CITY CDR INITIATIVE
Building Carbon Sink Cities

PATHWAYS TO CARBON SINK CITIES

PART 2: NEED-GAP ANALYSIS

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Date: November, 2025

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Executive Summary

Cities have an imperative to integrate carbon removal into their built environment. Any city aspiring to achieve a state of climate neutrality or net-zero greenhouse gas emissions will need carbon removal to balance residual emissions. In the unfolding climate crisis, urban carbon dioxide removal (CDR) can moreover contribute to global climate restoration. This report assesses how cities can support CDR at scale and what they need to succeed.

'Pathways to Carbon Sink Cities: Need-Gap Analysis' highlights the extraordinary opportunity for cities to become leaders in the carbon removal revolution. With early estimates suggesting a supply potential of ~1-16 Gt/CO_2 annually and a demand potential modelled after the 1,145 cities in the Race to Zero campaign of ~0.5 Gt/CO_2 annually, the need for municipal leadership on carbon removal deployment comes into focus.

Unlocking this opportunity requires empowering local governments. Today's multi-level governance net-zero climate action however does not incentivize cities. Guidance on addressing residual emissions and reflecting negative emissions in city GHG inventories is lacking. The city climate finance landscape is not set up to fund carbon removal projects in cities, making it challenging for cash-strapped local governments to take action.

Meanwhile, urban CDR can be leveraged to advance other urban priorities, from adaptation and resilience, to biodiversity promotion, soil quality improvement and environmental remediation. The Need-Gap Analysis also shows that cities have a wide array of tools to support CDR, both directly and through influence, but municipal administrations are not set up to take a systemic approach to CDR that allows for integrated planning in a whole-of-administration framework.

Governance innovation is needed to enable cross-administrative approaches that embrace climate action synergies between emissions reduction, carbon removal and adaptation, and unlock cross-sector benefits. This integrated approach will ensure that CDR projects enhance well-being, minimize risks, advance environmental justice, and secure social legitimacy – conditions essential to scaling CDR globally to meaningful levels.

Together with the report '***Pathways to Carbon Sink Cities: Vision Paper***', and the forthcoming ***Implementation Guide***, the Need-Gap Analysis projects a vision of our cities as future agents of climate restoration. Empowering local governments on their path to net-zero and beyond is a new mission that elevates carbon removal. It is a mission that is no longer optional but critical for global climate action.

GLOSSARY

AFOLU - Agriculture, Forestry, and Other Land Use
BioCCS - Biomass with carbon capture and storage
CAP - Climate Action Plan
CCS - Carbon capture and storage
CCU - Carbon capture and utilisation
CCUS - Carbon capture, utilisation or storage
CDR - Carbon dioxide removal
CHP - Combined heat and power plant
CO_2 - Carbon dioxide
CO_2eq - Carbon dioxide equivalent
CRCM - Carbon Removal Credit Mechanism
DAC - Direct air capture
DACS - Direct air capture and storage
DOC - Direct Ocean Capture
ERW - Enhanced rock weathering
ETS - Emissions Trading Scheme
EU - European Union
GHG - Greenhouse Gas Emissions
GJ - Gigajoule
Gt - Gigatonne
ha - Hectare
IPCC - Intergovernmental Panel on Climate Change
kg - Kilogram
kt - Kilotonne
kWh - Kilowatt-hour
LCA - Life cycle assessment
LULUCF - Land Use, Land Use Change and Forestry
MLG - Multi-level governance
mm - millimetres
MRV - Monitoring, reporting and verification
Mt - Megatonne
NBS - Nature-based solutions
NDC - Nationally determined contributions
OAE - Ocean alkalinity enhancement
PM - Particulate matter
SCS - Soil Carbon Storage
SOC - Soil organic carbon
TRL - Technology readiness level
UNFCCC - UN Framework Convention on Climate Change
WtE - Waste-to-energy plant
WWTP - Wastewater treatment plant

INTRODUCTION

Research on the role of cities in climate action has been drawing increased attention. The upcoming IPCC Special Report on Climate Change and Cities confirms the momentum behind sub-national climate action. Building on this, the City CDR Initiative is assessing and advancing carbon dioxide removal (CDR) and carbon sink opportunities in urban and peri-urban environments and the options local governments have to unlock this at scale. The Initiative recognizes that cities must accelerate emissions reductions and prioritize adaptation, and supports cities to increase carbon removal where this is complementary.

The IPCC's *Special Report on Global Warming of 1.5°C* (2018) already identified cities as one of four global systems capable of accelerating action, urging rapid transformation in buildings and infrastructure. Its *Special Report on Climate Change and Land* (2019) emphasized the links between climate, land use, food security and urbanization and called for integrated urban planning. While these reports showed the need for systemic change, more in-depth research and discussions regarding CDR in cities and the role of urban carbon sinks is needed. The City CDR's opportunity baselining assessment fills this gap with a three-part report series. The report's primary audience is local governments, specifically officials from environment and waste management, public works and infrastructure, planning and zoning, community development and health departments.

Pathways to Carbon Sink Cities: Need-Gap Analysis (Part 2), is the second report in a three-part series under the opportunity baselining assessment. It builds on the ***Pathways to Carbon Sink Cities: Vision Paper*** (Part 1) and sets the stage for the ***Pathways to Carbon Sink Cities: Implementation Guide (Part 3)***. Together, these three publications form a single narrative: the **Vision Paper** imagines the future of cities as carbon sinks, the **Need-Gap Analysis** explores what cities could do and the **Implementation Guide** shows how they might do it. More specifically, the Need-Gap Analysis investigates the urban CDR landscape, highlighting the many opportunities that come with embedding CDR in urban systems, infrastructure, policies and governance, and identifying the challenges and solutions to unlocking urban CDR at scale. In the process, the report reframes municipal power to transform urban environments and realize carbon sink ubiquity.

The Vision Paper was developed in collaboration with the Carbon Neutral Cities Alliance (CNCA), XPRIZE, Skidmore, Owings & Merrill (SOM), High-Level Climate Champions and Conservation International. The Need-Gap Analysis and the Implementation Guide were prepared by the City CDR Initiative consortium, which consists of 20 cities, 22 partners and 18 technology and project developers. The analysis relies in part on data collected from 15 of the cities and all of the developers on issues of governance, policy, urban systems and infrastructure. The survey of 15 cities in the consortium covered four separate questionnaires: General; Governance and accounting; Policy and regulation; and Systems and infrastructure. A total of over 300 questions were shared with the point persons for the cities, mainly officials with sustainability and climate responsibilities, including resilience and adaptation officers. They coordinated with colleagues to source the requested data, as needed. Developers were asked a set of seven questions pertaining to their reliance on municipal support, expectations of support, their infrastructure needs, and the co-benefits their solutions can realize.

This data repository will be expanded over time as new cities and developers join the City CDR Initiative, to help inform an increasingly granular understanding of the city CDR opportunity, the pathways to scale, and the realization of carbon sink cities. An overview of other sources used for this report is included at the end of the report.

CHAPTER 1:
THE LANDSCAPE

Cities around the world are grappling with the impacts of climate change and the options they have to reduce their greenhouse gas (GHG) emissions. While the frequency of extreme weather events is increasing, propelling urban resilience to the top of the municipal action agenda, the political economy for ambitious climate action is changing. National governments are, in some cases, taking a step back, creating a power vacuum that subnational leaders can step into if they have the right narrative and approach.

Adopting a new city climate action agenda that embraces synergies between emissions reduction, carbon removal and adaptation will require systemic and inclusive planning and implementation to succeed. This chapter investigates the urban carbon removal landscape, its opportunities, barriers, and pathways to scale, including a vision of our cities as future agents of climate restoration.

The GloCal Nature of Carbon Removal

Meeting global climate targets involves distinct roles for CDR in the short, medium and long term. Building out the global carbon removal architecture must begin now to realize exponential growth and achieve the necessary scale to take on these roles. Cities are critical nodes in this architecture, both for their own needs and for the public good they can realize by becoming 'carbon sink cities' and (once they have slashed GHG emissions) absorbing more CO_2 than they emit into the atmosphere.

For a long time, cities did not feature meaningfully in discussions on climate action. This is rapidly changing. The Intergovernmental Panel on Climate Change (IPCC) is preparing its first *Special Report on Climate Change and Cities*, due in 2027. This marks a long-awaited acknowledgment of cities as indispensable agents of change and as areas for climate action. Already home to 55% of the world's population – projected to reach 68% by 2050 – cities account for over 70% of consumption-based emissions and more than 80% of GDP in many countries, according to UN Habitat's *World Cities Report 2022*. Their central role in the climate challenge is undeniable – and the same is true for carbon removal.

CDR is the intentional process of removing CO_2 from the atmosphere. Carbon sinks are natural or human engineered reservoirs that absorb more carbon than they release.[1] In cities, natural sinks may include urban forests, parks and other green spaces, urban wetlands and coastal mangroves, urban soils, and waterways. Engineered sinks may include carbon-storing construction materials and durable products, biochar, and geological carbon storage.

The Fluid Roles of CDR

The *IPCC Sixth Assessment Report (AR6) Working Group III: Mitigation of Climate Change* (2022) defined three roles for CDR: supplement emissions reduction (short term), balance global residual GHG emissions to achieve net-zero (medium term) and enable net-negative emissions to mitigate temperature overshoot (long term).[2] The total volume of CDR required to limit global warming to well below 2°C, ideally 1.5°C above pre-industrial levels, depends on the scenario, with larger temperature overshoots requiring greater amounts. The *State of Carbon Dioxide Removal* (2nd Edition) estimates that 7–9 gigatonnes (Gt) CO_2 removal will be needed annually by 2050. Some of this will be deployed in or around urban environments. Early estimates for urban CDR show that a portfolio of methods can lead

[1] In its *Special Report on Global Warming of 1.5°C* (2018), the IPCC defined CDR as "anthropogenic activities that remove CO_2 from the atmosphere and store it durably in geological, terrestrial, or ocean reservoirs, or in products." A carbon 'sink' is "a reservoir (natural or human, in soil, ocean and plants) where a greenhouse gas, an aerosol or a precursor of a greenhouse gas is stored".

[2] While all CDR methods matter, only those that store for centuries to thousands of years can be used to durably counterbalance residual fossil emissions-given their long-lasting presence in the atmosphere.

to a global carbon storage potential of around 1 $GtCO_2$ annually.[3] If traditional building materials could be universally replaced with CO_2-storing alternatives, the upper bound of theoretical city CDR may be as high as 16Gt/CO_2 per year, though this artificial sink can also be used to store captured fossil emissions.[4]

In most cases, cities will need CDR to balance residual emissions to reach net-zero – or even net-negative – targets within their administrative boundaries. To implement these targets, cities need a deployment strategy. All 15 cities analyzed in this report have committed publicly to net-zero emissions, climate neutrality, or carbon neutrality. Eight explicitly reference the role of CDR, seven have policies in place or in development to incentivize CDR, and six have quantified their expected residual emissions and the corresponding CDR needs. This indicates that even when cities officially acknowledge the need for CDR, they may not yet be ready to formulate dedicated support. Conversely, cities can support CDR without having defined their residual emissions and CDR needs, or even formally acknowledging the need for CDR in the first place. Overall, cities may set targets before they have all the solutions needed to achieve them, as means of socializing political and societal acceptance.

The European Union (EU) program *EU 100 Climate Neutral and Smart Cities Mission* offers an early indication of the potential urban demand for CDR. The aggregate footprint from a total of 304 eligible cities who sent an Expression of Interest in the Mission and respected Mission criteria reached approximately 642 $MtCO_2eq$ in validated emissions[5], implying an average footprint of 2.1 $MtCO_2eq$ per city. According to the EU's Climate Mission, cities should strive to limit their residual emissions to those that are truly unavoidable, indicatively less than 20% of a recent baseline as part of an ambitious net-zero strategy. Applying this figure gives us an average of 0.42 $MtCO_2eq$ residual emissions per city or an aggregated total of about 128 $MtCO_2eq$ in residual emissions of the 304 cities, which may represent an upper threshold. Using this average annual CDR need and applying it to all the 1,145 Cities Race to Zero campaign participants suggests a potential demand of ~480 $MtCO_2e$ per year. The total potential demand increases significantly when cities include scope 3 or consumption-based emissions[6], though this is not commonly measured by cities today. Cities aspiring to net-negative emissions would further push up the total demand need.

While this is a material demand signal for the market, the opportunity extends far beyond carbon. Urban CDR can deliver cross-sector benefits when integrated into broader policy domains and embedded in existing systems and infrastructure. A systemic, citizen-centered approach to urban CDR ensures that projects enhance well-being, minimize risks and secure legitimacy – conditions essential to scaling CDR globally to meaningful levels.

Cities as Leaders and Testbeds

The urban area within municipal boundaries – and the surrounding peri-urban and rural areas beyond – are composed of natural and anthropogenic physical structures that have a vast potential for CO_2 removal and storage, including in the building stock itself. This potential carbon sink ubiquity makes municipal leadership indispensable.

But this comes with responsibility, which differs for developed versus developing economies: City CDR leadership represents all municipal government efforts taken to actively reduce CO_2 levels in the atmosphere, while maximizing synergies with broader municipal priorities and policies and prioritizing support for a positive living environment. Currently, the intervention opportunities for cities to contribute to CDR deployment and carbon sink development

[3] Source: Rodriguez Mendez, Q., Fuss, S., Lück, S. & Creutzig, F. Assessing global urban CO_2 removal. Nat. Cities 1–11 (2024) doi:10.1038/s44284-024-00069-x.

[4] Source: Roijen, E. V., Miller, S. A. & Davis, S. J. Building materials could store more than 16 billion tonnes of CO_2 annually. Science (2025) doi:10.1126/science.adq8594.

[5] Source: Ulpiani, G., Vetters, N., Melica, G., Bertoldi, P. Towards the first cohort of climate-neutral cities: Expected impact, current gaps, and next steps to take to establish evidence-based zero-emission urban futures. Sustainable Cities and Society, Volume 95 (2023) doi.org/10.1016/j.scs.2023.104572

[6] Although 13 of the 15 cities indicated that they monitor consumption-based emissions, this is not (yet) standard practice, though it is an emerging best practice and is recommended by leading organizations such as the Carbon Neutral Cities Alliance and C40 Cities who provide dedicated policy guidelines (available here and here).

are vast but underexplored. As a result, this potential has largely remained untapped and most cities have yet to implement strategies for CDR development or even for the management of residual emissions more generally. In practice, leadership in this space means developing separate strategies: first to quantify and minimize residual emissions (taking account of both technical and social limitations), and second to quantify and maximize carbon removals in a sustainable and just manner. Cities with the means and significant historical emissions must counterbalance all remaining emissions with carbon removal and should aspire to go beyond this level to actively contribute to climate restoration. Cities within poorer populations and more technically difficult situations for removals should be incentivized to explore and support local carbon removal development and deployment efforts.

The 2024 report *Pathways to Net-Zero Cities* showed that local governments can act unilaterally and in multi-stakeholder settings, wielding different levers based on their capacity and resources. Municipal governments can maximize synergies with other urban priorities by integrating CDR into urban systems and governance structures and connecting up with other policy domains.

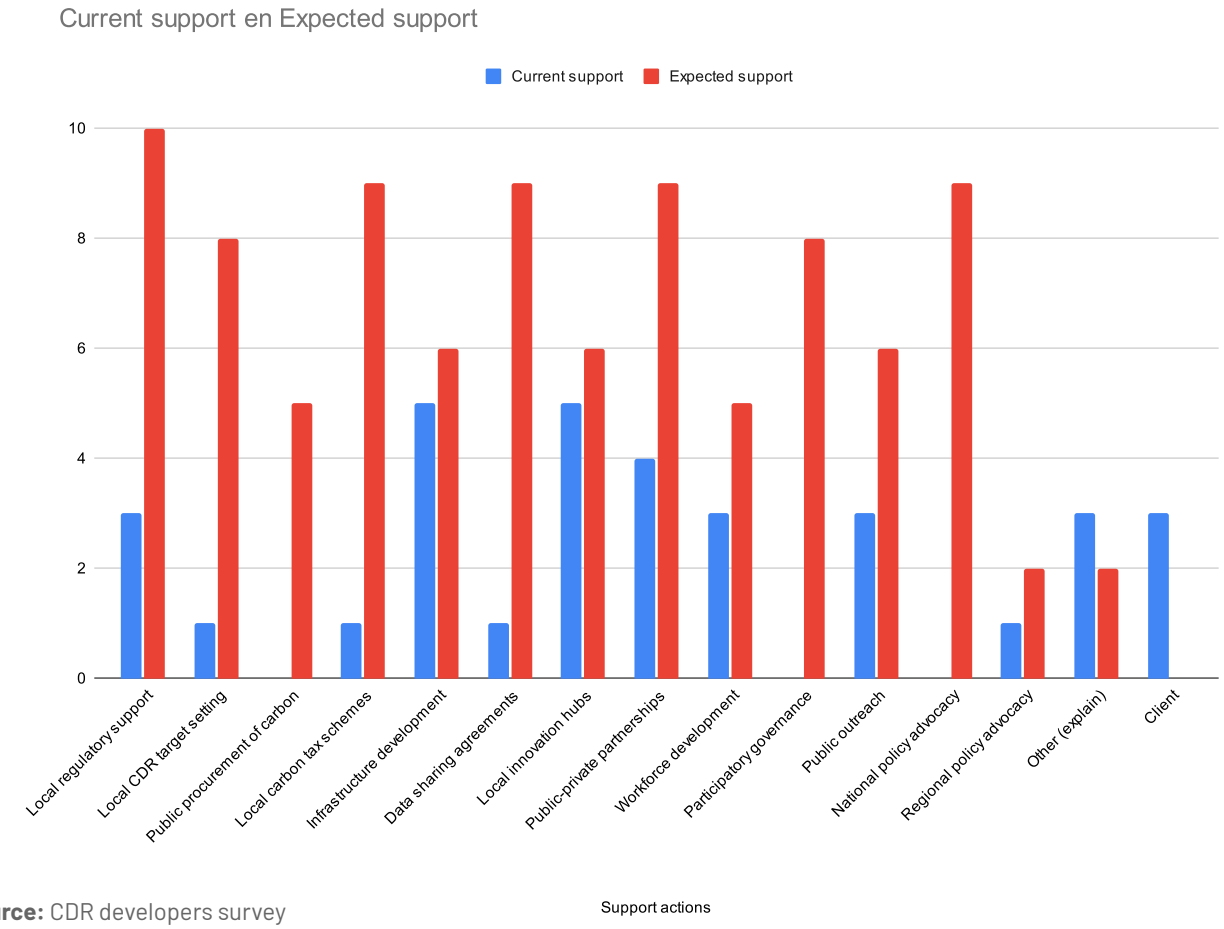
Five levers of municipal power:

- **Regulatory/policy levers:** set direction, enact binding rules, streamline governance.
- **Financial levers:** catalyze funding through a diversity of financing instruments.
- **Urban planning levers:** integrate spatial planning, design low-carbon zones.
- **Technological levers:** foster innovation through R&D support.
- **Political-economy levers:** secure community buy-in and social legitimacy.

The Municipal Toolbox

The analysis shows that cities have a wide array of tools to support CDR, both directly and through influence. Eighteen project and technology developers were interviewed for this report, all of which have an existing commercial focus on urban deployment. They were asked how municipal governments are currently involved in advancing their solutions and what roles they envision for municipal governments in the future. The survey made it clear that developers expect more government involvement across the board, indicating that developers consider municipal governments vital to their success. Some of the greatest discrepancies between current and expected involvement include local regulatory support, target setting, tax schemes, data sharing deals, participatory governance mechanisms, and national policy advocacy.

Figure 1: Replies from CDR project and technology developers to the question 'What roles do you envision for municipal governments in advancing your solution in the future?'



Source: CDR developers survey

Categorizing the replies according to the power levers reveals a preference for municipal governments to improve the political economy for urban CDR and driving policy and regulation to support project development than for providing financial support, developing dedicated enabling infrastructure, and supporting RD&I activities.

Figure 2: Categorized replies from CDR project and technology developers to the question '*What role do you envision for municipal governments in advancing your solution in the future?*'

Levers of Power	Categories of support actions	Times Mentioned
Regulatory/policy	Local regulatory support	**18**
	Local CDR target setting	
Financial	Public procurement of carbon credits	**14**
	Local carbon tax schemes	

Levers of Power	Categories of support actions	Times Mentioned
Urban planning	Infrastructure development	**15**
	Data sharing agreements	
Technological	Local innovation hubs	**15**
	Public-private partnerships	
Political-economy	Workforce development	**30**
	Participatory governance mechanisms	
	Public outreach	
	National policy advocacy	
	Regional policy advocacy	

More specifically, the municipal toolbox includes a wide range of approaches across the five power levers that can be leveraged to support CDR development and can be mutually reinforcing or beneficially sequenced, if designed well. Below is a non-exhaustive list of possible interventions.

Figure 3: Non-exhaustive list of possible municipal interventions in support of CDR development.

Levers of Power	Municipal Interventions
Technological levers	Create innovation labs and districts
	Develop stakeholder-supported CDR method specific innovation roadmaps
	Include CDR in innovation incubators and startup support programs
Regulatory/ policy levers	Strengthen protections for urban wetlands and other carbon-rich urban ecosystems
	Update regulations to encourage biochar-based stormwater filtration and ERW in treatment facilities
	Require waste-to-energy plants to implement CCS for biogenic CO_2
	Mandate composting with biochar in public food waste programs
	Mandate organic waste diversion to support biochar and compost production
	Create streamlined permitting for DAC-integrated buildings and infrastructure
	Require new biomass and biogas plants to implement CCUS for biogenic CO_2
	Incentivize retrofits of biomass and biogas plants to implement CCUS for biogenic CO_2
	Prioritize renewable and bio-based energy with CCUS in city procurement
	Offer fast-track permitting for renewable energy-CDR hybrid projects

Levers of Power	Municipal Interventions
Urban planning levers	Integrate CDR into adaptation strategies (e.g. green infrastructure for heat and flood resilience)
	Require impact assessments of development projects to include CDR potential
	Mandate biodiversity corridors and high-carbon-sequestration species in urban greening plans
	Align zoning with ecosystem-based CDR goals
	Require integration of blue carbon and wetland restoration in water management plans
	Integrate carbon farming metrics into land use strategies for green spaces
	Adopt zero-waste plans that track carbon flows
	Update building codes to prioritize carbon-storing materials
	Mandate carbon-sequestering green infrastructure in new building development and retrofits
	Update zoning laws to designate high-carbon sequestration areas
Financial levers	Provide tax incentives and grants for CDR-related businesses and tech developers
	Provide dedicated CDR innovation funding
	Update procurement rules to prioritize low-carbon goods and services
	Adjust procurement policies to prefer biochar-based compost and recycled construction materials
	Update procurement policies to prioritize carbon-storing materials
	Use resilience bonds to fund dual-benefit (adaptation + CDR) projects
	Use biodiversity bonds to fund dual-benefit (biodiversity + CDR) projects
	Provide subsidies for water systems incorporating carbon-positive technologies
	Tax abatements for developers exceeding carbon sequestration benchmarks
Political-economy levers	Develop city guidelines for biochar, ERW and regenerative practices in urban and peri-urban farming
	Embed CDR education in school curricula and public communications
	Require community consultation and participatory design in CDR strategy development
	Mandate teacher training on climate and CDR science

Source: Own work, adapted from Rodriguez Mendez, Q., Gevers Deynoot, C. et al. (in preparation)

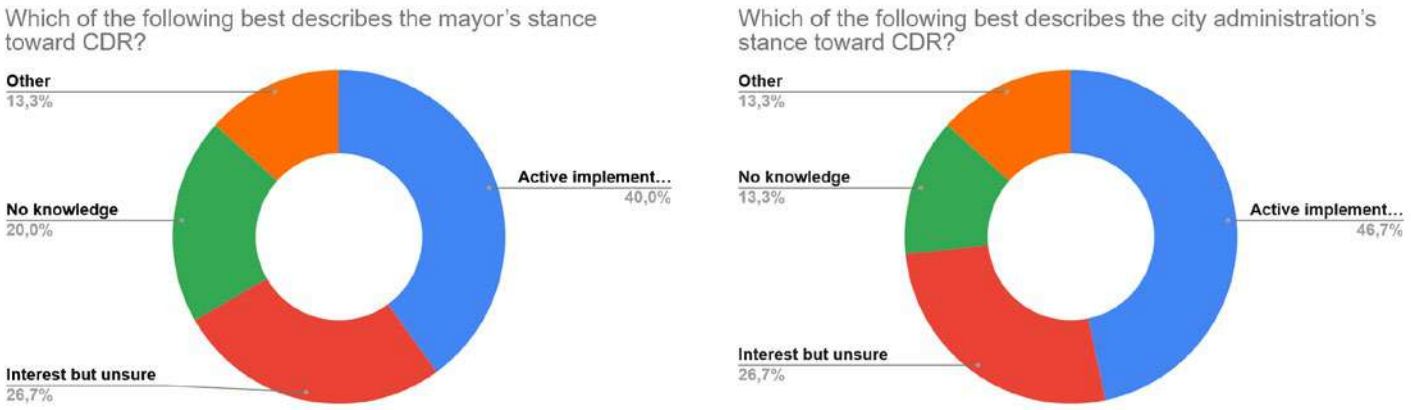
From the engagement with developers, it is clear that those with commercial focus on project deployment in urban environments also have mature ideas about the specific measures that could contribute to their success. Based on interviews, dedicated CDR innovation funding, tax incentives and grants jumped out. Also frequently mentioned was the need to update public procurement rules. This initial survey contrasts with developers' more general favouring of municipal support through policies and regulation and building social support. Further data collection and analysis is needed to refine this overview and compare it with the opinions and data from regulators, administrators, elected officials, political scientists, climate activists, and the general public.

Overall, a picture emerges of cities that not only drive demand and develop supply, but also build the societal legitimacy for CDR more generally. Pilots deployed across the built environment – *front yard projects* – can demonstrate progress, engage residents and align with broader policy goals. These projects generate powerful narratives that link CDR to citizens' everyday lives. Meanwhile local governments can use developers' expectations as a yardstick to determine the most technologically effective interventions. Local leaders and urban pilots are vital to building the societal case for carbon removal worldwide. Cities are where the 'battle for hearts and minds' can be won.

Closing the Knowledge Gap to Scale

Before growing public support for a systemic approach to CDR and carbon sink development, the persistent CDR knowledge gap must be closed. Hundreds of decarbonizing cities need CDR to accelerate mitigation and balance their residual hard-to-abate and socially necessary emissions to achieve carbon neutrality, net-zero or net-negative targets. The 15-city analysis shows that education across administrations and city leaders is crucial to secure both political mandate and organizational capacity for deploying CDR and carbon sinks.

Figure 4: Sentiment about CDR within municipal administrations.



Source: CDR Cities survey

City officials' concerns focus on a wide range of issues, including mitigation deterrence risks, lock-in effects, storage duration requirements, end-of-life rules for carbon-storing products, biomass sustainability, implementation complexities, lack of legal and regulatory frameworks, lack of business models, cost, community perception, and uncertain Monitoring, Reporting and Verification (MRV). These concerns can be addressed with sustained awareness-raising and capacity-building efforts, combined with tangible, high-profile pilot and demonstration projects. Below is an overview of the types of support that the respondents referenced.

Figure 5: City CDR support needs.

What support would your city need to begin or scale up carbon removal efforts?		
Capacity	Rating tools	Resources
Training	Citizen education	Transportation infrastructure
Technical assistance	Pilot projects	Storage infrastructure
Third-party MRV	Technical knowledge	Business models
Lead markets	Funding	

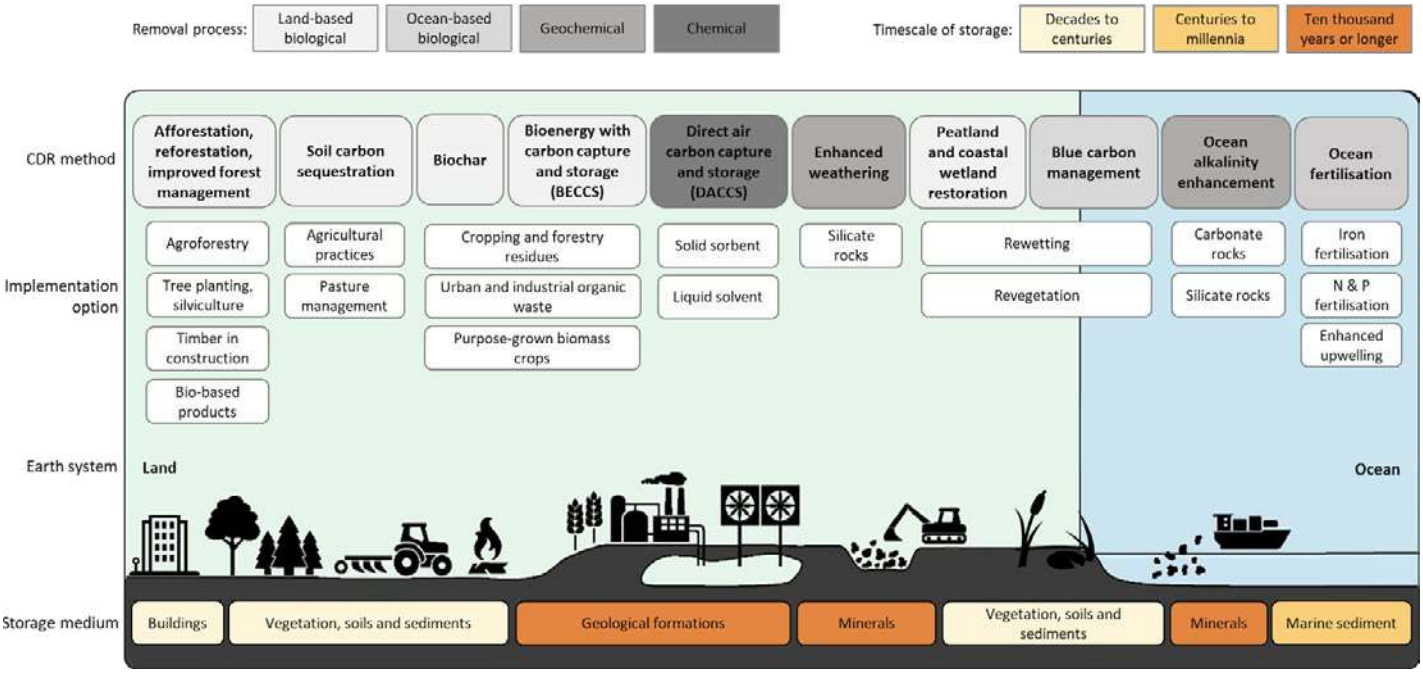
Source: CDR Cities survey

Methods and Synergies

CDR methods and carbon sinks come in many forms. Some have little potential for urban application, while others are mainly suited to urban environments. Methods differ in their deployment readiness, removal process, storage duration and medium, scalability, co-benefits, impacts, risks, and governance needs. Figure 5 gives a taxonomy of CDR methods, highlighting removal processes, storage duration and media, and implementation pathways, some connected to multiple CDR methods. These methods are at different stages of maturity: some have been deployed at scale for decades, others show large-scale deployment potential but have not yet been realized, and some have not yet been considered for deployment in the built environment but may hold potential.

Importantly, the more long-standing and best understood methods tend to be those with potentially short duration storage (such as afforestation), for which the regulatory and governance framework to ensure longer-term storage becomes especially critical. The pathways for implementing CDR methods in cities extend far beyond this list, each with their own considerations, technical challenges and opportunities, supply chain layouts, regulatory caveats and advantages, benefits, and municipal intervention opportunities.

Figure 6: Carbon dioxide removal taxonomy.



Source: IPCC Sixth Assessment Report, Working Group III: Mitigation of Climate Change, Cross-Chapter Box 8, Figure 1 | Carbon dioxide removal taxonomy.

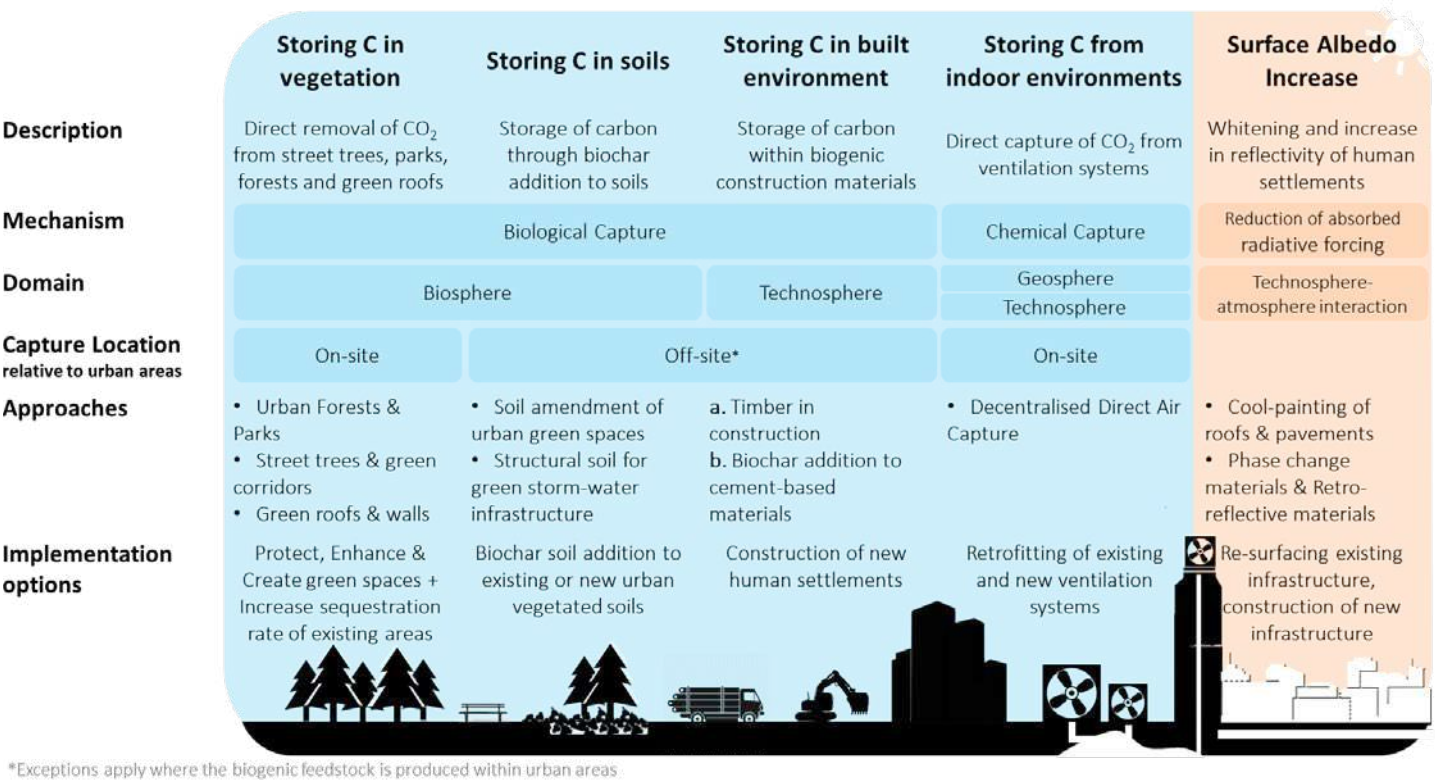
In the city context, CDR methods also differ in their integration potential with urban systems and infrastructure – such as energy, waste and water management – and the ability to be embedded in other policy domains, supporting goals such as adaptation, resilience, public health, and environmental justice. Deployment pathways vary widely, each with distinct supply chains and logistics, often extending far beyond the city's administrative borders (see section 'Supply Chains, Logistics, and Infrastructure'). Whether the capture occurs within the city, the storage elsewhere, or only a section of the supply chain is local, decisionmakers have the opportunity and means to shape and support these activities. For regional, national or global supply chains, decisionmakers can leverage their on-the-ground experience to inform higher-level decision-making.

Bringing CDR into the City

A common presumption is that cities are densely built spaces with little room for large new carbon removal capacity. This is not necessarily true. Identifying the true scale of the urban CDR opportunity is first and foremost about changing the perspective on how to deploy at scale. Instead of thinking about large-scale single carbon removal plants, scaling urban CDR and carbon sinks can only be done in a sustainable and equitable way if it is decentralized, embedded in existing urban systems and infrastructure, integrated into the very fabric of the built environment.

The illustration below shows the diversity of CDR methods and deployment pathways that are, in principle, feasible within an urban and peri-urban environments. Additional pathways include wastewater alkalinity enhancement, Direct Ocean Capture (DOC) in desalination plants, ex situ mineralization, and enhanced rock weathering on rooftops or coastal areas, to name a few. Local context will determine whether specific methods and pathways can be deployed.

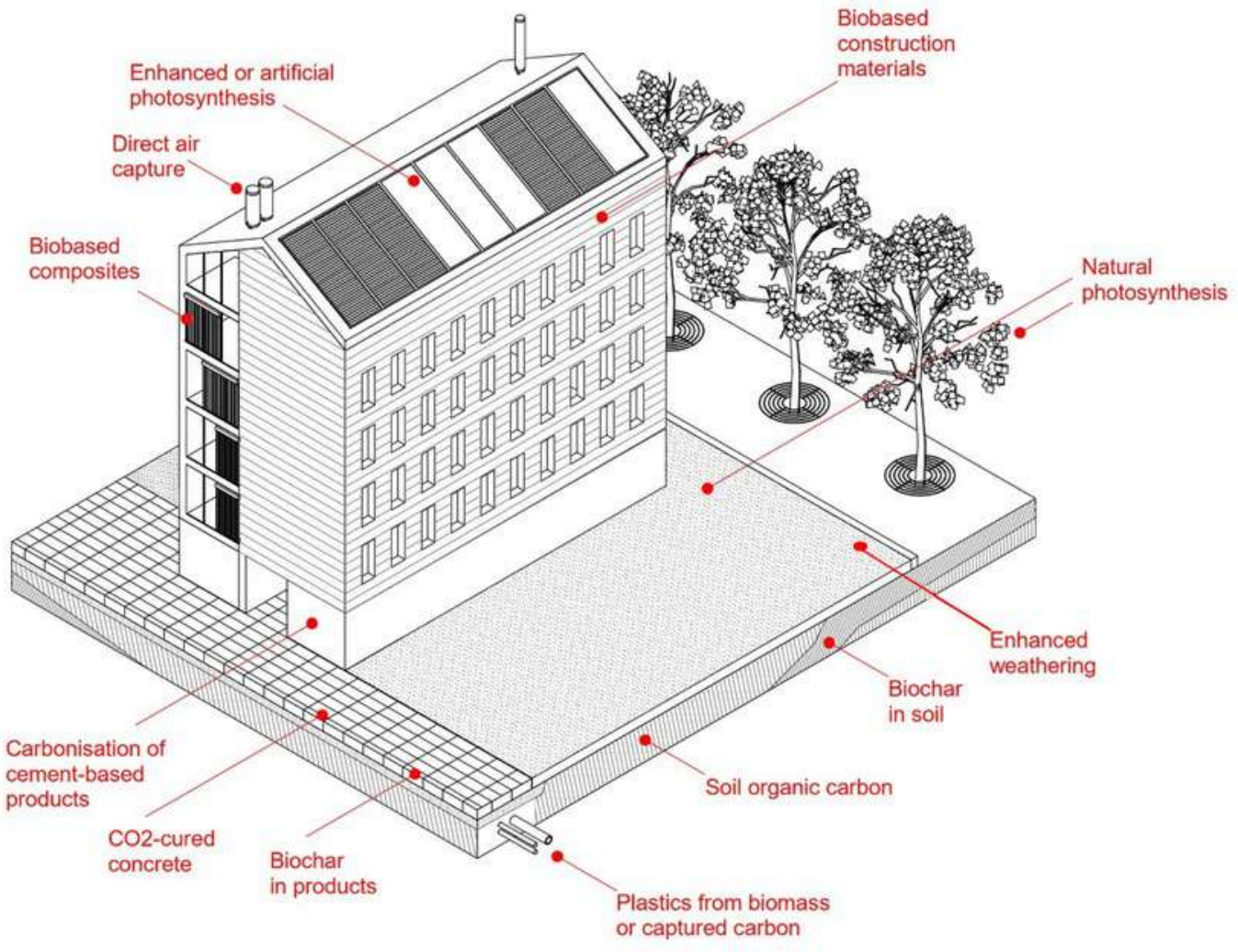
Figure 7: Carbon sink integration at a city level



Source: Rodriguez Mendez, Q., Fuss, S., Lück, S. & Creutzig, F. Assessing global urban CO_2 removal. Nat. Cities 1–11 (2024) doi:10.1038/s44284-024-00069-x.

Futhermore, there are many opportunities for integrating carbon sinks into and around building units. The image below showcases some of the CDR methods and deployment pathways at that scale, indicating the possibility for individual buildings to become net-negative. The image is intended as an illustration; not all of the carbon removal processes listed are material in scale, such as photosynthesis in gardens, and their introduction may not be justified by virtue of the carbon removal capacity alone.

Figure 8: Carbon sink integration at a building unit level



Source: Kuittinen, M., Zernicke, C., Slabik, S., & Hafner, A. (2021). How can carbon be stored in the built environment? A review of potential options. *Architectural Science Review*, *66*(2), 91–107

A systemic approach goes beyond individual buildings and embeds CDR and sinks physically within existing infrastructure, supported by aligned policies, regulations and governance. Relevant systems include wastewater treatment, solid municipal waste and construction waste management systems, urban green and blue corridors, disaster risk management infrastructure, and logistics services. Below is an overview of the main urban CDR pathways.

Table 1. Sample of urban CDR pathways

CDR methods	Urban implementation options
Biochar	Produce biochar from waste biomass available in the city, such as food waste and garden waste, sewage sludge, and urban green residues. Distribute the biochar in public parks and green roofs or use it as an additive in construction materials.
Direct Air Capture with Carbon Storage (DACCS)	Capture the CO_2 from the atmosphere, with stand-alone, decentralized modular units or integrated in large building designs and Heating, Ventilation, and Air Conditioning (HVAC) systems. Durably store the carbon in geological reservoirs or mineralized in construction materials used within the city.
Nature-based solutions (NbS)	Pursue local afforestation/reforestation projects, restore natural ecosystems within the city, including wetlands, apply soil sequestration techniques to urban farming, and build green corridors. Integrate natural materials for more durable storage, such as in wood-based construction and hemp-based construction materials.
Enhanced Rock Weathering (ERW)	Distribute silicate rocks or minerals directly in the city on rooftops, urban pathways or landfill sites, as well as near the built environment, in coastal areas, or on farmland.
Ex situ mineralization	Mineralize atmospheric or biogenic CO_2 ex situ in materials such as cement, concrete, and ceramics. Apply solid carbonate minerals surficially in gravel for roads and parking lots.
Ocean Alkalinity Enhancement (OAE)	Distribute alkalinity-enhancing minerals in water processing facilities such as municipal wastewater and desalination plants, as well as in open water, including rivers and coastal waters.
Bioenergy with Carbon Capture and Storage (BioCCS)	Integrate carbon capture technology with waste-to-energy plants and other bioenergy production plants. Store the biogenic emissions in geological reservoirs or durable products.

Source: Own work

Past research on CDR in cities has been limited, only considering a narrow set of methods and pathways. Further research into the deployment potential of different carbon removal methods and implementation pathways is critical to understand the scale of urban CDR. Imagining how different methods and sinks can be integrated into the built environment and what synergies can be realized with other municipal priorities must inform such a research agenda. Synergies are particularly relevant as they have the potential to foster social buy-in for CDR through urban transformation projects that include CDR, but are focused on delivering other benefits to residents.

Creating a Multiplier Effect

Carbon removal offers many synergies with other climate, environmental and social objectives. At a time when the political economy for ambitious climate action is receding across many parts of the world, local decisionmakers are tasked with strategically orienting municipal CDR interventions, the narratives used to 'sell' them to society, and the very design of the projects, to unlock impacts across multiple domains. When mitigation action is politically less salient, alternative approaches must be tested and implemented to enable progress by other means. This can, for example, come in the form of focusing on the jobs, health, energy security or economic benefits of a carbon removal project over its climate impacts.

In practice, the deployment of CDR in densely populated areas will always put a premium on those solutions that can be integrated in existing infrastructure and contribute to existing priorities. For example, cities hold substantial capacity

for interventions with adaptation-CDR co-benefits, primarily through nature based solutions (NbS) and carbon-negative concrete or carbon-storing materials that sequester and store CO_2 in resilient infrastructure. Adaptation and resilience, efforts often simultaneously remove CO_2 and advance a wide range of other priorities. This includes green and blue corridors to reduce urban heat and contribute to biodiversity and carbon removal; strengthening disaster resilience with carbon-negative concrete coastal defenses; managing stormwater via urban wetlands or biochar to enhance water retention and reduce harmful runoff; conserving biodiversity through urban forestry; improving food security via urban farming combined with biochar or enhanced rock weathering; and countering ocean acidification while enhancing carbon sequestration through ocean alkalinity enhancement via waste-water treatment.

Securing such synergies requires distributing responsibilities across municipal adaptation and resilience officers, stormwater utilities, infrastructure operators, and civil engineering firms. Many municipal administrations are already actively exploring synergies between adaptation and emissions reduction planning: 13 of the 15 cities we studied have this as a standard practice. Integrating CDR into adaptation and resilience planning can serve as a powerful lever to scale carbon removal while bringing additional resources and expertise to adaptation efforts. Similar synergies can be realized across other policy domains, such as waste management and circularity, decarbonization and the energy transition, biodiversity promotion, and public health.

The prospective 'Pathways to Carbon Sink Cities: Implementation Guide' offers a framework for cross-policy integration. The framework provides a strategic and practical approach to embedding CDR across urban policies. The first step is to focus on specific policy areas where CDR can have the greatest impact. A number of key policy verticals are identified, in which CDR policy and municipal policy intersect and can reinforce each other. Ten policy intersection factsheets can be found in the Annex to that report. These factsheets help operationalize the framework by offering insights for city officials on how to implement CDR solutions in different sectors, leveraging synergies and maximizing co-benefits.

The following policy areas are covered in the factsheets.

- Land use planning and zoning
- Urban design and infrastructure
- Waste management[8]
- Energy management
- Water management
- Agriculture and food systems
- Economic development
- Biodiversity and ecosystem services
- Adaptation and resilience
- Public education and community engagement

[8]The nexus between the circular economy and carbon removal is not yet explored under the City CDR Initiative but holds promise for synergies. The realization of a 'circular carbon economy' that tackles climate change through reducing, reusing, and recycling materials, while also capturing, utilizing, and storing carbon, may be feasible as a complementary measure, though can only have material value from a climate change mitigation perspective in a deeply decarbonized future. Further research is needed to understand the optimal pathways.

Supply Chains, Logistics, and Infrastructure

Efficient supply chains unlock carbon removal methods scaling potential. Municipal decisionmakers need a thorough mapping of the supply chain elements, management needs, infrastructure requirements, and the underpinning logistics when thinking about how to design their public interventions and CDR projects. Early consideration of these factors prevents bottlenecks, minimizes cost, reduces the environmental and social footprint, and informs workforce development.

Many CDR methods and urban pathways are still in an early stage of development. The complexity of the systems, diverse feedstock properties, and limited economic visibility are challenges that must be resolved to develop functional, optimized supply chains. Municipal governments play an important role in supporting urban CDR methods and supply chains; their ability to enable hard and soft infrastructure[8] development is vital. Adopting this role starts with understanding when to take ownership, assume a supporting role to the private sector, or simply 'stand aside'.

Defining Urban CDR Supply Chains, Logistics, and Infrastructure

Supply chains include the actors, assets, and processes needed to deliver a good or service, from sourcing materials to the delivery of the product and/or realization of the carbon removal. The non-exhaustive list below shows infrastructure assets that urban CDR project developers may need. These assets will often not be owned by the developers, who rent or lease the assets, or hire a third-party service provider that brings and operates the equipment. This is especially true for the infrastructure assets involving large-scale or specialized transport or public utilities. Most CDR companies are not yet established enough, to acquire all the assets, especially those that are capital-intensive.

Figure 9: Non-exhaustive list of potential hard infrastructure needs for urban CDR projects

Utilities and CDR integration infrastructure	
Land	Ports
Roads	Inland waterways
Railways	Renewable energy plant
Wastewater treatment plant	Bridges and boardwalks
Waste-to-energy plant	Stormwater management infrastructure
Combined heat and power plant	Waste gas treatment system
HVAC system	Biofuels production plant
Bio-ethanol production plant	Landfill

[8] Urban CDR and carbon sink development needs both hard and soft infrastructure. Hard infrastructure is physical, while soft infrastructure is institutional and service-based. Hard infrastructure consists of the physical, tangible systems that underpin a society, such as roads, bridges, railways and power grids. Soft infrastructure includes intangible services, such as the rulebooks governing vital systems, their funding, and the workforce development, as well as institutions, including the financial system, educational system, and systems of government, including law enforcement.

CO2 and feedstock transportation infrastructure	
CO_2 pipelines	Specialized vessels
CO_2 bearing rail tank cars	Specialized offshore structures
CO_2 bearing barges	Raw materials transportation infrastructure
CO_2 bearing trucks	Onshore specialized holding facilities for minerals or materials
CO_2 handling port facilities	Temporary CO_2 storage facilities
Biomass transportation network	Biomass storage silos
Carbon removal production infrastructure	
Pyrolysis reactor	CO_2 capture technology
CO_2 feed system	CO_2 utilization infrastructure
Drying system	Geological storage site
Mining equipment	Hydrological manipulation and control systems
Quarrying equipment	Soil and sediment management equipment
Dispersion equipment	Localized electricity grid
Grinding mills	Monitoring equipment
Crushing equipment	Tree support structures
Kilns	Specialized machinery
Mixers	

Source: Own Work

Logistics relies on infrastructure, which is the physical, digital and social backbone that allows logistics to function. Logistics acts as a facilitator of the supply chain. The logistics system that underpins urban CDR supply chains requires a combination of access to the right private and public infrastructure and the right logistics services. Below is an overview of the most prominent logistics services in CDR project supply chains and examples of how they apply to specific CDR methods and deployment pathways.

Figure 10: Overview of potential CDR project logistics

Logistics service	Description	Examples
Freight operations	Loading, transporting, unloading along a coordinated supply chain	Enhanced Rock Weathering (ERW) uses types of silicate rocks and minerals. These must be sourced from locations often far removed from the deployment area, such as rooftops. This may involve rocks being transported with trucks, trains, and ships or barges. Adequate coordination between a range of supply chain partners involved in the freight operations is vital, from the quarry to the deployment area.
Warehousing	Storing correctly to ensure material quality and support cost-efficiency	Biochar production often involves the use of different types of secondary biomass as feedstock. These may come from different sources and have diverging delivery timelines. The biomass feedstocks must be stored and handled before processing, at times in holding facilities to await the arrival of other feedstocks before going to the pyrolysis reactor. The finished biochar also requires storage, often under specific conditions, before sold or applied.
Inventory management	Having the right material in the right place at the right time at the right quality levels	In ex situ carbon mineralization, inventory management is crucial for optimizing the supply chain, ensuring operational efficiency, and enabling accurate MRV. Effective inventory management ensures a consistent and sufficient supply of alkaline materials to the reactor, preventing bottlenecks and optimizing plant output. As many ex situ processes use industrial waste products as feedstocks, inventory management tracks the volume, composition, and disposal methods of waste streams, while also managing the use of produced carbonated materials to avoid creating new environmental issues or carbon storage reversal risks.
Sorting	Sorting waste streams used as feedstock in carbon removal processes	When an ex situ mineralization process relies on construction and demolition (C&D) waste, the sorting is a key logistics service that is part of the project value chain, directly impacting the economic and technical viability of the process. The company sources waste streams from different origins and compositions, some of which are contaminated. Adequate sorting ensures that only suitable materials are processed, reducing processing costs, preventing contamination, and maximizing the recovery of valuable resources.
Packaging	Making materials and products suitable for transport or storage	Packaging is an important logistics service for some CDR methods and deployment pathways. For example, the role of packaging for bio-based construction materials is necessary to protect the materials from environmental factors, such as moisture, gases, odors and other elements, while maintaining structural integrity of the products, allowing for simple handling, and meeting economic viability standards.
Labelling	Enabling traceability and guiding handling along the supply chain	Labelling is a critical feature within the logistics of most CDR methods that involve sourcing processed materials or other intermediate products to deliver the final carbon removal service. For example, for the sorbents used in some Direct Air Capture (DAC) systems, labelling is vital for safety, regulatory compliance, quality control, efficient system operation, and accurate performance assessment. It involves detailed characterization and clear identification of the material's properties and handling requirements.

Logistics service	Description	Examples
Compliance	Ensuring regulatory compliance when handling goods and materials	Regulatory compliance is indispensable for CDR project logistics and operation. Compliance ensures adherence to all applicable environmental laws, regulations, and standards, providing a structured and accountable framework for project implementation and success. For ecosystem restoration projects, for example, regulatory compliance helps ensure adherence to legislation focused on clean water, endangered species, public health or general zoning laws and permitting rules. Compliance mitigates project risks and defends developers against legal penalties, fines, permit suspensions, stop-work orders, and lawsuits. It creates accountability and enables monitoring, building public and investor trust. Regulatory compliance is a precondition for public funding.
Data flows	Digital information flows amongst supply chain partners	Data flows are crucial for the logistics involved in CDR project supply chains. Data flows enable accurate monitoring, reporting, and verification (MRV) of carbon removal. Digital MRV helps streamline these processes for the purpose of carbon credit generation or regulatory compliance. For example, Waste-to-Energy (WtE) plants are in the process of being included in the EU Emissions Trading System (EU ETS). The plants are required to monitor, report, and verify their emissions. Turning them into Bioenergy with Carbon Capture and Storage (BECCS) plants reduces compliance costs by limiting the need for emission allowances, but this requires transparent MRV with optimal data flows.
Export/ import	Managing customs procedures and organizing insurance	CDR methods like DAC and BECCS tend to source components from abroad. They involve technologically advanced processes and rely on specialized machinery, chemical sorbents, and infrastructure that may not be produced domestically. This leads to a reliance on imports from international suppliers for parts, which require the management of customs procedures and insurance coverage. DAC, for example, uses chemical or physical processes to remove CO_2 from the atmosphere. Complex machinery includes fans, filters, and chemical processing units, which are often sourced globally.

Source: Own work

CASE STUDY: BIOCHAR SUPPLY CHAINS

Looking at biochar supply chains, for example, there are six distinct steps: feedstock growth and sourcing, feedstock processing, pyrolysis, storage, deployment, and the transportation between each step. The supply chain may be longer or shorter depending on factors such as whether the gas, heat or liquid by-product of the pyrolysis process is used, the location of the pyrolysis system in relation to the other steps of the supply chain, and the use of centralized or mobile pyrolysers. Some commentators have called for horizontal integration to produce different pyrolysis products, such as bio-oil, syngas, and biochar, at the same location. Diversification can be done at limited additional cost by alternating the feedstock, temperature, and processing technologies. With more diversification comes the need for greater multi-sector collaboration to navigate increased complexities.

Adequate policy and project design should cater to the specific use cases for these products and the associated supply chains. Pyrolysis products, for example, may be integrated into other products, such as refining the bio-oil into aviation or marine fuels, which come with their own distinct supply chain management needs. While robust, competitive markets for advanced pyrolysis products are gradually taking shape, municipal governments who are considering buying and owning their own municipal pyrolysis system are advised to maintain a thorough understanding of the supply chain steps, variations, stakeholders, and management needs. Municipal governments can improve efficiencies across the supply chain by creating dedicated platforms for collaboration amongst supply chain partners.

As with all CDR methods and deployment pathways, the commercial prospects of urban biochar deployment at scale are uncertain. Biochar use cases and associated supply chains differ significantly across locations and benefits. Any municipal biochar development and deployment strategy should factor in this heterogeneity and leverage it as a diversification opportunity that can reduce risk and increase the commercial viability of projects instead of being an obstacle to overcome.

The Carbon Sink City

How the idea of a city is framed defines the solutions that can be thought of in response to the demands of its citizens. Looking at the city as a space, the traditional view of a territory bounded by jurisdictional borders, holds little meaning. Cities do not stop at their legal boundaries. Cities are complex open systems characterized by countless flows of materials, energy, water, GHG emissions, information, capital, flora, fauna and people that are constantly 'exchanged' across their administrative boundaries.

As human settlements, cities are intricately enmeshed in the global governance of social and economic resources, ecosystem services, and regulatory systems. Mutual interdependencies with external regions is the rule and self-sufficiency within a bounded system the exception. The concept of 'urban metabolism' helps us understand the city as a boundaryless space.[9] Urban metabolism makes an analogy with the metabolism of individual organisms or even entire ecosystems. Cities resemble organisms in that they consume resources from their surroundings and excrete wastes, converting raw materials, energy and water inputs into the built environment, biomass and waste.

Looking at cities as agents, they appear predominantly bounded. Decision making capabilities and political will are still very much conditioned by the borders of cities. A municipal government does not hold absolute and inherent authority to act independently; its rights and responsibilities are defined and curtailed through legislation and charters, limiting autonomy in local affairs and tethering it to the laws of the prevailing state, provincial or national government. Municipal governments are also bound by the function that society attributes to the city. While they can exert influence far beyond their legal remit, expectations from individual citizens, businesses, and other stakeholders limit these soft powers. These expectations can be local, but are often a product of an era's zeitgeist.

In this Pathways to Carbon Sink Cities report series, the concept of cities as carbon sinks is presented as one response to the growing public call for more livable cities, driven by concerns about housing affordability, safety, environmental sustainability, and the overall quality of life. The benefits of connecting urbanization demand and consumption patterns to carbon removals are vast. It is also necessary in light of developmental demands in cities around inclusive growth, food sovereignty, and the imperative of green livelihoods.

Imagining Carbon Sink Cities

The Carbon Sink City is planned and managed so that its systems work together to remove and store carbon while delivering everyday services and protecting nature for the collective wellbeing. In a Carbon Sink City, carbon flows through the city and is captured in one place, durably stored or transformed in another, and in some cases reused as a feedstock for new durable products. Cities embed carbon-conscious design and planning into the very fabric of the urban environment, reframing carbon as a designed-for element of urban metabolism, with a ubiquitous presence of natural and artificial carbon sinks.

At its core, this vision sees the nature and the role of the city radically transformed. The city has cut its emissions to near zero, phased out fossil fuel use and eliminated high-carbon consumption amongst businesses and residents. It is now no longer a driver of emissions, but an active agent of restoration; a living, breathing carbon sink that safeguards the climate and offers healthier, more resilient and more inclusive spaces for its citizens while positively impacting communities further afield. This transition - from cities as extractive engines to cities as regenerative

[9] Urban metabolism translates into concrete urban planning practices by applying material and energy flow analysis to inform strategies for resource efficiency, waste reduction, and circularity. This involves using data from urban metabolism studies to design for disassembly and material reuse in construction, create industrial symbiosis networks, develop advanced waste management systems, implement targeted circular economy initiatives, and develop policy analysis tools like GHG accounting and modeling for decision-making.

ecosystems - represents a scientific and a technical imperative, as well as a profound design opportunity. It calls for new ways of measuring value and internalizing externalities, new forms of collaboration and new frameworks for planning and governance. Most of all, it challenges us to see cities not as passive backdrops to human activity, but as active participants in climate restoration.

'Urban metabolism' provides a powerful lens for this shift. By understanding cities as interconnected networks of flows – of materials, energy, water and carbon – we can begin to design, measure and redirect these cycles in ways that benefit people and the planet. Using urban metabolism as the central lens means three practical shifts. First, carbon is counted, traced and managed. Second, design and planning decisions are made with the explicit goal of increasing durable carbon storage while reducing emissions. Third, decisions are tested against measurable outcomes: net carbon balance for districts or the city, storage durability (how long carbon stays locked up) and co-benefits such as cooling, biodiversity, and jobs.

In addition to urban design embracing the principle of solidarity and creating buildings that 'give back more than they take', Carbon Sink Cities have streetscapes with carbon-storing pavements that mineralize CO_2 into durable surfaces, parks and landscapes that double as carbon sinks, bio-based capture technologies integrated into living systems, and wastewater processing facilities that remove carbon and increase the ocean's CO_2 absorption capacity. Streets and corridors become continuous green-blue networks – tree-lined avenues, permeable pavements, pocket wetlands and green roofs – that increase sequestration, reduce heat, and manage stormwater surges. Utilities are repurposed to circulate captured carbon alongside water and energy, storing it durably or feeding it back into industries for reuse.

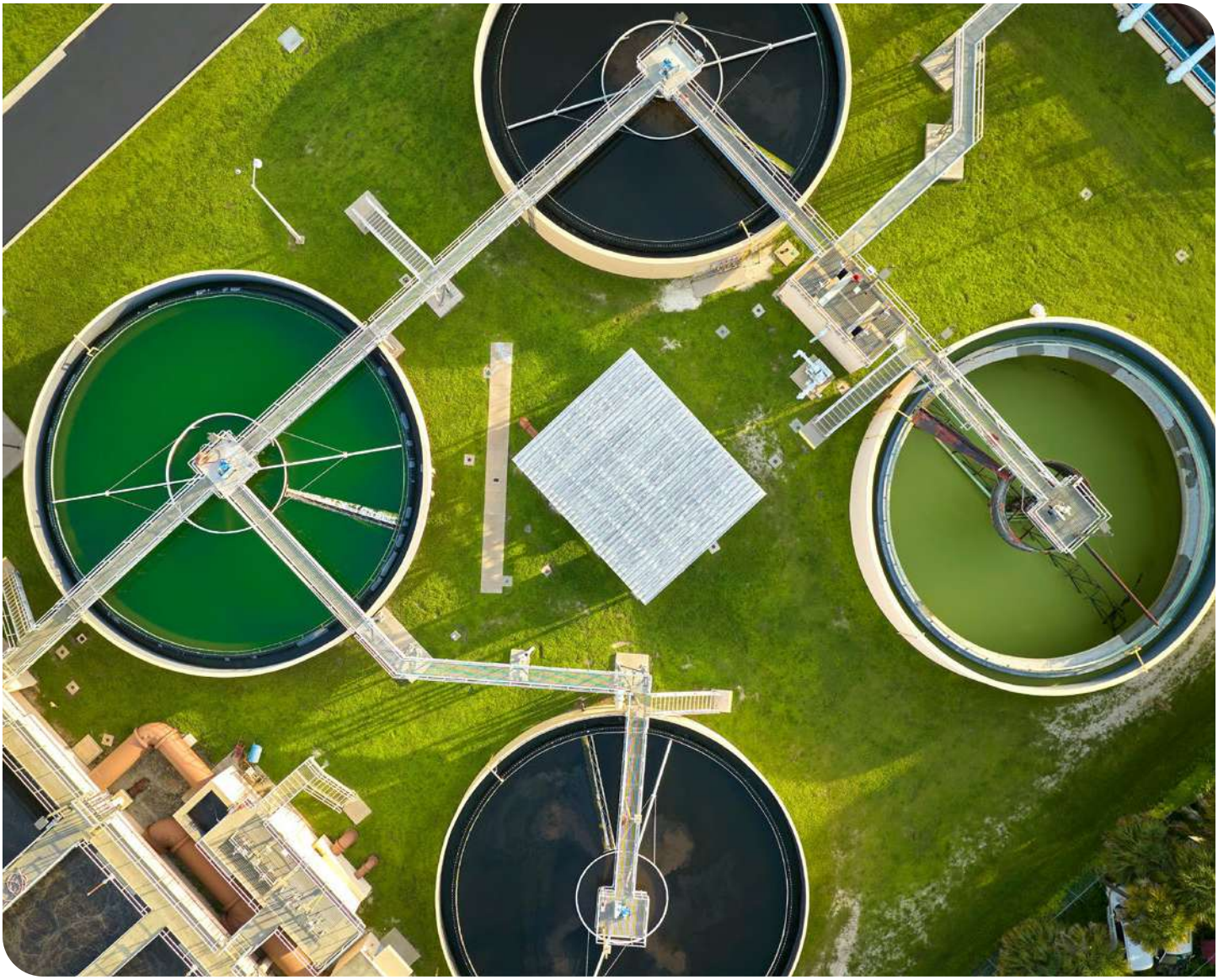
Carbon Sink Cities have the potential for positive feedback loops: urban ecosystems that regenerate their environment, create resilience in the face of a changing climate, and bring lasting value and prosperity to people worldwide. Crucially, urban CDR is not about layering extraordinary technologies onto ordinary systems, but about embedding carbon-conscious design and planning into the very fabric of how cities grow and operate. It is an iterative process of demonstration, deployment, and improvement that a city goes through gradually; becoming a Carbon Sink City is a multi-decade undertaking that cities can plan for but will realistically only be possible at scale in a 2050 timeframe.

The Empowered Agent

Transforming our cities from sources of risk into agents of restoration requires us to recognize and strengthen municipal agency. Today, municipal governments are highly-empowered agents in the fight against climate change. Through global and regional inter-city collaboration networks, they exert a growing influence on national and international climate action. This empowerment has helped drive mitigation, adaptation, and resilience across the urban agenda, which in turn has engendered urban planning visions that reimagine the future of our cities in ways that build resilience to deal with external shocks and ensure continued flourishing.

For example, the concept of 'sponge cities' stipulates that cities must become better at absorbing excess water from extreme rainfall, flashfloods, or other extreme water-related challenges caused by climate change. 'Nature-positive cities' actively strengthen, restore, create, and mimic natural ecosystems for a more sustainable balance. 'Regenerative cities' are cities that build a restorative, net-positive relationship with nature that improves and heals local ecosystems and communities.

These conceptual frameworks are critical components of what realizing a resilient city entails. A resilient city is one that can withstand and recover from various shocks and stresses, such as climate change impacts, economic downturns, or social disruptions, adapting and thriving and ensuring the well-being of its people, institutions, and systems. Realizing this ambition involves integrating all these visions and more into a holistic urban planning framework including carbon removal and the development of carbon sinks.



CHAPTER 2:
THE GOVERNANCE

To unlock the full potential of urban CDR, local governments must reorganize themselves to act strategically, navigate complex legal and institutional constraints, and collaborate effectively between departments, across levels of government, and with local stakeholders. This chapter examines the different roles of municipal governments, gaps and opportunities in the governance systems, gaps and opportunities for CDR in climate action planning and city GHG emissions inventories, city climate finance landscape, and environmental justice considerations that come with CDR strategy development and implementation.

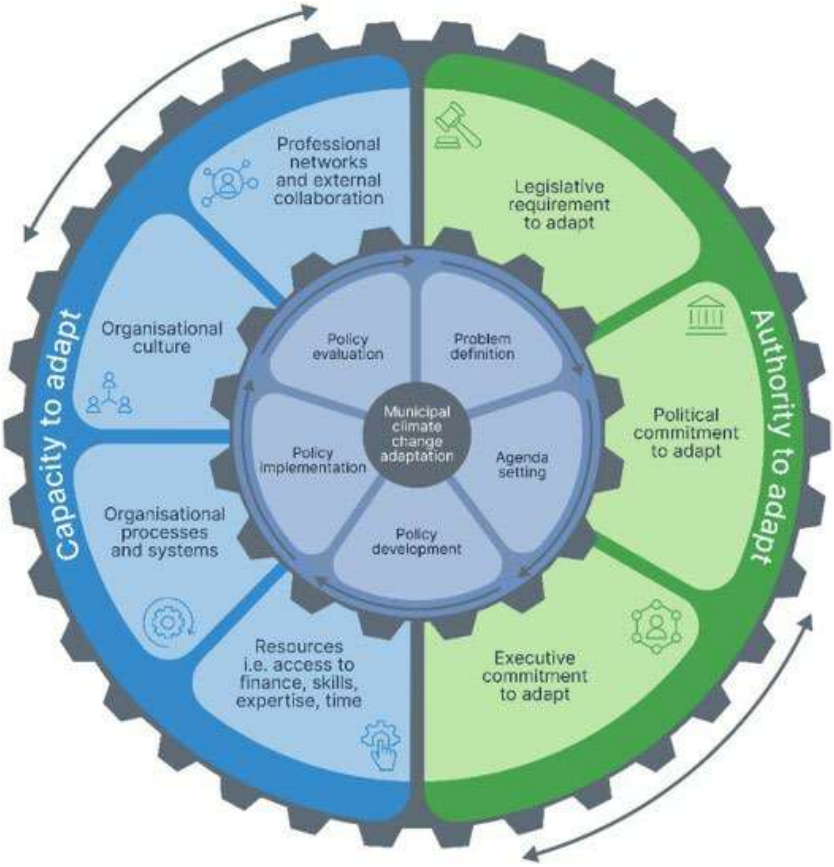
Municipal Administrations

Sustainability is cross-cutting by nature. It touches on practically all the domains of public policy and services delivered by local governments. Yet a variety of obstacles hinder the mainstreaming of sustainability across municipal departments. Organizing carbon removal as a cross-cutting issue will likely face the same challenges as the mainstreaming of other sustainability issues.

Authority to Act and Capacity to Act

Like carbon removal, climate change adaptation is another of climate action that has fairly recently been added to the municipal agenda. How cities adopt and implement adaptation policies can inform efforts to navigate institutional barriers when introducing carbon removal in municipal administrations. As part of a recent study on *Factors affecting the mainstreaming of climate change adaptation in municipal policy and practice*, researchers did a systemic literature review and looked at over 130 articles written about municipal adaptation action. The study identifies two overarching factors that determine how successful a local government is in mainstreaming adaptation and resilience: its 'authority to adapt' and its 'capacity to adapt' (hereinafter called the authority and capacity to act, respectively). A city's authority to act looks at the mandate it has received from its citizens and the national or sub-national government for municipal action. A city's capacity to act concerns the availability of resources, supporting networks and supportive organizational systems and culture.

Figure 11: Conceptual framework explaining how the authority and capacity to adapt can interact and influence each other.



Source: Rogers, N. J. L., Adams, V. M., & Byrne, J. A.)2023). Factors affecting the mainstreaming of climate change adaptation in municipal policy and practice: a systematic review. Climate Policy 23(10), 1327-1344.

CASE STUDY:

EXAMPLES OF FRAMING A CITY'S AUTHORITY AND CAPACITY TO ACT

The City of San Francisco has the political will and legal authority to develop supporting policies and regulations. While its financial resources and institutional capacity are limited, its regulatory powers, public support, a thriving research, development and innovation (RD&I) ecosystem, and its reputation as a leader in environmental stewardship give San Francisco significant influence in advancing and accelerating CDR in the region.

The City of Helsinki has the authority to pursue ambitious climate goals because of political commitment and a strong local democracy to back it up. The municipality has a monopoly on urban planning, the right to collect taxes and a surplus budget to make infrastructure investments to help achieve climate targets. In addition, it has substantial capacity to act by way of its institutional capacity, robust municipal budget, and national and international collaboration platforms to develop policies, implement programs and learn from peer cities.

The City of Stockholm has the authority to make urban planning decisions, develop policies, and implement programs to address urban challenges and pursue climate goals. This is based on a combination of significant regulatory powers and citizen buy-in for climate action, and leans on extensive institutional capacity, fiscal means, land ownership, and national support frameworks.

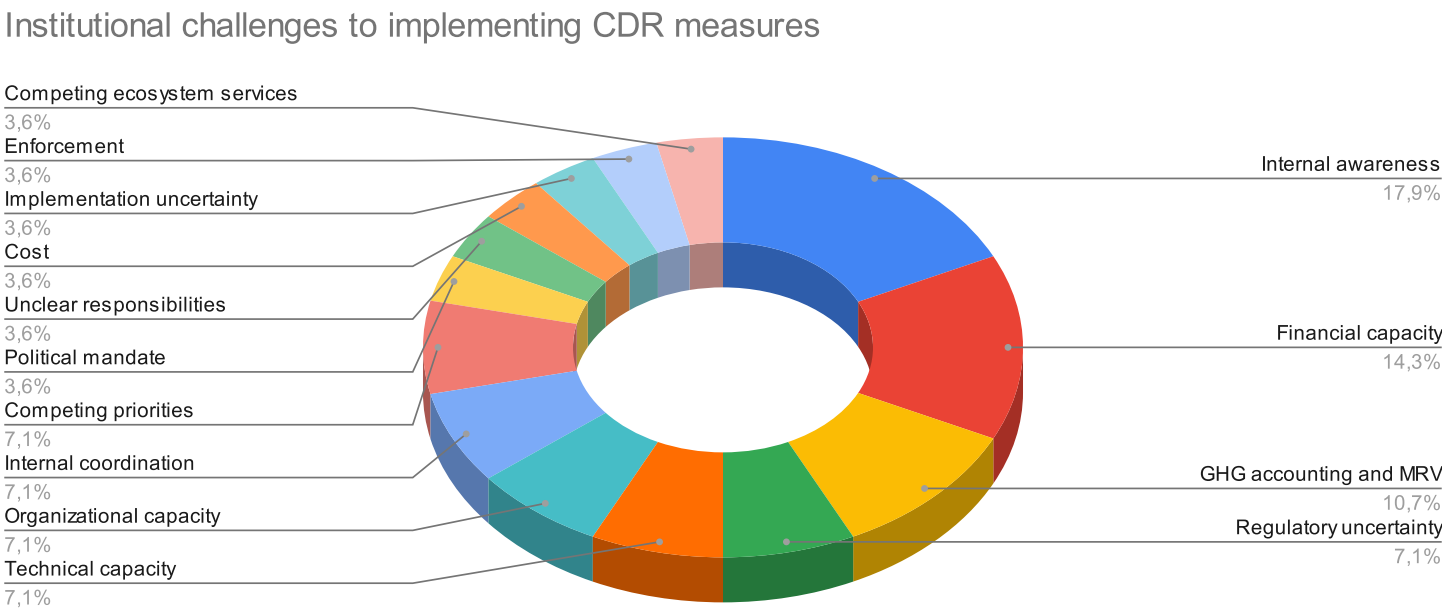
A government's capacity to act is shaped by its authority to act; its legal competencies, political commitments, and executive leadership. For example, a city with a so-called 'strong mayor' who is committed to climate action, a progressive climate policy framework, and the competencies to leverage critical urban planning instruments has a robust mandate to pursue adaptation and resilience measures. Conversely, municipal officials operating in a less supportive or even hostile environment for climate action may face a politically risky uphill battle to push for adaptation measures and need to find alternative approaches.

Institutional Barriers to Act on CDR

Local governments face a variety of barriers to supporting CDR, including at the institutional level. The most prominent barrier to municipal adaptation is the lack of political recognition. This is first and foremost connected to a pervasive lack of urgency. It may be further hindered by perceived inconsistency with the local or national political climate and leading influencers, a bias for short-term measures connected to election cycles, ideological dissonance, or political opportunism. Other key barriers include limited access to funding, data availability, organizational siloes, expertise gaps, clashing priorities within the administration, perceived lack of social licence, unclear mandate, scientific uncertainties, and the absence of higher subnational or national leadership in the country.

The CDR cities survey asked the 15 cities about the top three challenges to implementing carbon removal in their city. The results differ in certain respects from the challenges to introducing adaptation measures in cities. Rather than political recognition, respondents (typically officials in sustainability and planning functions) pointed to the lack of internal awareness as the most dominant institutional challenge to implementing carbon removal measures, followed closely by the lack of financial capacity. This reflects the fact that CDR is more nascent in municipal politics than adaptation; an educational gap remains to be closed before making an appeal to political support. In contrast to adaptation, CDR involves more complex carbon accounting and MRV, although most cities already engage with such challenges in emissions reduction.

Figure 12: Replies city representatives to survey.



Source: CDR Cities survey

But there are also major overlaps beyond funding constraints. Technical capacity or expertise gaps are prominent in both cases, as are the lack of internal coordination or (organizational siloes) and competing priorities. Both can suffer from the lack of a political mandate without which, any progress can only be incremental and small-scale.

A municipal administration's capacity to act is directly shaped by its mandate for change. The increased authority of cities to pursue climate adaptation and resilience planning has led to the creation of dedicated municipal adaptation strategies, public budgets, new specialized city networks such as the Resilient Cities Network, and governance innovations, such as the emergence of the Chief Resilience Officer following the Rockefeller Foundation's launch of the *100 Resilient Cities (100RC) program* in 2013 under which it funded the position in almost 100 local governments globally. New civil-sector and global multilateral programs have filled the urban resilience capacity-building space after 100RC's closure.

It is not immediately clear that this approach applies to carbon removal in the same way or that all cities are best served by it. In reality, local governments may follow a few basic universal structures that distribute executive and legislative powers, but they differ substantially in the way that they are organized to deliver public services and enable private sector activities in the most effective way. This is determined by a range of factors, which are often deeply local and historical, though there are external interventions that lead to governance innovation across many cities, such as 100RC. The governance innovation needed for a city to pursue a whole-of-administration approach to CDR has to be locally rooted, but would benefit from external interventions to foster the identification and exchange of best practices and create fertile ground for a diversity of innovations in urban CDR governance.

Multi-Level Systems

Organizing carbon removal within a municipal administration must take relations with other governance levers into account. A municipal government can support the development of carbon removal and sinks within its boundaries and beyond in numerous ways; the previously listed power levers (see "Cities as Leaders and Testbeds") elucidatethe variety of actions available. However, as power goes, its potency depends on the context. The five power levers operate in a complex multi-level governance interplay. The relationships with other governance stakeholders both constrain and enable municipal agency and provide the environment in which the role of CDR is constructed and contested.

Multi-level governance systems distribute authority and decision-making capabilities across multiple jurisdictions and levels of government, from local to national and international. Inherently global in its impact and local in its operation, the governance of carbon removal involves a web of overlapping and interacting authorities, including formal and informal processes, institutional frameworks that define roles, horizontal and vertical coordination between governments, private sector and civil society stakeholder engagement and different governance modes, from hierarchical to collaborative. Cities benefit from better understanding the roles and dependencies in this multi-level system. This will enable them to influence the governance context and create a more enabling environment for city-led CDR.

Recognition in the Global Governance of CDR

An entity must gain and maintain recognition to be successful in a multi-level governance context. Without recognition, its ability to participate in decision-making, secure resources and realize its objectives is severely hindered. This is relevant in domestic and global contexts. Today, municipal agency in global climate action is gaining much wider recognition in global fora. The *Coalition for High Ambition Multilevel Partnerships* (CHAMP) for Climate Action was created at COP28 in Dubai to strengthen cooperation between national and subnational governments in the planning, funding, implementation, and monitoring of climate strategies, including Nationally Determined Contributions (NDCs) under the Paris Agreement. CHAMP aims to maximize climate action and increase adaptation and resilience. The scope has yet to extend to cities' roles in CDR.

This lack of recognition extends beyond the governance of climate action into the domains of climate and social science, which in itself forms a science-based foundation for multilateral cooperation and national policymaking. Taking the upcoming IPCC Special Report on Climate Change and Cities as an example, an *early outline* showed that carbon removal in urban environments may only be considered indirectly or peripherally. If this occurs, an opportunity to recognize and empower cities in the multi-level governance of CDR will have been lost, undermining municipal agency, limiting fresh carbon removal supply, and hampering the emergence of local innovation and development clusters.

IPCC publications have huge signalling power. By concentrating the global state of research in a given area of climate science and distilling this in a digestible form for politicians and the society at large, the IPCC effectively dictates whether a climate intervention is mature enough for inclusion in international agreements and policymaking. It is difficult to justify substantial public funding in solutions that are excluded or treated peripherally in IPCC publications as this implies that such solutions are not based on science that is broadly accepted within the global community of scientists. The attention dedicated to CDR in the Special Report on 1.5°C from 2018 and the 6th Assessment Report in 2022 propelled this area of climate action onto the international stage in a way that few other publications could have.

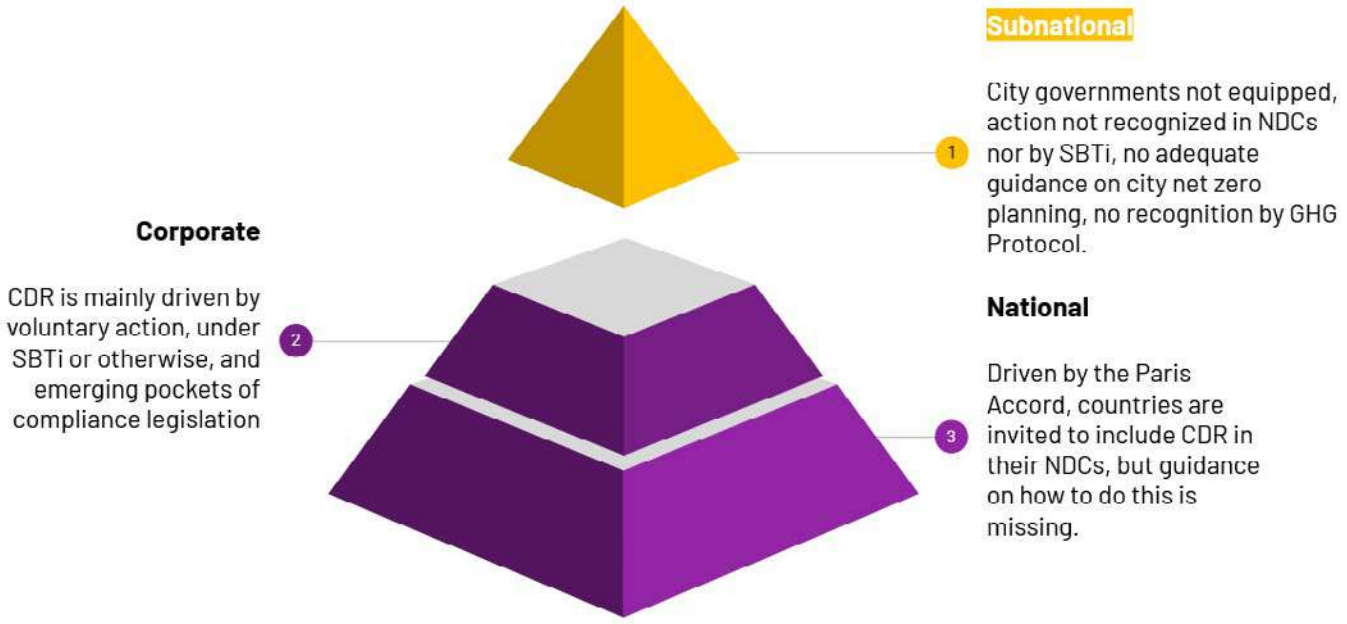
How Cities Factor into the NDCs

The signalling effect of recognizing municipal agency in enabling CDR in the upcoming IPCC Special Report goes even further. IPCC reports provide the scientific basis for international climate negotiations and inform how countries reference urban climate action and human settlements in their NDCs, which are essential in the multi-level governance of climate action. The Paris Agreement requires that NDCs reflect the "highest possible ambition" based on the best available science. Including urban climate action and subnational government stakeholders in NDC development, priority and target setting, governance and implementation, can increase ambition and improve NDC delivery. NDCs can inform municipal policies and priority setting, and the absence of recognizing the power of urban stakeholders can dampen the motivation to contribute to net-zero.

UN-Habitat published a report in 2024 on the *Urban Content of NDCs*. It found that urban references in NDCs most frequently cover emissions reduction in energy, transport, and waste, and adaptation in infrastructure and water. Since CDR intersects with all these domains, it should be positioned as a cross-cutting issue, alongside NbS. Urban CDR content can build on this recognition of NbS. Yet NbS references in current NDCs often overlook their carbon removal function, focusing instead on emissions reduction and co-benefits such as air and water quality – lintegrating carbon removal and adaptation priorities into the design of NbS interventions can enable more impact. A lack of guidance on developing and restoring urban carbon sinks may explain this undervaluation.

In the multi-level governance of CDR, the role of countries is to incorporate CDR goals into their NDCs and long-term net-zero strategies, which involves specifying the scope and scale of CDR needed to balance residual emissions and developing the accompanying regulatory frameworks, support schemes, and MRV systems. International collaborations to accelerate progress, such as the Group of Negative Emitters (GONE), further amplify their role. Aside from some emerging compliance schemes, the private sector is, for the moment, invited to contribute on a voluntary basis. Corporate net-zero standards such as the Science-Based Target initiative (SBTi) and reporting standards like the GHG Protocol, provide guidance to companies on how to use and account for carbon removal. This is not available to cities to the same extent. The illustration shows a simplified overview of how national governments, corporate actors, and subnational governments are recognized in the multi-level governance of net zero and the contribution to negative emissions.

Figure 13: Simplified overview of the multi-level governance of net zero.



Source: Own work

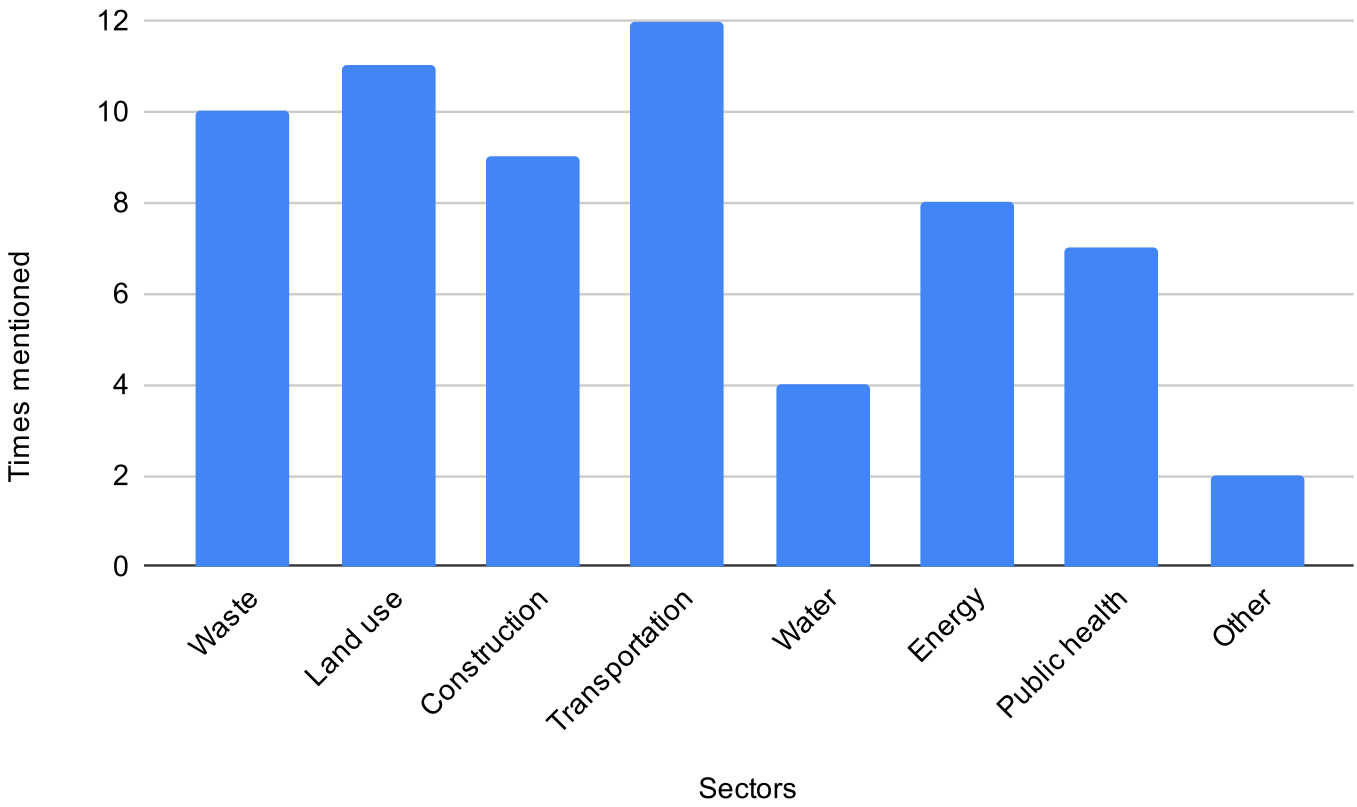
The next round of NDCs is expected to strengthen references to CDR. Ensuring that these references explicitly connect to urban priorities will be essential to empowering municipal administrations in the multi-level governance of CDR. This can set the stage for shared definitions and a standardization of CDR's inclusion in cities' climate action plans that aim for carbon neutrality, net zero emissions, or net negative emissions.

Working within National Policy Frameworks

Our 15-city analysis showed that 11 of the cities fall within a respective national urban policy framework. This means that the city is an integral part of a national government's coordinated strategy to guide the development of its cities toward certain economic, social and environmental goals. The city might influence this framework, but has no direct control and cannot operate contrary to it. The framework sets guiding principles for local governments and other stakeholders to ensure they act in line with the national priorities for urban planning, infrastructure, housing, mobility, and other important areas.

In addition to a national framework, all but 1 of the respondents indicated the need to deal with regional entities who maintain regulatory competencies regarding urban planning in the city. This could be the region, province, state, county, or some metropolitical council. In practice, however, cities will still have ample space to set their own course and sometimes that of others. 4 of the 15 respondents indicated that their local government has urban planning competences for neighbouring municipalities in areas such as zoning and land use, transportation, housing, infrastructure development and environmental protection. Below is an overview of the sectors that the respondents from the participating cities feel they have the most influence over, with education and ecosystem restoration mentioned as 'other' sectors.

Figure 14: City representatives' replies to the question *'In which of the following sectors does the city feel it has the most policy influence?'*



Source: CDR Cities survey

In the end, structured collaboration may be as important as the legal and political competencies a city has to drive ambitious climate action. This is particularly relevant for cities operating with a smaller sphere of control. Cities regularly band together, which can significantly expand their clout on the domestic and international stage. All of the cities conduct inter-city coordination and knowledge exchanges on climate action at a national level and 13 of the cities also do this at the international level.

Climate Action Planning

City Climate Action Plans (CAP) are vital for the transparent communication and coordination of a city's intended efforts to reduce its GHG emissions and adapt to climate change. They are roadmaps that provide a framework for measuring, tracking and addressing climate issues in key urban sectors such as transportation, energy, buildings, water, and waste management. CAPs guide a city's policies and investments for a more sustainable future.

The format and specific content of the plans still varies significantly, as each is tailored to a city's unique local context, emissions profile, and climate vulnerabilities. While there is not a set template for the CAPs, there has been an increased standardization of structural elements over the years as a result of shared frameworks developed by international organizations and regional alliances such as C40 Cities, the Global Covenant of Mayors, ICLEI, and others. We have analyzed the main climate action planning and reporting frameworks and guidelines and found that they do not address carbon removal as a structural element, even though the definitions of the different end goals imply the need for carbon removal.

Definitions are critical. Without shared definitions, there can be no shared language and any collective effort is consequently undermined. This is no different in climate action where various terms are used to describe a potential end-state of a city's decarbonization efforts. The terms have overlapping meanings, but are distinct. It is worthwhile to unpack them to understand what they mean for residual emissions and the ways to address them. This will help in the interpretation of the long-term climate action commitments cities make.

Thousands of cities have made climate commitments that use terms such as carbon neutrality, climate neutrality, net zero, or climate positive. Some have used such terms to formulate legally binding targets. Each of these terms has its own history and were nonexistent when the UN Convention on Climate Change (UNFCCC) was created in 1992.

- **Carbon neutrality:** Became mainstream in the 2000s. The goal was simple; balance carbon emissions released with carbon emissions removed, with offset credits an acceptable means to this end. It was not understood as requiring deep decarbonization as a priority. The definition of carbon neutrality has since evolved to prevent incentivizing the use of offset credits as a replacement for deep decarbonization.
- **Net-zero emissions:** Became more prominent after the Paris Agreement in 2015. The IPCC Special Report on 1.5°C turned it into the guiding principle for international climate negotiations and a central goal for countries globally. It is a state in which human-caused GHG emissions are balanced by anthropogenic removals from the atmosphere.
- **Net-negative emissions:** Introduced as part of the same IPCC report, it received broader traction when a handful of countries and companies committed to this goal publicly. According to the IPCC, a state of net negative emissions is realized when human activities remove more GHGs from the atmosphere than they emit.
- **Climate neutrality:** Defined by the IPCC as a state in which humanity has no net effect on the climate system, which however falls short of what is needed to restore a safe climate. This implies accounting for any negative regional or local biogeophysical effects of human activities.

Most of these terms were coined at a time when the CDR sector was much less developed than it is today. Few cities had mapped their residual emissions, let alone taken action to balance them through developing in-boundary carbon sinks or buying carbon removal credits. As a result, the guidance prepared for cities by authoritative organizations does not provide much to hold onto for pioneers who want to develop and restore natural or artificial carbon sinks. Today however, over 300 cities around the world have either proposed, pledged or committed to a net-zero target, according to the *Net Zero Tracker*. However, fewer than 10% of those targets meet all the Tracker's criteria for integrity, with 79% of cities failing to clarify how the use of offsets will be constrained in favor of direct emissions reductions and carbon removal.

Urban CDR Guidance Landscape

Net zero can only be realized through a portfolio of strategies, including the phasing out of fossil fuel, large-scale renewable energy, electrification of buildings and transport, dietary shifts, greater energy and material efficiency, and a general reduction in energy consumption. But carbon removal is a critical part of this net-zero portfolio as some urban emissions are technologically and socially impossible to get rid of. These hard-to-abate and socially necessary "residual" emissions[10] must be counterbalanced with CDR. It is then vitally important that cities have access to authoritative guidance on how to integrate CDR in their CAPs.

We analyzed the following global frameworks or guidelines from a range of leading organizations, networks, and initiatives to assess whether they provide meaningful guidance to cities on how to tackle residual emissions:

- Cities Race to Zero Campaign - Expert Peer Review Group *Race to Zero Interpretation Guide* (2022)
- International Organization for Standardization - *ISO Net Zero Guidelines* (IWA 42:2022)
- UN High-Level Expert Group (HLEG) - Report on '*Integrity Matters: Net-Zero Emissions Commitments of Non-State Entities*' (2022)
- Global Covenant of Mayors for Climate & Energy (GCoM), World Resources Institute (WRI) Ross Center for Sustainable Cities - *Integrity Matters for Cities, States and Regions: Follow-up recommendations for ambitious, high integrity, transparent, credible and fair subnational government net zero commitments* (2023)
- C40 Cities - *Cities Climate Transition Framework* (2025)
- C40 Cities - *Climate Action Planning Framework* (2020)
- C40 Cities and New York City - Guide on '*Defining carbon neutrality for cities and managing residual emissions: Cities' perspective and guidance*' (2019)
- ICLEI – Local Governments for Sustainability *Climate Neutrality Framework* (2020)

The analysis looked for the following characteristics:

- Is the guidance specific to cities?
- Is guidance offered on how a city can identify its genuine residual emissions?
- Is guidance offered on how to incorporate CDR in a city's climate target architecture?
- Is guidance offered on how to prioritize developing in-boundary sinks over credits?
- Is guidance offered on how a city can identify in-boundary carbon sink opportunities?
- Is guidance offered on how a city can plan for a portfolio of CDR methods over time?

[10] Residual emissions can be highly city-specific, but commonly include emissions from transport, industrial processes and product use, stationary energy, solid waste and wastewater, agriculture, forestry and other forms of land use.

Most of the guidelines that were analyzed do not have an exclusive focus on cities. In various cases, cities are lumped together with others in a bucket for non-state entities or sub-national governments. While certain universal rules for climate action planning are applicable, cities have unique characteristics compared to other sub-national governments that warrant tailoring of the guidance. Nevertheless, we have taken these guidelines into account in an equal manner to those targeting cities directly. See the Annex for a more detailed analysis.

Overall, major gaps were identified in the net-zero guidance to cities. All documents recognize that cities must prioritize emissions reductions but will have residual emissions to address to reach net zero. Cities are called upon to quantify their residual emissions, but none of them gives guidance on how to define and calculate genuine or legitimate residual emissions. Guidance on target setting is scarce. In some cases, they call for the 'target volume' of residual emissions to be adjusted as the city transforms and new decarbonization solutions become available (C40-NYC).

Most documents acknowledge that carbon removal is needed. The guidelines broadly agree on the fact that the portfolio of solutions must transition to durable removals to claim net zero status. To structure the carbon removal portfolio over time, some explicitly call for 'like-for-like' removals, matching GHG emissions with carbon removal methods that have similar characteristics, especially as regards their durability and the timescale of the carbon cycle (Race to Zero; ISO). Others call for a certain amount of 'dynamism' in the portfolio. They speak of the need for time-bound key performance indicators for any removal actions as part of a transition plan (HLEG), call for continuous improvement to gradually reduce reliance on credits as new technologies and methods become available (ISO) or generally dissuade cities from using credits (GCoM-WRI).

It is a missed opportunity that there is still limited guidance for cities on the use of CDR and development of carbon sinks. This is particularly salient in light of the hundreds of cities that have publicly expressed their support for net zero. The knowledge and capacity building gap has to be closed to help cities become more ambitious in taking climate action. This requires quality guidance on the planning of a residual emissions strategy, the development of in-boundary carbon sinks, and the use of carbon removal solutions over time.

GHG Inventory Management

A growing number of cities maintain a GHG emissions inventory as part of their climate action planning and reporting. It is an indispensable tool to better design and improve policies, track progress against measurable targets, and communicate accurately and transparently to external stakeholders. The emissions inventories are also important in facilitating data transference, to reflect what cities are doing in national level emissions inventories and tracking emissions performance against the global carbon budget.

The inventories serve as a foundation for voluntary and mandatory reporting programs. These programs crunch these large data sets not just to track progress, but also to allow for cross-comparison of specific data points in order to identify positive or negative trends that may be addressed with particular interventions. To enable high-quality guidance, the reported data must be comprehensive and follow a standardized template. The dominant accounting and reporting standard for cities is the *Global Protocol for Community-Scale Greenhouse Gas Emissions*, also known as the GHG Protocol for Cities (GPC). The GPC is the result of a collaboration between the World Resources Institute (WRI), C40 Cities Climate Leadership Group and ICLEI – Local Governments for Sustainability (ICLEI). In terms of scope, the GPC takes a territorial rather than consumption-based approach.

As it currently stands, the GPC offers limited guidance on how cities should reflect negative emissions from the use of carbon removal solutions and development of carbon sinks in their GHG inventory. The only thing it says about CDR is that cities should consider the ecological and ethical impacts and that such solutions "*should not be undertaken without careful consideration of the potential ecological and ethical impacts.*" It notes that "*carbon neutrality is achieved when annual gross GHG emissions are compensated by an equivalent amount of GHGs being removed through*

a combination of measures, such as carbon dioxide removal measures within the reporting boundary," but refers to the report *Defining Carbon Neutrality for Cities and Managing Residual Emissions* developed by C40 and New York City for further information. This report was developed in 2019. Much has happened since then in terms of both the science, solutions, momentum and policy innovations to unlock carbon removal.

The forthcoming Pathways to Carbon Sink Cities: Implementation Guide introduces guidance on integrating CDR into GHG inventories, particularly on distinguishing the accounting of carbon removals from emission reduction accounting, and illustrating how CDR can be embedded into urban policies, such as waste management, construction, energy, and land use.

City Climate Finance

As we have seen at the start of this chapter, funding is considered by far the biggest challenge to implementing CDR in cities. Unpacking the answers from the cities that were interviewed shows that this is not constrained to the need for state, national or supra-national funding, but extends to the need for greater access to mechanisms for international climate finance. In the 15-city analysis, only 7 cities indicated that they have access to national or international financial mechanisms to specifically support CDR implementation. The city climate finance landscape was analyzed to understand its suitability for funding urban CDR projects. Further guidance on how cities can navigate this landscape is included in the Implementation Guide.

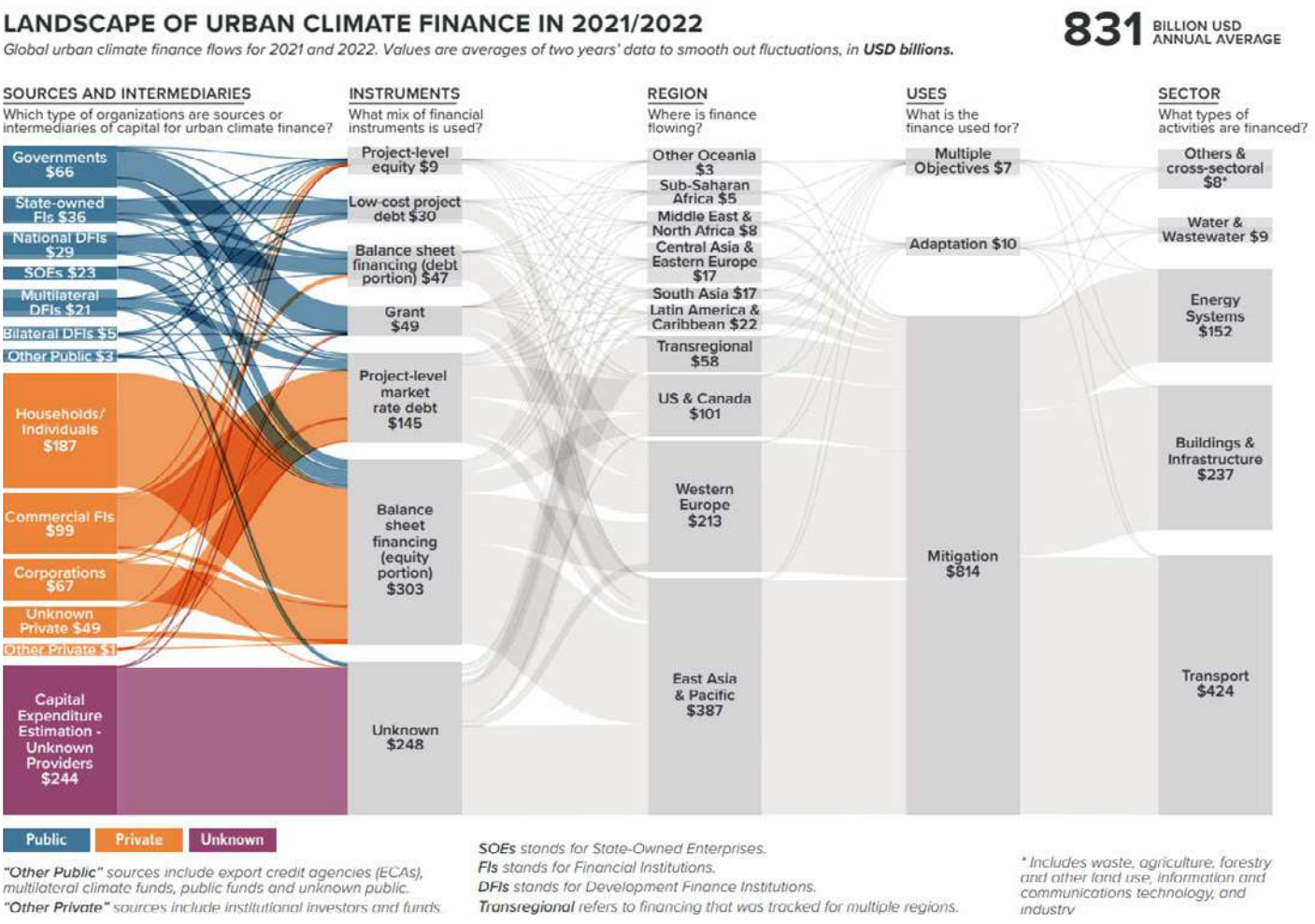
The governance of international city climate finance is shaped by a complex network of actors operating across global, national and local levels. Key players include:

- **National and local governments**, which set policies, legislation and regulations, mobilize resources, and implement climate projects on the ground.
- **Real estate investment and management companies** that invest in construction, redevelopment, renovation, and management of the building stock.
- **General population** that, depending on the city governance system, may vote directly to adopt or reject issuance of municipal bonds or loans, or affect policies through elections and legislative initiatives.
- **Development finance institutions (DFIs)**, such as the World Bank, regional development banks, and bilateral agencies, through concessional and non-concessional financing.
- **Multilateral climate funds**, including the Green Climate Fund (GCF), Global Environment Facility (GEF), and Climate Investment Funds (CIF) which channel climate-specific funding.
- **Corporations**, which invest in mitigation and adaptation projects, often through corporate social responsibility or supply chain decarbonization.
- **Households and individuals**, who contribute through energy efficiency upgrades, sustainable transport choices, and localized adaptation measures.
- **Investment and commercial banks**, which offer loans, bonds, and structured finance products for climate-related infrastructure.
- **Institutional investors**, such as pension and sovereign wealth funds, which can provide large-scale, long-term capital.
- **Venture capital (VC), private equity (PE), infrastructure and other funds**, which invest in innovative climate solutions and early-stage technologies.

In low- and qualifying middle-income developing countries, funding flows typically move from international climate finance mechanisms and DFIs to national treasuries or directly to sub-national entities, depending on the model. While traditional funding channels are often top-down – with central governments disbursing funds to cities – there is a growing trend toward direct access models, enabling city and regional governments to apply directly to climate funds, improving efficiency and responsiveness. Coordination platforms like the Cities Climate Finance Leadership Alliance (CCFLA) and the Leadership for Urban Climate Investment (LUCI) initiative facilitate dialogue, standard-setting and partnerships among stakeholders, while also addressing systemic challenges.

Despite progress, governance remains fragmented, with high transaction costs and capacity gaps in many cities, and a geographical discrepancy. According to CPI, urban climate finance was mainly directed towards cities in developed economies and China, while Emerging Markets and Developing Economies (EMDEs) received 11% of the total and Least Developed Countries (LDCs) received just 1%. These barriers limit cities' ability to plan, access and manage climate finance effectively, underscoring the need for streamlined processes, technical assistance and stronger institutional capacities at the local level.

Figure 15: City climate finance areas of focus



Source: Cities Climate Finance Leadership Alliance

According to the *2024 State of Cities Climate Finance Report* by the Climate Policy Initiative (CPI), 69% of city-level climate finance is sourced domestically, with 96% of private capital remaining within national borders. Notably, Sub-Saharan Africa is the only region where 69% of urban climate finance comes from international sources.

Primary City Climate Finance Instruments

The CPI report provides one of the most comprehensive analyses of urban climate finance flows to date. From a recorded $831 billion in urban climate finance for 2021–2022, $582 billion had sufficient granularity to allow breakdowns by instrument type, offering critical insights into how cities are financing climate action.[11] It is important to note that, while the report is pioneering and helps shape our understanding of urban climate finance flows, it omits risk management mechanisms like guarantees and insurance. This is due to the difficulty in accounting for their realized impact. Such mechanisms can, however, play a crucial role in supporting the deployment of projects.

Broadly speaking, city climate finance instruments can be grouped into two categories:

CORE FINANCING CATEGORIES

- Balance Sheet Financing (Equity)
- Balance Sheet Financing (Debt)
- Project-Level Market Rate Financing (Equity)
- Project-Level Market Rate Financing (Debt)
- Concessional Debt/Equity
- Grants

COMPLEMENTARY OR ENABLING FINANCE MECHANISMS

- Risk Mitigation Instruments (e.g., guarantees, insurance)
- Blended Finance structures
- Public-Private Partnerships (PPP)
- Leasing and Asset Finance Models
- Aggregation Models
- Land Value Capture (LVC)
- Carbon Markets and Emissions Trading
- Municipal Own-Source Revenue and Policy Instruments
- National Government Transfers
- International Climate Finance
- National, Regional and Municipal Climate Funds
- Payment for Ecosystem Services (PES)
- Viability Gap Funding

These instruments collectively shape the financing landscape for urban climate mitigation, adaptation and climate justice initiatives. They include direct funding mechanisms and enabling tools designed to de-risk investments, crowd in private capital, and enhance the financial viability of city-level projects. They are predominantly directed towards mitigation exclusively understood as emissions reduction, with adaptation receiving a very limited share. This is consistent across identified urban climate finance studies and may indicate an uphill battle for CDR to gain traction. Many CDR projects may be counted as mitigation, but categorizing them separately is necessary to differentiate from emissions reduction and elicit targeted climate finance.

[11] Residual emissions can be highly city-specific, but commonly include emissions from transport, industrial processes and product use, stationary energy, solid waste and wastewater, agriculture, forestry and other forms of land use.

Environmental Justice

As cities consider the future deployment of CDR, they must also look at the past. The impacts of historic emissions already impose greater harms on people who have contributed least to its causes. A normative response is needed to do justice to this reality and to ensure the effectiveness of future policies. CDR can help repair historic climate injustice if designed to do so, or (unintentionally) exacerbate injustice.

The central concern of climate justice is that those who contributed least to the problem are most affected by the impacts, given least say in the design of responses, and most likely to suffer collateral harms in 'sacrifice zones'. They may include poor and disadvantaged groups, the Global South, and future generations. Cities have many opportunities to promote climate justice beyond contributing to global emissions reduction. They can ensure inclusive climate policy making, prioritize emissions reductions of wealthier groups over poorer ones, avoid interventions that impose harmful side-effects on already disadvantaged groups, and support adaptation measures - and other interventions - that protect residents, and especially the most vulnerable, from climate impacts.

Besides preventing further damage, a form of compensation or restoration for past injustice could come in the form of CDR used as a tool to reverse climate change. The drawdown of atmospheric CO_2 benefits future generations and supports climate justice. If CDR development enables earlier global net-zero and thus a lower peak temperature, that benefits both future generations and the most vulnerable more generally. Carbon removal can contribute to genuine reparation for past inequalities in climate pollution and impacts. However, this requires supporting its reparative role to deal with 'legacy carbon', alongside deep and accelerated emissions cuts. It also means taking into account potential side-effects and systematic consequences that might exacerbate injustice on already poor or vulnerable communities, or offer a licence to pollute through carbon offsets.

Planning to Prevent Injustice

There is a risk that CDR undermines environmental and climate justice. CDR projects can impose direct justice impacts, notably through competition for scarce resources. And their indirect impacts may also be serious. When CDR is used instead of cutting avoidable emissions, it sustains existing unfairly distributed harms such as particulate air pollution from fossil fuel use - responsible for over 5 million deaths annually, according to a *modelling study* from 2023. In this scenario, CDR successfully removes CO_2 from the atmosphere to balance continued emission, but does less for environmental justice than the equivalent amount of emission cuts because of the harmful side-effects. When planning to use CDR to balance emissions, cities are advised to consider the broader social, economic and environmental impacts of both CDR and of the carbon-emitting activities that receive this 'licence to pollute'.

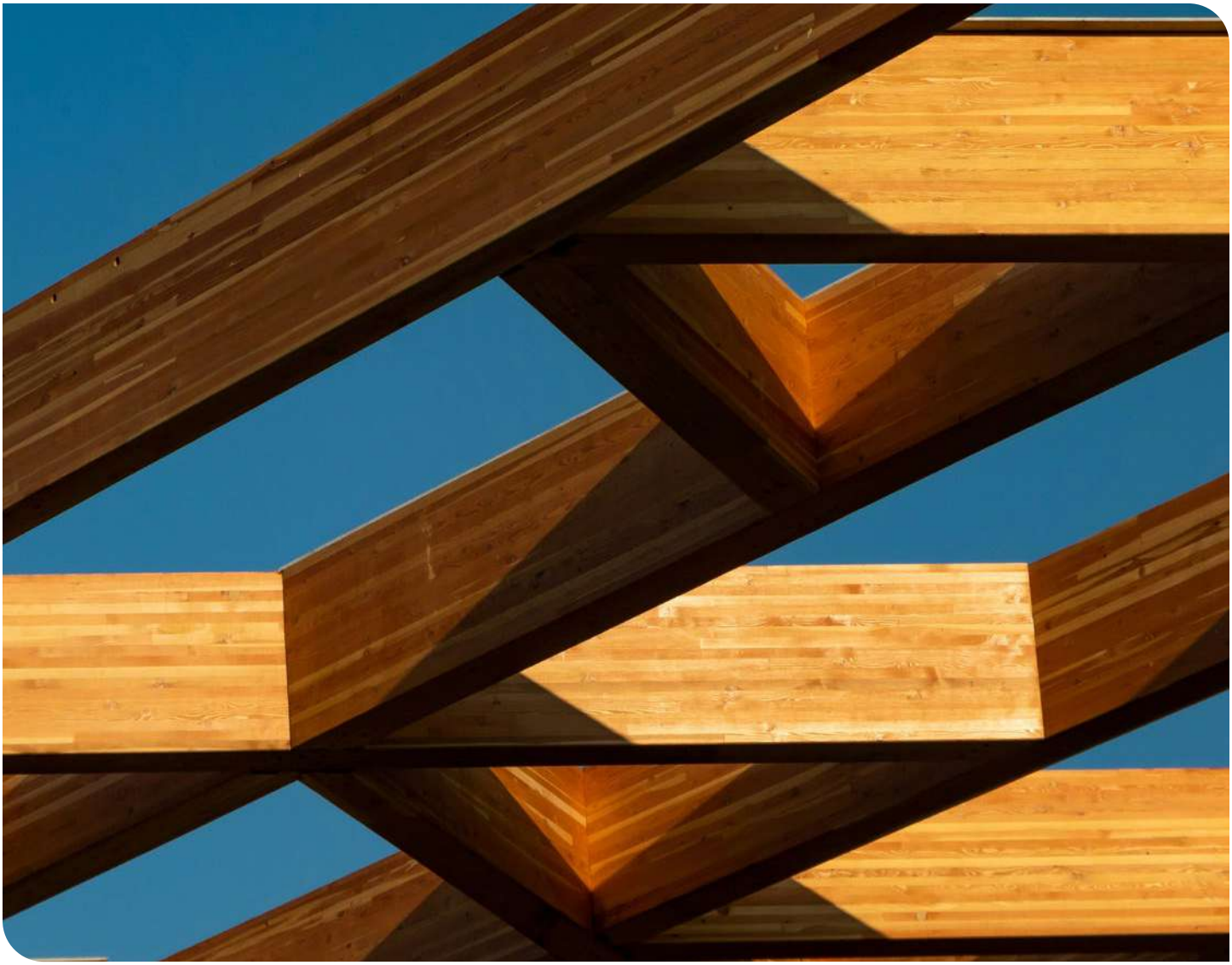
Climate justice also comes into play for cities when considering the use of carbon removal credits over in-boundary carbon sink development. There is a growing voluntary carbon market in which such credits are sold that cities have access to though limited control over. Considering that taxpayers money would be used to purchase such credits, cities could extract much greater value for their residents by supporting local CDR and developing in-boundary sinks where project design can contribute to other policy goals. Cities can also build or support alternative business models for CDR as a public service or utility, rather than selling removal credits for activities they control. In certain circumstances, municipal carbon crediting programs can secure local public revenue that in turn can be used to fund climate action. Yet with every ton of removed carbon that is used to balance avoidable emissions, the amount of CDR required to meet global climate targets increases.

A potential shortcoming of the market-based approach is that in practice most removal credits that have been sold so far have yet to be delivered. It is a market weakness that is in essence the result of the early stage of many CDR methods and deployment pathways. These so-called ex ante credits are an important tool for financing new projects by giving access to early-stage capital. However, promises of future removals can delay or deter emissions cuts now, but may never actually materialize. If the CDR involved proves impractical or too expensive to deliver, then not only the side-effects, but also uneven and unjust climate impacts of those emissions will remain. Cities must consider the differences between emissions cuts and removals and between different CDR methods and socio-political contexts.

CDR and the Just Transition

For CDR to contribute to a just transition it must be governed in a way that it is done for just purposes, implemented sustainably and responsibly at the right scales. Substantive public participation in decision-making is essential, particularly for marginalized and vulnerable groups. Even more, CDR projects can have potential employment and economic development benefits for local communities, which might be maximized if CDR is developed as a public asset or utility. At a time when CDR methods are generally still considered emerging technologies, lacking complete and stable socio-technical systems, ensuring these socio-economic benefits are distributed justly can strengthen the social legitimacy of the interventions.

Supporting climate justice with CDR requires careful planning. Cities should promote and scale CDR rapidly, but in ways and forms that avoid unjust side-effects and respect sustainability constraints. Just transition policies and practices can help, guiding investment, ensuring community engagement and participatory governance, and enabling community or public ownership of removal facilities. While it might be tempting to deploy CDR as an offset to maintain carbon intensive industries, especially those that are traditional local employers, just transition principles suggest otherwise. It runs counter to climate justice to use CDR to avoid the stranding or closure of fossil assets, but decisionmakers should ensure justice for workers and communities who are affected by such closures.



CONCLUSION & ACKNOWLEDGEMENTS

Cities face a growing number of challenges to remain livable and ensure resilience against external climate change impacts. In their quest for a more regenerative urban metabolism and a net-zero GHG footprint, they must develop and strengthen natural and engineered carbon sinks, while integrating carbon removal capabilities across urban systems, infrastructure, and the building stock. A group of leading cities is actively investigating the deployment of CDR, reinforcement of existing sinks and realization of new sinks within their urban environment. They are also looking at the tools they need to pursue this new mission.

This report shows that the potential scale of CDR and sinks in urban and peri-urban environments is material for the global climate effort, while the opportunity to secure social legitimacy for CDR can have major benefits for the carbon removal effort at large. However, in their attempts to pursue this opportunity, local governments are faced with a governance environment that is at best unhelpful and at worst actively undermining their chances of success. Throughout this analysis, critical needs and gaps have been identified and explained across a range of domains. Municipal administrations are not set up for cross-departmental action and multi-level governance systems largely fail to recognize city-led CDR efforts. Guidance from quality standards and other authoritative bodies on addressing residual emissions, setting carbon removal targets, and including CDR in city GHG inventories is still limited. Meanwhile, the city climate finance landscape has few opportunities for local governments to attract funding for CDR projects.

Overcoming the identified governance gaps is a condition for cities to step into the power vacuum left by national governments taking a step back on climate action. Having the right narrative and approach will also be critical for their success, including embracing synergies between emissions reduction, carbon removal and adaptation through integrated planning, while designing municipal interventions and carbon removal projects to deliver benefits across urban priorities. Local governments must reorganize themselves to navigate this governance landscape and collaborate strategically and effectively with other governance levels, peers, and local stakeholders, while taking into account environmental justice considerations to ensure equitability and secure support from communities. Through this approach, cities can unlock the full potential of urban CDR and become active agents of climate restoration.

ACKNOWLEDGMENTS

The development of this report has been a collaborative effort involving a large number of stakeholders. This includes contributions from all the member cities, partners and developers. Additional contributions were received from the strategic advisors involved in the City CDR Initiative, including Chris Neidl, Ross Kenyon, Eduardo Noboa, and Mokena Makeka. In addition, acknowledgements are in order for Quinn Antus at the Colorado Energy Office and Jonathan Koehn at Boulder City for their contributions to the case study on Colorado. Grant Faber and Aidan Preston have contributed in their individual capacity to gain a better understanding of urban CDR value chains. Finally, Giulia Ulpiani, Project Officer at the European Commission's Joint Research Centre and IPCC Lead Author, and the wider team at the JRC must be acknowledged for their contributions on residual emissions planning in the context of the EU Climate Neutral Cities Mission. This has been an important source for the report. Finally, the important work on carbon removal in cities by Quirina Rodriquez at the Potsdam Institute for Climate Research should be acknowledged. This report builds on key aspects from an academic article on 'Unlocking municipal agency for urban and peri-urban carbon dioxide removal' that was co-authored with Christiaan and is currently under review.

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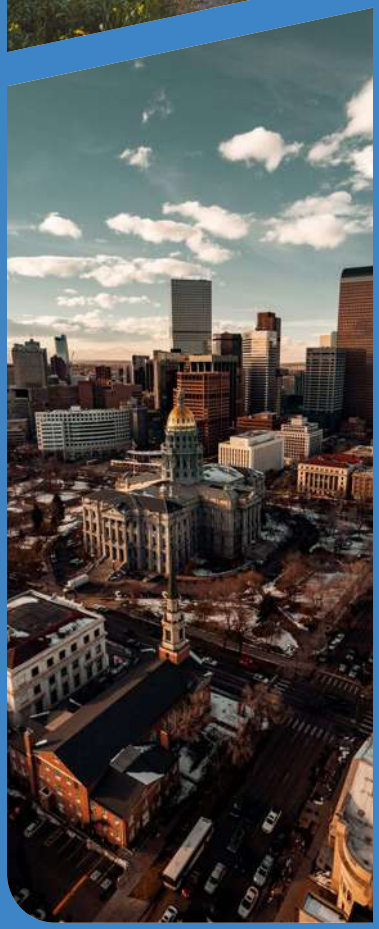
ANNEX



MULTI-LEVEL GOVERNANCE CASE STUDY: STATE OF COLORADO, UNITED STATES

Colorado shows how the multi-level governance of CDR can be organized efficiently and executed collaboratively with impact. Representatives from the state, Boulder County, and the City of Boulder attribute the state's success to the presence of a clear framework for action and flexibility for local implementation.

US states are characterized by a dynamic interplay of state law, home rule authority, and local initiatives, which creates a vibrant multi-level governance system for climate action that can function almost independently from the national level. The US system of 'cooperative federalism' allows states to pursue more aggressive climate action. Colorado has set ambitious climate targets and mandates for emissions reductions, carbon removal and adaptation and is collaborating far beyond the state. It has Memoranda of Understanding with carbon removal provisions with the State of Wyoming, Province of Alberta in Canada, and the United Kingdom.

Carbon removal plays a role in Colorado's net-zero plan, primarily to balance residual emissions from hard-to-abate sectors. It foresees the use of both nature-based and technological solutions. The *Colorado Carbon Management Roadmap* published in February 2025 points the way. The state's Air Quality Control Commission creates rules to meet the stated targets, affecting sectors like manufacturing, building energy performance, transportation, and utilities. The Colorado Energy Office and Resiliency Office offer guidance, funding and technical assistance to local governments. Meanwhile, the Office of Economic Development and International Trade works with economic development corporations across Colorado to identify the best location for projects, connect with stakeholders, and support triage.

The state government has so far taken a sector-by-sector approach to reducing GHG emissions, emphasizing innovative cross-sectoral climate solutions such as CDR and initiatives to help them scale faster than they would without support. Powerful initiatives that include CDR support and have incentivized local governments to take complementary action include: emissions reduction targets for heavy industry facilities through the Greenhouse Gas Emissions and Energy Management for Manufacturers in Colorado; financial support through the Colorado Industrial Tax Credit Offering; direct grants for industrial decarbonization under the Clean Air Program; and measures on reducing embodied carbon in state construction projects through the Buy Clean Colorado Act.

The remit of local governments to build on these efforts is significant. The presence of the state's legally binding net-zero target legitimizes ambitious action from local governments. While the state focuses on ensuring the integrity of CDR projects, absorbing risks and ensuring synergies with other policies, local governments can tailor implementation to local needs, such as through local permitting. Implementation accelerates when ambitious climate policy meets local values, while sharing a common goal, even if the exact targets and tools used differ. Adopting distinct emissions reduction and carbon removal targets based on defined levels of 'hard-to-abate' residual emissions strengthen this shared framework for action:

- Colorado State has a net-zero target for 2050 and interim targets for 2025 and 2030.
- City of Boulder has a net-zero target for 2035 and a net-negative target for 2040.
- Boulder County's goal is 80% emissions reduction by 2030 and net-zero by 2050.

Local implementation takes different forms. Both the City of Boulder and Boulder County have land use zoning and permitting authorities and oversee critical regulations such as local building and energy codes, along with broader land use authority. They also have authority over building deconstruction requirements, solid waste management and landfill practices that can be leveraged for carbon removal. Both the City and County use revenues from the local cannabis industry for climate innovation through the Energy Impact Offset Fund (EIOF).

The City of Boulder can establish its own local laws and ordinances, manage its own sales tax collection and administration independently of the state, issue stricter building energy codes than the state's baseline, and establish building performance standards. The City of Boulder made a bold move by passing a voter-approved Climate or 'Carbon' Tax in 2006 that is levied on utility bills. Revenues are used for projects including the implementation and advancement of climate and resilience strategies.

Combined, the City and County of Boulder own over 100,000 acres of open space that has been established to preserve the natural environment, prevent urban sprawl, protect wildlife habitats, and provide recreational and agricultural opportunities for current and future generations. By acquiring land, Boulder's Open Space and Mountain Parks (OSMP) and Boulder County Parks & Open Space manage and preserve the land's ecological, scenic and cultural value, while protecting and enhancing the carbon sink function for the long term.

But legal competencies are not the same as political competencies, as Boulder County has shown by co-founding the *4 Corners Carbon Removal Coalition* with Flagstaff, Arizona and other cities. As part of the coalition, the participating cities and counties pool resources to accelerate CDR projects. It has created a fund that offers grants for local CDR and landscape resilience initiatives. Working with other local

governments can help strengthen their position in the MLG of climate action. Colorado's *Communities for Climate Action* is a key organization that involves 46 communities advocating for stronger state and federal climate policy and exchanging best practices for local policymaking.

Where will Colorado go next? New governance and policy innovation needs are emerging as there is less low-hanging fruit. Local governments may look for further leadership from the state government to help reduce the costs of CDR solutions through regulated carbon markets, feed-in-tariffs, and new tax breaks. The sector-by-sector approach has delivered. The state government will have to clarify the trajectory for carbon removal deployment further by guiding local governments in the use of their tools. Leading lights such as Boulder County will no doubt continue to demystify carbon removal for other communities and advance charismatic projects that the state government can point to.

Sample of Cdr Methods & Urban Deployment Pathways

Hempwool insulation (Hempitecture)

Carbon-injected concrete (Carbon Upcycling Technologies)

Carbon capture from desalination plant (Capture6)

Carbon-storing concrete (CarbiCrete)

Enhanced Rock Weathering on rooftops (Carbon Neutral Initiative)

Wastewater Alkalinity Enhancement (Crew Carbon)

Decentralized Direct Air Capture (Yggdrasil Trees)

Carbon-storing port infrastructure (Paebbl)

Biochar from sewage sludge (PYREG)

Carbon removal park with biochar (Novocarbo)

Modular Direct Air Capture (Thalo Labs)

Coastal enhanced weathering (Vesta)

Bio energy with carbon capture and storage (Stockholm Exergi)

Mobile pyrolyzer for biochar (Applied Carbon)

Biopods for water treatment + biochar (Airbuild)

Microbial Electrolytic Carbon Capture (Equatic)

HVAC-connected Carbon Capsule (Carbon Reform)

Carbon negative concrete admixes and additives (ecoLocked)

Analysis City Climate Action Planning Frameworks & Guidelines

Organization		Guidance		Gaps					
Source	Background	Focus on Residuals	CDR Guidance	City Focus	Residual emissions	CDR target	Sinks vs credits	Sink opp.	Portfolio setup
Cities Race to Zero Campaign - Expert Peer Review Group *Race to Zero Interpretation Guide* (2022)	Cities Race to Zero is an official Partner of the *Race to Zero Campaign* led by the UN Climate Change High Level Champions. It is the result of a collaboration between ICLEI, C40 Cities, Global Covenant of Mayors, CDP, UCLG, WRI and WWF. The campaign has recruited over 1,000 cities. It requires participating cities to pledge to reach net-zero emissions by the 2040s or sooner and commit to a 1.5°C target, set a 2030 target and action plan and publish progress reports.	The guide calls on actors to prioritize reducing real world emissions, limit any residual emissions to those that cannot be eliminated and clarify how high quality credits and sinks are used to meet the target. The guide states that individual actors have reached net zero when "An actor reduces its emissions following science-based pathways, with any remaining GHG emissions attributable to that actor being fully neutralized by like-for-like removals [...] exclusively claimed by that actor, either within the value chain or through purchase of valid offset credits."	The Expert Peer Review Group recognizes the role of CDR. It stresses that "Any neutralisation of unabated emissions must transition to permanent removals of any residual emissions in order for a Race to Zero entity to claim a (net) zero status."	X	X	X	X	X	X

Organization		Guidance		Gaps					
Source	Background	Focus on Residuals	CDR Guidance	City Focus	Residual emissions	CDR target	Sinks vs credits	Sink opp.	Portfolio setup
ISO Net Zero Guidelines (IWA 42:2022)	The ISO Net Zero Guidelines are developed through a consensus-building process with over 1,200 experts. The Net Zero Guidelines serve as a global planning reference for cities and other entities to develop credible and holistic net zero GHG strategies in which residual emissions are balanced with human-led removals. The guidelines are intended to align territorial approaches to achieving net zero and value chain approaches by organizations and follow the Race to Zero Criteria.	The guidelines note that residual emissions must be limited to the minimum, in line with science-based pathways that are aligned with a high likelihood of limiting global warming to 1.5 °C. Net zero is achieved when all emissions are reduced as much as possible (usually by over 90%) and remaining, unavoidable residual emissions are balanced through permanent carbon removal.	The ISO Net Zero Guidelines recognize the role of CDR and call for early investment to scale and mature removal and storage capacity. Removals can be used once all emissions reduction actions have been exhausted and should focus on permanent or sufficiently long-term removals to counterbalance residual GHG emissions. The guidelines refer to the like-for-like principle. Once net zero is reached, actions must be taken towards reaching net-negative GHG emissions. The guidelines call for continuous improvement to gradually reduce reliance on credits as new technologies and methods become available.	X	X	X	V	X	V

Organization		Guidance		Gaps					
Source	**Background**	**Focus on Residuals**	**CDR Guidance**	**City Focus**	**Residual emissions**	**CDR target**	**Sinks vs credits**	**Sink opp.**	**Portfolio setup**
The UN High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities (HLEG) - Report on '*Integrity Matters: Net Zero Commitments by Businesses, Financial Institutions, Cities and Regions*' (2022)	UN Secretary-General, António Guterres, established a *High-Level Expert Group* on the Net-Zero Emissions Commitments of Non-State Entities to develop stronger and clearer standards for net-zero emissions pledges by non-State entities – including businesses, investors, cities and regions – and accelerate their implementation. The report looks at non-state actors, including cities and offers guidance on how to make credible net-zero pledges aligned with the 1.5°C goal.	The report is specific about how the pledge can be structured, noting that it should include interim targets for 2025, 2030 and 2035. The targets should lead to net zero by 2050 or sooner and be sustained after, on a pathway in line with IPCC or IEA net zero scenarios that limit warming to 1.5°C with no or limited overshoot. According to the report, "a city has achieved net zero when any residual emissions are neutralised by permanent GHG removals according to reports verified by a credible, independent third party based on publicly available data."	The HLEG recognizes the role of CDR and calls for time-bound key performance indicators for any removal actions as part of a transition plan. This goes beyond the Race to Zero Interpretation Guide.	X/V	X	X	X	X	X

Organization		Guidance		Gaps					
Source	**Background**	**Focus on Residuals**	**CDR Guidance**	**City Focus**	**Residual emissions**	**CDR target**	**Sinks vs credits**	**Sink opp.**	**Portfolio setup**
Global Covenant of Mayors for Climate & Energy (GCoM), World Resources Institute (WRI) Ross Center for Sustainable Cities - '*Integrity Matters for Cities, States and Regions: Follow-up recommendations for ambitious, high integrity, transparent, credible and fair subnational government net zero commitments*' (2023)	GCoM is the world's largest alliance of over 12,500 cities and local governments committed to fighting climate change. The WRI Ross Center is a program dedicated to helping cities become more accessible, healthy, equitable and environmentally friendly. Developed by an Expert Group convened by GCoM and WRI, this report serves as a sequel to the 'Integrity Matters: Net Zero Commitments by Businesses, Financial Institutions, Cities and Regions' report.	The report aims to apply the insights and guidance from the 2022 Integrity Matters report exclusively to subnational governments, including dedicated recommendations on implementation. The report calls for urgent and deep reduction of emissions to be prioritized. A city is considered net zero when it has achieved its long-term net zero target, set according to a methodology aligned with 1.5C and the latest science and "any residual emissions are justified with a transparent rationale for why these emissions cannot be mitigated."	The Expert Group does not explicitly recognize the need for carbon removal. It notes that residual emissions cannot be counted towards interim targets, but only towards the end target. However, further guidance should be developed on the treatment of residual emissions in the context of net zero. The report discourages the use of credits, stating a preference for mitigation or removal actions to be in-boundary.	X/V	X	X	V	X	X

Organization		Guidance		Gaps					
Source	**Background**	**Focus on Residuals**	**CDR Guidance**	**City Focus**	**Residual emissions**	**CDR target**	**Sinks vs credits**	**Sink opp.**	**Portfolio setup**
C40 Cities *Climate Action Planning Framework* (2020) and *Cities Climate Transition Framework* (2025)	C40 Cities is a network of the world's leading cities. The 'Cities Climate Transition Framework (CCTF)' updates the 'Climate Action Planning (CAP) Framework' originally published in 2018. The CAP Framework sets out the essential components of a climate action plan to deliver low-carbon resilient development consistent with the objectives of the Paris Agreement. The CCTF takes into account the recommendations of the report 'Integrity Matters for Cities, States and Regions' and the IPCC 6th Assessment Report.	The CAP Framework calls on cities to include an estimation of their residual emissions in an evidence-based emissions trajectory or carbon budget that is in line with the 2050 emissions neutrality (used interchangeably with net zero) target and interim target(s). The Framework indicates how a city can be net zero aligned, but does not describe when a city has reached a net zero state. The CCTF notes that "to achieve net zero emissions, the city must consider all emission sources and sector pathways, addressing emissions occurring in the city as well as those created elsewhere from urban consumption".	The CAP Framework nor the CCTF explicitly recognizes the role of carbon removal. This is particularly notable in the latter case as it endeavors to take the IPCC 6th Assessment Report into account, which called CDR necessary to meet global climate targets.	V	X	X	X	X	X

Organization		Guidance		Gaps					
Source	**Background**	**Focus on Residuals**	**CDR Guidance**	**City Focus**	**Residual emissions**	**CDR target**	**Sinks vs credits**	**Sink opp.**	**Portfolio setup**
C40 Cities and New York City Mayor's Office of Sustainability - '*Defining carbon neutrality for cities and managing residual emissions: Cities' perspective and guidance*' (2019)	In this guidance, C40 and NYC outline shared definitions, guidance and best practices on achieving carbon neutrality and dealing with residual emissions. This is sourced from cities, civil society partners and expert organisations. This guidance focuses on achieving citywide carbon neutrality and can be used in the early stages of climate action planning to bring residual emissions mitigation planning.	The guidance calls on cities to prioritize mitigation and adaptation, but notes the need for 'additional mechanisms' in the mid-term to realize carbon neutrality. Referencing the IPCC Special Report on 1.5°C (2018), the guidance states that all 1.5°C pathways include CDR and that "in order for a city to be carbon neutral, it must ensure that all emissions reach net-zero regardless of control." A city must identify its target year residual emissions in its GHG emissions reduction trajectory, which should be updated every 5 years and be informed by the best available science.	This guidance explicitly recognizes the role of carbon removal as a means to balance residual emissions and achieve a state of net zero. It allows for high-integrity carbon credits to balance residual emissions, but calls for this to be capped to prioritize and maximize direct reductions in gross emissions. The guidance also describes the benefits and risks of early versus later use of carbon credits or CDR deployment.	V	X	X	V	X	V