Chapter 6:

Resilient Infrastructure as an Accelerator of Transformative Climate Action in Cities

Quick facts

1. Resilient infrastructure is a critical element of urban climate action to achieve the Sustainable Development Goals, the Paris Agreement, the Sendai Framework and the New Urban Agenda.

2. Infrastructure around the world is being affected by climate change, and the costs resulting from damaged assets, expensive repairs, service disruptions and loss of life are expected to increase.

3. The world still faces a glaring infrastructure gap, leaving the majority of people in developing countries vulnerable to climate change.

4. Most urban infrastructure needed to achieve resilience has yet to be built, offering the possibility to build it more sustainably and inclusively.

5. Investing in resilient infrastructure construction, operation and maintenance can generate long-term financial benefits to cities and national economies.

Policy points

1. Infrastructure needs to be resistant to the effects of climate change, but this in itself is not sufficient to accelerate effective climate action.

2. Transformative infrastructure should build the social and economic resilience of inhabitants to climate change, address both the drivers of climate change and vulnerability, and be delivered in a way that contributes to broader and positive lasting societal change.

3. Community-led service provision models and other forms of participation empower communities to shape urban infrastructure and adapt more effectively to the challenges of climate change.

4. By recognizing and incorporating informally built and managed infrastructure, cities can harness their potential to contribute to sustainability goals while enhancing their own resilience.

5. Blue-green infrastructure and nature-based solutions can be transformative accelerators of climate action in cities.

Infrastructure plays a critical role in shaping the ways in which human activities drive climate change, and in turn the ways in which climate change impacts on humans. How the various infrastructures associated with cities—including housing, basic services, transportation systems or energy production—are constructed, maintained and operated has major implications for mitigation and adaptation.

The use of buildings are responsible for 17.5 per cent of global greenhouse gas (GHG) emissions, while transport and waste account for 16.2 per cent and 3.2 per cent respectively.[1] When the embodied emissions from construction are added to this, the use and construction of buildings alone is responsible for 37 per cent of emissions.[2] Thus, planning and developing infrastructure in these sectors are pivotal in mitigating global warming. Urban infrastructure networks are already experiencing the severe physical impacts of climate change, affecting economic productivity, human well-being and health. This takes place in a context in which current infrastructure is inadequate to meet the basic needs of urban residents in many cities around the world.

Yet, resilient infrastructure provides significant opportunities to achieve effective people-centred climate action in cities and urban areas. Not only can well-designed and managed infrastructure accelerate pathways to net-zero urban futures, but it can also protect communities from the inevitable negative impacts of climate change. Moreover, infrastructure can play a transformative role in reshaping the relationships between urban residents and their surroundings in ways that contribute to lasting and climate-resilient development.

As a large share of urban infrastructure remains to be built, meeting future infrastructure needs will be paramount for reducing global emissions and building both human and ecosystem resilience to climate change. Current investments in infrastructure, fall far short of the US$3.7 trillion required every year until 2040.[3] The global infrastructure deficit affects millions of people in rapidly expanding cities, particularly in low- and middle-income countries, where residents lack access to basic infrastructure services such as energy, water and sanitation, waste management and transportation.

Climate-resilient urban infrastructure that addresses drivers of vulnerability can enhance adaptive capacity and improve the quality of life of urban populations while safeguarding against climate risks

Climate-resilient urban infrastructure that addresses drivers of vulnerability can enhance adaptive capacity and improve the quality of life of urban populations while safeguarding against climate risks. Strategies such as integrating low-carbon informal livelihoods into city-wide service provision models, designing culturally appropriate and energy-efficient housing, and engaging diverse groups in participatory planning processes for infrastructure projects can enhance resilience and contribute to global sustainability goals.

This chapter begins by providing a typology of resilient infrastructure that accelerates effective climate action, followed by an exploration of the state of global infrastructure, how it is contributing to GHG emissions, and how it is being damaged by climate-related impacts. The following sections subsequently examine the different categories of infrastructure in more detail: infrastructure that is *climate-resistant*, infrastructure that contributes to *resilience*, and infrastructure that is *transformative*. The final section of the chapter focusses on mechanisms for delivering transformative infrastructure, with a particular focus on the planning, policy, governance and financing conditions that are necessary to enable this.

6.1. The Role of Urban Infrastructure

Urban infrastructure is directly or indirectly responsible for a significant proportion of GHG emissions, yet it is also key in building the resilience of urban areas to environmental shocks. As a result, urban infrastructure and urban responses to climate change "both configure and are configured by" each other.[4] The New Urban Agenda (NUA) commits to the promotion of "equitable and affordable access to sustainable basic physical and social infrastructure for all", and recognizes the significance of infrastructure in driving resource efficiency and resilience—a point reinforced by the recently adopted 2023 United Nations Habitat Assembly Resolution on Urban Planning and Sustainable Infrastructure.

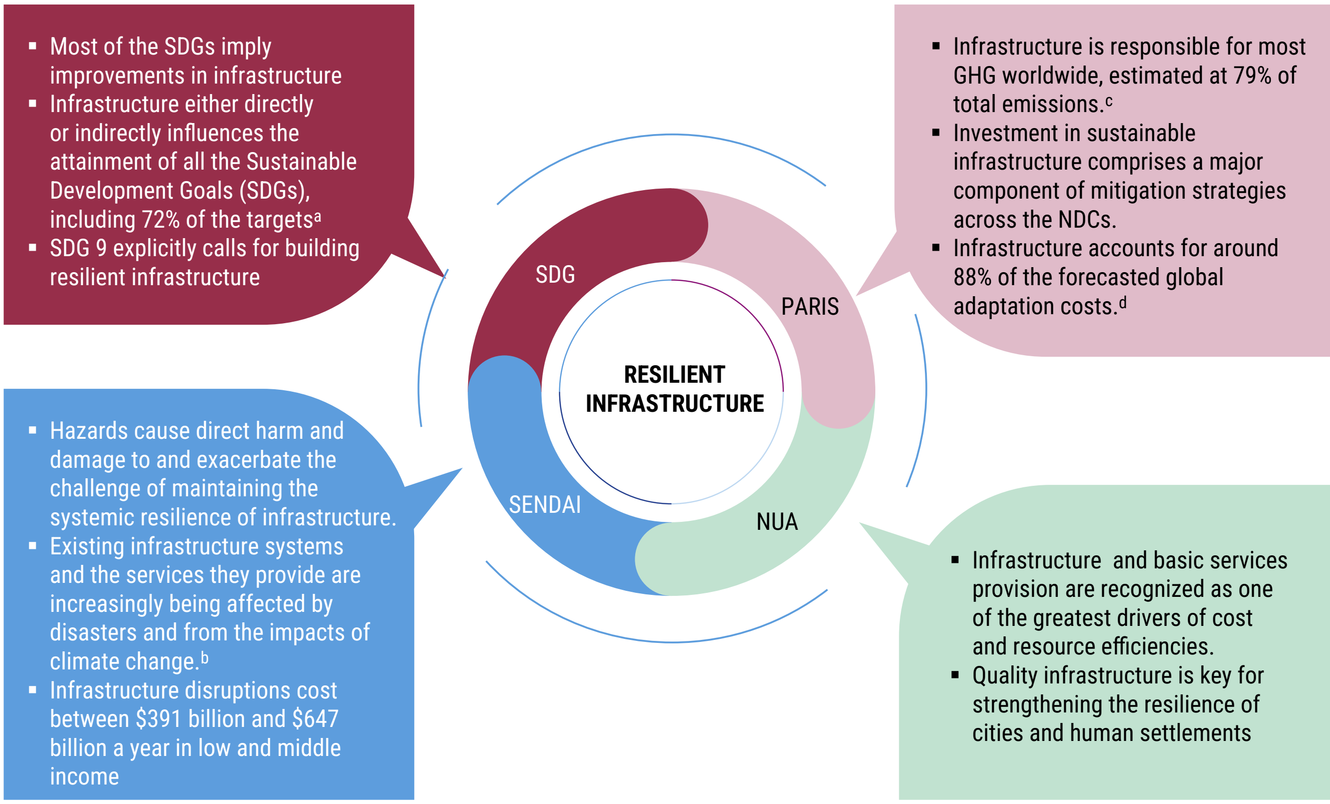
6.1.1. The impact of inadequate urban infrastructure

Inadequate or outdated physical infrastructure and service delivery mechanisms can have dramatic effects on human well-being, the economy and the environment,[5] with particularly deleterious effects for issues of equity and sustainability. This is a global challenge, but is particularly evident in developing countries. The lowest levels of provision can be found in Sub-Saharan Africa, where only 22 per cent of the urban population have access to piped water,[6] and South Asia, where only 23 per cent have access to safely managed sanitation.[7]

These averages mask huge differences between and within cities, with low-income neighbourhoods and secondary cities being particularly disadvantaged. For example, though globally the percentage of people living with inadequate sanitation provision is declining, the improvement is not equally distributed: countries with little or no access to wastewater treatment infrastructure in the year 2000 were also those most likely to show no improvement (or even a deterioration) in coverage by 2015.[8]

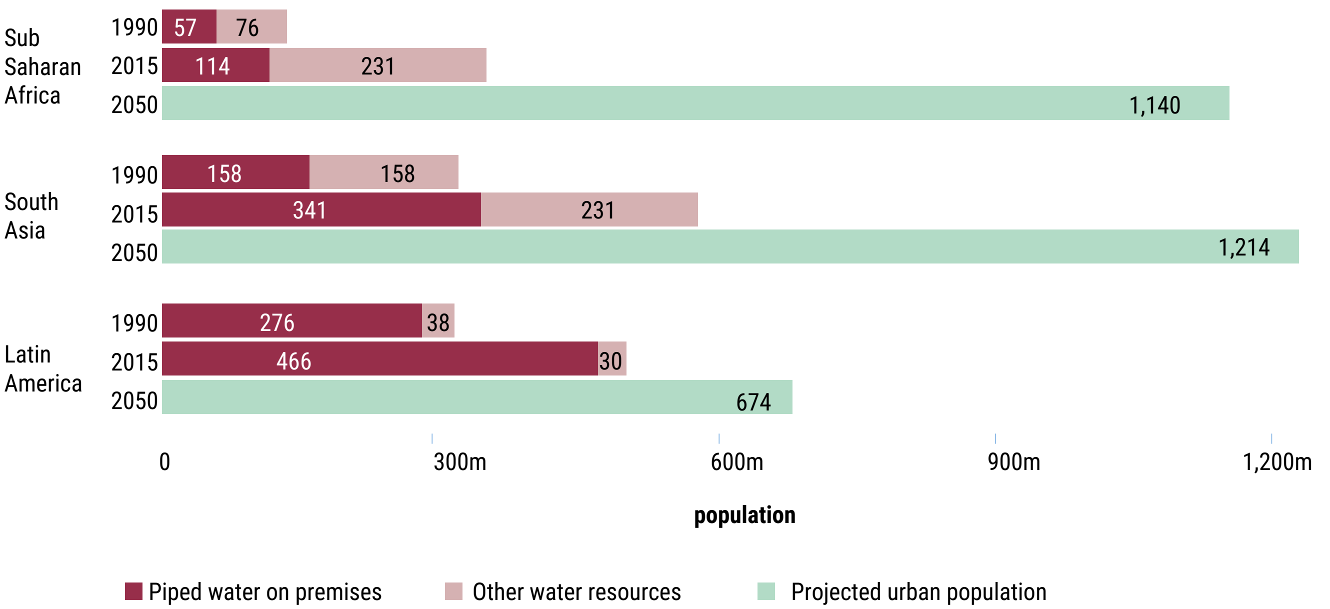
It is also the cities of the developing world where 90 per cent of all population growth is now taking place,[9] placing still further pressure on already inadequate infrastructure systems. Close to 1.1 billion people worldwide reside in slums and informal settlements: in effect, "the world is producing new slum dwellers faster than it can address existing slums".[10] In informal settlements, as well as in many planned neighbourhoods in low-income countries, access to basic public infrastructure can be inadequate or non-existent.

Figure 6.1: The connections between resilient infrastructure and major global sustainability frameworks



Source: [a] Thacker et al., 2019; [b] Thacker et al., 2021, p. 12.; [c] Thacker et al., 2021, p. 13; [d] Hallegatte et al., 2019b, p. 2.

Figure 6.2: Access to water in developing countries



Source: Mitlin et al., 2019; WHO & UNICEF, 2017; UN DESA, 2017.

Sidewalk repair in Jakarta, Indonesia © Shutterstock

6.1.2. Barriers to inclusive infrastructure access

In many cases, it is not only the physical absence of infrastructure that precludes inhabitants from accessing basic services. As Chapter 4 explained, institutional factors such as lack of access to social and financial services, exclusion from city-wide development plans, and limited access to information act as multipliers of risk.[11] These can serve to exclude populations based on socioeconomic features such as income-level, ethnicity, legal status, and gender.

These institutional factors can severely hinder people's ability to respond to climate-related shocks. For example, water supplies are frequently contaminated by solid and human waste, leading to serious public health issues that are particularly dangerous for children.[12] Many informal settlements are situated in areas that are exposed to natural and geographic hazards such as flooding, landslides, subsidence and local air pollution, for example from nearby industries.[13] The risks associated with the increased incidence of natural disasters caused by human-induced global warming are exacerbated in informal settlements by overcrowded living conditions, unsafe housing, poor health and inadequate infrastructure.[14]

In cities of developed countries, the most pressing infrastructure challenges tend to relate to upgrading and modernizing ageing infrastructure. Still, certain places experience higher levels of relative poverty, where often already marginalized and minority groups live in areas characterized by underinvestment in urban infrastructure. Characteristics like current urban form (dense or sprawling), the level of inequality, average and per capita income level, the city's economic base (industry- or service-oriented), the presence of corruption in government, and the power of those with vested interests such as incumbent firms, vary greatly from city to city. For example, it has been shown that higher levels of corruption strongly correlated to lower overall infrastructure quality.[15] As a result of these different characteristics and development pathways, the infrastructure needs and challenges of cities and urban areas can vary significantly, as shown in Table 6.1.

In cities of developed countries, the most pressing infrastructure challenges tend to relate to upgrading and modernizing ageing infrastructure

Table 6.1: Infrastructure challenges in different types of urban areas

City type	Definition	Infrastructure challenges	Examples
Megacity	A city with a population of 10 million people or more	Severe traffic congestion, high energy consumption, high pollution levels, housing shortages, gentrification and high cost of living	Tokyo, Japan Sao Paulo, Brazil Cairo, Egypt New York, USA London, UK
Medium city	A city with a population of between 1 million and 10 million people	Balancing growth with infrastructure expansion, economic diversification, scaling infrastructure and social services	Cape Town, South Africa Melbourne, Australia Rome, Italy
Small city	A city with a population of less than 1 million people	Limited budgets, attracting and retaining businesses and talent, modernizing infrastructure	Heidelberg, Germany Wellington, New Zealand Gaborone, Botswana
Low-income	Cities in countries with a low GDP per capita	Limited financial resources, often rapid urbanization, high number of informal settlements, inadequate city-scale infrastructure	Dhaka, Bangladesh Kathmandu, Nepal Port Moresby, Papua New Guinea Kinshasa, DRC
High-income	Cities in countries with a high GDP per capita	Ageing infrastructure, high environmental impact, technological integration	Oslo, Norway Sydney, Australia Vancouver, Canada Osaka, Japan
Coastal	Cities located on or near a coastline	Climate change and sea-level rise, environmental degradation, disaster preparedness	Miami, USA Shanghai, China Rio de Janeiro, Brazil Barcelona, Spain
Inland	Cities located away from coastlines, possibly in landlocked regions	Overcoming geographic isolation, resource management, economic diversification	Denver, USA Vienna, Austria Urumqi, China Asunción, Paraguay
Fast growing	Cities experiencing rapid population and/or economic growth	Managing urban sprawl, strain on infrastructure services, high environmental impact	Bangalore, India Nairobi, Kenya Lima, Peru Houston, USA
Stable	Cities with stable, moderate growth rates	Balancing growth and sustainability, avoiding economic stagnation	Munich, Germany Kigali, Rwanda Calgary, Canada
Shrinking/ declining	Cities experiencing population loss and economic decline	Reduced tax base, maintaining (outdated) infrastructure with limited funds	Detroit, USA Leipzig, Germany Yokohama, Japan Valparaiso, Chile
Centralized	Cities where decision-making is highly concentrated at the national or central government level	Potential lack of local fiscal, human, and/or technical capacity, limited responsiveness	Paris, France Moscow, Russia Bangkok, Thailand Riyadh, Saudi Arabia
Decentralized	Cities with significant local autonomy in decision-making	Coordination with higher levels of government, funding limitations when reliant on central transfers	San Francisco, USA Berlin, Germany Curitiba, Brazil
Elected local government	Cities governed by elected officials with high levels of public participation	Balancing diverse interests, efficient decision-making	Copenhagen, Denmark Toronto, Canada Stockholm, Sweden
Selected local government	Cities governed by appointed officials or leaders with centralized, often top-down decision-making	Limited public participation, potential for discontent with large-scale infrastructure projects	Dubai, UAE Beijing, China Hanoi, Vietnam

Yet no matter the specific urban circumstances, every city stands to benefit from investing in green and climate-resilient infrastructure. Where this is done in an inclusive manner, it can support poverty reduction, address inequalities and cultivate more participatory, non-hierarchical relations between governments and citizens, opening up possibilities for more just and sustainable futures.[16]

6.1.3. A framework for accelerating climate action through infrastructure

While significant resources are now being channelled towards urban infrastructure that responds to climate change impacts, the approaches to these often exist on a continuum that can be broadly categorized as follows (see Figure 6.3):

- *Climate-resistant* infrastructure withstands climate shocks and continues to provide the services with which it is associated in situations of natural disaster or crisis. Though it can bring significant benefits in reducing physical damage to assets, its solutions may privilege technical priorities over socioeconomic concerns, potentially ignoring or even reinforcing inequalities.

- *Resilience-building* infrastructure delivers health-promoting or other basic services that help urban residents to develop their adaptive capacity so that they are better able to respond to climate-induced shocks. Typically, recognizing that vulnerability to climate change impacts is determined by social as well as environmental factors, communities will be actively engaged in the design and development of infrastructure to align with local needs and minimize negative impacts.

- *Transformative* infrastructure addresses the drivers of both GHG emissions and vulnerability in a way that leads to wider and more structural reform as part of the transition towards inclusive and sustainable cities. Its approach goes beyond conventional participatory approaches in that it actively seeks to reconfigure social and economic exclusion, with infrastructure seen as a tool to deliver broader justice-based outcomes.

Conversely, poorly planned and implemented, or badly maintained infrastructure can actively erode the resilience of cities, particularly of low-income residents. This framework is illustrated in Figure 6.3. While these approaches often exist on a continuum and the distinctions between them may at times be blurred, Table 6.2 demonstrates the differences in how these various infrastructures respond to key vulnerabilities.

Figure 6.3: A typology of resilient infrastructure in the context of climate change

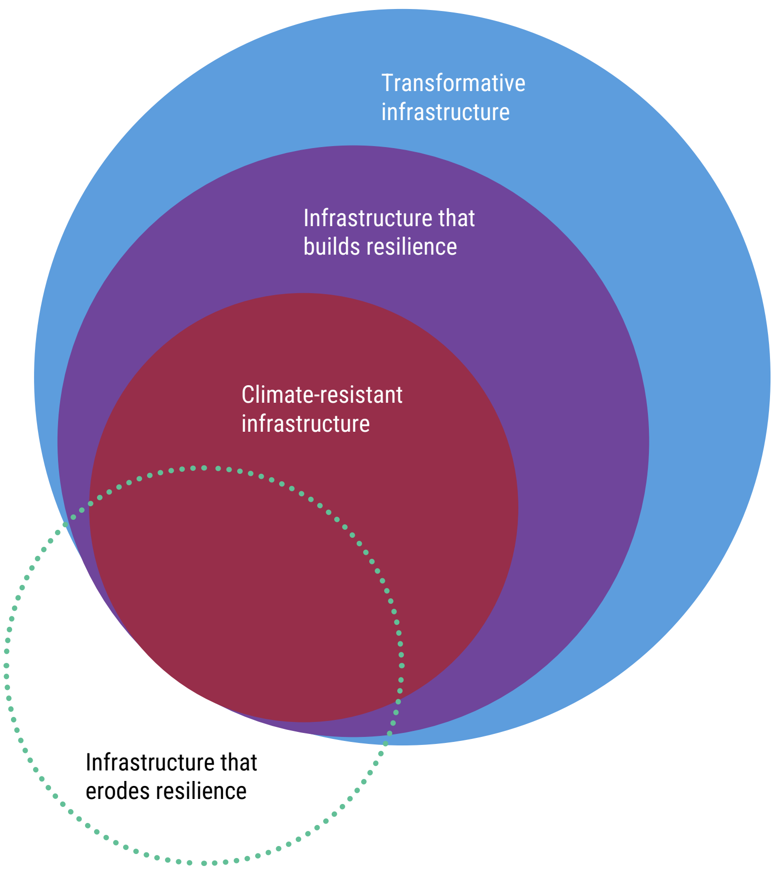


Table 6.2: How different types of resilient infrastructure can impact non-climate-related drivers of vulnerability

Driver of vulnerability	Infrastructure that erodes resilience	Climate-resistant infrastructure	Resilience-building infrastructure	Transformative infrastructure
Informal livelihoods	Replacement of informal with formal livelihoods (that many informal workers cannot access)	Provision of infrastructure that is capable of withstanding climate-related shocks and stresses, but which is implemented without specific concern for how it will affect vulnerable or marginalized groups and low-income or informal settlements	Integration of informal livelihoods in service provision models	Integration of low-carbon informal livelihoods into city-wide service delivery models
Poor quality housing and overcrowded living conditions	Gentrification of existing neighbourhoods		Community-led upgrading that supports incremental design	Low-carbon, culturally appropriate housing that enhances residents' access to urban services and social networks
Inadequate access to basic services	Improved service access that only serves certain groups		Improved service access for those who need it most	Participation in planning, design and delivery of low-carbon service models
Insecure land tenure	Eviction of those without land titles (often without fair compensation)		De-facto tenure rights recognized	Legitimization of informal and communal land rights
Environmental stresses	Local environmental degradation		Community-based management of the local environment	Enhancement of local environment and contribution to global environmental goals
Social protection	No social protection for (informal) workers		Improved access to non-contributory social protection schemes	Universal social protection (contributory and non-contributory) schemes extended to all formal and informal workers

This framework provides the central point of reference for much of the analysis that follows in this chapter. While the next section takes a step back to describe global infrastructure trends more generally and their contribution to GHG emissions and climate change, later sections will describe in greater detail the distinct challenges and opportunities of the different approaches (climate-resistant, resilience-building and transformative). In particular, it will highlight the importance not only of building current and future climate change impacts into infrastructure as a minimum, but also the unique pathways to deeper change that inclusive, socially informed policies can bring.

This chapter does not focus on infrastructure that erodes resilience, but it is important to acknowledge that experiences of maladaptation are widespread. Examples certainly exist of infrastructure that is planned and implemented by private developments, municipal authorities, and national governments without regard for whether or not it is fit for purpose in relation to current and anticipated climate threats. A common characteristic of maladaptation is that vulnerabilities are shifted from one community to another.

For example, the recent construction of seawalls in Fiji to protect people from rising sea-levels has inadvertently made those living close to the new infrastructure more exposed to flooding, as it is now more difficult for stormwater to drain into the sea. Changes in sediment deposits from the seawall intervention also shifted vulnerability to communities further along the coast.[17] The implementation of adequate environmental safeguards—as a minimum standard—should increasingly prevent construction of infrastructure that is likely to fail when exposed to hazards. Similarly, the adoption of appropriate social safeguards should prevent the development of infrastructure that impedes the well-being or livelihoods of urban residents.

6.2 Infrastructure and Climate Change

Cities are engines of economic growth, sites of innovation, and spaces for social transformation and political inclusion. These achievements are in large part possible due to the availability and quality of urban services and infrastructure.[18] This section identifies the types of infrastructure that exist in urban areas, examining its contribution to GHG emissions and the extent to which it in turn is negatively affected by disasters and climate change. Sustainable, inclusive urban service provision is fundamental for ensuring the living standards of all citizens and residents, managing a city's ecological footprint, and harnessing opportunities for prosperity.

6.2.1 Types of urban infrastructure

Urban service delivery encompasses the physical systems that make a city, as well as the totality of interactions, rules, norms and values that govern those infrastructures. It is increasingly recognized that "green" (or natural) infrastructure, as well as "blue" (related to water) infrastructure also plays a critical role in climate action. Taken together, physical and natural infrastructure "form the foundation on which human settlements are built and function" and include water and sanitation, waste collection and management, transport and energy.[19] Information and communications technology (ICT) is also increasingly recognized as a separate category of infrastructure. Housing can also be considered an infrastructure (see Box 6.5), since it is the primary means by which citizens access other basic urban services[20] and exercise their right to citizenship.[21] Finally, protective infrastructure (such as stormwater drainage, seawalls and dykes) is a subset of the built environment with the specific purpose of reducing risks to people and other infrastructure.

Infrastructure exists and is used at various scales—from appliances and utilities within the household, to transnational distribution networks. The focus of this chapter is primarily on neighbourhoods (community infrastructure) and cities (trunk infrastructure), as these have the most direct bearing on urban lives, well-being and productivity—and are closely linked with and dependent on each other. The main elements of this infrastructure are shown in Table 6.3.

Table 6.3: Neighbourhood and urban infrastructure

Sector	Actual or Potential Examples	
	Neighbourhood (community infrastructure)	Urban (trunk infrastructure)
Energy	Distributed renewable energy sources, including rooftop solar panels or small wind turbines	Large-scale power generation and distribution systems, often involving centralized power plants and extensive grids
Transport	Local cycling lanes, pedestrian pathways, and community-based transportation initiatives	Major road networks; railways and airports; centralized public transportation systems
Water and Sanitation	Individual or community-level rainwater harvesting; decentralized wastewater treatment; local well-based or groundwater sources	City-wide water storage and reticulation networks; city-wide sewage collection and treatment plants
Waste Management	Household composting, recycling initiatives and community clean-up programs	Large-scale collection systems; incinerators; landfills
ICT	Household and community networks	City-wide networks, servers, etc.
Protective infrastructure	Micro-drainage; small-scale river or coastal protection.	Stormwater drains; sea walls; river embankments; dykes.
Housing	Individual homes, including self-built and informal housing	Whole neighbourhoods, including apartment blocks
Health facilities	Neighbourhood public health facilities (e.g. community clinics, maternity and neo-natal clinics)	Large-scale health facilities (e.g. general hospitals)
Education and other social services	Early childhood and primary schools that serve local neighbourhoods; community halls, religious facilities, etc.	Secondary and tertiary institutions that serve city/national scale; other large public institutions

Box 6.1: Informal infrastructure and climate change

A significant proportion of the built environment in cities in low- and middle-income countries is both constructed and managed informally. Where public services often fall short, alternative providers step in to meet the demand. While some operate within formal legal frameworks, many function semi-formally or informally, and by doing so fill gaps in crucial services such as transportation and water provision.

This is notable for various reasons. First, informal settlements have been described as "perhaps the most striking representation of a global infrastructure crisis that has beset an increasingly resource-constrained world",[22] highlighting the extreme inequality both within and between cities in access to basic services. Second, informal infrastructure is often not accounted for in official infrastructure-related inventories. Third, informal infrastructure usually falls outside of formal (i.e. authority-led) building, planning and occupational health regulations, meaning it can be unreliable or unsafe, both for those who work in providing it as well as for consumers. Fourth, those working in—as well as relying on—informal infrastructure and services are disproportionately excluded groups, subject to intersectional vulnerabilities such as those around gender and caste.[23] All these issues are exacerbated by the fact that informal settlements are disproportionately located in low-lying or disaster-prone areas that are especially exposed to climate change risks: furthermore, their residents are typically poor and marginalized, undermining their social resilience to negative impacts.

These alternatives often come at a high cost, disproportionately affecting low-income residents who have little choice but to rely on them. Furthermore, the quality and safety of these alternative services can be compromised: for example, water from informal vendors may be unsafe as well as expensive, while informal transport services can be unreliable and contribute to congestion and pollution. At the same time, the attitude of local authorities can exacerbate these challenges: alternative service providers are frequently stigmatized and often face obstacles such as harassment from authorities. This hostility persists despite their significant contributions, such as informal waste pickers who can play a vital role in recycling and reducing GHG emissions (see Box 6.3). As argued later in this chapter, a key element in building transformative urban climate action is for greater integration between formal and informal infrastructure systems—something that can only occur if national and local governments are willing to recognize informal operators.

Alternative service providers range from private operators like minivan drivers to community-based organizations and small businesses. Frequently seen examples of informal infrastructures include water kiosks, where residents can access clean water from communal taps or standpipes, and small-scale renewable energy systems such as rooftop solar panels. Informal waste management systems, such as community-based recycling initiatives and makeshift waste collection points, play a crucial role in managing solid waste in areas where formal waste disposal services are limited or non-existent. Informal ICT networks, from community-run internet cafes to mobile phone charging stations, facilitate communication. Informal transport options, including shared minibus taxis and motorcycle taxis, provide affordable and flexible mobility solutions for residents in areas underserved by formal public transportation networks.

6.2.2 Blue-green infrastructure

An increasingly significant sub-category of infrastructure falls under the broad definition of "blue-green infrastructure". This refers to the network of natural and nature-based elements integrated into urban areas to provide a range of ecological, social and economic benefits. These features can be designed to mimic or incorporate natural processes to reduce risk of flooding, regulate urban temperatures and improve air quality, among other gains. Through the restoration and regeneration of natural ecosystems, networks of green areas can generate co-benefits for climate change mitigation and adaptation as well as human physical and mental health.[24] Their integration into wider urban planning can also be an effective way to enhance the flexibility and multi-functionality of urban spaces.

Blue-green infrastructures can help achieve effective climate action through both mitigation and adaptation, leveraging natural processes that enhance water infiltration and regulate temperatures. Vegetation can sequester carbon dioxide and aid temperature reduction through evapotranspiration, contributing to reduced energy demands by enabling passive cooling and insulation. Meanwhile, natural buffer zones like mangroves help reduce the risk of coastal flooding and erosion. Furthermore, investing in the protection of ecosystem services through the development of green infrastructure is a cost-effective and sustainable way to build urban climate resilience, while also generating employment opportunities. One study found that ecosystem restoration creates 3.7 times as many jobs per dollar as oil and gas production.[25]

Besides strengthening resilience to environmental shocks, these forms of infrastructure offer substantial social benefits as spaces for recreation, community gathering, food production and biodiversity. Encompassing a wide range of approaches, including urban agriculture, street trees, green roofs, parks, community gardens, bioswales, retention ponds and the restoration of floodplains and watersheds,[26] they can also be combined with conventional "grey" infrastructure. While these hybrid "green-grey" approaches may be more effective than either strategy applied in isolation, they are not yet widely used.[27]

Box 6.2: Social, secondary or soft infrastructure

As well as the predominantly physical, engineered systems that make up a city's built environment, a wider host of institutions must exist in order for a city to function. Though less visible, this infrastructure is equally important in building resilience to climate change as it is the foundation for economic activity and human well-being. Variously referred to as "social", "soft" or "secondary" infrastructure, this mostly spans the policies, resources and services that allow citizens to participate in productive social and economic activities. This includes social services, public education, healthcare, welfare and adequate income. Though this chapter focuses primarily on the role of hard (both physical and green-blue) infrastructure in building urban climate resilience, where relevant it also draws out connections with soft infrastructure.

Soft solutions can play a crucial role in responding to environmental challenges, as demonstrated in Jodhpur, India, where the revival of traditional practices has helped strengthen local resilience to rising temperatures and drought. While climate-sensitive approaches such as rainwater harvesting have been passed down from generation to generation for centuries, since the advent of piped water this knowledge has slowly been eroded. However, recognizing the value of these tried and tested approaches, the authorities in Jodhpur incorporated elements into the development of the city's Heat Action Plan. The implementation strategy involved culture-based climate action that integrated the preservation of cultural heritage, such as traditional water systems and historic sites, as a tool to build climate resilience while also safeguarding the rich cultural identity of the city. The initiative also advocated for integrating traditional architectural practices into modern buildings to reduce energy consumption and mitigate the effects of urban heat islands. Furthermore, women—who are disproportionately impacted by extreme heat and other climate change—are recognized as crucial bearers of local climate knowledge.

Consultation for Jodhpur's heat action plan © Siddhartha Das/GRRID Corps

Source: Madapala & Kanji, 2024; RGUKT Srikakulam & GRRID Corps, WCR Case Study submission.

6.2.3 Global distribution and trends in infrastructure

As the world has rapidly urbanized, it has increasingly been covered by infrastructure in all its forms. This is illustrated by the growing prevalence of "anthropogenic mass", comprising manmade materials such as concrete, aggregates, bricks, asphalt, processed metals and plastics. At the beginning of the 20th century, anthropogenic mass was equal to only 3 per cent of global biomass—but by 2020 it exceeded biomass for the first time.[28] Much of this infrastructure is in urban areas: indeed, "to the extent the twenty-first century is the 'urban century', its material expression appears likely to be an 'infrastructure century'".[29]

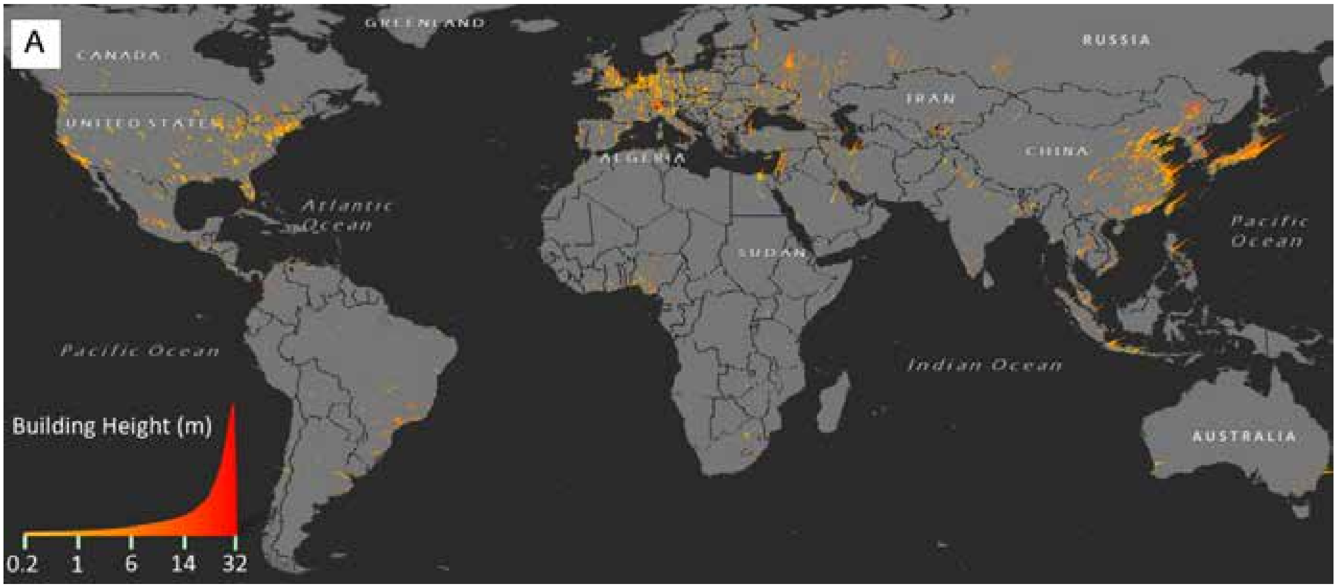
This infrastructure is distributed highly unevenly around the world. The top three countries with the largest amount of urban built-up infrastructure—China, the United States, and Japan—together account for approximately 50 per cent of the global total.[30] The gaps between high- and low-income countries are stark: the built-up infrastructure in 45 developed countries (home to 16 per cent of the global population) is roughly equivalent to that of 114 developing countries where 74 per cent of the global population reside.[31] This is vividly illustrated in Figure 6.4, which clearly shows the concentration of built-up height in North America, Europe and East Asia.

It is estimated that a further 30 billion tonnes of anthropogenic mass is added each year on average, with wide implications for natural hazards, biodiversity, and various climatic and biogeochemical cycles.[32] This is particularly notable in emerging economies: the total floor area of buildings globally is expected to double by 2060, with most of this growth expected in Asia and Africa.[33] The need for further investment in infrastructure is therefore significant, with one estimate suggesting that US$6.3 trillion is required each year between 2016 and 2030 to sustain growth and meet basic needs.[34] Given that urban infrastructure generally lasts between 30 and 100 years, whatever countries and cities choose to construct now will have profound economic and environmental repercussions—for better or worse—for many years to come.[35]

The past two decades have seen major shifts in infrastructure developments. Across Asia, particularly in East, South and Southeast Asia, rail and metro infrastructure has been growing at an accelerated rate. Of the 89 new metro systems that have opened since the year 2000, around two thirds were built in Asia.[36] A significant trend in Europe has been in the recommitment for long-distance train routes: while some of this is associated with the expansion of high-speed networks, institutional arrangements such as the European Green Deal's emphasis on rail travel as a component of achieving climate goals, along with greater cross-border collaboration, are at least as significant. Similarly, improvements in solar photovoltaic technology (and associated reductions in cost) have been instrumental in making this available across South Asia—but government initiatives (such as India's National Solar Mission), institutional innovations (such as the Net Metering Policy in Bangladesh) and other incentives have also contributed to the rapid expansion of this infrastructure at both large scale and in micro-grid / off-grid settings.

There are also emerging qualitative trends in infrastructure, including a shift towards "infrastructure decentralization".[37] Decentralized infrastructure can be more resilient through in-built redundancies, and by limiting the places in the network that can lead to a "single point of failure". In the face of climate change, cities that rely on a single or limited number of places for energy generation or wastewater processing are highly susceptible to climate shocks.

Figure 6.4: Global urban built-up heights derived from satellite observations [the colour and height of the bar represent built-up heights in each 500m grid]



Source: Zhou et al., 2022

A distributed infrastructure network is a particular form of decentralization, where a large diversity of providers and consumers are connected with each other.[38] Nature-based solutions (NbS) to infrastructure exemplify a distributed system, and much of the resilience of NbS is derived from the dispersed yet interconnected aspect of these ecological services. These shifts will require infrastructure designers and developers to incorporate connectivity and whole-systems thinking in their plans. Indeed, infrastructure provision in informal settlements often emerges in a decentralized and distributed manner. In many cases, these systems are providing lessons for governments to reconsider conventional approaches: for example, in Trivandrum, India (see case 12 in the Case Study Annex), the city's centralized waste management was reconfigured around "micro-composting centres" for higher collection and recycling rates.

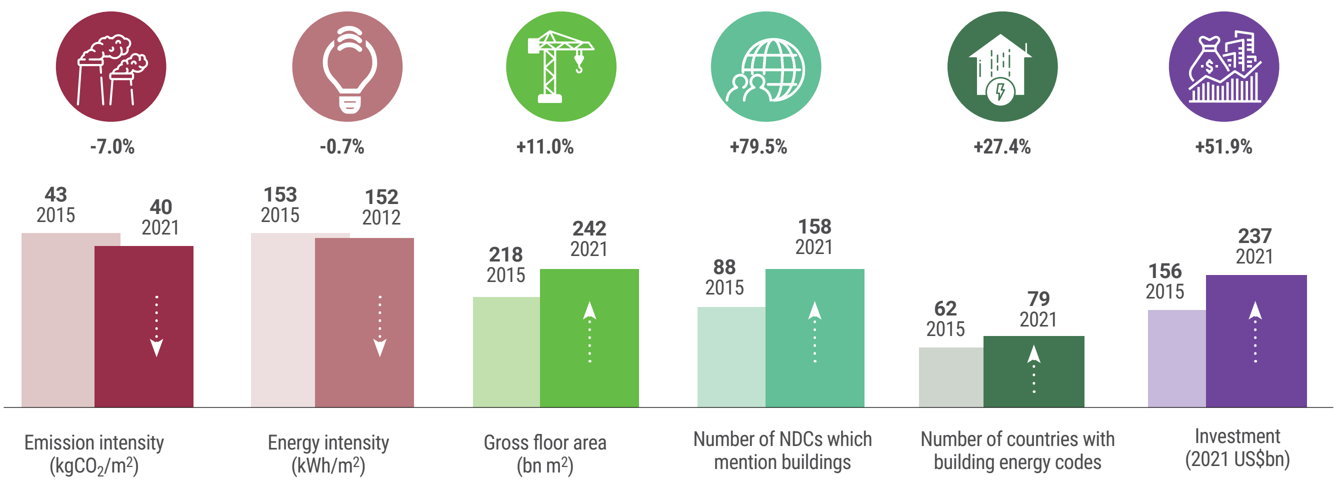
6.2.4 Infrastructure and emissions

As highlighted in Chapter 1, the urban share of global GHG emissions is substantial and continues to increase. While not all of these urban emissions are associated with infrastructure, the IPCC concludes—with very high confidence—that "the construction of new, and upgrading of existing, urban infrastructure through 2030 will result in significant emissions".[39] Infrastructure contributes to GHG emissions through its entire lifecycle, from construction to its use and disposal. For a subset of major cities globally (members of the C40 climate network), emissions from building and infrastructure construction are expected to form the single largest category of consumption-based emissions (21 per cent) between 2017 and 2050, with 60 per cent of these being associated with the production and delivery of building materials.[40]

Annual emissions from buildings operations have reached an all-time high of 12 billion tonnes of CO_2e.[41] These emissions have grown significantly over time: non-residential buildings generated 54 per cent more CO_2 in 2019 than in 1990, with residential buildings generating 32 per cent more CO_2 during the same period.[42] When including estimated CO_2 emissions from producing buildings materials, buildings represented around 37 per cent of global CO_2 emissions in 2021.[43] Although incremental improvements are being made in reducing emissions intensity and energy intensity per unit of building area, the gross floor area is increasing at a more rapid rate—meaning that the overall trends are of increased emissions from buildings (Figure 6.5). Indeed, as the total floor area of buildings is expected to double between 2025 and 2065, primarily in Asia and Africa[44] – given the lack of stringent energy codes in many countries in these regions, this presents a significant opportunity for improved alignment with net-zero goals.[45]

The UNEP Global Buildings Climate Tracker confirms that despite progress at the policy level, such as expanded building energy codes, there must be greater efforts to reduce emissions overall and to improve building energy performance, given this trend of increasing floor area: it concludes that there is "a growing gap between the actual climate performance of the sector and the necessary decarbonization pathway".[46] Data from the Global Infrastructure Hub estimates that only 60 per cent of infrastructure projects currently have a GHG emissions target that is aligned to net-zero: of these, only one third have a target that is firmly science-based (Figure 6.6).[47] In this regard, the extent to which the emissions generated are fully accounted for, can be as significant as the targets themselves. For instance, while Asia is leading the way in net-zero targets for infrastructure assets, Europe has the most comprehensive net-zero targets that also typically include so-called "Scope 3" emissions—those linked to all used and imported goods and services needed to build the infrastructure.

Figure 6.5: Global buildings and energy trends (2015 and 2021)

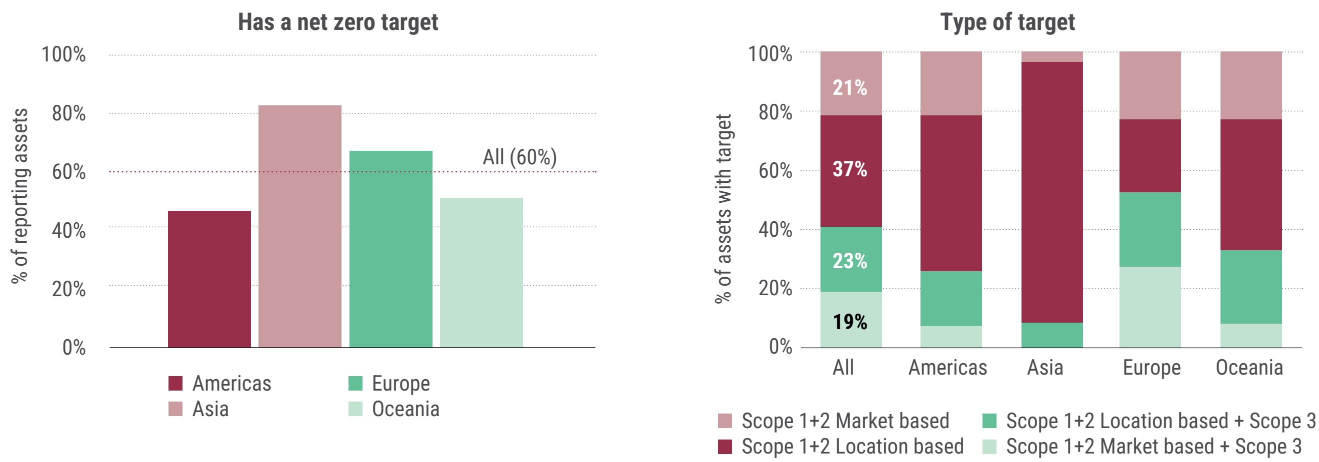


[1]Values included for the baselines have been updated from previous versions of the Buildings-GSR due to both historic input data updates for emissions and floorspace, and also deflation factors for US$. The proportional changes between previous years remains similar.

Source: UNEP, 2022b.

Damage to infrastructure caused by natural disaster, Durban, South Africa © Shutterstock

Figure 6.6: Net-zero targets of infrastructure assets



Source: Global Infrastructure Hub, 2023.

The way in which infrastructure is operated and maintained throughout its lifecycle also has a significant impact on its performance in relation to climate change. As well as direct reductions in emissions through more efficient performance, appropriate maintenance can extend the lifespan of infrastructure assets, reducing the need for additional construction and its associated costs and emissions.[48] This can also help to ensure that infrastructure remains able to cope with different shocks and stresses associated with climate change.

6.2.5 Infrastructure losses from disasters and climate change

Infrastructure is already being adversely affected by disasters and climate change. The Coalition for Disaster Resilient Infrastructure estimates an average annual loss of approximately US$700 billion in infrastructure and buildings, of which 70 per cent can be attributed to climatic hazards.[49]

A World Bank assessment estimated that power generation and transport infrastructure alone incur losses of US$30 billion a year on average from natural hazards, with low- and middle-income countries shouldering about US$18 billion of the total amount.[50] These losses are expected to increase significantly as a result of climate change: the Economist Intelligence Unit estimates present losses of US$4.2 trillion by 2100 under a 2°C scenario, rising to US$13.8 trillion in a 6°C scenario.[51] While most infrastructure is currently still concentrated in the global north, as low- and middle-income countries are more vulnerable, they are expected to incur the highest infrastructure losses. While they only account for about one third of the total exposed value of infrastructure, they represent 54 per cent of the risk to climate change.[52] These infrastructure losses can be disaggregated by types of infrastructure, as illustrated in Table 6.4.

Table 6.4: Observed and expected climate impacts on different infrastructure sectors

Infrastructure Sector	Examples of Observed and Expected Impacts
Energy	Current annual damages of €0.5 billion per year in Europe; projected to increase 1612 per cent by the 2080s 33.9 per cent of Chinese population vulnerable to electricity supply disruptions from floods or droughts Power system costs in USA expected to increase by US$50 billion by 2050
Transport	7.5 per cent of road and railway assets exposed to 1-in-100 year flood events each year, with total global expected annual damages of US$3.1 to 22 billion (mean of US$14.6 billion) Damage to transport infrastructure in Europe could rise from €0.5bn per year to over 10 billion by the 2080s Increased failure of transport infrastructure (e.g. melting of asphalt, inundation of underground systems, bridge failures, flooding of ports and airports in coastal zones)
Water and sanitation	Substantial climate risks expected from droughts, flooding and storm surges
Waste	Potential damage to landfill sites and other waste processing infrastructure Disruption to collection schedules
ICT	Damage to key ICT assets (cables, masts, pylons, data centres, telephone exchanges, base stations, switching centres) Damage to underground ICT infrastructure from ground shrinkages arising from droughts and heatwaves
Protective infrastructure	Sea walls, flood protection and other infrastructure damaged by events that exceed their capacity
Housing	Negative effects on housing stock (including physical damage and loss of property value), from climate impacts including flooding, heat, and wind
Health	Increasing damage to healthcare facilities (hospitals, clinics, residential homes)
Education and other social services	Increasing damage to educational and other social services facilities; disruption to education through use of schools as emergency shelters

Source: Dodman et al., 2022.

Table 6.5: Impacts of infrastructure disruption on firms and households

Sector	Direct Impacts	Coping Costs	Indirect impacts
Energy	Reduced utilization rates (US$38bn/year) Sales losses (US$82bn/year) Lower productivity of family firms Diminished well-being	Other sources of generation (initial investment and operating costs)	Service disruption Higher barriers to market entry Inability to provide on-demand services and goods Constrained access to jobs, markets and services Health impacts on individuals and households (including medical costs, lost income)
Transport	Reduced utilization rates (US$107bn/year) Congestion and loss of time Higher fuel costs	Increased inventory to cope with disruptions	
Water (and Sanitation)	Reduced utilization rates (US$6bn/year) Diminished well-being and loss of time	Costs for other water sources	
Tele-communications (and ICT)	Reduced utilization rates Diminished well-being	Reliance on more expensive temporary alternatives	

Source: Hallegatte et al., 2019b (based on tables 0.1 and 0.2 of reference).

Beyond the direct costs of damage, the effects of disrupted infrastructure services have multiple impacts on both urban firms and urban households. Indeed, the "indirect losses associated with service disruption are often greater than the value of asset loss and damage."[53] These range from reduced utilization rates, to asset damage or dysfunction, to requirements for alternative investments to cope with damage, and to lower individual productivity and well-being, as illustrated in Table 6.5. Sub-standard and poorly maintained infrastructure assets are particularly at risk of causing disruption to essential services and interlinked indirect losses.

Infrastructure can also be affected by compound risks. These occur when a single hazard causes impacts across multiple sectors: for example, when urban flooding from extreme precipitation disrupts transport infrastructure and networks, ICT networks and energy generation. These can also lead to cascading risks, whereby failures in one system (for example, electricity generation and distribution) directly lead to failures in other systems set up to manage potential threats (such as stormwater pumping stations).

6.3 Climate-resistant Infrastructure

As discussed in the introductory section, this chapter proposes a framework for infrastructure development that exists on a continuum between *climate-resistant*, *resistance-building* and *transformative* approaches to infrastructure development. This section begins by examining the particular opportunities and challenges surrounding climate-resistant infrastructure.

Climate-resistant urban infrastructure is planned, designed, built and operated in ways that take into account future climate-changed conditions,[54] enabling it to withstand and recover rapidly from natural disasters, extreme weather events and other environmental shocks and stresses. It can enhance a city's overall resilience to climate-related disaster by minimizing disruptions to essential services during disasters while reducing economic losses by minimizing damage to critical infrastructure. By being responsive to the increased frequency and intensity of climate-related disasters, it also enhances the ability to recover quickly and adapt to changing conditions. Besides incorporating sustainable design principles to reduce its carbon footprint, it encourages responsible land use planning to minimize vulnerability to climate impacts.

6.3.1 Opportunities: improved security and investment potential

Investing in climate-resistant infrastructure can lead to long-term cost savings. For example, by preventing damage to critical infrastructure such as water supply systems, transportation networks and power grids, measures like improved construction standards and flood protection will reduce the financial burdens associated with frequent repairs and upgrades.

Climate-resistant infrastructure projects also have the potential to attract investment and spur wider economic development. Investors are increasingly drawn to cities that demonstrate a commitment to safeguarding their assets against climate-related risks. Resilience measures can create jobs and stimulate local economies during both construction and operation, attracting commerce and innovation organizations that are drawn to the services on offer after completion. There will also be knock-on positive effects: improved infrastructure can in turn enhance public health, minimizing the associated healthcare costs and likely also preventing additional disaster recovery costs.

Climate-resistant infrastructure offers significant opportunities for enhancing the safety and well-being of urban populations during extreme climate events. In the face of climate change and an increasing frequency of natural disasters, such as hurricanes, floods and wildfires, cities with climate-resistant infrastructure are better equipped to protect their inhabitants and allow them to recover more quickly. As highlighted in Chapter 3, robust disaster response mechanisms, early warning systems and resilient building designs can significantly reduce the risks associated with these events. A proactive approach minimizes the displacement of affected communities and can prevent loss of life.

6.3.2 Challenges: unintended consequences and overlooked local realities

Infrastructure projects, even when designed to be climate-resistant, can have environmental consequences, such as the altering of natural drainage patterns or disruption of ecosystems. These negative environmental externalities can reduce or even reverse any mitigation or adaptation gains achieved by the project in the first place. Responses to the challenges of climate change have generally focused on technological efficiency and innovation, sometimes at the expense of ensuring equitable access to climate-resistant infrastructure for all community members. Urban adaptation and resilience-building interventions can also be "financially speculative, economically exclusive, and socially discriminatory".[55] Investment in climate-resistant infrastructure that helps close the infrastructure gap but leads to environmental externalities and greater exposure to risk is "ultimately self-defeating".[56]

The issue of equitable access to the benefits of climate-resistant infrastructure and its services are a key challenge. Infrastructure that is implemented using a business-as-usual approach, without concern for local circumstances and affected stakeholders, can exacerbate existing disparities or create new ones.[57] For example, green infrastructure and nature-based solutions may lead to gentrification if implemented without proper consideration of the social, economic and environmental needs of the most vulnerable or at-risk communities.[58] Unequal access to infrastructure and its services, regardless of the resilience of that infrastructure, perpetuates a vicious cycle of poverty and deprivation that becomes increasingly difficult to escape.

Such consequences are in part brought about by increasing systems complexity. Infrastructure policies often remain confined within silos, hindering holistic and integrated approaches to resilience-building. This compartmentalization limits the capacity to address interconnected challenges effectively. In particular, a reliance on technological solutions as a panacea for building resistance to climate change risks overlooking the critical socio-political dimensions of infrastructure development. Inflexibly built infrastructure is also likely to result in institutional or technological lock-in, providing little leeway to integrate more sustainable practices in future or adapt in the face of changing environmental conditions.[59]

Innovations in service delivery are often evaluated based on their economic value and potential opportunities for wealth creation, rather than on the public value they create.[60] The urgency of climate change may be able to leverage greater investment for green and climate-resistant infrastructure where returns are expected, but taken alone this may serve to legitimize technocentric ecological engineering approaches that can be exclusionary,[61] rather than contributing to the "radical rethinking of current infrastructure models" that is needed.[62] More attention should therefore be paid to putting in place transformative governance structures around physical and engineering systems.[63]

6.4 Resilience-building Infrastructure

In many cases, the delivery of infrastructure projects has occurred at the cost of certain groups of urban residents, often entrenching existing inequalities and vulnerabilities. In response, global agendas have been increasingly foregrounding justice in their principles. Such approaches highlight the need to align social and environmental goals with urban planning priorities, as set out in the SDGs and the NUA (see Figure 6.1). If designed and implemented appropriately, infrastructure can build the social and economic resilience of citizens and communities, making them better prepared to respond to the impacts of climate change. Improving the provision of infrastructure and services particularly in deprived urban areas is crucial for addressing poverty and inequality, which in turn is necessary for the development of inclusive, resilient cities. Following on from the previous section on climate-resilient infrastructure, this section explores the second category of infrastructure discussed in the framework earlier in this chapter (6.1.3.): *resilience-building* infrastructure.

6.4.1 Opportunities: more inclusive and sustainable provision for all

Low-carbon urban infrastructure can enhance resilience for all urban residents by reducing inequalities within and between cities. For example, by investing in sustainable public transit networks and the integration of non-motorized transport infrastructure such as cycling lanes and pedestrian zones, cities can improve mobility options for residents of all income groups. This, in turn, reduces traffic congestion and air pollution, promoting cleaner air and better health outcomes for vulnerable communities. By prioritizing low-carbon urban infrastructure, cities can create more inclusive and sustainable environments, ensuring that the benefits of a cleaner, safer and healthier urban life are accessible to all.

To address the existing infrastructure deficits in informal settlements requires significant investment in climate-resilient trunk infrastructure to which community-led service provisions models can then connect. This in turn requires financial and political partnerships between local authorities and informally settled communities—a considerable challenge in contexts where governments have refused to recognize these groups. However, besides the compelling moral justification for inclusive interventions, targeting infrastructure in ways that reduces poverty and inequality is often more economically attractive.

As argued in Chapter 1 of this report, cities must not overlook the role that urban informality plays in building sustainable and just urban futures, particularly in developing countries. This is particularly true with regard to resilience-building urban infrastructure. In cities of the Global South, "heterogeneous infrastructure configurations" and a variety of non-uniform modes of service delivery have long existed.[64] In such situations, a host of initiatives of varying degrees of formality and with varying levels of state support have evolved to fill delivery gaps.[65] For the majority of residents in fast-growing cities in developing countries, most if not all urban services and infrastructure are accessed via such decentralized and often informal channels.

Cities must not overlook the role that urban informality plays in building sustainable and just urban futures

Even though many of these decentralized systems have functioned efficiently for years, often serving populations who would otherwise have no alternatives, they are often cast aside as a nuisance. This is despite the fact that many "alternative" infrastructure systems have arisen in response to specific place-based needs and can generate new capacities for providing and governing urban infrastructure and its associated services. If they are considered at all, it is through discussions on how to formalize informal service delivery mechanisms or how to replace decentralized, low-tech operations with uniform, state-of-the-art systems. Going forward, cities should seek to harness the potential of informality to provide services, create jobs and contribute to poverty alleviation, whilst ensuring that necessary social protections and appropriate regulations are in place.[66]

Escalators in an informal settlement in Medellin, Colombia © Julius Mwelu/UN-Habitat

Box 6.3: The vital role of informal waste collection in India

Cities in the Global South are uniquely positioned to adopt "disruptive, innovative yet practical" low-carbon measures.[67] One example is the opportunity to develop economic structures that promote the recovery, recycling, reuse and repair of so-called waste materials. In many cities, informal waste collection not only plays a vital role for low-income communities excluded from official municipal services, but also serves as an important livelihood source for thousands of waste pickers. Various estimates suggest that between 0.5 and 2 per cent of the global urban population currently work in the informal waste economy.[68]

A case in point is India, where the thriving informal waste economy currently employs more than 1.5 million people in its cities alone.[69] Waste pickers are responsible for collecting a substantial portion of the country's recyclables, saving them from landfill, yet their valuable contribution is all too often overlooked. Indeed, working conditions for informal waste collectors can be extremely challenging, characterized by unsanitary environments, health hazards, lack of access to basic equipment and official harassment. Like other forms of social infrastructure that play a crucial role in promoting sustainability and resilience, the effectiveness of informal waste collection networks is heavily influenced by the willingness of authorities to support their work.

With this in mind, in 2004 the Self-Employed Women's Association (SEWA), a trade union for working women in Ahmedabad, established a ground-breaking partnership with Vejalpur municipality to deliver door-to-door collection services to 45,000 households. While the local authorities provided items such as handcarts and gloves along with a monthly salary, SEWA provided technical training on safety protocols and client engagement. The project proved a success: the income of female waste pickers quadrupled, health outcomes improved and as much as 70 per cent of all waste was recycled through the initiative.

Such partnerships with the informal waste sector offer alternatives to more expensive investment in solid waste infrastructure while generating larger social and economic benefits. Nevertheless, despite their demonstrated value, informal waste collectors depend on the continued engagement and openness of governments to maintain these arrangements. Following the incorporation of Vejalpur with Ahmedabad Municipal Corporation (AMC), the work was ultimately tendered to a private contractor. This shift reflected a wider preference, in India and elsewhere, for privatized, technology-intensive solutions over informal solutions. To support marginalized informal workers and improve environmental outcomes, however, cities in India and elsewhere should engage with the positive elements of the SEWA initiative to inform future collaborations.

Source: Oates et al., 2018; Oates et al., 2023.

6.4.2 Challenges: trade-offs and competing objectives

Implementing resilience-building infrastructure is not invariably straightforward. In many cases, trade-offs need to be navigated: greater urban density can lower infrastructure development costs, for instance, but potentially increase vulnerability to urban heat island effects. Another key challenge is that the integration of both socioeconomic and climate objectives into infrastructure projects may demand higher upfront costs. This can deter investment, especially in resource-constrained environments where it is often important to have a clear and profitable business case to attract private capital. Public-private partnerships and governance structures can sometimes favour private interests over public welfare. As discussed earlier in this chapter, such projects must also consider equity concerns. Effective community engagement is crucial in this regard, as insufficient involvement can lead to projects that do not align with the needs and desires of local residents. However, communities are themselves not homogeneous and some stakeholders (particularly those with access to more resources) may be more vocal than others.[70]

Combining multiple objectives in infrastructure projects increases complexity and uncertainty. It may be challenging to quantify and measure the success of these projects, making it harder to secure funding and support. Determining the appropriate metrics to evaluate the success of integrated projects can be challenging. Climate resilience and socioeconomic equity indicators may not always align or may require trade-offs. Policy and regulatory barriers may also prevent the optimization of synergies between climate and development goals. When not explicitly aligned and integrated with goals of climate and socioeconomic resilience, a lack of policy coherence can lead to contradictory outcomes.

Integrated infrastructure requires careful urban land use planning to ensure that land use decisions complement the infrastructure's objectives. Poor planning can result in unintended consequences, such as sprawl or increased vulnerability. A more sprawled urban form can make for highly inefficient land use, which tends to drive up costs of infrastructure: by one estimate, up to six times more than infrastructure in more compact urban forms.[71] Where formal land systems cannot keep pace with urban growth, infrastructure provision becomes a greater challenge, but retrofitting infrastructure is both more expensive and socially and technically challenging.

6.5. Transformative Infrastructure

Ensuring that infrastructure is resilient to climate change should be seen as "a means to achieving more resilient societies, rather than an end in itself".[72] As was highlighted in the World Cities Report 2022, "equitable access to urban services is a necessary, but not sufficient condition. Cities must be transformed at a deeper level in their governance and decision-making structures, planning approaches, institutions and priorities of political leaders".[73] Resilient infrastructure can be a vehicle through which to achieve these and other—transformative—human development goals. In this regard, urban infrastructure can be a useful tool for addressing structural vulnerabilities, thereby building equity and social justice.

Transformative infrastructure—the final, and most far-reaching, of the approaches discussed in the introductory framework (6.1.3.)—is frequently derived from rights-based approaches that focus on capacity-building, meaningful participation of the most vulnerable groups, and their access to basic services and key resources, including financing.[74] Infrastructure that addresses the drivers of both climate change and vulnerability, delivered in a way that contributes to broader and positive lasting societal change—for example, by institutionalizing meaningful participation—can be considered transformative.

6.5.1 Integrating the informal sector into city-wide service delivery models

Informal, self-organized or community-based initiatives have the potential to be more participatory than conventional top-down service provision. They often serve populations that might otherwise be marginalized or excluded from formal, regulated service delivery, and many are also low-carbon. For example, scalable, modular and renewable energy technologies reduce the need for larger centralized power stations and grid connections for the fast-growing population of urban households in Africa. The environmental benefits as especially evident when these decentralized solutions displace polluting fuels such as paraffin and charcoal.[75]

At the same time, it is essential to recognize that the informal economy also faces significant challenges and limitations that, if unaddressed, could limit and even reverse infrastructural resilience. Many informal service providers operate outside of formal regulations and standards, which can result in substandard or unsafe infrastructure that may not withstand and could even worsen climate impacts. In addition, informal workers and businesses frequently face challenges in accessing physical and technical resources, such as land, financing and training. They are also likely to be more vulnerable to the adverse effects of climate change than others: their precarious livelihoods, lack of social protection and weak or non-existent health and safety regulations all limit their capacity to respond to shocks such as extreme weather events.

An effective transformative approach will not only focus on integrating informal systems into formal systems but also help address the systemic issues that contribute to their exclusion and poor functioning

While climate-resilient approaches to infrastructure development may seek to identify and incorporate informal systems, an effective transformative approach will not only focus on integrating informal systems into formal systems but also help address the systemic issues that contribute to their exclusion and poor functioning. This includes, in particular, the widespread reluctance of local and national governments to recognize informal operators. However, fostering partnerships with alternative providers can facilitate rapid and cost-effective service delivery to marginalized communities, avoiding the replication of carbon- and capital-intensive Global North development trajectories. Partnerships across sectors, exemplified by initiatives like Slum/Shack Dwellers International federations,[76] empower communities to address collective needs, improve infrastructure and engage with local authorities, which can lead to more substantive and meaningful collaboration.[77] As Figure 6.7 illustrates, the process of including informal service provision in cities begins with their recognition, but ultimately should be fully integrated with formal systems through collaborations, partnerships and institutional support.

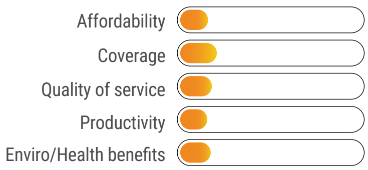
Alongside the necessary long-term efforts that focus on enhancing large-scale city-wide infrastructure networks, place-based and decentralized solutions may also prove effective in certain contexts, such as informal settlements or peripheral areas with low population density. To expand access to essential services in an inclusive and climate-resilient way, cities could integrate existing low-carbon alternative service providers into a comprehensive city-wide system—rather than displacing them in favour of formal or conventionally modernist services. Working with local businesses, informal operators and community-based organizations, city authorities could establish regulatory frameworks to ensure basic service quality, safety and affordability for underserved populations. In sectors like transport, water and sanitation, the public sector is ideally positioned for planning and oversight, assisting alternative operators to meet mutually agreed quality standards and regulatory frameworks to ensure accountability and scalability.

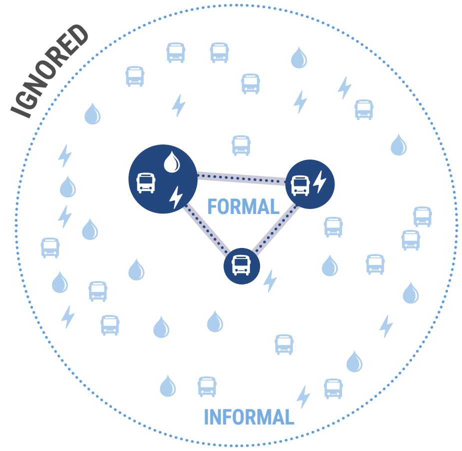
Hybrid service delivery models, blending conventional networks with alternative services, can be implemented to cater to diverse income levels and address specific local needs. Particularly in cities with limited resources and capacity, gradual improvements of informal services can enhance productivity and quality without immediate formalization. For example, initiatives such as fleet renewal programs, coupled with institutional support, have succeeded in modernizing and greening informal transport in various cities.[78]

Figure 6.7: Costs of ignoring/benefits of integrating informal sector service providers

Ignored - Formal systems may serve core neighbourhoods but peripheral areas and informal settlements are connected. They must rely on unrecognized, informal systems with high environmental and health costs

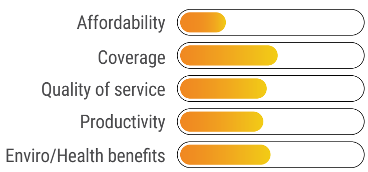
CITY-WIDE IMPACTS

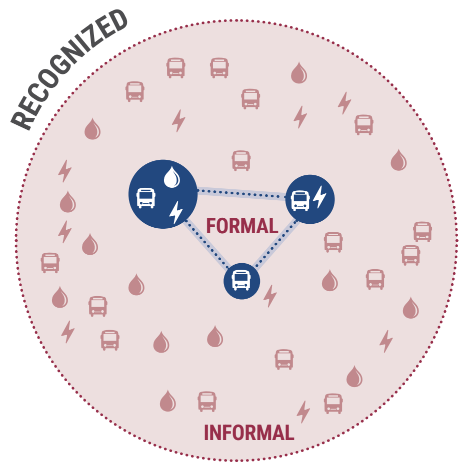




Recognized - The first steps in improving services and access are recognizing informal systems and increasing transparency about their operations and usage

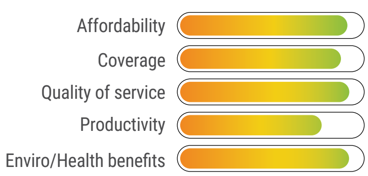
CITY-WIDE IMPACTS

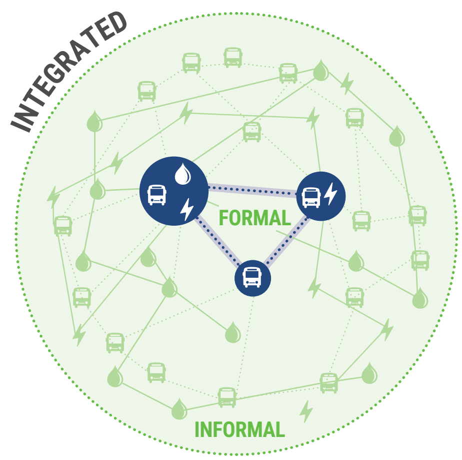




Integrated - Once recognized, integration with formal systems through partnerships, financial assistance, and supportive regulations can enable more efficient, safe and affordable access for all

CITY-WIDE IMPACTS





Source: Mahendra et al., 2021.

Box 6.4: The transformative impact of streetlights in Jinja, Uganda

Jinja in eastern Uganda is one of five cities included in the Government of Uganda's Transforming the Settlements of the Urban Poor in Uganda (TSUPU) programme. As part of TSUPU, a municipal development forum (MDF) was established in the city, with the intention of bringing together local government, the urban poor and other stakeholders to align urban development priorities.

Together with the National Slum Dwellers Federation of Uganda (NSDFU), the MDF conducted participatory enumeration in the informal settlement of Kibugumbata, home to 6,000 people. The mapping exercise generated discussions about the settlement's challenges with both income generation activities and safety after dark, prompting deliberations on the solar streetlights that were being rolled out in the centre of Jinja. Despite initial reluctance from Jinja Municipal Council (JMC) to implement solar streetlights in a less central location, the MDF was able to earmark 20 solar streetlights for Kibugumbata, with financial contributions from Slum/Shack Dwellers International and JMC itself.

The project spearheaded capacity building for a green transition by training five local youths as solar technicians and led the project installation in March 2018. Since then, local residents report feeling safer, and business owners are able to operate for up to five hours more every day. The solar technicians receive a stipend from JMC for maintaining the streetlights, and have also found work with domestic clients elsewhere in the city. The municipality's willingness to invest in the informal settlement has generated a perceived increase in tenure security.

Cities can maximize the co-benefits of transitions, by looking beyond the environmental aspects of sustainability to trigger wider organizational and institutional change. The spillover effects of the energy transition can go far beyond emissions reductions: linking distributed technologies to new forms of social organization can offer new ways of meeting energy demand, whilst simultaneously empowering marginalized groups and creating meaningful multistakeholder partnerships to tackle urban development challenges. This case is particularly relevant for Ugandan cities since the devolution of service delivery to city authorities has led to irregularities in electricity supply, meaning municipalities must look for new ways to both meet the basic needs of residents and power municipal infrastructure.

Source: Gillard et al., 2019.

6.5.2 Nature-based solutions as a transformative accelerator

Urban infrastructure should of course not generate adverse ecological impacts. This means incorporating the principles of ecosystem protection and restoration into infrastructure provision. Ecosystem-based Adaptation is recognized internationally under the Convention on Biological Diversity (CBD14/5), while the related concept of NbS includes a broader range of approaches. Through the associated social, environmental and economic co-benefits that NbS can generate, up to 115 of the 169 SDG targets can be accelerated.[79] A wide range of NbS to resilience have been implemented, ranging from increasing tree cover and green spaces to address the heat island effect (in Barcelona and Durban), increasing permeable surfaces and wetlands (as in China's sponge cities programme), and mangrove restoration to support coastline regeneration and disaster risk reduction (as seen in Semarang, Indonesia).[80]

Many of these interventions—particularly ones which include community planning and participation—are a common feature in resilient infrastructure, yet when integrated into a broader strategy encompassing complex city-wide ecosystems, they have the potential to be transformative. NbS are also cost-effective. One estimate placed the typical costs for a nature-based intervention on average to be only half the cost of conventional grey infrastructure of the same capacity.[81]

Despite the co-benefits and cost reduction potential, however, only 0.3 per cent of all infrastructure investments is currently aimed at NbS

Despite the co-benefits and cost reduction potential, however, only 0.3 per cent of all infrastructure investments is currently aimed at NbS.[82]

Nature-based infrastructure can also be a vehicle through which to challenge dominant knowledge paradigms and contribute to knowledge diversity. Transformative processes that link scientific, Indigenous, local, practitioner and other forms of knowledge are more effective, sustainable, and contextually appropriate, and are more likely to generate legitimate, relevant and effective climate action.[83] In addition to more conventionally accepted forms of knowledge, philosophies from Indigenous movements like *buen vivir (sumak kawsay)* and *ubuntu* could provide insight into ways to develop more equitable, culturally sensitive and contextually appropriate solutions. They emphasise harmony with nature, community well-being, a holistic understanding of development and collective responsibility. Incorporating these Indigenous knowledge principles into urban infrastructure planning could leverage the capacity of infrastructure to stimulate new social and economic orders, transforming human-nature relations in the

Modern street, green urban sustainable development, bike ways and sponge garden system in modern neighbourhood in Estonian capital city, Tallinn, Estonia © Shutterstock

process. This must go beyond the rhetorical mobilization of Indigenous discourses[84] and instead embrace the possibility of rethinking the relationship between humans, infrastructure and nature. Infrastructure should be seen not as having a single purpose but rather as contributing to a range of social, environmental and economic objectives that represent multiple values.

6.5.3 The value of justice-based approaches to infrastructure implementation

As discussed earlier in this chapter, infrastructure projects can actively harm local populations if imposed without proper consideration of their needs and realities. The intersection of environmental risk and social vulnerability is why resilience-building infrastructure must acknowledge and reflect the variety of challenges that communities, particularly in low-income or informal settlements, face. However, though participation is a crucial and powerful tool, transformative approaches to infrastructure typically go further by adopting a justice-based lens. This approach aims to rectify entrenched social and economic inequalities through infrastructural interventions that not only do not reinforce these issues or even factor them into their development, but actively seek to resolve them by catalysing lasting change.

Transformative approaches to infrastructure typically go further by adopting a justice-based lens

The concept of justice is often used to assess whether policy interventions—whether in the realm of urban development or climate change—are achieving desirable outcomes. Considering different forms of justice is essential when considering the transformational potential of resilient urban infrastructure. The most common framings that are used are distributional and procedural justice or equity. Distributional justice ensures inclusive and sustainable outcomes of an infrastructure project, for example promoting equal access for all stakeholder groups to the infrastructure and the services it offers. Distributional outcomes might also involve a fair and sustainable contribution to climate mitigation or adaptation goals, for example ensuring vulnerable communities have fair access to any services the infrastructure offers, like protection from extreme weather or access to clean energy.

Procedural justice involves inclusive and transparent processes, where all—including marginalized groups—are actively enabled to participate in decision-making.[85] Strong political commitment ensures meaningful involvement in project design and implementation. As well as being more procedurally fair, infrastructure projects that have incorporated diverse viewpoints in design and planning stages tend to better meet community needs, enhance social cohesion, and to be more likely to contribute to climate goals.

More recent analysis has highlighted the significance of other forms of justice when assessing climate change responses.[86] Corrective justice responds to historical wrongdoing and addresses the needs of people who have been negatively affected by actions in the past. In relation to infrastructure, this could include an explicitly "redistributional" agenda in ensuring that under-served groups are prioritized in the provision of new infrastructure. Transitional justice recognizes that policies need to be sequenced over time to achieve desired outcomes (e.g. net-zero emissions) and that the steps towards this also need to be taken in a way that they do not produce less just intermediate outcomes. Finally, recognitional justice[87] expands the focus on procedures to explicitly highlight the historical, cultural, and regional factors and circumstances driving injustice, and the need to recognize these throughout planning and implementation of all urban activities.

Box 6.5: The transformative potential of connecting resilient urban infrastructure to adequate affordable housing

Housing is seldom seen as a core element of urban infrastructure, but is more usually identified and treated as a distinct sector for policies, planning and interventions. Despite this, housing is inevitably and intimately linked with urban infrastructure systems. Decisions made about housing ripple through the broader urban landscape, influencing energy use, transportation patterns, water management, waste generation, community resilience, and overall urban sustainability.

The framework proposed in this chapter for assessing the resilience of infrastructure can also be applied to housing. Poorly built or maintained structures actively detract from the resilience of their residents, increasing their susceptibility to harm from climate-related events. Climate-resistant structures address this direct issue, by providing shelter that can withstand climate impacts—but unless they simultaneously address issues such as accessibility and affordability, they are unlikely to contribute to the overall resilience of inhabitants.

There is also the potential for housing to be transformative: through incorporating sustainability principles (including low-carbon construction and operation) and inclusive design in ways that contribute to broader societal and urban change. Several factors are key:

- *Construction and materials*: the use of robust materials (climate-resistant) and the inclusion of water and energy efficiency features (resilience/transformation).
- *Location*: the positioning of housing in relation to infrastructure and other services, livelihoods, and social networks (contribution to resilience). Housing situation in close proximity to public transit, employment centres and amenities reduces the need for private transportation; while including planning for basic services (water, sanitation, waste management, energy) in settlement design generates efficiencies and improves resilience of households.
- *Urban form*: liveable urban density can improve the efficiency and quality of service provision, leading to more efficient energy use, transportation and delivery of services and hence reducing the overall carbon footprint of urban areas (transformation). Mixed-use development projects enable residents to access essential services and amenities within their communities (transformation).
- *Governance of design and implementation*: engaging residents in the process of planning, design and construction of housing (and associated infrastructure such as disaster / emergency shelters) can ensure that housing meets their specific needs, while also incorporating local knowledge about hazards, vulnerabilities, and responses to these (transformation).

In conclusion, while climate-resistant housing can provide significant protection from the physical impacts of natural disasters and environmental shocks, a transformative approach goes far beyond this. By integrating climate concerns with wider challenges around poverty, social precarity and exclusion, it not only fosters greater resilience but also helps address fundamental inequalities within the housing sector. A great example of housing as a form of climate action can be seen in the La Borda Cooperative Housing project, included in the Case Study Annex of this report.

6.6 Financing Transformative Urban Infrastructure

There is a global deficit in infrastructure, and the way in which this infrastructure is provided and managed will have profound implications for global emissions and resilience. Millions of people, especially in fast-growing cities in low- and middle-income countries, are facing the consequences of substandard infrastructure, often at significant social and economic cost. Though the construction of new urban infrastructure is necessary to meet growing demand, underfunding and poor maintenance of existing infrastructure are also key factors resulting in inadequate electricity, water, sanitation and transport systems.[88]

6.6.1 The business case for investing in transformative urban infrastructure

There are significant opportunities for savings generated by low-carbon cities. Low-carbon urban actions could generate a stream of savings equivalent to US$16.6 trillion by 2050.[89] At the city level, improved and inclusive access to resilient infrastructure can yield cascading benefits for the entire city and even beyond.[90] For example, costs associated with healthcare and lost productivity due to inadequate sanitation are estimated to be around US$223 billion per year.[91] Conversely, every US$1 invested in water and sanitation on average yields an economic return of US$5.5 in time savings, better health and productivity.[92]

One distinctly urban opportunity capitalizes on the concentration of people and land uses in urban areas that enable the compact city-public transport nexus as a tool to lower emissions.[93] Given that the transport

Given that the transport sector represent the fastest-growing source of global emissions, shifting national transport budgets from building road infrastructure to support public transport can have a transformative impact

sector represent the fastest-growing source of global emissions,[94] shifting national transport budgets from building road infrastructure to support public transport can have a transformative impact.[95] While public transit is included a key policy measure in 39 per cent of NDCs,[96] its global take-up has been too low. Unless this changes, transport may remain a key hurdle in efforts to mitigate global warming.[97]

The incremental costs of designing more resilient assets in the power, water and sanitation, and transport sectors are relatively low: the World Bank estimates that these are only 3 per cent greater than overall investment needs. Perhaps more significantly, the same report concludes that investing in more resilient infrastructure is beneficial in almost all scenarios, with every US$1 invested in middle- to upper income countries delivering an average of US$4 in benefits over an infrastructure's entire lifetime. Paradoxically, the expected impacts of climate change mean this investment in resilience is "even more necessary and attractive: on average, it doubles the net benefits from resilience".[98] As Chapter 3 highlighted, data on the location and potential impact of climate hazards is important, as the maximum benefits can be realized if investments are made where they are most needed.

6.6.2 Future needs and costs

Figures on the future costs of infrastructure vary considerably, but there is consensus that current investment is insufficient to meet the demands of constructing new infrastructures and maintaining existing assets. The Coalition for Disaster Resilient Infrastructure estimates the annual investment needed to not only address infrastructure deficits, but also achieve the SDGs and net zero targets by 2050, could be as high as US$9.2 trillion.[99] Other estimates from the World Bank show that developing countries need to invest approximately 4.5 per cent of GDP annually to deliver "ambitious" and "high efficiency" infrastructure in different sectors.[100] In Asia alone, the Asian Development Bank has estimated that US$1.7 trillion needed to be invested annually until 2030 to maintain the region's growth momentum and respond to climate change.[101]

Most of these estimates also stress the significant gap in what is needed to meet demand. According to one calculation, there is an annual global demand for infrastructure investment of US$3.7 trillion, but only US$2.7 trillion is being expended—amounting to an annual "infrastructure gap" of US$1 trillion.[102] The Global Infrastructure Outlook estimates

Box 6.6: Calculating infrastructure returns: Direct, indirect, induced and catalytic impacts

To fully capture the value that transformative infrastructure can bring, whether at the planning phase or during subsequent monitoring and evaluation, it is important to account for all the returns. This means recognizing not only the immediate and readily identifiable benefits it brings, but also the wider ripple effects it may bring to local residents and economies in its wake. According to the World Bank, these can be separated into four broad categories, listed below:

- *Direct impacts*: "those generated by the infrastructure itself, through initial construction and ongoing operations and maintenance of the infrastructure". For instance, the development of the TransMilenio Bus Rapid Transit (BRT) system in Bogotá, Colombia, created thousands of construction jobs, including roles for engineers, construction workers and planners, while ongoing operations provide employment for drivers, maintenance staff, and administrative personnel.
- *Indirect impacts*: these encompass "the employment and economic activity supported by the supply chain impacts following the initial investment in the infrastructure". In the case of the BRT, these include the economic activity generated in the supply chain, such as through the production of buses and the sourcing of construction materials.
- *Induced impacts*: "the knock-on effects of increased household spending of those employed in the direct and indirect jobs, often in the local area but also reaching outside the local catchment". These are seen through the boost in local economies as incomes earned by those employed in direct and indirect roles, leading to increased spending in retail shops, restaurants, and service providers near the BRT lines. In addition, improved access to public transport has enabled more people to access employment opportunities, contributing to higher household incomes and improved living standards.
- *Catalytic impacts:* "where the investment supports longer term changes or spill-over effects which impact productivity in other parts of the economy". These can include significant environmental benefits. The BRT system has reduced traffic congestion and emissions by offering a reliable public transport alternative, leading to better air quality and lower GHG emissions, while also contributing to improved public health outcomes.

Viewed together, these various impacts draw out a picture of complex, mutually interacting benefits that can be characterized as transformative. Urban development around BRT stations has spurred new residential and commercial properties, promoting urban regeneration. The system has reduced travel time, made transportation more accessible and affordable for low-income populations especially, enhancing social equity and inclusion. All these impacts have boosted overall economic productivity by increasing connectivity between businesses and a larger workforce, and by reducing the time and money required for logistics.

Source: World Bank, 2021a.

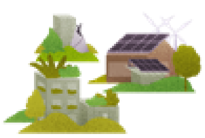
that a global infrastructure investment of US$93.7 trillion is required between 2016 and 2040 for both new and replacement infrastructure, equivalent to 3.5 per cent of GDP—based on current trends, this is a gap of US$14.0 trillion.[103]

Given these resource constraints, ensuring efficient and cost-effective investments in infrastructure is paramount. Data on expenditure on maintenance are less readily available than that on the construction of new assets, but it is clear that renovating or extending the lifespan of infrastructure assets both saves money and reduces the use of new, virgin materials.[104] For example, in the Netherlands the estimated cost to producers and consumers of an asset failing is ten times that of the cost of repair.[105]

Ensuring access to the necessary funding, particularly in regions where the need is most acute, poses enormous difficulties. In developed countries, debt and equity financing instruments are already being deployed to fund ambitious infrastructure projects. But even financing "business-as-usual" infrastructure is a huge challenge in many parts of the world. While 55 per cent of public investment is undertaken by subnational governments in OECD countries,[106] subnational governments in developing countries face severe barriers in accessing finance due to unreliable intragovernmental transfers, creditworthiness, reliance on intergovernmental transfers, and limited own-source revenue systems (see Chapter 9). Most cities in low- and middle-income countries have lower credit ratings than their national government's international rating, with the result that commercial investors tend to concentrate urban infrastructure financing in high-income countries.[107] While as much as US$384 billion of climate finance has been invested in urban areas annually, this is barely 8 per cent of what is required globally, with shortfalls especially evident in developing countries in Sub-Saharan Africa and the Middle East and North Africa.[108]

More positive trends can be observed in private investment, such as the observable, albeit slow, shift towards investment in cleaner energy sources. The share of green private investment in infrastructure has increased significantly over the past decade, though there has been a slight dip since 2020, and non-green investments in infrastructure still outweigh those in green infrastructure.[109] There is also strong growth in the use of sustainable instruments such as green bonds and green loans to finance infrastructures.[110]

Financing transformative infrastructure faces many of the same challenges as financing other forms of urban climate action, as is explored in greater detail in Chapter 9. However, the high upfront costs and the long timeframe of many transformative infrastructure projects can further exacerbate these challenges. It is worth noting that a wide range of broader socioeconomic and environmental impacts can accrue



A wide range of broader socioeconomic and environmental impacts can accrue over an infrastructure's lifespan that go beyond the purely financial costs and benefits of infrastructure investment

over an infrastructure's lifespan that go beyond the purely financial costs and benefits of infrastructure investment: as illustrated in Box 6.6, these can contribute to transformative urban change. Investment in infrastructure for renewable energy generation alone could lead to more than 38 million new green jobs by 2030.[111] Accounting for these wider impacts can help to better identify possible returns to investment, and can help to build the business case for leveraging private sector finance.

6.6.3 Integrating climate resilience and mitigation into asset management

Effective public infrastructure asset management is a key component of resilience infrastructure. It enables governments to increase their financial viability, creditworthiness and public confidence by anticipating future costs, demonstrating accountability for expensive assets and enhancing transparency. Over an infrastructure's entire lifecycle, upfront investment in infrastructure may only account for 15 to 30 per cent of expenditure, while the remainder is attributable to operations and maintenance.[112] As a result, a long-term approach to infrastructure planning is essential, integrating these various operational costs and updating capital plans throughout the lifecycle.

Sustainable asset management also involves factoring in climate change considerations, ensuring that the construction, operation and maintenance are resilient and do not aggravate its negative impacts. This does not mean that no new infrastructure can be built on account of embodied GHG emissions, but that it should be done in a way that supports transformative change and works to lower climate vulnerability in the long run. It also requires a holistic approach to the range of assets in a city, integrating its physical, engineered systems with its blue-green infrastructures.

It is important, too, to consider how system redundancy can be increased by increasing the diversity of approaches taken to infrastructure service provision, rather than only striving for monolithic technical solutions. Should one component of the system fail, well planned redundancy can minimize disruption of essential services and interlined indirect losses. Infrastructure asset management can integrate considerations of climate resilience by adopting an adaptive approach that allows the original design to be modified over time to address different climate change scenarios: for example, by implementing modular construction methods or even including a plan in case of relocation or abandonment. This may also include adapting existing byelaws, codes, regulations, policies, development plans and operational protocols, such as the mandating of waterproof or heat resistant materials where flooding or wildfires are likely to occur.

There are challenges and trade-offs to this approach, including the lag time between costs and benefits (meaning that the bulk of benefits of increased climate resilience will occur beyond the budget-cycles typically considered by decision-makers), as well as the uncertainty of future climate impacts. While most maintenance in local governments tends to be reactive, this can hinder the building of resilience across an interdependent asset management system. Proactive and preventative asset maintenance can reduce the likelihood of infrastructure failure by strengthening capacity to respond to climate shocks and stresses.

Overall, managing assets with climate resilience in mind can generate a range of benefits, including more reliable service provision, increased asset life and reduced cost.

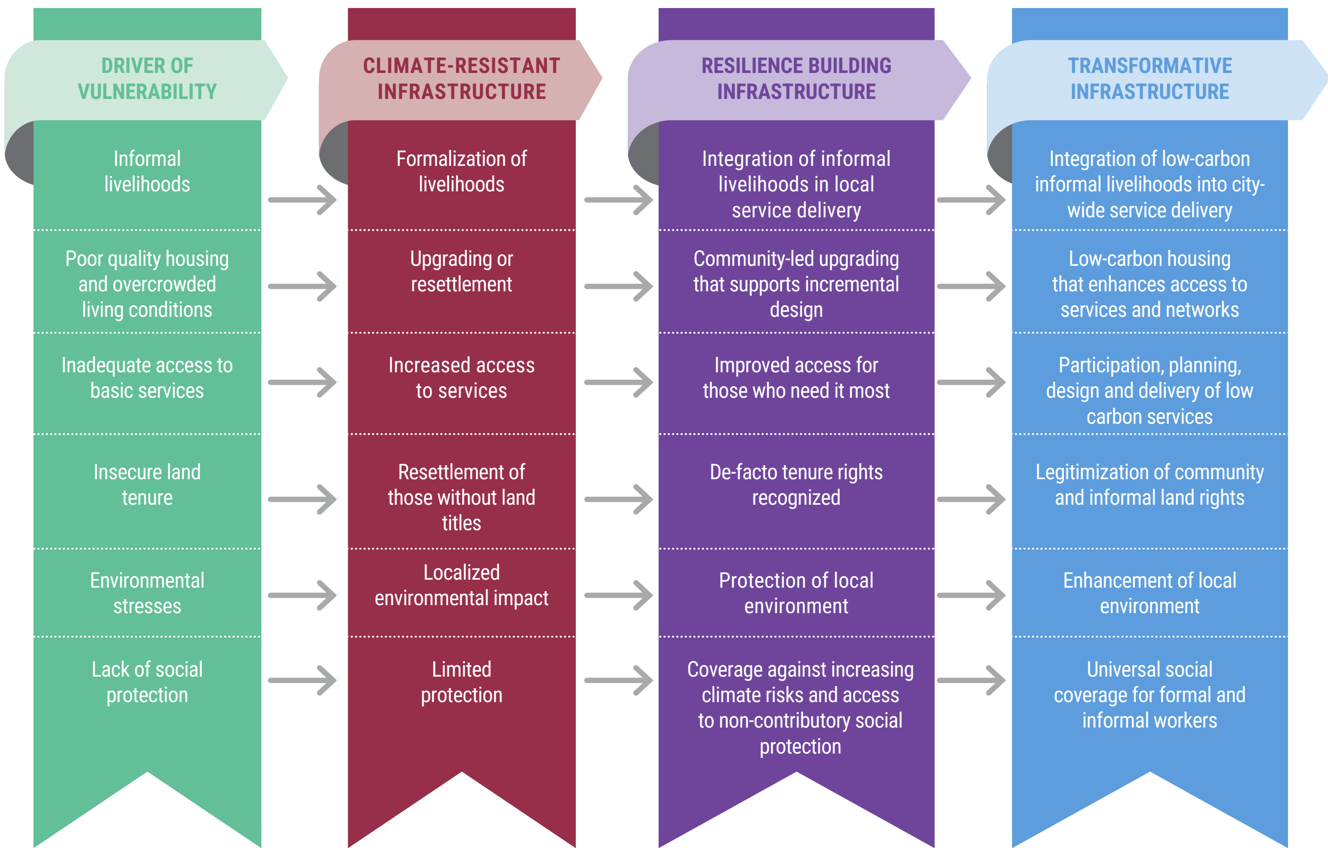
6.7 Policy lessons for Delivering Transformative Infrastructure

Infrastructure plays a fundamental role in shaping the sustainability, prosperity and well-being of cities and their residents. The way in which infrastructure has developed in recent years—whether through formal planning or through informal processes—is a key determinant in the level of risk that cities face from climate change, and the contributions that they make to GHG emissions. Moreover, given the rapid and ongoing growth in infrastructure and the associated transformation of the built environment, patterns of infrastructural development in the coming years and decades will be among the main factors shaping the extent to which effective climate action can take place.

This chapter has so far identified three components of climate responsive infrastructure: namely, infrastructure that is *climate-resistant*, infrastructure that contributes to *resilience*, and infrastructure that is *transformative*. These roles of infrastructure are in many ways successive, in the sense that it is difficult to realize transformative infrastructure without it also being climate-resistant and contributing to building resilience. This concluding section offers action-oriented policy guidance that can enable local governments to achieve transformative infrastructure. The framework demonstrates that meaningful activities can be taken in all urban settings, and that these can range from initial starting points to more advanced and ambitious plans and programmes.

Perhaps the most important conclusion from this analysis is that approaches to infrastructure that accelerate effective climate action in cities do not need to be undertaken sequentially. Indeed, it may be possible for cities which currently lack "resilient urban infrastructure" to consider the development of infrastructure in ways that immediately achieves more transformative goals. The frameworks of city-wide service delivery and NbS demonstrate how transformative approaches to infrastructure can address basic human needs, urban economic priorities and the imperatives of climate change even in resource-constrained settings. Finally, the specific examples around livelihoods, housing, social protection and local environmental actions show how this can be implemented in ways that achieve people-centred climate action in cities.

Figure 6.8: Main drivers of climate vulnerability and the ways these are addressed by different types of resilient infrastructure



6.7.1 Pathways towards transformative infrastructure

Integrate low-carbon informal livelihoods into city-wide service provision models. By recognizing and incorporating the diverse economic activities of informal workers into the broader urban fabric, cities can harness their potential to contribute to sustainability goals while *enhancing their own resilience*. This integration into city-wide systems can expand access to essential services, ensuring quality, safety and affordability while supporting the livelihoods of marginalized communities. Partnerships between city governments and informal communities can facilitate more rapid and efficient infrastructure improvements, at the same time creating jobs and supporting local economic development.

Integrated service delivery models can be realized by supporting and regulating localized, on-site infrastructure solutions and ensuring the cost of these is not borne by vulnerable communities. This can be achieved through the provision of direct fiscal support, such as by offering subsidies or tax breaks to local initiatives or paying for community/household connections to central systems. Non-fiscal support can be equally valuable, such as providing land or premises, equipment, training, and technical and business expertise to service providers who are contributing to resilience-building activities. In addition, the reform of procurement procedures can ensure that informal and community-based actors who are contributing to sustainable service delivery are able to participate in tender processes.

Promote low-carbon, culturally appropriate housing that enhances residents' access to urban services and social networks. Traditional, vernacular and informal forms of housing are often already low-carbon and adaptive to prevailing climatic conditions in a way that is *climate-resistant*. Prioritizing sustainable and, where appropriate, vernacular building practices can deliver housing solutions that both respond to the needs of residents and reduce carbon emissions.[113] Such housing initiatives enhance the quality of life for residents whilst *contributing to the overall resilience* of urban communities. Adopting supportive building codes and standards can help guide people and construction companies towards more sustainable options. To ensure building codes remain accessible and affordable to low-income residents, it is important to leverage local knowledge systems. To be truly *transformative*, scientific, Indigenous, local, and practitioner knowledge in resilience-building processes should be used to develop contextually appropriate and sustainable solutions, and building regulation.

Facilitate participation in the planning, design and delivery of low-carbon service models. Encouraging community-led service provision models and other forms of participation in the planning, design and delivery of low-carbon service models empowers communities to shape their own urban environments and adapt to the challenges of climate change. By meaningfully involving residents—including representatives from all relevant stakeholder groups, such as formal and informal workers, women and men, youth, people with disabilities, migrants, people from different religious backgrounds—in decision-making processes, cities can leverage local knowledge and expertise to develop innovative infrastructure solutions that builds resilience of diverse populations.

Rights-based, participatory approaches generally lead to more successful infrastructure outcomes. They should be part of wider efforts to improve the inclusivity and efficacy of governance structures, including by encouraging inter-agency cooperation and collaboration to enhance policy coherence. These activities should be accompanied by adequate fiscal transfers to, and technical support for, local governments and other actors involved in infrastructure delivery processes, particularly in informal settlements. Governments should establish mechanisms for continuous community involvement, feedback and decision-making throughout the infrastructure lifecycle.

Leverage inclusive land use planning, including through the recognition of informal and communal land rights. Cities can improve access to basic services for marginalized communities by recognizing customary tenure and the rights of informal settlements and communal land users, thereby both reducing their vulnerability to climate change impacts and increasing their right to the city. This can both strengthen social cohesion and facilitate greater investment in sustainable infrastructure and services, for example by increasing the ability of residents to make changes that advance mitigation and adaptation action.[114] Such recognition and integrating is a critical enabling factor for developing integrated urban land use plans that *build resilience* by complementing infrastructure objectives and prevent unintended consequences such as urban sprawl. Inclusive and effective land use planning can also help unlock access to sustainable and innovative financing mechanisms such as land value capture.

Minimize exposure to climate exposure through land use planning that avoids or discourages development in high-risk areas such as floodplains and coastal zones. Zoning regulations and incentives can help to identify priorities, for example by designating areas for green space and highlighting areas that are especially vulnerable to climate risk. Infrastructure investment should be prioritized in marginalized areas. Where informal settlements are located in low-risk conditions, in-situ upgrading can be carried out to simultaneously enhance the security of tenure, increase access to basic services and amenities, and reduce inequality. *Transformative* upgrading programmes must be part of integrated urban land use plans that complement infrastructure objectives and prevent unintended negative consequences such as urban sprawl, particularly in fast-growing cities. Such integrated land use planning can only reach its maximum potential when governments at all levels strive for policy coherence by aligning climate resilience and socioeconomic equity goals across different levels of government and sectors.

Prioritizing blue-green infrastructure and eco-system-based adaptation enhances local environments and contributes to global sustainability goals. By prioritizing blue-green infrastructure and eco-system-based adaptation, cities can improve air and water quality, mitigate the urban heat island effect, enhance biodiversity, and reduce vulnerability to flooding. Urban infrastructure that offers new forms of relationships between humans and nature can be achieved by integrating diverse forms of knowledge including scientific, Indigenous, local, and practitioner knowledge. Doing this in a *transformative* way that ensures all urban dwellers have access to these facilities and the services they offer—for example, by ensuring local communities are involved in the planning and delivery of nature-based infrastructures—can benefit local residents by providing recreational and ecological amenities. A lack of community participation in the implementation of NbS can lead to technocratic pitfalls and *erode* resilience. Incorporating blue-green infrastructure into the upgrading of informal settlements, as well as into wider urban development, can enhance socio-cultural connections and deliver environmental and economic benefits that support local livelihoods.[115] Alignment of infrastructure development with the goals set out in global agendas, including the SDGs and the NUA, will help to achieve global sustainability objectives, such as the reduction of GHG emissions and the conservation of natural resources.

Provide protection against existing climate risks through access to universal social coverage for formal and informal workers. Labour rights, healthcare, housing benefits, income support and other forms of soft infrastructure ensure that all residents, regardless of their formal employment status, have the resources and support they need to withstand and recover from climate impacts. In addition to centralized funding, this can be done by supporting initiatives that bring together low-income urban residents in savings groups, federations and other associations that empower communities in addressing their collective needs. Including considerations around accessible social protection for informal and formal workers in infrastructure service provision enhances the adaptive capacity of urban communities. These protections are essential components for meeting any sustainable development goals.[116]

Conduct risk assessments that include different forms of justice. As highlighted in Chapter 3, making infrastructure *climate-resistant* requires comprehensive risk assessments that consider the interaction between climate hazards, asset locations and vulnerabilities, which may use advanced data analytics and modelling to identify potential impacts of climate change on urban infrastructure, accounting for both current and future conditions. Such risk assessments can help *build resilience* by guiding effective disaster response mechanisms that include evacuation plans, emergency shelters, and rapid deployment of resources during and after extreme events. These risk assessments and disaster risk assessment can become increasingly advanced and nuanced, by integrating the principles of just transitions into urban infrastructure projects, ensuring that they support both social justice and environmental sustainability. Risk assessments based on the principles of just transitions can be *transformative* if they help to inform decisions about prioritization of infrastructure for communities that have been negatively affected by urban development processes.

Monitor and evaluate performance. A fundamental component to ensure infrastructure is *climate-resistant*, but also *builds wider resilience,* is to establish systems for ongoing monitoring and evaluation of infrastructure performance under climate stressors. Monitoring needs to inform continuously improvements to infrastructure resilience through regular preventative (as well as reactionary) maintenance that ensures it is adaptive to changing conditions. To measure the way in which infrastructure contributes to wider community resilience, it is important that metrics and indicators are set up that are able to capture these impacts. Infrastructure that *builds resilience* and *is transformative* can have higher upfront costs than infrastructure that is merely climate-resistant, so the societal benefits of resilience-building and transformative infrastructure need be well accounted for, to make evident why the higher upfront costs are justified. This requires a reconsideration from infrastructure as an engineering question, to a societal and environmental one, which requires that engineers and planners liaise with and work in close collaboration with other disciplines.[117]

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