sector. Project development and preparation facilities have an important role in originating, developing and curating investor-ready pipelines and pushing the investor envelope by helping potential investors to understand and relate to urban development in the climate context, by socializing new business models and by managing and pricing real and perceived risks.

In summary, despite the significant challenges in mobilizing financing for sustainable urban development, progress is being made and it is positive to see the wealth of innovation available, especially among SMEs, which can be tapped by stakeholders to accelerate Asia's transition to smart cities.

ANNEX

The Annexes made reference to can be found under the following link: https://unepccc.org/climate-technology-progress-reports/

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ACRONYMS

ADB	Asian Development Bank
AI	Artificial Intelligence
AMI	Advanced Metering Infrastructure
AR6	IPCC Sixth Assessment Report
ASEAN	Association of Southeast Asian Nations
BEMS	Building Energy Management Systems
BESS	Battery Energy Storage Systems
BIPV	Building- Integrated Photovoltaics
CNG	Compressed Natural Gas
COP	Conference of Parties
CTCN	Climate Technology Centre and Network
CTPR	Climate Technology Progress Report
DER	Distributed Energy Resources
DMS	Demand-Side Management
ECBC	Energy Conservation Building Code
ECLAC	United Nations Economic Commission for Latin America and the Caribbean
ESG	Environmental, Social, and Corporate Governance
EU	European Union
EV	Electric Vehicle
GCAP	Green Climate Action Plan
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas Emissions
GIS	Geographic Information Systems
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
IGES	Global Environment Strategies
IMT-GT	Indonesia- Malaysia-Thailand Growth Triangle
INDC	Intended Nationally Determined Contributions
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ITS	Intelligent Transportation Systems
LRT	Light Rail Transit
MIGHT	Malaysia Industry Government Group for High Technology
NbS	Nature-based Solutions
NDC	Nationally Determined Contribution
NGO	Non-governmental Organization
NMT	Non-motorized Vehicles
NZEB	Nearly Zero-Energy Buildings
PED	Positive Energy District
PFAN	Private Financing Advisory Network
PV	Photovoltaics
R&D	Research and Development
SaaS	Software as a Service
SDG	Sustainable Development Goals
SME	Small and Medium-sized Enterprises
TEC	Technology Executive Committee
UN	United Nations
UNEP	United Nations Environment Programme
UNEP-CCC	United Nations Environment Programme - Copenhagen Climate Centre
UNFCCC	United Nations Framework Convention on Climate Change
VIP	Vacuum-Insulated Panel
WB	World Bank
WHO	World Health Organization
WMO	World Meteorological Organization

UN environment programme

CTCN UN Climate Technology Centre & Network

United Nations Climate Change
Technology Executive Committee

UN environment programme copenhagen climate centre