

# Locking in positive climate responses in cities

Well-intended climate actions are confounding each other. Cities must take a strategic and integrated approach to lock into a climate-resilient and low-emission future.

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Cities are home to much of the world's population and are key actors in climate mitigation and adaptation efforts. Many have stepped forward to show climate leadership, but it is not clear whether urban strategies for adaptation constrain or facilitate mitigation, and vice versa. Efforts to understand, develop and implement adaptation and mitigation strategies typically operate in silos, with limited interaction. Despite the increased prevalence and ambition of city-level mitigation and adaptation plans, there are few efforts aiming at creating synergies or avoiding trade-offs between them.

Moreover, climate responses in cities are particularly vulnerable to the inertia built into certain infrastructures, technologies, institutions, and behavioural norms. These can create path dependencies that constrain the effectiveness of mitigation or adaptation actions for long periods, creating what we refer to as a carbon lock-in<sup>1</sup>.

Present and near-term actions that restrict our ability to drastically curb future emissions for long periods have new significance in the context of the urgency created by the Paris Agreement to limit global warming to well below 2 °C.

Here we argue that cities need to better integrate urban strategies for mitigation and adaptation to climate change, and consider the lock-in risks of their climate responses. Analysing lock-in inherent in mitigation actions and adaptation pathways can strengthen opportunities to create synergies and reduce trade-offs between these responses, which have been poorly integrated in research and practice so far. We present two frameworks that can help cities design strategies that maximize synergies and lock in low-emission, resilient development pathways.

## Adaptation-mitigation interdependencies

The interdependencies of climate adaptation and mitigation measures are deep-seated in urban areas, where they play out through land use, infrastructure and the built environment, individual behaviour and policy<sup>2</sup>. The sheer number of actions and the

subtlety of many of the interactions coupled with a siloed approach to delivering climate action leads to unintended outcomes — synergies with magnified positive effects at times, but often unforeseen negative impacts elsewhere extending into the future<sup>3,4</sup>.

An overview of classes of adaptation and mitigation actions and whether these can create synergies or trade-offs is presented in Fig. 1. For example, high-efficiency buildings with solar heating tanks improve adaptation to warmer urban centres but also mitigate emissions through saving and generating energy. Green roofs synergistically reduce both urban heat islands and building energy use. Urban planning can also create synergies. In Helsinki, Finland, the district heating and cooling system uses recycled wastewater and waste energy to improve energy efficiency for summer cooling, while also reducing risk of power outage during periods of peak demand<sup>5</sup>. Replanting of trees in Colombo, Sri Lanka, is helping to protect biodiversity, provide flood protection to infrastructure, and increase carbon sequestration<sup>4</sup>. Figure 1 indicates that more potential synergies arise from the urban heat island effect and disaster risk reduction as well as new construction techniques, and that tradeoffs are more common in urban energy and transportation shifts.

Conversely, increasing urban density may reduce transportation energy use, but can increase flood risks and intensify urban heat island effects<sup>4,6</sup>. In the city of Jena, Germany, high-density design resulted in greater energy and transport efficiency and improved waste management, though at the cost of green space for urban cooling<sup>4</sup>. The long life span of urban form prolongs these effects. The underlying mechanisms of these trade-offs or synergies can be universal, but policy choices can and need to be context-dependent, based on a careful weighing of local issues, priorities, and goals.

## Interdependencies and lock-in risks

A well-designed climate strategy needs to focus on choices that avoid locking into high-emission pathways and low-resilience

urban futures. Adaptation and mitigation actions in cities are particularly prone to lock-in due to the longevity of land-use decisions and infrastructure choices, which may shape urban emission pathways and resilience for decades or centuries to come. For example, recognizing the large share of heating and cooling energy use in their emissions portfolio, many cities in the Global North started to offer subsidies to accelerate energy retrofits. However, these are usually small sums per building and thus result in only 10–30% thermal energy savings as opposed to the 70–90% possible through whole-building, systemic solutions<sup>7</sup>.

The dominant paradigm for urban mitigation strategies is to prioritize investment in 'low-hanging fruit'. However, easy investments with fast returns, such as boiler replacement, can prevent holistic, systemic, deep mitigation opportunities, such as a whole-building retrofit that becomes much less financially viable after a new boiler is installed. Avoiding this 40–80% building thermal-energy-use lock-in would require a fundamentally different approach to traditional energy efficiency incentives through coordinated, strategic actions and innovative financing.

Lock-in can also be positive. Eastern European cities maintain public transport as the dominant means of urban mobility. This results in much lower transport emissions decades after communism, a legacy of centrally planned infrastructure and prevailing norms.

In many urban parts of Africa and Asia there are opportunities to escape the negative carbon lock-in associated with developed world cities through investments in clean energy and decoupling from national grids. Access to energy is often limited and unreliable in many cities. Electricity provision through subsidies for minimally energy-intensive urban infrastructure and devices, such as portable solar panels and other sources of locally generated renewable energy, can reduce the need for high-emission central generation capacities and high-investment power transmission infrastructure.

		Adaptation strategies													
		Emergency risk reduction	Insurance	Urban planning and zoning regulations	Design guidelines	Neighbourhood watch programmes and safety nets	Education and capacity building	Health and livelihoods	Resilient energy installations	Water and wastewater adaptive management	Inland and coastal flood protection	Climate proof infrastructure (for example, transportation)	Wetland restoration	Green roofs and walls	Green space and bioswales
Mitigation strategies	Urban design and form	+		+ <sub>a</sub>	++			+	+ <sub>b</sub>	++	+ <sub>c</sub>		--	+	-- <sub>d</sub>
	Modal shift, mobility services, traffic optimisation	+		++	- <sub>e</sub>			+ <sub>f</sub>			-	++			--
	High-efficiency, low-emissions, smaller vehicles	+	-		-				-- <sub>g</sub>			+			
	Low-energy demanding, heat-resistant architecture	+	+		++ <sub>h</sub>	+	+	++ <sub>i</sub>	+	+ <sub>j</sub>		+ <sub>k</sub>		++	
	High-efficiency appliances and equipment									+					
	Energy efficient and low-carbon urban industries						+	+		+	+			++	
	High performance operation of buildings				+			+	+ <sub>l</sub>	+ <sub>m</sub>				+ <sub>n</sub>	
	Reducing Urban Heat Island (such as white and green surfaces, green infrastructure)		+	++ <sub>o</sub>	++		+	+	--		+		++	++	+ <sub>p</sub>
	Infrastructure-integrated renewable energy systems generation	++			+				++ <sub>q</sub>		-- <sub>r</sub>				
	Fuel switch to low(er) carbon generation	+		+					++	- <sub>s</sub>		-		+	
	Affordable low-carbon, durable construction materials; timber infrastructure	- <sub>t</sub>		+	+				++ <sub>u</sub>			+ <sub>v</sub>			
	Carbon capture and utilization in construction materials														
	Lifestyle, behaviour, choices, sustainable consumption and production, sharing economy, circular economy	+		+ <sub>w</sub>		+	++		+	+					+ <sub>x</sub>

<sup>a</sup>Urban design for optimized adaptation and mitigation may coincide or compromise each other. <sup>b</sup>Building orientation, height, and spacing can help reduce need for cooling units<sup>4</sup>. <sup>c</sup>Flood protection may compromise urban design best serving mitigation purposes. <sup>d</sup>Maximizing compact urban design can reduce green space areas. <sup>e</sup>Urban designs best serving disaster risk reduction or adaptation needs may compromise the energy efficiency of the transport system <sup>f</sup>Traffic optimization results in improved air quality; modal shift typically results in more activity, that is, health gains. <sup>g</sup>Increased vehicular air conditioning will increase transport emissions. <sup>h</sup>In heat-prone regions design guidelines may prioritize the availability of mechanical cooling to reduce health risks, exacerbating emissions. <sup>i</sup>Very high efficiency buildings with heat recovery ventilation have major health and welfare benefits. <sup>j</sup>High-efficiency buildings often also manage water resources efficiently. <sup>k</sup>In heat-prone regions design guidelines may prioritize the availability of mechanical cooling to reduce health risks, exacerbating emissions, but otherwise the synergies are dominant. <sup>l</sup>High-performance operation of buildings will increase the efficiency of mechanical cooling. <sup>m</sup>High-performance operation typically also extends to better water management. <sup>n</sup>Green roofs will improve energy efficiency and operation of building. <sup>o</sup>Enhances climate security resilience against extreme events. <sup>p</sup>Green space will reduce urban heat islands and reduce risk of flooding. <sup>q</sup>Renewable energy reduces risk of power loss during extreme events. <sup>r</sup>Energy dependency on pumping water from flooding. <sup>s</sup>Some small-scale energy generation technologies require water resources. <sup>t</sup>Timber infrastructure may be less resilient to disasters than conventional ones. <sup>u</sup>Utilizing lightweight construction and phase-change materials (PCM), solar heat can be absorbed by PCM, in turn improving thermal regulation of buildings while also reducing energy, heating and cooling<sup>4</sup>. <sup>v</sup>Climate-proof infrastructure could utilise timber; in other cases it needs to rely on concrete. <sup>w</sup>Incorporating institutions and stakeholders into planning can improve lifestyle choices of city as a whole. Integrated approaches encourage more stakeholders to engage in the project, as multiple sectors and institutions are impacted by the adaptation and mitigation efforts<sup>4</sup>. <sup>x</sup>Experiencing biodiversity has been proven to improve life quality and environmental consciousness.

**Fig. 1 | Key interactions between urban mitigation and adaptation strategies.** Adaptation strategies (x axis) are colour coded to be consistent with a portfolio-based approach to urban adaptations. In the portfolio approach, adaptation strategies are consistent with policies (blue), community-based adaptations (purple), engineering systems (pink), and ecosystem-based adaptations (yellow)<sup>4</sup>. Cells rate the strength of the interaction: -- (dark red), strong trade-off; - (light red), some trade-off; blank, no substantial trade-off or synergy; + (light green), some synergy; and ++ (dark green), strong synergies.

It is therefore crucial that cities start consistently considering the lock-in implications of their climate responses when designing their adaptation and

mitigation strategies. Rapidly urbanizing cities in the developing world especially have the opportunity to leapfrog the carbon-intensive and ecologically

destructive development path of the past, as they address challenges associated with informality and evolving governance structures<sup>4</sup>.

Key urban mitigation strategy	Infrastructural lock-in	Institutional lock-in	Behavioural lock-in
Urban design, land-use planning, relocation	Urban form, structure and density; utility networks	Urban decision-making not able to plan for long-term benefits	Preference for low to medium density parts of the city
Modal shift, shared mobility, mobility services, traffic optimization	Public transport infrastructure is long-lasting	Shared urban mobility schemes have lower investment needs	Incumbent industries oppose transformational change
High efficiency, low-emission, smaller vehicles	Charging points, autoservices infrastructure may be lacking	Shared mobility requires behavioural change	Accepted public and non-motorised transport locks culture in
Low-energy demanding, resilient, cool architecture	High-performance buildings can have 90% lower emissions versus conventional ones	Policies in favour of private versus public transportation	Automobiles as status symbols
High-efficiency equipment and building operation	(Relatively short lifetimes)	Financing challenges to many 'small' investments with long payback	Resistance to ventilation systems, opening windows
Reducing UHI (including white and green surfaces, and so on)	Lack of space for urban greening. Availability of construction materials with high albedo	Poor and outdated building codes and regulations	Cultures favouring certain construction aesthetics
Infrastructure-integrated renewable energy systems generation	Existing infrastructure may limit opportunities	Unfavourable financial incentives and tax regimes; incumbents	Lack of ability to judge potential financial and other gains
Fuel switch to low(er) carbon generation	Infrastructure is often not available	Financial policies, incumbents; stranded assets	High, or perceived higher cost of lower carbon technologies
Affordable low-carbon, durable construction materials; timber infrastructure	Alternative utilization of biomass resources	Market inertia; stranded assets and incumbents	Lack of awareness; culture of taste
Carbon capture and utilization in construction materials	Inertia from existing industries	Lack of adequate carbon pricing	Fear of losing jobs from innovations; concern about potential risks
Lifestyle, behaviour, sustainable consumption and production, sharing economy, circular economy	Lack of choice of alternative infrastructure	Competition between states and cities for regional prosperity	Resistance to change, long inertia in cultures, norms and values

**Fig. 2 | Infrastructural, institutional and behavioural lock-in mechanisms for key mitigation strategies.** Red, negative lock-in; green, positive lock-in; and orange, can be both positive or negative lock-in. Shades represent the strength of the lock-in.

## Urban lock-in

While there is abundant literature that conceptualizes the problem of negative lock-in, identifying the diverse concrete lock-in risks in urban areas, and actions that can create a positive lock-in, is a major knowledge gap<sup>1</sup>. For instance, there was not one single submission to the largest cities and climate change conference to date, the IPCC 2018 Cities and Climate Change Science Conference, that mentioned either lock-in or path dependence. Building on the key mitigation and adaptation strategies identified in the previous section and using the characterization of lock-in types in ref. <sup>1</sup>, Figs. 2 and 3 propose a framework for how the concrete lock-in risks and opportunities can be identified in specific urban areas, for mitigation and adaptation, respectively. The entries in the tables suggest examples of relevant lock-in risks and opportunities, but they need to be augmented by strategies for specific cities. They highlight that the same phenomenon can sometimes be turned from negative into positive lock-in.

## Trade-offs and synergies

Choices about adaptation and mitigation made today in cities will have a long-lasting impact for decades and centuries to come. To assume that one could design cities far in advance, or that cities would develop as designed, would be to misunderstand the nature of cities. Yet, avoiding negative lock-ins and catalysing positive ones will require strategically planned action that is embedded alongside other urban development processes, and sustained through continuous review and evaluation of lock-in risks and opportunities.

Limited understanding of lock-in risks and opportunities represents a considerable gap in our knowledge, yet it has disproportionately significant practical implications for tackling climate change, exacerbated by rapid urbanization in many regions and the urgency of climate action to meet the Paris Agreement. Interdisciplinary research is urgently needed to better understand the nature and extent of lock-in characteristics, assess their implications for mitigation and adaptation actions, and

develop new tools and business models that will enable implementation. □

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Key urban mitigation strategy	Infrastructural lock-in	Institutional lock-in		Behavioural lock-in
Emergency risk reduction	Tidal barriers	Climate-specific policies		Evacuation fatigue
Insurance	(Lack of) incorporation of evolving climate risks for infrastructure	Private	Government	Time-scale mismatch
Urban planning and zoning regulations	Long-term infrastructure built with outdated zoning guidelines	Re-evaluate and update zoning regulations as climate changes		Short-term profit motivation for developers
Design guidelines	Building placement and design can significantly impact city heating	Regular need to re-evaluate and update design guidelines		Design guidelines for adaptation are used by architects and planners
Neighbourhood watch programmes and safety nets	Lack of urban observatory facilities	Government support for cooling stations		Caring community groups and support for vulnerable populations
Education and capacity building	Schools located in flood-prone areas	Government support for resilient job creation		Education promotes resilient behaviour
Health and livelihoods	Infrastructural design impacts health and wellbeing	Human resource planning for heat alerts		Green jobs
Resilient energy installations	Generators and planned fuel supply	Facility upgrades in capital planning		Homeowners adopting resilience measures
Water and wastewater adaptive management	Long-lived operational facilities, such as reservoirs and pipelines	Embedded flexibility to alter policy as new information comes to light		Demand-side modification
Inland and coastal flood protection	Levees and berms	(Lack of) multi-jurisdictional coordination		Living in coastal flood-prone areas
Climate-proof transportation and infrastructure	Long-lived urban systems	Choice of major mobility systems		Difficulty of shifting habits
Wetland restoration	Increases resilience to flooding	Wetland protection policies		Migration from flood-prone areas
Green roofs and walls	Biophysical species requirements	Need for ongoing subsidies		Increasing awareness
Green space and bioswales	Green area designed with lack of public inclusion	Maintenance costs		Recreational use

**Fig. 3 | Infrastructural, institutional and behavioural lock-in mechanisms for key adaptation strategies.** Red, negative lock-in; green, positive lock-in; and orange, can be both positive or negative lock-in. Shades represent the strength of the lock-in. The colours in the left-hand column are explained in the Fig. 1 caption.

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