Mitigation co-benefits of climate change adaptation: A case-study analysis of eight cities

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Abstract

This research explores the approaches eight cities – Durban, Cape Town, London, Manchester, Surat, Indore, Montreal, and Vancouver – are taking to plan for mitigation co-benefits of adaptation strategies. The approaches set out in city adaptation plans are analysed and compared to provide insight into the uptake of mitigation co-benefits in terms of the extent to which they are strategically planned for and the types of measures utilised. The research also identifies common barriers cities face that prevent the implementation of co-benefit approaches. Finally, drawing on approaches taken by the cities that comprehensively plan for adaptation-mitigation co-benefits, three actions are outlined to serve as recommendations for cities to help catalyse the uptake of co-benefits and avoid trade-offs in adaptation planning.

Delivering mitigation co-benefits of adaptation actions was a strategic aim of five of eight cities. Four of these cities comprehensively identified mitigation co-benefits of planned adaptation measures. Certain types of co-benefits were more commonly utilised by cities, such as ecosystem-based strategies and building design measures. The alignment of adaptation and development goals is a more common aim than the alignment of adaptation and mitigation. Incentives to meet multiple policy priorities, reduce costs, and increase resource efficiency can deliver co-benefit approaches that cover adaptation, mitigation, and development goals.

Highlights:

- Urban climate change agenda furthered by aligning adaptation plans with development goals
- Near-term benefits delivered by aligning adaptation, mitigation and development
- Synergistic adaptation-mitigation planning leads to inclusion of co-benefits and avoidance of trade-offs.
- Informal networks can enhance coordination required for co-benefit approaches

Keywords

Climate change adaptation, cities, urban climate policy, co-benefits, policy formation, city governance

1. Introduction

Cities will play a significant role in achieving global climate change mitigation goals. The concentration of people, economic activity, and assets makes potential losses induced by climate impacts uniquely high in urban areas. Cities are consequently important sites for implementing ambitious adaptation to climate risks. The Intergovernmental Panel on Climate Change (IPCC) Special Report on the Global Warming of 1.5°C identified urban systems among the five key system transitions to limit global temperature increase to 1.5°C (IPCC 2018a). There is now increasing evidence that cities across the world are setting ambitious mitigation targets, developing adaptation plans, and implementing programmes as part of climate change policies. A review of climate change action plans in Europe (Reckien et al. 2018), revealed that 66% of the 885 EU cities analysed have a plan aimed at addressing adaptation, mitigation or both, and this growing response to climate change can be observed globally (Aylett 2015).

1.1 Co-benefits in cities

The urban context amplifies interactions between adaptation and mitigation because cities contain strongly integrated systems, with the functioning of one sector or service highly dependent on others it exists alongside (Rosenzweig et al. 2010). Land use, energy, water systems, waste services, transport infrastructure, biodiversity and public health interact to form the nexus on which cities function.

As a result, actions taken to address climate change mitigation can positively or negatively contribute to adaptation and other societal objectives. Similarly, for actions that enhance adaptation to climate impacts, 'adaptation' is the main benefit whilst the co-benefit may be emission reductions or enhanced equity. The IPCC (2018a) defines co-benefits as "the positive effects that a policy or measure aimed at one objective might have on other objectives, thereby increasing the total benefits for society or the environment". These effects depend on the local context in which the action takes place, as well as governance factors such as implementation practices. Adaptation measures have the

potential to deliver co-benefits for mitigation by increasing carbon sinks or reducing emissions, for example, by encouraging low- and zero-carbon alternatives in sectors such as transport and buildings.

Mitigation or adaptation measures can also result in trade-offs, or adverse side-effects i.e., negative effects on other objectives, thereby reducing the total benefits for society or the environment (IPCC 2019). For example, adaptation measures can directly or indirectly lead to increased energy demand in transport, water management, building materials, and cooling and ventilation requirements (Viguie and Hallegatte 2012; Urge-Vorsatz et al. 2018).

There is no uniform approach to planning globally due to the large variation in the institutional processes that drive climate action in cities (Aylett 2015). The socio-economic and political context of a city significantly shapes the ability to prepare for and respond to climate risks and impacts. Poverty, inequality, population growth, political instability, informality, and depleting natural resources are endemic in cities across the world. Climate change threatens to exacerbate existing pressures whilst bringing new challenges to the fore, and the threat that climate change poses to years of hard-fought development in cities is significant. Meanwhile, a growing evidence-base is setting out the many linkages between climate change, water and food provision, air quality, physical and mental health, gender equality and other sustainable development objectives. These linkages have led some to argue for greater integration of climate change with the sustainable development agenda (Swart and Raes 2007; Wilson and McDaniels 2007; Rodriguez et al. 2018). Similarly, the IPCC finds that the systemic transitions necessary to limit global warming to 1.5°C in both urban and rural areas requires a mix of adaptation and mitigation options, and that these options are "most effective when aligned with economic and sustainable development" (IPCC 2018b). This could mean the interplay between climate and the urban system, its translation into risks and differential vulnerability of sectors and systems might undermine sustainable development goals.

1.2. Mitigation co-benefits of adaptation actions

Mitigation co-benefits of adaptation actions are explicitly referenced in Article 4 of the Paris Agreement, which notes that "mitigation co-benefits resulting from Parties' adaptation actions and/or economic diversification plans can contribute to mitigation outcomes under this Article" (UNFCCC 2015).

Integrating mitigation and adaptation results in better accrual of benefits through improved project efficiency, aligned implementation objectives and reducing uncertainties (Hennessey et al. 2017) allowing for achieving multiple goals simultaneously (He et al. 2019). The integration of mitigation and adaptation actions is evidently not a new concept (Ayers and Huq 2009; Biesbroek et al. 2008; Thornbush et al. 2013; Shaw et al. 2014; Urge-Vorsatz et al. 2018), with existing research also focusing on the importance of 'mainstreaming' or systems approaches (Swart and Raes 2007; Bai et al. 2018).

Despite the growing awareness around co-benefits, they are not well integrated into urban policies. Existing research suggests that barriers to taking more integrated approaches to climate change planning arise from conceptual differences around goals and perceived benefits and beneficiaries (Ayers and Huq 2009; McEvoy et al. 2006). Inadequate awareness of the interactions between adaptation and mitigation also acts as a barrier (Wang 2013), whilst lack of resources and capacity to engage in the two can lead to prioritisation of one over the other (Roberts et al. 2011; Wang 2013). At the local level, lack of awareness among policymakers (Rahman and Mori 2020), a lack of coordination of responsibilities and interaction between departments that address adaptation and mitigation can act as barriers to a co-benefit approach (Laukkonen et al. 2009). Barriers can arise at the policy level, the organisational level, and the practical level (Landauer et al. 2015).

The priority allocated to mitigation and adaptation varies between different levels of government. Often, mitigation strategies are set primarily at the national level in response to internationally agreed targets and the role of local governments is to determine how to contribute to meeting these targets in

the most cost-efficient way and look to the long-term consequences of their decisions. In recent years, however, there has been a shift as more cities have committed to ambitious local targets and initiatives. Adaptation, on the other hand, tends to be much more localised; risk is assessed at the local or regional level and responses are developed accordingly, often accruing shorter-term benefits through the reduction of vulnerability to current and projected climate variability (McEvoy et al. 2006; IPCC 2014). Planning for mitigation and adaptation also engages different stakeholders and decision-makers. Mitigation efforts are often concentrated to a small number of powerful, industrial stakeholders. Although, higher ambition implies much wider engagement. Adaptation involves stakeholders across more dispersed scales and sectors (IPCC 2014).

Existing research demonstrates some understanding of the likely barriers to co-benefit approaches at national and local government levels, in particular cities, or in relation to specific policy areas, such as ecosystem-based adaptation. The literature also includes documentation of synergistic and conflicting relationships between adaptation and mitigation measures. However, a lesser researched area is whether cities are accounting for these relationships when developing climate change plans. Quantitative research to date has provided a snapshot of *which* cities are engaging in climate adaptation and mitigation (Reckien et al. 2018, 2019). Some studies have used analytical frameworks that assign scores to evaluate the level of integration of climate mitigation and adaptation in cities' climate action plans (Lee et al. 2020; Grafakos et al. 2019). These studies, while providing a very good overview of urban efforts, have largely focused on European cities, leaving a large gap in understanding cities in the Global South (Reckien et al. 2018, 2019; Grafakos et al. 2019; Sharifi 2020). Existing studies in developing countries focus on case studies for individual cities (Pathak and Shukla 2016; Lwasa 2010). Therefore, this study adopts a case-study approach of eight cities in four countries to analyse how cities are engaging in adaptation and mitigation planning and a deeper analysis of factors influencing these approaches.

This paper provides insights by looking across cities at their published adaptation plans. It aims to answer i) to what extent are cities planning for mitigation co-benefits through adaptation planning?;

ii) which types of adaptation measures are utilised in co-benefit approaches?; and iii) what are the barriers to the adoption of co-benefit approaches and what actions can cities take to improve the uptake of co-benefits. It concludes with successful approaches that can be utilised by local policymakers, city planners and practitioners to support implementation of co-benefit approaches.

2. Research design and Methods

A thorough review of the adaptation plans of eight cities was conducted. This study takes adaptation programmes and planning as a starting point and identifies whether potential co-benefits and trade-offs with mitigation are considered. In the remainder of this section, we briefly introduce the case studies, the co-benefits framework, and interview process.

2.1 Case studies

Eight cities were chosen as a focus of this study: London, Manchester, Montreal, Vancouver, Durban, Cape Town, Surat and Indore. All cities have produced at least one plan of which adaptation is the sole focus or a significant component. The plans assessed are listed in Table 1.

Two cities were chosen from four countries, spanning four world regions. Two selection criteria were applied: i) Cities had produced at least one plan with adaptation being a significant component; and ii) the city had a reasonably well-developed adaptation plan that provided enough detail for a case study analysis. Furthermore, the likelihood of engaging potential interviewees was considered. After an initial screening of peer-reviewed and grey literature, eight cities were shortlisted. This selection allowed for a balance between variety and comparability.

Each city's adaptation plan identified a range of climate impacts, most commonly, flash flooding, extreme heat and water scarcity (City of Cape Town 2017; City of Vancouver 2012, 2018; EThekwini Municipality 2014; Greater London Authority 2018; Montreal 2017; Resilient Surat 2017; Indore City Resilience Strategy Team 2012; Manchester Climate Change Agency 2016). Each city's vulnerability

to climate risks and adaptive capacity varies as well as the carbon dioxide (CO_2) emissions per capita of each of the four countries (see Table 1).

Historical responses to climate change and engagement with adaptation and/or mitigation planning also varies by city, as evidenced by the number of adaptation and/or mitigation plans published in the past. Some cities, like Manchester, Montreal, Durban, Surat and Indore had produced only one climate change adaptation plan at the time this research was conducted. Others, namely London, Vancouver, and Cape Town, had produced more. The way in which cities situate their adaptation plans also differs, for example, some combine adaptation and mitigation (Durban, Cape Town, Manchester), and others produce standalone adaptation plans (Montreal, Vancouver). Three cities (London, Surat and Indore) developed broader plans that targeted adaptation and other policy priorities, namely resilience or the environment in general. The types of socio-economic challenges the cities face, such as poverty, unemployment, and inequality, also differ. An overview of these contextual factors is provided in Table 1.

Table 1: Overview of case study cities and adaptation plans (up to 2018)

	City details			Adaptation†	Climate impacts as identified in each city's adaptation plan					Adaptation plan details				
City	Country/ Region	City pop^	National HDI (score / rank)	ND-GAIN vulnerability / readiness score	Flash floods	Sea level rise	Extreme heat	Water scarcity	Storm surge	Local government	Type of adaptation plan	Adaptation plan name	First adaptation plan	Implementation plan
London	UK/ Europe	8.5	0.909/16	0.300/ 0.688	X	X	X	X		Greater London Authority	Environment plan (including A&M)	London Environment Strategy, 2018	N	Y
Manchester		2.7			X		X	X		Manchester City Council	Joint A&M Plan	Manchester Climate Change Strategy, 2016	Y	Y
Montreal	Canada/ North America	1.7	0.920/10	0.294/ 0.674	X	X	X	X	X	City of Montreal	Standalone A Plan	Climate Change Adaptation Plan, 2017	Y	Y
Vancouver		2.5			X	X	X	X	X	City of Vancouver	Standalone A Plan	Climate Change Adaptation Plan, 2012; 2018	N	Y
Durban	South Africa/ Africa	3.6	0.666/119	0.402/ 0.408	X	X	X	X		eThekwini Municipality	Joint A&M Plan	Durban Climate Change Strategy, 2014	Y	Y
Cape Town		4.5			X	X	X	X	X	City of Cape Town	Joint A&M Plan	Cape Town Climate Change Policy, 2017	N	N
Surat	India/ South Asia	4.5	0.624/131	0.497/ 0.340	X	X	X	X		Surat Municipal Corporation– partnered with 100 RC; ACCRN	Resilience strategy	Surat Resilience Strategy, 2017	Y	N
Indore		2			X		X	X		Indore Municipal Corporation – partnered with ACCRN; Rockerfeller Foundation	Resilience strategy	Indore Resilience Strategy for Changing Climatic Scenarios, 2012	Y	N

^In millions. Data year: 2013-2014

*Mt per capita; 2018 (World Bank 2021)

†Data for 2018. The ND-GAIN vulnerability and readiness scores are only available at the national level and there will be some differences at the city level (ND-GAIN 2020)

Urban climate action cannot be independent of the governance context within which it falls. Influencing factors include national policies and regulations, state level plans and coordination between different levels of government and the role of other actors. For example, India's hierarchical urban governance structure is also reflected in mechanisms in place for addressing climate change. While the National Action Plan on Climate Change (NAPCC) lies with the central government, its implementation is through the State Action Plan on Climate Change (SAPCC) developed by state government (Dubash et al. 2013; Rattani 2018).

In the UK and Canada, strong national policies and institutions and more power at the local level enables cities to take bold action on climate responses. For example, the UK Government and the devolved administrations agreed to strong action on climate as recommended by the Climate Change Committee. Within this context, London's Climate Action Strategy adopts ambitious targets and plans for adaptation and mitigation. In South Africa, the powers and capacities of local governments vary widely (Croese et al. 2020). Hickman and Stehle (2019) show that in the absence of a coherent national climate policy, some local governments such as Durban, Johannesburg and Cape Town have undertaken distinct climate action with some support from transnational networks.

National policies can enable urban action through various means including national climate strategies and targets or sectoral strategies supported with by funding. In India for example, actions in the urban energy, waste and transport sector have been enabled by national government schemes or programmes like Smart City Mission or the Solar City Programme.

While there is context specificity to national climate action and governance structures, the case studies from widely different contexts offer the opportunity to understand why cities undertake climate actions and how these actually happen. Given the variations across cities even at the regional level, it was important that the selection includes case studies with sufficient differences in order leave certain contextual factors open for investigation, while sufficient similarities exist to narrow the otherwise broad scope of the research (Bhattacherjee 2012).

2.2 Adaptation measures and identification of mitigation co-benefits and trade-offs

A detailed review of city plans was carried out for all eight cities for factors relating to adaptation planning. These include the type of adaptation plan developed, for example, a 'joint' adaptation/mitigation plan, a 'standalone' adaptation plan or an environment plan with adaptation integrated, whether this plan was the first in the city's history, whether it was supplemented by an implementation plan, and whether it was developed with partners e.g., 100 Resilient Cities (100 RC) or the Asian Cities Climate Change Resilience Network (ACCRN). The analysis included plans that were available at the end of 2018. In some instances, the adaptation plans examined have been updated or substantiated by subsequent plans and strategies, however these were not considered for the study.

First, a review of existing peer-reviewed literature (Hallegatte 2009; Raymond et al. 2017; Urge-Vorsatz et al. 2018; Swart and Raes 2007) was conducted to develop identify city-level adaptation measures and the corresponding mitigation co-benefits of such measures (see Supplementary Material: Table 1).

City-level adaptation strategies were classified into four categories, depending on the type of measure. These include: policy strategies, hard infrastructure strategies, ecosystem-based strategies, and cross-cutting strategies. 'Policy strategies' include top-down strategies that determine the type of urban development or building design that is permissible. This includes by-laws, regulations, standards and codes. 'Hard infrastructure strategies' are strategies that rely on hard/grey infrastructure to increase resilience to climate impacts. 'Ecosystem-based strategies', also referred to as green infrastructure, are measures that rely on natural features to increase the health of an ecosystem, or increase the quantity and role of ecosystem services. Finally, 'cross-cutting strategies' encompass activities such as awareness campaigns and education that stimulate climate resilient lifestyles or behaviours. These can be driven by top-down government policy measures, or bottom-up and community driven initiatives.

A detailed review of the adaptation plan was carried out for each of the selected cities. This involved studying the objectives of the adaptation plan or strategy and the individual measures discussed within the plan. The adaptation measures were analysed according to the categorisation described above. For each adaptation measure outlined, it was recorded whether a co-benefit or trade-off with climate change mitigation was explicitly recognised in the city plan. For example, it was recorded whether the plan noted that adaptation measure A leads to 'carbon storage potential' (co-benefit) or adaptation measure B leads to 'increased greenhouse gas emissions' (trade-off). Ambiguous references to co-benefits and trade-offs were also recorded, such as adaptation measure C leading to 'reduced energy demand'. Such references suggest that factors other than mitigation potential, such as reduced costs, may have motivated the adaptation measure.

2.3 Interviews

Secondly, semi-structured interviews were conducted to a) explore factors that contribute to a city's approach to co-benefits, and b) determine the barriers to adopting and implementing a co-benefit approach and actions to support the uptake of co-benefits.

Interviewees were chosen based on their proximity to and knowledge of the adaptation planning process and any continued involvement with the adaptation agenda, such as implementation of adaptation initiatives. A total of eight interviews were conducted. This included five representatives from local government agencies responsible for adaptation planning across four cities (Indore, Durban, Manchester, London); one representative from a development agency responsible for producing the adaptation plan (Indore); and two representatives from national governmental departments responsible for climate change planning, implementation and/or advising strategy (India, UK).

One research limitation is that interviews were not conducted with individuals in all cities. This was due to lack of access to such individuals. However, the interviews covered four cities in three world

regions, providing a balanced overview of barriers and enablers across regions. Furthermore, to partially address this limitation two interviews were conducted with experts with a global expertise on climate change and cities. One of these interviewees is engaged with the IPCC, including the IPCC Cities and Climate Change Science Conference in 2018. The second global expert is part of a global urban climate change network. These experts are also involved in adaptation planning in their cities, and so hold a global expertise on cities while also a good understanding of regional issues relating to human settlements. They were therefore able to provide a wider perspective. The close relationship between interviewees and the adaptation plans analysed as well as city adaptation agendas more broadly allowed for findings to closely reflect experiences of those responsible.

The interview structure was based on the types of barriers and enabling factors found in a review of existing literature. These are displayed in Table 2 (see also Section 1.2: Mitigation co-benefits of adaptation actions). These were categorised into higher level 'themes': governance and institutions; decision-making and planning processes (formal and informal); local government tools; policy strategies to promote co-benefits (e.g., green infrastructure). Each city's adaptation plan was then mapped against these themes, to identify whether any potential barriers or enabling factors to adaptation-mitigation synergies might be present.

From this basis, the structured aspect of the interview ensured that the interviewees were asked to consider the role of each 'theme'. The unstructured aspect of the interviews allowed for questions tailored to the individual case study. This provided an opportunity to corroborate findings in the existing literature, whilst leaving opportunity to uncover approaches to co-benefits, barriers and enabling factors that were not already covered in existing research.

Table 2: Barriers and enabling factors to adaptation-mitigation synergies
(Landauer et al. 2015; Laukkonen et al. 2009; Swart and Raes 2007; McEvoy et al. 2006; Ayers and Huq 2009; IPCC 2014; Wang 2013; Hamin and Gurran 2009)

Theme	**List of specific barrier or enabler**
Governance and institutions	Governance frameworks that provide vertical and horizontal integration
	Formation of climate change responsibility in local government structure

	Local government leadership and jurisdictional control
	Institutional links between policy and local planning e.g. through coordination mechanisms and multistakeholder groups
	Consideration of the role of 'shadow spaces/systems' in shaping the agenda and in decision-making e.g. informal institutional links, developing trust
Decision-making and planning processes (formal and informal)	Strategic planning processes or decision-making processes that consider both Adaptation and Mitigation simultaneously and resolve competing goals
	Explicit considerations of win-win or low regret solutions combined with the identification of examples of maladaptation
Local government tools	Changes in regulation and policy to promote synergies/ avoid trade-offs
	Improvement of guidance to promote synergies/avoid trade-offs
	Development of practical tools to help urban decision makers e.g. integrated assessment modelling
	Emphasising development/localized quality of life impacts to get buy-in and acceptance of measures
Policy areas to promote synergies	Green infrastructure
	Behaviour change & demand-side measures
	Hard infrastructure measures
	Land-use and spatial planning
	Retrofitting

3. Results and Discussion

3.1 Uptake of mitigation co-benefits in cities

Table 3 displays the uptake of adaptation measures in city-level adaptation plans, and corresponding mitigation synergies and mitigation trade-offs of cities' adaptation options (as identified in Supplementary Material: Table 1). Linking adaptation planning to mitigation action was a strategic aim for five out of the eight cities. London, Manchester, Vancouver, Durban, and Cape Town all explicitly referenced their intention to identify linkages between adaptation measures and mitigation (EThekwini Municipality 2014; Greater London Authority 2018; City of Cape Town 2017; City of Vancouver 2012, 2018; Manchester Climate Change Agency 2016). Four of these (Durban, Cape Town, London, and Vancouver) comprehensively outlined adaptation measures with mitigation synergies. The analysis of city plans revealed that, generally, those cities that had a strategic aim to achieve mitigation co-benefits were able to account for synergies and trade-offs comprehensively. However, this is not always the case, as Manchester's plan made few explicit references to mitigation co-benefits from its chosen adaptation strategies despite stating an aim to take a co-benefit approach.

Across the case studies, planning for co-benefits does not seem to be limited to cities with greater resources. Durban and Cape Town, both municipal governments with higher levels of poverty and informality, are proactive in prioritising adaptation-mitigation synergies within their climate plans. This is not uniform, however, as the two Indian cities, with the highest vulnerability to climate change[1], lowest HDI index score, and lowest CO_2 emissions per capita, did not engage with the mitigation co-benefits that adaptation measures might have (Indore City Resilience Strategy Team 2012; Resilient Surat 2017).

Whilst four cities comprehensively identified mitigation co-benefits, there are variations across chosen adaptation measures and strategies. Certain strategies, such as ecosystem-based adaptation strategies and building design measures, were utilised to a greater extent compared than other adaptation strategies (Table 3). Mitigation co-benefits of ecosystem-based adaptation strategies are the most widely recognised, although most cities do not include wetland restoration within this. Among the ecosystem-based strategies, green roofs and green spaces were the most common strategies where co-benefits were accounted for. Inland and coastal flood protection, resilient energy installations and wetland restoration are less mentioned in these city plans, even though all the case studies face flooding impacts from climate change (see Table 1). The results also show that more cities were able to identify co-benefits of the chosen actions compared to trade-offs (see Table 3). This might be because trade-offs are more difficult to identify and measure.

In contrast to the other cities examined, Surat, Indore and Montreal do not explicitly outline any co-benefits or trade-offs with mitigation in their adaptation plans (Resilient Surat 2017; Indore City Resilience Strategy Team 2012; Montreal 2017). However, the analysis shows that the measures included in the adaptation plans developed by Surat and Indore, and to a lesser extent Montreal, could lead to positive mitigation outcomes, even though the plans do not explicitly recognise this. This

[1] According to the ND-GAIN vulnerability score compared to the other case study cities, see Table 1

suggests there may be alternative incentives to engaging with these measures. For example, while Surat does not explicitly acknowledge mitigation co-benefits, many of the adaptation measures in the city's plan, such as cool roofs, passive ventilation, and rainwater harvesting, could lead to mitigation co-benefits. While mitigation co-benefits are not an explicit objective, incentives to increase cost and resource efficiency can indirectly lead to synergistic approaches.

3.2 Uptake of local development co-benefits in cities

The case study analysis set out to analyse whether adaptation plans identified mitigation co-benefits. However, the analysis of the adaptation plan of the case-study cities found that the alignment of adaptation with development is a more common aim than the alignment of adaptation and mitigation. This suggests that mitigation synergies are not the only synergies driving the choice of adaptation measures. Cross-cutting adaptation measures, such as conservation of water resources, are common across city plans, for example, yet the potential mitigation co-benefits are rarely recognised. Of the five cities that seek mitigation co-benefits of adaptation strategies, all five also seek development synergies (although to varying extents). Moreover, the alignment of adaptation and development goals is a more common aim than the alignment of adaptation and mitigation. In fact, all eight city plans analysed recognised the importance of achieving development co-benefits from adaptation planning.

London, Manchester, and Vancouver aimed for mitigation co-benefits from adaptation planning as part of a more holistic approach and placed no greater importance on mitigation co-benefits compared to development co-benefits. This included benefits to human health and wellbeing, environmental health, economic development, and employment (Greater London Authority 2018; Manchester Climate Change Agency 2016; City of Vancouver 2012). Earlier studies have made the same observation that London and Manchester are more advanced in the UK in terms of adaptation and mitigation implementation process integrated into the local planning process (Heidrich et al. 2013). Cape Town and Durban also pursued development co-benefits in their adaptation plans, with a focus on ecosystem health and socio-economic development (EThekwini Municipality 2014; City of Cape Town 2017). In Durban, for example, there is a clear focus on protecting and enhancing the health of

natural ecosystems, and the role of ecosystem services and natural capital in facilitating both adaptation and mitigation efforts is comprehensively recognised (EThekwini Municipality 2009). The link between biodiversity, adaptation and mitigation is a main driving force of Durban's co-benefit approach. The plan includes multiple ecosystem-based adaptation strategies, such as 'maintain, restore and enhance coastal ecological infrastructure', 'encourage green roofs', and 'protect and restore riparian vegetation to protect the integrity of riverbanks and biological buffers against flooding' (EThekwini Municipality 2014). However, there were fewer explicit references to development goals compared mitigation goals in both the Durban and Cape Town city plans.

In the three cities that did not explicitly outline mitigation co-benefits in their adaptation plans (Indore, Surat, and Montreal), synergies between adaptation and development were fundamental aspects (Indore City Resilience Strategy Team 2012; Resilient Surat 2017; Montreal 2017). This suggests a higher importance placed on synergies with development objectives within these cities.

Table 3: Uptake of adaptation measures and corresponding mitigation synergies and mitigation trade-offs of cities' adaptation options

A. Mitigation co-benefits of chosen adaptation measures

	Policy strategies		**Hard infrastructure strategies**				**Ecosystem-based strategies**				**XCS***
	Urban planning & zoning	Urban design guidelines; building strategies	Resilient energy installations	Water & wastewater adaptive management	Inland/ coastal flood protection	Climate proof infrastructure	Wetland restoration	Green roofs & walls	Green space, waterways, bioswales	Avoiding/ reducing impervious surfaces	Awareness, education; behaviour change
London					-						
Manchester											
Montreal											
Vancouver			-								
Durban					-						
Cape Town											
Surat											
Indore											

B. Mitigation trade-offs of chosen adaptation measures

	Policy strategies		**Hard infrastructure strategies**				**Ecosystem-based strategies**				**XCS***
	Urban planning & zoning	Urban design guidelines; building strategies	Resilient energy installations	Water & wastewater adaptive management	Inland/ coastal flood protection	Climate proof infrastructure	Wetland restoration	Green roofs & walls	Green space, waterways, bioswales	Avoiding/ reducing impervious surfaces	Awareness, education; behaviour change
London	-	-			-			-		-	-
Manchester			-					-		-	-
Montreal								-		-	-
Vancouver	-	-		-		-		-		-	-
Durban	-	-		-		-	-	-		-	-
Cape Town				-			-	-		-	-
Surat		-						-		-	-
Indore				-				-		-	-

*Cross-cutting strategies.

Green indicates that the city explicitly identified the corresponding mitigation co-benefit or trade-off in its adaptation plan; Red indicates that the city did not explicitly identify the corresponding mitigation co-benefit or trade-off in its adaptation plan; A mixed green and red cell indicates that the city explicitly identified certain mitigation co-benefits or trade-offs, but did not explicitly identify others; Yellow indicates ambiguity in the city's communication regarding mitigation co-benefits or trade-offs in its adaptation plan; Grey indicates that the adaptation measure was not included in the city's adaptation plan; '-' indicates that there was no corresponding mitigation co-benefit or trade-off to be accounted for (e.g., no mitigation trade-offs of green roofs/walls, impervious surfaces, behaviour change).

3.3 Barriers to including mitigation co-benefits in adaptation planning

The interviews highlighted four factors that act as barriers to planning for mitigation co-benefits of adaptation action. These findings are summarised in Table 4.

Pre-existing limitations to adaptation planning and implementation

A significant barrier to the consideration of mitigation co-benefits in adaptation planning are pre-existing challenges to adaptation planning and implementation. This was evident across all cities in which interviews took place. Many cities are struggling to get adaptation on the agenda, and where adaptation planning is present, cities are often focused on strengthening relatively weak plans. Interviewees noted that adaptation to future, uncertain climate change was viewed as an unobtainable luxury for cities that are coping with more immediate issues. Efforts to integrate climate change into governmental strategies is ongoing, but requires time and cities are struggling to mainstream adaptation agendas (*interviewees*, national government India, local government agency UK). The complexity of adaptation is an obstacle to its development as a policy area, and the ability of cities to overcome this barrier is low (*interviewees*, development agency India, local government agency UK). As cities are struggling with adaptation as it is, synergistic planning is seen as an extra complexity and use of limited resources (*interviewee*, development agency, India). It is a step to be taken once adaptation planning is more firmly established at the city-level.

Another pre-existing limitation is insufficient resources for adaptation (Grafakos et al. 2020). For example, Vancouver's 2012 adaptation strategy referenced a 'lack of secured funding' in relation to over half the actions outlined in its implementation plan (City of Vancouver 2012). Indore and Surat's resilience strategies were both funded externally, by ACCCRN and 100RC and would likely not exist without external financial support. Implementation is challenging, with one interviewee noting that Indore has only implemented one of the proposed actions in their strategy. Funding for implementation in both cities comes from state government, which affects a city's flexibility in approaching climate change strategies. To acquire the buy-in and funding necessary to implement any

strategies at all, Indore and Surat both stated they aligned their adaptation strategies with state and national level priorities (*interviewees,* state government agency, India; official with the Government in India). Similarly, strategies might need to 'tie in with ministerial priorities', particularly when local government resources are limited (*interviewee,* planning and advising agency, UK). Cities often rely on state or national-level guidance and regulatory frameworks for adaptation planning (Lehmann et al. 2015). This can reduce the freedom to engage with planning for co-benefits if it is not prioritised by the funder or national guidance.

Technical capacity to understand and measure co-benefits

The second barrier identified in this study is the differing levels of technical advancement between adaptation and mitigation measures across cities. It is often viewed as easier to quantitively define, measure, and set city-level targets for mitigation (*interviewees*, planning and advising agency, UK; local government agency, UK) and determine how to effectively meet these targets. By contrast, defining metrics and targets for adaptation is more nascent and considered more complex (*interviewee,* planning and advising agency, UK), with qualitative rather than quantitative indicators providing a better picture of resilience (*interviewee,* local government agency, UK). For example, many co-benefits of adaptation actions relate to health and wellbeing of people or impacts on ecosystems which are not easily quantifiable. While some quantitative indicators for adaptation are developed, these are still not used widely (Puppim de Oliveira 2013). Capacity to develop such indicators at a city-level is often lacking (*interviewee*, local government agency, Durban). Unlike mitigation, there is often no historical data for adaptation indicators, for example for temperature data for hospitals, care homes or schools (*interviewee*, planning and advising agency, UK). This makes it difficult to establish a baseline and measure progress. Also, in contrast to emissions reduction requirements, there are often no statutory obligations to report on adaptation (*interviewee*, local government agency, UK). Moreover, developing adaptation indicators that also cut across mitigation indicators to understand how interactions work, is seen as challenging (*interviewee*, local government agency, UK).

Prioritisation of adaptation or mitigation

The prioritisation of adaptation or mitigation often depends on the local environment and needs. In cities that are highly vulnerable to climate change and have low emissions, adaptation can be prioritised over mitigation. Adaptation can reduce vulnerability in the near-term and can be closely linked to development goals, which are often seen as a priority for such cities (*interviewee*, development agency, India; *interviewee*, local government agency, Durban). On the other hand, adaptation can be deprioritised in cities that perceive the impacts of climate change as low risk, or who perceive the city as having high adaptive capacity (*interviewees*, local government agency, UK). In both cases, adaptation and mitigation are often pursued with unequal urgency and therefore granted unequal financial and other resources. Prioritising one over the other can mean that a choice is made between the two, and the other can drop off the agenda completely (*interviewee*, local government agency, India). This acts as a barrier to aligning the objectives of adaptation and mitigation during the planning process, and the de-prioritisation of identifying potential co-benefits or trade-offs with other objectives.

Priorities also differ because of climate risks and local development concerns. This explains why Surat and Indore, both being growing Indian cities, chose to focus on different sectoral strategies and implementation mechanisms.

Governance structure, Institutional capacity and coordination

As the third barrier highlights, climate change adaptation and mitigation 'have different drivers, and different goals' (*interviewee*, local government agency, UK). This means that the institutions that have evolved to address them are often separate entities (Landauer et al. 2015). While this in itself is not a barrier to synergistic planning, there is a need for robust mechanisms to enable cross-departmental communication and coordination of planning. Formal coordination mechanisms are often lacking, if present at all (*interviewees,* local government agency, Durban; local government agency UK; planning and advising agency, UK). The case study analysis found little evidence of formal mechanisms to ensure adaptation and mitigation planning was coordinated. In the instances

where formal mechanisms that linked adaptation to mitigation were evident, these were limited to the planning process. Two of the case study cities, Durban and Vancouver, used a framework to test proposed adaptation measures (EThekwini Municipality 2014; City of Vancouver 2012). These frameworks included specific criteria on the possibility of maladaptation as well as mitigation synergies. Less structured and more informal mechanisms are also relevant. For example, the mitigation and adaptation functions of the Greater London Authority met during the development of the London Environment Strategy. The case study analysis showed that there is a greater tendency towards trade-offs with mitigation objectives (see Table 3B) in the adaptation plans of cities that did not indicate that they coordinated between adaptation and mitigation institutions (Montreal, Surat, Indore, and Manchester).

Cities took different approaches to situating their plans within the overall local government agenda and policy context. For example, As Table 3 shows, London comprehensively achieves co-benefits between adaptation, mitigation, and development. In 2011, the city published its first adaptation strategy as a standalone plan (Greater London Authority 2011). In 2018, the London Environment Strategy became 'London's first holistic and integrated strategy for the environment', acknowledging that 'integrated solutions are needed' (Greater London Authority 2018). Adaptation and mitigation are two of seven focus areas. On the other hand, Cape Town's joint adaptation mitigation strategy is the city's first integrated climate change policy, within which the adaptation component now 'stands alongside' rather than act as a 'subcomponent' of the environment strategy (City of Cape Town 2017). This change was driven by an assessment that the previous positioning of climate change under the environment strategy 'did not facilitate a holistic approach to responding to climate change' (City of Cape Town 2017).

3.4 Actions to facilitate co-benefit approaches

The interviews also revealed that several cities showed relative success in integrating mitigation co-benefits through adaptation planning. The analysis highlights several factors that can enable cities to implement co-benefit approaches more successfully. These factors act as recommended actions for

city authorities as they proceed with climate change planning. These findings are summarised in Table 4.

First, focusing on co-benefits with development can create political buy-in for the climate change agenda, and commitment from stakeholders (Puppim de Oliveira 2013) (*interviewee,* local government agency, Durban). Policies and programmes that address adaptation, mitigation *and* development can be cost-effective, more efficient, and create immediate and near-term benefits which is particularly important when mitigation is seen as an 'intangible gain' by some cities (*interviewee*, development agency India, state government agency, India). Literature also shows policy experiments in cities are often framed around local economic benefits and this may be an important approach to ensure these achieve transformative change and long-term sustainability (Chu 2016). Co-benefit approaches that target political priorities such as livelihood creation can create a political incentive to pursue adaptation-mitigation measures (*interviewees,* local government agency, Durban). For example, in Durban, 'biodiversity provided the first link between adaptation and mitigation' (*interviewee,* local government agency, Durban). Now, Durban's community ecosystem-based adaptation programmes combine adaptation and mitigation, with biodiversity protection and employment opportunities. This aligns with the city's more established development agenda and, therefore, helps generate political buy-in for action on climate change (*interviewee*, local government agency, Durban). In Indore, an ongoing challenge is access to potable water for all citizens, which is under greater stress by projected climate impacts. The city's strategy is therefore primarily aimed at adaptation and development, and outlines building resilience in the water sector through the conservation of local water sources and rainwater harvesting. However, the need for cost efficiency through reducing energy demand can simultaneously lead to mitigation. This shows how adaptation, mitigation and development can merge under one strategy, even if these co-benefits are not explicitly recognised in the planning phase. Furthermore, it is not only important to simple identify the co-benefits of adaptation action – communicating these to local communities and those actually implementing the measures leads to higher uptake and participation in adaptation action (Rahman and Mori 2020). This is especially important due to the localised nature of many adaptation measures.

Second, identifying co-benefits and integrating them into adaptation action plans involves multi-level governance and cross-sectoral coordination (Puppim de Oliveira 2013). Cities can create and utilise informal networks to enhance coordination when adaptation and mitigation are institutionally separate (*interviewee,* local government agency Durban). Informal networks, communication, and coordination can fill the gap created by a lack of formal structures that connect these institutions. Effective use of informal networks requires emphasising how adaptation and mitigation would help reach others' goals as well as any shared, longer-term goals for the city (*interviewees*, local government agency, UK; local government agency, Durban). An informal meeting between adaptation and energy teams within the Greater London Authority 'provided an opportunity to discuss proposed policies, identify conflicts, and co-benefits in a less structured way' (*interviewee,* local government agency, UK). This can ultimately create the momentum and political buy-in necessary to establish formal institutions through which climate change adaptation and mitigation can be further linked (*interviewee,* local government agency, Durban). Formal mechanisms could include establishing working groups between adaptation and mitigation arms within government that meet regularly, as is the case with the Durban Climate Change Strategy Technical Task Team. This could focus on identifying and avoiding trade-offs, as well as taking opportunities to enhance synergies during the development phase of new plans and programmes. At the national level, for example, the UK's Committee on Climate Change combines adaptation and mitigation expertise in their reports in areas such as land-use and housing.

Finally, adaptation planning processes can be improved by tools and frameworks to identify co-benefits and trade-offs of proposed measures. Examples include decision-making tools that *explicitly* include the identification and consideration of possible synergies and trade-offs for proposed adaptation options.

The Vancouver Climate Change Adaptation Strategy and the Durban Municipal Adaptation Plan comprehensively outlined interlinkages with mitigation (City of Vancouver 2012; EThekwini Municipality 2014). The development of both of these plans included assessments against a set of

criteria that explicitly considered potential consequences on mitigation objectives. Vancouver utilised a multi-criteria assessment during the planning process (City of Vancouver 2012). Durban's strategy also noted past use of a multi-criteria assessment through which possible adaptation measures were ranked against nine criteria, one of which being the 'extent to which the option mitigates or exacerbates GHGs' (EThekwini Municipality 2009). This suggests that when cities use these tools, they comprehensively included mitigation synergies and avoid trade-offs. Cities could include multi-criteria assessments that rank adaptation strategies against a range of criteria such as impact on emissions and development goals.

These tools and frameworks can also include other important criteria, including ancillary benefits, cost/funding considerations, and whether strategies can lead to 'no-regret' or 'win-win' outcomes. This involves moving away from the more traditional cost-benefit analysis and its associated limitations such as how to calculate costs and benefits under climate uncertainty, which discount rate to choose, and ethical issues related to economic analysis (Bai et al. 2018). Alternative frameworks provide a more holistic assessment of the possible impacts of the adaptation options under consideration and provide a robust basis to inform decision making.

Table 4: Barriers and enabling factors identified

Barrier identified	**Summary of findings**
Pre-existing limitations to adaptation planning and implementation	- City-level ability to develop adaptation as a policy area is limited (*interviewees,* development agency India, local government agency UK) - Cities struggle to mainstream adaptation agendas (*interviewees*, national government India; local government agency UK) - Synergistic planning is an added complexity and use of limited resources (*interviewee*, development agency, India) - When adaptation plans are externally funded, it affects a city's flexibility in approaching strategies due to a need to align with other priorities (*interviewees,* state government agency, India; official with the Government in India; planning and advising agency UK)
Technical capacity to understand and measure co-benefits	- Easier to quantify and define city-level targets for mitigation (*interviewees*, planning and advising agency, UK; local government agency, UK) - Lack of capacity to develop indicators at a city-level (*interviewee*, local government agency, Durban) - Limited historical data for adaptation indicators to build on (*interviewee*, planning and advising agency, UK)

Prioritisation of adaptation or mitigation	- Adaptation and mitigation often pursued with unequal urgency depending on the city context and so granted unequal resources (*interviewee*, development agency, India; local government agency, Durban; local government agency, UK) - Prioritising one over the other can mean that a choice is made between the two (*interviewee*, local government agency, India)
Governance structure, institutional capacity and coordination	- Lack of both formal and informal mechanisms that coordinate across departments to coordinate planning for adaptation and mitigation (*interviewees*, local government agency, Durban; local government agency UK; planning and advising agency, UK).
Enablers identified	**Summary of findings**
Link synergistic planning to development priorities	- More efficient, and creation of immediate and near-term benefits when addressing adaptation, mitigation and development in one set of plans (*interviewees*, development agency India, state government agency, India; local government agency, Durban) - Link to wider development priorities such as employment opportunities, access to potable water etc. in order to enhance political buy-in (*interviewee*, local government agency, Durban)
Multi-level governance and cross-sectoral coordination	- Utilise informal networks to enhance coordination across departments (*interviewees*, local government agency, UK; local government agency, Durban) - Create formal mechanisms that allow adaptation and mitigation arms within government to meet regularly (*interviewees*, local government agency, UK; local government agency, Durban)
Develop assessment tools and frameworks	- Create tools and frameworks that allow explicit assessment of the potential consequences of adaptation strategies on mitigation (and/or wider development) objectives (*interviewees*, local government agency, Durban; local government agency UK; planning and advising agency, UK).

4. Conclusions

The study conducted an in-depth analysis of climate adaptation plans for eight cities in four countries to assess how comprehensively cities account for mitigation co-benefits and what the barriers are to adopting a more integrated approach. The studied plans ranged from standalone adaptation plans (Montreal, Vancouver) to joint adaptation mitigation plans (Durban, Cape Town, Manchester), and broader plans that targeted adaptation and other policy priorities, such as environment and development (London, Surat, Indore).

The study finds that there is variety in the ability of the cities to identify co-benefits or trade-offs with mitigation in their adaptation plans. Cities that did explicitly list the intention to consider mitigation co-benefits or trade-offs in their adaptation plans (London, Manchester, Vancouver, Durban, and

Cape Town) were able to plan for synergies comprehensively but not systematically, with some co-benefits and trade-offs unaccounted for. The mitigation co-benefits of ecosystem-based adaptation strategies are the most widely explicitly recognised. The results also show that cities were more easily able to identify co-benefits of their chosen adaptation measures for mitigation, compared to the trade-offs for mitigation. This might be because trade-offs are more difficult to identify and measure. The interviews revealed that development and use of decision-making tools such as multi-criteria assessments that rank adaptation strategies against a range of criteria (such as impact on emissions, for example) could help in the identification of co-benefits and trade-offs.

The interviews found that one of the key barriers to co-benefit approaches includes limited technical capacity of local governments to integrate mitigation and adaptation. This could also be a result of a siloed or sectoral approach to climate change planning in cities, due to a lack of integration between governance institutions and funding sources. Informal networks can help link different decision-making processes and stimulate innovation (Holscher et al. 2019) which can facilitate coordinating between different departments creating suitable conditions for integrated climate action (Buck et al. 2021).

Limited funding for developing city adaptation responses appeared to a constraint. Two of the eight cities analysed depended on external organisations to develop and fund their plans. This can influence the ability of cities to consider the impacts that adaptation options might have on mitigation when developing their adaptation plans. This could have a positive effect as international networks, such as C40 and 100 Resilient Cities, could leverage their role in the planning process to influence cities to prioritise integrated approaches to adaptation and mitigation. Funders could provide guidance similar to the classification system of co-benefits and trade-offs between adaptation and mitigation which was developed for this research and in the literature. Similarly, as cities often have to develop their plans to be in line with national guidelines, it may be beneficial to influence higher levels of government or international networks to promote integrating adaptation and mitigation in planning. Influential policy vehicles such as sectoral plans should explicitly encourage integrated approaches.

In the cities where adaptation-mitigation co-benefits were not a specific aim in the planning process, other incentives such as monetary savings or development benefits can still lead to a synergistic approach. The case of Surat shows that although cities might not explicitly acknowledge mitigation co-benefits, incentives to reduce cost and increase efficiency (such as in water distribution) can lead to positive outcomes for both adaptation and mitigation.

All eight case studies assessed recognised the importance of achieving development objectives in their adaptation planning. In the cities assessed, the alignment of adaptation responses with developmental aims was a more common aim than the alignment of adaptation and mitigation responses. Cities are doing so by leveraging measures that respond to key societal objectives with nearer-term benefits to create greater momentum behind the climate agenda. Cities, such as Vancouver, with a longer history of adaptation planning may use more structured and formal methods to assess the interactions between adaptation, mitigation, and development measures to inform decision making. Cities focused on meeting more immediate development needs, such as Durban, are utilising informal coordination methods to show that integrated strategies can meet multiple policy priorities in cost-effective way. If the climate change agenda recognises city priorities and harnesses the relationships and interdependencies between adaptation, mitigation, and development, then these agendas can complement rather than compete against each other. Cities may then be more likely to set themselves on climate resilient development pathways.

Ambitious climate mitigation and adaptation goals cannot be met independent of the sustainable development goals. Opportunities to align urban climate actions and the Sustainable Development Goals (SDGs) set out in the 2030 Agenda for Sustainable Development have been highlighted in literature (Roy et al. 2021; Sharifi et al. 2021). Literature shows that mitigation and adaptation actions that address poverty and gender can contribute to meeting multiple SDGs (Reckien et al. 2017). However, some of these synergies and trade-offs are not well understood, and impacts on SDGs are difficult to measure. Also, urban action is largely dependent on local priorities and capacities and governance which makes such an integrated approach challenging to implement

Further research could analyse country-specific case studies and provide recommendations to increase integrated approaches that are particularly relevant within the national context. This research was heavily orientated to the planning phase of adaptation. Further research on the implementation of co-benefit measures for a larger sample of cities would provide a good overview of what is happening in practice and challenges cities in different contexts face to putting their visions into practice. Finally, a focus on achieving integrated approaches in key sectors of the economy where risk of trade-offs is particularly high or where there is significant opportunity to achieve multiple aims may provide vital guidance as governments focus attention on sector-specific action.

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Supplementary Material

Table 1: A classification of urban adaptation measures with corresponding mitigation synergies and trade-offs

Strategy type	Adaptation measure	Climate impact targeted	Mitigation synergy rationale	Mitigation trade-off rationale
Policy strategies	Urban planning and zoning regulations	Extreme heat; flooding	Can lead to low emissions urban design and mobility services, promote a low-carbon fuel switch and low-carbon construction materials, reducing UHI, and cause system and behavioural changes e.g. promoting circular economy in construction. Example: high density urban areas with vegetative protection	Planning and regulations could compromise urban form that contributes to mitigation
	Urban design guidelines and building standards	Extreme heat; flooding	Can lead to low carbon urban design and form through high performance buildings, heat resistant and low-energy architecture, reducing need for mechanical cooling units, require infrastructure-integrated renewable energy systems generation, low-carbon construction materials	Emissions from air conditioning, or increased vehicle use from design guidelines such as provision of car spaces
Hard infrastructure strategies	Resilient energy installations	Extreme heat; flooding	Renewable energy installations reduce the need for fossil-fuel intensive energy generation	Can lead to greater emissions if these are not renewable energy based
	Water and wastewater adaptive management	Water scarcity	Using grey water or harvested rainwater systems reduces energy demands on emissions-intensive centralised water systems and can lead to higher performance in buildings further reducing energy demand	Desalination and water transport can increase emissions; removal of stormwater can rely on energy-intensive pumping, particularly when impervious surfaces reduce storage and infiltration opportunities
	Inland and coastal flood protection	Flooding	N/A	Flood protection such as sea walls and dikes use carbon-intensive grey infrastructure and often lock in dependence on further protection
	Climate-proof	Extreme heat;	Building heat resistant infrastructure and	Climate-proofing infrastructure may rely on

	infrastructure (e.g. transport)	flooding	using low-carbon materials, such as timber, and retrofitting old buildings and infrastructure can reduce emissions	concrete which is more energy intensive that other materials e.g. timber. Climate-proofing infrastructure may require mechanical cooling systems in heat-prone areas, such as underground transport, thereby, adding to emissions
Ecosystem-based strategies	Wetland restoration	Extreme heat; flooding	Provides a natural barrier against flooding - can act as a carbon sink, as well as a cooling mechanism to reduce UHI effect	N/A
	Green roofs and walls	Extreme heat	Green roofs and walls can contribute to mitigation-enhancing urban form, heat-resistant architecture and energy efficient operations of buildings, reducing UHI effect	N/A
	Green space, waterways and bioswales	Extreme heat; flooding	Re-naturalising river systems e.g. through establishing backwaters and channel features, creating natural banks, and maintaining vegetated areas for flood retention increases carbon sequestration and ventilation and air circulation from outside the city, reducing UHI effect. Can also motivate low-carbon lifestyle choices	Green space compromises the mitigation effects of compact urban design and more efficient transport through reduced journey time
	Avoiding or reducing impervious surfaces	Flooding	Offers protection against extreme precipitation events by slowing water runoff, enhancing water infiltration, reducing peak discharge	N/A
Cross-cutting strategies	Promotion of certain behaviour changes, formal education initiatives and awareness raising	Extreme heat; flooding; water scarcity	Formal education in schools or public awareness campaigns that promote low-carbon lifestyles or sustainable consumption	An awareness campaign that promoted higher energy use such as use of air conditioners during a heat wave.

Based on Urge-Vorsatz et al, 2018; Raymond et al, 2017, Hallegate, 2009, Swart and Raes, 2011