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Bridging the scale between the local particular and the global universal in climate change assessments of cities

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Felix Creutzig[1,2,3], Timon McPhearson[4,5,6,7], Ronita Bardhan[8], Camille Belmin[9], Winston T. L. Chow[10], Matthias Garschagen[11], Angel Hsu[12], Şiir Kılkış[13], Sheikh Tawhidul Islam[14,15], Nikola Milojevic-Dupont[1], Minal Pathak[16], Rafael H. M. Pereira[17], Pourya Salehi[18] & Diana Ürge-Vorsatz[19]

Identifying gaps in urban climate change assessment is crucial for developing the new Intergovernmental Panel on Climate Change (IPCC) special report on cities. To bridge the gap between the understanding of local interventions and global climate goals, we call for the strengthening of assessment tools such as urban typologies, case study synthesis and big geospatial data studies. We sort research gaps into five overarching themes: (1) urban form, (2) data and artificial intelligence, (3) policies and governance, (4) system transformation and (5) potentials, costs and losses. Using these methods for categorizing and analyzing cities based on shared characteristics will enable the tailoring and scaling of local climate solutions to global contexts.

Cities, urban areas and other human settlements are central arenas in the global effort to combat climate change. The concentration of population, resources and assets in urban areas facilitates innovation and economic development, creating the potential for mitigation and adaptation, but it also poses specific vulnerability challenges. Despite the critical role cities have in contributing to and addressing climate change, mayors and policy officials still have insufficient information, as well as varying capacity and resources to advance climate action at the city level (that is, action in urban areas, at the administrative municipal level and in specific places). The *Special Report on Climate Change and Cities* (hereafter, SR-Cities) by the Intergovernmental Panel on Climate Change (IPCC), building on chapters on cities and climate change in previous assessment reports (for example, ref. 1), aims to fill these knowledge gaps and provide examples of replicable and scalable solutions[2,3].

In this Perspective we synthesize the results of a three-day virtual workshop held by 50 participants from all world regions. The workshop used a structured approach (mapping the state of the art, brainstorming, clustering of topics and research questions) to identify crucial gaps in the assessments of cities and climate change (for more details, see https://www.mcc-berlin.net/fileadmin/data/C18_MCC_Publications/Cities_Climate_Change_Assessment_Gaps_Jan_24.pdf). We call for experts at the nexus of urbanization and climate change research to address these gaps with systematic reviews and tailored

[1]Potsdam Institute for Climate Impact Research Potsdam and Berlin, Berlin, Germany. [2]University of Sussex, Brighton, UK. [3]Technical University Berlin, Berlin, Germany. [4]Urban Systems Lab, The New School, New York, NY, USA. [5]Cary Institute of Ecosystem Studies, Millbrook, NY, USA. [6]Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden. [7]Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences, Stockholm, Sweden. [8]University of Cambridge, Cambridge, UK. [9]International Institute for Applied Systems Analysis, Laxenburg, Austria. [10]Singapore Management University, Singapore, Singapore. [11]Department of Geography, Ludwig-Maximilians-University Munich (LMU), Munich, Germany. [12]University of North Carolina at Chapel Hill, Chapel Hill, NC, USA. [13]The Scientific and Technological Research Council of Türkiye (TÜBİTAK), Ankara, Türkiye. [14]Institute of Remote Sensing and GIS, Jahangirnagar University, Savar, Bangladesh. [15]Regional Centre for Space Science and Technology Education in Asia and the Pacific (RCSSTEAP), International Innovation Institute, Beihang University, Hangzhou, China. [16]Ahmedabad University, Ahmedabad, India. [17]Institute for Applied Economic Research (Ipea), Brasília, Brazil. [18]ICLEI – Local Governments for Sustainability, Bonn, Germany. [19]Central European University, Vienna, Austria. e-mail: creutzig@pik-potsdam.de

Table 1 | Assessment methods and tools

Assessment method	Description	Case study
Typologies, benchmarking and overarching assessments on potentials, cost–benefits, co-benefits and impacts	Typologies organize cities in classes of similar characteristics, bridging the gap between the idiosyncratic urban and universal global. Typologies can be specific for mitigation, adaptation, governance and other issues. They can inform global mitigation and adaptation scenarios[8].	Typologies of cities in the Global South demonstrate the transformative role that people–place narratives have in fostering a more sustainable and equitable urban future[67].
Case-study synthesis and systematic reviews	There are more than 100,000 case studies on cities and climate change. Case-study synthesis, meta-analyses and systematic reviews are crucial steps to identify robust (reproducible) results and findings. Synthesis can include gray literature and municipal documents and is especially relevant for identifying knowledge on under-researched, fast-growing cities in the Global South.	A systematic review shows the effect of climate-induced migration to cities around the world; for example, in South Asia and Sub-Saharan Africa[68].
Big geospatial data	New sources of large-scale geospatial data, including satellite imagery, ground truth and geolocated interactions, enable detailed analysis of urban form features and infrastructure management, to provide tailored information to supports investment and decision-making processes for municipal leaders.	A spatially explicit analysis of the role of urban form on urban climate in Beijing, Cairo and Santiago finds that compact green urban tissue is necessary to cope with urban warming, but city-specific characteristics need to be respected[69].
Ex post policy analysis	Ex post policy analysis is a retrospective evaluation method to identify the impacts and effectiveness of implemented policies by comparing before and after policy metrics for, for example, the amount of sectoral or urban-wide greenhouse gas emissions.	Ex post policy analyses across continents show that climate and energy policies often fall short of delivering positive social outcomes[70].
Backcasting, urban climate modeling, urban sectoral simulation and participatory scenario development	Backcasting and participatory scenario design is a strategic planning approach where stakeholders define a desired future and reverse-engineer the steps to achieve it. This method ensures the incorporation of diverse perspectives by involving multiple participants in scenario creation. It uses models and simulation tools, such as urban climate forecasts and spatial planning, to evaluate future emissions and pathways towards net zero.	Ten cases in Africa, Europe and North America show the value of participatory backcasting for climate change adaptation planning[71].
Big social data	Big social data from major platforms can be analyzed to track public sentiment and discussions related to climate change and its mitigation in cities, providing real-time insights into people's opinions and concerns. By systematically aggregating and analyzing these data, researchers can identify trends, measure public engagement, and tailor communication and policy strategies to effectively address urban climate challenges.	Analysis of 25 million people on X (formerly Twitter) in Brazil investigated how citizens engage with the social media presence of climate authorities, demonstrating that citizens interact with public posts but do not relate weather events to climate change[72].

Assessment on cities and climate change can aggregate scientific insights and make them useful for decision-makers by using systematic assessment-making tools, thus also avoiding the risk of bias.

studies, to provide evidence for the SR-Cities and, in turn, support urban decision-makers with evidence of how to urgently address the climate crisis.

Our contribution highlights a critical challenge for the SR-Cities—balancing the complex interaction between local actions and their global consequences, and between urban impacts and their overall planetary effect. Central to achieving this endeavor is the use of key assessment methodologies and tools, such as urban typologies, which classify cities on the basis of their characteristics and allow for a broader understanding of the interactions between urban forms, impacts and management practices. Other methods, such as case-study synthesis and systematic review, big geospatial and big social data, ex post policy analysis, and backcasting are also crucial for synthesizing the relationship between cities and climate change (Table 1).

To organize the many topics and issues that aim to address climate change and that are relevant for cities, we structure the gaps in urban climate change assessment into five key themes, each characterized by three topics and related questions (Fig. 1): (1) urban form, (2) costs of and investments for climate action, losses due to climate change, and mitigation potentials, (3) policies and governance and (4) data management, all encompassed by (5) system transformation. Methods can be allocated to the themes (for example, urban form assessments rely on typologies and case-study synthesis; Fig. 1). Common to these themes is the integrated assessment of impacts, adaptation and mitigation, with many of these solutions closely linked to local development objectives such as housing, income generation, mobility, food, thermal comfort, water provisions and health. However, domain-specific expertise and studies will remain crucial as evidence-oriented cornerstones of urban climate assessments.

The set of methods, and in particular the choice of typologies, reflects the need to identify the myriad differences between cities and local (climate) environments, while simultaneously addressing the need for standard operating frameworks that can provide the basis for designing contextualized solutions across spatial regions and scale. It may also help researchers and decision-makers to understand which transformative measures are transferable between cities and places.

Urban form, geography and land use

Research increasingly shows that spatial variables are not an afterthought, but are central among the drivers of CO_2 emissions[4] and climate change exposure, vulnerability and adaptive capacity[5]. Obtaining a deeper understanding of the past and future changes of such variables to guide decision-making and relevant data integration for such analyses is becoming increasingly important.

Existing urban climate assessments consider the role of spatial arrangements and urban form (for example, ref. 1). However, they often remain broad in their focus, simply emphasizing the role of density, proximity between people and activities, and CO_2 emissions, as well as the role of land cover and green infrastructure in adapting to climate hazards such as flash floods.

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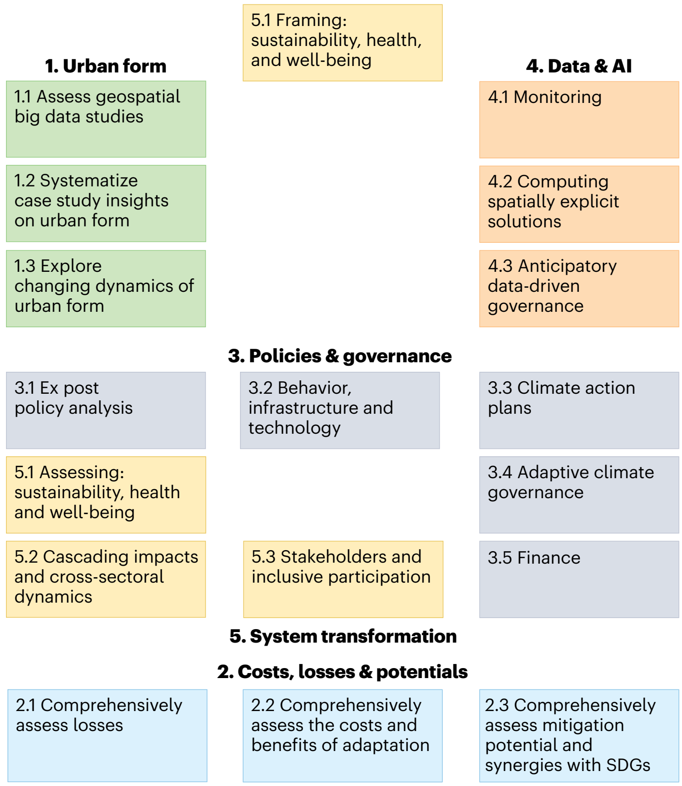

Fig. 1 | Assessment gaps and relevant assessment methodologies and tools. The adequate assessment of cities requires a back-and-forth between the context-specific and the universal. Typologies offer a bridge between these domains. Boxes represent gaps, and the relevant main tools to generate knowledge about these gaps are indicated (definitions are provided in Table 1).

BOX 1

Urban form and microclimates—data gaps in Global South cities

One of the key roles of geospatial models is mapping urban form features that influence local and microclimates, which in turn affect climate hazard impacts and exposures. An inherent challenge in this endeavor is the mismatch between the granularity of available urban data, which captures, for example, individual exposures from the arrangement of land use and land cover, and the coarser resolution of regional climate data. This discrepancy obscures the variability caused by different urban forms, presenting a substantial hurdle to climate-sensitive urban planning. A solution lies in geospatial methods potentially using AI to increase the spatial resolution of climate data models, particularly in data-poor contexts. These technologies have the potential to capture the intra- and inter-urban form variability responsible for heterogeneity in urban microclimates in greater detail[73,74]. AI tools such as Microsoft AI for Earth or Arup's UHeat combine geospatial analysis with dynamic urban temperature data to estimate urban heat island intensity. However, these methods require substantial data and are typically trained on well-planned, data-rich cities. This disadvantages some of the most climate-vulnerable cities—especially in the Global South—which have often developed organically, without planning, and suffer from data scarcity. Additionally, one-size-fits-all urban heat solutions can lead to unintended consequences, such as increased relative humidity, which is particularly concerning for tropical cities in the Global South, where mitigation measures such as tree planting may exacerbate heat stress[75,76]. Addressing this disparity requires AI models trained in Global South urban contexts, as well as studies that explore the transferability of insights between cities[77].

Three specific assessment topics emerge as relevant at the intersection of urban form and climate change. First, there is a need to assess the capabilities of novel high-resolution studies that make use of big spatial data and geospatial artificial intelligence (AI) to compute climate-relevant metrics and their association with built environments. Recent studies show that the effect of urban form on amplifying heat stress[6] or vehicle kilometers traveled[7] can be detected at high resolutions (<1 km^2). These studies need to be synthesized and critically assessed (also considering their limitations), then effectively communicated to urban planners, while other studies need to address data scarcity in cities in the Global South (Box 1).

Second, it is important to systematize case-study and modeling evidence to develop a comparative and global perspective on urban forms. This is crucial for urban decision-makers, as it helps them to identify which results and insights are most relevant to their specific cities. A useful approach to achieve this goal is the construction of typologies based on a range of urban characteristics and climate-related objectives. This method has been demonstrated at low resolution for metrics such as greenhouse gas emissions and energy use (for example, ref. 8). Recent studies provide comparative evidence on which types of tree are more effective in cooling urban environments across climate zones[9], and which urban form features affect commutes across continents[10].

Third, it is essential to understand the evolution of urban form over time and its effects on the temporal trends of CO_2 emissions and energy use, as well as climate exposure and vulnerability. This challenge includes recognizing the role of path dependency in urban form[11], in addition to the possibilities and timescales of adapting existing urban form and providing new urban structures, in particular in the rapidly urbanizing developing economies of Asia and Africa. Recently, there has been increasing interest in modeling urban change. However, the influence of urban growth on a global scale, for example, in terms of emissions, climate and land-use change, needs further attention[12]. Few studies have explored the implications of urbanization under different socioeconomic pathways. For cities in the Global South this may imply alternative narratives—going beyond a narrow climate focus to a broader set of development objectives including delivering on both basic and enabling human needs. Prospective studies by urban climate modelers, in turn, will be helpful to understand how a changing climate affects cities across different climatic zones and built environments to inform adaptation to climate hazards, for example, in-city resettlement from high-exposure urban areas. These studies include constructing local scenario storylines and modeling them to compare scenarios for energy, emissions, vulnerability and development impacts. Such studies will guide subnational action. For example, alternative urbanization scenarios comparing the future impacts of mitigation or adaptation actions can guide local policymakers to prioritize action. This challenge includes recognizing the role of path dependency in urban form[11], in addition to the possibilities and timescales of adapting existing urban form and providing new urban structures, in particular in Asia and Africa's rapidly urbanizing developing economies. Indeed, urban planning itself often creates the climate exposure and vulnerability of tomorrow. Social housing in European cities, for instance, can lead to the accumulation of highly vulnerable populations in areas with future heat exposure if scenarios of future climate impacts are not adequately considered in the planning process, as exemplified in the case of Bonn, Germany[13]. Jointly modeling urbanization and climate change is key to identify local effects and prepare adequate responses and planning strategies, as clarified for the case of Can Tho City, Vietnam, where urbanization effects (impervious surfaces) have led to compound flooding risks[14]. Such studies guide subnational action; for example, alternative scenarios comparing future effects of mitigation or adaptation scenarios assessed at the state or city level can guide local policymakers on prioritizing actions.

Another aspect to consider over time is how changes in urban forms (such as reallocating street space or implementing urban gardening projects) and retrofitting strategies influence the quality of life in urban contexts for different individuals and groups. Addressing this question requires the collaborative efforts of urban planners and behavioral scientists[15].

Potentials, costs, co-benefits and trade-offs, and losses

A global analysis of mitigation and adaptation potentials in cities and human settlements is central for understanding the opportunities of urban action and its role in addressing climate change. Studies have analyzed interactions between urbanization and climate change vulnerability at the national level[16], and have evaluated climate adaptation plans for cities at both global and regional scales[17,18]. Nonetheless, an improved understanding of what classes of city could benefit most from which mitigation and adaptation measures is still missing, and grouping these cities into a global typology would enable this analysis. Connecting global urban mitigation and adaptation typologies to scenarios would also be invaluable to map how climate measures from local governments contribute to international climate governance processes, including the United Nations Framework Convention on Climate Change (UNFCCC) and targeted Nationally Determined Contributions (NDCs). Comprehensive datasets that include socioeconomic indicators are essential to enable this form of clustering of urban typologies with mitigation and adaptation measures[19]. AI models could be leveraged to analyze cities on the basis of similarities in their characteristics and climate actions to identify patterns and commonalities that facilitate targeted strategies. Scenario mapping and modeling is also an essential method to assess potential outcomes of different urban typologies responding to climate challenges and assess potential effects of policy interventions.

Mitigation and adaptation actions can result in substantial gains in social, health, economic, well-being and other outcomes. However, these positive synergies are rarely quantified, monetized or included in decision-support assessments, perpetuating insufficient action and leading to further missed opportunities for societal co-benefits. The trade-offs and equity implications of climate actions, such as higher energy prices, issues around access, and displacement are documented in the literature. An improved understanding of context-specific trade-offs can help to minimize these impacts, particularly to low-income urban residents. An integrated approach to mitigation and adaptation planning can also contribute to urban equity by targeting the most vulnerable populations and areas. For example, in cities, marginalized groups are often most susceptible to the urban heat island effect due to a lack of green spaces and higher concentrations of heat-absorbing surfaces[20]. The mitigation and adaptation strategies of planting trees and creating green spaces, as well as establishing cooling centers that provide relief during extreme heat events, can be guided by evidence-informed targeted implementation to prioritize the most heat-affected underserved neighborhoods for tree planting and ensure the accessibility of cooling centers[21].

Impacts, along with adaptation and mitigation measures, come with financial costs, but mitigation and adaptation measures also bring benefits for cities. The estimated amplifying impact of climate change on Hurricane Sandy in 2012 accounted for US $8 billion in damage alone[22], which is 13% of the total costs. Heat waves in France between 2015 and 2019 are estimated to have cost €25 billion[23]. However, reliable estimates of the financial costs of climate impacts on urban infrastructure remain limited, especially in the Global South. Valuing the loss of lives and productivity impacts is scarce. Similarly, the economic benefits of mitigation measures have only been investigated in case studies. For example, green roofs pay back in less than seven years in Hong Kong[24]. One study identified that some river flood risk reduction strategies in Europe provide a four-fold return on investment[25]. Although these examples demonstrate that cost-effective adaptation measures are available, it is less clear whether such solutions scale on a global level and across different context conditions. In mitigation, there is a large amount of evidence of the monetized co-benefits of urban transport solutions related to time saved in traffic, air pollution and better health[26]. Robust assessments of co-benefits can be a useful entry point for climate actions in developing-country cities facing multiple priorities and often limited resources.

A global typology of what types of city could benefit most from different mitigation and adaptation measures is still missing. Connecting global urban mitigation and adaptation typologies to scenarios would also be invaluable to map how climate measures from local governments contribute to international climate governance processes including the UNFCCC and targeted NDCs. Studies have analyzed the feedbacks between urbanization and climate change vulnerability at the country scale[16] and have evaluated climate adaptation plans of cities at global and regional levels[17,18].

Mitigation and adaptation actions can result in substantial further gains in social, health, economic, well-being and other outcomes. However, these positive synergies are rarely quantified, monetized or included in decision-support assessments, perpetuating insufficient action and leading to further missed opportunities for societal co-benefits.

Also, a systematic assessment of costs and benefits remains missing[27], especially with a focus on their fiscal consequences for municipalities. Many cities lack the capacity to undertake these complex assessments on costs and benefits. Given uncertainty around the quantification of co-benefits and their timing, combined with short-termism, cities perceive upfront investments as higher costs, making climate action less compelling. More work is needed to understand losses and specific adaptation strategies for all types of city, but more specifically for those with a large share of informal housing and jobs. Understanding both economic and non-economic losses and damages. as well as potentially avoided impacts from mitigation efforts[28], is critical for immediate and near-term decisions around housing and infrastructure provision.

Policies and governance

Ex post policy analysis, policy sequencing and policy packaging are critical components of effective climate action in urban contexts. They enable cities to refine and optimize their approaches to reducing greenhouse gas emissions and enhance resilience. Ex post policy analysis involves evaluating the outcomes of implemented policies to understand their effectiveness, unintended consequences and areas for improvement. For instance, post-implementation reviews of congestion charging in cities such as London or Stockholm provided insights into new traffic patterns, emissions reductions and public acceptance, informing subsequent adjustments[29,30]. In the realm of adaptation, protocols to assess ex post the effectiveness of different modes of social protection—one of the main instruments to counteract vulnerability—have not yet been applied in a coherent manner to the context of climate change-related social protection schemes or urban-focused instruments. Policy sequencing refers to the strategic ordering of policy implementation to build on the momentum of earlier measures, such as initiating with public awareness campaigns before rolling out more stringent regulations such as efficiency or flood protection standards

Table 2 | Sociocultural, infrastructural and technological factors facilitating the adoption of climate action in cities

Services and provisions	Sociocultural	Infrastructure and urban form	Technological adoption
Mobility	Positively normed cycling and shared (transit) mobility	Highly accessible compact urban form and transit networks City-wide shared and affordable mobility systems	Uptake of battery electric vehicles and electric two and three wheelers AI-based urban planning
Building energy	Adaptive appliance usage Air-drying of clothes Low-temperature washing Limiting growth in floor space	Compact urban form Focus on multifamily buildings versus single-family ones High-efficiency buildings, passive houses	Heat pumps, smart metering and retrofitting Sustainable defaults High-efficiency appliances Eco-design
Food provisioning systems	Diet shift Reduced food waste, food sharing Growing food locally, access for vulnerable groups particularly during disasters	Urban food environments Enabling food-sharing networks through digitalization/partnership with the private sector	Hydroponics Advanced food-production technologies applicable at local scale
Energy (prosumer)	Raising awareness of alternative energy systems (for example, PV)	Energy-positive buildings PV integrated into infrastructure (parking)	Low-cost PV and similar energy systems
Thermal comfort (heat stress)	Adaptive behavior Climate-appropriate working hours and schedules (siesta, for example) Cultivating climate-appropriate thermal comfort norms and expectations	Vernacular architecture and urban form tailored to local climate Green spaces and wind channels in urban canyons Shading of buildings, sidewalks and transport stops, shaded workspaces for informal workers	Smart thermostats Phase-changing building materials Digital early warnings
Water	Water saving as norm Restricting luxury pools and watering in drought	Sponge cities, dams, road elevation, climate-resilient freshwater access Mandating rainwater harvesting for new buildings	Digital monitoring and management
Health	Active travel, health foods, inclusive healthcare provisioning	Zero-emission energy system, less car travel (air quality), street design for safety, climate-resilient healthcare	Electric two, three and four wheelers
Resource use (circular economy, waste reduction)	Regular second-hand markets Repair cafes/communities	Durable, long-lived infrastructure Focusing on repurposing, retrofits and repair versus building new	Affordable repair and maintenance services, convenient selective waste collection
Social protection	Access to social protection for vulnerable and informal residents	Risk-sensitive planning and housing to reduce overall losses	Digital technology for registry and payout
Carbon dioxide removal		Afforested cities, biochar for energy and urban agriculture	Building-scale direct air capture, wood-based buildings

The structure is motivated by a demand-side perspective proposed in ref. 35, but adapted to both mitigation and adaptation concerns in cities. PV, photovoltaic.

for buildings. Policy packaging involves combining multiple policies to leverage synergies and mitigate trade-offs, as exemplified by pairing renewable energy incentives with grid modernization projects to enhance energy sustainability while addressing infrastructure limitations. Policy evaluation must also consider the sustainability of impacts and benefits. Recent ex post policy analysis identified the most effective policy packages to curb road transport emissions in Europe[31]. Similar analysis is required for other urban climate policy instruments and packages and in other contexts.

The evidence on climate actions is mixed in terms of their effectiveness in implementing actions and achieving intended outcomes, and even less is known about Global South cities due to the limited reporting of progress from those regions[32]. Systematic studies of urban climate reporting and action (for example, refs. 18,33) can support networks' roles as catalytic agents by identifying effective strategies cities have implemented that can be transferred to similar contexts. City networks must ensure the engagement of cities from less-wealthy countries[34], underrepresented cities, as well as the inclusion of different stakeholders, such as urban policymakers, professionals and academics, to ensure plans and actions have a higher buy-in and therefore a higher likelihood of sustained impacts.

The 'avoid–shift–improve' framework[35] categorizes policy instruments into those that avoid unnecessary emissions, shift to lower-emission options and improve efficiencies. Examples include urban planning to avoid car dependency, promoting public transit to shift travel modes and advancing insulation to improve the energy efficiency of buildings. Within the IPCC, avoid–shift–improve has morphed into a classification into sociocultural, infrastructural and technology adoption measures. Although researchers formally evaluate mitigation measures as part of a demand-side perspective[36], what is missing is a specific assessment of avoid–shift–improve measures in urban contexts that also extends to pathways for achieving net-zero cities and incorporating adaptation measures. What is also needed is an extension of the policy-oriented framework to contextualized governance settings, including an understanding of how community engagement, local knowledge and traditional practices shape the desirability and feasibility of avoid–shift–improve policy action.

For example, although the potential of urban carbon dioxide removal has been assessed, including urban trees, rooftop albedo, biochar and building-scale direct air capture[37], there is a lack of understanding of how and whether these options can contribute to net-zero goals or whether alternative means of tackling residual emissions still exist at the point source of emissions. Also, a similar classification and organization of options is missing for adaptation measures. We thus suggest that a future urban assessment could categorize urban mitigation, adaptation and net-zero options from a service-provisioning lens and into sociocultural, infrastructural and technological adoption measures (Table 2). This would not only allow an accessible sorting of options, but would simultaneously address their relationship to service accessibility in cities.

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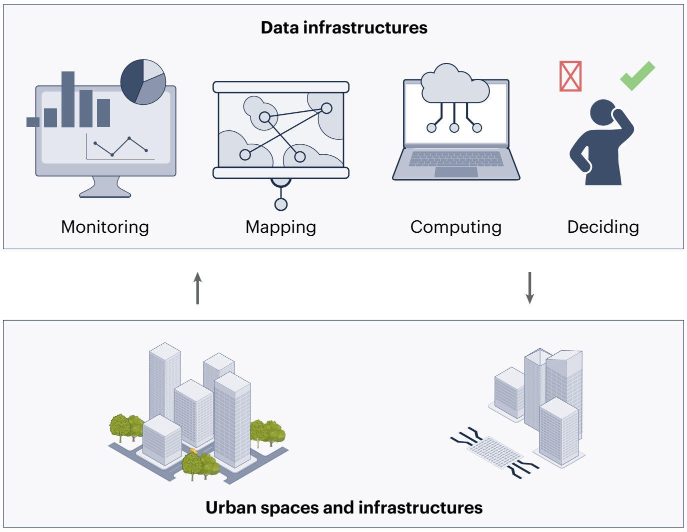

Fig. 2 | Urban data and physical infrastructure. The governance of urban spaces and infrastructures will increasingly be complemented by digital governance, requiring monitoring, mapping, computing and inclusive decision-making as key components of the required data infrastructure.

Finally, adaptive governance frameworks, relying on real-time monitoring and feedback from communities, are essential for cities to respond dynamically to the challenges and opportunities presented by climate change[38]. They are particularly useful when uncertainty is high and when various contingencies and complexities require flexible adjustments, as highlighted for the case of ecosystem services in urban green spaces[39]. Aggregate evidence on when adaptive governance is adequate, reflecting cultural and social context, and how it is best implemented will provide crucial guidance to municipalities, but as yet this remains insufficient.

Data management, technology and smart cities

To facilitate effective urban climate governance, precise, comprehensive and up-to-date urban-level data regarding climate impacts and vulnerabilities, greenhouse gas emissions and mitigation, as well as adaptation responses, is critical, albeit not sufficient[40]. Data-driven governance, in principle, is enabled by rich big data, which are becoming increasingly available through advances in technology and cloud computing[41].

In terms of mitigation, three reasons support the need for improved monitoring and data availability at the urban scale. First, accurate greenhouse gas inventories enable cities to identify the primary sources of emissions and target reduction efforts where they can be most effective, aiding the optimization of resource allocation. Second, monitoring provides essential data to assess the efficacy of existing climate policies and adaptation measures, facilitating feedback loops and iterative policy adjustments and fostering flexible and adaptive management practices. Third, robust greenhouse gas tracking supports transparency and accountability in urban climate governance. It empowers local stakeholders, including residents, businesses and advocacy groups, with the information needed to participate in climate action discussions and hold decision-makers accountable for their commitments.

For adaptation, high-resolution data on current as well as future climate hazards (for example, flood zones and urban overheating) are essential to guide adaptation planning. However, it must be coupled with data on the spatial distribution of vulnerable people and infrastructure throughout a city—not only today but also in the future. Such data are currently lacking in many cities or cannot be effectively integrated and used due to siloed data-holding within different branches of city administrations and data protection regulation. For heat-action planning in Indian cities, for example, a vulnerability assessment combining information on the age structure of households, the detailed locations of their residences and medical preconditions would be essential to improve ad hoc support[42]. Micro-census data and geospatial big data analysis within cities therefore needs to be expanded to enable effective adaptation planning.

Gaps exist in urban emissions inventories, both in developed and developing countries. Such incompleteness is in part due to difficulties in measuring emissions from diffuse, non-point sources, which may make up a small proportion of the total but can be substantial globally[43]. This includes methane emissions from urban natural gas distribution[44], methane from solid-waste dumpsites, or sequestration from urban trees. Approaches using satellite images, open data, citizen science and so on, in combination with machine learning[45], have been piloted in a few cities but are not used extensively. The building capacity of diverse urban professionals including policymakers and other local stakeholders, such as local academic institutions, research organizations and non-governmental organizations, may enhance granularity.

Precise data, such as on urban form, can be leveraged to compute low-carbon urban solutions[6,46]. The results can also be used for predictive modeling, which is especially useful for low-carbon and resilient urban planning, as in the case of Porto, Portugal, where high-resolution metrics of travel, heating and cooling demand have been used to simulate urban planning solutions that could minimize urban CO_2 emissions[7]. Similarly, this approach can also be used to evaluate the CO_2 emissions consequences of planned new settlements[47].

Anticipatory, data-driven governance (Fig. 2) may help to create more responsive urban environments under high uncertainty[48]. Internet of Things devices, sensors and connected systems provide real-time data to develop such mechanisms. Chinese cities, such as Hangzhou and Beijing, lead the world in combining sensors with computing infrastructure, and its integration in decision-making. For example, the Haidan City Brain in Beijing pioneers the use of AI for anticipatory governance through pattern recognition and the prediction of urban environmental and social dynamics[49], but also social surveillance. European cities, by contrast, are only just starting to build synergies between digital infrastructure and urban governance, especially in a climate change context. Although there is a lack of research that assesses data-driven urban governance in the European Union (EU), the emergence of programs such as the 'EU-Mission for 100 climate-neutral and smart cities'[50] or the EU-funded project 'AI4Cities—Accelerating carbon neutrality' is indicative of an experimental stage that is mainly channeled through EU agendas. Cities in low- and middle-income countries and some in developed countries do not yet have the capacity to take advantage of digitalization. In some cases, higher digitalization may also result in the exclusion of those without access to digital infrastructure[51]. Future research is required to conduct a coherent and comparative assessment around the use and risks of AI for enabling anticipatory, data-driven governance in the context of climate change.

Better urban data can be an important tool for social and just transition[52]. Human-centric data approaches are particularly valuable because they ensure that the needs and perspectives of all urban residents, including vulnerable and marginalized groups, are considered in planning[53]. This inclusivity can mitigate the risks of data exclusion and digital divides, as well as ensuring that responsive and adaptive urban environments are equitably distributed across a city. In today's data-rich urban landscape, there is an opportunity to collect human-centric data that can be integrated into city-planning exercises. To enable this transformation, important knowledge gaps need to be addressed regarding the processes of data collection and usage by city governments and other relevant actors. Upstream, at the data collection stage, more knowledge is required to understand which climate change mitigation use cases can be supported by existing data[54,55], such as high-resolution building-stock data, and to determine the most effective processes for achieving the necessary data quality when it is not yet available. Downstream, related to the usage of modeling results by city officials, more research is needed that investigates how policymakers in different regulatory contexts and with different levels of digital literacy can take on modeling results and deploy data-driven solutions. Overall, more knowledge is required to understand the barriers, risks and contexts prone to success and failure in this space.

System transformation for sustainability

Both means and ends are closely entangled in urban policies, and holistically aligning different goals is central for a system transformation. It is important to leverage synergies between climate action and other elements of the United Nations' Sustainable Development Goals (SDGs) such as health (for example, via better air quality due to reduced use of fossil fuels, or better health due to active travel) in cities[56], especially as financial resources to achieve goals remain scarce and political momentum for climate-only action can be slow or unstable. Similarly, equity is central to urban climate strategies, ensuring that actions do not disproportionately affect vulnerable populations. This involves equitable service provisioning and access to opportunities and resources, inclusive decision-making processes, targeted measures to protect vulnerable groups from extreme climate impacts, empowering of marginalized communities, as well as targeting mitigation policies for the highest emitters within cities. For example, millions continue to be exposed to extreme heat, particularly in the Global South. Heat-action plans must incorporate measures for protecting vulnerable populations (for example, construction workers) from exposure, as well as long-term transformation to enhance resilience (such as climate-proof housing).

Our knowledge about systemic feedback, impact cascades (that is, primary impacts leading to secondary impacts, leading to tertiary consequences) and compounding impacts is limited. In Bangladesh, flood disasters cause people from smaller towns to seek refuge in larger cities, straining urban services not designed for the influx. City authorities, lacking the budgets to expand services, face damaged infrastructure they cannot afford to repair. Additionally, coastal cities are becoming uninhabitable not just due to inadequate city services but also because of increased water salinity in rivers due to climate change. This salinity disrupts the water supplies needed for industrialization, domestic use and agriculture, leading to industry breakdowns, job losses and economic instability, further weakening cities, particularly in coastal areas.

A deeper understanding of systemic feedback from population dynamics is critical to make accurate projections and assessments of urban systems, as population numbers and flows condition urban planning. For example, rapid urbanization and the provision of services such as energy access can substantially affect population dynamics[57], but such feedback is rarely included in models. Similarly, changes in population composition, for example, age and education, can affect societal outcomes such as attitudes towards sustainability or adaptive capacity[58]. Also, conflict and climate-induced migration, specific to urban areas, will probably lead to shocks in urban systems in the future, so a better understanding of such dynamics is critical.

System transformation also requires a profound reconfiguration of the relationship between people and the natural systems on which they depend, as well as how their value is perceived and measured, especially in urban areas where people have become highly disconnected from them[59]. This transformation can be difficult to quantify, and insights from qualitative research as well as the humanities and the arts should be better integrated into assessments on urban sustainability. For example, important discourses from the humanities, such as 'making kin'[60], a concept coined by Donna Haraway that suggests extending the process of attention and care between humans and nonhumans, have the potential to be transformative if mainstreamed and included in policy agendas or major public communication campaigns.

Knowledge from community-based practice is also valuable in fostering systemic change in the context of urban sustainability. Urban community-based projects, such as urban gardening and foraging or community composting, especially when they engage with people from a mixed socioeconomic background, can provide insights into practical ways to engage and collaborate with natural processes and inspire efforts to protect and preserve urban ecosystems[59]. Institutional and non-institutional education structures, such as universities or grassroots urban projects, by creating practice-based programs or curricula that actively seek inclusion and diversity, already have a pivotal role here[61]. Projects such as the Floating University in Berlin (https://floating-berlin.org/) or Klasse für Alle from the University of Applied Arts Vienna (https://klassefueralle.uni-ak.ac.at/) provide good examples, yet the knowledge gained should be better integrated in assessment reports.

Addressing siloes in governance is essential for fostering integrated approaches to urban planning that combine sectors such as food systems, mobility and energy to achieve co-benefits. Siloed governance structures often hinder effective collaboration and the holistic management of urban challenges. For example, integrating food systems with urban mobility planning can reduce food miles and associated emissions while simultaneously improving access to fresh produce in urban areas. A systemic approach requires platforms for cross-sectoral collaboration to address the interconnected challenges being faced by cities[62]. In the case of climate adaptation, there is a lack of understanding of how the use of key concepts such as risk, vulnerability and adaptive capacity differs across stakeholders[63].

Effective urban governance and planning for climate change requires a clear understanding of existing barriers such as financial limitations, regulatory constraints and stakeholder resistance. Research also shows that anti-elitist identity struggles and right-wing populism are key hurdles to climate action and require inclusive policy fora (without legitimizing unethical discourses[64]). Identifying these obstacles is the first step toward leveraging points of influence and opportunities for innovation within urban systems, enabling more streamlined and impactful climate action strategies.

Making the IPCC report on cities

In this Perspective we have organized the research gaps into five overarching themes: (1) urban form, (2) costs, losses and potentials, (3) policy and governance, (4) data and AI, and (5) system transformation, and we have proposed a set of methodologies and tools that can be used to address those gaps.

A key finding of this Perspective is that systematic reviews of case studies and typologies of urban settlements are of critical importance in addressing these assessment gaps. Urban typologies have a critical role in providing a systematic way to categorize cities and to extrapolate findings from specific cases to broader applications. Systematizing case studies and meta-analyses can help develop a comparative and global perspective on urban forms, as well as identify effective urban climate strategies that can be applied in many cities, with more or less adaptation to local contexts.

Other key methodologies include ex post policy analysis, which can address policy gaps by evaluating existing urban climate policies. There remains a substantial need for data and evidence on what works and what does not for the management of physical urban spaces, particularly data-driven approaches. This requires not only the development of new technologies, but also the strategic collection and analysis of urban data, with a focus on under-researched regions, in particular in fast-growing cities in developing countries. Finally, geospatial models can be used to identify low-carbon urban form modifications and map urban form features that shape local and microclimates, which in turn influence risks and exposures associated with climate hazards.

A key challenge is to apply insights from one city to other different cities. Scaling urban solutions across cities, particularly in data-sparse settings, requires addressing both the generalizability and replication challenges inherent in urban research[65]. Approaches to scaling include comparative analysis, meta-analysis and the synthesis of case studies, which extract shared insights from diverse contexts[66]. Data-driven investigations across cities and machine-learning techniques further enable the identification of generalizable predictors and intervention priorities. Additionally, functional international climate networks facilitate knowledge exchange and the adaptation of successful innovations across cities. To enable effective scaling, future research must focus on overcoming reproducibility and variability challenges by leveraging big data and advanced statistical methods, drawing from disciplines such as sociology and psychology, which have faced similar issues. Emphasizing community engagement through citizen science and participatory practices is also crucial to ensure that solutions are both context-sensitive and scalable.

Addressing these research gaps requires a collaborative approach, engaging multidisciplinary teams that include climatologists, urban planners, technologists, social scientists and humanities scholars. Applying urban climate assessment methodologies, combined with subsequent assessment by the IPCC, could greatly increase the practical application and relevance of the SR-Cities for urban climate action. Only through a coordinated and comprehensive research agenda can we hope to provide the robust, actionable knowledge needed to ensure that cities contribute effectively to combating global climate change while enhancing urban liveability and resilience for all urban residents.

References

1. Lwasa, S. et al. Urban systems and other settlements. In *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Shukla, P. R. et al.) (Cambridge Univ. Press, 2022).
2. Bai, X. et al. Six research priorities for cities and climate change. *Nature* **555**, 23–25 (2018).
3. Solecki, W. et al. A conceptual framework for an urban areas typology to integrate climate change mitigation and adaptation. *Urban Clim.* **14**, 116–137 (2015).
4. Haberl, H. et al. Built structures influence patterns of energy demand and CO_2 emissions across countries. *Nat. Commun.* **14**, 3898 (2023).
5. Demuzere, M. et al. Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. *J. Environ. Manage.* **146**, 107–115 (2014).
6. Zekar, A., Milojevic-Dupont, N., Zumwald, M., Wagner, F. & Creutzig, F. Urban form features determine spatio-temporal variation of ambient temperature: a comparative study of three European cities. *Urban Clim.* **49**, 101467 (2023).
7. Silva, M., Leal, V., Oliveira, V. & Horta, I. M. A scenario-based approach for assessing the energy performance of urban development pathways. *Sustain. Cities Soc.* **40**, 372–382 (2018).
8. Creutzig, F., Baiocchi, G., Bierkandt, R., Pichler, P.-P. & Seto, K. C. Global typology of urban energy use and potentials for an urbanization mitigation wedge. *Proc. Natl Acad. Sci. USA* **112**, 6283–6288 (2015).
9. Mehrotra, S., Bardhan, R. & Ramamritham, K. Outdoor thermal performance of heterogeneous urban environment: an indicator-based approach for climate-sensitive planning. *Sci. Total Environ.* **669**, 872–886 (2019).
10. Wagner, F. et al. A causal discovery approach to learn how urban form shapes sustainable mobility across continents. Preprint at http://arxiv.org/abs/2308.16599 (2023).
11. Henderson, V. J., Peng, C. & Baruah, N. *Colonial Legacies: Shaping African Cities (SERC Spatial Economics Reseach Centre 44 SERC discussion paper PAPER 226)* (2017).
12. Chen, G. et al. Global projections of future urban land expansion under shared socioeconomic pathways. *Nat. Commun.* **11**, 537 (2020).
13. Puntub, W. et al. Linking science and practice in participatory future-oriented assessment and planning of human heat stress vulnerability in Bonn, Germany. *J. Environ. Plan. Manag.* **66**, 1918–1937 (2023).
14. Huong, H. T. L. & Pathirana, A. Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. *Hydrol. Earth Syst. Sci.* **17**, 379–394 (2013).
15. Creutzig, F. & Reisch, L. A. A joint research agenda for climate action bridges behavioral sciences and urban planning. *Commun. Psychol.* **2**, 101 (2024).
16. Garschagen, M. & Romero-Lankao, P. Exploring the relationships between urbanization trends and climate change vulnerability. *Clim. Change* **133**, 37–52 (2015).
17. Araos, M. et al. Climate change adaptation planning in large cities: a systematic global assessment. *Environ. Sci. Policy* **66**, 375–382 (2016).
18. Reckien, D. et al. How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28. *J. Clean. Prod.* **191**, 207–219 (2018).
19. Santos dos, G. F. et al. Socioeconomic urban environment in Latin America: towards a typology of cities. *Sustainability* **15**, 6380 (2023).
20. Hsu, A., Sheriff, G., Chakraborty, T. & Manya, D. Disproportionate exposure to urban heat island intensity across major US cities. *Nat. Commun.* **12**, 2721 (2021).
21. Gilligan, C. Cooling effects of urban trees are strongest in under-resourced neighbourhoods. *Nat. Rev. Earth Environ.* **4**, 517 (2023).
22. Strauss, B. H. et al. Economic damages from Hurricane Sandy attributable to sea level rise caused by anthropogenic climate change. *Nat. Commun.* **12**, 2720 (2021).
23. Adélaïde, L., Chanel, O. & Pascal, M. Health effects from heat waves in France: an economic evaluation. *Eur. J. Health Econ.* **23**, 119–131 (2022).
24. Peng, L. L. H. & Jim, C. Y. Economic evaluation of green-roof environmental benefits in the context of climate change: the case of Hong Kong. *Urban For. Urban Green.* **14**, 554–561 (2015).
25. Dottori, F., Mentaschi, L., Bianchi, A., Alfieri, L. & Feyen, L. Cost-effective adaptation strategies to rising river flood risk in Europe. *Nat. Clim. Change* **13**, 196–202 (2023).
26. Creutzig, F. & He, D. Climate change mitigation and co-benefits of feasible transport demand policies in Beijing. *Transp. Res. D Transp. Environ.* **14**, 120–131 (2009).
27. Brandt, J., Goyal, N., Moroney, M., Janaskie, S. & Hsu, A. Ambient air pollution and consumer spending: evidence from Spain. *PLoS ONE* **19**, e0292245 (2024).
28. Kotz, M., Levermann, A. & Wenz, L. The economic commitment of climate change. *Nature* **628**, 551–557 (2024).
29. Bernardo, V., Fageda, X. & Flores-Fillol, R. Pollution and congestion in urban areas: the effects of low emission zones. *Econ. Transp.* **26–27**, 100221 (2021).
30. Chamberlain, R. C., Fecht, D., Davies, B. & Laverty, A. A. Effects of low emission zones and congestion charging zones on physical health outcomes: a systematic review. *Lancet* **400**, S30 (2022).
31. Koch, N., Naumann, L., Pretis, F., Ritter, N. & Schwarz, M. Attributing agnostically detected large reductions in road CO_2 emissions to policy mixes. *Nat. Energy* **7**, 844–853 (2022).
32. Hsu, A. et al. Performance determinants show European cities are delivering on climate mitigation. *Nat. Clim. Change* **10**, 1015–1022 (2020).
33. Burley Farr, K., Song, K., Yeo, Z. Y., Johnson, E. & Hsu, A. Cities and regions tackle climate change mitigation but often focus on less effective solutions. *Commun. Earth Environ.* **4**, 439 (2023).

34. Heikkinen, M., Karimo, A., Klein, J., Juhola, S. & Ylä-Anttila, T. Transnational municipal networks and climate change adaptation: a study of 377 cities. *J. Clean. Prod.* **257**, 120474 (2020).
35. Creutzig, F. et al. Towards demand-side solutions for mitigating climate change. *Nat. Clim. Change* **8**, 260–263 (2018).
36. Creutzig, F., Roy, J. & Minx, J. Demand-side climate change mitigation: where do we stand and where do we go? *Environ. Res. Lett.* **19**, 040201 (2024).
37. Rodriguez Mendez, Q., Fuss, S., Lück, S. & Creutzig, F. Assessing global urban CO_2 removal.*Nat. Cities* **1**, 416–423 (2024).
38. May, C. K. Complex adaptive governance systems: a framework to understand institutions, organizations and people in socio-ecological systems. *Socio Ecol. Pract. Res.* **4**, 39–54 (2022).
39. Green, O. O. et al. Adaptive governance to promote ecosystem services in urban green spaces. *Urban Ecosyst.* **19**, 77–93 (2016).
40. Hughes, S., Giest, S. & Tozer, L. Accountability and data-driven urban climate governance. *Nat. Clim. Change* **10**, 1085–1090 (2020).
41. Creutzig, F. et al. Upscaling urban data science for global climate solutions. *Glob. Sustain* **2**, e2 (2019).
42. Rivas, S. et al. *Guidebook: How to Develop a Climate Action Plan for Cities in India*. JRC Science for Policy Report (European Commission, 2022).
43. *Greenhouse Gas Emissions Information for Decision Making: A Framework Going Forward* (National Academies Press, 2022).
44. Sargent, M. R. et al. Majority of US urban natural gas emissions unaccounted for in inventories. *Proc. Natl Acad. Sci. USA* **118**, e2105804118 (2021).
45. Hsu, A., Wang, X., Tan, J., Toh, W. & Goyal, N. Predicting European cities' climate mitigation performance using machine learning. *Nat. Commun.* **13**, 7487 (2022).
46. Berrill, P. et al. Comparing urban form influences on travel distance, car ownership and mode choice. *Transp. Res. D Transp. Environ.* **128**, 104087 (2024).
47. Nachtigall, F., Wagner, F., Berrill, P. & Creutzig, F. Built environment and travel: Tackling non-linear residential self-selection with double machine learning. *Trans. Res. D Trans. Environ.* **140**, 104593 (2025).
48. Quay, R. Anticipatory governance: a tool for climate change adaptation. *J. Am. Plan. Assoc.* **76**, 496–511 (2010).
49. Xu, Y., Cugurullo, F., Zhang, H., Gaio, A. & Zhang, W. The emergence of artificial intelligence in anticipatory urban governance: multi-scalar evidence of China's transition to city brains. *J. Urban Technol.* https://doi.org/10.1080/10630732.2023.2292823 (2024).
50. Kılkış, Ş., Ulpiani, G. & Vetters, N. Visions for climate neutrality and opportunities for co-learning in European cities. *Renew. Sustain. Energy Rev.* **195**, 114315 (2024).
51. Climate-neutral and smart cities. *ec.europa.eu* https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en (2024).
52. Wagner, F. et al. Using explainable machine learning to understand how urban form shapes sustainable mobility. *Transp. Res. D Transp. Environ.* **111**, 103442 (2022).
53. *On the Importance of Human-Centricity and Data* (World Economic Forum, 2021).
54. Milojevic-Dupont, N. et al. EUBUCCO v0.1: European building stock characteristics in a common and open database for 200+ million individual buildings. *Sci. Data* **10**, 147 (2023).
55. Chamberlain, H. R. et al. Building footprint data for countries in Africa: to what extent are existing data products comparable? *Comput. Environ. Urban Syst.* **110**, 102104 (2024).
56. Creutzig, F. et al. *Seeking Synergy Solutions: How Cities Can Act on Both Climate and the SDGs* (SDSG, 2024).
57. Belmin, C., Hoffmann, R., Pichler, P.-P. & Weisz, H. Fertility transition powered by women's access to electricity and modern cooking fuels. *Nat. Sustain.* **5**, 245–253 (2022).
58. Lutz, W. & Muttarak, R. Forecasting societies' adaptive capacities through a demographic metabolism model. *Nat. Clim. Change* **7**, 177–184 (2017).
59. Amel, E., Manning, C., Scott, B. & Koger, S. Beyond the roots of human inaction: fostering collective effort toward ecosystem conservation. *Science* **356**, 275–279 (2017).
60. Haraway, D. J. *Staying with the Trouble: Making Kin in the Chthulucene* (Duke Univ. Press, 2016).
61. Daniel, J. L. & Wiek, A. The role of universities in fostering urban and regional sustainability. In *Institutional and Social Innovation for Sustainable Urban Development* (Routledge, 2012).
62. Creutzig, F., Goetzke, F., Ramakrishnan, A., Andrijevic, M. & Perkins, P. Designing a virtuous cycle: quality of governance, effective climate change mitigation, and just outcomes support each other. *Glob. Environ. Change* **82**, 102726 (2023).
63. Hügel, S. & Davies, A. R. Public participation, engagement and climate change adaptation: a review of the research literature. *WIREs Clim. Change* **11**, e645 (2020).
64. Aasen, M. & Sælen, H. Right-wing populism and climate policies: explaining opposition to road tolls in Norway. *Transp. Res. D Transp. Environ.* **105**, 103222 (2022).
65. Sudmant, A., Creutzig, F. & Mi, Z. Replicate and generalize to make urban research coherent. *Int. J. Urban Sci.* **0**, 1–22 (2024).
66. Creutzig, F. et al. Towards a public policy of cities and human settlements in the 21st century. *Npj Urban Sustain.* **4**, 29 (2024).
67. Salama, A. M. et al. People–place narratives as knowledge typologies for social sustainability: cases from urban contexts in the Global South. *Buildings* **14**, 1001 (2024).
68. Chung, J., Buswala, B., Keith, M. & Schwanen, T. Climate mobilities into cities: a systematic review of literature from 2011 to 2020. *Urban Clim.* **45**, 101252 (2022).
69. Lemoine-Rodríguez, R., Inostroza, L. & Zepp, H. Does urban climate follow urban form? Analysing intraurban LST trajectories versus urban form trends in 3 cities with different background climates. *Sci. Total Environ.* **830**, 154570 (2022).
70. Lamb, W. F. et al. What are the social outcomes of climate policies? A systematic map and review of the ex-post literature. *Environ. Res. Lett.* **15**, 113006 (2020).
71. van der Voorn, T. et al. Advancing participatory backcasting for climate change adaptation planning using 10 cases from 3 continents. *Clim. Risk Manag.* **42**, 100559 (2023).
72. Ponciano, L. How citizens engage with the social media presence of climate authorities: the case of five Brazilian cities. *Npj Clim. Action* **2**, 44 (2023).
73. Milojevic-Dupont, N. & Creutzig, F. Machine learning for geographically differentiated climate change mitigation in urban areas. *Sustain. Cities Soc.* **64**, 102526 (2021).
74. Bardhan, R., Gupta, P. & Majumdar, A. GeoInFuse—a data-driven information fusion for intra-urban form classification in data-scarce heterogeneous cities. *Cities* **127**, 103762 (2022).
75. Jamei, E. et al. Urban design parameters for heat mitigation in tropics. *Renew. Sustain. Energy Rev.* **134**, 110362 (2020).
76. Li, X.-X. & Norford, L. K. Evaluation of cool roof and vegetations in mitigating urban heat island in a tropical city, Singapore. *Urban Clim.* **16**, 59–74 (2016).
77. Horst, H. A., Sargent, A. & Gaspard, L. Beyond extraction: data strategies from the Global South. *New Media Soc.* **26**, 1366–1383 (2024).

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Author contributions
F.C. conceptualized the paper, designed the figures and drafted a first version of the manuscript and the tables. C.B. and N.M.-D. refined and contributed to Table 1. T.M., R.B., C.B., W.C., M.G., A.H., Ş.K., S.T.I., N.M.-D., M.P., R.H.M.P., P.S., D.Ü.-V. and D.S. provided text, input, feedback and references to the full manuscript, supported the specifications of Table 2, and helped to balance out the overall text.

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Additional information
Correspondence should be addressed to Felix Creutzig.

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