Infrastructure for a Climate-Resilient Future

OECD

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BETTER POLICIES FOR BETTER LIVES

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Preface

The impacts of climate change are becoming increasingly evident, with the frequency and severity of extreme events such as floods, heatwaves, and wildfires surpassing historic norms. Globally effective climate action is essential, to simultaneously accelerate the net zero transition and mitigate the severity of future events, while also building resilience to locked-in climate change impacts.

Sustainable infrastructure has a key role to play in meeting our shared mitigation objectives, from renewable energy generation and transmission, to low or zero carbon transportation modes, to more efficient industrial facilities, among many others. In parallel, both existing and new transport, energy, telecommunications and water infrastructure will need to be adapted and made more resilient to a changing climate as well as evolving risks from extreme events. This will require climate resilience to be taken into account at all stages of the infrastructure project lifecycle, including planning, design, construction and maintenance.

Investments in climate-resilient infrastructure offer benefits well beyond the management of societal and economic risks from climate change. For example, nature-based solutions to resilience, such as the creation of urban wetlands, afforestation and vegetation restoration can protect biodiversity, mitigate pollution and contribute to more liveable cities.

The investments needed to seize these opportunities are significant: according to OECD, World Bank and UN Environment analysis, an annual investment of USD 6.9 trillion in infrastructure will be necessary by 2030 to ensure infrastructure investment is compatible with the Sustainable Development Goals and the Paris Agreement.

At a time of significant pressure on public finances and debt sustainability, no government can meet these investment needs alone. Unlocking private investments in climate resilience will require long-term project planning, reducing regulatory barriers, effective risk-sharing arrangements and, when required, the targeted and strategic use of public support to attract private financing – particularly when the timeline for resilience investment returns may constitute a barrier to private sector participation.

This report, an important output of the OECD's High Level Approach to Enhance and Better Integrate OECD Work on Infrastructure (2024), leverages the expertise of several OECD committees to demonstrate how to integrate climate resilience in infrastructure development – from planning to financing to construction. Launched at the OECD Infrastructure Forum on 9 April 2024, the report provides evidence-based policy recommendations and highlights the experiences of jurisdictions around the world including developing economies, ultimately with the goal of supporting better infrastructure policy for better lives.

Mathias Cormann,

OECD Secretary-General

Foreword

Climate change affects infrastructure assets and their operations in diverse ways. Slow onset events can wreak havoc over time, while extreme weather events can cause damage and disruption in a matter of days or even hours. Climate change makes infrastructure assets and operations subject to increasingly long disruptions, with growing implications. Most infrastructure assets are interdependent with other systems with a range of societal and economic functions relying on them. The failure of infrastructure can thus cause a wide range of cascading impacts.

There is a strong economic case for investing in the climate resilience of infrastructure. While climate-resilient measures can increase the lifespan of infrastructure, they also play an essential role in protecting investment returns and ensuring business continuity. Investments in climate resilience have been shown to have a net-positive impact over time.

Infrastructure for a Climate-Resilient Future offers a comprehensive account of the main policy areas that should be considered to ensure that infrastructure is resilient to the impacts of climate change. The report covers adaptation trends, planning, financing, Nature-based Solutions and multi-level governance. In so doing, it offers insights for policy makers seeking to evaluate and improve their legal, regulatory and institutional frameworks for infrastructure governance.

Achieving climate-resilient infrastructure systems requires a whole-of-government approach, combined with strong collaboration among public and private sectors, and other international and local actors. This report brings together contributions from across OECD committees to discuss how to strengthen infrastructure resilience.

The report builds on examples of international good practice from OECD members and non-member countries, as well as OECD recommendations and analysis on infrastructure. It was developed using the Organisation's multi-disciplinary, multi-sectoral, multi-stakeholder, evidence- and consensus-based approach to analysis and policy advice. Secretariats involved in climate adaptation, governance, financing, development and regional development have contributed, ensuring a comprehensive approach to infrastructure in the context of climate resilience. The report features contributions from the OECD's Environment Directorate, Directorate for Financial and Enterprise Affairs; Public Governance Directorate; Centre for Entrepreneurship, SMEs, Regions and Cities; and the Development Centre.

This report was authored by Catherine Gamper, Anges Szuda (Chapters 1 and 4), Edwin Lau, Robert Addison (Chapter 2), Michael Mullan, Mamiko Yokoi-Arai (Chapter 3), Annalisa Primi (Chapter 5) and Isabelle Chatry, Courtenay Wheeler and Justin Chen (Chapter 6) under the supervision of Kumi Kitamori, with support from Virginie Marchal.

It benefited from consultation with the OECD Investment Committee, the Working Party on Finance and Investment for Environment Goals, the Public Governance Committee, the Working Party of the Leading Practitioners on Public Procurement, the Regional Development Policy Committee, the Expert Group on Multi-level Governance and Public Investment for Regional Development and the Network of Senior Infrastructure and Public-Private Partnership Officials.

The report was prepared for publication by Lucinda Pearson.

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Global average temperatures set a record in 2023, rising to around 1.4 °C above the preindustrial average. Behind this rise lies the growing frequency and severity of extreme events such as heatwaves and floods, as well as gradual onset changes such as droughts and inundation by rising seas. Some future climate impacts are now inevitable, but the consequences of those impacts are not. Enhanced efforts to prepare for the impacts of climate change are a vital complement to mitigation efforts.

Infrastructure and climate resilience are closely linked. First, climate change poses direct and indirect risks to infrastructure assets and service provision, such as when roads melt, reservoirs run dry and tunnels flood. Impacts in one area can lead to downstream economic and social impacts as disruptions ripple through infrastructure networks. Second, infrastructure can exacerbate climate-related risks. Sparks from electrical transmission lines, for example, can ignite wildfires, and heavy rains can set off catastrophic dam failures. Third, climate change will create new demands for infrastructure, such as reinforcement of flood defences.

Given these challenges, there is an urgent need to make climate resilience standard practice for infrastructure. Choices made today about infrastructure provision will have impacts for decades to come; it is vital to build resilience rather than lock in vulnerability. In practice, this means that infrastructure should be planned, designed, built and operated in ways that anticipate, prepare for and adapt to a changing climate. This complements efforts to ensure that infrastructure contributes to the transition to net zero. Climate resilience should be considered from the outset for new assets. Ageing infrastructure may need to be replaced or adapted to meet today’s needs. Existing assets may need to be retrofitted or operated differently to account for climate change impacts over the course of the asset’s life.

There is a compelling economic argument for investing in climate-resilient infrastructure. Well-targeted and timely investments can help protect lives and livelihoods, improve service reliability, reduce maintenance, extend asset lifetimes and generate co-benefits. Every dollar invested in climate-resilient infrastructure yields about four dollars of benefits.

Unlocking this potential requires a whole-of-government approach to embed climate resilience across the infrastructure life cycle. This includes assessing and understanding current and future risks to infrastructure assets and operations under climate change. Those risks must then be integrated into infrastructure planning and decision making. A clear business case is needed for investing in climate resilience. Climate resilience investments require adequate financing through diverse channels that establish incentives for greater financing.

This report draws on contributions from across policy areas to analyse the status of climate-resilient infrastructure, identify areas of emerging good practice and provide insights to help governments harness the potential of building infrastructure for a resilient future.

Policy insights

Systematically integrate climate change into infrastructure planning to ensure the resilience of infrastructure systems and manage interdependencies

- Climate resilience should be mainstreamed into planning to ensure that infrastructure can withstand future climate-related risks. At the same time, stakeholders should be involved in decisions that will affect the placement and impact of infrastructure as well as land use. Methodologies to select projects should deliver high levels of resilience and technical tools to operate and maintain for resilience over the life cycle.
- Key considerations for strengthening planning include the following:
    - Strengthen co-ordination among the actors that deliver and operate infrastructure, identify interdependencies among infrastructure systems and develop ways to share information about vulnerabilities to climate risks among infrastructure operators and stakeholders.
    - Use planning, policy and fiscal settings to signal future investment in resilient infrastructure and set out requirements for actors that deliver and operate infrastructure to meet resilience standards.
    - Use data and new techniques during the maintenance and operations phase to ensure service levels continue to be met in the face of increasing climate-related risks.

Mainstream climate resilience into infrastructure financing and investments to make climate-resilience the norm for all investments and unlock capital for adaptation

- Finance flows for climate-resilient infrastructure are insufficient to address the growing impacts of climate change. Market failures, policy misalignments and lack of risk awareness are preventing public and private investment decisions to account for the benefits of increased climate resilience.
- Key elements of such an approach include:
    - Use reporting and disclosure regimes to ensure that climate resilience is part of the financing considerations as a norm.
    - Ensure project preparation facilities can include the provision of technical support and guidance or financial support to plan for climate-resilience.
    - Mobilise private financing and investment by encouraging physical risk disclosure, addressing regulatory barriers, ensuring effective risk sharing and, where appropriate, the strategic use of public support including blended finance to incentivise financing for climate resilience.
    - Explore the full range of potential funding sources for climate resilient infrastructure to cover upfront costs, as well as ensuring adequate maintenance. Innovative financing approaches, such as land value capture, can provide a useful complement to traditional funding streams such as taxes and user charges.

Unlock the potential of Nature-based Solutions (NbS) for providing cost-effective and flexible infrastructure services, as well as social and environmental co-benefits

- NbS can substitute, complement or safeguard conventional climate risk reduction solutions. However, unleashing the potential of NbS will require integration across the policy, regulatory, finance and institutional frameworks that enable infrastructure development, and incorporation in technical training programmes for designers and operators of infrastructure.
- Strengthening use of NbS includes the following actions:
    - Examine technical norms, standards and regulations to ensure a level playing field for the use of NbS compared to conventional infrastructure.

- Build capacity for NbS through development of knowledge tools such as databases of good practices, networking and capacity building platforms.
- Adjust valuation approaches so the benefits of NbS are considered in policy and project appraisal, design and selection processes.

Address the unique challenges and opportunities faced by developing countries

- For developing countries, the imperative of climate-resilient infrastructure goes hand in hand with the need to close the infrastructure gap. Addressing social equity and inclusion is paramount when planning climate-resilient infrastructure in developing countries, where inadequate infrastructure can disproportionately affect vulnerable and marginalised communities.
- International co-operation can help address the specific needs of developing countries through the following actions:
    - Share knowledge and provide technical assistance in private and public sector capacities, including through co-operation and co-ordination mechanisms; update legal frameworks and development of climate adaptation and resilience capacities, especially through enhanced tools and institutional strengthening.
    - Share know-how in research, development and deployment of adapted measures for climate-resilient infrastructure.
    - Increase investment and financing; enhance mobilisation of multilateral development banks and development finance institutions beyond direct financing and in areas such as project preparation, screening and due diligence to financing and signalling.

Take an integrated approach to create more climate-resilient regions and cities

- Climate-resilient infrastructure can help communities adapt to climate change as part of long-term regional and urban development. Regional and local governments will play an essential role in building climate-resilient infrastructure. Subnational governments were responsible for 69% of climate-significant public investment in OECD countries. They have the mandate to plan, deliver, fund and maintain much of the climate-resilient infrastructure required. They also have responsibilities for setting local framework conditions for climate resilience investment.
- The following approaches can help national, regional and local governments to support the delivery of climate-resilient infrastructure for regions and cities:
    - Adopt a place-based approach to tailor resilience actions to support systemic and integrated policy action at a local level together with communities.
    - Harness multi-level governance to help align climate resilience actions across levels of government through enhancing co-ordination and reinforcing local government capacity.
    - Support subnational government finances to help identify appropriate local revenue streams for resilience, to better mobilise funding to where it is most needed and to unlock climate finance at a local level.

1 Closing the climate resilience gap in infrastructure

Infrastructure is key to a well-functioning society by enabling the circulation of people, goods and information. However, storms, floods or wildfires induced by climate change have led to widespread infrastructure failure and damages. Projections suggest that infrastructure will be increasingly exposed to climate impacts. This chapter introduces the rationale for building climate-resilient infrastructure as part of fostering broader sustainability and quality of infrastructure. It demonstrates how social and economic resilience to climate change hinge on the ability of infrastructure to adapt to and absorb climate impacts. Finally, it provides an overview of how planning, financing and design need to consider climate resilience, topics covered in more detail in the other chapters.

Key policy insights

- Infrastructure – like other economic assets – is exposed to the growing impacts of climate change. The climate resilience of infrastructure plays a fundamental role in the ability of society and economies to adapt to and absorb negative impacts of climate variability and extreme weather events.
- Climate-resilient infrastructure describes infrastructure that is planned, designed, constructed and operated in a way that anticipates, prepares for and adapts to a changing climate. Such infrastructure can withstand and recover rapidly from disruptions caused by changing climatic conditions throughout its lifetime. It concerns both new assets, as well as existing ones, which may need to be retrofitted or operated differently to account for climate change impacts.
- Building climate-resilient infrastructure creates significant opportunities. Climate resilience can increase the lifespan of infrastructure, protect investment returns and ensure business continuity. It has been shown to lower the cost of damages and repairs throughout the lifetime of infrastructure.
- Ensuring infrastructure is climate resilient involves several distinct steps. It starts by assessing current and future risks to assets and operations under climate change, followed by integrating climate risks into planning and decision making. Climate resilience investments require adequate financing and technical capacity. Since climate risks evolve continuously, performance measurement of resilience measures is needed to adjust operation and maintenance over time.

1.1. Introduction

Infrastructure is key for supporting a well-functioning society by enabling the circulation of people, goods and information. It provides connectivity and key resources such as water or energy, which sustain critical functions for society. As such, it has an essential role in ensuring the well-being of people and the functioning of the economy.

Infrastructure is significantly exposed to the impacts of climate change. Storms, floods or wildfires induced by climate change have led to widespread infrastructure failure and damages. The costs of damage incurred by infrastructure due to extreme weather events account for two-thirds of government contingency (OECD/The World Bank, 2019[1]). In light of projections, infrastructure will likely be increasingly exposed to climate impacts.

At the same time, infrastructure can play an essential role in building more resilient economies and societies by reducing their vulnerability to current and future climate shocks. If infrastructure continues to operate despite an adverse weather event, communities and businesses can continue functioning and better absorb shocks to their assets.

Climate-resilient infrastructure is planned, designed, constructed and operated in a way that anticipates, prepares for and adapts to the changing climate. As such, it can withstand and recover rapidly from disruptions from changing climatic conditions throughout its lifetime. This concerns both new assets, as well as existing ones, which may need to be retrofitted or operated differently to account for climate change impacts (OECD, 2018[2]).

Infrastructure is capital intensive and long-lived, with some assets lasting decades or centuries. Decisions today about the location, design and nature of infrastructure have long-term effects. This includes whether investments deliver objectives and anticipated benefits over their lifetime, as well as whether they need to be retrofitted in the context of climate change.

This chapter introduces the rationale for building climate-resilient infrastructure, demonstrating the opportunities it provides. It briefly identifies the steps to mainstream climate resilience into planning, developing and operating infrastructure over its life cycle. Subsequent chapters explore these issues in more depth. While the report draws primarily on experiences from OECD countries, it dedicates Chapter 5 to exploring insights from resilience building in developing countries.

Box 1.1. Climate resilience as a vital element of resilient, sustainable and quality infrastructure

Climate-resilient infrastructure is an essential element of the broader efforts to achieve resilient infrastructure. Broader infrastructure resilience includes resilience to natural hazards unrelated to climate (such as earthquakes) but also to human-induced risks (such as terrorist attacks or industrial accidents) (OECD, 2021[3]). The OECD defines this broader resilience as the "ability to resist, absorb, recover from or successfully adapt to adversity or a change in conditions" (OECD, 2014[4]).

Resilience is an essential part of both sustainable and quality infrastructure investment and development. While the concepts of sustainable and quality infrastructure overlap, they both represent broader concepts than climate-resilient infrastructure.

Sustainable infrastructure includes built and/or natural systems that provide a range of services. These ensure economic, social and environmental sustainability throughout the entire infrastructure life cycle (from planning to decommissioning and repurposing), in line with the Sustainable Development Goals (SDGs) (OECD, 2021[3]). Sustainable infrastructure is thus a broader concept than resilience, encompassing considerations of usefulness, viability, efficiency, technical stability, financial sustainability and good governance. At the same time, it is environmentally and socially sustainable, contributing to both climate change adaptation and mitigation.

Quality infrastructure represents an even broader concept. Apart from aligning with the SDGs and contributing to their delivery, it aims to maximise the economic, social, environmental and development impacts of infrastructure (OECD, 2021[5]). Furthermore, it focuses on raising the economic efficiency of infrastructure throughout its life cycle, while integrating environment and social considerations, and enhancing resilience. The OECD has been championing quality infrastructure through several initiatives, including support for the development of the G20 concept for quality infrastructure investment.

1.2. The rationale for building climate-resilient infrastructure

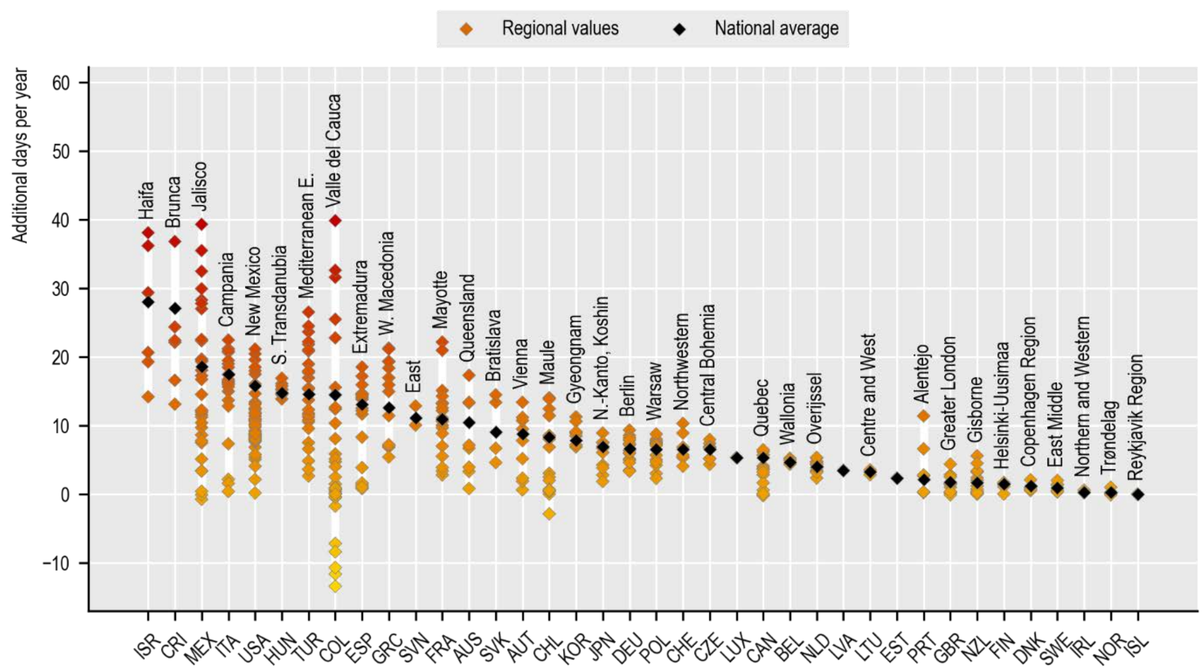
1.2.1. Climate change is causing increasingly severe damages and disruptions to infrastructure

Greenhouse gases (GHGs) emitted into the atmosphere to date have already led to considerable warming and, as a consequence, intensified climate risks. Global mean temperatures exceeded pre-industrial levels by over 1.4°C in 2023 (Copernicus, 2023[6]). Most land areas have experienced an increase in the frequency and intensity of heavy precipitation events since 1950 (IPCC, 2021[7]). Similarly, the duration, frequency and intensity of droughts have increased in many regions of the world since the middle of the past century (Spinoni et al., 2014[8]). In Europe, the areas and people affected by droughts rose by nearly 20% between 1976 and 2006 (European Commission, 2007[9]). The duration of the fire weather season[1] also increased by 27% globally between 1979 and 2019, with notable increases in western North America, southern Europe, Australia, western and central Asia, and most of Africa (Jones et al., 2022[10]; OECD, 2023[11]). Average sea levels to date have risen by 21-24 cm compared to pre-industrial levels (Lindsay, 2022[12]).

There are important spatial variations in the manifestation of these hazards. Although temperatures are rising across the globe, the impact of extreme heat differs across and within countries. There are large territorial disparities in the exposure of both people and assets to heat stress (Figure 1.1).

Figure 1.1. Warming temperatures create unequal heat stress impacts within countries

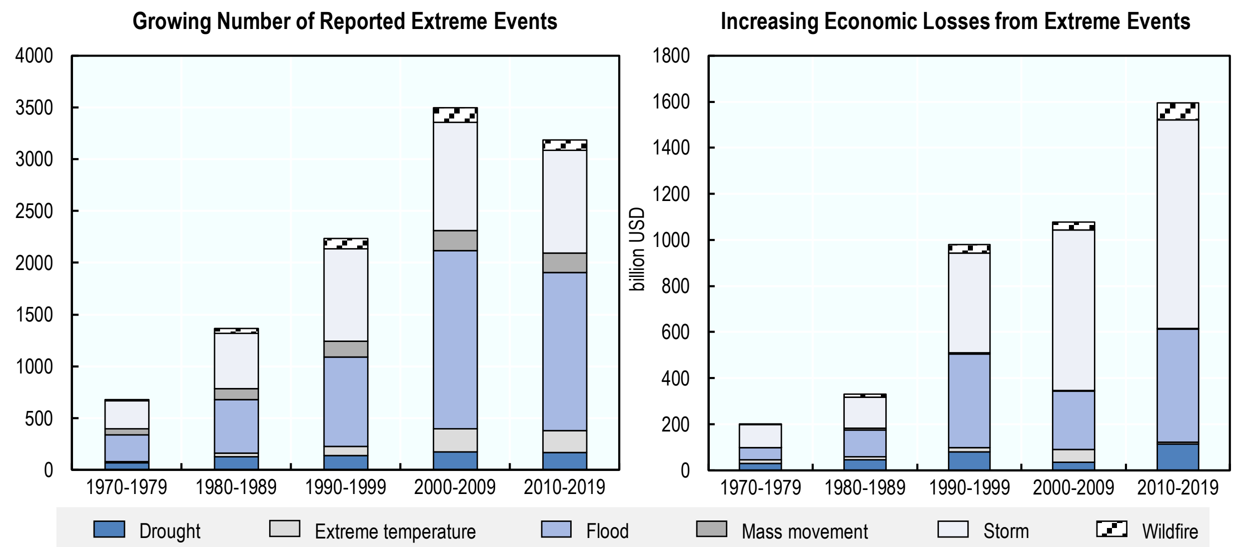
Additional days of strong heat stress per year in OECD large regions (TL2), 2017-21 compared with 1981-2020



Source: OECD (2023[13]), Territorial Approach to Climate Action and Resilience, https://doi.org/10.1787/9d143ae1-en.

In the past five decades, the number of climate-related extreme events increased fivefold (WMO, 2021[14]). In parallel, economic losses from disasters increased sevenfold between the 1970s and the 2010s from an average USD 198 billion to USD 1.6 trillion (Figure 1.2). Infrastructure assets make up an important share of the economic damages. This, in turn, multiplies the losses (e.g. forgone income) for businesses whose operations are disrupted.

Figure 1.2. The number of reported extreme events and economic losses have grown



Note: Monetary value calculated in USD, adjusted for inflation with 2021 as the base year.
Mass movements include avalanches, landslides, mudslides, rockfalls and sudden subsidence.
Source: Based on EM-DAT (2023[15]), International Disasters, https://www.emdat.be/publications/.

Climate change affects infrastructure assets and their operations from both slow and rapid onset events. Climate change impacts from slow onset events result from hazards that occur and are sustained over long periods (e.g. limited water availability due to drought). Conversely, a rapid onset event, such as storms disrupting telecommunications networks, can damage and disrupt infrastructure in a matter of days or hours.

Different infrastructure sectors are threatened by different climate hazards (Table 1.1). For example, while droughts can severely hinder riverine transport, they have limited effects on rail, air and road transport. In contrast, high temperatures may affect road infrastructure at highways and airports, as well as railway lines, while leaving sea and river transport routes largely unaffected (although workers may be substantially affected by extreme heat). Overall, the potential impact of climate change on infrastructure depends on the type of climate hazard, and its interaction with the vulnerability and exposure of infrastructure to it.

Table 1.1. Climate risks affecting selected types of infrastructure in different ways

Infrastructure type		Climate hazard	Infrastructure impacts
Transport	Land (roads, railways)	Extreme heat	Pavement softening (rutting), thermal rail expansion (buckling)
		Extreme precipitation	Washouts, flooding of roads and railways
		Riverine flooding	
		Storm surges and sea level rise	Inundation and de-stabilisation of coastal road and railway lines
		Storms, high winds	Blockage of roads and railways due to fallen trees and other damaged assets
		Permafrost melt	Buckling and destabilisation of roads and railways
	Riverine	Droughts	Riverine transport routes (temporarily/seasonally) becoming unnavigable
		Riverine floods	Damage to ports, ships and cargo, riverine transport routes temporarily becoming unnavigable
		Storms, high winds	
	Marine	Sea level rise and storm surges	Inundation and erosion of ports
		Temperature rise	Changing demand for ports and Arctic waters become navigable
		Storms, high winds	Damage to ports, ships and cargo, certain transport routes (temporarily) becoming unsafe
	Aviation	Storms, extreme precipitation, cold waves, wildfire (smoke)	Disruptions to flight schedules, damage to aircraft and airport infrastructure, risks to safety (e.g. accidents), need for extensive de-icing of aircraft and runways, impacts on mechanical operations, runway buckling
Energy	Hydropower	Droughts	Reduced hydropower production, with the possibility of stranded assets if drops in water levels persist
		Floods	Damages to hydropower plants
	Nuclear	Droughts and/or high temperatures	Reduced availability of cooling water
		Riverine flooding	Damage to assets, safety issues, pollution
		Sea level rise and storm surges	
	Solar	Extreme temperatures	Reduced efficiency of solar panels
	Energy sector overall	Extreme temperatures	Increased demand for cooling, increased pressure on the power grid
		Sea level rise, storm surges	Inundation and/or erosion of coastal power plants, cooling systems, transmission and distribution lines
		Wildfires	Damage to power production assets, transmission and distribution lines
		Riverine flooding	Disruption of energy supply due to flooding of transmission lines or power plants
		Storms, high winds	Power outages, damage to power production assets, transmission and distribution lines
Telecommunications		Extreme heat	Overheating of data centres
		Riverine floods	Flooding and/or erosion of data centres, radio/television stations, telecommunications, distribution lines, etc.
		Sea level rise and storm surges	
		Extreme precipitation	
		Storms, high winds	Damage to telecommunications towers, distribution lines
		Wildfires	Burning of transmission cables, telecommunications towers
Water supply, waste- and stormwater infrastructure		Extreme heat	Increased evapotranspiration from reservoirs, increased need for water treatment
		Extreme precipitation	Sewage overflows, overtopping of dams, levees and reservoirs, increased need for water storage capacity
		Riverine flooding	Contamination of water sources, overtopping of dams, levees and reservoirs, increased need for water storage capacity
		Droughts	Reduced water supply
		Sea level rise and storm surges	Salinisation of water supply, inundation and/or erosion of water treatment infrastructure, including outfalls

Note: This table illustrates potential climate hazards and impacts for various infrastructure types but does not provide an all-encompassing list of infrastructure types, climate hazards and impacts.
Source: Based on OECD (2018[2]). Climate-resilient infrastructure, https://doi.org/10.1787/4fdf9eaf-en; IISD (2021[16]), Advancing the Climate Resilience of Canadian Infrastructure: A Review of Literature to Inform the Way Forward, https://www.iisd.org/system/files/2021-07/climate-resilience-canadian-infrastructure-en.pdf.

Infrastructure damages caused by extreme weather events in recent years provide concrete examples of how climate change is affecting infrastructure. Due to Hurricane Sandy, for example, regional infrastructure networks in the greater New York and New Jersey areas suffered around USD 17.1 billion in direct damages (Martello and Whittle, 2023[17]). Disruptions caused by extreme events are increasing. In the United States, the number of blackouts caused by extreme weather events increased from 5 to 20 annually in the 1990s to between 50 and 100 in the early 2010s (Castillo, 2014[18]; Chang, 2016[19]). Table 1.2 provides a non-exhaustive overview of examples of recent infrastructure damage induced by extreme weather events caused by climate change.

Table 1.2. Selected events induced by climate change and their damage to infrastructure

Year	Type of event	Location	Link to climate change	Infrastructure damage
2018	Wildfire ("Camp Fire")	United States	Climate change was found to have doubled the extreme weather that fed the wildfire (Williams et al., 2019[20]; Goss et al., 2020[21]).	19 000 assets destroyed, including homes, hospitals, schools and business buildings (Fischer et al., 2021[22]).
2019	Strom ("Typhoon Hagibis")	Japan	The typhoon was found to be 67% more likely due to climate change (Li and Otto, 2022[23]).	Levees destroyed at 135 locations; 10 trains and 120 carriages damaged in a flooded depot. Due to damages to power and water infrastructure, 22 000 households lacked power, while 133 000 homes were without water for over two weeks (Tulane University Law School, 19 March 2021[24]).
2021	Ahr Valley Floods	Germany	Climate change increased the intensity of the rainfall associated with the floods by 3-19% and heightened their likelihood by 1.2 to 9 times (Tradowsky et al., 2023[25]).	Over 50 bridges, 600 km of rails and 3 federal highways damaged and out of operation for months. Buildings, the transport infrastructure and sector suffered around EUR 14 billion of direct and indirect damages (Prognos, 2022[26]).
2022	Drought	Europe	The drought was found to be 5 to 20 times more likely due to high temperatures associated with climate change (Schumacher, 2022[27]).	30% lower hydropower generation in the first six months of 2022 for the French utility company, EDF, resulting in income loss of EUR 1.4 billion (Franke, 2022[28]). Severe fluvial transport disruptions on the Danube and Rhine Rivers (CCNR, 2023[29]).

Source: CCNR (2023[29]), CCNR Market Observation – Annual Report 2023, https://www.ccr-zkr.org/files/documents/cpresse/cp20231006en.pdf.

Climate impacts on infrastructure can be even more consequential in developing countries, due to limited resources and adaptive capacity, as well as inadequate infrastructure design (Chapter 5). Furthermore, inequalities – manifesting, for example, in unequal housing conditions and access to health care and infrastructure services – exacerbate vulnerabilities in many developing countries to infrastructure disruptions. In 2019, following a drought in India, reservoirs dried up in the city of Chennai, which had disproportionate effects on impoverished residents (Sebastian, 2022[30]). In 2023, two major dams collapsed after heavy storms around the city of Derna, Libya, leaving at least 4 300 people dead and 40 000 displaced (Zachariah, 2023[31]).

Climate change impacts can have more consequential impacts on particular places within countries. For example, heatwaves particularly affect cities. This occurs because the temperature tends to be higher in cities than in surrounding areas due to the urban heat island effect. In the past five years, almost half of OECD cities witnessed a summer daytime heat island effect of more than 3°C (OECD, 2022[32]). Differing spatial distribution of climate hazards, overlaid atop different physical, economic and social characteristics of regions and cities, means there is a strong spatial dimension to consider (see Chapter 6).

1.2.2. Failure in infrastructure systems ripples through the economy, communities and the environment

As most infrastructure assets are interdependent with other systems and a range of societal and economic functions rely on them, the failure of infrastructure can cause a wide range of cascading impacts, both indirect and direct (Vallejo and Mullan, 2017[33]). As an illustration of indirect damages, 20 million properties in England are at risk from utility failures during a flood. This is eight times more than the number of properties (2.4 million) at risk of riverine or coastal flooding (Hall et al., 2019[34]). The 2011 floods in Thailand – triggered by a particularly intense monsoon season – led to considerable direct damage and disruption to infrastructure. The Don Mueang Airport in Bangkok, for example, required USD 52 million in repairs and was closed for months (Adams et al., 2014[35]). Flood damage to manufacturing plants in Thailand disrupted supply chains worldwide. In Canada and the United States, vehicle production fell by 50% in Honda's factories (Adams et al., 2014[35]) because of floods. Similarly, droughts – and associated low water – on the Rhine River in 2018 prevented shipping on 80% of days between June and December (Prognos, 2022[36]). This had severe implications on plants relying on the river for the transport of raw materials and products in Germany's Ruhr region. The interruption of logistics chains for chemical, petroleum products, ores, other raw materials and goods caused a loss of EUR 5 billion to Germany's economy in the second half of 2018 (CCNR, 2019[37]).

By affecting assets and basic services, direct and indirect infrastructure damages have major social impacts. During Hurricanes Irma and Maria in 2017, telecommunications infrastructure on the islands of Puerto Rico, Saint Martin, Dominica, and Antigua and Barbuda were destroyed just when they were critical to issue extreme weather warnings and support emergency response (GSMA, 2018[38]). Damages to infrastructure assets can also disrupt the movement of people. In 2012, Hurricane Sandy restricted the travel of 5.4 million passengers (Vallejo and Mullan, 2017[33]). Similarly, the 2008 Great Ice Storm in the People's Republic of China (hereafter "China") left 5.8 million people stuck on railway stations. Indeed, in one single highway segment in Hunan province, the Great Ice Storm stranded 200 000 vehicles with 60 000 passengers (Zhou et al., 2011[39]).

Power cuts associated with infrastructure failures also affect many people. The aforementioned ice storm left 4 million inhabitants of the city of Chenzhou without electricity for several weeks during the Chinese New Year celebrations (Zhou et al., 2011[39]). After Hurricane Katrina in 2005, 2.7 million people were left without electricity (Hall et al., 2019[34]). Similarly, the 2021 Typhoon Rai (Odette) in the Philippines left 269 cities and municipalities without electricity, while 348 suffered from network interruptions (OCHA, 2021[40]). During the 2009 heatwave in Australia, half a million people were left without power in Melbourne as the heat stress caused power outages in the electricity transmission network (McEvoy, Ahmed and Mullett, 2012[41]).

Ecosystem damages associated with infrastructure failures can also be significant. In 2012, Hurricane Sandy in the United States led to the release of nearly 42 billion litres of sewage, contaminating freshwater systems (Kenward, Yawitz and Raja, 2013[42]). After the collapse of two major dams in Derna, Libya following Storm Daniel in 2023, polluted sediments and debris flooded parts of the El Kour Natural Park, harming wildlife in Ramsar-protected coastal lagoon areas (CEOBS, 2023[43]).

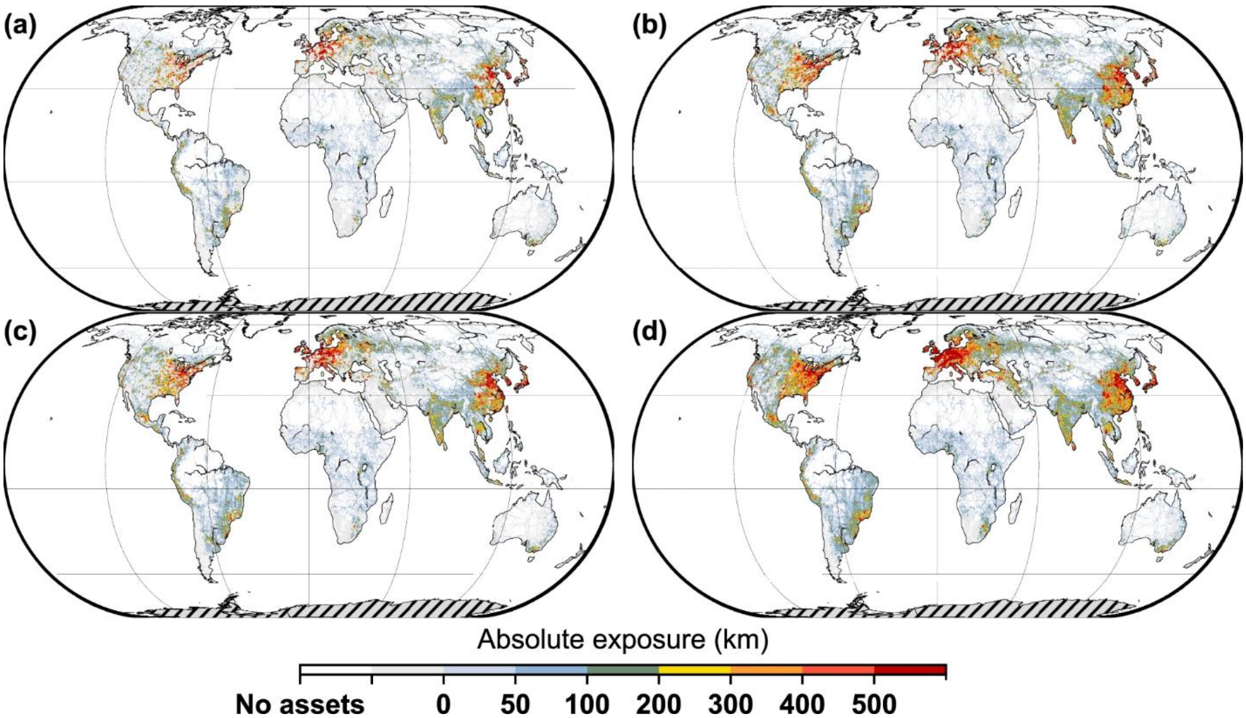
1.2.3. Climate change will put more pressure on infrastructure in the future

Without rapid GHG mitigation efforts, the Earth's temperatures will continue to rise, and thereby increasingly expose infrastructure to climate risks. For example, the land area flooded during a 100-year storm is projected to increase by 64% by the end of the 21st century under a high (RCP 8.5) emissions scenario, with strong geographical variations (see Chapter 6). This will threaten an extra 1.9 million homes worth USD 882 billion by flood risk in the United States alone (Thiele et al., 2020[44]). In the state of Alaska, without adaptation, the cumulative total infrastructure damage is estimated at USD 5.5 billion by the end of the 21st century under a high (RCP 8.5) emissions scenario and USD 4.2 billion under a moderate (RCP 4.5) scenario (Melvin et al., 2017[45]). In Europe, damage to infrastructure from extreme weather events is projected to increase tenfold by 2100 without adaptation measures, reaching EUR 3.4 billion per year (Forzieri et al., 2018[46]).

Climate change will significantly affect power infrastructure. The efficiency of thermal and nuclear power plants is likely to decrease with more frequent droughts and higher temperatures (Hallegate, Rentschler and Rozenberg, 2019[47]). A 1°C temperature rise already reduces nuclear power output by 0.8% (Linnerud, Mideksa and Eskeland, 2011[48]), while the efficiency of photovoltaic systems decreases by 0.5% (Patt, Pfenninger and Lilliestam, 2013[49]; Hallegate, Rentschler and Rozenberg, 2019[47]). Usable hydropower capacities could decrease by 61-74% by 2040-69 under a low (RCP 2.6) to high (RCP 8.5) emissions scenario. These reductions are due to reduced streamflow associated with climate change in the areas of most hydropower plants (van Vliet et al., 2016[50]). Similarly, usable thermoelectric power capacity is expected to decrease by 81-86% by 2040-69 due to reductions in streamflow capacity and water temperature rise (van Vliet et al., 2016[50]). In addition, sea level rise induced by climate change could require relocation of power plants. About 30% of power generation capacity in Bangladesh will have to be relocated between 2030 and 2100 due to inundations induced by sea level rise (Khan, Alam and Alam, 2013[51]).

Similarly, climate change will affect transport infrastructure. Under a moderate (RCP 4.5) emissions scenario, 6.8 million km of global road and rail transport assets will be exposed to more frequent extreme precipitation events by the middle of the 21st century, which will rise to 11 million km by its end (Liu et al., 2023[52]). Particularly exposed areas will include the eastern coast of North America, large parts of Europe, Japan, the Korean Peninsula and the eastern coast of China (Figure 1.3). In the United States, road and railway infrastructure exposed to extreme precipitation will exceed 1.14 million km (representing a third of total transport assets) by mid-century and 2 million km (two-thirds of total assets) by the late 21st century. In China, nearly 1.3 million km and over 1.9 million km of roads will be exposed to extreme precipitation by the mid- and late 21st century, respectively (Liu et al., 2023[52]). In addition, 13 000 km of roads and 100 airports are at risk of damage due to permafrost melt in the Arctic region by 2050 under the same climate scenario, affecting nearly 4 million people (Hjort et al., 2018[53]). If a high (RCP 8.5) emissions scenario takes effect, close to 200 airports and over 850 seaports in Europe will face the risk of inundation by 2080 due to sea level rise and storm surges (Christodoulou and Demirel, 2018[54]). Globally, the world's sea ports are projected to be under very high risk due to various climate change impacts. Under a high (RCP 8.5) emissions scenario, 14% of port operations are projected to be at high risk by the end of the 21st century compared to less than 4% today (Figure 1.4). Coastal flooding and overtopping driven by sea level rise would disrupt operations the most.

Figure 1.3. Exposure of road and railway assets to extreme precipitation under different climate scenarios



Note: By 2030-59 (a and c) and 2070-99 (b and d) under a moderate (RCP 4.5) emissions scenario (a and b) and a high (RCP 8.5) emissions scenario (c and d).

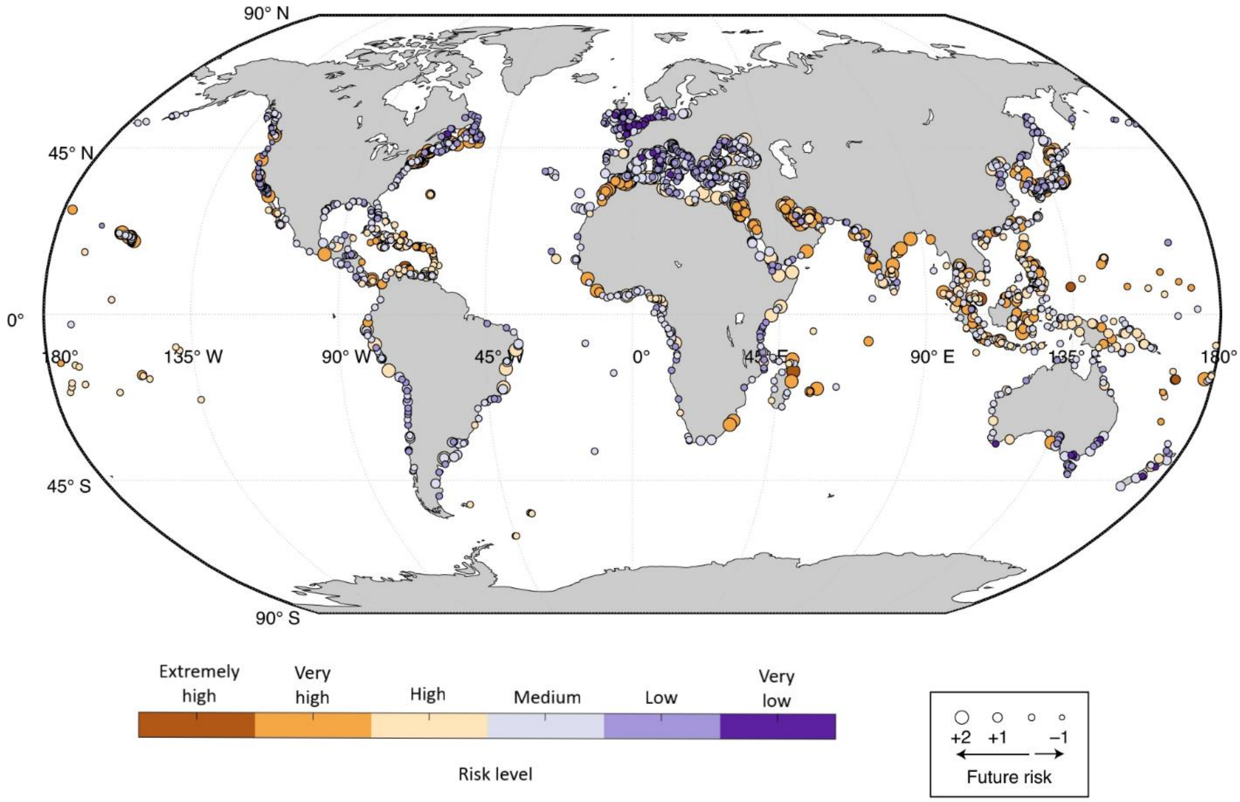
Source: Liu et al. (2023[52]), Global transportation infrastructure exposure to the change of precipitation in a warmer world, https://doi.org/10.1038/s41467-023-38203-3.

Water and wastewater infrastructure will also face significant impacts due to climate change. Expected precipitation changes will put pressure on the resilience of several water reservoirs. Under medium (RCP 4.5) and high (RCP 8.5) emissions scenarios, water supply from the Descoberto reservoir in Brazil, for example, is expected to decrease by 15-50% (Chaves, da Silva and Fonseca, 2023[55]). In the United Kingdom, drought-induced water shortages could cost up to GBP 40 billion (under a medium emissions scenario with dry climate and high population growth) in the next three decades (NIC, 2018[56]). Under a moderate (RCP 4.5) emissions scenario, 208 million people in China could be exposed to the flooding of wastewater treatment plants by mid-century due to increased frequency of 1-to-30-year return floods (Hu et al., 2019[57]).

Changing climate conditions combined with demographic, economic and other developments will also affect societal infrastructure needs. For example, increasing climate hazards will increase the need for infrastructure assets with protective functions. These include sea walls or protective oyster reefs and mangroves to safeguard people and assets from sea level rise and enhanced coastal erosion. Chapter 4 discusses how Nature-based Solutions (NbS) can support these changing infrastructure needs in the context of climate change.

Figure 1.4. Climate-risk levels for seaports worldwide

In 2100, under a high (RCP 8.5) emissions scenario



Note: The map is based on a multi-hazard analysis, including changes in sea level rise, tropical cyclones, storm surges, wind, waves, precipitation and temperatures.
Source: Based on Izaguirre et al. (2021[58]), Climate change risk to global port operations, https://doi.org/10.1038/s41558-020-00937-z.

1.3. The opportunity of climate resilience building

While climate resilience measures can increase the lifespan of infrastructure, they also play an essential role in protecting investment returns and ensuring business continuity. While addressing climate risks can increase design and implementation costs, the benefits are considerable. Spending on infrastructure resilience *ex ante* can reduce repair costs and maintenance needs over time, as well as lower the cost of service disruptions and damages. For example, the state of Florida in the United States invested USD 19.2 million to enhance resilience to wind and water damage, avoiding losses of more than USD 81 million when Hurricane Matthew struck in 2016 (C2ES, 2018[59]). Similarly, enhancing resilience of transport infrastructure to future floods is estimated at 3-10% of project investment costs, but this investment can lower annual future flood damages by 42% (Hall et al., 2019[34]). In low- and middle-income countries, more resilient infrastructure was estimated to have USD 4.2 trillion of net benefit, providing a return of USD 4 for every invested USD 1 (Hallegate, Rentschler and Rozenberg, 2019[47]). In China, every CNY 1 invested in climate-resilient infrastructure could deliver CNY 2-20 over a 30-year period (Ding et al., 2021[60]). In the city of Wuhan, for example, the benefits of investing in “sponge city” infrastructure to enhance resilience to heavy precipitation outweigh the costs more than twice over three decades. The benefits derive from the avoided socio-economic costs of waterlogging, reduced municipal water pollution control costs and increased groundwater recharge (Ding et al., 2021[60]).

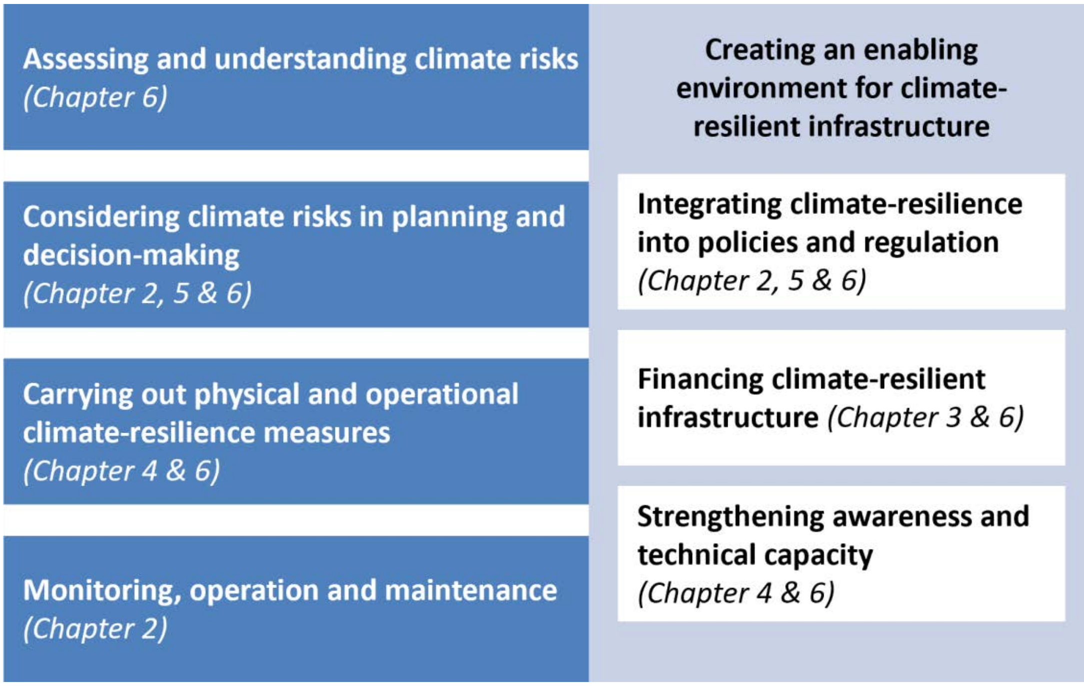
Additional social, environmental and economic co-benefits can provide further incentives to invest in climate-resilient infrastructure. On the socio-economic level, it is estimated that each USD 1 billion invested in flood-resilient infrastructure in the United States could create 40 000 jobs (Khan, McComas and Ravi, 2020[61]). While environmental aspects must be carefully monitored to avoid potential trade-offs, climate resilience measures can benefit the environment. At Lake Mälaren in Sweden, for example, a project to make the Slussen lock climate resilient has provided a more natural water balance, benefiting plants and wildlife along the lake and its Natura 2000 protected sites (Vallejo and Mullan, 2017[33]). NbS offer climate resilience building with a wide range of social and ecosystem co-benefits (Chapter 4). In the state of Alabama in the United States, for example, restoring around 6 km of oyster reefs in Mobile Bay helped protect the shoreline from coastal erosion by reducing wave energy (by 91%) and height (by 53%). At the same time, it provided seafood equivalent to half of total oyster harvests in Alabama, lowering nitrogen pollution (World Bank and World Resources Institute, 2022[62]).

Furthermore, it would be costly to delay action. Postponing climate resilience measures in infrastructure can lock in infrastructure damages and service disruptions, as well as costs incurred for repair and retrofit needs. In low- and middle-income countries, the cost of delaying climate resilience investments in infrastructure by ten years was estimated at an additional USD 1 trillion (Hallegate, Rentschler and Rozenberg, 2019[47]). In the United States, it is estimated that road repairs due to increasing temperatures would reach a cumulative USD 200-300 billion by 2100 in the absence of adaptation measures (Chinowsky, 2022[63]). Early adoption of climate resilience measures can thus help save future costs and offer comparative advantages by providing robust and reliable infrastructure services.

1.4. Climate resilience building for infrastructure: An overview of this report

This section introduces the four distinct steps involved in climate resilience building (Figure 1.5), which the following chapters will elaborate in more detail. The first step assesses current and future risks to infrastructure assets under climate change. This is followed by integrating climate risks into infrastructure planning and decision making. Once adequate financing measures are in place and matched with appropriate technical capacity, the third step involves implementing physical and operational measures to ensure climate resilience of assets. Finally, infrastructure projects are monitored over time to adjust operation and maintenance measures to evolving climate risks.

Figure 1.5. The steps of building climate-resilient infrastructure



1.4.1. Assessing and understanding climate risks

Assessing climate risks is the first step to building climate-resilient infrastructure. As defined by the Intergovernmental Panel on Climate Change, climate risks comprise the interactions of climate hazards (caused by an event or trend related to climate change), with the vulnerability (perceptibility to harm) and exposure of assets and people to them (IPCC, 2014[64]).

Most OECD countries have produced national climate-risk assessments, which include some degree of analysis of the infrastructure sector (OECD, 2018[2]). Climate-risk data is often not downscaled enough to inform infrastructure risk assessment at the asset level. Given the strong spatial dimension of future climate risks and vulnerabilities, a place-based approach to understand local impacts is relevant (Chapter 6). OECD work on subnational climate hazard data contributes significantly to close this knowledge gap (see the OECD Laboratory for Geospatial Analysis).

It is important to understand both current and projected climate risks. In the context of climate change, the frequency and intensity of climate impacts are expected to change. Although projections of future climate hazards are largely available across OECD countries, their integration into hazard models remains limited (OECD, 2023[11]).

An analysis of risks to infrastructure assets should map interdependencies between these assets and networks. As climate change impacts can cascade through infrastructure systems (Section 1.2.2), understanding how interdependencies affect infrastructure networks is crucial for minimising climate change impacts (OECD, 2018[2]). To that end, collaborations between infrastructure operators are essential. The EU's Critical Infrastructure Warning Information Network, for example, helps exchange information on different kinds of hazards and vulnerabilities, as well as strategies and measures to reduce risks to critical infrastructure (OECD, 2018[2]; European Commission, n.d.[65]). Stress testing can also identify how infrastructure will operate under future climate scenarios. It assesses where systems may fail due to severe or plausible disruptive events (both episodic or prolonged), analysing the ability of systems both to withstand and overcome these disruptions (OECD, 2018[2]; Linkov et al., 2022[66]). Applied to understand interconnectedness in systems, stress testing can help understand cascading impacts triggered by climate change in infrastructure networks and beyond (Linkov et al., 2022[66]).

1.4.2. Considering climate risks in infrastructure planning and decision-making processes

Once climate risks are mapped and assessed, they must be considered in planning and decisions across the whole life cycle of infrastructure. Several tools facilitate the mainstreaming of climate resilience across the various stages of infrastructure. Prior to defining individual projects, governments at all levels can prepare and develop climate-resilient national, regional or urban development plans (Box 1.2). Accompanying spatial plans and master plans can strategically define what can be built, and where (Chapter 6). This ensures that climate risks are considered as part of the overall built environment, allowing for interactions with other infrastructure and non-infrastructure assets to be understood (OECD, 2023[13]; OECD, 2023[67]). By 2050, 68% of the world's population are expected to live in urban settings (compared to 55% in 2018) (UNDESA, 2018[68]). Integrating climate resilience into urban development plans will thus become ever more critical.

Co-ordination across levels of government is essential for spatial planning as subnational governments have the key competencies in this area (OECD, 2017[69]; OECD, 2013[70]). The project appraisal phase, for example, can conduct an environmental impact assessment (EIA). Among other environmental impacts, an EIA assesses whether a project exacerbates climate change impacts elsewhere, as well as their vulnerability to climate change. In the European Union, directive 2011/92/EU introduced mandatory EIAs for certain large-scale projects. This policy was amended with 2014/52/ EU, strengthening the focus on climate change adaptation and resilience in the screening, scoping and assessment phases of projects (Vallejo and Mullan, 2017[33]; Dallhammer et al., 2018[71]).

A key challenge in planning and decision making for infrastructure resilience is uncertainty. Uncertainty stems from climate models, which are subject to continuous change based on global GHG mitigation efforts, their impact on changing hazard projections and the interplay with social, economic and environmental development. Adaptive and flexible planning can respond to changing climate impacts over the infrastructure's lifetime, enabling adjustments in the face of uncertainty. Scenario planning, for example, aims to accommodate a range of potential conditions through approaches like real options analysis (OECD, 2018[2]). In adaptive planning, multiple actions, including alternative pathways for policy development and investment, are developed in the planning phase. Based on pre-defined trigger points, decision makers can adopt alternative pathways dependent on how circumstances evolve. The adaptive pathways approach was used for the first time in the Thames Estuary 2100 project in the United Kingdom. The Thames Barrier was built to protect the city of London from coastal and tidal flooding. Further adaptation measures (e.g. a moveable or permanent tidal barrier to drain the river) will be taken when certain levels of sea level rise are reached (Hall et al., 2019[34]). Chapter 2 will provide further details on planning and decision making for climate-resilient infrastructure.

Box 1.2. Mainstreaming climate-resilient infrastructure through a national development plan: The case of the Philippines

Mainstreaming climate resilience into national development plans can provide an important starting point for including climate resilience in infrastructure development. In the Philippines, the Philippine Development Plan (PDP) 2023-28 is a foundational document delineating the policies and projects to fulfil the nation's objectives over the next six years. The PDP is a cornerstone for guiding budget allocations and ensuring alignment with objectives, which heightens its usefulness for infrastructure – a significant budgetary component. A full chapter of the PDP is dedicated to the expansion and upgrading of infrastructure, with the aim to embed climate resilience into infrastructure design. Another chapter is dedicated to further strengthening climate and disaster resilience within the country. Such policy objectives – particularly those concerning infrastructure – set out a management framework for the country's major infrastructure projects. In so doing, they help support local and national stakeholders to prioritise their investments. With the National Economic Development Agency (NEDA) working on target indicators to monitor implementation of the PDP, there is a unique opportunity to ensure its goals are translated into specific targets. As part of the Sustainable Infrastructure Programme in Asia, the OECD works with the Philippines to help the country improve the quality and sustainability of new and existing infrastructure through capacity building, including on climate resilience.

Source: (OECD, 2021[72]; NEDA, 2023[73]).

1.4.3. Carrying out physical and operational climate resilience measures

Building climate resilience of infrastructure assets encompasses both physical and operational measures. Physical measures include creating permeable surfaces to reduce flood risk from heavy precipitation events. Operational measures include changing the timing of maintenance to make infrastructure resilient to increasingly frequent climate hazards (OECD, 2018[2]). Both types of measures have to be chosen and adapted over time to consider evolving climate-risk patterns.

Physical climate resilience measures

Physical climate resilience measures in the infrastructure sector can encompass both engineered or "grey" measures, as well as NbS. Depending on the climate risks and the infrastructure sector concerned, various grey measures and NbS, as well as a combination of the two, can be applied to ensure climate resilience. Table 1.3 gives a selection of such measures. Chapter 4 will focus on how NbS can and are increasingly used for building climate resilience of infrastructure.

The scientific community is embracing both traditional and novel approaches to build climate resilience. Scientists welcome the use of traditional approaches to build climate resilience, including lifting infrastructure to decrease its exposure to climate hazards such as floods. At the same time, they are increasingly researching and implementing innovative approaches. These include smart technologies and materials such as self-healing concrete with bacteria that produce limestone. This can fill cracks that appear in construction materials, preventing water ingress and further damage (Jonkers et al., 2010[74]).

Likewise, the integration of traditional approaches and NbS continues to evolve. Some stakeholders have combined traditional stabilisation with living shorelines that integrate habitats, like oyster reefs, marsh plants and submerged aquatic vegetation. In addition to preventing erosion and reducing wave energy (i.e. decreasing impact during storm surges), these combined approaches enhance biodiversity (Gittman et al., 2015[75]).

Table 1.3. Physical resilience measures to tackle climate risks for different types of infrastructure

Infrastructure type	Climate hazard(s)	Possible impacts on infrastructure	Grey solutions	Nature-based solutions	Integrated grey and nature-based solutions
Storm- and wastewater infrastructure	Extreme precipitation	Overloading of storm- and wastewater infrastructure, resulting in potential floods	Retrofitting urban drainage pipes to increase capacity, build concrete swales or concrete retention pools	Urban gardens and other green spaces, bioswales, bio retention pools, riparian vegetation restoration and management, urban wetlands	Green roofs on top of buildings, permeable pavements
Water supply infrastructure	Droughts	Reduced source of potable water	Reservoirs, dams, aqueducts	Watershed restoration and management (reforestation, afforestation, management of riparian wetlands and forests)	Watershed restoration around dams and reservoirs to balance water supply
Marine/coastal infrastructure (e.g. ports, docks, coastal roads and buildings)	Sea level rise and storm surges	Coastal flooding, enhanced coastal erosion	Seawalls, dykes, groynes, breakwaters, gabions, artificial berms	Conservation, management and restoration of oyster reefs, coral reefs, coastal wetlands (e.g. mangroves, salt marches), sand dunes, beaches	Restoring mangrove belts supported by seawalls, dykes, breakwaters, etc.
Transport infrastructure	Riverine floods	Inundation and blockage of road, rail and riverine transport routes, airports	Elevating and strengthening dykes and levees, constructing reservoirs to store excess water during floods	Renaturalised and extended floodplains, wetland/forest restoration and conservation	Combine dykes and levees with renaturalised floodplains, allow more room for rivers and restore forests and wetlands

Source: Based on Silva Zuniga et al. (2020[76]), Increasing Infrastructure Resilience with Nature-based Solutions (NbS), http://dx.doi.org/10.18235/0002325; ISSD (2021[16]), Advancing the Climate Resilience of Canadian Infrastructure: A Review of Literature to Inform the Way Forward, https://www.iisd.org/system/files/2021-07/climate-resilience-canadian-infrastructure-en.pdf

Operational climate resilience measures

Operational measures encompass hazard and risk assessment, awareness raising and risk communication, or organisational and regulatory measures (Section 1.4.5) that set out infrastructure design standards or procurement rules (OECD, 2023[11]). They can also involve introducing maintenance patterns to enhance resilience of infrastructure assets and networks in light of changing climate risks (OECD, 2018[2]). Furthermore, they can entail land-use regulations to ensure that new infrastructure is built outside of areas subject to high climate risks.

In recent years, a growing number of building and infrastructure codes and standards were developed to ensure the climate resilience of infrastructure assets. For example, Canada introduced building and infrastructure codes informed by climate resilience that target several risks, such as wildfires, floods, permafrost thaw and extreme heat (Infrastructure Canada, 2023[77]). Providing further examples, Table 1.4 lists selected measures in different infrastructure sectors.

Table 1.4. Organisational measures and corresponding physical measures for climate-resilient infrastructure

Infrastructure type	Climate hazard(s)	Possible impacts on infrastructure	Organisational climate resilience measures	Physical climate resilience measures (NbS and grey solutions)
Hydropower production infrastructure	Extreme precipitation	Increased sedimentation and overtopping of reservoirs	Improved operating strategies and rules with adjusted management and maintenance measures to current and projected hydrological conditions (e.g. increased debris removal).	Strengthen and heighten dams to allow for overtopping; develop sediment control measures upstream (e.g. sediment bypass tunnels); better slope management (e.g. watershed protection, reforestation, afforestation); enhanced reservoir capacity.
Electricity transmission infrastructure	Wildfires	Burning of transmission lines and poles	Introduce new management patterns for vegetation management (make it earlier or all year-round dependent on changes in the wildfire season). Ensure land-use regulations restrict the installation of power transmission lines in areas of high wildfire risk. Mandate the use of concrete or steel poles for transmission lines in infrastructure and building codes.	Place distribution and transmission lines underground; replace wooden poles with concrete or steel ones; manage vegetation, create buffer zones around infrastructure assets.
Water supply infrastructure	Droughts	Limited availability of potable water	Introduce demand side management of water use for other purposes; enhance water re-use; improve operating strategies and rules with adjusted management and maintenance measures to current and projected hydrological conditions.	Better slope management (e.g. watershed protection, reforestation, afforestation); enhanced reservoir capacity to be able to store more water for dry periods.

Source: Based on (OECD, 2018[2]; IISD, 2021[16]).

1.4.4. Monitoring, operation and maintenance

Monitoring is key to ensure the adaptive management of infrastructure assets. It is important to monitor the performance of resilience measures for new assets and networks, as well as that of existing ones. In both cases, monitoring at regular and appropriate intervals ensures that infrastructure continues to operate safely and guarantees continuity of services. Once monitoring is completed, the operation of infrastructure needs to be adjusted and appropriately maintained in accordance with the unfolding climate scenario.

The failure of the Toddbrook reservoir's spillway following heavy precipitation in the United Kingdom in 2019 underscored the importance of appropriate monitoring and maintenance. In 2018, the dam was monitored as required by legislation and the inspecting engineer correctly identified the risk. However, the recommendation for full maintenance in the next 18 months had no sense of urgency. Consequently, the spillway's breach happened before maintenance, leading to evacuation of 1 500 people (Balmforth, 2020[78]). Chapter 2 provides further information on the monitoring, operation and maintenance of infrastructure to ensure climate resilience.

1.4.5. Creating an enabling environment for climate-resilient infrastructure

Policies and regulations for climate-resilient infrastructure

Policies and regulations at national and subnational level are key tools to facilitate the climate resilience of infrastructure (Section 1.4.2). This first involves incorporating climate resilience into infrastructure policy and planning frameworks and strategies. For example, the United Kingdom's National Infrastructure

Strategy in 2020 incorporated climate change adaptation (HM Treasury, 2020[79]). Climate resilience considerations also have to be integrated into sectoral infrastructure policies. Chapter 2 provides details on policy development for climate-resilient infrastructure, while Chapter 5 gives further insights on the topic in a developing country context.

Apart from mainstreaming climate-resilient infrastructure into national policies, policy and regulatory frameworks at national and subnational levels should be complementary. Climate risks are spatially specific, and can thus be different from one place to another. Given subnational authorities have responsibilities for land-use planning, permitting, and infrastructure planning and operation, their policies must facilitate climate-resilient infrastructure. Chapter 5 provides further details on multi-level governance and subnational policy frameworks for climate-resilient infrastructure.

Finally, regulations play a key role in ensuring the climate resilience of infrastructure by mandating certain criteria (e.g. the application of certain technical codes and standards) (Section 4.3). In Finland, for example, the Electricity Market Act of 2009 requires that electricity distribution networks are designed, constructed and maintained so that storm or snow interruptions are no longer than 6 and 36 hours in densely-populated and other areas, respectively (Vallejo and Mullan, 2017[33]). Besides introducing new regulations that require climate resilience measures, existing regulations should be updated in light of changing climatic conditions. As noted, the failure of the Toddbrook reservoir reinforced the importance of updating climate resilience measures (Section 1.4.4). The reservoir was compliant with the relevant Reservoirs (Safety Provisions) Act, but after a major flood part of the dam's spillway failed, an independent review found the dam was not safe to withstand a maximum possible flood (Balmforth, 2020[78]).

Financing climate-resilient infrastructure

Increased finance is crucial for climate-resilient infrastructure systems, which will require efforts to ensure efficient use of public finance and clarifying the roles of different levels of government. At the same time, it is important to unlock private finance. Encouraging infrastructure owners and operators to disclose climate risks can raise awareness of the importance of investing in climate resilience measures. Similarly, infrastructure standards, labels and taxonomies play a key role in encouraging resilience investments. For example, the Blue Dot Network aims to help ensure the mainstreaming of climate resilience criteria into infrastructure investments in addition to broader resilience and quality infrastructure considerations (OECD, 2022[80]).

Several other approaches unlock additional finance for climate resilience. These include developing pipelines for investable projects and structuring financial products for climate-resilient infrastructure, such as bonds. Chapter 3 discusses these approaches in depth and Chapter 6 provides additional insights to the topic from a subnational perspective.

Strengthening awareness and technical capacity

Infrastructure planners, designers and operators, as well as all actors working across infrastructure pipelines, need the appropriate awareness of climate resilience and the right technical capacity to implement it. A growing number of training programmes have emerged to support this capacity- building process. For example, Engineers Canada – the umbrella organisation of the Canadian regional regulators of the infrastructure profession – established the Infrastructure Resilience Professional (IRP) Credentialling Program in 2016. The programme's online courses help infrastructure practitioners incorporate climate resilience into planning, design and management (CRI, 2023[81]). Similarly, the Environment Agency England commissioned the Chartered Institution of Water and Environmental Management to offer training on property flood resilience (PFR). The training ensures that industry professionals can appropriately choose and implement PFR measures for properties based on the PFR code of practice (CIWEM, n.d.[82]; CIRIA, 2023[83]). Additional courses are offered in river and coastal flooding for flood risk management professionals (CIWEM, n.d.[84]). At a local level, many city governments are starting to appoint Chief

Resilience Officers to manage resilient infrastructure programmes within their communities (Muzzini, Maslauskaite and O'Regan, 2022[85]).

More technical tools are being released to help implement climate-resilient infrastructure. The Design Value Explorer, for example, was developed by Infrastructure Canada, the National Research Council of Canada, Environment and Climate Change Canada, and the Pacific Climate Impacts Consortium. This web-based tool assesses 19 climate factors relevant for infrastructure design (e.g. annual precipitation). It draws on historic data and future climate projections to support engineers, architects and infrastructure planners in designing climate-resilient infrastructure throughout Canada (NRC, 2023[86]). Another example would be the European Commission's technical guidance on how to climate-proof future infrastructure projects. It sets out principles and practices for the identification, classification and management of physical climate risks when planning, developing, executing and monitoring infrastructure projects (Eur-Lex, 2021[87]). Chapter 6 provides further information on the subnational aspects of strengthening awareness and technical capacity for climate-resilient infrastructure.

Besides formal training programmes and technical tools, peer learning exchanges and international co-operation also have a key role in strengthening awareness and technical capacity. This is especially true in the context of a developing country. For example, the OECD's Sustainable Infrastructure Programme in Asia supports countries in Central and Southeast Asia through capacity development and policy advice throughout various stages of infrastructure development and investment.

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Notes

[1] The annual period in which meteorological conditions are conducive to fire.

2 Planning for climate-resilient infrastructure

Effective governance for infrastructure can enable governments to anticipate and respond to threats posed by climate change. This chapter examines how countries can identify risks and respond by engaging the actors and stakeholders that deliver, operate and use infrastructure, identify interdependencies among infrastructure systems and share information about vulnerabilities to climate risks. It also examines how countries can use policies and regulation both to provide incentives for infrastructure providers and to impose mandatory requirements on them. Finally, the chapter examines how infrastructure providers can collect data and use technologies during the operations and maintenance phase of the infrastructure life cycle to improve resilience.

Key policy insights

- Countries need a holistic approach to plan and fund infrastructure to address the threats posed by climate change. Countries can set the foundations for climate-resilient infrastructure in three ways. First, they can co-ordinate the actors that deliver and operate infrastructure. Second, they can identify the interdependencies among infrastructure systems. Third, they can develop ways to share information about vulnerabilities to climate risks among infrastructure operators and stakeholders.
- Countries can work with a wide range of stakeholders to identify climate-related risks and evaluate their likelihood and severity in the context of all risks (climate and non-climate).

  Countries can use planning and policy settings to signal the government's intended investment in resilient infrastructure and set out requirements for actors to deliver and operate infrastructure to meet resilience standards.
- Countries can also establish national and subnational budgeting arrangements so they are well positioned to invest in climate-resilient infrastructure over the long term. In addition, given the many actors that operate and use infrastructure, countries should establish principles for fair and equitable allocation of costs and benefits between government, subnational governments, private investors, citizens and other parties.
- Finally, countries can use data and new techniques during maintenance and operations to maintain service levels in the face of increasing climate-related risks. For example, new technologies – such as remote sensing, big data, Internet of Things, cloud technologies and machine learning – are transforming how infrastructure is operated and maintained.

2.1. Introduction

Given the risks posed by all-hazards and threats, including climate-related risks, countries need a holistic approach to plan and deliver infrastructure. The changing intensity and frequency of climate risks mean that infrastructure assets and networks may face significantly different risk profiles over their lifespan. Infrastructure providers must avoid the risk of locking in vulnerability, and also plan for infrastructure assets to perform better as climate risks increase. Infrastructure assets will thus need to be designed, built, maintained and operated in ways that consider how risks are changing over the full life cycle. In this context, the *OECD Recommendation on the Governance of Infrastructure* highlights the need to improve governments' approach to delivering resilient infrastructure and work with the private sector and civil society to achieve it.

This chapter sets out the steps for countries to reinforce infrastructure resilience to current and future climate-related risks. It recognises the importance of planning infrastructure that can withstand future climate-related risks, while involving stakeholders in decisions that will affect the future placement of infrastructure and how land will be used. The chapter also recognises the importance of methodologies to select projects that deliver high levels of resilience and technical tools to operate and maintain for resilience over the full life cycle. Finally, while the focus of this report is on climate resilience, the chapter includes case studies and cross-country comparisons of how countries prepare for a wide range of risks. It stresses the importance of an all-hazards approach and illustrates how countries can apply lessons from a wide range of risks to climate-related risks.

2.2. Co-ordinate between public and private infrastructure providers

2.2.1. Co-ordinate the actors

Given the wide range of actors affected by decisions relating to planning, delivering and maintaining climate-resilient infrastructure, countries need to involve national and subnational governments, state-owned enterprises, the private sector and other relevant parties. Engagement and partnership with citizens on decisions about climate-resilient infrastructure are also important (Section 2.7). Ideally, such broad participation in governance would involve sectoral ministries and agencies overseeing infrastructure delivery and regulation across all infrastructure sectors, as well as those in charge of resilience to all-hazards and threats. It is also important for countries to note that the actors may vary depending on the lifecycle stage. Several countries use co-ordination at the centre of government to manage the interests of stakeholders and make relevant trade-offs for effective resilience policies. Countries often also adopt multi-level governance approaches to support public investment at the relevant scale and to co-ordinate actions among and across levels of government (see Chapter 6).

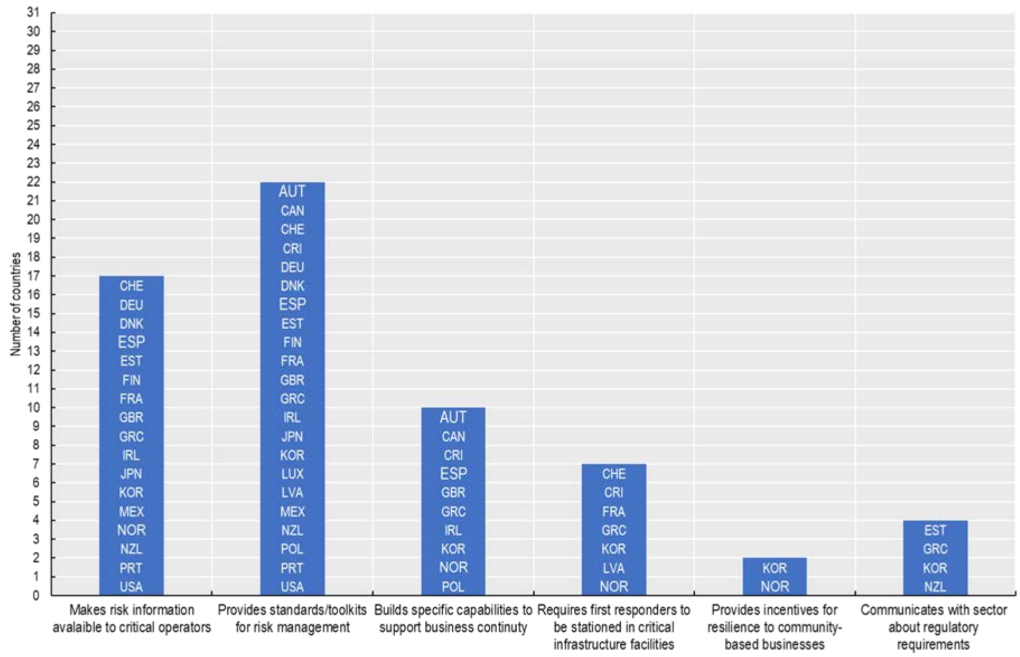
Effective co-ordination requires governments to assume multiple and complex roles. Risk managers and officials in charge of the governance of all risks, including those related to climate, must co-ordinate across several functions in government. In so doing, they must ensure that, on behalf of the general interest, resilience objectives can be achieved, while balancing the relevant trade-offs.

Co-ordination is essential since actors may have conflicting visions for climate-resilient infrastructure, which can have both technical and financial implications. As an important first step towards better co-ordination, governments should partner with infrastructure operators from national and subnational governments, and the private sector. Together, they need to agree on a common vision for climate-resilient infrastructure and on shared and achievable resilience objectives (OECD, 2019[1]). This matters because, while operators and governments agree on the need to protect assets and maintain service, they may differ on the level of resilience required, the means to achieve it and the applicable regulations. These measures have financial implications and raise questions about who will take on additional costs to invest in resilience (see Chapter 4). Resilience visions can also be defined at a regional or local level, allowing for more targeted, place-based approaches as climate risks can be more concentrated in some places than others (see Chapter 6).

Establishing partnerships between governments and operators (public and private) can help develop a common vision of resilience in critical infrastructure and define shared objectives. Policy issues include deciding on the acceptable duration of “down time”, maintaining a level playing field among operators and circumventing free-riding in competitive sectors. Engaging stakeholders with the public, in regular meetings, institutionalised dialogues and joint exercises can foster consensus (OECD, 2019[1]). A common vision for resilience can also allow infrastructure operators to plan for an agreed level of service. This will enable them to plan maintenance so that infrastructure can perform to an agreed level in the face of risks.

Recent data show that many OECD countries have laid the foundations for co-ordination. In 2022, of OECD countries for which information is available, 25 of 27 had established a national strategy for critical infrastructure resilience (93%). In addition, 21 (78%) had designated a lead institution. Whether or not they had a strategy, 29 of 31 OECD countries (94%) had defined “critical infrastructure” in 2022, and all 32 OECD countries with available data had identified critical infrastructure sectors. Moreover, 19 of 23 countries (82%) reported they had established national inventories of critical infrastructure assets, systems or functions (OECD, 2021[2]). Figure 2.1 shows how governments within OECD countries co-operate with critical infrastructure operators to enhance resilience.

Figure 2.1. Government measures to enhance resilience of critical infrastructure



Source: OECD (2022[3]), *Questionnaire on the Governance of Critical Risks*, https://qdd.oecd.org/subject.aspx?Subject=GOV_RISK.

2.2.2. Consider the interdependencies among different infrastructure assets and networks

Countries can also better plan the resilience of infrastructure by adopting methodologies and metrics that identify investment priorities among critical functions, systems and assets. This requires a good understanding of how disruptions can affect infrastructure assets and where dependencies and interdependencies at the subnational, national and international levels could amplify their impacts. Once priority nodes and hubs are found across interdependent systems, countries need to assess their resilience with relevant indicators and to compare actual and expected results to identify gaps (OECD, 2019[1]).

Many OECD countries (14) research links between different types of critical risks (OECD, 2022[3]), but they can go further with a three-tier approach. First, they can map the interdependencies (physical, digital, geographic, logical) between critical infrastructure assets and systems. This is key to estimating the full impact of service loss in case of disruption. Second, a criticality assessment allows countries to classify systems, networks and assets based on the impact of their disruption on a range of pre-established criteria. Third, resilience analysis and stress tests help identify weak points where potential failures are more likely. As a final step, developing relevant indicators for infrastructure assets and systems enables the best comparison of their level of resilience (OECD, 2019[1]).

2.2.3. Establish ways of sharing information

By sharing information, stakeholders can better understand the context for climate resilience, including their own roles. Countries can foster resilience of infrastructure by establishing information-sharing platforms with operators of critical infrastructure. This will enable all relevant infrastructure stakeholders to obtain a comprehensive and shared understanding of risks and vulnerabilities. Types of information include an asset or network's ability to perform during natural hazards in particular locations, their expected life in the face of growing threats, arrangements for reinstatement of infrastructure in the event of outages and anything else that may affect operations of other infrastructure providers. Sharing such information helps operators understand their own vulnerabilities, their dependencies on other infrastructures, and how disruptions to their services could affect other infrastructures or even their own. These platforms must be secure and confidential with clear rules of access to allow a trusted sharing of sensitive information. It is also important for countries to note that the types of information that need to be shared could vary depending on the lifecycle stage.

As one key challenge to voluntary information sharing, parties can be concerned their information may be publicly disclosed. Operators are not inclined to share sensitive information about their vulnerabilities, their critical dependencies and any disruptive incidents outside of safe circles. Disclosure may lead to liability, affect competitiveness in the market or damage a firm's reputation.

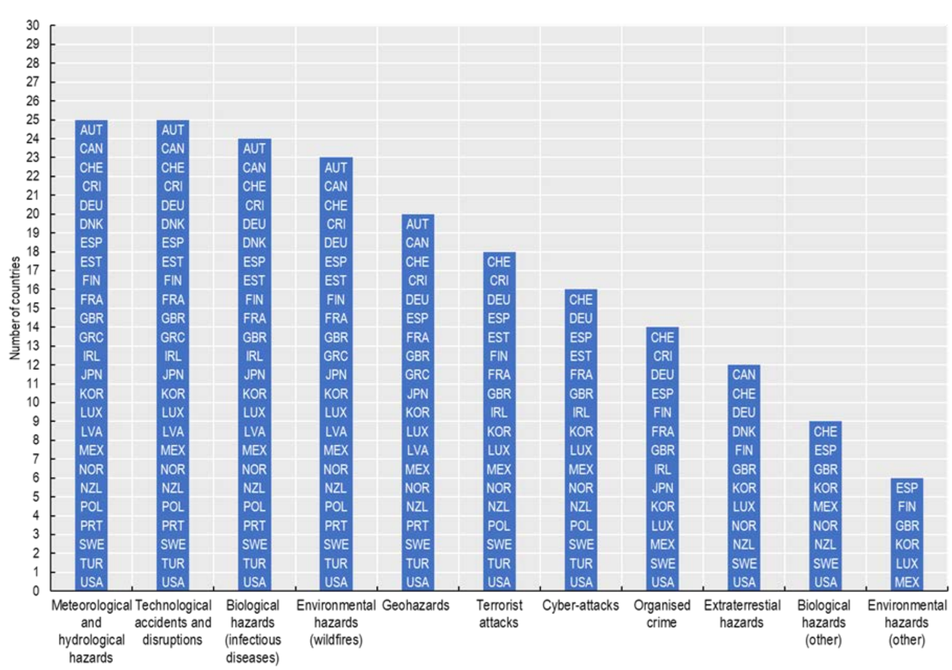
Information sharing can also be viewed as an opportunity. Transparency of risk information can strengthen operators' accountability and reinforce resilience measures. In a world characterised by interconnected systems, interdependent infrastructure systems are as vulnerable as their weakest link. Therefore, sharing information at the international, national and sub-national levels helps create a common understanding among infrastructure operators of how to reach an acceptable level of resilience (OECD, 2019[1]).

2.3. Identify the risks to infrastructure

2.3.1. Take an all-hazards approach

When planning infrastructure, countries need to consider resilience to climate-related risks within a wider context of potential risks, including cyber threats, terrorism and pandemics. Taking an all-hazards approach is important because the hazards facing critical infrastructure constantly evolve. In response, countries need to be agile and flexible in the face of new, emerging threats, ensuring they do not become too preoccupied with particular threats and risk being caught out by new ones. This approach also helps countries stay focused on the level of disruption posed to infrastructure by particular risks rather than being fixated on any specific risk events. Figure 2.2 shows where common climate-related risks, such as natural hazards, sit alongside other types of critical risks for OECD members.

Figure 2.2. Types of hazards and/or threats identified as potential critical risks



Source: OECD (2022[3]), *Questionnaire on the Governance of Critical Risks*, https://qdd.oecd.org/subject.aspx?Subject=GOV_RISK.

2.3.2. Identify the severity, likelihood and anticipated impact of risks

By understanding the risks posed to their infrastructure, countries can identify the likelihood and magnitude of a risk event. Such an analysis could project economic damage, social disruption and environmental impacts. As well as assessing and understanding their climate risks, countries can also assess future projected risks (Chapter 1). Box 2.1 shows how the United Kingdom and Canada identify the severity, likelihood and impact of risks.

Box 2.1. Identifying the severity, likelihood and impact of climate risks

United Kingdom

The Department of Environment, Food and Rural Affairs identifies eight factors to consider when accounting for the impacts on infrastructure of events induced by climate change:

- Hazard: the potential for loss of life, injury or other health impacts, damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.
- Exposure: people, ecosystems, services, resources that could be adversely affected.
- Vulnerability: the propensity or predisposition to be adversely affected.
- Adaptive capacity: the ability to adjust to a risk event.
- Sensitivity: the degree to which a system is affected, either adversely or beneficially, either through direct or indirect effects.
- Timing: attention should be paid to activities that have long-term time horizons, lifetimes or implications. This may also include decision lead times.
- Tipping points (and thresholds): the critical points where the climate changes from one stable state to another stable state. These can involve biophysical, engineering, performance or policy thresholds (or tipping points), above which much larger impacts occur.
- Irreversibility: given uncertainty of many risks, decisions that would be difficult or expensive to revise in future should receive additional scrutiny.

Canada

The Climate Lens is a project-level requirement applicable to Infrastructure Canada's Investing in Canada Infrastructure Program and Disaster Mitigation and Adaptation Fund. It aims primarily to raise awareness of climate change risks and impacts associated with projects and encourage improved choices by project planners, designers and decision makers. The Climate Lens also supports Infrastructure Canada in measuring its progress towards meeting its climate goals.

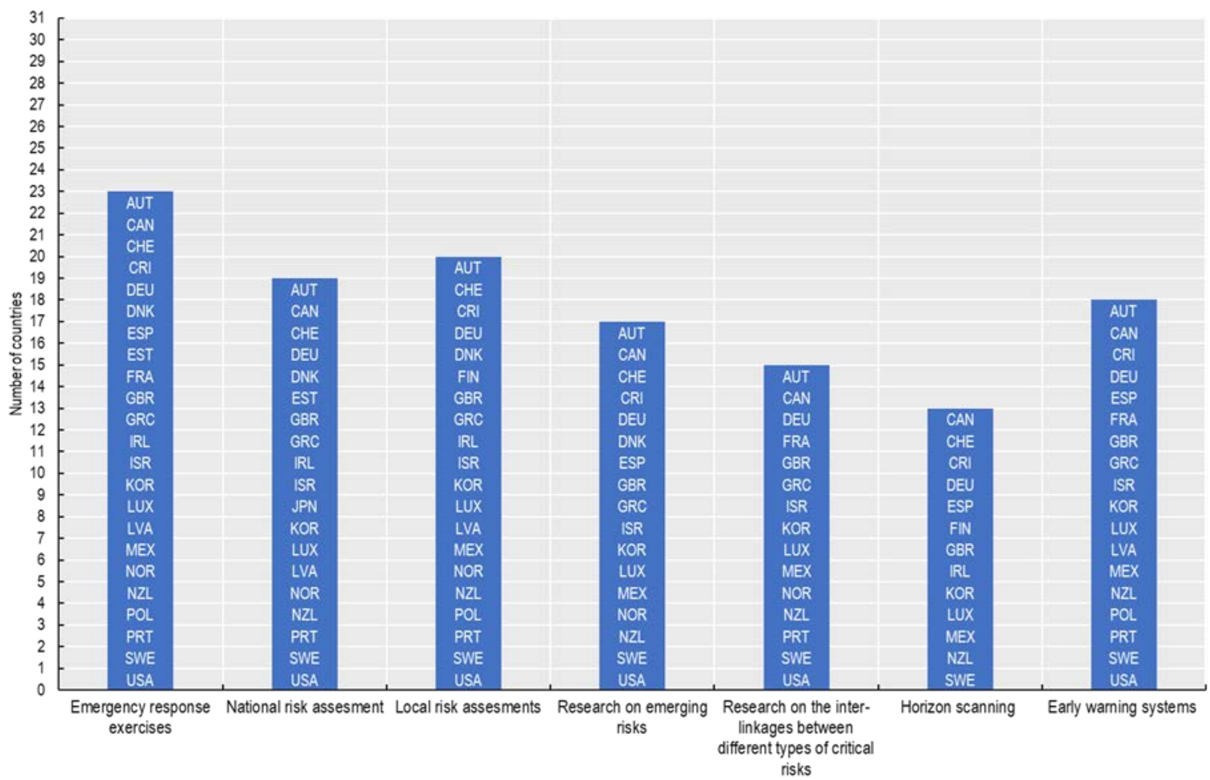
The Climate Lens looks at the anticipated greenhouse gas emissions from an infrastructure project, as well as its risk and resilience to disruptions or impacts related to climate change. It assesses climate resiliency through four steps:

- Assess the severity or consequence of the hazard's impact on the project.
- Assess the likelihood of the hazard's impact on the project.
- Identify the number and level of risks of each hazard on the project.
- Record the risks.

Source: DEFRA (2020[4]), Accounting for the Effects of Climate Change –Supplementary Green Book Guidance, https://assets.publishing.service.gov.uk/media/5fabacf98fa8f56da26ba375/Accounting_for_the_Effects_Of_Climate_Change_-_Supplementary_Green_Book_.._.pdf; INFC (2023[5]), Investing in Canada Infrastructure Program Climate Lens – General Guidance, https://www.infrastructure.gc.ca/pub/other-autre/cl-occ-eng.html#Introduction.

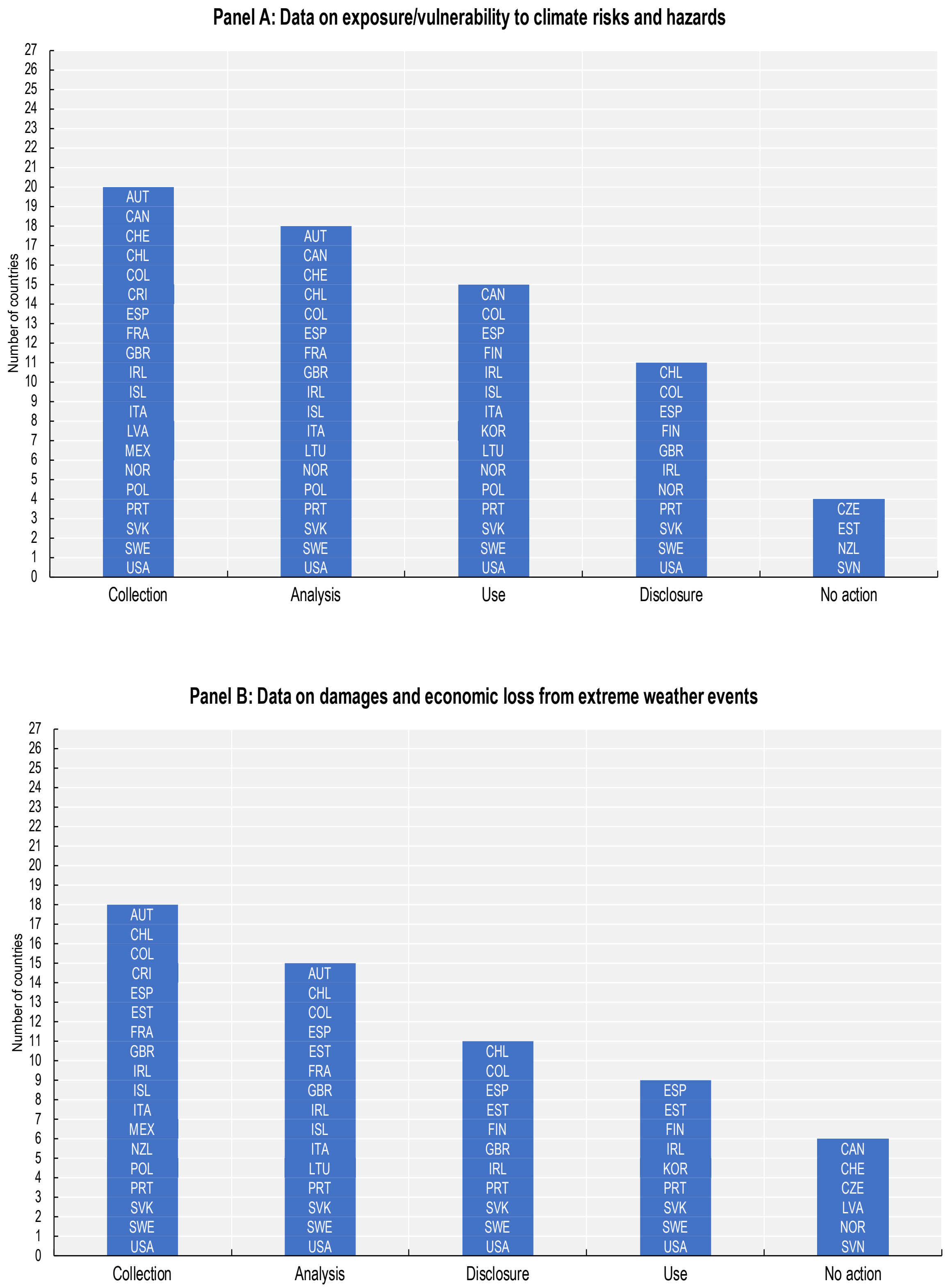
Figure 2.3 shows different methods of OECD countries to anticipate all types of risks. Figure 2.4 shows how countries use data gathered regarding the exposure, vulnerability, damages and economic losses to infrastructure as a result of climate risks and hazards.

Figure 2.3. Measures to develop capacity to anticipate risk



Source: OECD (2022[3]), Questionnaire on the Governance of Critical Risks, https://qdd.oecd.org/subject.aspx?Subject=GOV_RISK.

Figure 2.4. How countries use data on the exposure and vulnerability to climate risks and hazards, and on damages and economic losses from extreme events



Source: OECD (2022[3]), Questionnaire on the Governance of Critical Risks, https://qdd.oecd.org/subject.aspx?Subject=GOV_RISK.

2.4. Set long-term plans and policies that address climate resilience (national and subnational)

2.4.1. Delivering greater certainty to citizens and the private sector through long-term plans

Long-term plans set out the timeframe and sequencing of key investments in infrastructure, including steps to deliver new, resilient infrastructure or to upgrade the resilience of existing infrastructure. Long-term plans set out the future use of land. To that end, they designate areas as off-limits for future development. They also protect corridors or sites for future infrastructure and identify timeframes for such development.

Long-term development plans vary across countries (OECD, 2017[6]), but the common types used in national, regional and urban contexts generally include:

- development strategies (e.g. urban development strategy), which provide high-level cross-sectoral goals for development for national or subnational levels
- spatial plans (strategic spatial plans, master plans), which specify and protect future land use and infrastructure corridors
- capital works plans that define specific project commitments either by place or by sector.

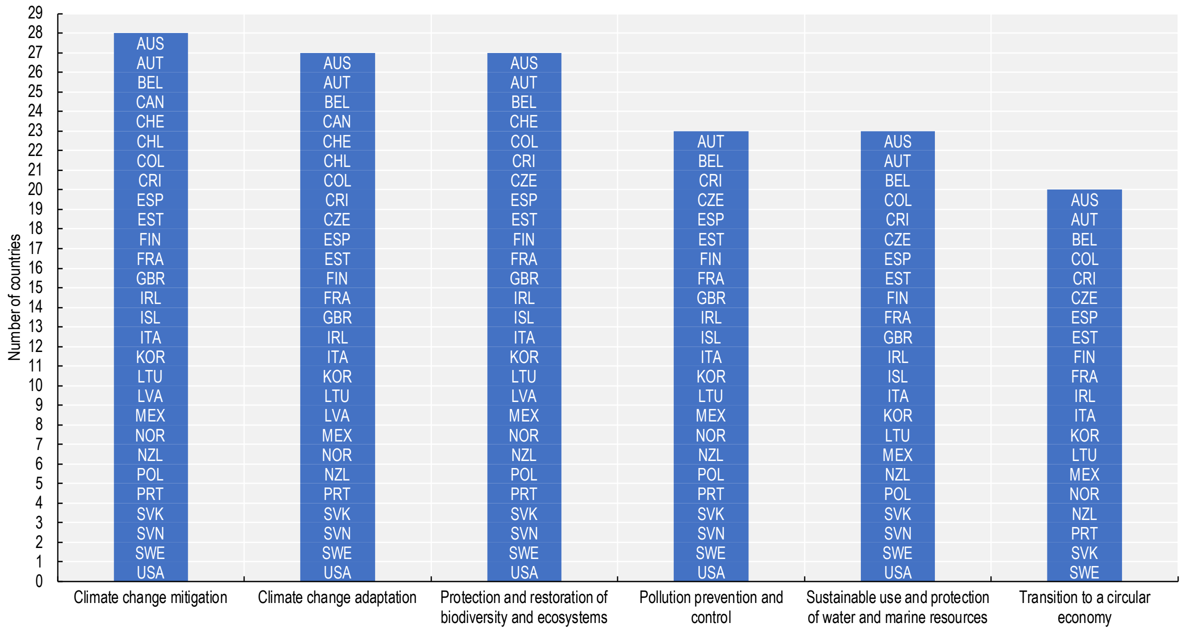
This is not always a perfectly linear process given unexpected events can happen at any time, which can create an immediate imperative to reinstate infrastructure. However, over the long-term, it is important that these three types of long-term plans align. Therefore, infrastructure commitments deliver on high-level policy objectives and the land required to deliver them is identified and protected and made available in advance.

Land-use choices matter for climate resilience. OECD countries have a range of systems for land-use regulations that shape the development trajectory of different places. Subnational governments often have key competencies for these systems (OECD, 2017[7]). Some examples of regulations include land-use planning processes, and environmental and building code regulations. These help define what can be built and where. Given the close link between land use and infrastructure planning, government should closely consider existing land-use planning systems through a place-based approach for development of public infrastructure (Chapter 6).

Capital works plans are also important for delivering climate-resilient infrastructure. Given the long-term nature of climate risks, the long lead times to deliver major physical assets and the many decades these assets may be operating, countries need capital works plans to ensure climate-resilient infrastructure. For long-term risks like climate change, long-term planning is essential to deliver as much certainty and predictability to citizens as possible. This is especially important for those living in areas with uncertain futures. Rising sea levels and increased storm and wildfire events, for example, may make some places uninhabitable. The well-being and security of people require certain and predictable decisions about when to make key investments to protect citizens from future risks or when to relocate settlements, if necessary.

Figure 2.5 shows environmental and climate-related dimensions for OECD members to consider in developing national or sectoral infrastructure strategies.

Figure 2.5. Environmental and climate-related dimensions for national or sectoral infrastructure strategies



Source: OECD (2022[3]), Questionnaire on the Governance of Critical Risks, https://qdd.oecd.org/subject.aspx?Subject=GOV_RISK.

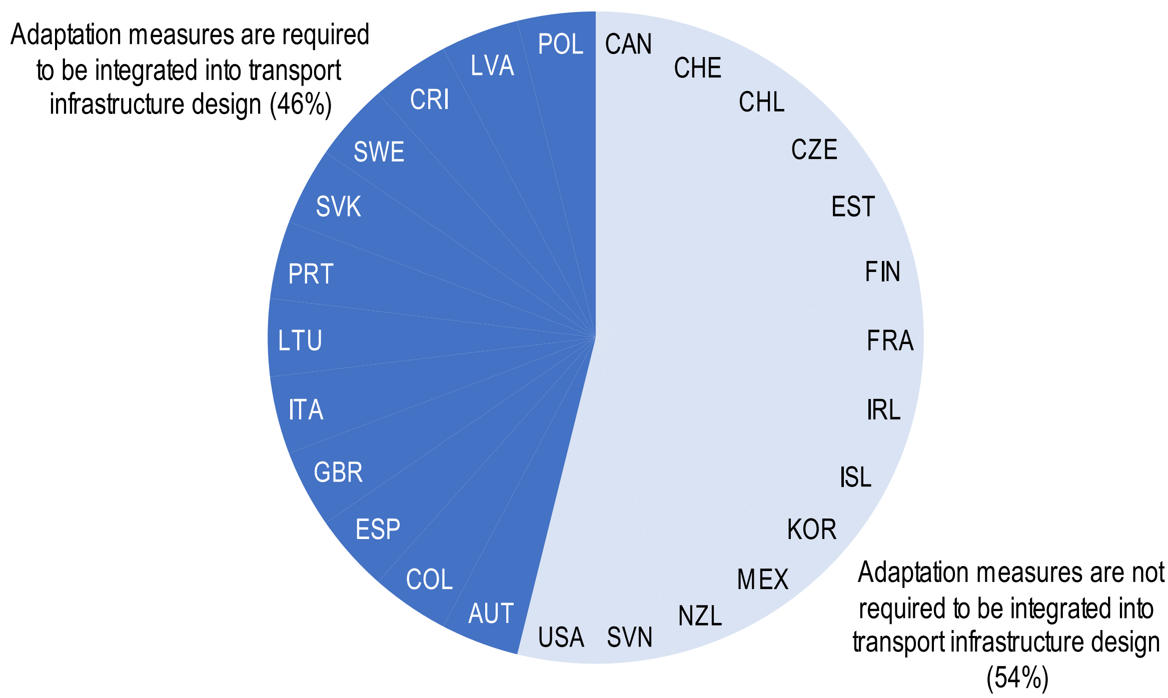
2.4.2. Setting policies that enable and incentivise the planning and delivery of resilient infrastructure

Countries can plan for better infrastructure resilience by defining a mix of policy tools that incentivise operators' investments in resilience and achieve shared objectives. Such measures should address the entire infrastructure life cycle – from planning and operations to maintenance and renewal or retrofits. Of 29 OECD countries surveyed, 26 use the results of risk anticipatory measures to inform strategic policy decisions (OECD, 2022[3]). Meanwhile, 20 also have guidance on adaptation for national or subnational levels (OECD, 2022[8]).

Governments can choose from a variety of policy tools and mechanisms to advance implementation of resilience objectives – from voluntary frameworks and incentive mechanisms to regulatory or legal tools. Many operators have a keen interest in maintaining the continuity of their services and their reputation by investing in resilience. However, investments in resilience often imply costs up front, even if these should be compensated by greater reliability of service and resilience to shocks. Additional requirements imposed by governments to strengthen resilience may result in further costs ultimately borne by customers, citizens and businesses. Governments should tailor public policy instruments to provide effective incentives for operators to invest in resilience, while managing financial repercussions. Chapter 5 discusses the national policies required in the developing world. It is also important for countries to note that different regulatory interventions and incentives may be required depending on the lifecycle stage. For example, the measures needed to require or incentivise capital investment in resilience could be different from measures to require or incentivise investment in operations and maintenance.

The regulatory approach provides clear and measurable obligations. Regulations, for instance, can set reliability requirements or require business continuity plans, insurance mechanisms and minimum security standards. Figure 2.6 shows an example of the regulatory approach in action, showing the extent to which OECD countries require adaptation measures to be integrated into the design of transport assets.

Figure 2.6. Requirement to integrate adaptation measures into transport infrastructure design in OECD countries

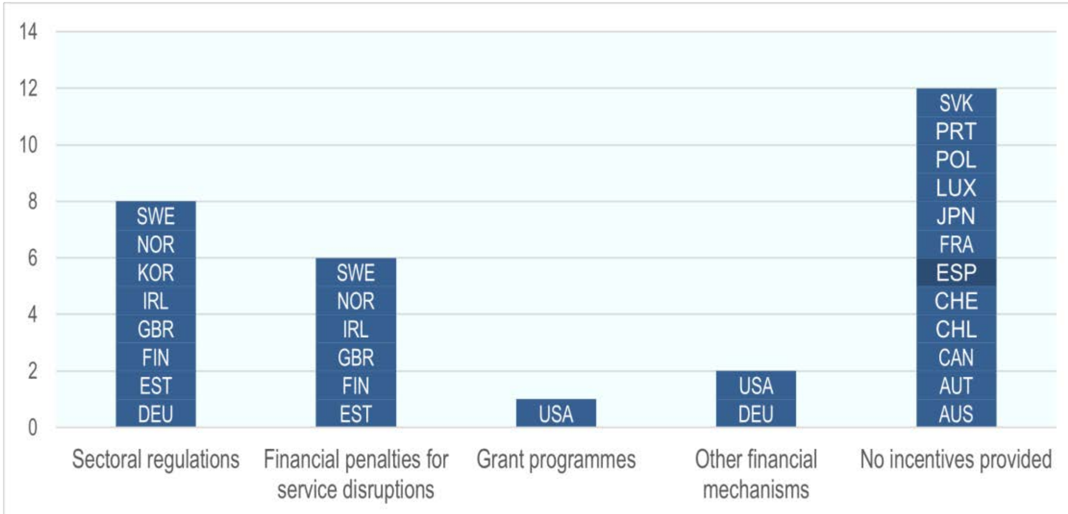


Source: OECD (2022[8]), Survey on the Governance of Infrastructure, https://data-explorer.oecd.org/vis?lc=en&fs%5b0%5d=Topic%2C1%7CGovernment%23GOV%23%7CGeneral%20government%23GOV_GG%23&pg=20&fc=Topic&bp=true&snb=22&df%5bds%5d=dsDisseminateFinalDMZ&df%5bid%5d=DSD_QDD_GOV_INFRA_PH_2%40DF_GOV_INFRA_PH_2&df%5bag%5d=OECD.GOV.

When too prescriptive, the regulatory approach can prove costly, rely on outdated technology and lead to compliance challenges. Making operators compensate customers or imposing other penalties for disrupted service can be an efficient way to incentivise resilience investments, notably in public-private partnerships. Such approaches also provide operators with a choice in ways to increase their resilience. Voluntary frameworks, such as resilience guidelines, awareness-raising activities or the sharing of good practices, are often preferred options to engage stakeholders. However, the voluntary approach may lead to uncertain outcomes. Regulatory measures need to strike the right balance between public financial support and private investments measures. Cost-benefit analysis can prioritise the most effective ways to share the costs of achieving shared resilience objectives.

Figure 2.7 shows different incentives that countries use to enhance resilience of critical infrastructure.

Figure 2.7. Incentives for operators to invest in critical infrastructure resilience



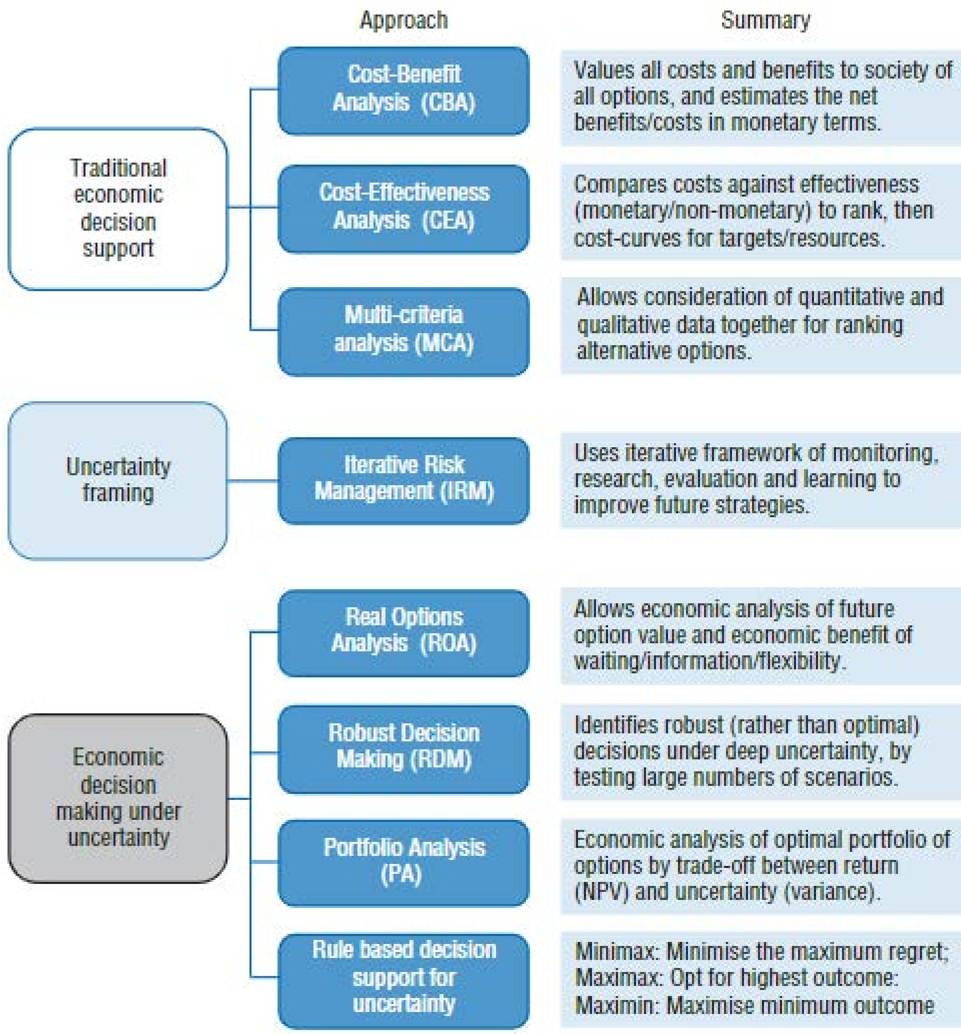
Source: OECD (2021[2]), *Government at a Glance 2021*, https://doi.org/10.1787/1c258f55-en.

2.4.3. Ensure analysis of projects identifies solutions that capture the wider benefits of resilience

Appraisal tools can assess the present and future benefits and costs of resilience projects, such as the reinstatement of infrastructure after landslips. Considering the weight of different factors can help inform how to respond to a natural hazard event. Factors could include the frequency of such events and the costs to people's lives and businesses, or lack of access to essential services. For example, cost-benefit analysis can help decide whether a like-for-like replacement of an asset or a solution is the best approach. Would a more resilient long-term solution generate greater or fewer benefits? Figure 2.8 shows a full range of project selection tools and how they can be applied when considering the costs and benefits of different climate-resilient infrastructure options.

Project risk appraisal can help providers and operators to respond and anticipate infrastructure emergencies. When natural hazard events occur, emergency service operators and infrastructure providers must respond quickly to reinstate infrastructure. This can enable people to resume their lives as soon as possible. However, rather than waiting for natural hazard events, project appraisal can be applied to at-risk sites outside of emergency in anticipation of such events (OECD, 2023[9]). Box 2.2 shows a methodology from New Zealand, a country highly exposed to natural hazard risk, for monetising the benefits of resilience.

Figure 2.8. Decision tools to support adaptation



Source: OECD (2015[10]), *Climate Change Risks and Adaptation: Linking Policy and Economics*, OECD Publishing, Paris, https://doi.org/10.1787/9789264234611-en.

Nature-based Solutions (NbS), explored in Chapter 4, can generate additional social, economic and environmental co-benefits, especially when integrated with other comprehensive approaches. The co-benefits of NbS can be challenging to measure. A combination of traditional appraisal tools and non-traditional methods allows for more inclusive reporting on indicators that grasp the benefits of NbS, including in an environmental impact assessment (EIA). In addition, this combination of approaches can be integrated into cost-benefit analysis for the assessment and comparison of project alternatives. It can then be further complemented with, for example, multi-criteria analysis, which allows for comparing project alternatives on their scores on both quantitative and qualitative criteria. Such a comprehensive approach allows for a fairer comparison with projects that do not necessarily score high on monetary outcomes but do have benefits to nature and social indicators (OECD, 2023[11]).

Box 2.2. Measuring the benefits of resilience

New Zealand is especially prone to events like earthquakes, volcanic activity and extreme weather events that cause floods and landslides.

To help identify projects with greater resilience, the New Zealand Transport Agency developed a methodology for monetising the benefits of resilience. This methodology estimates resilience benefits against the non-disrupted state. If options are being considered with different levels of resilience, the value of an option relative to base can be assessed as:

Value of option relative to the base case =

- net change in benefits in non-disrupted state plus
- net change in benefits of resilience

Where:

Net increase in benefits of resilience = Net reduction in expected costs of disruption

- expected costs of disruption under the Base Case minus
- expected costs of disruption under the Option.

In a hypothetical example, flooding costs EUR 1 million annually in disruptions along an existing route. An alternative route provides transport cost savings valued at EUR 3 million per year. The new route is also subject to some flooding, but the annual cost of disruption is estimated at EUR 0.4 million. The annual benefits of the alternative route relative to the base case are then estimated as EUR 3.6 million (EUR 3 million plus a EUR 0.6 million reduction in disruption costs).

The methodology also factors in a wider range of costs and impacts, including user costs (diversion, waiting times); other direct costs (loss of life, injury, repair, reinstatement); and indirect impacts (wider economic benefits).

Source: McWha and Tooth (2020[12]), Better measurement of the direct and indirect costs and benefits of resilience, https://www.nzta.govt.nz/assets/resources/research/reports/670/670-Better-measurement-of-the-direct-a.

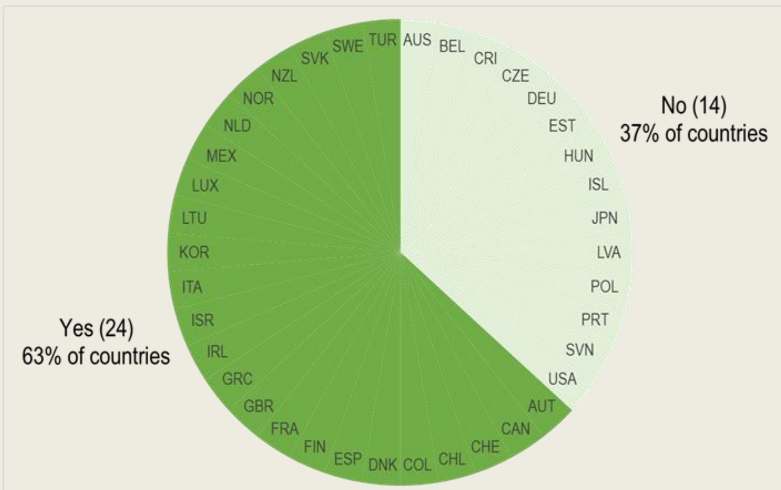
Overall, countries could make greater use of methodological tools to integrate environmental and climate considerations into project appraisal. All OECD countries for which data are available require an EIA to evaluate the possible impacts of a transport infrastructure project. However, only 68% (19 of 28) systematically use assessment results to inform project selection and prioritisation. Similarly, while 63% (17 of 27) require a climate impact assessment to estimate potential emissions of a transport infrastructure project, only 44% (12 of 27) systematically use results to select or prioritise projects. Less than half of OECD respondents (12 of 26 or 46%) require climate change adaptation measures to be integrated into the design of transport infrastructure projects. Finally, only 35% (9 of 26) systematically use climate resilience criteria to inform project selection and prioritisation (OECD, 2023[13]).

2.5. Use capital budgeting arrangements to incentivise and deliver climate-resilient infrastructure

Box 2.3. Green budgeting in OECD countries

Green budgeting is relevant to the provision of climate-resilient assets. It ensures that capital budgeting frameworks include development priorities, such as national emission reduction and adaptation strategies, to inform budget decisions in the context of scarce resources. OECD countries are considering climate change in forecasting, modelling and fiscal risk management to strengthen their budget approaches.

Figure 2.9. OECD countries actively using green budgeting approaches in 2022



These policy developments contribute to better informed budget decisions on capital investment by considering climate resilience alongside other objectives in the budget:

- **Forecasting:** The composition of public revenue and expenditure is changing as a result of climate-related policies. This has implications for budget forecasts and the government's fiscal position. Ministries of finance are including these changes in budget forecasts. In addition, independent fiscal institutions, such as fiscal councils, are including climate change considerations when forming a view on the sustainability of public finances.
- **Modelling**: Modelling the expected impacts of capital expenditure proposals can consider climate resilience. However, it can also consider the expected impact on emissions and capacity constraints on the implementation of the proposals.
- **Fiscal risk management**: Fiscal risk frameworks increasingly have regard for physical risks caused by extreme weather events, and transition risks from policies that are designed to deliver on climate commitments, specifically net-zero emissions under the Paris Agreement.

Sources: OECD (2022[14]) Green Budgeting Survey, https://qdd.oecd.org/subject.aspx?Subject=GOV_GREENBUD; OECD (2015[15]), Recommendation of the Council on Budgetary Governance, https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0410; OECD (2023[13]), *Government at a Glance 2023*, https://doi.org/10.1787/3d5c5d31-en.

2.5.1. Establish budgeting arrangements for long-term investment in climate-resilient infrastructure

Decisions about the financing of resilient infrastructure can result in large spending commitments. Most OECD countries (67%) have adopted green budgeting, a term that refers to integrating climate and environmental considerations into budget processes to help inform funding and resource allocation decisions. Box 2.3 shows that 24 of 36 OECD countries were actively using green budgeting approaches in 2022 to help prioritise capital and current expenditure in governmental budgets. Green budgeting approaches are also emerging at a subnational level (OECD, 2022[16]).

2.5.2. Establish principles for the fair and equitable financing of resilient infrastructure

Given many parties are involved in infrastructure resilience, costs should be apportioned equitably among relevant parties. At the same time, the process should acknowledge that many parties will have limited ability to finance their full share of resilience. Countries should avoid enabling or incentivising operators from continuing to build infrastructure where it will be of greater risk in the future. These include in areas exposed to incrementally increasing risks such as rising sea levels, coastal erosion and flooding. Chapter 3 provides more information on linking planning to financing and use of innovative funding tools. Chapter 6 highlights how subnational governments can finance climate resilience investments.

Most OECD countries (20 of 29 respondents) promote resilience in infrastructure by financing adaptation and preventive measures (OECD, 2022[8]). However, countries can also address financing constraints by considering the following:

- Identification of key beneficiaries: Parties, such as property owners or private infrastructure providers, may stand to benefit from public investment in resilience. If so, it may be appropriate for them to contribute a financial share (through development contributions, land value capture instruments, taxation, etc.)
- Share of cross-subsidisation: Some parties simply will not be able to fund their share of investment in resilience. Since the costs of climate change will fall unevenly on certain groups, some cross-subsidisation will be necessary. This will be particularly the case for communities in developing countries and less developed places within these countries. In many such countries, subnational governments may bear the brunt of paying for climate resilience. Consequently, national governments may have a role to support them (see Chapter 6).
- Equity: Some stakeholders will be better placed to finance resilient infrastructure than others. Vulnerable communities may need additional financial support from national governments or third parties to meet an acceptable level of resilient infrastructure. In some cases, for example, it may be deemed appropriate that private parties contribute to their community's resilience. In such scenarios, cost-sharing mechanisms, such as pay-as-you-go schemes, might be feasible. In other cases, there may be significant inequities. For example, subnational governments may be unable to raise the funding needed from their constituents. If this happens, central governments could raise debt directly or provide credit enhancement (such as guarantees) to subnational governments (see Chapter 6).
- Incentives and disincentives: Disincentivise asset owners and landowners from building infrastructure in high-risk places in the future. One effective way to do this is to transfer a reasonable and proportionate share of financial risk upon them. It is also reasonable that private asset owners and property owners pay for some resilience costs, given they are the direct beneficiaries of the investment.
- Compensation and liability: Understanding who is financially liable if land is deemed no longer habitable is an important step. This can help determine the appropriate financial contributors and

therefore the appropriate funding and financing mechanisms. Insurance can provide a buffer in case of a disaster, although the limitations of this approach should be acknowledged (ICSI, 2023[17]).

2.6. Adequately involve stakeholders in decisions about resilient infrastructure

Decisions about large, physical assets need input from stakeholders for both social and economic reasons. Roads, water services, electricity infrastructure and public facilities have an immediate impact on people's well-being, on the productivity and operations of businesses, and on the policy decisions of national and subnational governments. Another important aspect of stakeholder engagement involves land acquisition, where public works providers have recourse to acquire private land holdings. Governments need to be transparent, fair and timely with decisions that affect the property and wealth of people and businesses, especially when engaging with affected property owners (OECD, 2023[9]).

Box 2.4. Stakeholder Engagement on Coastal Climate Resilience in Denmark

In response to climate risks related to sea level rise and intensified storm surges, Denmark undertook the "BaltCICA" (2009-2012) and "Cities and the Rising Sea Level – Dialogue on Climate Adaptation" (2018-2022) initiatives to encourage the resilience of its coastal cities. Both projects placed significant emphasis on citizen participation to shape climate adaptation strategies.

BaltCICA, focused on issues of coastal retreat and threats to groundwater quality, facilitated citizen involvement through a scenario workshop during which stakeholders engaged in discussions about future scenarios and adaptation options. This workshop culminated in a citizen summit, where participant deliberation on adaptation options influenced the adaptation strategy for the local municipality, which was subsequently shared across Baltic countries. The "Cities and the Rising Sea Level" project took a comprehensive approach to citizen participation with the aim of improving the knowledge base for climate resilience in Denmark more broadly. Workshops, consultations, and online climate citizens' meetings brought together stakeholders, experts, and citizens to discuss themes such as nature, transportation, housing and business, and newsletters and articles encouraged continuous engagement among citizens.

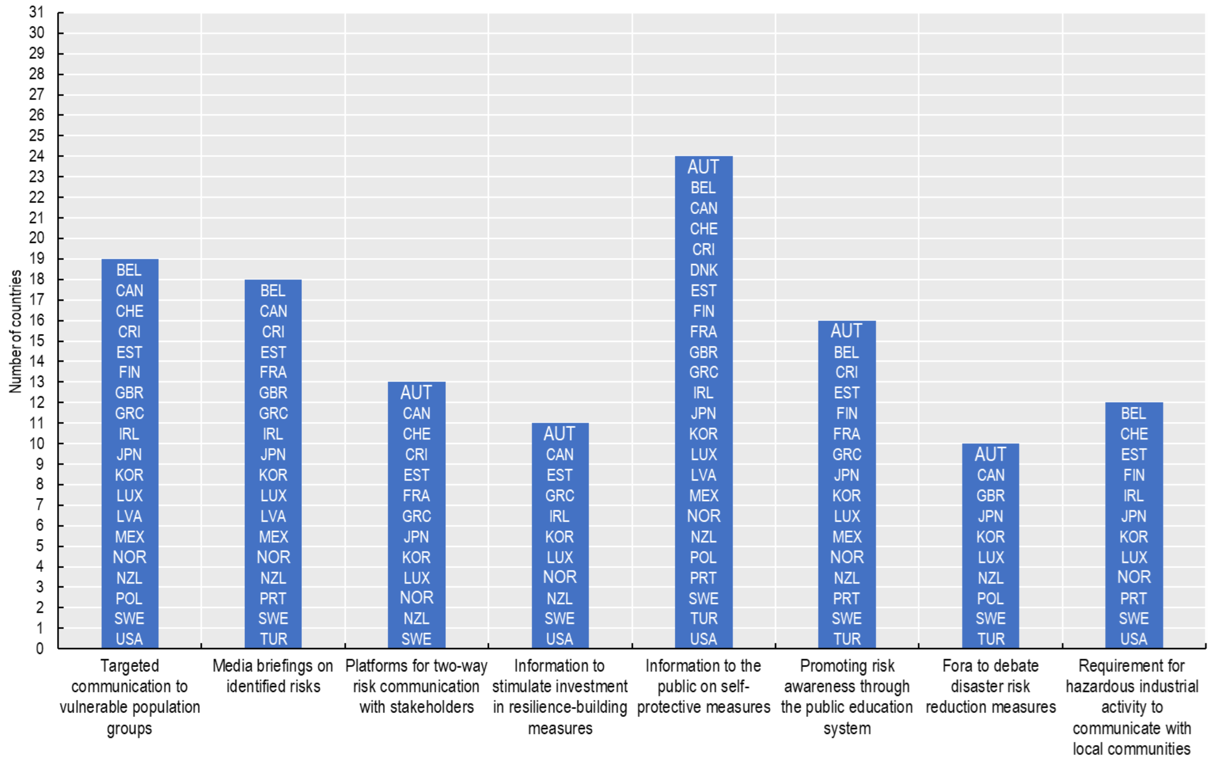
Source: (Tekno, n.d.[18]), Cities and rising sea levels – Securing coastal cities against future sea level rise? https://tekno.dk/project/hvordan-skal-vi-sikre-kystbyer-mod-fremtidens-havstigninger/.

2.6.1. Helping stakeholders understand the economic, social and environmental benefits and costs of meeting different levels of resilience

Given that countries will face constraints in funding all of their resilience activities, they need to engage with citizens and other stakeholders on risk levels they can tolerate compared with the costs of addressing them. This is particularly important because different communities will face different types and levels of risk, and will also have varying capacity to fund efforts to increase resilience through infrastructure. By exchanging in dialogue about risks and the options to address them through planning, delivery and maintenance of infrastructure, government can understand the risk appetite of citizens and stakeholders.

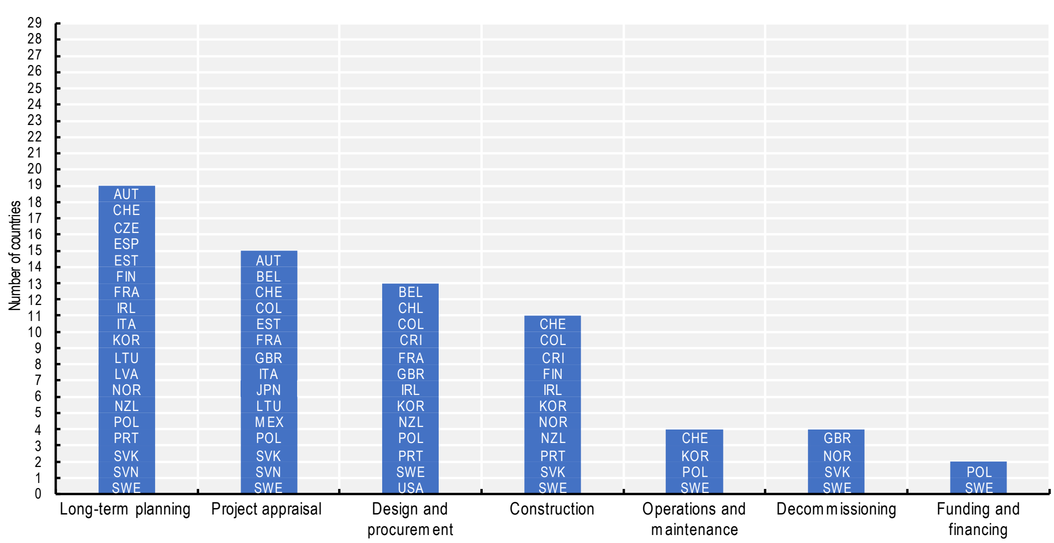
Figure 2.10 shows the types of information-sharing measures commonly used by OECD countries. Figure 2.11 shows the infrastructure life cycle stages that require consultation with stakeholders on environmental or climate-related impacts. Figure 2.12 shows the methods countries use to engage stakeholders.

Figure 2.10. A whole-of-society approach to risk communication



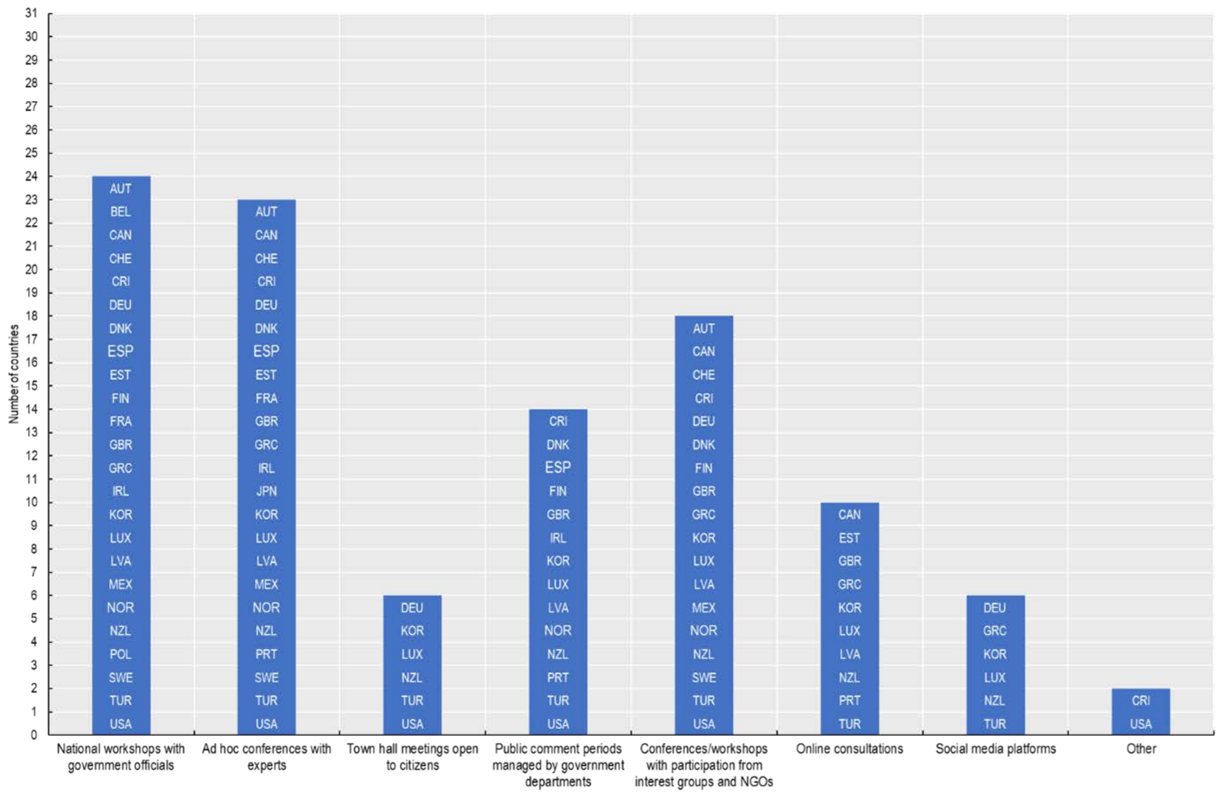
Source: OECD (2022[3]), Questionnaire on the Governance of Critical Risks, https://qdd.oecd.org/subject.aspx?Subject=GOV_RISK.

Figure 2.11. Mandatory stages of consultation on environmental or climate-related impacts of infrastructure investments in OECD countries



Source: (OECD, 2022[8]) Survey on the Governance of Infrastructure, https://data-explorer.oecd.org/vis?lc=en&fs%5b0%5d=Topic%2C1%7CGovernment%23GOV%23%7CGeneral%20government%23GOV_GG%23&pg=20&fc=Topic&bp=true&snb=22&df%5bds%5d=dsDisseminateFinalDMZ&df%5bid%5d=DSD_QDD_GOV_INFRA_PH_2%40DF_GOV_INFRA_PH_2&df%5bag%5d=OECD.GOV.

Figure 2.12. Mechanisms for engaging national and subnational stakeholders



Source: OECD (2022[3]), Questionnaire on the Governance of Critical Risks, https://qdd.oecd.org/subject.aspx?Subject=GOV_RISK.

2.7. Collect data and use innovative techniques to better maintain and operate assets and networks

Because infrastructure is long-lived, countries need to build, maintain and renew it to withstand the risks both for today and tomorrow. This will be particularly relevant to infrastructure exposed to risks that are incrementally increasing. Such risks include sea level rise, coastal erosion, more frequent and severe storm events, and other risks induced by climate change. The severity, likelihood and return rates of risks will increase over time. Consequently, planning and funding of maintenance and operations of assets and networks will be vital. This will allow infrastructure to deliver an acceptable level of service over the full life cycle.

Given the expense of building climate-resilient infrastructure, countries may want to adopt innovative methods to strengthen existing operations. Countries will need to provide new public and private capital investment in infrastructure. However, many countries will struggle to meet rising expectations for infrastructure through new capital commitments alone. To uphold an acceptable level of resilience, countries can collect more data, monitor performance and adopt innovative methods to maintain and operate existing infrastructure. In this way, they can defer new capital commitments while meeting service that citizens need to uphold their well-being.

2.7.1. Collect data to inform decisions about the resilience of assets and networks

Countries often face challenges gathering information and data about their assets and networks, such as on past construction, repairs and an asset's usage and performance. Keeping records on public assets up to date is technically demanding, involving valuation and revaluation of non-financial assets. In addition, most countries do not reflect non-financial assets in the government's financial statements. Only a few countries, such as Estonia and Ireland, produce comprehensive asset registers (IMF, 2020[19]).

Few countries regularly produce exhaustive maintenance expenditure data. Thanks to better data availability, including at a cross-country level, most empirical studies focus on specific sectors such as transport. In Canada, information is gathered through the Annual Capital and Repair Expenditures Survey, and in the United Kingdom through the Annual Report on the Government Major Projects Portfolio (OECD, 2021[20]).

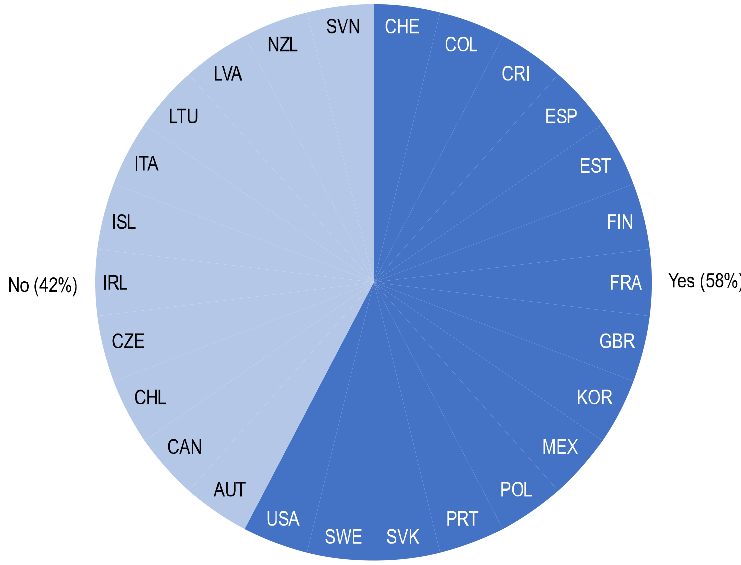
2.7.2. Monitor the performance of assets and networks

Continuous monitoring, which increases accountability and early adoption of resilience measures, can take several forms. Beyond regular performance assessments to prioritise investment in resilience, other monitoring tools include fines for non-compliance. In addition, positive incentives such as recognition or awards for implementation of good practices, open access evaluations or rankings can maintain attention on resilience. In Korea, the Ministry of Interior and Safety makes public the annual evaluation ranking of disaster response capacities among critical infrastructure operators. The resulting peer pressure creates additional incentives for operators to keep up their public image (OECD, 2021[20]).

Evaluation of climate impact can inform decisions for both current and future infrastructure projects. For climate-related risks, systematic evaluation of projects' climate impact brings to light key considerations, risks and mitigation strategies. This information can lead to better decisions in both current and future infrastructure projects. Figure 2.11 shows the extent to which OECD countries evaluate infrastructure systematically. Such monitoring and mitigation measures could inform planning and design of infrastructure with the least environmental and climate impact.

While over half of surveyed countries (15 of 26 or 57%) monitor and mitigate environmental and climate change risks throughout operation, maintenance and decommissioning of assets, there is room for improvement. For example, a good practice comes from France, which has launched a methodological guide to assess the impacts of projects on greenhouse gas (GHG) emissions. The guide proposes an avoid-reduce-compensate (ERC) sequence throughout construction, operation and decommissioning of assets. This is required for projects for which GHG emissions are quantified and significant impacts are identified. The guide illustrates examples of ERC measures at different stages of the life cycle and recommends monitoring their progress, as well as their effectiveness (MTES, 2022[21]).

Figure 2.13. Use of mechanisms to monitor and mitigate environmental and climate change risks throughout operation, maintenance and decommissioning of assets in OECD countries



Note: Data for Australia, Belgium, Denmark, Germany, Greece, Hungary, Israel, Japan, Luxembourg, the Netherlands, Norway and Türkiye are not available.
Source: OECD (2022[8]), Survey on the Governance of Infrastructure, https://data-explorer.oecd.org/vis?lc=en&fs%5b0%5d=Topic%2C1%7CGovernment%23GOV%23%7CGeneral%20government%23GOV_GG%23&pg=20&fc=Topic&bp=true&snb=22&df%5bds%5d=dsDisseminateFinalDMZ&df%5bid%5d=DSD_QDD_GOV_INFRA_PH_2%40DF_GOV_INFRA_PH_2&df%5bag%5d=OECD.GOV.

2.7.3. Apply innovative methods of maintaining and operating assets and networks

New technologies such as remote sensing, big data, Internet of Things, cloud technologies and machine learning are transforming how infrastructure is operated and maintained. Infrastructure technology, or InfraTech, can integrate material, machine and digital technologies across the infrastructure life cycle – from development to delivery and operations. InfraTech also improves resilience by enabling faster and more targeted responses to disruptive shocks or shifts in supply and demand. For example, a digital twin of an infrastructure asset or network can be continuously updated with big data from multiple sources. This, in turn, enables improved testing of what-if scenarios, analysis of the interdependency of multiple systems, and simulation of risks and vulnerabilities – all towards building the asset's resilience. Figure 2.14 depicts how these technologies can help build intelligent infrastructure.

Several obstacles, both technical and bureaucratic, stand in the way of integrating digital technologies into the infrastructure life cycle. Many actors and jurisdictions are involved in planning and delivering infrastructure, but their approaches may not be in sync. Lack of national standards and approaches hampers broader take-up of digital technologies, interoperability and benefits at scale. In addition, some innovative solutions rely on new technologies that are still relatively un-tested or un-proven. Uncertainty about technologies may reduce the willingness of some actors to invest in their use. At a deeper level, new technologies for monitoring, delivering and predicting infrastructure maintenance require fundamental changes in regulatory, audit and decision-making processes. This implies the continued shift of public sector decision-making processes to focus on outcomes, to be more open to external stakeholders and to work in real time on the basis of data and analysis (OECD, 2021[20]). As emerging countries are particularly lacking when it comes to digital technologies, this could be an area where more advanced countries are able to provide technical assistance in the future. Chapter 6 details strategies for international co-operation on infrastructure development and management through discussion of the UNCDF Climate Adaptive Living Facility.

Figure 2.14. Building intelligent infrastructure for resilience

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3 Unlocking finance for climate-resilient infrastructure

As weather patterns diverge from historic norms, the physical impacts of climate change are becoming increasingly visible. Climate change is both heightening risks to infrastructure services and influencing demand for them. Investing in climate-resilient infrastructure systems is cost effective, can save lives and support continued economic growth. However, such investment faces a significant finance gap and challenging macroeconomic conditions. This chapter explores the crucial role that finance can play in achieving climate-resilient infrastructure. It highlights the need to make climate resilience the norm for all infrastructure financing and investments by increasing awareness around climate-related risks, improving risk-sharing arrangements and strengthening the enabling environment. The chapter also highlights the potential of using public finance to unlock private investment in infrastructure.

Key policy insights

- The mainstreaming of climate resilience into infrastructure financing and investment is the exception rather than the norm. Finance flows for climate-resilient infrastructure are limited relative to the levels needed to address the growing impacts of climate change.
- There is a compelling economic argument for investing in climate-resilient infrastructure. Investing upfront in climate resilience can yield benefits over the lifetime of the asset. These benefits can include greater service reliability and quality, lower maintenance costs and reduced exposure to climate-related risks. In many cases, they lower overall costs to address climate risk.
- Weaknesses in the enabling environment and lack of risk awareness are preventing consideration of the benefits of increased climate resilience in public and private investment decisions. A systemic approach is needed to make physical climate risk visible in investment decisions, and thereby demonstrate that resilience is a source of value rather than just a cost.
- Mobilising private financing and investment will be critical for achieving resilient infrastructure systems. Addressing regulatory barriers, ensuring effective risk sharing and, in some cases, the strategic use of public support will be critical for unlocking this potential.
- Integrating climate resilience into long-term planning, and linking planning to financing, will be critical for ensuring the effective use of public resources, reducing perceived risk to the private sector and building in flexibility to address uncertainty over time.
- Given pressures on existing funding sources for infrastructure, there is an important role for developing new funding models, including land value capture.

3.1. Introduction

The physical impacts of climate change are becoming increasingly visible, as weather patterns diverge from historic norms (See Box 3.1). Climate change is exacerbating risks to the provision of infrastructure services due, for example, to the flooding of transport links. It is also influencing demand for infrastructure services. Milder winters and warmer summers, for example, will reduce energy demand in winter and increase it in summer, while rising seas will require improvements in coastal defences.

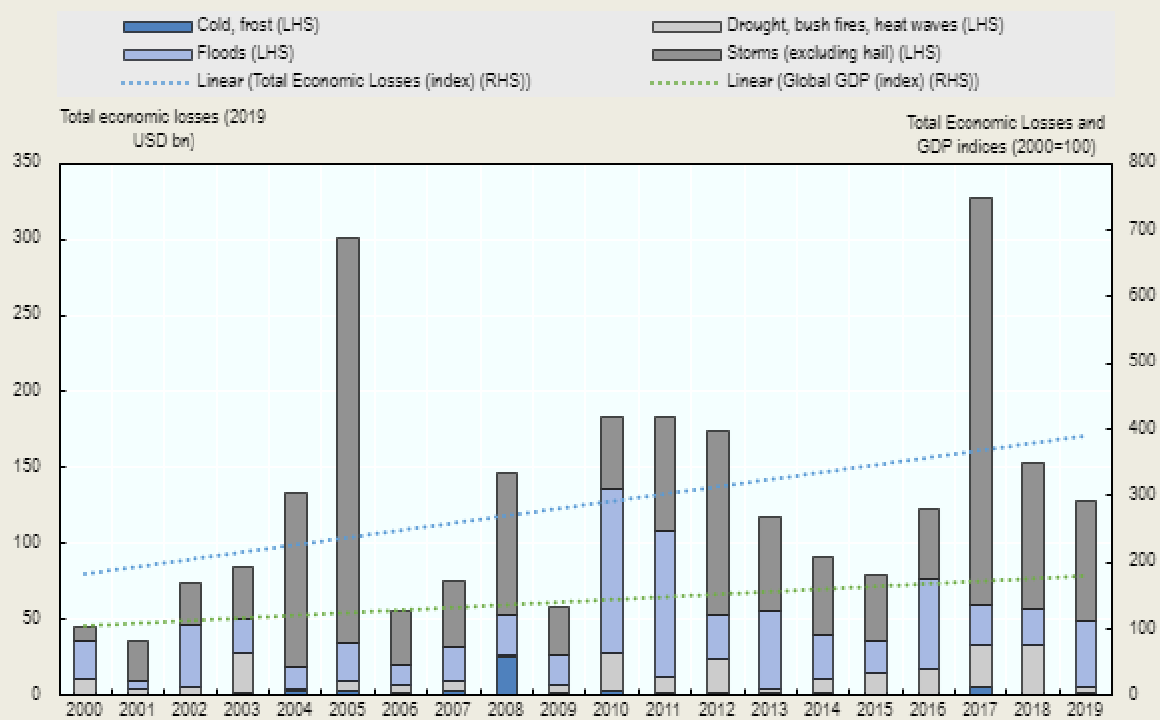
Investing proactively to achieve climate-resilient infrastructure systems is cost effective, can save lives and support continued economic growth. For example, one major study found an average of USD 4 of benefits for every USD 1 invested in climate-resilient infrastructure (Hallegatte, Rentschler and Rozenberg, 2019[1]). Analysis in the United States found that adaptation could reduce annual losses to infrastructure by an order of magnitude (Neumann et al., 2021[2]). However, this potential has yet to be fully realised. Mobilising finance for climate-resilient infrastructure – and ensuring that all infrastructure finance is climate resilient – will be critical to achieve climate-resilient infrastructure systems.

The need to increase investment flows for climate-resilient infrastructure exists against the context of a significant overall infrastructure finance gap and challenging macroeconomic conditions. The economic consequences of COVID-19, and subsequent economic difficulties and geopolitical issues, have contributed to rising public debt, inflation and interest rates (OECD, 2023[3]). This has increased the cost of new infrastructure, limited the capacity of the public to finance new investments and diverted the private sector to other areas. Given these pressures, and the urgent need to enhance resilience to climate change, it will be essential to maximise the impact and efficiency of public investment, in parallel to unlocking increased private investment.

Box 3.1. Historic losses from weather-related catastrophes

Data from Swiss Re's *sigma* database indicate that losses from weather-related catastrophes have been increasing at a faster rate than global gross domestic product (GDP). This is consistent with an increase in weather-related hazards – such as drought, floods and wildfires – driven by climate change. The trend is also influenced by improvements in reporting and increases in the value of the assets located in exposed areas. Annual average economic losses from weather-related catastrophes were more than 200% higher in 2015-19 than in 2000-04 (in constant dollars).

Figure 3.1. Economic losses from weather-related catastrophes



Note: This figure shows reported total economic losses resulting from weather-related catastrophes for all countries between 2000 and 2019 (LHS, in constant 2019 USD billion), as well as the trend in total losses and trend in global GDP (RHS, trend line based on an index with 2000=100).
Source: OECD calculations based on loss data provided by Swiss Re *sigma* and GDP data reported in the IMF World Economic Outlook database (Swiss Re, 2020[4]).

There are two critical elements to the climate-resilient infrastructure financing challenge1:

- **Making climate resilience the norm for all new infrastructure investments**: targeted, early action to mainstream climate resilience into infrastructure projects adds an average of 3% to total project costs (Hallegatte, Rentschler and Rozenberg, 2019[1]). As such, this challenge is predominantly about mainstreaming climate resilience into **business-as-usual** finance flows and decision making rather than the total volume of finance required.

- **Investing in infrastructure that targets climate resilience**: additional infrastructure investments will be required to address climate impacts. This includes construction of protective infrastructure such as flood defences. It also includes new investments to address weaknesses in existing infrastructure systems, such as burying transmission lines or adding redundancy to transport networks. Additional finance will be needed for these investments.

Integrating climate resilience into infrastructure assets influences the business case for investing in those assets. This is context specific, but generally there is a trade-off between capital costs and revenues. Integrating climate resilience can (modestly) increase capital costs, but it should lead to more reliable revenues, lower maintenance requirements, lower risk and potentially higher co-benefits. However, the capital costs are visible, while the benefits will materialise over time. As a result, these benefits are not fully valued in public and private decision making. Consequently, investment in resilience looks like a cost to be minimised rather than a source of value to be realised.

Unlocking finance for climate-resilient infrastructure will require understanding the value of enhanced resilience (the "climate resilience dividend"). This value needs to be reflected in investment decisions. Furthermore, financial structures must match the needs of potential investors, which could be a particular challenge in emerging and developing markets.

This chapter highlights the need to enable finance to flow to investments in climate-resilient infrastructure:

- Strengthen key areas of the enabling environment to help capture the resilience dividend within public and private investment and hence support finance flows at the project level through better risk awareness.
- Implement a strategic approach to understand how climate risks will affect infrastructure systems, determining priorities and then building resilience into investment pipelines.
- Harness finance and funding sources for climate-resilient infrastructure.

3.2. Overview of finance flows for climate-resilient infrastructure

Increasing finance for climate-resilient infrastructure fits within the broader challenge of filling the infrastructure finance gap (see Box 3.2). Trillions of dollars of additional investment will be required every year for infrastructure investment: there are widespread needs to replace and retrofit ageing infrastructure, in particular. Developing countries have an urgent need to expand access to infrastructure services, such as clean water and electricity, to support progress towards the Sustainable Development Goals (SDGs). This can be particularly challenging in low-income countries that face climate-related disasters (see Chapter 5).

A key driver of infrastructure investment needs is the transition to net zero. The transition will require significant increases and reallocation of investments to decarbonise key infrastructure sectors. This includes large-scale rollout of renewables and electrification of the transport sector. The OECD report Investing in Climate, Investing in Growth (2017) estimated that USD 6.9 trillion of investment in infrastructure is required annually on average between 2016 and 2030 to meet development and climate needs globally. More recent analysis has estimated the transition to clean energy alone will require USD 4.5 trillion of investment per year by the early 2030s (IEA, 2023[5]).

Box 3.2. Mobilising institutional investment for infrastructure

Mobilising private investment will be critical for filling the overall infrastructure finance gap, given the scale of financing needs and continuing pressures on public budgets. Institutional investors have been identified as a key finance source for two key reasons: the scale of assets under management (estimated at USD 53 trillion in 2022 for pension assets) (OECD, 2023[6]) and the potential for matching long-term infrastructure assets to long-term liabilities. Institutional investors surveyed by the OECD with approximately USD 9.8 trillion of assets under management in 2022 allocated USD 302.6 billion (representing 3%) to infrastructure investments (OECD, 2024[7]).

The following areas have been identified for unlocking this potential:

- Increase standardisation, where feasible, in terms of contractual terms, data, technical specifications, etc.
- Bundle infrastructure investments to match investor needs.
- Improve the enabling environment for investment in infrastructure, including capacity, strong institutions and having an independent judicial system.
- Develop market for infrastructure through government development of project pipelines and more predictable policy.
- Examine the risk allocation and risk sharing between public and private sectors to ensure investable projects. In developing countries, use blended finance instruments to match the risk and return expectations of institutional investors.

Source: (OECD, 2024[7]; OECD, 2023[6]; OECD, 2020[8]; OECD, 2020[9]).

There is no recent, comprehensive and global dataset on infrastructure finance flows. One study estimated that global infrastructure investment was USD 2.3 trillion in 2015 (Global Infrastructure Hub, 2017[10]). In 2022, G20 governments budgeted USD 978 million for infrastructure investment, which is around 1% of GDP. The private sector invested a further USD 424 billion in infrastructure projects globally, allocating 71% of tracked private funding to projects in high-income countries. A third source of finance is corporate private investment in infrastructure, such as private utilities financing projects from their own balance sheet. Corporate finance exceeds project finance in some sectors, but there are no data available on overall trends. Based on the data available, global infrastructure investment likely remains below required levels, as bankable projects are not sufficiently developed, especially in emerging economies and developing countries. A business case is needed to increase the flow of private finance towards climate resilience.

The Climate Policy Initiative (CPI) examined the extent to which finance flows for infrastructure were consistent with five principles of climate resilience (e.g. ensuring physical climate risk assessments inform project design) (CPI, 2022[11]). These principles build on Mullan and Ranger (2022[12]) and are aligned with the approach of this report (Chapter 1). The CPI analysis found that USD 31 billion of infrastructure finance went towards climate-resilient projects in 2019/20, accounting for a small fraction of overall infrastructure investment. At a city level, similar analysis has found that only 9% of total urban climate finance was committed to climate adaptation, with the remainder targeted at mitigation (CCFLA, 2021[13])(Chapter 6).

These estimated flows for climate-resilient infrastructure are a fraction of overall needs. Hallegatte, Rentschler and Rozenberg (2019[1]) estimate mainstreaming climate resilience increases the costs of infrastructure projects by 3%. Applying this increase to the estimated USD 6.9 trillion required for total infrastructure investment (OECD/The World Bank/UN Environment, 2018[14]) would equate to USD 207 billion per year. In addition, financing additional infrastructure towards weather-related disasters, such as flood defences, and addressing existing infrastructure assets are likely to generate significant costs. For example, upgrades to flood protection in London alone are estimated at USD 20 billion over the course of this century (DEFRA and EnvAgency, 2023[15]).

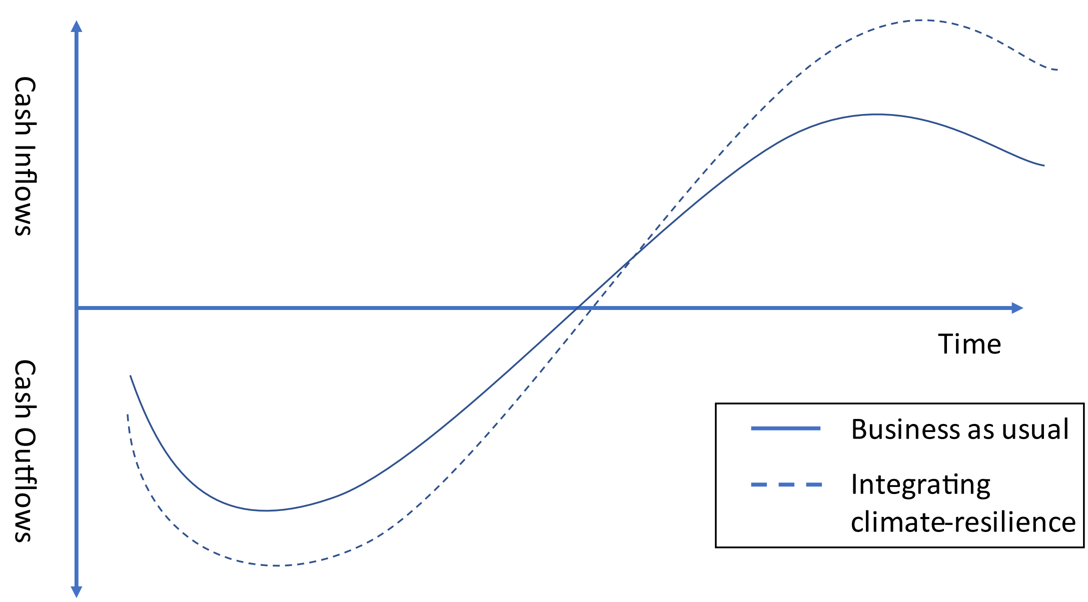
3.3. Mainstreaming climate resilience into infrastructure finance

For an infrastructure project to be financially viable, projected revenues need to cover operating costs (OPEX) and provide a return on investment for the capital expenditure (CAPEX) commensurate with the risk. The attractiveness of an investment is therefore enhanced by shorter lead times before operation, lower CAPEX, lower OPEX, lower risk and/or higher projected revenues.

This consideration applies to publicly funded infrastructure too. However, public projects are usually assessed based on their expected social costs and benefits over the lifetime of the asset. This is the case even if the benefits do not directly accrue to the government. For example, public investment in flood defences is partly justified based on the expected reductions in flood damage over time, even where those benefits accrue predominantly to property owners. As with privately financed infrastructure, increases in expected social benefits and/or reductions in upfront costs will improve the viability of a project.

Figure 3.2 shows how these factors can affect the cash flow of infrastructure assets by strengthening climate resilience over the life cycle of an asset. Initial preparatory work to understand vulnerability to climate risks and develop adaptation options can increase upfront costs. This, in turn, could increase project timelines. Longer timelines decrease the expected return from the project. However, these upfront costs should be more than offset by more reliable future cash flows. Revenues will be more predictable as there is less likelihood of unanticipated disruption and lower economic losses. Revenues may also be higher if the perception of increased reliability and lower risks lead to increased demand relative to alternatives. Climate-resilient infrastructure should also be at less risk of damage or premature obsolescence due to future climate change impacts. In principle, this reduction in risk should result in lower financing costs and/or lower insurance premiums towards damages over the life cycle of the infrastructure asset.

Figure 3.2. Stylised impact of climate resilience on project cashflow



Source: Build Resilience to Unlock Investment (Mott MacDonald, n.d.[16]) https://www.mottmac.com/views/build-resilience-to-unlock-investment#:~:text=Our%20methodology%20helps%20to%20quantify,the%20resilience%20of%20their%20infrastructure.

However, consideration of climate resilience remains the exception rather than standard practice (OECD, 2018[17]; CPI, 2022[11]). As a key underlying challenge, decision makers in the public and private sectors do not consistently consider physical2 risks. As such, there is no incentive to invest upfront when the benefits of those investments are not perceived as relevant. This perception can be due to a lack of capacity and awareness to understand and manage climate risks. The benefits of increased resilience may also not translate into cashflow due to weaknesses in the enabling environment and insufficient data on the business case for investing in climate resilience. Such weaknesses can include insufficient regulation, inappropriate design codes and moral hazard arising from the expectation of government bailouts if a climate-related disaster occurs. Other weaknesses are transition risks due to changing demand and supply patterns from climate change.

Examples of good practices from across the OECD demonstrate how to strengthen the enabling environment to help make climate resilience the norm. These practices target the barriers that prevent investment decisions from considering the economic benefits of climate resilience. They also provide incentives to support greater investment. The following four areas will be critical for driving increased finance flows for climate-resilient infrastructure: promoting transparency and awareness, mainstreaming climate resilience into public funding, examining regulation of privately owned infrastructure and examining risk financing arrangements.

3.3.1. Increasing transparency and awareness of climate-related risks in investment decisions

Increased transparency on climate-related risks will help investment decisions integrate physical climate risks and potential future costs, providing a market signal to better manage relevant risks. A general lack of awareness of these risks can be material to investors, due to the perceived complexity of those risks and the lack of comparable data and metrics. The following tools and mechanisms can help address these challenges.

Disclosure

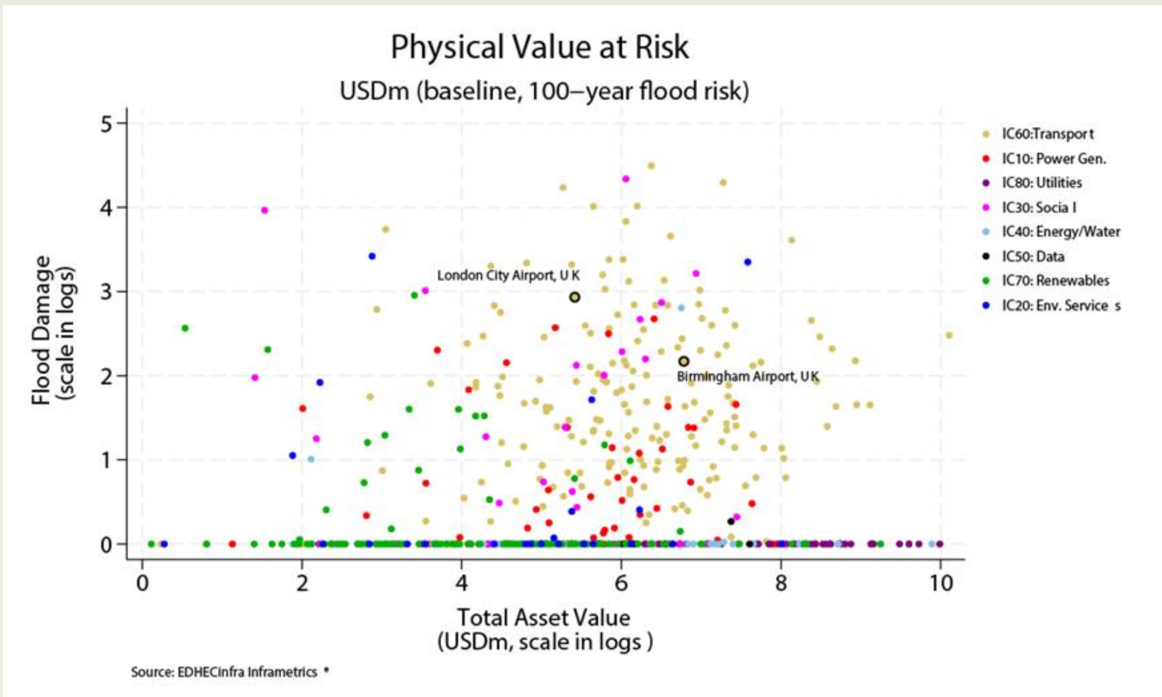
Requirements on infrastructure operators to disclose climate-related risks have been used to raise awareness within organisations, while also helping efforts to understand interdependencies between infrastructure networks. In the United Kingdom, the Climate Change Act includes the Adaptation Reporting Power, which requires utility companies to assess risk and publish how they intend to manage those risks. An evaluation of the most recent round of reports found the quality was generally high. There was evidence it was leading to increased preparedness in the infrastructure sector (CCC, 2022[18]).

Broader efforts within the financial sector to disclose climate-related risks should also provide an impetus to make physical climate risk visible. One study found that physical climate risks could reduce the net asset value of infrastructure portfolios by an average of 4%, and 27% in a worst-case scenario (EDHECInfra, 2023[19]). The Task Force on Climate-related Financial Disclosure (TCFD) recommendations provided a voluntary basis for reporting (TCFD, 2021[20]). These have informed the International Financial Reporting Standards (IFRS) Sustainability Disclosure Standards, which are intended to be integrated into regulatory frameworks across jurisdictions. As the standards focus on financially material information, they would cover infrastructure-related risks (insofar as they are expected to be financially material). The EU European Sustainability Reporting Standards have a broader perspective. They also cover the impact on the environment (“double materiality”) and a broader set of environmental, social and governance factors.

Box 3.3. Infrastructure asset values and physical climate risk

EDHECInfra has modelled the potential exposure of infrastructure assets to physical climate risks (storms, floods and cyclones). This analysis shows that risk exposure varies significantly across infrastructure assets, but the transport sector is particularly exposed to flood risk.

Figure 3.3. Exposure to physical climate risk by asset value of infrastructure sectors



Source: It's getting physical: Some investors in infrastructure could lose more than half of their portfolio to physical climate risks by 2050 (EDHECInfra, 2023[21]) https://edhec.infrastructure.institute/wp-content/uploads/2023/07/p1102.pdf

Most listed companies carry out sustainability reporting. This is not standardised in most cases but includes elements of climate resilience. In many cases, it reflects TCFD recommendations. Climate resilience can be informed through governance, strategy and risk management of the TCFD recommendations. Critically, it requests organisations to disclose their processes for identifying, assessing and managing climate risk (TCFD, 2021[22]). Such sustainability reporting provides important disclosure of an organisation's level of engagement and management of climate risk. Applying such reporting to infrastructure assets would support improved reporting on climate resilience.

Further action would help translate these disclosure requirements into greater visibility of physical climate risk. An analysis of reports under the TCFD found that less than half covered physical climate risks. Furthermore, they tended to treat risks only partially, covering a subset of potential climate hazards. Disclosures were not readily comparable between institutions due to different metrics and assumptions (Zhou and Smith, 2022[23]). Addressing these gaps will require common metrics and assumptions, building on work already undertaken (EBRD and GCECA, 2018[24]). It will also require efforts to provide underlying data and information on climate-related hazards, such as regularly updated hazard maps.

Standards, labels and taxonomies

Robust analysis of the exposure of infrastructure assets to physical climate risks is a crucial element for mainstreaming climate resilience into infrastructure finance. A growing ecosystem of private data providers has emerged to help make risk visible in investment decisions. However, recent analysis has found that results from different providers are inconsistent, even when using the same analytical approach (Hain, Kölbel and Leippold, 2022[25]). Efforts to facilitate the sharing of data and best practice methodologies would facilitate better understanding and consistency in the analysis of climate risk over time.

The Physical Climate Risk Assessment Methodology (PCRAM) provides a common approach for analysing the impact of physical climate risks on infrastructure investments (Mott MacDonald, n.d.[16]). This approach is also intended to provide a common language for discussing physical climate risks between the infrastructure and financial sectors. PCRAM translates physical climate risks and adaptation measures into key performance indicators, such as (financial) internal rate of return and life cycle costs, across possible future scenarios. The Institutional Investors Group on Climate Change is further developing PCRAM.

Infrastructure standards and labels also have a critical role in making the resilient dividend visible. Standards that integrate climate resilience provide a signal that climate risks have been identified and managed. In so doing, they provide a means for operationalising resilience requirements within contracting processes. However, further efforts are required to mainstream climate resilience across standards covering the infrastructure life cycle (Cançado and Mullan, 2020[26]). As an encouraging sign, resilience is being integrated into two major initiatives to improve the quality of infrastructure investments: the Blue Dot Network (strengthening resilience is a core motivation behind its development) and FAST-Infra (adaptation and resilience is one of its four pillars of sustainability). Moreover, resilience is considered in sustainability standards that regulate the issuance and subscription of various capital market instruments from which infrastructure projects receive financing (Box 3.4).

Green finance taxonomies provide a positive signal for investment in climate-resilient infrastructure. The EU Taxonomy for Sustainable Activities provides criteria by which investments, including infrastructure, can be identified as contributing significantly to climate change adaptation. The base requirement is to identify and address climate risks, while also encouraging use of Nature-based Solutions (NbS) or green-blue infrastructure.

Box 3.4. Improving climate resilience of infrastructure through standards and guidelines of GSS bonds

Standards and taxonomies that bring forward climate resilience in infrastructure finance can be further mainstreamed through their application in sustainable bonds issuance. Debt markets use a growing number of guidelines to regulate the issuance and subscription of bonds that achieve green and social objectives, including climate adaptation and resilience. For instance, green, social and sustainability (GSS) bonds allow investors to contribute to the green transition, as well as social causes, by using the proceeds of bonds to finance eligible projects. The sustainable debt market has grown substantially in the last 15 years, reaching in 2023 H1 a total of USD 4.2 trillion of issuance to date, with green bonds accounting for most issuances.

In the framework of these bonds, issuers employ standards and guidelines to ensure sound green and/or social credentials of financed projects. Private sector issuance standards include the International Capital Market Association (ICMA) Sustainable Finance Principles and Guidelines for green and social bonds, and the Climate Bonds Initiative (CBI) Climate Bonds Standard and Certification for green bonds. Such voluntary guidance aims at defining the nature, scope and characteristics of GSS instruments. In so doing, it sets a framework for the identification, financing, monitoring and impact reporting of eligible projects that receive the proceeds of GSS bonds.

Both ICMA and CBI green bond standards classify adaptation and resilience-related activities through dedicated eligible project categories, even though underlying definitions are not as standardised. Establishing standardised guiding principles and taxonomies in climate resilience and adaptation funding is crucial; they help define eligible projects and ensure comparability for investors. Moreover, standards need to be linked to finance to enable effective allocation of funds to projects with maximum resilience and adaptation benefits. This, in turn, facilitates transparent tracking of progress and fostering collaboration among stakeholders.

Sustainable infrastructure as an asset class can be at the core of various projects that receive funding through GSS bonds issuance. By definition, sustainable infrastructure covers multiple eligible project categories in terms of applicability of labels. This is true especially in climate adaptation and resilience project categories where the characteristics of these projects match with adaptation and resilience definitions employed by private sector standards for use-of-proceeds bonds.

In general, using standards and taxonomies related to climate resilience in financial markets applications might benefit both the financing mechanisms and the standards themselves. With respect to financing mechanisms, the standards and taxonomies have a strong sustainability component. Meanwhile, using them in a financing application might increase their development, focus and applicability.

Source: Sustainable Debt Market Summary H1 2023 (Climate Bonds Initiative, 2023[27])https://www.climatebonds.net/files/reports/cbi_susdebtsum_h12023_01b.pdf .

Applying mandatory climate risk screening provides a further tool for identifying and managing climate-related risks. A critical tool for governments is the application of climate risk screening within Strategic Environmental Assessment (SEA) and environmental impact assessment (EIA) processes. Lending institutions have also adopted risk screening to manage their exposure to climate-related risks. For example, the European Investment Bank screens all its financed projects to make sure they are adapted to climate change.

3.3.2. Mainstreaming climate resilience into public funding

Public funding arrangements for infrastructure may need to be revised to ensure they are conducive to the mainstreaming of climate resilience into infrastructure finance. Critical areas for achieving this include budget allocations, project appraisals and procurement.

Climate change will affect budgetary needs for infrastructure. The role of the budget process in supporting climate resilience is not systematically considered. Moreover, there is a lack of data on how well budgetary processes and outcomes align to climate resilience (Mullan and Ranger, 2022[12]). Consequently, infrastructure may be provided at the lowest upfront cost rather than maximising net benefits over the lifetime of the asset. There can also be distortions if different institutions share funding responsibilities. For example, the European Structural and Investment Funds cover capital costs, but regional and local authorities cover operations (See Chapter 6). Green budgeting approaches are not yet widespread. However, governments are exploring such approaches to support the more effective allocation of public resources towards green priorities. The Region of Brittany (France) and the City of Venice (Italy) provide two examples (OECD, 2022[28]).

Public sector approaches for project appraisal and procurement should consider the performance of projects over their entire life cycle, including the effects of climate change. For example, the United Kingdom has developed supplementary guidance for integrating climate change adaptation into policy appraisal decisions, including methods for accounting for uncertainty (HM Treasury, 2023[29]). A growing number of OECD countries, including EU member states, Japan and the United States, have adopted life cycle costing within their procurement frameworks. Procurement processes can also facilitate innovation by specifying performance standards rather than requiring use of specific technologies or approaches. The use of standards (discussed above) can be used to identify relevant performance standards.

Public-private partnerships (PPPs) are long-term contracts in which the private sector delivers and funds public infrastructure, sharing the associated risks (OECD, n.d.[30]). The success of PPPs in delivering climate-resilient infrastructure depends crucially on how climate-related risks are allocated within the contract. Failures to adequately define risks in advance, misallocation of risks and differences between the de facto and de jure allocation of risk have all been found to undermine resilience (OECD, 2018[17]). Efforts to build capacity for climate-resilient PPPs are under way. For example, the Global Centre on Adaptation developed a training course and certification on this theme for infrastructure practitioners (GCA, n.d.[31]). The World Bank's PPP Legal Resource Centre provides an inventory of resources for designing and implementing climate-resilient PPPs. In any of these efforts, an open and competitive procurement of projects and anti-corruption measures will be essential to ensure a robust foundation for infrastructure development.

3.3.3. Economic regulation of privately owned Infrastructure

Many OECD countries have natural infrastructure monopolies – such as water supply and sanitation networks, or electricity distribution – that are owned, provided and managed by private utility companies. Given their monopoly position, these private utilities are subject to economic regulation of service standards and price levels. This has been the usual model in the United States and increasingly common in OECD countries since the wave of privatisations in the 1980s and 1990s.

The incentive and ability of regulated utilities to invest in climate-resilient infrastructure will depend upon the regulatory regime that governs them. Typically, these regulatory models aim to balance service quality and price, while allowing investors to earn a reasonable return. For example, in the United States, state Public Utility Commissions determine prices, allowable investments and service standards for privately owned utilities that provide electricity, gas, telecoms and water (Monast, 2021[32]).

Several aspects of utility regulation can be involved to mainstream climate resilience into investment decisions depending on the specific regime. In the United Kingdom, for example, the water regulator has an explicit objective to "deliver a resilient water sector", which is then reflected in its operations.

The following elements of the regulatory framework could be examined to support investment by regulated utilities in climate-resilient infrastructure:

- **Allowable investments**: ensure that rules determining whether investments are reasonable account for the value of increased climate resilience.
- **Performance standards**: determine whether rules are suitable for a changing climate, both in terms of risks to infrastructure provision (e.g. loss of service) and also risks from infrastructure provision (e.g. failures of dams or wildfires from electricity distribution networks).
- **Additional requirements**: regulators can also support efforts to make physical climate risks visible through requirements to undertake stress tests, identify interdependencies and develop adaptation plans.

As with other aspects of regulatory policy, there is a need to balance competing objectives such as between affordability and reliability. The risk-based approach (outlined in Chapter 1) provides a basis for making trade-offs and communicating clear expectations, objectives and targets to guide investment decisions.

3.3.4. Ensuring risk finance and risk-sharing arrangements provide incentive for risk management and enable rapid recovery

The allocation of climate-related risks, both contractually and in practice, provides a critical driver for investments in climate resilience. These risks include damage to infrastructure assets from climate extremes, loss of service (e.g. power cuts) and premature obsolescence of assets that were not designed to account for climate change. Unclear or misallocated risks can generate moral hazard, reducing the incentive to invest in adaptation and exacerbating the cost of climate extremes by delaying reconstruction. These can represent contingent liabilities for governments, even if the infrastructure is privately owned. The OECD Recommendation on Building Financial Resilience to Disaster Risks outlines best practices for managing the financial consequences of extreme events.

The appropriate model for allocating risks between parties will be context specific. The OECD's Principles for Private Sector Participation in Infrastructure (OECD, 2007[33]) reiterate the general principle that risks should be allocated to the party best able to assess and manage those risks. In the context of climate resilience, this implies that relevant risks should be identified and clearly allocated through contractual and legal provisions. The legal allocation of risk should align with the ability of different parties to bear the risks. For example, following severe flooding in Colombia in 2010/11, the government strengthened requirements for infrastructure concessionaires to secure adequate insurance coverage for extreme events (OECD, 2014[34]).

Box 3.5. Insurance for public assets

Governments (national or subnational) could acquire indemnity-based property insurance coverage from private insurance markets to protect against damages to publicly-owned infrastructure assets (and other public assets). In some cases, ministries responsible for managing public assets are required or encouraged to purchase adequate insurance coverage from private markets (e.g., Colombia, Viet Nam).

In a few countries, a public insurance arrangement has been established to provide insurance coverage for publicly-owned assets, including infrastructure assets. In Australia, Comcover insures the public assets of the federal government and collects premiums from the ministries responsible for those assets. A number of state governments in Australia have established similar arrangements. In the Philippines, a public insurer (Government Service Insurance Service (GSIS)) provides insurance coverage for all public properties owned by both national and local levels of government. All government agencies and government-controlled operations are required to acquire insurance for their assets from GSIS. GSIS transfers some of the risks that it has assumed to international reinsurance markets. In Iceland and France, programmes established to support the availability of insurance for natural hazard (and other disaster) risks provide coverage for publicly-owned assets (including infrastructure assets) as well (in Iceland, the acquisition of this coverage by public asset owners is mandatory).

Many governments (implicitly) self-insure these risks. To that end, they do not make any *ex ante* arrangements to manage the financial impacts of climate-related catastrophes on public assets (i.e. any damage or losses are funded using budgetary tools or *ex post* debt financing). The transfer of public infrastructure risks to private insurance or reinsurance markets will be most beneficial for countries that face constraints in fiscal capacity or access to debt markets as post-disaster reconstruction of public infrastructure can entail significant costs that, if uninsured, would have to be borne by the public sector. Public insurance arrangements that pool public asset risks could allow for countries to achieve greater risk diversification prior to transferring those risks to private reinsurance markets, which should result in reduced insurance costs.

Source: Building Financial Resilience to Climate Impacts: A Framework for Governments to Manage the Risks of Losses and Damages: (OECD, 2022[35]) https://doi.org/10.1787/9e2e1412-en

The insurance sector plays a critical role in enhancing the efficient management of climate-related risks and encouraging climate resilience in various ways.[3] Most obviously, the acquisition of insurance coverage by private or public owners of infrastructure assets provides, in exchange for a premium, a source of funding to respond to any damages and losses from a storm, flood or other weather-related catastrophe (Box 3.5). Quick access to funding can support speedier rehabilitation of damaged infrastructure assets. It can also reduce the level of service disruption (and income loss in the case of revenue-generating assets). For example, cities in the Philippines are buying parametric insurance through a joint insurance pool to reduce insurance costs and ensure rapid disbursement of pay-outs following disasters (Box 3.6).

Box 3.6. Philippine City Disaster Insurance Pool

The Philippines sits in one of the world's most disaster-prone areas, exposed to many climate hazards such as typhoons, floods and droughts. In the wake of disasters, funding is needed for humanitarian response and rebuilding for greater resilience. While Philippine cities have access to disaster recovery funds, mobilising funding quickly can be a challenge. Delays in early recovery measures can hurt short-term well-being and long-term recovery.

With technical assistance from the Asian Development Bank (ADB), the Philippine Department of Finance developed the Philippine City Disaster Insurance Pool (PCDIP) to provide rapid post-disaster pay-outs for local governments. It enables city governments to jointly buy insurance through a single platform. This reduces the price of premiums by sharing risk, sharing set-up costs, increasing funding stability and reducing capitalisation requirements. Capitalised by an ADB loan, the PCDIP is tailored to the specific needs and capacities of city governments to deliver timely payments and build financial sustainability in the long run. The PCDIP also operates as a platform for knowledge sharing and capacity building.

The insurance works as follows:

- An external provider provides risk modelling to set each city's premiums.
- City governments buy parametric insurance based on the type of natural hazards they perceive as a threat. They select the frequency and preferred size of pay-outs, given the funding available for premium payments. Parametric insurance allows for more rapid disbursement than traditional non-parametric insurance. It pays out based on physical features of the disaster (such as wind speed) rather than damages suffered (which can take more time to determine).
- Once a disaster strikes, an independent scientific agency verifies the parameters driving pay-outs. Pay-outs can be expected in no more than 15 business days of qualifying disaster events.

A pilot consisting of ten cities is under way, the first such scheme in Southeast Asia. The increased predictability of and access to pay-outs is expected to boost cities' fiscal resilience and create more fiscal headspace for post-disaster response and recovery.

Source: G20/OECD Report on the Collaboration with Institutional Investors and Asset Managers on Infrastructure: Investor Proposals and the Way Forward (OECD, 2020[9]) https://web-archive.oecd.org/2020-07-24/560068-Collaboration-with-Institutional-Investors-and-Asset-Managers-on-Infrastructure.pdf

The insurance sector also has significant expertise in risk assessment and risk management that can be transferred through the process of acquiring insurance. The purchase of insurance coverage will normally involve an assessment of climate (and other) risks to the asset. It will also advise on how infrastructure operators can mitigate that risk through investments in adaptation and risk reduction.

Insurance can have a critical role in pricing climate-related risks. The premium charged for insurance coverage usually reflects the risk level. As such, it can provide an incentive for infrastructure operators to invest in risk reduction to benefit from reduced premiums. Insurance is one among many approaches to funding rehabilitation of damaged infrastructure. Some infrastructure operators (public and private) may choose to manage those costs through self-insurance (including savings or reserves) or risk financing (loans and debt).

3.4. Mobilising additional finance for resilient infrastructure systems

The scale and severity of climate change impacts will shape demands and needs for infrastructure services. There is thus a need to not only make all infrastructure assets climate-resilient, but also mobilise additional finance to meet these changing needs and demands. For example, changes in tourism patterns driven by climate will shape demands for transport links. Increased drought risk will require packages of measures that could include increased storage capacity, reclaiming water, demand-reduction management practices and renovation of pipes to reduce leakages. Mainstreaming resilience at the project level is necessary but not sufficient to achieve the needed transformation and awareness towards the risk. This section explores opportunities to shape and deliver a strategic approach to unlocking both public and private finance for the additional investments needed to achieve climate-resilient infrastructure services.

3.4.1. Developing a pipeline of investable projects

Strong infrastructure planning processes (see Chapters 2 and 6) provide the foundation for identifying needs arising from a changing climate. In the Netherlands, for example, the Delta Programme identified the need to strengthen 1 500 km of flood defences by 2050 as part of a broader package of measures (Ministry of Infrastructure and Water Management, 2023[36]). In Paris (France), the local authority identified measures to address the consequences of increasingly severe and frequent heatwaves. This, in turn, identified the potential for NbS to reduce urban temperatures (Ville de Paris, 2023[37]) (see Chapters 4 and 6).

Overall, strategic planning should be strengthened and linked to the development of pipelines of bankable projects. In Ghana, the Global Centre on Adaptation's National Infrastructure Investment Pipelines process brought in expertise from multilateral development banks (MDBs) at the outset. This ensured that results would be useful for building a project pipeline. In the United Kingdom, the National Infrastructure Commission has integrated resilience into its regular assessments of the country's infrastructure needs (NIC, 2023[38]). In general, infrastructure pipelines should be integrated into broader development plans at the relevant spatial levels (see Chapters 5 and 6).

Integrating climate resilience from the outset of the infrastructure planning process increases flexibility to identify possible needs for climate-resilient infrastructure. As such, this can facilitate implementation of innovative or cross-cutting approaches, such as NbS. It can also help mainstream climate resilience at the project level. This is possible because these processes can make use of the data and information gathered during planning rather than having to start with a blank sheet for each project.

The specific challenges faced by developing countries in mobilising private sector finance are explored further in Chapter 5.

Technical assistance for project preparation

Translating plans for new infrastructure into bankable projects can be lengthy, complex and uncertain. However, this process is at the crux of addressing the infrastructure investment gap, especially in emerging economies and developing countries. This can be particularly the case for climate-resilient infrastructure, given the need to incorporate climate data into project design. Technical and/or financial support, including for project preparation facilities, reduces the risk of projects being stuck on the drawing board. As such, it also helps generate a pipeline of bankable projects. In addition, it provides an opportunity to integrate climate resilience from the outset of the project development, when there is generally more flexibility to make changes.

Governments can support development of financially viable infrastructure investments through technical assistance and guidance for project developers. For example, the United States Environmental Protection Agency hosts the Water Infrastructure and Resiliency Finance Center, which helps local communities to identify and implement options for financing resilient infrastructure. This initiative includes networking between local authorities, and providing training and links to potential funding mechanisms (see also Chapter 6).

Scaling up the resources and effectiveness of project preparation facilities would help drive increased investment flows for climate-resilient infrastructure (IEG, 2023[39]). For example, the Global Infrastructure Facility supports preparation of projects that deliver development impact. The Facility, instigated by the G20, has financial support from seven countries and the World Bank. It partners with developing country governments and MDBs to cover infrastructure planning, as well as project definition, structuring and procurement. It is committed to ensuring that supported projects are aligned with climate change objectives (GIF, 2023[40]).

Currently, most MDBs have project preparation facilities that support sustainable infrastructure and address green transition ambitions, including climate resilience.

3.4.2. Structuring financial products for climate-resilient infrastructure

Expanding use of green/resilience bonds

Green, social and sustainability (GSS) bonds are financial products that enable investors to channel financing towards the achievement of sustainability objectives, while also ensuring stable financial returns (Box 3.7). These instruments are well established in financial markets, having gained substantial trading volume within the last decade due to high market preference.

GSS bonds finance sustainable activities by employing proceeds to fund infrastructure projects that achieve positive green and/or social impacts. Among GSS bonds, green bonds hold the largest issuance and subscription shares by representing almost 85% of the GSS bonds market (Luxembourg Stock Exchange, 2023[41]). They fund projects that range from climate change mitigation to biodiversity conservation. The popularity of GSS bonds has been growing over the past decade, given that they provide a ready investment opportunity into sustainable finance.

Adaptation and resilience projects are generally eligible for green bond financing but are not used as frequently as their mitigation counterparts. One analysis found that only 4% of green bond issuance (by value) was linked to adaptation (Munday, Bullock and McMahon, 2023[42]). In a different analysis, 13% of GSS bonds and 23% of issuers screened by the Climate Bonds Initiative in 2022 had some degree of resilience-related use-of-proceeds (CSI, 2022[43]).

Expanding use of green bonds will require addressing the limited knowledge and capacity to assess climate risk and identify eligible projects. Screening criteria for resilience-related activities are high level, complicating identification of eligible projects. Moreover, even when resilience projects are identified, they often do not reach the minimum bond issuance size required by investors. They may also be issued in soft currencies, which do not match investors' preferences (GCA, 2021[44]). These challenges can be especially acute for subnational governments that may have constraints on borrowing, and lower technical and financial capacity (see Chapter 6).

Blue bonds provide another potential instrument for financing climate-resilient infrastructure. These bonds – which are one possible type of adaptation bond – fund projects and initiatives that promote sustainable marine and ocean-related conservation activities. Within this bond category, sovereign entities are among the most active issuers, funding various projects to strengthen marine conservation and resilience. Climate-resilient infrastructure projects can receive funding from blue bonds, provided they comply with standards and taxonomies used by issuers to screen the eligibility of projects (see Box 3.7).

Box 3.7. Cases of adaptation, resilience and blue bonds that could inform climate resilience of infrastructure assets

Seychelles sovereign blue bond

The Republic of Seychelles launched in 2018 the world's first sovereign blue bond in 2018. It is , designed to demonstrate the potential for this type of instrument to support sustainable marine and fisheries projects in the country. The bond's issuance, raising USD 15 million and with a ten-years maturity, was supported by the World Bank Treasury, which provided a USD 5 million World Bank partial credit guarantee.

Proceeds from the bond financed the expansion of marine protected areas, and improved governance of priority fisheries and the development of the Seychelles' blue economy. The bond fell, under the sector categories of terrestrial and aquatic biodiversity conservation, and environmentally sustainable management of living natural resources and land use.

The bond is not issued in accordance with any issuance framework and does not comply with international private sector standards for GSS bonds issuance. However, it makes use of internationally recognised schemes and practices for sustainable fisheries.

The Netherlands' green bonds and blue projects

The Netherlands' sole green bond was issued in 2019 and raised EUR 15.6 billion. It focuses on climate change adaptation, one of the pillars of the country's environmental strategy in the context of both national and international initiatives. The bond holds the CBI Certification Mark.

The related green bond framework aligns with the proposed EU taxonomy criteria regarding flood risk prevention and protection, and Nature-based Solutions for flood- and drought-risk prevention and protection. In addition, it addresses the applicable "do no significant harm" criteria and minimum social safeguards on a best-efforts basis.

Some financed projects can be defined as "blue" since they are part of the Delta Programme. This programme ensures that flood risk management, freshwater supply and spatial planning will be climate-proof and water resilient by 2050.

Expenditures include reinforcing flood defence infrastructure, monitoring and management of water levels, water distribution infrastructure and related measures to anticipate on higher water levels. These are consistent with SDGs 6 and 13, and with the EU taxonomy environmental objectives of climate change adaptation and sustainable use and protection of water and marine resources.

Fiji sovereign adaptation bond

In 2017, Fiji became the first developing economy to issue a sovereign green bond (USD 19.5 million). The related framework was developed in compliance with the ICMA Green Bond Principles. It considered eligible use-of-proceeds such as resilience to climate change, water efficiency and sustainable management of natural resources, among others.

In practice, 91% of proceeds were allocated to climate adaptation activities. Financed projects tackled construction and renewal of water collection, treatment and supply infrastructure, forest management and afforestation, among others.

The issuance of such a bond created a business case for climate change adaptation. In a developing economy, it is hard to mobilise the private sector to collect large-scale financing.

Source: (World Bank, 2018[45]; Ministry of Economy, 2019[46]; DSTA, 2020[47]; The Nature Conservancy, 2023[48]).

Blending public finance to support private investment

The strategic use of public resources can be used to improve the risk-return profile for infrastructure investments. This can take the form of government guarantees, equity stakes and concessional debt finance. For developing countries, this includes blended finance, which is defined by OECD as “the strategic use of development finance for the mobilisation of additional finance towards sustainable development in developing countries” (OECD, n.d.[49]). Blended finance is primarily made available by MDBs and donors. While it contributes to basic development, it also looks to establish the market foundations that will eventually attract private investors (Migliorati, 2020[50]). Blended finance focuses on achieving development and impact through mobilisation of private capital. It is considered catalytic because, by mobilising capital, it creates a direct causality that unlocks further mobilisation and potential investment (OECD, 2018[51]).

In OECD countries, governments use tools such as guarantees to make investing in domestic infrastructure more appealing for private investors and to support subnational governments’ access to finance (see Chapter 6). For example, the UK Infrastructure Bank administers government guarantees to qualifying projects to mobilise private finance. It also provides access to other concessional finance for private sector and local authorities.

At the international level, initiatives such as the Private Infrastructure Development Group (PIDG) can enable blended financing to be more systematically mobilised. In other words, it links donor funding more directly to private sector capital mobilisation. The latest annual strategy for PIDG commits to only funding infrastructure projects that contribute to climate adaptation, resilience and/or mitigation (PIDG, 2023[52]).

When early adaptation goals and implementation efforts accompany private sector financing, blended finance can be effective to ensure adaptation is well supported. In particular, it can be used as an incentive to mainstream adaptation elements into project development. For this, early engagement is key, including identification of the types of financial structures to be used.

Grants can be used to support integration of adaptation into early stages of projects, and also improve the return for climate-resilient infrastructure. To that end, it could provide funding for feasibility studies or early-stage adaptation when cash flow can be uncertain. Private financing will be protected by a junior tranche from concessional finance and a mezzanine tranche from concessional public financing (OECD, 2023[53]).

3.4.3. Identifying relevant funding streams

Finance for climate-resilient infrastructure depends upon securing sufficient funding to repay the capital costs, cover ongoing operations and maintenance, and provide a return to investors (if applicable). Insufficient funding can undermine climate resilience by preventing projects from going ahead. It can also lead to insufficient maintenance that reduces asset lifetimes and increases vulnerability to climate change impacts (Hallegatte, Rentschler and Rozenberg, 2019[1]).

Funding mechanisms will depend upon the type of asset and broader context. However, the funding streams relevant for climate-resilient infrastructure will generally be the same as those for any type of infrastructure and subject to the same considerations. These funding streams typically include (OECD, 2022[54]):

- **Taxes** – provision of grants and subsidies from general taxation, earmarked tax revenues. These revenues may be transferred between levels of government.
- **User charges** – payments from beneficiaries of the infrastructure services provision, such as road tolls, utility tariffs, sales of services.
- **Ancillary revenues** – advertising, sale of data, property income (e.g. rents from retail in transport hubs).

- **Land value capture** – capturing some of the increment in property values that results from infrastructure provision.
- **International transfers** – official development assistance, climate finance, philanthropy, EU funding.

Filling the funding gap for climate-resilient infrastructure may need to depend largely on taxes and user charges given the scale of investment required. Shifting the burden of infrastructure provision to user charges can support efficiency and generate additional resources. However, distributional impacts need to be identified and managed such as by combining water pricing with targeted subsidies for low-income households.

Transfers can be particularly relevant for climate-resilient infrastructure by helping address financial constraints faced by those communities most affected by climate change. At the national level, this includes transfers to subnational authorities (see Chapter 6). At the international level, climate finance is a valuable resource for supporting climate-resilient infrastructure investment in developing countries. Between 2016-21, 31% of public climate finance for adaptation went to two infrastructure sectors: water supply and sanitation (21%) and transport and storage (10%) (OECD, 2023[53]). Average public climate finance for these sectors is around USD 5.4 billion per year, predominantly provided as concessional loans.

The following sections explore some newer instruments that can be used to fund climate-resilient infrastructure.

Public funding for resilience benefits

Governments are directly supporting provision of climate-resilient infrastructure through grants and subsidies to cover upfront capital costs. This can be done by providing dedicated funding streams for climate resilience, or by prioritising climate-resilient proposals when allocating grants for infrastructure. The EU Structural and Investment Funds includes grants for infrastructure provision in member states. In keeping with the EU’s commitment for 30% of the budget to support climate action, some grant programmes have criteria that favour climate-resilient proposals. The US Inflation Reduction Act included more than USD 1 billion of funding for incentives and grants to support installation of climate-resilient infrastructure. Canada has established a CAD 2 billion Disaster Mitigation and Adaptation Fund (Infrastructure Canada, n.d.[55]) that subsidises construction or retrofitting of resilient infrastructure.

Governments could also support delivery of “resilience services” following the model of payments for ecosystem services. Projects that reduce stormwater runoff, such as through provision of green infrastructure, generate credits. These credits have a market value because they can be sold to other property owners who can use them to meet their own regulatory requirements for stormwater management. In principle, this approach could be extended to other forms of positive externality – such as reducing urban heat island effect or providing protection from other forms of flood risk. This has been implemented in some areas for measures to reduce stormwater runoff and, hence, the risk of surface flooding. The District of Columbia (United States) implemented a Stormwater Retention Credit Trading Programme, for example.

Harnessing land value capture for climate-resilient investments

Some forms of investment in climate resilience will result in increases in the value of nearby land. For example, construction of flood defences can increase the value of homes nearby, which may no longer be at risk of flooding events. NbS (see Chapter 4) for flood management can also create amenity value through, for example, the creation of urban green space. Capturing some of these gains can provide local governments with an important source of revenue to pay for climate resilience (OECD, 2022[54]).

The term “land value capture” refers to various taxes, user charges and fees, and other revenue sources that seek to capture this gain. Most countries have these instruments in some form, but a majority lack a legal definition of, or justification for, land value capture. Working with partners, the OECD has developed a taxonomy with five types of value capture instruments (OECD/Lincoln Institute of Land Policy, PKU-Lincoln Institute Center, 2022[56]):

- **Infrastructure levy**: taxes or fees levied on landowners possessing land that has gained value due to government-initiated infrastructure development
- **Developer obligations**: cash or in-kind contributions that defray costs for additional infrastructure or services that need to be provided due to private development
- **Charges for development rights**: cash or in-kind contributions payable in exchange for development rights or development potential above a set density baseline
- **Land readjustment**: the practice of pooling fragmented land parcels for joint development, with owners transferring a portion of their land for public use
- **Strategic land management**: the practice of governments actively buying, developing, selling and leasing land to advance public needs and recoup value increments borne through public action.

All of these instruments for land value capture can be relevant for climate resilience. Infrastructure levies, for example, can be applied to property owners benefiting from public infrastructure that is created to protect assets facing increased climate risks. Similarly, developer obligations and charges for development rights can help ensure that upfront investments protect new assets. In Germany, for example, urban renewal measures – including for climate adaptation – are charged back to local landowners (Box 3.8).

Box 3.8. Infrastructure levy for urban renewal measures in Germany

In Germany, the urban renewal measures levy (Städtebauliche Sanierungsmaßnahmen) applies in designated renewal areas. Local governments implement these charges and receive the revenues by recovering the land value increase. Landowners, tenants, leaseholders and other affected parties have the right to participate in consultations. The levy is widely used and accepted. Examples where a landowner pays a levy include:

- green and open spaces for climate protection and adaptation
- construction or expansion of renewable energy systems
- renewed infrastructure to reduce the pollution and noise from buildings, businesses and traffic facilities
- equipment of areas with playgrounds and sports fields.

Source: Global Compendium of Land Value Capture Policies (OECD/Lincoln Institute of Land Policy, PKU-Lincoln Institute Center, 2022[56]) https://doi.org/10.1787/fa744789-en

Asset recycling

Asset recycling is the process of selling or divesting assets, and using proceeds to fund another investment. This provides short-term funding but does not generate any "additional" funding over the long term as future income from the assets is forgone (OECD, 2022[54]). Asset recycling can support climate finance and in particular climate resilience, which may struggle to attract financing that requires an identified revenue stream.

In asset recycling, the private sector partner takes over the financing risk, while the public owner supports the transaction through information and data sharing. However, for transactions related to climate finance and climate resilience, the public sector partner may need to take on a bigger share of financial risk. This could engage the public sector by risk sharing, which would unlock financing towards climate resilience.

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Notes

[1] As outlined in Chapter 1, these two elements should be guided by a risk-based approach, which balances any additional costs of achieving enhanced resilience against the expected benefits across a range of scenarios.

[2] Physical climate risks encompass the risks arising from the consequences of climate change. These consequences can be bothw direct (such as damage to assets) and indirect (such as changing patterns of demand for infrastructure services).

[3] See (OECD, 2023[58]) for a more comprehensive overview of the potential insurance sector contribution to adaptation.

4 Harnessing Nature-based Solutions for climate-resilient infrastructure

Nature-based Solutions (NbS) are getting more attention in national and international policy debates. They are increasingly viewed as cost-effective and flexible solutions that can help countries adapt to the accelerating impacts of climate change, including on infrastructure. Yet while NbS are often praised for generating social and environmental co-benefits, understanding and actual use of NbS for infrastructure remain limited. This chapter focuses on how NbS can be part of the toolset of measures to build climate resilience into infrastructure. It shows how NbS can be used as substitutes, complements or safeguarding measures to grey solutions. The chapter reviews successful applications of NbS in climate resilience building of different sectoral infrastructures. It sketches the enabling factors needed to increase consideration of NbS in infrastructure planning and development.

Key policy insights

- Nature-based Solutions (NbS) have significant potential to enhance climate resilience of infrastructure in cost-effective and flexible ways that harness social and environmental co-benefits.
- NbS can build climate-resilient infrastructure as substitutes, complements or safeguards to grey solutions. They can be used in both urban and rural settings, and to address all types of climate risks.
- To enhance their use, NbS need to be better and consciously integrated into the policy, regulatory and institutional frameworks that enable infrastructure development. They also need to be incorporated in the technical training programmes of designers and operators of infrastructure.
- A number of national and international initiatives are under way. They foster the use of NbS for enhancing climate resilience in infrastructure, while reaping their benefits for mitigating climate change, enhancing ecosystem services and protecting biodiversity.

4.1. Introduction

Nature-based solutions (NbS) are measures that protect, sustainably manage or restore nature. In so doing, they aim to maintain or enhance ecosystem services to address a variety of social, environmental and economic challenges (OECD, 2020[1]). NbS are gaining increasing attention in national and international policy debates as cost-effective and flexible solutions that can help countries adapt to the accelerating impacts of climate change, including their infrastructure. While NbS are often praised for generating social and environmental co-benefits, understanding and actual use of NbS for infrastructure remain limited. This chapter demonstrates the usefulness of NbS for climate-resilient infrastructure and identifies ways to strengthen their use.

4.2. The rationale for using NbS to enhance climate resilience in the infrastructure sector

Infrastructure is highly vulnerable to the impacts of climate change, and this vulnerability increases the exposure of entire economies (Chapter 1). Infrastructure makes up two-thirds of government contingent liabilities based on the impacts and costs to date of extreme events related to climate change (OECD/The World Bank, 2019[2]). Estimates show that infrastructure will represent about 66%[1] of total adaptation costs globally by mid-century if the world acts to ensure continuity of essential services for populations and protect them from climate impacts (Thacker et al., 2021[3]).

NbS have gained popularity for climate resilience building in the infrastructure sector in both national and international policy agendas. A recent presidential executive order made NbS a national priority in the United States. This order, together with the Bipartisan Infrastructure Law (The White House, 2022[4]), recognises NbS for their role in building climate-resilient infrastructure. It also matches earmarked funding sources for realising NbS projects (Section 4.4.3). Published in 2013, the European Union's Green Infrastructure Strategy has also focused on the preservation, restoration and enhancement of green infrastructure. Over the past decade, it has aimed to help stop biodiversity loss and deliver ecosystem services for people (European Commission, n.d.[5]). For its part, the Roadmap of the G20 Working Group on Disaster Risk Reduction recently highlighted the importance of climate-resilient infrastructure and the role of NbS (G20 Brasil 2024, n.d.[6]).

Accompanying these policy ambitions, several funding instruments have been promoting use of NbS for climate-resilient infrastructure. In the European Union, these instruments include financial resources as part of the overall EUR 5.4 billion LIFE (European Commission, 2021[7]), the EUR 95.5 billion Horizon 2020 (European Commission, n.d.[8]) and the European Regional Development Fund's Greener Europe programme stream with EUR 104 million (European Commission, n.d.[9]) between 2021-27. Similarly, some countries have targeted programmes. In Germany, for example, the Federal Action Plan on Nature-based Solutions for Climate and Biodiversity invests EUR 4 billion to scale up NbS to strengthen climate resilience (BMUV, 2022[10]; OECD, 2023[11]). Meanwhile, the recent resolution of the United Nations Environment Assembly (UNEA) underlined the importance of harnessing NbS to achieve the Sustainable Development Goals (SDGs), including SDG 9 on infrastructure (UNEA, 2022[12]).

While awareness levels of NbS have historically been low, NbS continue to attract attention among decision makers, accompanied by support for NbS measures by citizens. For example, 70% of surveyed subnational governments in Hungary[2] used NbS through the concept of green and blue infrastructure over the past decade. Meanwhile, nearly 80% of subnational authorities in the country considered NbS important for climate change adaptation and reduction of climate risks (OECD, 2023[13]). Similarly, citizens indicate trust and preference for using NbS compared to grey solutions: 60% of respondents in a representative EU-wide survey would choose NbS over grey alternatives to tackle social, environmental and economic challenges (European Union, 2018[14]). In addition, surveys in a wide range of cities, such as in Catania, Italy and in Catterline, United Kingdom, indicate the appreciation of citizens for NbS. They associate them with purer air, recreational opportunities, mental well-being, landscape improvement, biodiversity benefits and risk reduction (Anderson et al., 2022[15]; Sturiale, Scuderi and Timpanaro, 2023[16]).

Different definitions of NbS emphasise distinct aspects. The International Union for Conservation of Nature (IUCN) defines NbS as "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016[17]). In so doing, it places strong emphasis on restoring and conserving nature (OECD, 2020[1]). The European Commission puts a stronger focus on cost effectiveness (De los Casares and Ringel, 2023[18]), defining NbS as "solutions to societal challenges that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits, and help build resilience" (EEA, 2021[19]). The UNEA defined NbS as "actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits" (UNEA, 2022[12]).

For the purpose of this publication and following earlier OECD work, NbS are defined as measures that protect, sustainably manage or restore nature, with the goal of maintaining or enhancing ecosystem services to address a variety of social, environmental and economic challenges (OECD, 2020[1]). This definition acts as an umbrella term that encompasses several approaches. These include ecosystem-based adaptation, eco-disaster risk reduction and green infrastructure (OECD, 2020[1]). As such, the definition encompasses various aspects of the term, including protection and restoration of natural features, as well as the creation of features mimicking nature (Silva Zuniga et al., 2020[20]). The definition also ensures that NbS do not adversely affect the natural environment or biodiversity. NbS can be provided as standalone solutions, as well as features to complement grey "engineered" solutions – i.e. built structures and mechanical solutions (World Bank, 2021[21]). No pre-defined scale is adopted through this definition. In other words, a green roof covering a limited surface can be considered as NbS just as much as a landscape-wide forest restoration project that spans hundreds of hectares (ha).

As substitutes, complements and safeguards to grey infrastructure (Section 4.3), NbS can strengthen climate resilience. Mangroves, coastal wetlands, coral and oyster reefs can reduce risks from coastal floods, storm surges and erosion induced by climate change, while healthy forests and riparian wetlands mitigate riverine flood risk induced by climate change. For example, when Hurricane Irene hit the United States in 2011, the city of Middlebury in the state of Vermont experienced half of the peak discharge as the city of Rutland 50 kilometres (km) upstream, despite a larger drainage area. Middlebury benefited from 6 000 km of wetlands that mitigated flood risk, saving an estimated USD 1.7 million in damages (Opperman and Galloway, 2022[22]). Bioswales, bioretention ponds and permeable pavements can lower the impact of heavy precipitation events on urban wastewater infrastructure, protecting people and economic activities from flash floods. Meanwhile, green roofs, street trees and green façades can provide much needed cooling from increasing temperatures.

NbS can also mitigate the negative impact of infrastructure assets and networks on ecosystems. For example, some large infrastructure projects are planned in locations of major natural carbon sinks or biodiversity hotspots, such as the Amazon or the Congo basins, as well as forests in Southeast Asia (Ermgassen, 26 November 2019[23]). Infrastructure development threatens about one-sixth of species at risk of extinction that are on the IUCN Red List (Ermgassen, 26 November 2019[23]). While not a panacea, integrating NbS as substitutes and complements to grey infrastructure can help tackle these challenges; working with ecosystems can harness biodiversity and contribute to carbon sequestration.

While NbS could provide significant benefits, they must be implemented effectively. Effective research and design are crucial to ensure that NbS do not lead to maladaptation such as the application of unsuitable species in a given environment. To avoid such maladaptation, especially biodiversity loss, policy makers need an understanding of the baseline conditions at different levels. They must also assess the landscape-scale factors affecting the integrity and the structure of the NbS (Sowińska-Świerkosz and García, 2022[24]).

4.3. NbS as a substitute, complement or safeguard of grey infrastructure

Through providing physical protection against climate risks, NbS can be used as a substitute, complement or safeguard of grey infrastructure (Silva Zuniga et al., 2020[20]). As a substitute, NbS can act as an alternative to grey infrastructure solutions, often offering more co-benefits than their grey counterparts. For example, oyster reefs can help reduce coastal erosion and flooding during storm surges, offering alternatives to breakwaters. In the United States, the restoration of 5.9 km of oyster reefs in Mobile Bay in the state of Alabama reduced wave height by 53% and wave energy at the shoreline by 91%. It thus helped reduce coastal erosion, while producing 6 500 kilogrammes (kg) of seafood annually (equivalent to half of total harvested oysters in Alabama in 2015) and reducing nitrogen pollution (World Bank and World Resources Institute, 2022[25]).

While substituting grey infrastructure with NbS is not always an option, it is estimated that at least 11% of the global infrastructure need could be built with nature (Bassi et al., 2021[26]). In some sectors, such as water and sanitation, this share reaches up to 25%. It is less in irrigation (20%), transport and energy efficiency (10%) and energy supply (5%) (Bassi et al., 2021[26]). Together, NbS could deliver annual cost savings of USD 248 billion to cover infrastructure needs compared to grey options. At the same time, they would deliver USD 489 billion of added benefits per year, primarily due to ecosystem services (Bassi et al., 2021[26]).

As a complement, NbS are combined with grey solutions to provide better overall resilience for infrastructure networks and people. Around Tanzania's capital, Dar es Salaam, a combination of NbS (restoration of 3 000 square metres [m^2] of coral reefs and 1 245 ha of mangroves) and grey infrastructure (2.8 km of sea walls, groynes and sea defence structures) protect communities from sea level rise and rain-induced flooding, directly benefiting around 58 000 people (UNEP, 2022[27]). Such combined NbS and grey solutions are increasingly important in building resilience. As the bursting of large dams during the

2013 flood on the Elbe River demonstrated, grey structures cannot offer 100% protection against floods in all cases. NbS, such as the restoration of riparian vegetation, the reconnection of rivers with floodplains and the revitalisation of wetlands, can help reduce flood risk (Haase, 2017[28]). Completed in 2018, a EUR 35 million project in the Lödderitzer Forest in Germany removed the existing dyke and reconstructed it farther from the river. The project reconnects 600 ha of forest floodplains with the Elbe, allowing more space for the river. It is thus expected to lower flood risk by 0.3 m for a 100-year return flood in the city of Aken through a combination of NbS and grey solutions (WWF, 2019[29]).

As a safeguard, NbS can be put in place to protect grey infrastructure assets, ensure their safe functioning and enhance their operable life. In the United States, for example, Hurricane Sandy and other storms damaged road infrastructure through flooding, storm surges and erosion. In response, a marsh and wetland re-stabilisation project in Little Egg Harbor aims to protect coastal road infrastructure from flooding in the state of New Jersey. This will benefit the area's 20 000 residents and tourists (Worth, 2021[30]). In the Philippines, mangroves act as living safeguards to avert more than USD 1 billion in damage to residential and industrial infrastructure, while protecting over 600 000 people from flooding annually (Tercek and Beck, 2017[31]). For their part, green roofs can retain 50-100% of stormwater (World Bank and World Resources Institute, 2022[25]). Consequently, many cities use these roofs to reduce pressure on grey stormwater infrastructure given increasingly frequent and intense heavy precipitation events.

The advantages of NbS in building climate-resilient infrastructure

Besides protecting against climate risks, NbS can also enhance the lifespan of grey infrastructure assets and networks, as well as help improve their efficiency, when adopted as a safeguard or complement to grey infrastructure. In South America, for example, the impact of climate change on river flows is making precipitation patterns increasingly variable. To counteract these effects, as well as reduce sedimentation, 44 million trees were planted in the catchment of the Itaipú hydropower dam that provides 90% and 19% of electricity to Paraguay and Brazil, respectively. The project restored, reforested and preserved more than 100 000 ha of land. Reducing sedimentation and ensuring more stable river flows strengthened the dam's resilience and operations. The project has brought USD 45 million of direct financial benefits to the dam's operation alone (Rycerz et al., 2020[32]). In the United States, flood managers in the Sacramento Valley in the state of California complemented levees and other grey flood protection infrastructure by reconnecting 60 000 ha of floodplains via the Sutter and Yolo bypasses. By reducing about 80% of discharge during floods, the bypasses and floodplain reconnection reduce pressure on levees and combined NbS and grey solutions. This helps protect the city of Sacramento from floods (Opperman and Galloway, 2022[22]).

Furthermore, NbS can provide flexible and adaptive solutions in the context of climate change. Due to their natural adaptive and regenerative capacity, many NbS can adapt to changing climatic conditions, thus helping manage uncertainties associated with climate change. For example, coastal wetlands can migrate upwards in response to rising seas (if sea level rise is within certain limits and there is undeveloped space to expand) (Borchert et al., 2018[33]; UNEP, 2022[34]). This can be a particular advantage of NbS when compared to grey solutions. Unlike grey infrastructure built to replace them, mangroves can more easily adapt to a changing climate through their natural adaptive and regenerative capacity, and thus protect communities from storms (Van Zanten et al., 11 November 2021[35]). Similarly, NbS have the potential to recover following extreme weather events. Unlike sea walls, mangroves can recuperate following hurricane damage (as long as hurricanes do not alter ground topography) (Imbert, 2018[36]; UNEP, 2022[34]). Thus, as dynamic solutions, NbS can help avoid the lock-in grey infrastructure could bring.

4.3.1. The economic rationale for NbS to enhance climate resilience in the infrastructure sector

Though overall estimates are difficult to make, growing evidence demonstrates the economic benefits of NbS. In Canada, NbS for infrastructure in the province of Ontario directly generated CAD 4.64 billion in gross domestic product (GDP) and CAD 8.6 billion in gross revenues in 2018. By 2030, this could increase to CAD 13.2 billion in gross revenues and CAD 7 billion in direct GDP (GIO, 2020[37]). In Singapore, the Active, Beautiful, Clean Waters Programme re-naturalised rivers, streams and lakes. By shrinking the flood-prone area by 100 times (from 3 200 ha to 32 ha), the USD 300 million investment between 2007-11 helped save over USD 390 million in water costs (Kapos et al., 2019[38]). In the United States, the restoration of coral reefs in Puerto Rico and Florida offers similar savings. The reefs have the potential to save nearly USD 273 million per year in avoided direct and indirect flood damages (Storlazzi et al., 2019[39]). Overall, in the United States, coral reefs are estimated to provide annual flood protection benefits worth USD 1.8 billion and save more than 18 000 lives every year (Storlazzi et al., 2019[39]). In Viet Nam, aquaculture expansion had damaged mangrove forests. A USD 9 million investment was launched to restore these forests along the shore of 166 communes. The project aims to reduce coastal erosion and flood damage, saving USD 15 million in avoided damages (World Bank and World Resources Institute, 2022[25]). Globally, the estimated value of avoided flood damage by mangroves was at least USD 65 billion (Menéndez et al., 2020[40]; World Bank and IBRD, 2023[41]).

Estimates show that NbS for infrastructure cost half as much as grey alternatives, while generating 28% more in added value (Bassi et al., 2021[26]). In terms of coastal protection, salt marshes and mangroves are two to five times less expensive than submerged breakwaters to lower wave heights by 0.5 m and reduce coastal erosion (Narayan et al., 2016[42]; Dasgupta, 2021[43]). Furthermore, investors could save up to an estimated USD 248 billion annually by replacing grey solutions with NbS for only 11% of the global infrastructure need (i.e. in cases where it is practical and feasible to do so), while generating USD 489 billion in benefits (Bassi et al., 2021[26]). Using this logic, New York City in the United States invested USD 1.5 billion over nearly three decades to protect the watershed that provides the source of its water. This avoided spending around USD 8-10 billion to build a water filtration plant (Gartner et al., 2013[44]).

These cases show that NbS are generally cheaper than grey solutions, but the reverse can also be true. This makes it key to quantify the value creation (added benefits) and avoided losses for making the case for NbS. For example, installation costs of permeable pavements can be two to three times higher than that of asphalt and concrete. Meanwhile, the installation of green roofs is two to five times more expensive than that of their traditional counterparts (World Bank and World Resources Institute, 2022[25]). In addition, green roofs require more frequent maintenance than their traditional counterparts to maintain good results (Enzi et al., 2017[45]). In certain cases, long-term maintenance costs are borne by different actors than those covering the one-time investment in the installation of NbS. For example, the national government might (co-) finance the installation of urban green spaces, while local authorities cover long-term maintenance costs.

However, the added benefits of NbS can often justify their implementation. Permeable pavements can reduce runoff volumes by 90% (World Bank and World Resources Institute, 2022[25]). Similarly, green roofs can retain 50-100% of excess precipitation in cities. Moreover, their longer lifespan and co-benefits can compensate for their implementation (World Bank and World Resources Institute, 2022[25]). In Australia, a case study found that a green roof in the city of Sydney can be up to 20°C cooler than its traditional counterpart (Irga et al., 2021[46]). The same study found a green roof can ensure building insulation, increase urban biodiversity (particularly of avian and insect species) and reduce air pollution.

NbS can also offer substantive economic benefits as safeguards to grey assets, as well as combined solutions. In the United States, a case study of stormwater management explored options for the city of Philadelphia in the state of Pennsylvania. It found that hybrid solutions (combining NbS and traditional options) created over 23 times more added benefits than grey solutions alone. Examples of NbS included green roofs and permeable pavements, while traditional options included storage tunnels. These hybrid solutions generated USD 2 846 million in benefits compared to USD 122 million for grey solutions. The benefits were generated through increased environmental aesthetics, heat stress reduction, and water and air quality improvements (Stratus Consulting, 2009[47]). Similarly, the city of Portland in the state of Oregon invested in urban NbS, such as bioswales. These complement grey solutions to tackle growing quantities of sewage and stormwater runoff. In so doing, the city has reduced peak flows by 80-94% in the target areas since 2007. A USD 9 million investment in NbS combined sewer overflows and lowered pressure on grey infrastructure. It thus delivered USD 224 million in reduced maintenance costs (World Bank and World Resources Institute, 2022[25]).

NbS also show to have net positive labour market impacts. While numbers for the infrastructure sector are unavailable, around 75 million people already work on NbS. This translates to 14.5 million full-time equivalent jobs as many of these employment opportunities are part-time (ILO, UNEP and IUCN, 2022[48]). The city of Rennes in France estimated that labour costs represent 80-99% of maintenance costs for green spaces (Barometres, 2017[49]), creating several long-term job opportunities. In particular, the creation and management of urban green spaces can establish one to five full-time jobs per hectare, while using NbS for watershed improvement can create one to three jobs (WWF and ILO, 2020[50]). The protection of coastal ecosystems is estimated to create 17 jobs for every USD 1 million spent (Edwards, Sutton-Grier and Coyle, 2013[51]). In Canada, NbS for infrastructure directly employed over 84 000 people in the province of Ontario in 2018, a figure that could grow to 103 000 by 2030 (GIO, 2020[37]).

NbS can also benefit the economy by helping to partially counterbalance rising temperatures that lead to reduced productivity. Even under a 1.5°C temperature rise scenario, conservative estimates forecast that 2.2% of total working hours could be lost by 2030 due to high temperatures globally – equivalent to 80 million full-time jobs. This could cost USD 2 400 billion in 2030 (nearly nine times more than in 1995), with low- and middle-income countries experiencing more profound impacts (Kjellstrom et al., 2019[52]). Green spaces can contribute to lower these impacts by reducing extreme temperatures. They do this both through evapotranspiration and by a favourable material composition that allows them to avoid heat absorption better than an engineered surface. For example, an 850 m^2 green wall on a public building in Vienna, Austria provided a cooling benefit of 712 kilowatt hours (kWh). This is equivalent to the production of 80 air conditioning units of 3 000 watts working for eight hours (Enzi et al., 2017[45]), thus lowering air temperatures in the building. Capitalising on such natural cooling benefits, a 20% increase in green areas (e.g. small parks, street trees, green roofs and walls, etc.) in Glasgow, United Kingdom could reduce surface temperatures by 2°C in 2050. This would reduce the extra urban heat island effect predicted for the city under a high warming scenario by a third to a half (Emmanuel and Loconsole, 2015[53]).

Through their strong risk reduction potential, NbS can also be put in place to ensure the insurability of infrastructure assets in the context of increasing climate risks. To reduce insurance loss value and insurance payments for claims over time, the insurance sector is increasingly turning towards NbS (Costa et al., 2020[54]; EIB, 2023[55]). In the United States, a project setting back levees on the Missouri River reduced flood risk for 1 455 homes, offering protection against 160-to-200-year return floods. By allowing the river to flow in a more ecological manner and reconnect around 420 ha of floodplains with the river to avoid the overtopping of levees, the project halves insurance property premiums (MunichRe, 2022[56]). Recently, academics and insurance providers collaborated to study further how the combination of NbS with insurance can boost coastal resilience and cover the increasing protection gap. The study drew on earlier research that showed how capitalising on the potential of coral reefs could lower wave energy and protect shorelines against storm damages and flooding. It found that a hypothetical 5 km coral reef restoration costing USD 6.45 million could lower and reduce risk of coastal flooding due to storm surges by 50% in a two-year period. In so doing, it could lower insurance premiums for coastal assets by over 56% in five years (Reguero et al., 2020[57]).

4.3.2. Social and environmental co-benefits of NbS

In addition to boosting the resilience of infrastructure assets, NbS can bring several environmental and social co-benefits that act as significant incentives for their implementation. Through enhancing human well-being and the quality of life in diverse ways, social co-benefits are often drawn out as an important advantage of various NbS measures. NbS protect people from climate risks and other natural hazards. Mangroves, for example, protect around 15 million people every year from flooding (Menéndez et al., 2020[40]). Several NbS measures capitalise on this protective potential of NbS. In the United States, the USD 60 million "Living Breakwaters" project grows oyster reefs off the coast of Staten Island. It protects residents from storm surges and coastal flooding in the nearby metropolitan area around New York City (Thiele et al., 2020[58]).

Health benefits offer further incentives to realise NbS projects. By helping reduce the urban heat island effect, NbS can help save the lives of citizens vulnerable to heat exposure. Inspired by evidence that green roofs can lower indoor air temperatures by 1.5-3 °C, a simulation study found that installation of green roofs could reduce deaths of the elderly. In Hungary, for example, green roofs on all buildings with elderly residents would reduce heatwave-related mortality in the city of Szeged by 63% by 2030. The benefits of green roofs were even higher (up to 71%) in the municipality of Çankaya, Türkiye (Marvuglia, Koppelaar and Rugani, 2020[59]). Similarly, trees are estimated to lower temperatures by 7-15°C through shade and evapotranspiration, thus mitigating the urban heat island effect (UNEP, 2021[60]), while providing health benefits due to cleaner air. Indeed, trees in ten of the world's megacities alone are estimated to provide a health benefit of USD 482 million annually due to reduced air pollution (Endreny et al., 2017[61]). In Spain, 200 000 trees in the city of Barcelona were estimated to have removed 5 000 net tonnes of CO_2 and 305 tonnes of polluting compounds in 2008 (Ajuntament de Barcelona, 2013[62]; Cohen-Shacham et al., 2016[17]). Moreover, urban green areas are estimated to remove 1.97-3.8 g of ozone per square metre every year (Aevermann and Schmude, 2015[63]; Le Coent et al., 2021[64]). Furthermore, as green roofs can lower sound transmission by 10-20 decibels, several NbS measures deliver health benefits by lowering noise levels (Liberalesso et al., 2020[65]).

One of the key environmental co-benefits of NbS is their carbon sequestration potential. Mangroves, for example, can store over 900 tonnes of carbon per hectare (Alongi, 2012[66]). At the same time, wetlands protect people from floods. Sri Lanka, for example, has a project to restore and protect wetlands, woodlands, swamps, freshwater lakes and grasslands around the capital of Colombo. The wetlands absorb up to 90% of the city's GHG emissions and clear the air, while protecting residents from flooding. Combined with grey solutions (e.g. pumping stations and water diversion tunnels), the project benefited 2.5 million citizens (World Bank, 2023[67]). In addition, in the Republic of South Africa, a study found that 67 000 m^3 of green roofs in the city of Tshwane could store over 25 000 kg of carbon annually. At the same time, they could reduce energy needs by close to 690 000 kWh, saving 605 tonnes of CO_2 emissions every year (WWF, 2021[68]).

NbS can also help reduce pollution and enhance the quality of ecosystems by air, soil and water quality improvements. Moreover, if implemented effectively, NbS also help create positive outcomes for biodiversity. For example, wetlands can lower concentrations of nitrate of water flowing through them by over 80% (Millennium Ecosystem Assessment, 2005[69]). This helps reduce eutrophication, as well as protect freshwater animals from toxic nitrate levels. Since 1998, the 0.6 ha Hovi Research Wetland in Finland has reduced nutrient runoff from agricultural processes, as well as prevented eutrophication and harmful nutrient concentrations for living beings. In a decade, the wetland reduced phosphorous and nitrogen concentrations by an average of 62% and 50%, respectively. As a result, the wetland retained 90% of soil material and nutrient load flowing into it. Waters running through the wetland reached a cleaner status than those purified at water treatment plants (WWF Finland, 2013[70]). Similarly, bioswales and rain gardens were observed to clean stormwater of heavy metals by up to 90% (World Bank and World Resources Institute, 2022[25]).

Besides protecting coastlines from storm surges and tidal erosion, oyster reefs also have a significant potential to purify water. A single oyster on average purifies close to 190 litres of water from algae, phosphorus, nitrogen and other substances every day (NCCOS Video, 2 March 2020[71]). As regards biodiversity, the choice of species should be considered carefully to ensure measures create biodiversity-based resilience and multi-functional landscapes. For instance, non-native plantings can decrease erosion or urban heating but have negative impacts on biodiversity (Seddon et al., 2020[72]).

Overall, for NbS to maintain its multiple benefits sustainably, NbS should remain effective under changing climate conditions. This requires incorporating adaptive management strategies that allow for adjustments over time based on monitoring and evaluation (see Monitoring and evaluation), planning for future climate scenarios. For example, coastal NbS, like mangrove restoration, should consider projections of sea level rise.

4.4. Scaling up the use of NbS for infrastructure resilience

Despite the great potential of NbS to help build climate resilience in the infrastructure sector, their use remains scattered and mainly applied at pilot scales. NbS continue to be promoted in several policy frameworks, such as the EU Green Infrastructure Strategy or EU Biodiversity Strategy (EEA, 2021[19]). However, despite this progress, a recent study warns the application of NbS in the European Union remains mostly limited to small-scale projects (EEA, 2023[73]). Indeed, of nearly 1 400 NbS projects in the European Union and the United Kingdom, nearly three-quarters covered less than 1 km^2 (EIB, 2023[55]). While this may be the appropriate scale for certain NbS (e.g. green roofs, green façades), the low coverage demonstrates that NbS projects are mostly implemented on small spatial scales.

The main reason for limited uptake of NbS lies in the absence of an enabling environment for their use. Traditional policy, regulatory and financing frameworks present hurdles that prevent NbS from being considered on equal footing as grey solutions, which are perceived as simpler, less risky and more familiar. Moreover, NbS require distinct spatial scales, and often longer timescales for their intended benefits to materialise compared to grey solutions. These factors also act as barriers to NbS uptake (OECD, 2020[1]). In addition, as NbS require working with dynamic ecosystems, their planning, implementation and maintenance requires a special set of skills (OECD, 2020[1]). Limited technical capacity among public and private sector actors represents an additional barrier to upscale the use of NbS (OECD, 2021[74]; OECD, 2020[1]). This is often combined with low levels of awareness on NbS, leading decision makers, infrastructure planners and citizens to often focus on “conventional” grey solutions instead of NbS.

To promote wider uptake of NbS, national governments need to design innovative institutional, policy, regulatory and financial frameworks. These should enable the use of NbS by both public sector agencies and authorities, as well as private actors. Most relevantly, complex governance arrangements, the lack of coherence across sectoral regulations and limited financing must not inadvertently discourage different actors from embracing NbS. Investing in raising awareness and technical capacity are also key. Often, public and private sector actors have little knowledge on the use and benefits of NbS, and they see them as too expensive and difficult (OECD, 2020[1]).

4.4.1. Enabling environment

Institutional arrangements

Governance arrangements are often ill-suited to foster NbS planning and implementation. As NbS cut across sectoral boundaries, geographical areas and jurisdictions, they usually require the collaboration of a diverse policy and practitioner community (Bisello et al., 2019[75]). NbS planning and implementation build on regulations, policies and instruments that go beyond a single agency’s responsibility or jurisdiction. Instead, NbS fall into the mix of measures that can be employed by many actors. These include environmental ministries, national flood and drought management agencies, public works or infrastructure agencies, infrastructure operators, and regional and local authorities. Moreover, other non-governmental actors (e.g. landowners and Indigenous communities) also play an important role in their uptake (OECD, 2020[1]). For instance, the creation of green spaces to mitigate the risk and impact of flooding might require the co-operation of different stakeholders. These could range from spatial planning agencies and private actors to housing, environment and water management authorities across different levels of government. This requires a cross-sectoral and cross-governmental approach to raise awareness or enhance technical capacity, as well as to improve the policy and regulatory environment for NbS. Nevertheless, the different actors involved tend to work in silos, with limited collaboration and co-ordination across sectors (Nature Squared, 2021[76]; OECD, 2023[77]; OECD, 2021[74]).

To upscale use of NbS, it is therefore vital to create an institutional framework that enables and promotes co-ordination, co-operation and knowledge exchange across agencies, sectors and levels of government (i.e. national, regional and local authorities). Notably, co-ordination among governmental bodies should foster synergies across policies and initiatives relevant for NbS, mainstream benefits of NbS to accelerate action and address trade-offs between them where necessary (OECD, 2021[74]; OECD, 2020[1]). Moreover, the institutional framework needs to define clear mandates, roles and responsibilities across the different phases of the NbS life cycle, i.e. from project design, appraisal and approval to construction, operation, monitoring and maintenance (OECD, 2023[77]). This can help facilitate co-ordination when combined with information sharing, partnerships and exchange of good practices, while also avoiding overlapping projects, inertia and duplication (OECD, 2020[1]).

Successful NbS projects also depend on governance arrangements that engage with non-governmental actors throughout the life cycle to ensure their sense of ownership. This process, for example, can involve private landowners who contribute to financing NbS. It could also engage citizens, including Indigenous peoples and other diverse social groups who can co-design projects with urban planners. Involving non-governmental actors often requires development of innovative tools and mechanisms, such as public consultation exercises. However, it can offer significant benefits from NbS throughout all stages of the project – from design to maintenance (OECD, 2023[77]; OECD, 2021[74]; OECD, 2020[1]).

Policy and long-term planning

Policies, including long-term strategies, roadmaps and sectoral strategies across different levels of government, play a vital role in scaling up NbS for climate-resilient infrastructure. An increasing number of governments define a long-term strategic vision for NbS, recognising its role in climate resilience building. This helps promote the wider adoption of NbS by public and private players and enhance the climate resilience of infrastructure.

At the international level, the Kunming-Montreal Global Biodiversity Framework set a globally agreed ambition for countries to promote NbS at national level. In keeping with the agreement, at least 30% of degraded ecosystems should be under effective restoration (Target 8) by 2030. It also set out to restore, maintain and enhance nature's contributions to people through ecosystem services (Target 11) by the same date. For its part, the European Commission launched a Strategy on Green Infrastructure[3] in 2013, which highlighted the potential of ecosystem-based approaches to enhance climate resilience. Most relevantly, the strategy aims at creating an enabling framework for green infrastructure implementation. This will ensure ecosystem-based approaches become standard for spatial planning and territorial development, even at the national level (European Commission, 2013[78]).

Ambitions to increase implementation of NbS, notably in support of infrastructure, are also reflected in national-level policy planning. France's Green and Blue Framework represents the national green development strategy, supporting resilience to climate change via green and blue infrastructure. Land use and landscape planning throughout the country needs to consider the framework (Office Français de la Biodiversité, 2022[79]). Similarly, Germany and England provide a strategic framework for the development of green infrastructure via Germany's Federal Green Infrastructure Concept (BfN, 2017[80]) and Natural England's Green Infrastructure Framework (Natural England, 2024[81]).

Besides strategies dedicated to scaling up NbS in the infrastructure sector, NbS are also increasingly recognised within infrastructure policy frameworks, which highlight their role in building climate resilience.

In the United States, the Bipartisan Infrastructure Law in 2022 recognised that NbS can act as infrastructure and help enhance the operable lifetime and overall performance of grey infrastructure (The White House, 2022[4]). Accompanying the law, the White House released a roadmap identifying five strategic areas for scaling up NbS (The White House, 2022[4]). Similarly, the National Infrastructure Strategy in the United Kingdom recognises the role of NbS in enhancing climate resilience (HM Treasury, 2020[82]).

Such dedicated strategies at the national level provide overarching policy directions to facilitate use of NbS for climate-resilient infrastructure. However, they need to be mainstreamed across key environmental policies and actions. With their role in enhancing climate resilience across various sectors of the economy, adaptation strategies are key instruments to promote NbS for building resilience of several sectors, including infrastructure. Across the OECD, many countries include NbS as part of their national adaptation plans (NAPs) or strategies. For example, national adaptation policies from Australia, Canada, Denmark and Norway consider NbS as a complementary approach to grey infrastructure in certain sectors, such as wetlands and urban greening. Moreover, Australia's National Climate Resilience and Adaptation Strategy 2021-2025 also recognises the key role of NbS to address coastal, river and urban flooding (OECD, 2020[1]). In addition, biodiversity strategies also have a key role in promoting NbS. Many European countries mention NbS as part of overarching national biodiversity strategies, including Austria, Belgium, Finland, Germany, Greece, Hungary, Italy, Luxembourg, Malta and Spain. In addition, throughout the European Union, the EU Biodiversity Strategy to 2030 encourages investments in green and blue infrastructure, as well as systematically including NbS and healthy ecosystems in urban planning (European Commission, n.d.[5]).

Although overarching national climate and biodiversity strategies are instrumental to promote use of NbS, governments also need to mainstream NbS into other sectoral policies relevant to infrastructure. Sectors such as transport, water management and disaster risk reduction can help NbS gain traction for climate-resilient infrastructure and drive their implementation on the ground (OECD, 2021[74]). Some countries have started mainstreaming NbS into sectoral policies for different areas. For instance, Mexico, the United States, the United Kingdom and New Zealand refer to NbS as a key strategic measure for coastal protection (OECD, 2020[1]). In the Netherlands and in Belgium, NbS has a central role in plans for restoration of rivers. In Italy, natural retention measures are included in the National Strategic Plan for the EU Common Agricultural Policy. They are identified as a solution to integrate mitigation of hydro-geological risk with the protection and restoration of ecosystems and biodiversity. In Germany, a new water strategy recognises the importance of NbS in water infrastructure development (BMUV, 2021[83]). Similarly, the EU Action Plan on the Sendai Framework or Disaster Risk Reduction 2015-2030 promotes NbS for disaster risk reduction. Meanwhile, the Urban Agenda for the European Union explicitly refers to promoting NbS and green infrastructure in urban areas to enhance climate change adaptation and resilience (EEA, 2021[19]).

Despite this growing recognition of NbS in sectoral strategies, several gaps remain in their mainstreaming. This is partly due to potential conflicting interests between NbS and other policy objectives. For instance, many NbS measures consume land, which can conflict with other policies, especially in urban and peri-urban areas. Further work is needed to understand trade-offs and synergies between different policy objectives and inform appropriate safeguards to avoid unintended consequences of NbS (OECD, 2021[74]; OECD, 2020[1]). Finally, it is important to recognise the role of subnational strategies in ensuring the mainstreaming of NbS throughout all levels of government (Chapter 6).

A growing number of subnational governments recognise NbS. In the capital of Hungary, the implementation of NbS is supported by Green Infrastructure Development and Maintenance Action Plan (Dezső Radó Plan) of the city of Budapest (City of Budapest, 2021[84]; OECD, 2023[13]). Similarly, in the United Kingdom, the Green Infrastructure Strategy (2015-25) in the city of Leicester facilitates use of NbS to enhance resilience to climate change impacts (Leicester City Council, 2015[85]).

Mainstreaming NbS into both sectoral and subnational policies must consider challenges that can differ markedly depending on the region and sector, highlighting the need for context-specific approaches. NbS implementation depends on factors such as climate risk exposure and vulnerability; capacity to implement measures; and policy, regulatory, institutional and cultural contexts. For instance, in arid and semi-arid regions, water resource scarcity and land degradation pose significant challenges to the establishment and survival of new vegetation. In the Sahel, efforts to create a “Great Green Wall” have faced challenges due to the extreme variability of rainfall and the fragile nature of the soil, making it difficult to sustain tree growth (IISD, 2022[86]). Urban areas are often faced with challenges related to limited space. Different challenges also exist between sectors. Spatial planning may face challenges related to land tenure and access rights, complicating the implementation of NbS. Meanwhile, the agricultural sector needs to overcome challenges related to balancing food production and security with ecological conservation that may reduce yields (FAO, 2019[87]; World Bank, 2019[88]).

Equally important is the role of local authorities in considering local communities in planning and implementing NbS. They can ensure that NbS are tailored to address specific local challenges, leverage traditional knowledge and foster community ownership. For example, local authorities in cities across Latin America, including Medellín in Colombia and Quito in Ecuador, have worked with communities to identify areas for green development. They have integrated these spaces into social programmes to address issues such as public health and recreation (C40, 2019[89]; DW, 2019[90]).

Regulatory framework

The regulatory frameworks governing spatial planning, land use, water supply and building codes can play a key role to unleash opportunities for NbS and promote their implementation on the ground (OECD, 2020[1]). For instance, spatial planning determines how housing, infrastructure development and land preservation are envisaged, and hence the role for NbS. Similarly, building codes comprise legal prescriptions on the materials and design for new and existing buildings, which could create opportunities for use of NbS. In recent and ongoing reforms to building codes, countries have started promoting use of NbS. For example, some require a minimum for green space areas on and around new buildings, as well as permeable material in driveways to increase water absorption and retention capacities (OECD, 2021[74]).

As mentioned above, prevailing norms and technical standards consider grey infrastructure as the main, or only available and feasible, option. This has resulted in a bias towards exclusive use of grey infrastructure by governments, local authorities and private actors. To upscale use of NbS, regulatory frameworks and requirements should be reformed to make them fit for NbS, or even make them the default option. In Norway, for example, the central government provides guidelines for adaptation planning to encourage subnational governments to use NbS in their land-use and general planning processes. In 2018, it introduced a requirement for both counties and municipalities to consider use of NbS in planning processes before the use of alternatives such as grey infrastructure. If subnational authorities choose grey infrastructure, they must justify their decision to the central government (OECD, 2021[74]; Norwegian Ministry of Local Government and Rural Affairs, 2018[91]). Similarly, in the United States, the Living Shoreline Protection Act of 2008 in the state of Maryland sets out the prioritisation of measures that preserve the natural environment. It allows use of grey infrastructure only under specific circumstances (State of Maryland, 2008[92]).

Some countries have already started updating their regulatory norms and technical standards to enable use of NbS.

- In the United States, the US Army Corps of Engineers streamlined the permitting process for living shorelines. This aims to incentivise these measures and correct the comparative advantage of hard infrastructure projects in terms of shorter timeframes to receive permits (OECD, 2020[1]). In another example, Executive Order 13690 in 2021 set out the Federal Flood Risk Management Standard requiring federal agencies to amend their floodplain policies to consider NbS (The White House, 2022[93]).

- In the United Kingdom, all new buildings in Wales over 100 m^2 must have sustainable drainage systems (SuDS) in place for surface water, such as infiltration ponds, street trees, green roofs and other green surfaces. This aims to facilitate the filtration of water following heavy precipitation. Before construction can begin, the SuDS installations must comply with the statutory SuDS standards, and be approved by the SuDS Approving Body in local authorities (Welsh Government, 2019[94]). In England, SuDS are compulsory for all new developments of ten homes or more. Indeed, it is considering amendments to legislation that make SuDs standards mandatory for all new homes (Defra, 2023[95]).
- In Switzerland, the Building and Construction Law in the city of Basel was amended in 2002 to mandate green roofs on all new and renovated buildings in the city. The amendment included requirements for green roofs such as use of native soils and a mix of native species, and compulsory consultations with the city's green roof expert for roofs above 1 000 m^2. As a result, Basel has one of the highest per capita area of green roofs globally (Somarakis, Stagakis and Chrysoulakis, 2019[96]).
- In Canada, in 2009, the city of Toronto became the first North American city to adopt a green roof bylaw. It stipulates green roofs for new developments covering more than 2 000 m^2 (City of Toronto, 2009[97]).
- The uptake of green roofs has also increased in other cities around the world. In the United States, New York and San Francisco passed legislation requiring green roofs for certain developments. Meanwhile, Washington, DC, encourages use of green roofs through its stormwater management regulations (New York City, n.d.[98]; San Francisco, 2017[99]; DC.Gov, 2019[100]). Via binding land-use plans, around half of Germany's municipalities have also made green roofs compulsory in new urban development projects (van der Jagt et al., 2020[101]).

Despite these good examples, challenges remain to ensure the regulatory framework enables and promote the scaling-up of NbS. Regulatory frameworks, ranging from land-use zoning to permitting and safety and performance codes, are often too complex to navigate. Consequently, they can result in high resource and transaction costs.

4.4.2. Promoting NbS at the project level

NbS need to be part of infrastructure planning and design more systematically, more frequently, and at a larger scale. To that end, decision-making processes on public infrastructure investments should consider NbS, especially at the design, appraisal, procurement and selection phases.

Promoting the use of NbS in project design, appraisal and selection

Benefits and costs are assessed as part of project preparation, especially project design and appraisal. Appraisal guidance is key to ensure NbS are considered on an equal footing with grey solutions. Historically, it has been difficult to quantify the economic benefits of NbS, particularly at the project level, which often acted as a barrier for using NbS. Traditional valuation approaches and appraisal tools, notably cost-benefit analysis (CBA), have not considered social, environmental and economic co-benefits from NbS. Nor have they typically considered the value of nature or that of its loss. Consequently, grey infrastructure is often favoured over NbS (Bassi et al., 2021[26]). These methods have often failed to consider other specificities of NbS, such as the longer timescales required for their benefits to materialise. Thus, they fail to (fully) consider their benefits (Kuhl and Boyle, 2021[102]). Furthermore, these valuation methods often failed to fully consider the potential benefits of NbS with respect to climate change. Different climatic conditions may increase the need for cooling benefits or stormwater runoff reduction, heightening the value of NbS. Furthermore, under changing conditions, NbS may operate more efficiently than grey solutions (Kuhl and Boyle, 2021[102]).

Traditional appraisal tools can also be combined with or replace new methods to ensure a more comprehensive analysis and reporting on indicators. This can help grasp the ancillary social, environmental and economic advantages of NbS and their benefits to build climate resilience. This can be applied within environmental impact assessment (EIA) with the results also used to inform the appraisal process, including the CBA. Moreover, the use of CBA to compare alternative options can be complemented with multi-criteria analysis, which compares project alternatives on both quantitative and qualitative criteria. It therefore enables a fairer comparison with projects that do not necessarily score high on monetary outcomes but do have benefits according to nature and social indicators (Department for Levelling up, Housing and Communities, 2009[103]; OECD, 2023[104]).

Efforts are under way to overcome the persistent challenge of undervaluing NbS in CBAs. In the United States, for example, the Office of Management and Budget is reviewing central guidance on CBA to ensure federal agencies can better consider NbS in federal regulatory and funding decisions (The White House, 2022[93]). In addition, the country is developing a National Strategy for a System of Natural Capital Accounts. This aims to allow tracking of the economic benefits of investing in NbS (The White House, 2022[93]). Similarly, in 2009, the Netherlands developed the biodiversity points method. This measures the amount and quality of ecosystem services and biodiversity and their changes (i.e. the project's impact) in a standardised way. National guidance on CBA recommends use of biodiversity points with calculations including use of climate scenarios to account for changing climate impacts (Bos and Ruijs, 2019[105]).

Furthermore, methodologies have emerged that can better capture the economic benefits of NbS. Sustainable asset valuation (SAVi) enables investors and policy makers to consider the cost of economic, social and environmental risks and externalities over a project's lifetime (IISD, 2023[106]). SAVi also accounts for risks overlooked in traditional valuation approaches. This includes, for example, how water shortages may influence the attractiveness of a wastewater treatment plant in a decade's time.

Over recent years, these methodologies demonstrated in several cases that NbS benefits outweigh their implementation and planning cost in a range of contexts. For example, studies found the benefit-cost ratios of preserving mangroves for coastal protection were more than five-to-one (World Bank and IBRD, 2023[41]). Similarly, the benefits of planting street trees – including cooling and less stormwater runoff – were found to outweigh the cost over 30 times in the city of Tshwane, Republic of South Africa (WWF, 2021[68]) (Table 4.1). The assessment of the costs and benefits of NbS is particularly vital in economies with limited financial resources, especially developing countries, to engage their limited resources as efficiently as possible.

Table 4.1. Cost effectiveness of NbS vs. grey solutions based on alternative valuation approaches

Location	NbS	Grey solution	Issue it aims to tackle	Description
Aarhus, Denmark	Retention pond	Closed basin	Heavy precipitation	Creating a retention pond was found to be almost 11 times cheaper than a closed basin to reduce pressure on the sewage system. While both structures are estimated to have the same operable lifespan, annual maintenance costs of NbS were estimated to be 4.6 times cheaper (Núñez Rodríguez et al., 2023[107]).
São Paulo, Brazil	Forest restoration	Dredging of reservoirs	Deteriorating water quality	The restoration of 4 000 ha of forest to reduce sedimentation was found to be USD 4.5 million cheaper than dredging of water reservoirs to enhance water quality for the city's 22 million residents, while generating a net benefit of USD 69 million over three decades (Ozment et al., 2018[108]; GCA, 2019[109]).
Barantas River Basin, Indonesia	Land restoration measures (agroforestry, riparian bamboo plantations and absorption wells)	Water reservoir	Floods, erosion and deteriorating water quality	Land restoration measures were found to be more cost-effective solutions to address water scarcity and ensure the water provision for residents and industry compared to building a water reservoir. In addition, over two decades, NbS measures are expected to deliver USD 104-131 million of net benefits through averted flood and erosion damages, combined with carbon storage, improved water quality, bamboo production and job creation (Bassi et al., 2021[110]; Bechauf et al., 2022[111]).
Paterson Park Precinct, Johannesburg, Republic of South Africa	Stream re-naturalisation	Concrete culvert	Floods and water scarcity	A fully NbS approach (the complete re-naturalisation of a stream) was found to bring USD 10.6 million in averted flood damages over 40 years compared to a hybrid option combining NbS with a concrete culvert (which would have avoided USD 9.4 million in damages in the same period). The NbS option would also provide additional water supply worth around USD 3 million for the city over four decades through enhanced soil permeability (Wuennenberg, Bassi and Pallaske, 2021[112]; Bechauf et al., 2022[111]).

Project selection and prioritisation offer a further opportunity to promote NbS in infrastructure projects, but this first requires defining indicators and/or targets specific for NbS. Each project should then make clear how it contributes to or affects such NbS indicators or targets. For example, the European Environment Agency has developed a set of indicators to measure the share of green areas in cities and the distribution of green urban areas for urban infrastructure projects (EEA, 2021[113]).

Procurement and delivery of NbS

Public procurement represents another regulatory instrument the public sector can use to promote NbS at the project level (OECD, 2020[1]). Green public procurement, adopted in a number of countries (European Commission, 2008[114]), includes technical requirements and contract clauses that encourage use of NbS. For example, it requires use of specific construction materials or native plant species that can bring environmental, flood or drought management benefits to the management of public buildings or spaces (OECD, 2021[74]).

4.4.3. Financing NbS

Investments in NbS face a significant gap (Chapters 1 and 3). While figures on NbS investment in the climate-resilient infrastructure sector are lacking, it is estimated that only USD 154 million is spent per year on NbS globally. This is less than half of the USD 384 million needed annually by 2025. Moreover, it is only a third of the annual USD 484 billion by 2030 required for limiting global atmospheric warming below 1.5°C, halting biodiversity loss and land degradation (UNEP, 2022[115]). Only 0.3% of all funding dedicated to urban infrastructure is estimated to finance NbS measures (WEF, 2022[116]). This demonstrates the scale of the funding gap for NbS in the infrastructure sector.

Historically, besides the overall funding gap, a large majority of funding for NbS is scattered across various funding sources. This results in a patchwork of options that stakeholders have to navigate when planning and implementing NbS projects for climate-resilient infrastructure. Previous OECD analysis in Hungary, the United Kingdom and Mexico underlined this notion (OECD, 2023[13]; OECD, 2021[74]). For example, several funds provide opportunities for funding NbS in the United Kingdom. These include the GBP 200 million COVID-19 recovery measure to construct SuDS and water storage areas (Defra, 2020[117]). However, overall funding for NbS measures remains scattered (OECD, 2021[74]). In addition, NbS projects generally remain small-scale. Of 1 364 NbS projects studied in the United Kingdom and the European Union, 72% covered less than 1 km^2. Moreover, 81% had less than EUR 10 million in overall investment and the total budget was less than EUR 1 million for 44% (EIB, 2023[55]). Overall, the typical investment in NbS projects in the European Union is less than EUR 2 million per project and most projects are financed by multiple funding sources (EIB, 2023[55]).

To overcome the funding gap, more governments have recently started investing in NbS for climate-resilient infrastructure as part of standalone initiatives or overarching programmes. Between 2015 and 2018, Peru invested USD 300 million in 209 NbS as part of public investment projects through the *invierte.pe* programme. This aims to incentivise use of NbS as complements, safeguards or alternatives to grey infrastructure that build climate resilience (OECD, 2020[118]). In 2022, Germany dedicated EUR 4 billion to the Federal Action Plan on Nature-based Solutions for Climate and Biodiversity (BMUV, 2022[10]), part of which fosters synergies for boosting NbS for climate resilience. In the United States, the government allocated USD 8.7 billion to strengthen the climate resilience of transport systems, including through NbS. Meanwhile, it allocated USD 8.6 billion to restore and conserve coastal habitats, helping protect communities from storms (The White House, 2022[4]). In addition, the G20 Sustainable Finance working Group is working on increasing funding for NbS to strengthen climate resilience under the Brazilian Presidency of the G20 in 2020 (G20 Brasil 2024, 2024[119]). Despite these recent funding envelopes for NbS, further dedicated funding sources will be required to realise the full potential of NbS in enhancing the climate resilience of infrastructure.

Funding options

Several options can be used to fund NbS interventions (Chapter 3) (Table 4.2). These options can include sources from public funding, such as subsidies, taxes or tax reductions. They can also provide options for the private sector to partially or fully play a role in funding NbS through, for example, green bonds, loans or payments for ecosystem services (PES). Indeed, besides further increasing public funding for NbS, significant potential lies in scaling up private investments for funding NbS measures. Overall, private investments for NbS only make up around 17% of NbS funding. The remaining 83% are largely covered by public sources based on global estimates (UNEP, 2022[115]).

Private investments in NbS did start to grow recently. Between 2021 and 2022, for example, private financial flows for NbS increased by USD 2.3 billion (UNEP, 2022[115]). However, further potential could be tapped to scale up private finance for ensuring the climate resilience of infrastructure via NbS. A recent study covering close to 1 400 NbS projects in the European Union and the United Kingdom found only 3% of projects had private sector financing. This funding paid for over half of the overall project costs (EIB, 2023[55]).

Several vital measures could increase private finance. A portfolio of bankable NbS projects could be developed in co-ordination with relevant stakeholders. In addition, innovative financing mechanisms, such as blended finance, green bonds, PES or land value capture, could be harnessed (World Bank, 2022[120]; OECD, 2023[121]).

Table 4.2. Financing options for NbS to enhance climate resilience in the infrastructure sector

Option	Description	Example
Subsidies	Rebating the initial installation costs, subsidies are common ways to incentivise the installation of NbS for infrastructure.	Frankfurt, Hamburg and Stuttgart provide subsidies for green roofs, if minimum substrate depth of 8-12 cm is guaranteed. Subsidies on average for green roof installation across eight German cities are over 40 EUR/m^2.
Taxes	Special taxes or tax increments can be used to finance climate-resilient infrastructure projects.	A moderate annual parcel tax of USD 12 per parcel was levied (after approved by a ballot from residents) to finance restoration of wetlands in the San Francisco Bay area.
Tax reductions	Tax reductions (e.g. property tax reduction, stormwater fee discount, etc.) to encourage the use of NbS.	In Mexico City, property tax reductions of 10-25% are offered depending on the type of green roof installed. Hannover and Hamburg offer 50% and 70% reductions in stormwater fees, respectively, if owners adopt green roofs.
Green bonds	Green bonds are debt instruments that are exclusively used to finance projects providing environmental benefits. They can help rapidly raise funds for climate-resilient infrastructure investments from multiple investors and pay them back gradually.	The Netherlands issued nearly EUR 6 million in green bonds to finance the Room for the River project.
Insuring NbS	Natural assets (e.g. coral reefs, dunes, etc.) can be protected by parametric (event-based) insurance products.	As Hawaii's coral reefs protect communities from coastal risks, a parametric insurance product was set up to ensure funds for the reefs restoration in case wind speed rates exceed 57 mph.
Insurance discounts for risk reduction	The insurance sector can promote use of NbS by providing discounts on insurance premiums.	The United States Federal Emergency Management Agency's National Flood Insurance Program has a voluntary community rating scheme. Through this scheme, residents of communities that restore or conserve wetlands, green spaces or natural elements of the landscape that reduce flood risk receive a 5-45% discount on their flood insurance premiums.
Grants	Grants provided by governments or private donations can fund NbS projects with specific objectives, usually selected as a result of a competitive application process.	In the state of Massachusetts, coastal communities can apply to fund NbS under the Coastal Resilience Grant Program by the Massachusetts Office of Coastal Zone Management. Projects funded in 2023 included dune and salt marsh restoration works to enhance resilience to storms.
Loans	Loans can involve market-rate loans by private institutions, concessional loans by development finance banks, subnational or national governments, or subsidised loans.	The Natural Capital Financing Facility set up by the European Investment Bank and the European Commission in 2015 offered loans between EUR 1-15 million to finance NbS for public buildings (e.g. green roofs, rain garden), green and blue infrastructure until 2022. Similarly, in the United States, the Shore Up Connecticut Loan Program provided a low-interest loan of up to USD 300 000 to help homeowners in the state of Connecticut located in flood-hazard zones finance flood resilience retrofits. Borrowers must comply with certain resilience criteria to receive the loan (e.g. elevate homes one foot above the 500-year flood level).
Payments for ecosystem services (PES)	PES encompass diverse tools (e.g. sustainable forest management). These can be financed via direct public or private payments, as well as tax incentives (giving preferential tax rates to those providing ecosystem services) and other innovative ways.	To reduce sedimentation of the hydropower plant on the Reventazón River in Costa Rica and ensure biodiversity protection, farmers received PES. In return, farmers protected and reforested areas within the catchment and implemented specific agroforestry measures to help control erosion and harness environmental goals.

Source: (Adaptation Clearing House, 2013[122]; EIB, n.d.[123]; Green Finance Platform, n.d.[124]; Massachusetts Government, n.d.[125]).

4.4.4. Capacity to design, implement and maintain NbS

Despite the growing demand for NbS, skills gaps and capacity barriers remain a key obstacle for their use. Informing and enhancing capacity to design, implement and maintain NbS are therefore important to scale up use of NbS. Good practice databases, networking and capacity building platforms can help existing projects inspire new ones. Several EU-funded initiatives provide such platforms for NbS professionals, funded via the LIFE, Horizon 2020, Interreg and other funding instruments (OECD, 2023[13]) (Box 4.1). Many national governments complement these platforms by domestic initiatives. The Atlas of Natural Capital provides a repository of nature capital, including use of NbS for infrastructure solutions in the Netherlands (Atlas Natural Capital, n.d.[126]). In France, the Ministry of Ecological Transition and Territorial Cohesion has a website focusing on NbS, including case studies on climate-resilient infrastructure and NbS (Ministry of Ecological Transition, 2023[127]). Similarly, the Swedish Environment Protection Agency has a website gathering relevant information and tools to support NbS (and green infrastructure specifically) for climate-resilient infrastructure (Naturvårdsverket, n.d.[128]).

Box 4.1. EU-funded platforms facilitating NbS for climate-resilient infrastructure

The Urban Nature Atlas, developed through the Horizon 2020-funded Naturvation project, provides a repository of over 1 000 NbS projects in European cities and beyond, many of which address infrastructure challenges. The "analyse" function of the platform allows users to better understand NbS projects by comparing them (e.g. their economic, social and environmental impact, implementation focus, scale, finance, governance) (UNA, 2023[129]; UNA, 2023[130]). Similarly, the Horizon 2020-funded Nature4Cities project created a platform to share NbS projects, including those focusing on climate-resilient infrastructure. Besides the database of projects, the platform also provides a networking platform for NbS professionals to discuss common challenges with peers. In addition, it provides NbS experts and municipalities with tools relevant for project development (e.g. tools for EIA, socio-economic assessment, project selection, implementation models) (Nature4Cities, 2017[131]). For its part, Network Nature provides a knowledge repository of experience and tools from over 30 Horizon 2020 projects. It also channels the latest results from scientific research, as well as providing capacity building events and networking for professionals working with NbS (NetworkNature, 2023[132]). Furthermore, it is connected to the EU's OPPLA platform, which shares, obtains and creates knowledge and research on NbS, as well as acting as a networking platform for professionals working with NbS (OPPLA, 2023[133]). Climate-ADAPT of the European Environment Agency provides a platform of projects with an adaptation focus, including several detailed case studies that enhance infrastructure resilience (EEA, n.d.[134]). Focusing specifically on the water sector, the EU Directorate General Environment's Natural Water Retention Measures Platform provides a list of solutions, practical guidelines and case studies for developing nature-based green infrastructure.

Guidelines also play an important role in the implementation of NbS. In the United States, to facilitate scaling up of NbS, the federal government released the Nature-based Solutions Resource Guide as a compendium of 30 federal NbS examples. This includes several climate-resilient infrastructure projects, as well as other tools and guidance (The White House, 2022[135]). Similarly, the United States' National Oceanic and Atmospheric Administration (NOAA) published several guidelines for planning and implementing NbS for climate-resilient infrastructure. These included guidelines on CBA for assessing NbS against specific climate hazards, amending land-use codes and financing options (NOAA, n.d.[136]). In addition, the United States' Environment Protection Agency has guidelines to facilitate the planning, design, operation and maintenance of NbS for enhancing climate resilience in the infrastructure sector (EPA, 2023[137]). In Canada, the not-for-profit International Institute for Sustainable Development (IISD) hosts the Nature-Based Infrastructure Global Resource Centre. It provides examples of asset valuations of NbS project case studies to help make the business case for NbS benefits (NBI Global Resource Centre, n.d.[138]).

Professionals working with NbS in planning, design and implementation need the right knowledge to facilitate good outcomes for NbS projects. This is especially true because NbS management in infrastructure can require different skills than that of grey solutions. Such professionals include engineers planning NbS interventions, decision makers approving NbS projects, workers maintaining NbS on a day-to-day basis and others. NbS-specific knowledge includes understanding ecological and socio-economic environments, how NbS measures interact under different climate scenarios and the interaction of NbS with planned/existing grey infrastructure. For instance, pests may affect trees that are planted to protect watersheds from increasingly frequent heavy precipitation events. NbS may require alternative considerations compared to traditional risk and uncertainty assessments for grey solutions; alternative workforce skills and knowledge; and alternative actions to manage uncertainty effectively (Browder et al., 2019[139]), such as planting a mixture of tree species to make them less prone to pests than monoculture.

Recognising the information gap for professionals working with NbS, several countries and not-for-profit actors started to provide training and advice. To help local authorities, associations and other relevant actors enhance their knowledge on planning, designing and maintaining NbS, Germany's Ministry of Environment (BMUV) and Federal Agency for Nature Conservation (BfN) opened the Competence Centre for Nature-based Solutions (Kompetenzzentrum Natürlicher Klimaschutz, KNK) as part of the Action Programme on Nature-based Solutions for Climate and Biodiversity in 2023. It provides advice on NbS projects and funding opportunities, offers networking opportunities and organises training events on NbS (Kompetenzzentrum Natürlicher Klimaschutz, 2023[140]). The Nature-Based Infrastructure Global Resource Centre hosted by IISD in Canada offers free training courses for infrastructure planners, policy makers and investors on NbS for infrastructure (NBI Global Resource Centre, n.d.[138]). Meanwhile, NOAA in the United States offers several courses for coastal managers and planners to implement NbS to manage coastal climate risks (NOAA, 2023[141]). Providing training for a broader audience, the IUCN Academy offers courses on NbS that enable participants from all sectors to gain a Professional Certificate on NbS (IUCN, n.d.[142]). Providing training on NbS procurement and public private partnerships respectively, Germany's Competence Centre for Innovative Procurement and the Global Center on Adaptation also offer targeted courses (Mačiulytė and Durieux, 2020[143]; GCA, 2021[144]). Despite these efforts, however, several countries still lack targeted initiatives to scale up NbS (OECD, 2023[13]).

4.4.5. Monitoring and evaluation

Monitoring and evaluation (M&E) is key to ensure that NbS fulfil the functions for which they were built. As NbS involve working with dynamic ecosystems, they may not be able to deliver all intended project objectives. For example, pests may invade urban trees, which may erode their capacity to reduce extreme temperatures. Similarly, climate change may influence ecosystem processes in yet unknown ways, affecting the ability of NbS to deliver their risk reduction potential. If such negative inclinations are found during M&E processes, further steps in the maintenance phases are needed to deliver NbS interventions (Somarakis, Stagakis and Chrysoulakis, 2019[96]). It is thus crucial to develop an appropriate set of indicators that compare the outcomes of NbS projects to previous long-term trends at regular intervals based on indicators (Somarakis, Stagakis and Chrysoulakis, 2019[96]). M&E findings should then inform the adjustment of design or maintenance of NbS.

The selection of indicators for monitoring NbS projects depends on the specific aims of the project, including selection of appropriate monitoring timeframes (Kumar et al., 2021[145]). Overall, NbS indicators can be classified into i) process indicators (actions implemented compared to those planned, e.g. the number of seedlings planted); and ii) result indicators (assessing the outcomes achieved by the project compared to a baseline, e.g. change in the number of bird populations) (IISD, 2023[146]). Ensuring that indicators are monitored for appropriate timeframes is also central for the success of monitoring efforts. Long enough timeframes for monitoring are not only key to the resilience of project outputs but are also central for the appropriate maintenance of NbS projects over their lifetime (Section 4.4.2).

Existing practices in monitoring NbS

While historically several NbS projects lacked appropriate monitoring, some recent projects have started to develop indicators that can track resilience. For example, following completion of the Nosy Hara marine protected area rehabilitation in Madagascar, several indicators are monitored. These concern, among others, the resilience of the coral reefs (e.g. occurrence of coral diseases, fishing pressure, nutrient pollution, temperature variability) and increases in the number of species, coral growth (IISD, 2023[146]).

Thanks to Earth observation programmes and satellite monitoring techniques, ever expanding spatial resolutions and temporal scales have become available for long-term monitoring of NbS projects (Somarakis, Stagakis and Chrysoulakis, 2019[96]; Chrysoulakis et al., 2021[147]). These are often combined with *in situ* measurements on site (e.g. the monitoring of urban temperatures, particulate matter, species diversity). Such measures offer complementary data to provide a comprehensive picture on the performance of NbS (Somarakis, Stagakis and Chrysoulakis, 2019[96]). In Valladolid, Spain, a 350 m^2 green façade was constructed on the El Corte Inglés shopping centre to reduce urban temperatures while improving air quality and building aesthetics. *In situ* techniques measure mean and peak daytime temperatures, as well as concentrations of nitrogen oxides and particulate matter concentrations (European Commission, 2021[148]).

Following the development of indicators and the availability of datasets, monitoring approaches can become increasingly comprehensive, encompassing the different stages of the project's lifecycle. In Norway, a green flood barrier was constructed in the Lillehammer municipality to reduce flood risk due to snowmelt and extreme precipitation in the Gudbrandsdalen Valley. It ensures the new barrier – which replaced the old artificial barrier with natural materials – allows more space for the river. In all, 47 indicators were developed in five areas to monitor the project. These comprise i) risk reduction (e.g. peak flow volume, extent of the flooded area, exposed residential areas); ii) technical and feasibility aspects; iii) environment and ecosystem (e.g. chemical water parameters, diversity in species); iv) effects on the society (e.g. number of visitors, the number of new pedestrian and cycle paths); and v) effects on local economy (e.g. number of jobs created) (European Commission, 2021[148]).

Another example is the indicator repository developed by Gonzalez-Ollauri et al. (2021[149]). They established over 40 indicators to assess NbS effectiveness in limiting risk of landslides and erosion. Their overarching "Rocket Framework", which can be applied to different climate risks, enables the assessment of wider ecosystem functions and services. The NbS key performance indicators are categorised into a socio-ecological and an eco-engineering domain. The first represents economic impacts (e.g. income generation), as well as ecosystem services and co-benefits (e.g. accessibility of green spaces, recreation activities) brought about by implemented NbS. The latter refers to provision of tangible functions seeking to manage or mitigate the climate hazard (e.g. soil mass movement and deformation, and land exposure).

4.5. Conclusions

Overall, NbS have significant potential to achieve climate resilience in the infrastructure sector. While NbS cannot be a panacea for all future issues related to climate impacts, they have an important role in strengthening resilience. As the chapter demonstrated, NbS are gaining increased attention in national and international policy agendas, with a growing number of funding streams and capacity building tools mobilised to promote their use. However, the use of NbS still remains limited compared to their potential in resilience building. This calls for policy and institutional frameworks to encourage the use of NbS considering their specificities. Similarly, the design, appraisal, procurement and selection phases of infrastructure projects, including adjusting valuation approaches, should ensure the benefits of NbS are considered appropriately. Overcoming the finance barriers for NbS projects is also an important milestone for strengthening use of NbS for climate-resilient infrastructure. Despite recent funding boosts in some countries, investments in NbS face a significant gap. This forces stakeholders to navigate scattered funding sources across a patchwork of options. Ensuring enhanced public funding for NbS, combined with appropriate incentives for the private sector to invest in NbS, is thus a key step for scaling up NbS for climate-resilient infrastructure. In parallel, it is also important to enhance the capacity to design, implement and maintain NbS. Finally, strengthening M&E of NbS helps ensure adaptative management is based on dynamic ecosystem needs and changing climate scenarios. This plays a key role in guaranteeing that NbS delivers the functions for which they were implemented.

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Notes

[1] The estimate does not count buildings unlike the Thacker et al. (2021[3]) study.

[2] The survey was conducted by the Prime Minister's Office, Hungary in 2021 with 48 subnational governments responding to it (OECD, 2023[13]).

[3] GI is defined in the Strategy as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas" (European Commission, 2013[78]).

5 Making infrastructure climate resilient in developing countries

As climate change accelerates, developing countries face heightened risks of extreme weather events, sea level increases and other natural disasters. This chapter delves into the imperative of making infrastructure climate resilient in the context of developing countries. Presenting perspectives from Africa, Asia and Latin America, and focusing on competitiveness-related infrastructure, the chapter clarifies the specific needs and challenges of these economies. From energy infrastructure to transportation and digital networks, this chapter underscores the need to improve planning and implementation capacities, as well as to update international partnerships to foster climate-resilient infrastructure for sustainable development.

Key policy insights

- Developing countries are among the most vulnerable to the adverse impacts of climate change.
- Developing countries differ deeply in terms of infrastructure gaps, developmental aspirations and vulnerability to climate change and natural disasters.
- Some developing countries are particularly vulnerable and exposed to growing climate-related risks, notably Least Developed Countries and Small Island Developing States.
- For developing countries, the imperative of climate-resilient infrastructure goes hand in hand with the need to close infrastructure gaps to sustain their industrialisation aspirations. This requires updating planning processes to ensure policy coherence and the integration of climate-resilience considerations across the spectrum of government policies – from infrastructure and innovation to trade, industry and investment policies.
- Addressing social equity and inclusion is also paramount when planning climate-resilient infrastructure in developing countries. In these countries, even more than in advanced economies, vulnerable and marginalised communities often bear the brunt of climate impacts. They are disproportionately affected by inadequate infrastructure, hampering their economic inclusion prospects and perpetuating poverty cycles.
- Making infrastructure climate resilient in developing countries calls for a "mindset shift" in domestic and international policies. Domestically, it requires identifying the hidden opportunities for local innovation arising from changing infrastructure design to address the specific needs of given locations, to participating actively in international forums to help develop emerging standards. Internationally, it requires defining new partnerships where developing countries are both emerging markets for investment and key partners to co-develop climate-resilient solutions for sustainable development.
- Three areas stand out as critical for renewed forms of partnership between advanced and developing countries. These can ensure infrastructure is planned, built and operated in a forward-looking way in developing countries:
    - knowledge sharing and technical assistance in private and public sector capabilities, including on co-operation and co-ordination mechanisms; and updating of legal frameworks and development of prevention capacities, especially through enhanced tools and institutional capacities for risk and impact assessment
    - partnerships for research and development, deployment of technologies and tailored business solutions for climate-resilient infrastructure
    - increased investment and financing, and enhanced mobilisation of multilateral development banks and development finance institutions that also go beyond direct financing into areas such as project preparation support, screening and due diligence, financing and signalling, and de-risking of private sector investment.

5.1. Introduction

As the impacts of climate change intensify, the need for climate-resilient infrastructure has emerged as a critical priority (see Chapter 1). The escalating frequency and severity of climate-related events, such as extreme storms, floods, droughts and heatwaves, are placing unprecedented strain on infrastructure systems, including in transportation, energy, water and telecommunications. These infrastructures and their effective functioning are key for sustainable development. Making them climate resilient is therefore a shared priority for countries at all levels of economic development.

The imperative for climate-resilient infrastructure in developing countries is underscored by the disproportionate impact of climate change on these nations. These countries contribute the least to global greenhouse gas (GHG) emissions in per capita terms. Yet they often bear the brunt of climate-related disasters due to their geographical location, limited adaptive capacity and socio-economic vulnerabilities. Developing countries face unique challenges in adapting to the growing challenges posed by the climate crisis due to limited resources and inadequate infrastructure. In addition, the lack of resilient infrastructure hampers efforts to achieve the Sustainable Development Goals, perpetuating cycles of poverty and inequality.

Addressing these challenges necessitates a multifaceted approach that integrates climate resilience into infrastructure planning, design and implementation processes. Developing countries, in particular, must take proactive steps to update their national and local policies, business practices and social awareness.

Governments in developing countries must prioritise climate-resilient infrastructure in national and local development policies and strategies, integrating climate risk assessments, adaptation measures and community engagement into decision-making processes. Additionally, they need substantial support from the international community to enhance capacities to plan, finance, build and operate climate-resilient infrastructure. Investments, international partnerships, including financial assistance, technology transfer and capacity building, are indispensable.

This chapter focuses on the challenges, needs and aspirations of developing countries when it comes to climate-resilient infrastructure. In line with OECD good practices, it recognises the pressing need for strategic planning, project preparation, risk assessment and resilient construction practices, as well as maintenance and operational excellence. It identifies key areas for strengthened international co-operation and partnerships to ensure that developing countries build climate-resilient infrastructure that can sustain economic development and industrialisation. The chapter recognises that developing countries are not monolithic; each has distinct needs. Some, including Least Developed Countries (LDCs) and Small Island Developing States (SIDS), are particularly at risk and in need of international support.

This chapter has three sections. First, it briefly discusses the growing impact of climate change and natural disasters in developing countries. Second, it focuses on specific challenges of developing countries to make infrastructure resilient in the face of climate change and natural disasters. Third, it examines local, national and international policy responses.

5.2. Climate change is taking a high toll on developing countries

Climate change is having increasingly severe impacts globally, and it disproportionately affects developing countries. More extreme weather events, such as hurricanes, floods and droughts, are taking place. Regardless of the different ways to measure economic impact, the toll of these events on developing countries is profound (see also Chapter 1). Globally, the number of reported natural disasters more than doubled during 2000-19 compared with the previous decade, with developing nations bearing a disproportionate burden (UNDRR, 2020[1]). The economic loss attributed to geophysical-, climate- and weather-related disasters is estimated to have averaged globally USD 170 billion per year over the past decade (UNDRR, 2022[2]).

Although developing countries contribute the least to global warming in per capita terms, they are the most vulnerable to climate change. Climate change is exacerbating the frequency and severity of natural disasters in developing countries. This amplifies existing vulnerabilities and increases the risk of disaster-related impacts.

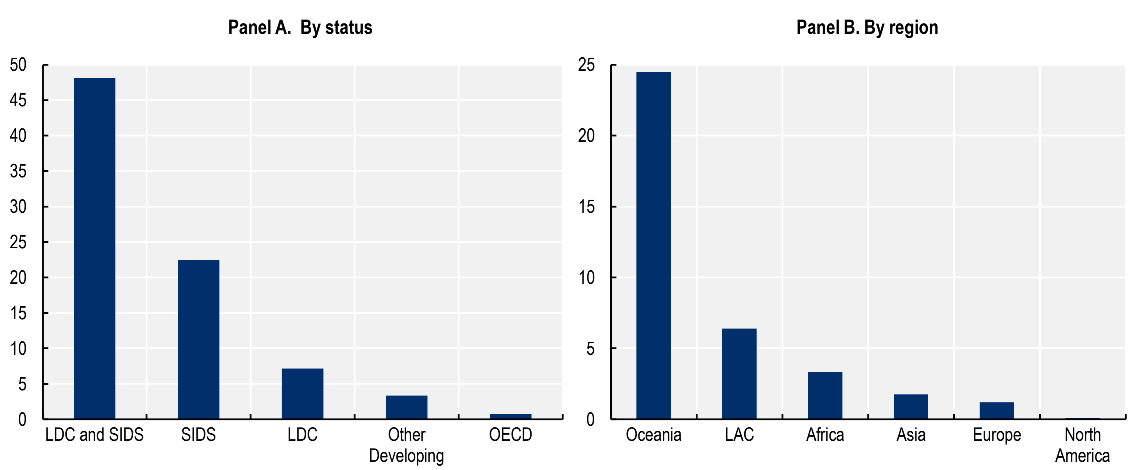
Rising temperatures, changing precipitation patterns and rising sea levels contribute to more intense and frequent extreme weather events, such as storms, floods and droughts. Such events disproportionately affect developing countries. About 3.3-3.6 billion people live in regions with considerable development constraints and high vulnerability to climate change risks (IPCC, 2023[3]).

Climate resilience and resilience to natural disasters are closely connected in the case of developing countries due to several factors that exacerbate these countries' vulnerabilities:

- **Geographical vulnerability**: Many developing countries are located in regions prone to climate-related hazards. Coastal areas, for example, are susceptible to hurricanes and typhoons. Other areas are also prone to floods, droughts, hurricanes and heatwaves. All these events are exacerbated by climate change. Among developing countries, SIDS and LDCs are those most severely affected by climate change and natural disasters. Between 2000 and 2020, SIDS and LDCs had an average of 23 and 7 natural disasters per 1 000 square kilometres, respectively (Figure 5.1, panel A). This translates to between 10 and 30 times more disasters than experienced in OECD countries. Additionally, countries that are both SIDS and LDCs, such as Haiti and Solomon Islands, are even more affected as they tend to be geographically situated in disaster-prone regions (Figure 5.1, panel B). Other measures of vulnerability yield similar results. When it comes to floods, for instance, Bangladesh and Viet Nam have the highest shares of their population exposed to flooding – 58% and 46%, respectively (Figure 5.2) and (Box 5.1).

Figure 5.1. SIDS and LDCs have the highest global exposure to natural disasters

Average number of natural disasters per 1 000 square kilometres, 2000-20

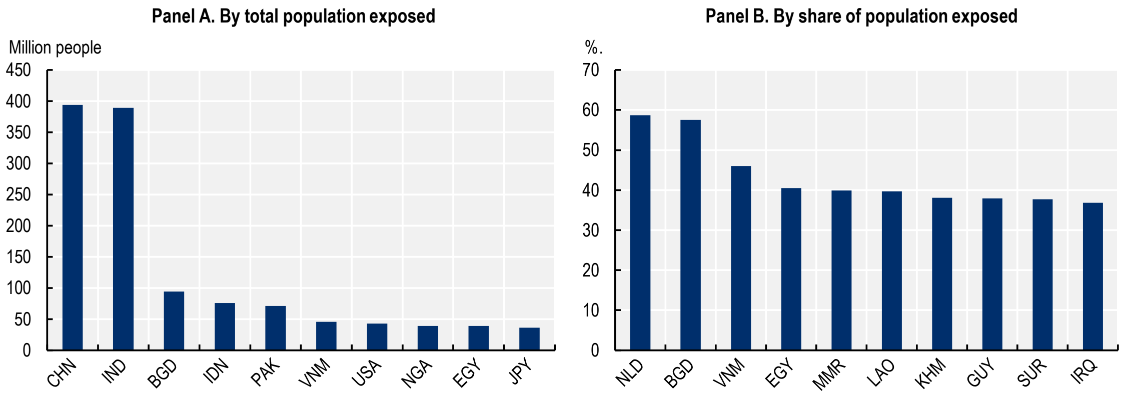


Note: In Panel A, the categories are not mutually exclusive. "Other developing countries" include all DAC recipient countries that are non-LDC including low-middle income and upper-middle income countries. Analysis follows the UN Geographical and Income Classification System https://unstats.un.org/unsd/methodology/m49/.

Source: Based on EM-DAT (2023[4]), International Disaster Database, www.emdat.be/; World Bank (2023[5]), World Development Indicators, https://data.worldbank.org; OECD (2024[6]), *Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters*, OECD Publishing, Paris.

Figure 5.2. Developing countries are particularly exposed to floods

Top ten countries with highest exposure to floods, by total population exposed and by share of exposed population to total, 2020



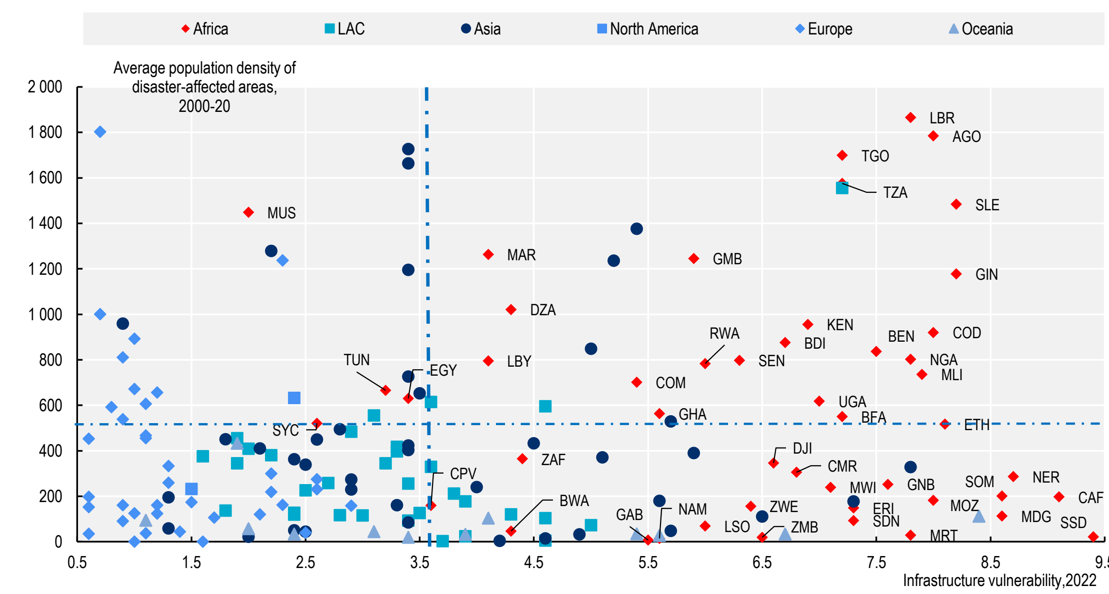
Note: People directly exposed to inundation depths of over 0.15 metres in the event of a 1-in-100-year flood. It considers people's exposure to all current flood risks i.e. pluvial, fluvial and coastal flooding.
Source: Based on Rentschler, Salhab and Jafino (2022[7]), Flood exposure and poverty in 188 countries, https://doi.org/10.1038/s41467-022-30727-4; OECD (2024[6]), *Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters,* OECD Publishing, Paris.

- **Economic vulnerability**: Economic losses caused by climate change tend to be higher in high-income countries in absolute values. However, losses in lower-income countries are greater relative to their gross domestic product (GDP), with SIDS and LDCs the most affected within the developing world. Estimates show that high- and upper- middle-income countries lose between 0.1% and 0.3% of their annual national GDP due to climate change and natural disasters. However, low and lower middle-income countries lose on average between 0.8% and 1% of their national GDP to disasters per year (UNDRR, 2022[2]). SIDS represent two-thirds of the countries that suffer the highest relative negative impact of climate change on GDP. They are estimated to lose between 1-9% of their GDP per year due to climate change and natural disasters (OECD, 2023[8]).
- **Dependency on climate-sensitive sectors: Most** developing countries rely heavily on climate-sensitive sectors such as agriculture, fisheries, forestry and tourism for livelihoods and economic development. Natural disasters, exacerbated by climate change, can devastate these sectors, leading to food insecurity, loss of income and economic instability. Consequently, the impacts of climate change pose significant threats to the livelihoods, well-being and economic development prospects of populations in developing countries. For instance, Hurricane Irma in 2017, the strongest hurricane recorded in the Caribbean to date, affected more than 1.2 million people in the region. It resulted in substantial economic losses, including the collapse of 80% of agricultural production in Haiti and neighbouring countries and territories (OECD, 2023[9]; 2023[10]). Some countries are advancing in increasing their planning and prevention capacities in the face of such disasters. Saint Lucia, for example, is a Caribbean island highly exposed to climate change and strongly dependent on tourism. It has improved its national policy for infrastructure resilience to climate change by setting up a National Integrated Planning and Programme Unit to elaborate the infrastructure agenda. The Unit oversees a comprehensive national infrastructure assessment that considers economic, environmental and social needs, as well as the potential impact of new infrastructure plans on the Paris Agreement targets (OECD, 2023[11]).
- **Limited access to climate information and early warning systems, and poor infrastructure:** Most developing countries lack access to timely and accurate climate information and early warning

systems (EWS), hindering their ability to prepare for and respond to natural disasters. They also have inadequate infrastructure and limited institutional capacity to address risks up-front and react to disasters. The high population density of the areas most affected by natural disasters induced by climate change further impedes effective disaster risk management and climate resilience efforts. This is particularly relevant in Africa where infrastructure is twice as vulnerable on average as it is in Latin America and in Asia, and five times as vulnerable as it is in Europe. This magnifies the social and economic impact of natural disasters in these areas (Figure 5.3).

Figure 5.3. Africa's weak infrastructure increases its vulnerability to climate change and natural disasters compared to other world regions

Average population density of natural disasters most affected areas and infrastructure vulnerability, 2000-20



Note: The dotted lines reflect the global averages of the respective variables. The average population density is calculated within a 1 km radius of the disaster event. Infrastructure vulnerability is the normalised arithmetic average of three categories that give equal weight to 11 indicators. These include access to electricity, Internet users, adult literacy, road density, access to water sources, access to health facilities, health expenditure per capita and population density. It takes a value of 1 to 10, with 10 as the most vulnerable.

Source: OECD/UN/UNIDO/ITC (forthcoming[12]), *Production Transformation Policy Review of Togo*, based on INFORM GRI 2022: Index for Risk Management; European Commission (2022), https://drmkc.jrc.ec.europa.eu/inform-index and SEDAC Gridded Population of the World, Version 4 (GPWv4), https://cmr.earthdata.nasa.gov/search/concepts/C1597158029-SEDAC.html.

Building resilience to climate change is crucial to ensure sustainable development pathways for developing countries. The pursuit of industrialisation and economic growth in these countries is driving growing demands and plans for infrastructure development, especially to support trade and production. Therefore, these new infrastructure investments must be planned, built and operated in a forward-looking and climate-resilient way. In addition, as these economies strive to achieve development, pursue growth and improve living standards, they tend to rely on energy-intensive industries that contribute to GHG emissions. This, in turn, aggravates their exposure to climate change. Therefore, investing in mitigation and adaptation measures to enhance resilience is critical both for climate risk management and sustainable industrialisation.

Box 5.1. Bangladesh needs to reduce its climate change vulnerability to sustain economic progress

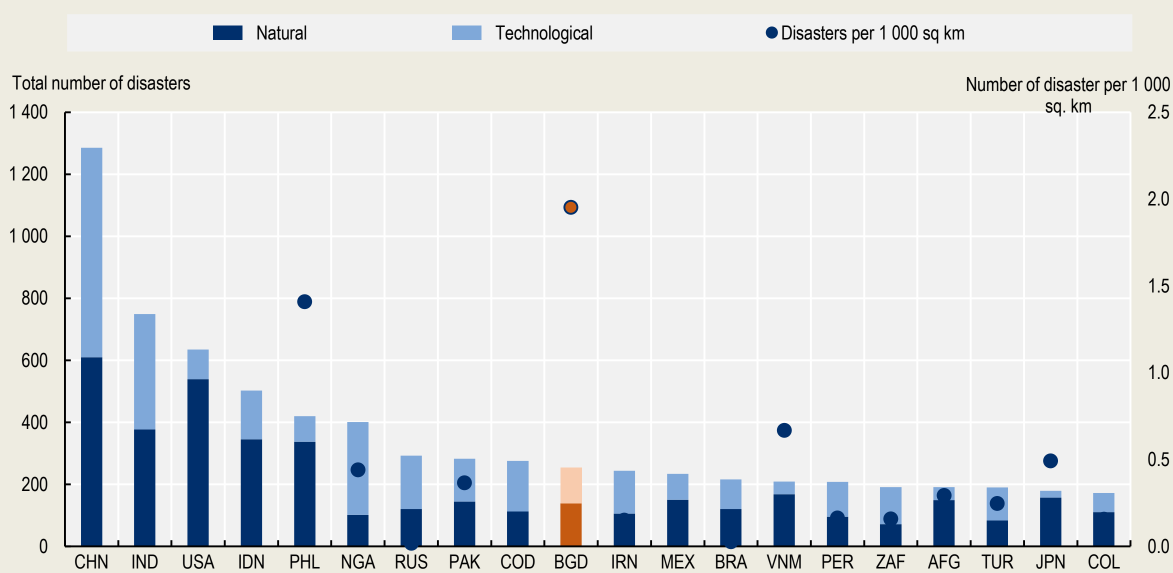
Bangladesh, the biggest graduating LDC, is one of the countries most affected by natural disasters (Figure 5.4). Over 50% of Bangladesh's land is less than 6 metres above sea level, and approximately 80% of its population is exposed to risks from extreme weather.

The high and increasing climate vulnerability of Bangladesh is exacerbated by rapid urbanisation, high population density and gaps in infrastructure, which compound with industrial and technological hazards. This leads to substantial economic losses in sectors like agriculture, logistics and manufacturing. Floods, driven by storms and heavy rainfall, frequently disrupt energy supplies, even with flood protection structures in place at thermal power plants. At the same time, they affect domestic agricultural production, while disrupting transport and logistics. The vulnerability to natural disasters increases business uncertainty and trade unpredictability, increasing the costs of investing and doing business in Bangladesh.

Easing vulnerability to climate change and natural disasters in Bangladesh is a human and an economic imperative that requires urgent attention to sustain future progress. To minimise the impact of climate change and consequent natural disasters on industrial development, Bangladesh needs to increase its prevention, reaction and re-building capacities. International partnerships are key in this respect. Bangladesh benefits from support from the International Monetary Fund under the Resilience and Sustainability Facility, Extended Fund Facility and Extended Credit Facility. These programmes address both immediate challenges, such as current account imbalances and reserve losses, and long-term structural concerns, including targeted domestic reforms to tackle climate vulnerability.

Figure 5.4. Bangladesh is among the most exposed countries to natural disasters in the world

Top 20 exposed countries and number of disasters 1 000 square kilometres (sq. km), 2000-21



Source: OECD/UNCTAD (2023[13]), Production Transformation Policy Review of Bangladesh: Investing in the Future of a Trading Nation, https://doi.org/10.1787/8b925b06-en.

5.3. Developing countries need to close infrastructure gaps through the lens of climate resilience

Developing countries face significant infrastructure gaps in a range of sectors – from transport to energy, water and digital infrastructure. The gaps hinder their development prospects, international competitiveness and domestic industrialisation efforts. Closing these gaps is essential to unlock their economic potential, foster social inclusion and achieve sustainable development.

This chapter focuses on building climate resilience in competitiveness-related infrastructure (e.g. transport and digital networks, energy systems). Climate resilience plays a pivotal role in development strategies and in shaping the economic attractiveness and potential of a given location in national, regional and international markets. In addition, developing countries face growing pressures to build infrastructure assets to meet their industrialisation and job-rich development strategies. This calls for increased attention to ensure this new infrastructure is built in a forward-looking way. It must be able to withstand and minimise the impacts and risks associated with climate change and the growing frequency and impact of extreme weather events and natural disasters (Box 5.2).

Box 5.2. What is meant by competitiveness-related infrastructure?

Competitiveness-related infrastructure refers to assets, facilities and systems that have a direct effect on the economic performance and competitive capabilities of a given location. It includes transportation networks (roads, ports, airports, railways), energy facilities (power plants, grids), telecommunication networks and data centres.

Source: OECD (2024[6]), *Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters*.

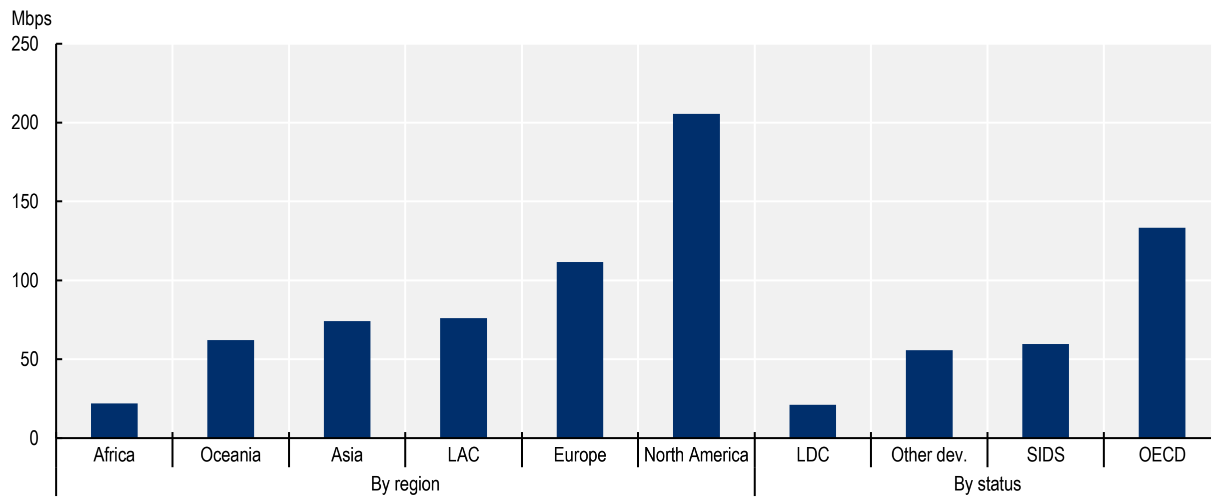
5.3.1. Significant gaps persist in competitiveness-related infrastructure in developing countries

Developing countries lag in terms of quality, coverage and access to digital infrastructure. In these countries, people and businesses suffer from lower speeds and relatively more unstable connections. For instance, Internet speed (fixed broadband) in Africa is nine times slower than in North America, which has the highest average speed of any region (Figure 5.5). Disparities are also profound between developing countries. Within Africa, Egypt has the fastest Internet; as of December 2023, its speed is 13 times faster than in Niger, which has the slowest Internet in the continent. It would take, for instance, 11 minutes to download a 5 gigabyte file in Egypt, versus 2.5 hours in Niger, and only 2 minutes in Chile, the country in the OECD with the fastest Internet (OECD, 2023[14]).

Developing countries continue to lag both in density and quality of transport infrastructure. Their needs for up-to-date and climate-resilient transport infrastructure are increasing. Population growth, urbanisation and the growth of logistics-intensive industries, including e-commerce, are increasing the need for inclusive, efficient and modernised transport infrastructure and logistics.

Adequate transport infrastructure, such as roads, ports and railways, improves connectivity within and between regions, facilitating the movement of goods, services and people. For example, the Mombasa-Nairobi Standard Gauge Railway in Kenya has enhanced connectivity between the port city of Mombasa and the capital of Nairobi, reducing transportation costs and facilitating trade. The expansion of port facilities in Viet Nam and Bangladesh has increased their capacity to handle international trade, supporting export-oriented industries and economic development.

Figure 5.5. Broadband Internet speed, by region and income status, 2023



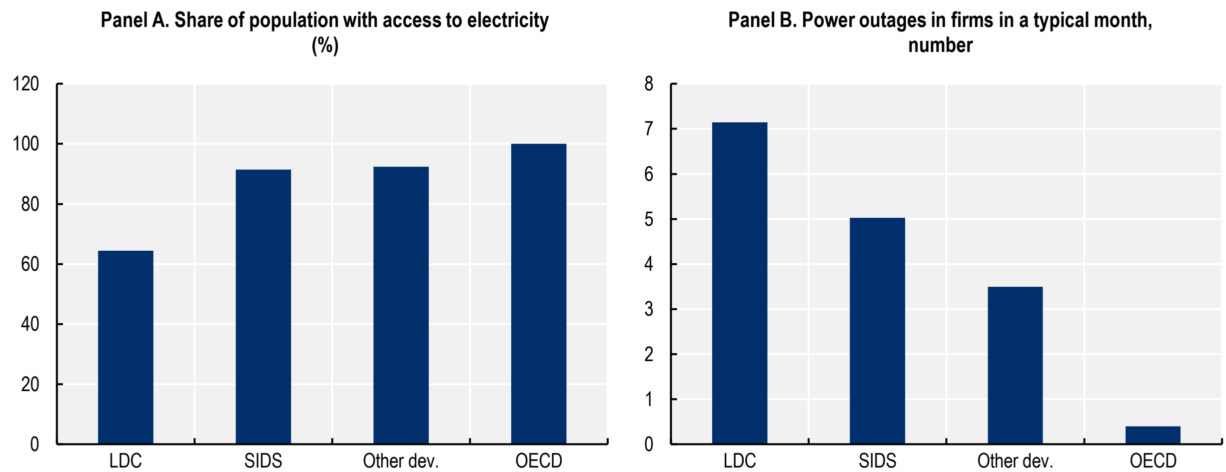
Note: As of December 2023. Data refer to fixed broadband.
Source: Based on Ookla (2023[15]), www.speedtest.net/global-index; adapted from OECD (2024[16]), *Start-up Asia: Chasing the Innovation Frontier*, OECD Publishing, Paris.

Since developing countries are highly exposed to climate risks, they need to build climate resilience into their infrastructure. Despite some progress towards this goal, major gaps persist. For example, only 22% of rail lines were electrified in Africa (based on six countries: Morocco, South Africa, Democratic Republic of Congo, Algeria, Zimbabwe and Tunisia). By contrast, 65% and 56% of rail lines are electrified in Asia and Europe, respectively. In Latin America and the Caribbean, data are only available for Chile (39%) and Argentina (2%) (International Union of Railways, 2023[17]).

Moreover, infrastructure is increasingly needed in new areas to satisfy emerging demand. Mega-regional trade agreements have been signed, including the African Continental Free Trade Area (AfCFTA), the Regional Comprehensive Economic Partnership and the Comprehensive and Progressive Trans-Pacific Partnership. These agreements will shift the geography of supply chains. These changes, coupled by emerging geopolitical concerns such as the ongoing quest for critical minerals, are driving the growing need for infrastructure in new locations.

Developing countries also suffer from major energy infrastructure gaps. For instance, 36% of people on average in LDCs did not have access to electricity in 2021. Even when electricity is accessible, it is unreliable and unstable. For instance, power outages are much more common in developing countries, which has a major impact on industrial competitiveness. On average, firms in OECD member countries experience less than one power outage in a typical month. By contrast, the numbers of such outages are 7.1 in LDCs, 5 in SIDS and 3.5 in other developing countries. Developing renewable energy infrastructure can open significant opportunities for climate resilience, industrialisation and green growth in developing countries (Box 5.3).

Figure 5.6. On average, 36% of people in LDCs do not have access to electricity, 2021



Source: Adapted OECD/UN/UNIDO/ITC (forthcoming[12]), *Production Transformation Policy Review of Togo*, based on World Bank (2023[5]), World Development Indicators, https://data.worldbank.org/indicator.

Box 5.3. AfCFTA could be a game changer for innovative, renewable and climate-resilient energy infrastructure in Africa

Africa has some of the highest potential in renewables, which it could leverage to complement its energy resources. This could, in turn, become a springboard to develop industrial and innovation activities around renewables. In solar, for instance, Africa holds an estimated 60% of the world's best resources but only 1% of installed photovoltaic capacity (IEA, 2022[18]). AfCFTA could be a game changer in this respect, provided it is matched with industrial strategies, large fiscal mobilisation and cross-border co-operation on standards.

AfCFTA increases the market for energy. So far, countries in Africa have been mostly trading electricity bilaterally. The five African Power Pools have varying levels of integration and have been hampered by a lack of infrastructure, along with regulatory mismatches and gaps (Odetayo and Walsh, 2021[19]). Other regional initiatives, such as the launch of the African Single Electricity Market in 2021, are also expected to build on the momentum of AfCFTA to create an operational continental electricity market.

AfCFTA has no special provisions for green goods. However, its Investment Protocol refers to fostering investment aligned with sustainable development, including mitigating and adapting to climate change.. Such provisions would complement the improved trade and better investment climate in the continent expected from the agreement. Ultimately, AfCFTA could help link industrialisation and the greening of the energy matrix. In this way, it could prove to be a lever for renewables.

African countries will need to take three key actions to take advantage of opportunities from AfCFTA:

- **Mobilise investments and link industrial strategies to the green transition**. Large initiatives are needed that go beyond pilot and microgrid projects to stimulate demand and generate, in turn, the energy needed for green industrialisation on the continent. IEA (2022[18]) estimates that annual energy investments in Africa will need to double from their current levels to nearly USD 192 billion annually to meet the continent's energy goals.

- **Advance on quality systems and certification for renewables**. For example, certification for green hydrogen is at an early stage and mostly led by large consumer markets. Ensuring that African countries have a voice in the definition of such standards is critical. To that end, they must update their metrology and conformity assessment infrastructures to meet these standards.
- **Consider including green industrialisation to the AfCFTA agreement protocols in negotiations**, such as those related to services (Asafu-Adjaye et al., 2021[20]).

Source: OECD (2023[14]), Production Transformation Policy Review of Egypt: Spotlight on the AfCFTA and Industrialisation, https://doi.org/10.1787/3ac95e0c-en.

Competitiveness-related infrastructure, including transportation networks, energy systems and water supply, are highly vulnerable to climate-related hazards, such as flooding, sea level rise and extreme weather events. The susceptibility of infrastructure assets to climate-related risks poses significant challenges to sustainable industrialisation and development. Their disruption compounds the challenges faced by developing nations, limiting their capacity to sustain economic competitiveness and growth. These challenges are compounded by the major human and social costs caused by the damage of infrastructure assets. By investing in climate resilience, these nations can mitigate the adverse impacts of climate change and promote sustainable industrialisation.

5.3.2. Addressing infrastructure gaps and ensuring climate resilience in infrastructure are twinned goals for developing countries

Tackling the two objectives simultaneously will allow developing countries to accelerate progress towards sustainable development and improve their competitiveness and capacity to capture value from the global marketplace. Existing infrastructure needs to be improved to ensure climate resilience. Meanwhile, new infrastructure needs to be built in a forward-looking way considering its climate resilience, as well as its capacity to mitigate climate change. Integrating climate resilience considerations into infrastructure planning, design, construction and operation in developing countries, as well as in advanced nations, is essential to ensure the longevity and effectiveness of infrastructure investments (see Chapter 2).

Moreover, resilient infrastructure can enhance the adaptive capacity of communities, facilitate economic resilience and reduce the socio-economic costs of climate-related disasters. In so doing, it can help reduce the persistent inequalities in developing countries. Enhancing the climate resilience of infrastructure will also reduce dependency on costly post-disaster recovery and reconstruction efforts, freeing up resources for long-term development priorities. This last consideration is of particular importance for developing countries that struggle to access finance and mobilise resources.

Integrating climate resilience into infrastructure development strategies in developing countries is a key component of sustainable development and forward-looking industrialisation strategies. It contributes to achieving critical objectives, including the following:

- **Supporting economic stability**, by reducing the risk of infrastructure damage and disruptions from extreme weather events. This stability is crucial for attracting long-term investment and fostering sustained economic growth. Investors are more likely to commit resources to countries with resilient infrastructure that can withstand climate shocks, ensuring the continuity of operations and returns on investment.
- **Safeguarding critical assets and services**, such as transportation networks, energy systems, water supply and telecommunications. For example, reinforcing coastal infrastructure, such as seawalls and flood barriers, protects ports and transportation routes from rising sea levels and storm surges, ensuring the uninterrupted flow of goods and services.

- **Minimising life-cycle costs** by reducing the need for frequent repairs and emergency maintenance due to climate-related damages. By investing up-front in resilient design and construction techniques, developing countries can avoid costly retrofitting and reconstruction.
- **Reducing the risk premium**. Insurance companies and risk assessors increasingly consider the resilience of infrastructure assets when underwriting policies and assessing risk exposure. By investing in climate-resilient infrastructure, developing countries can reduce insurance premiums and financial liabilities associated with climate-related risks.
- **Fostering innovation and technological development**. Prioritising resilience to climate change in infrastructure drives the development of new materials, design approaches and construction techniques that enhance resilience. This fosters a culture of innovation and entrepreneurship, creating opportunities for the growth of local industries and adoption of cutting-edge technologies in infrastructure development. Climate-resilient infrastructure also preserves ecosystems as wetlands, forests and natural waterways by integrating Nature-based Solutions into infrastructure design, including green roofs, permeable pavements and natural drainage systems. In this way, it fosters bioeconomy development and generation of sustainable economic value from natural assets (see Chapter 4).
- **Increasing integration and partnerships with global markets**. Adhering to international standards, regulations and agreements to address climate change and promote sustainable development enhances credibility and reputation on the global stage. This, in turn, supports access to international financing, partnerships and co-operation.

5.4. Updated national policies and international partnerships will be key to ensure progress

The infrastructure gaps outlined in the previous section are not new. Developing countries have long suffered from historical underinvestment and poor infrastructure development. However, it is becoming more urgent for them to close these gaps or risk falling further behind. Developing countries are increasingly exposed and vulnerable to climate change and natural disasters. Their aspirations for industrialisation compel them to boost infrastructure investment and ensure climate resilience. Indeed, advanced countries are prioritising modernisation and upgrading of infrastructure. By prioritising climate resilience, they are preparing for the green and digital economy. Yet their actions risk perpetuating gaps between advanced and developing countries. To avoid falling further behind, developing countries need to mobilise adequate investments.

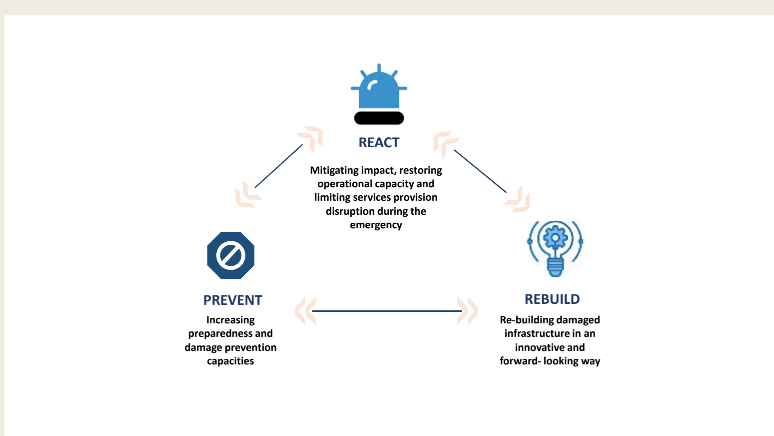
Investments in infrastructure in developing countries also support the global economy. Major infrastructure gaps in developing countries directly influence global economic performance through their impact on supply chain security, resilience and stability. This means infrastructure upgrading in developing countries also benefits advanced economies.

Box 5.4. Guiding policy actions to make infrastructure resilient to natural disasters: A three-pillar framework

The *Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters* presents actionable principles to ensure infrastructure resilience to natural disasters. It draws from global good practices and in-depth analyses of infrastructure projects in Colombia, Ghana, India, Indonesia, Japan, Mozambique and the United States. It presents a three-pillar framework to guide policy actions and foster implementation of the G20 Principles for Quality Infrastructure Investment (G20, 2019[21]). Three distinctive and interconnected areas state the importance of developing national and local government capacities:

- **Preventing**: This area is linked to actions, tools and physical characteristics of the infrastructure that enable damage prevention and/or minimisation. This includes cost-benefit analysis, disaster risk assessments from the early stage, disaster risk management, early warning systems, social safety nets and strategic preventive maintenance, as well as structural measures and new designs such as construction of levees for flooding.
- **Reacting**: This area is linked to the actions taken and tools used in response to a natural disaster to restore operational capacity and mitigate service provision disruption. It provides short-term countermeasures such as alternative infrastructure options and services. This also includes regulatory and economic instruments that help implement disaster risk management in a timely manner. Access to emergency finance, for example, can support swift recovery of social and economic functions and services. This could minimise the severity and duration of disruption.
- **Re-building**: This area is linked to actions, tools and plans, including changes in the physical characteristics of the infrastructure. These shape how the disrupted infrastructure is rebuilt in effective, efficient and forward-looking ways, considering shifts of economic, environmental and social demands over time. Re-building encompasses deployment of advanced, efficient and low-emission technologies, and changes to infrastructure design and access. It also involves protecting and restoring ecosystems, and engaging stakeholders. This allows for transformative economic growth and strengthens competitiveness, while ensuring environmental sustainability and inclusivity. Including climate resilience criteria in re-building actions is essential to reduce climate vulnerability.

Figure 5.7. A three-pillar framework for infrastructure resilience to natural disaster



Source: OECD (2024[6]), *Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters*.

Developing countries need to strengthen their capacities to ensure infrastructure is resilient in the face of climate and natural disasters. National and local governments need to reinforce capacities in three main areas: prevention, reaction and re-building. They need to update the regulatory framework, identify appropriate financing mechanisms and funding sources; define effective measurement and monitoring systems; and identify appropriate consultation mechanisms for stakeholders to guide actions in each of the three phases (Box 5.4).

5.4.1. The regulatory framework for infrastructure projects should take into account climate resilience

This section discusses the relevance of international good practices and presents concrete cases based on the experience of developing countries. It focuses on four areas where significant improvements are needed in developing countries: the regulatory framework; the role of development banks; innovation and technological capabilities; and government co-ordination and implementation capacities.

The **regulatory framework** plays a crucial role in ensuring climate-resilient infrastructure in developing countries. To that end, it provides the necessary policies, standards and guidelines to ensure infrastructure investments are aligned with climate adaptation and mitigation goals.

It is essential that developing countries participate in the definition of global climate resilience standards for infrastructure. These are norms, codes and guidelines that govern the design, construction and operation of infrastructure projects. They define the minimum requirements for infrastructure resilience, including considerations such as climate risk assessments, adaptive design strategies, durability and maintenance.

Box 5.5. India has adopted a life-cycle approach to infrastructure that increased resilience to natural disasters in its highway projects

India has implemented measures to ensure its highway projects are resilient to natural disasters at all stages of the process – from planning and design through construction, operation, maintenance and end-of-life.

In the planning phase, a risk assessment encompasses the lifespan of assets. India studies an area’s topology, geography and hydrology to avoid higher-risk areas or else ensure that mitigation systems can match the risks effectively. Additionally, it uses disaster exposure mapping (e.g. earthquakes) to determine areas requiring specific levels of investment to mitigate different types of disaster.

During the construction phase, India opts for tailored structural features such as flexible pavements, reinforced embankments, retaining walls and proper drainage systems. The country has also incentivised use of high-quality and tested materials, such as high-strength concrete, to ensure the durability and resilience of its highway projects.

India mandates regular preventive maintenance and inspections to uphold the integrity of infrastructure assets. It established disaster management plans, outlining response measures and evacuation routes in advance to expedite emergency response. Additionally, India has implemented an automatic traffic management system to help emergency responders act more quickly during natural disasters.

Source: OECD (2024[6]), *Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters*.

The regulatory framework mandates the inclusion of climate risk assessments in the planning and design of infrastructure projects. This involves evaluating the potential climate-related hazards, vulnerabilities and impacts that infrastructure assets may face over their life cycle. Climate risk assessments inform decision-making processes, helping identify suitable adaptation measures and design strategies to enhance the resilience of infrastructure projects against climate change impacts.

The regulatory framework can incentivise climate-resilient infrastructure investments through various mechanisms, such as tax incentives, subsidies, grants and preferential financing terms. Through financial incentives for climate resilience, governments encourage developers, investors and infrastructure operators to prioritise resilient design, construction and maintenance practices. Incentivising climate resilience helps overcome market barriers and fosters a conducive environment for sustainable infrastructure development.

The regulatory framework should also ensure and enforce compliance with climate resilience standards and requirements through monitoring, inspection and enforcement mechanisms. Regulatory authorities oversee implementation of climate resilience measures in infrastructure projects, ensuring that developers and operators adhere to prescribed standards and guidelines. Non-compliance may result in penalties, fines or project delays, incentivising stakeholders to prioritise climate resilience in infrastructure development. It is important to clarify responsibilities in terms of who conducts the risk assessment and who follows up with necessary actions. Failure to do this could undermine the value of the risk assessment.

Increasing government anticipation and adaptation capacities is key to ensure resilience in the face of climate and natural disasters. The regulatory framework must be adapted as needed, while ensuring stability and security of economic operations.

Box 5.6. Monitoring and measuring disasters impact is key for better prevention, reaction and re-building: The experience of Mozambique

In Mozambique, the national road network faces significant exposure to natural hazards, particularly flooding and cyclones. With 40% of the country situated less than 200 metres above sea level and a coastline stretching over 3 000 kilometres, Mozambique is vulnerable to the impacts of intense rainfall and frequent cyclones. Historically, reliance on outdated data for preventive measures, such as building embankments, has proven insufficient in mitigating the risks exacerbated by climate change. This has led to more vulnerability.

To address these challenges, Mozambique has identified risks and hazards in collaboration with the National Meteorological Institute and the development of hazard maps. By using new data and spatial forecasting techniques, the country has pinpointed areas most at risk and prepared direct response actions accordingly. Additionally, new design standards were implemented in 2019 through reforms of the legal framework. These introduced measures such as changing slopes, cutting trees and constructing embankments to enhance road resilience and reduce vulnerability to natural disasters.

Source: OECD (2024[6]), *Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters*.

5.4.2. Development banks should step up to close infrastructure gaps and ensure climate resilience

Development banks – multilateral development banks (MDBs), development finance institutions (DFIs) and national development banks – are key partners to close infrastructure gaps in developing countries and addressing climate resilience. By leveraging their resources and expertise, development banks can complement other sources of financing, including from the private sector. In so doing, they help countries build climate-resilient infrastructure, foster sustainable development and improve the resilience of communities to future climate risks (see Chapter 3).

To fully perform their role as an enhancer of climate-resilient infrastructure in developing countries, development banks would benefit from more capital. In developing countries, the role of international and national development banks for climate-resilient infrastructure comprises the following five areas:

- **Financial support:** Development banks provide financing for climate-resilient infrastructure projects in developing countries through a variety of instruments, including loans, grants and guarantees. They often offer concessional terms and flexible financing options to support projects that incorporate climate resilience measures, such as climate risk assessments, adaptation strategies and resilience-enhancing technologies. Additionally, development banks can leverage their financial resources to attract co-financing from other sources, including the private sector and international climate finance mechanisms.
- **Technical assistance and capacity building:** Development banks offer technical assistance and capacity building support to enhance the readiness and implementation of climate-resilient infrastructure projects. They also actively structure and prepare infrastructure projects, which includes providing technical expertise in climate risk assessments, engineering design, project management, and monitoring and evaluation. Development banks also facilitate knowledge exchange and sharing of best practices among countries facing similar climate challenges. This helps build local capacity and expertise in climate-resilient infrastructure development.
- **Policy and regulatory support:** Development banks play a crucial role in shaping policy and regulatory frameworks that promote climate-resilient infrastructure development. They work closely with governments to strengthen regulatory standards, codes and guidelines related to climate resilience in infrastructure planning, design and construction. Development banks also advocate for policy reforms that incentivise investment in climate-resilient infrastructure and integrate climate risk considerations into national development strategies and sectoral plans.
- **Project screening and due diligence:** Development banks conduct rigorous screening and due diligence processes to ensure that infrastructure projects under consideration are climate resilient and environmentally sustainable. This includes assessing climate risks and vulnerabilities, evaluating the resilience of proposed infrastructure designs and technologies, and considering long-term climate impacts and adaptation strategies. Development banks also incorporate climate resilience criteria into project appraisal and approval processes, guiding investment decisions towards projects that enhance resilience and reduce vulnerability to climate change.
- **Knowledge sharing and innovation:** Development banks facilitate knowledge sharing and innovation in climate-resilient infrastructure by supporting research, pilot projects and knowledge exchange platforms. They invest in research and development of innovative technologies and approaches that enhance climate resilience in infrastructure, such as green infrastructure, Nature-based Solutions and resilient urban planning. Development banks also promote learning and capacity building through workshops, seminars and conferences, fostering a culture of innovation and continuous improvement in climate-resilient infrastructure development.

5.4.3. Innovation and technology are pivotal to strengthen disasters' prevention and reaction capacities

Innovation, and traditional and digital technologies can be important allies in strengthening prevention and reaction capacities of developing countries.

Developing countries have limited capacities in the use of EWS and Multi-Hazard Early Warning System (MHEWS). MHEWS, which address multiple hazards simultaneously, are key to increase countries' prevention capacities. Only 11 LDCs have a MHEWS in place, and EWS covers only 46 of 100 people. In terms of regions, South America has the lowest share of countries reporting having a MHEWS (25%), followed by Africa (30%) (Figure 5.8).

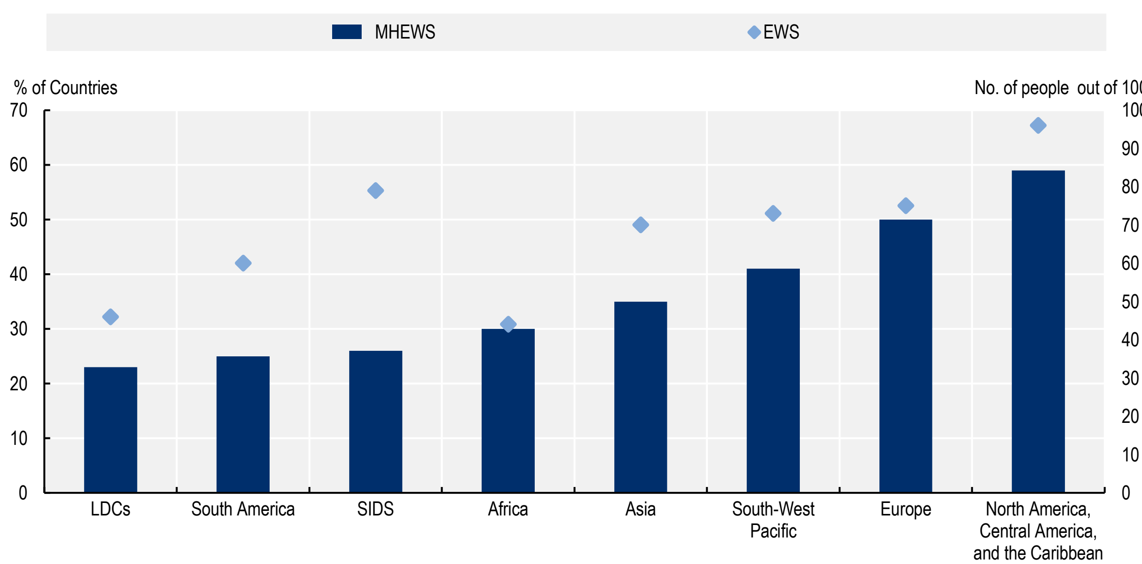
Innovative technologies can further maximise investments in EWS infrastructure. For instance, AI help develop EWS for extreme weather events, enabling communities to prepare for them and respond effectively. In particular, they can help identify and assess vulnerabilities in communities and infrastructure, provide real-time information on weather patterns, and improve the accuracy and precision of climate models, allowing for more effective policy responses (Jain et al., 2023[22]).

Despite the persistent gaps in this area, some progress has been made. For example, Mozambique has an EWS that enables the country to track potential hazards, issue timely alerts and act to minimise the impacts on people's lives and property. This system integrates new technology, infrastructure and community action to ensure effective communication and response.

Two key institutions ensure the effective functioning of the national EWS. The National Meteorology Institute (INAM) uses satellite imagery, radar data and observations from a network of monitoring stations to produce meteorological warnings. For its part, the Institute of Social Communication disseminates alerts through its network of 70 community radios. Additionally, trained community brigades are mobilised to warn at-risk communities, guiding them to safety before extreme weather events occur (OECD, 2024[6]).

Figure 5.8. Developing countries have limited capacities for early warning systems

EWS coverage (number of people out of 100, secondary axis) and MHEWS coverage (share of countries, primary axis), 2019



Note: EWS: Early warning systems; MHEWS: Multi-Hazard Early Warning System.
Source: OECD (2024[6]), *Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters*, OECD Publishing, Paris, based on WMO (2020[23]), 2020 State of Climate Services: Risk Information and Early Warning Systems, World Meteorological Organization, Geneva.

Box 5.7. Re-building effectively through technology and international partnerships: The case of Ghana

In response to the pressing need for a power substation adjacent to Accra's thriving commercial hub, Ghana faced a dual challenge of land scarcity and heightened flood risk in available areas. To overcome this hurdle, a bulk supply point was built in a flood-prone area in the central business district. As a result, the area is able both to react to an emergency and to increase preparedness. Through international co-operation, technology adoption and capacity building, the project increased energy supply and strengthened the resilience of energy infrastructure to flooding.

Ghana has received substantial support for climate resilience from the Japan International Cooperation Agency (JICA). JICA provided a JPY 4.2 billion grant [about EUR 38.5 million] to build and retrofit the substation. In collaboration with the Ghanaian government, Mitsubishi took charge of construction and retrofitting, leveraging innovative technology and methods to minimise disruptions to commercial activities. These efforts included use of underground drills and installation of crucial flood and disaster mitigation technologies such as automated pumps and fire-resistant walls. These measures helped both to build the station and to mitigate the impact of subsequent floods, ensuring uninterrupted power supply to the commercial hub.

Technology transfer was integral to success, alongside well-planned operation and maintenance strategies executed by a team of well-trained and skilled staff. Thorough understanding of flood risks and meticulous project planning were pivotal to ensure effective mitigation strategies. The construction of the facility was carried out by a joint venture: Mitsubishi Corporation (a Japanese trading house), Hitachi Plant Construction (a Japanese plant construction company) and Yurtec (a Japanese electricity facility and engineering company). Leveraging their superior technology, diverse experience and project management capabilities, these companies played a pivotal role in the successful execution of the project. Collaboration among private providers and the construction company involved also contributed to success.

The project was implemented with significant support from the Ghanaian government through various agencies, including the Ghanaian government through various agencies including the Ministry of Energy, the Ministry of Finance, the Energy Commission, the Electricity Company of Ghana, Ghana Railway, Ghana Water. With their collaboration, the project was able to commence construction of the substation. Cutting-edge technology was also employed for advanced monitoring, real-time data analytics, and predictive capabilities, ensuring efficient operation and maintenance. In addition, it integrated advanced technologies to enable operations with minimal disruption during maintenance.

The project's impact assessment revealed remarkable successes, with a 95% reduction in the rate of power shortages compared to 2013. Despite facing two major floods in 2020 and 2022, the substation remained resilient, experiencing no disruptions to its operations. This resilience underscores the efficacy of the implemented flood mitigation strategies, including use of automated pumps and other technological innovations. Japan's significant support, coupled with Ghana's collaborative efforts, exemplifies the benefits of international co-operation and the strategic integration of cutting-edge technology in bolstering infrastructure resilience against natural disasters.

Source: OECD (2024[6]), *Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters*.

Developing countries need to shift from a "technology transfer" to a "co-creation" mindset. In this way, they can foster innovative local and international partnerships to co-develop climate-resilient solutions. Developing countries lag in innovation and technological capabilities in most areas, including climate resilience. The top 20 countries for patent applications for climate change adaptation technologies accounted for 92% of the total.

Despite the notable rise in the share of these patents held in the People's Republic of China [hereafter "China"] and India, OECD countries lead in total number. Since the 2000s, the share of these patents in China rose from 1% to 17%. For its part, India accounts for 2% of the world total. Meanwhile, OECD countries accounted for 75% of the world total in 2019-21 [authors' elaboration with data from OECD (2022[24])]. Partnerships between developed and developing countries in this field is essential. It allows developing countries to increase their adaptation capacities and also enhances the global capacity to respond to climate change.

5.4.4. Improving governance and institutional capabilities will be essential to support climate-resilient infrastructure

Developing countries need to improve their governance and institutional capabilities to plan, build and manage infrastructure effectively, and to ensure they proceed in a climate-resilient way.

Inclusive processes to engage stakeholders can be key for ensuring infrastructure is planned, built and operated in a climate-resilient way. This involves creating mechanisms for public consultation, community involvement and stakeholder collaboration. Together, they ensure that infrastructure projects address the needs, concerns and priorities of local communities and vulnerable groups (see Chapter 2).

Enhancing governance and institutional capacities of national and local governments is essential as they play an important role in implementing innovative policies to make infrastructure climate resilient. Equipping people in the public and private sectors with adequate technical skills is crucial. For example, in Ghana, the Ministry of Roads and Highways has prioritised capacity building for staff, equipping them with the skills to carry out their responsibilities effectively. Newly recruited technical staff within the agencies undergo mandatory in-house training; this training ensures that all staff, regardless of academic background, are well prepared for their roles. Additionally, development partners such as the Japanese Development Cooperation Agency and the African Development Bank play significant roles in supporting Ghana's training programmes, as well as providing concessionary facilities for road projects.

It is important to pay attention to capacity building and community empowerment at the local level (OECD, 2024[6]). Local authorities are close to the ground, and able to understand the reality of growing climate change in their communities. From this vantage point, and by prioritising a system approach in policy reforms, they are key players in mitigating the impact of climate change on infrastructure. However, local communities in developing countries, especially in LCDs, face a severe shortage of fiscal and technical capacities. Targeted actions are needed to empower them and leverage their capacities to ensure climate-resilient infrastructure (SNG-WOFI, OECD-UCLG, 2022[25]) (Chapter 6).

Enabling cross-border collaboration at the national and local level is also essential. Geological interconnections cross national frontiers. This requires the creation of mechanisms for joint data collection and use, and for joint planning. In this way, neighbouring countries can factor the cross-border impact of climate change and natural disasters into national responses. In the context of Mozambique's interconnected hydrographic basins, for example, cross-border issues must be considered when developing infrastructure resilience to natural disasters. The interconnected nature of hydrographic basins means that activities upstream can have significant downstream impacts, including the potential for increased flood risks and changes in water flow patterns. Therefore, effective co-ordination and collaboration with neighbouring countries are essential to address shared challenges and mitigate the transboundary impacts of natural disasters (OECD, 2024[6]).

Box 5.8. Knowledge management and impact assessment in the aftermath of disasters increases future prevention capacities: The experience of Indonesia

Addressing Indonesia's vulnerability to natural disasters requires a multifaceted approach. It should encompass robust disaster preparedness, early warning systems, infrastructure resilience and community engagement. Enhancing the resilience infrastructure is imperative to support Indonesia's development efforts. Strengthening building codes, implementing land-use planning measures and investing in resilient infrastructure are critical steps towards mitigating the impacts of disasters. Furthermore, enhancing public awareness and community resilience through education and capacity-building initiatives helps foster a culture of preparedness and response at the grassroots level.

In Indonesia, the Jakarta metropolitan area deserves special attention. As Indonesia's capital and one of the most populous urban centres in Southeast Asia, the area faces unique challenges and vulnerabilities related to natural disasters. Situated on the northwest coast of Java Island, Jakarta is particularly susceptible to a combination of geological, hydro-meteorological and environmental hazards.

The Jakarta Mass Rapid Transit (MRT) project aimed to mitigate traffic congestion in the metropolitan area, while addressing disaster risks such as heavy rainfall, floods, land subsidence, sea level rise and earthquakes. Underground facilities were redesigned, including rain screens, flood panels and mount-up entrance that prevented flooding water from flowing into underground stations. These actions helped reduce impacts of weather-related events. In addition, the local government released reports on flood prevention and organised awareness-raising events to alert and prepare the population.

The Disaster Prevention Policy aimed to ensure safe evacuation of passengers during emergencies, focusing on MRT Jakarta. A crucial success factor was the emphasis on building knowledge, skills and capacities throughout planning and construction. These activities prioritised resilience to natural disasters.

MRT Jakarta actively engaged in capturing, disseminating and reusing knowledge gained from firsthand experiences to enhance its practices. The project organised retrospective events to discuss the initial phase, compiling valuable lessons learnt at its Internal Knowledge, Information, Education Center. Additionally, MRT Jakarta published a series of books covering construction, and operation and maintenance aspects, providing valuable insights for future projects.

Furthermore, MRT Jakarta played a significant role in a study on flood management by the Community of Metros Benchmarking Group (COMET). This initiative resulted in a comprehensive benchmarking report among all COMET members, allowing metros to compare flood management practices and learn from each other. By actively participating in knowledge-sharing platforms like COMET, MRT Jakarta contributed to the collective learning and improvement of flood management practices in metro systems.

Source: OECD (2024[6]), *Compendium of Good Practices on Quality Infrastructure 2024: Building Resilience to Natural Disasters*.

Developing countries will need to invest in closing their infrastructure gaps in a way that is environmentally sustainable, minimises risks from climate change and turns infrastructure into an accelerator of economic and social transformation. This will demand a transformative agenda that links infrastructure development to national aspirations for industrialisation and innovation. It will also require international partnerships for resource mobilisation, innovation and collaboration.

5.5. Conclusions

The urgency for global and national action on climate-resilient infrastructure in developing countries cannot be overstated. The consequences of inaction are dire, with the most vulnerable countries and communities bearing the greatest burden. For developing countries, the imperative of infrastructure resilient to climate and natural disasters goes hand in hand with the need to close infrastructure gaps to sustain countries' aspirations of industrialisation.

Five policy issues are of paramount importance:

- There is a pressing need to **build capacities for comprehensive risk assessments** to inform infrastructure planning and decision-making processes in developing countries. These assessments should incorporate climate projections, vulnerability assessments and socio-economic factors to identify areas of high risk and prioritise adaptation interventions. Additionally, integrating climate resilience into infrastructure design and construction standards is essential to ensure that new infrastructure investments are resilient to future climate impacts.
- **Enhancing institutional capacity and governance frameworks** is crucial for effective climate-resilient infrastructure development. This includes strengthening regulatory frameworks, improving co-ordination among government agencies, fostering multi-stakeholder partnerships, supporting subnational governments and enhancing community engagement in decisions. Building institutional capacity is essential to ensure effective implementation and maintenance of climate-resilient infrastructure projects. Capacity building in improving and updating the regulatory framework is also important in developing countries to ensure that rules and standards incentivise resilience across the whole project life cycle, integrate climate risk assessments, enforce compliance and facilitate stakeholder engagement.
- **Financing mechanisms** must be mobilised to support climate-resilient infrastructure in developing countries. This includes both public and private sector investment, as well as leveraging international climate finance mechanisms such as the Green Climate Fund and the Adaptation Fund. Innovative financing mechanisms, such as climate bonds and public-private partnerships, can also play a key role in mobilising resources for climate-resilient infrastructure projects, including at the subnational level (see Chapter 6). Governments, national development banks, as well as MDBs and DFIs, are key players in this field. They are crucial for financing, technical assistance and capacity building, de-risking investments and attracting private investments (see Chapter 3). To meet the growing infrastructure needs in developing countries and to ensure that infrastructure is resilient against climate and natural disasters, it will be important to increase the capitalisation of MDBs and DFIs so they can meet the growing demand.
- **Technology transfer, co-development of innovative solutions and capacity building** are critical for enhancing the technical expertise and knowledge needed to implement climate-resilient infrastructure projects. This includes transferring climate-resilient technologies, building local capacity for project design and implementation, and fostering knowledge exchange among countries facing similar climate challenges. Investing in research and development of climate-resilient technologies tailored to the specific needs of developing countries is also essential.
- **Addressing social equity and inclusion considerations** is also paramount in climate-resilient infrastructure in developing countries. Vulnerable and marginalised communities often bear the brunt of climate impacts, which affect them disproportionately because of inadequate infrastructure. This also hampers their economic inclusion prospects, therefore perpetuating poverty cycles. Climate-resilient infrastructure projects must be designed and implemented in a way that promotes social equity, ensures access to essential services for all and empowers local communities to actively participate in decision-making processes.

Developing countries can build the necessary competitiveness-related infrastructure that is resilient to the impacts of climate change, fosters sustainable development and improves the resilience of communities to future climate risks. To that end, they must prioritise risk assessments, enhance institutional capacity, mobilise financing, promote technology transfer and capacity building, and consider social equity.

Governments in developing countries need to take a proactive stance towards climate-resilient infrastructure and prioritise it as part of their industrialisation and competitiveness efforts. The private sector and the international community should step up and support them with adequate means. Now is the time for shared and decisive action to build a world more resilient to climate and natural disasters, leaving no one behind.

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6 Building climate-resilient infrastructure with regions and cities

This chapter explores how taking an integrated approach can help create more climate-resilient regions and cities. It highlights the unequal vulnerability of different places to climate change, their varying capacities to build climate resilience, the critical role of regional and local governments, and the interdependency of infrastructure systems across sectors and places. Addressing these challenges will require working together with regions and cities to build climate-resilient infrastructure by i) adopting a place-based approach; ii) harnessing multi-level governance; and iii) supporting subnational government finances. The chapter provides insights and case studies to help national, regional and local governments build climate-resilient infrastructure and communities.

Key policy insights

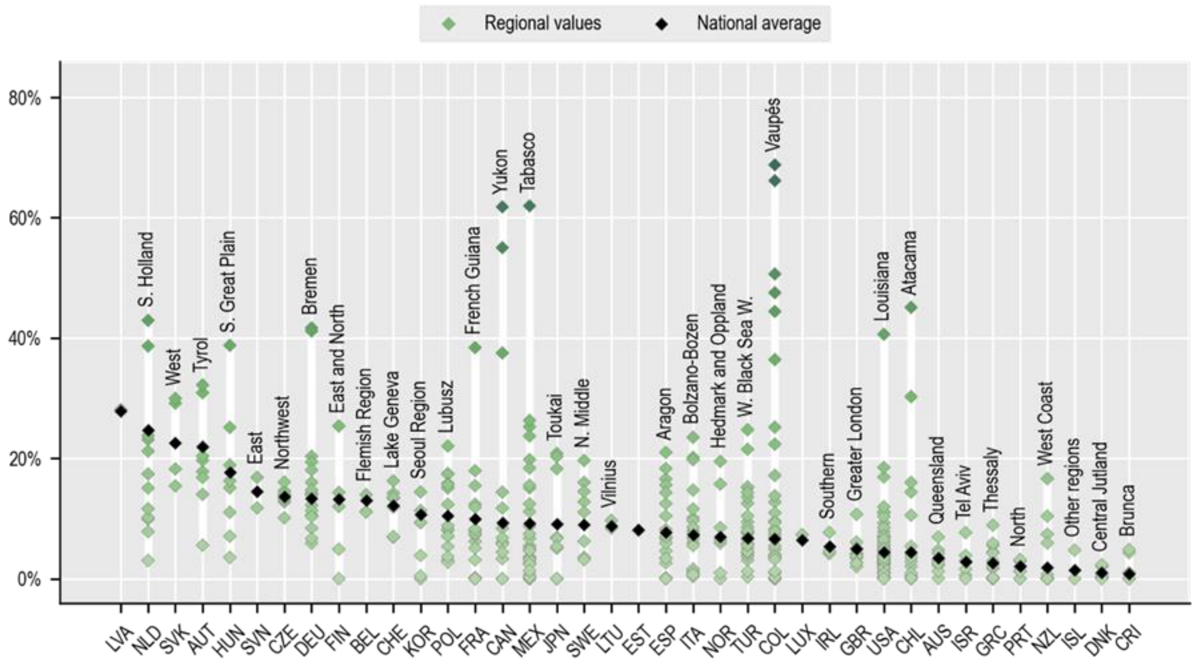
- Climate change presents asymmetric challenges and opportunities across places. Vulnerability against climate change results not just from climate hazards but also from communities' evolving social-economic characteristics. These features are unevenly distributed across space and can interact to create cascading and compounding effects. Investing in climate-resilient infrastructure can help communities build resilience against climate change and support long-term regional and urban development objectives.
- Regional and local governments will play an essential role in building climate-resilient infrastructure. Subnational governments were responsible for 69% of climate-significant public investment in OECD countries in 2019. Subnational governments have the mandate to plan, deliver, fund and maintain climate-resilient infrastructure services and the local framework conditions for climate resilience investment.
- This chapter presents three approaches that national, regional and local governments can take to support the delivery of climate-resilient infrastructure with regions and cities:
    - **Adopt a place-based approach** to help embed local characteristics in policies for building climate resilience. This involves targeting resilience actions towards the places most at risk, supporting systemic and integrated policy actions at a local level and engaging deeply with communities. For example, regions and cities can set up climate risk decision-making frameworks, develop climate-aware spatial plans and better communicate trade-offs around climate resilience.
    - **Harness multi-level governance** to help align climate resilience actions across levels of government. This can support climate resilience at the relevant scale by co-ordinating actions across and among levels of government, and by reinforcing subnational government capacity. For example, regions and cities can set up contracts with each other and with national governments to co-ordinate resilience across jurisdictions or to pool technical and fiscal resources to harness economies of scale.
    - **Support subnational government finances** to help regions and cities mobilise sustainable funding and financing resources for local climate resilience actions. This can involve ensuring access to appropriate revenue streams for resilience, mobilising finance to where it is most needed and unlocking climate finance at a local level. For example, governments can reform subnational fiscal frameworks to support self-funding, integrate climate resilience into intergovernmental transfer schemes and facilitate use of green, social and sustainable bonds.

6.1. Introduction

While climate change is a global phenomenon, its impacts are felt at a local level. Moreover those impacts are asymmetric, affecting different regions and cities differently. For example, across OECD countries, there are large gaps across regions within countries in the percentage of the population exposed to river flooding (Figure 6.1Figure 6.1) due to differing geography but also human settlement patterns. Climate change can compound upon regions and cities' differing physical, economic and social characteristics, capacities and vulnerabilities to create cascading effects (OECD, 2023[1]). In addition, climate change impacts are also influenced by, and depend upon, other factors. These include the complex interplay with other megatrends, such as demographic change, digitalisation and globalisation (OECD, 2022[2]).

Figure 6.1. Regions vary in their exposure to the impacts of climate change

Population exposure to 100-year river flooding in OECD large regions (TL2), 2015



Source: (OECD, 2023[1]), *A Territorial Approach to Climate Action and Resilience*, https://doi.org/10.1787/1ec42b0a-en.

Regional and local governments are on the frontline of building climate resilience (Box 6.1). In many OECD countries, subnational governments have competencies for key areas related to climate resilience – from infrastructure provision and building permitting to land-use planning (OECD/UCLG, 2022[3]). Indeed, subnational governments are responsible for 63% of climate-significant[1] public expenditure and 69% of climate-significant public investment in OECD countries (OECD, 2022[4]). They have key responsibilities for building infrastructure resilience against both extreme weather events (such as cyclones) (UNDRR, 2015[5]) and slow onset events (such as rising temperatures) (UNFCCC, 2012[6]). The scale of the challenge for regional and local governments is large. Cities in emerging economies are estimated to need private investment of USD 29.4 trillion by 2030 to make their infrastructure and services more climate resilient (IFC, 2018[7]). Even though the costs are significant, the returns on investing in climate-resilient infrastructure can be high – every dollar invested in resilience could generate four dollars in benefits (World Bank, 2019[8]).

Resilience building and adaptation are not just about reacting to negative impacts but also about taking advantage of potential opportunities (OECD, 2022[2]; OECD, 2021[9]). The need for greater investment in both climate adaptation and mitigation infrastructure could provide opportunities for regions and cities to transform economically (OECD, 2023[10]). At the same time, climate change creates asymmetries across regions with respect to opportunities. For example, in the average OECD country, the gap between the regions with the highest and lowest share of green jobs is seven percentage points (OECD, 2023[11]). Whether dealing with challenges or opportunities, place-based solutions are needed to address the impacts of, and increase the resilience of, regions and cities to climate change.

Box 6.1. Actions for regional and local governments to build climate-resilient places

Regional and local governments can be "laboratories for innovation", driving advancements in climate adaptation. These governments are responsible for many physical and operational actions needed to help build regional and urban climate resilience and meet broader development aspirations.

To build long-term climate resilience, regional and local governments should adopt a place-based approach by deploying a range of physical and operational actions tailored to their jurisdictions. While physical infrastructure investment will be essential, operational actions can sometimes be more effective and efficient to build resilience against climate hazards. Getting operational actions right also contributes to the resilience of infrastructure systems. To that end, it reduces asset exposure to climate hazards, which can in turn reduce the volume of physical infrastructure needed (and the associated embodied emissions).

Table 6.1. Key actions that regional and local governments can take to build climate resilience

	Physical	Operational
	Adaptation	
Reduce **exposure** to climate hazards	• Site infrastructure and housing in less exposed locations • Build protective infrastructure to shield communities and assets	• Develop land-use plans to prevent future development in at-risk locations • Support managed retreat for existing at-risk communities
Reduce **vulnerability** against climate hazards	• Retrofit infrastructure and buildings to higher standards • Build new infrastructure and buildings to higher standards • Adopt Nature-based Solutions (see Chapter 4)	• Enhance community preparedness against hazards • Purchase insurance against climate losses and damages • Establish "rainy day" funds
	Mitigation	
Reduce **incidence** and **severity** of climate hazards *(not focus of this report)*	• Facilitate renewable energy construction • Encourage low-carbon construction approaches • Provide sustainable options for transportation	• Design the built environment to reduce fossil fuel consumption (e.g. reduce commuting distances, reduce heat islands) • Manage electricity consumption to reduce demand, especially at peak times • Facilitate the phase-down of polluting industries

Finance can have an important role to support investment in regions and cities (OECD, 2023[12]; OECD, 2022[13]). Most climate finance at a subnational level flows towards investments in mitigation rather than adaptation, although both are needed. In 2021, adaptation finance accounted for only 27% of total climate finance for developing countries (OECD, 2023[14]). At the subnational level, only 9% of climate finance flows for cities are being mobilised for adaptation and resilience projects; the remainder are directed towards mitigation or dual-use projects (Negreiros et al., 2021[15]).

Given the complex and decentralised nature of climate risks, building climate resilience and addressing challenges related to climate change will require adopting a place-based approach, harnessing multi-level governance and supporting subnational government finances. These are elaborated below and in Table 6.2:

- Adopting a **place-based approach** can help target action to place-specific needs, build linkages across policy domains and develop community-appropriate solutions. This approach acknowledges the uneven spatial distribution of climate change risks and opportunities, and the need for co-ordination across policy domains and community engagement. It calls for governments to consider the differing risks, capacities and aspirations of different places when designing interventions.

- Harnessing **multi-level governance** can help co-ordinate policy actions, support action at the right scale and harness competencies across all levels of government. This approach acknowledges that competencies are shared across levels of government. As climate change risks and opportunities cross jurisdictional boundaries, co-ordinated approaches and local capacity are needed. It calls for governments to co-ordinate vertically and horizontally to align priorities and responsibilities.
- Supporting **subnational government finances** can help ensure that subnational governments have the fiscal capacity to invest in resilience, to mitigate the negative impacts of climate change and to leverage opportunities. This approach acknowledges the limited revenue potential of many local adaptation investments, limited local financial capacity and the insufficient flow of climate finance towards local adaptation projects. It calls for governments to recognise subnational governments' constraints when designing funding and financing schemes to build resilience.

Table 6.2. Policy challenges and actions for building climate-resilient regions and cities together

Element	Related policy challenges		Related policy actions
Place-based approach	Uneven spatial distribution of climate risks, actions and costs Complex interactions across policy domains linked to climate resilience Strong community attachment to place	>>	Target responses towards places most at need to tackle the risks or leverage opportunities from climate change Support systemic, integrated and cross-sectoral policy action Develop solutions adapted for community needs
Multi-level governance	Competencies shared across levels of government Climate risks that cross jurisdictional boundaries Different characteristics and scales of infrastructure networks and solutions Insufficient capacity where it is needed	>>	Vertically co-ordinate across levels of government to harness shared competencies Horizontally co-ordinate among levels of government to act at the relevant scale Build regional and local government capacity for resilience
Subnational finance	Limited revenue potential of subnational resilience investments Limited subnational financial capacity Limited climate finance adaptation flows towards subnational governments	>>	Identify alternative subnational revenue streams to fund resilience investments Target fiscal transfers to places where they are most needed to build long-term resilience Mobilise private finance for subnational governments, including climate finance

The OECD Recommendation on Regional Development Policy and the OECD Recommendation on Effective Public Investment Across Levels of Government provide guidance on supporting the development of more resilient regions and cities (Box 6.2). These two recommendations take a holistic view of the factors that support long-term regional development and improved well-being, focusing on both physical and operational policy actions. The two recommendations highlight the importance of a place-based, multi-level governance and subnational finance approach for resilience.

Box 6.2. Place-based, multi-level governance and subnational approaches for resilience

The OECD Recommendation on Regional Development Policy provides countries with a comprehensive policy framework to support the design and implementation of effective regional development policies for inclusive economic growth, well-being, environmental sustainability and resilience. It outlines that regional development policy is long-term, cross-sectoral, place-based and multi-level, and helps improve the contribution of all regions to national performance and reduce inequalities between places and between people.

The OECD Recommendation on Effective Public Investment Across Levels of Government helps governments assess the strengths and weaknesses of their public investment capacity and set priorities for improvement. At the core of the Recommendation is a focus on a place-based and multi-level governance approach to investment, which can support countries to maximise investment returns. The Recommendation contains 12 principles that support better management and implementation of public investment across all levels of government.

Source: OECD (2023[16]), *OECD Recommendation on Regional Development Policy*, https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0492; OECD (2014[17]) Recommendation of the Council on Effective Public Investment Across Levels of Government, https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0402.

6.2. Integrated place-based approach for climate resilience

Adopt a **place-based approach** to target responses towards places most in need, address local risks and leverage local opportunities and support cross-sectoral policy action that builds climate resilience jointly with local communities

A place-based approach acknowledges the role of place in shaping economic, social and environmental outcomes, including for climate resilience. Place-based policy solutions are tailored to the specific circumstances of different places. They consider the uneven and evolving distribution of factors such as natural resources, environmental hazards, human capital, social capital, connective infrastructure and governance institutions. As a result of their contexts, places not only experience different outcomes but also have different potentials, and different development pathways to reach them (OECD, forthcoming[18]).

6.2.1. Target responses to places most vulnerable to climate impacts

The increasing impacts of climate change are unevenly distributed across space. Climate change is increasing the risk of both natural and technological hazards. Natural hazards include flooding, rising sea levels, extreme heat, tropical cyclones, droughts and others (IPCC, 2021[19]). Technological hazards include grid blackouts, dam failures and others, which often result from the failure of critical infrastructure due to climate hazards (UNDRR, 2023[20]). While climate change is increasing risk across OECD countries (see Chapter 1), the magnitude of change differs greatly across places within countries. Potential hazards are spread unevenly across space. Moreover, the exposure of cities to climate change and their resilience against it also differ based on their physical, social and economic characteristics.

The impacts of climate change can compound existing vulnerabilities. Often, lower socio-economic communities are not just more vulnerable to, but also more exposed to, climate change. Among the global urban population, the poorest 20% have greater adaptation gaps than the richest 20% (IPCC, 2021[21]). The compounding and cascading impacts of climate change can hit disadvantaged communities the hardest. The systems they rely upon – economic (e.g., jobs), social (e.g., health care) and infrastructure (e.g., sanitation) – can already be less resilient to climate change (OECD, 2023[1]). For example, places with a shrinking population could have greater per capita costs to provide climate-resilient infrastructure services (OECD, 2022[22]). Indeed, by 2040, 14 OECD countries are expected to experience a shrinking population, which will be especially concentrated in small- and mid-sized cities and remote regions. This could make building climate resilience even more challenging.

On the flip side, regions and cities can also harness opportunities presented by climate change. While climate mitigation is not the focus of this report, it is closely linked with resilience and can present economic opportunities (OECD, 2021[23]). For example, Nature-based Solutions, such as mangrove restoration, can offer both mitigation and adaptation benefits, on top of potential recreation, food and tourism value (see Chapter 4). Some regions are vulnerable to climate-related industrial transitions (OECD, 2023[10]). However, they can also leverage their existing assets, capacities and skills to reap green and digital dividends (OECD, 2023[11]). Regions with less frequent or severe climate hazards could see their relative attractiveness grow. Regions important to the green transition (such as those containing critical mineral deposits, advanced manufacturing capabilities or renewable energy resources) might have an advantage in attracting the investment and talent needed to build climate resilience (OECD, 2023[24]).

By understanding the spatial distribution of climate risk, place-based approaches can help ensure that policies are optimised to local characteristics and needs. They can proactively articulate resilient development pathways that enhance regions and cities' competitiveness and help them specialise smartly, based on local strengths, challenges and aspirations (OECD, forthcoming[18]). This is especially relevant for developing countries given their vulnerabilities against climate change and ambitious development aspirations (see Chapter 5).

Regional and local governments play an important role in identifying and communicating climate risks. However, the exact impacts of climate change remain uncertain at the more granular regional and local levels in some countries due to data and modelling limits (OECD, 2021[25]). Indeed, a quarter of municipalities in the European Union do not assess the climate resilience of potential infrastructure investments (EIB, 2023[26]). Further, vulnerability assessments must consider local asset and population exposure against climate hazards, which requires detailed data (Aligishiev, Massetti and Bellon, 2022[27]). Exposure on its own does not necessarily imply vulnerability since many infrastructure assets are 'protective' (that is, they can reduce the exposure and vulnerability of other assets).

Given the scale of the challenge to build climate-resilient infrastructure, many regional and local governments will be unable to act on their own. Certain regional and local governments could face barriers in planning, financing or delivery. National governments will need to support regions and cities, targeting places that are most vulnerable to climate hazards and least able to respond on their own (OECD, 2023[28]; OECD, 2021[9]; OECD, 2019[29]; Matsumoto and Bohorquez, 2023[30]). Box 6.3 shows how cities are increasingly vulnerable to climate hazards, requiring urban-oriented solutions to build their resilience.

Box 6.3. Cities are increasingly vulnerable to the impacts of climate change, but they are also drivers of resilience

Since cities contain a high density of people and assets, they are particularly exposed to climate hazards – the costs of inaction are high. Three in five cities globally with more than half a million residents are at high risk of natural disasters (UN, 2018[31]). Cities are affected differentially by climate hazards such as heat stress and rising sea levels. By 2050, over two-thirds of the global population could live in urban areas, with most growth in sub-Saharan Africa and South Asia. Growing cities need to not only climate-proof but also significantly scale up infrastructure (IEA, 2023[32]), putting pressure on supply chains and capacities (Lall et al., 2021[33]).

Urban-oriented solutions can build cities' resilience and mobilise their capacities for change. Coastal cities, for example, can take a blue urban approach to improve coastal management, protect natural ecosystems and reduce their vulnerabilities to disasters (Donovan, 18 May 2017[34]). A blue urban approach calls for water-sensitive urban development by acknowledging the interactions between terrestrial and aquatic areas of cities. While survey results show that cities expect the blue economy to help them create jobs, boost growth and adapt to climate change, they also demonstrate that climate change is the biggest threat to the blue economy (Lassman, 2022[35]). Developing resilient, inclusive, sustainable and circular blue economies will require a functional city basin approach to water resource management, highlighting the need for inter-municipal and urban-rural co-ordination (OECD, 2022[36]). In the United States, cities could access over USD 21.7 billion in federal funding to build coastal resilience, climate-proof coastal infrastructure, protect coastal ecosystems and grow the blue economy (Urban Ocean Lab, 2023[37]).

Source: Matsumoto and Ledesema (2023[38]), *Building systemic climate resilience in cities*, https://doi.org/10.1787/f2f020b9-en.

All levels of government can support a more place-based approach for climate resilience and help deliver more climate-resilient infrastructure. To do so, governments can take the following actions:

- **Better understand the spatial distributions of climate hazards, exposures and vulnerabilities at a granular level to inform decision making**. In the United States, the state of California has developed an online multi-hazard map to help residents identify the risk of climate hazards (California Governor's Office, 2015[39]). Multiple governments can also co-fund scenario-based, multi-hazard modelling within their region to achieve economies of scale.
- **Define clear criteria for when resilience interventions should be made to prioritise limited resources**. Governments can develop a multi-criteria decision-making framework based on climate risks and impacts to prioritise grant-making, lending and investment projects for the most effective actions. In Australia, the Resilient Homes Program in New South Wales defines grant eligibility criteria based on detailed flood mapping (Box 6.4). Criteria can also be published to strengthen subnational planning capacity and ensure investments are aligned across governments and with the private sector. Criteria can also be used to help define when and how to rebuild in – or when to retreat from – high-risk locations.
- Consider strategic managed retreat options to reduce exposure to climate hazards and re-direct funding towards development-oriented investment. In coastal areas exposed to rising sea levels or in areas at increased risk of flooding, governments and communities may avoid repeatedly rebuilding. This can reduce the potential for rising insurance costs by supporting communities to relocate. After repeated floods in the city of Lismore, for example, the Australian and New South Wales governments developed a programme to support managed retreat (Box 6.4).

Box 6.4. Resilient Homes Program of New South Wales in Australia

In early 2022, the Northern Rivers region of New South Wales (Australia) experienced devastating floods following heavy rainfall. In the city of Lismore previous flood records were surpassed by 2 metres. The heightened recurrence of such events due to climate change poses long-term challenges as communities need to recover from economic and social disruptions from infrastructure damage, property damage and community displacement.

In response, the Australian federal and New South Wales governments initiated the Resilient Homes Program. Overseen by the NSW Reconstruction Authority, the programme aims to reduce the number of homes in severe-risk flooding areas by offering federal and state financial assistance to homeowners.

Recently released flood mapping and analysis classified areas with flood risks into four priority groups based on the likelihood and impact of potential floods. Homes in areas with the three highest priority groups are eligible for home buybacks, while those in the lowest priority group are eligible for home raising and retrofits. Home raising involves elevating or relocating homes above flood levels, while retrofits focus on upgrading and repairing liveable areas for increased resilience against future floods.

Through its proactive approach, the programme is reducing the concentration of homes in severe-risk zones, minimising potential damage and increasing flood resilience within the affected region. Around AUD 700 million has been allocated to finance home buybacks, raisings and retrofits. Property buybacks will be based on the market value of the home prior to the floods, while eligible homeowners can access grants of up to AUD 100 000 for home raising and up to AUD 50 000 for retrofits.

Source: New South Wales Government (2023[40]), Flood mapping and analysis released to support NRRC's buyback priorities, https://www.nsw.gov.au/departments-and-agencies/department-of-regional-nsw/news-updates/flood-mapping-and-analysis-released-to-support-nrrcs-buyback-priorities.

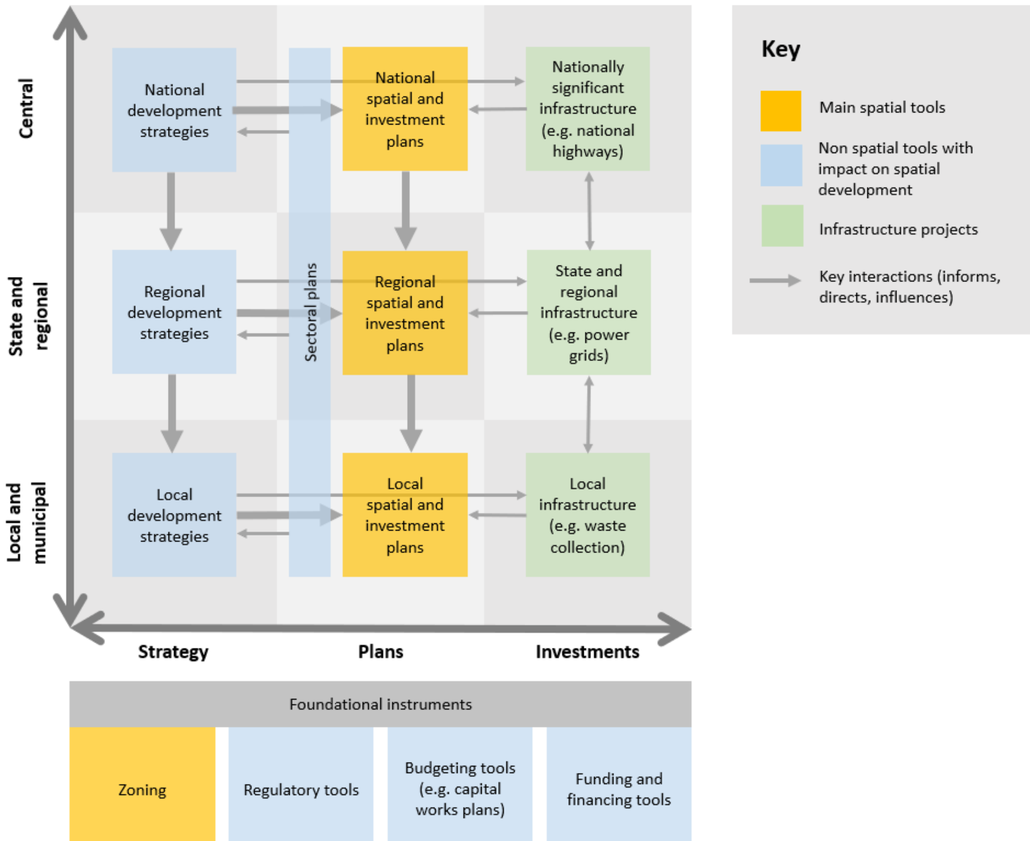
6.2.2. Develop systemic and integrated strategies for regional and urban climate resilience

Climate change is a cross-cutting issue with complex, interlinked and varying place-based impacts. As climate change shifts the competitive advantages, challenges and aspirations of regions and cities, there is a corresponding need to update and future-proof development strategies and make the built environment more resilient. Given the essential role of infrastructure to help regions and cities meet their development goals, it is crucial to embed climate-resilient infrastructure into development strategies (OECD, 2023[16]). The links between climate change and other megatrends, such as demographic change, digitalisation and geopolitical competition, highlight the need to adopt an integrated approach. Climate resilience needs to be mainstreamed within regional and urban development strategies and plans more broadly (OECD, 2022[2]). Within these overarching strategies, infrastructure can be a tool to steer development in a more climate-resilient direction, and in doing so, make infrastructure itself more resilient. Failure to do so can have cascading effects, further hampering development efforts (Matsumoto and Bohorquez, 2023[30]).

Making regions and cities more climate resilient requires adopting systems thinking and supporting integrated approaches (OECD/The World Bank/UN Environment, 2018[41]; OECD, 2023[1]). This means thinking of regions and cities as open systems, influenced by the interaction of both internal and external systems across various scales (Matsumoto and Bohorquez, 2023[30]). The complex interactions between infrastructure and other policy areas highlight the need to minimise conflicts and harness synergies across sectors and policy areas (WEF, 2022[42]), as well as avoid unintended consequences of resilience-building actions. This is often done most effectively at a local level. There are key links, interactions and feedback loops between development strategies, spatial planning, land-use policy and infrastructure planning (Figure 6.2). Governments need to think beyond individual assets to deliver climate-resilient systems by mobilising high-level strategies such as development strategies, masterplans, zoning, transit-oriented development and building regulations (OECD, 2023[12]). Once these strategies and plans define opportunities for creating resilient infrastructure projects, governance processes for planning individual infrastructure projects can be strengthened (see Chapter 2).

Figure 6.2. Development strategies, spatial planning and infrastructure planning are inextricably linked

Typical typology of development, spatial and infrastructure plans in OECD countries



Note: National-level plans are not always present in federal country (where present, may primarily act as co-ordinating tool for state and regional plans). Regional-level plans are not always present in decentralised unitary countries.
Source: Authors' elaboration, building on OECD (2017[43]).

Governments at all levels have policy tools to influence regional and urban development. Governments need to co-ordinate both infrastructure delivery and maintenance, as well as future infrastructure needs, through three key actions:

- **Develop cross-sectoral regional and urban development strategies to provide a consistent overarching vision for supporting climate-resilient development**. Development priorities should be consistent with climate-resilient objectives. In Singapore, for example, the government has mapped areas at risk of inundation during the development of its new Master Plan, which has informed the planning for the proposed "long island" to protect against rising sea levels (Box 6.5).
- **Develop spatial plans that discourage or prevent development and investment in areas exposed to climate hazards**. Limiting development in flood-prone areas can reduce the amount of infrastructure exposed to floods (Box 6.4). Countries such as Chile, Costa Rica and Uruguay are mandating environmental analysis of spatial and territorial planning to align land use with sustainability (OECD, 2023[44]).
- **Tailor regulatory frameworks to allow for the management of local climate impacts and empowerment of local actors.** National building standards (such as homes to be built using wind-resistant materials) can be useful to set a common baseline for quality. However, these are not

necessarily appropriate everywhere. In some cases, places experiencing higher or lower risk from climate hazards could strengthen or relax local regulations and building codes accordingly. However, there is a risk that less consistent regulatory standards could increase compliance costs.

Box 6.5. Singapore Long Island land reclamation

Singapore is exposed to rising sea levels due to its coastal and low-lying geography. An estimated 70% of land in Singapore sits less than 5 metres above sea level. The East Coast area has experienced multiple flooding events due to high tides, heavy rainfall and storm surges. Flooding could disrupt and damage essential infrastructure (such as the East Coast Pathway and Changi Airport) with potentially broader impact on Singapore and Southeast Asia.

To reduce Singapore's vulnerability against rising sea levels, the "Long Island" concept proposes land reclamation off the East Coast. This would form a protective island, elevating land to create a continuous coastal defence. Coastal outlet drains would be redirected into a new freshwater reservoir with tidal gates and pumping stations. Stakeholder input and local community feedback are ongoing and helping to shape the development of these plans.

The "Long Island" would serve multiple purposes, offering coastal protection against rising sea levels and floods, and enhancing water resilience with establishment of the new reservoir. The initiative could also potentially add around 20 kilometres of waterfront parks, tripling the length of parks in the area and providing new recreational opportunities.

Source: Singapore Urban Development Authority (2023[45]), 'Long Island', https://www.ura.gov.sg/Corporate/Planning/Master-Plan/Draft-Master-Plan-2025/Long-Island.

6.2.3. Build resilience jointly with local communities

Working closely with local communities to deliver resilience-building solutions has many advantages. Local communities can provide insights and relationships that can make planning resilience-building actions more effective. Understanding stakeholders' needs and preferences is essential for designing appropriate resilience-building actions and becomes particularly important when difficult trade-offs must be made (see Chapter 2). By engaging transparently with local communities from the very start of infrastructure planning, governments can help secure stakeholder buy-in, increase community confidence in the process and minimise risk of local opposition. This is especially important as climate change affects a broad swathe of society and can be political.

Governments need to consider the strong impacts of climate-resilient infrastructure on communities. Such impacts can be concentrated (e.g. decisions on where protective infrastructure needs to be sited can have negative local visual impacts). Actions such as managed retreat can be difficult given people's attachment to place and communities. Nonetheless, managed retreat will be necessary in some places given the great risks and likely high costs of continuing to inhabit highly exposed locations. Designing managed retreat with affected communities can help ease the disruptive effects of resettlement, preserve shared ties and identities, and facilitate openness to new opportunities (Hino, Field and Mach, 2017[46]).

There are also intergenerational equity considerations. Insufficient climate resilience has a greater impact on future generations because they are likely to experience larger impacts of climate change. Yet current generations are necessarily the ones making decisions around climate resilience. This creates moral hazards for current decision makers to invest in less resilient infrastructure. They could benefit from potential immediate savings but would not pay the full cost of reduced climate resilience. Managing these trade-offs requires effective stakeholder engagement.

Governments need to strengthen engagement with local stakeholders across the infrastructure life cycle in three key ways to co-deliver resilience:

- **Seek diverse and representative inputs throughout the infrastructure life cycle but particularly when developing local spatial plans**. Governments can assemble citizen panels that represent local socio-demographic characteristics. Hachioji City (Japan) is using digital technologies to make stakeholder engagement more inclusive and accessible (Box 6.6), especially for young people. This can be important because young people will likely be more exposed than older people to climate change over their lifetimes yet have historically been under-represented in stakeholder engagement. Consultation is also relevant when shaping overarching policies. Between 2018 and 2019, Peru consulted with Indigenous communities to develop its Climate Change Law, culminating in 152 agreements, of which 147 were successfully implemented (OECD, 2023[44]).
- **Support transparent engagement processes to help resilience policies be successful**. Transparency can build public confidence in engagement processes and outcomes. For example, governments can publish submissions received during consultation as one way to limit the disproportionate impact (or "capture") of special interest groups. This can prevent resilience-building actions being disproportionally directed towards the groups with the greatest capacity to engage. It can also help build public understanding of the issue at hand and encourage other stakeholders to have their say, especially if they do not feel existing submissions reflect their viewpoints.
- **Considering and communicating trade-offs during stakeholder engagement can support more productive discussions.** There are rarely perfect solutions to building resilience against climate change. Governments need to communicate the inherent trade-offs involved in climate-resilient infrastructure to help communities make informed and practical decisions. For example, governments can develop and model scenarios to help communities understand the impacts of various resilience-building actions. Governments can also ask communities to rank the importance of outcomes (such as lower climate risk versus lower cost of resilience building) to better understand community priorities. Further, they can develop digital platforms for communities to explore alternative models of development (Box 6.6).

Box 6.6. Japan Project PLATEAU

PLATEAU is a 3D city open data platform covering 117 cities across Japan. It is a type of digital twin, or digital representation of physical objects. Led by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), PLATEAU mapped administrative data held by local governments to spatial data. MLIT has collaborated with local governments, industry and academia to explore use cases, including mapping underground infrastructure, modelling climate policies and automating permit processes.

Digital twins like PLATEAU can help make public engagement more inclusive and interactive, leading to greater community buy-in. These tools enable innovative technologies, such as augmented reality, to support public engagement. Users can visit sites virtually, visualise proposed infrastructure and interact with others without having to travel. The use of innovative technologies can also increase participation of young people, who are often under-represented in community engagement.

Local governments across Japan have used PLATEAU to gather citizen voices during infrastructure planning. For example, the local government of Hachioji City in Tokyo ran a gamified workshop to generate and visualise redevelopment ideas for a brownfield site. Users found it convenient to visualise data and found the online environment conducive to productive discussion. The workshop attracted a diverse audience, with over a third of participants under 30 years of age (a demographic not typically engaged with traditional investment planning).

Beyond stakeholder engagement, cities are using PLATEAU to support a range of resilience-building actions. For example, Tottori City is using PLATEAU to simulate flooding scenarios and improve evacuation routes. Meanwhile, Nagoya is running thermal environment simulations to assess the impact of climate change on extreme heat and the urban heat island effect.

Source: Japane Ministry of Land, Infrastructure, Transport and Tourism (2022[47]), XR技術を活用した市民参加型まちづくり, https://www.mlit.go.jp/plateau/use-case/uc22-015/

6.3. Multi-level governance for climate resilience

Harness multi-level governance to support resilience at the relevant scale, co-ordinate actions across and among levels of government, and build local capacity

Multi-level governance refers to the complex public governance across and within several layers of government, which are constantly evolving (OECD, 2017[48]). Given climate resilience and infrastructure are shared responsibilities across and within levels of government, it is important to understand and improve multi-level governance systems to support effective climate resilience actions across all regions and cities (OECD, 2013[49]). Managing relationships between and within levels of government is important. Since policy competencies are almost always shared, poor co-ordination threatens the effective delivery of climate-resilient infrastructure (OECD, 2014[17]). Key shared competencies often include spatial planning, sectoral regulation, pipeline selection, funding, project design, project delivery and maintenance.

Acting at the right scale is critical. The optimal scale of infrastructure depends on the complex interplay between infrastructure systems and local characteristics. All infrastructure systems need to be resilient to climate change. However, the right scale of action varies across infrastructure sectors and across different climate hazards, and they do not always match administrative boundaries. There can also be important interactions between jurisdictions. Actions in one place can affect climate resilience in another, as is the case with developments that impact a river system. Thus, there is a strong need for multi-level co-ordination across levels of government.

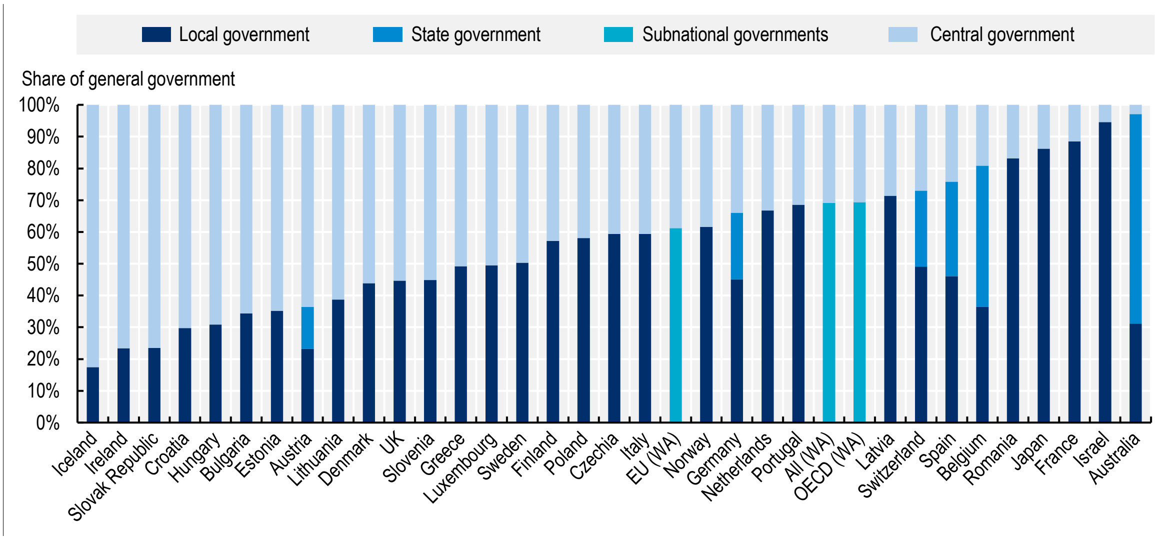
6.3.1. Strengthen vertical co-ordination across levels of government

The cross-cutting nature of climate change calls for all levels of government to deliver climate- resilient infrastructure. The large number of, and complex relationship between, governments across local, regional, national and supranational levels can make aligning these efforts difficult. The encouraging progress of many governments in mainstreaming climate change creates a stronger need for inter-agency co-ordination to align different sectoral and policy perspectives into a coherent unified vision. Further, governments often have different priorities, face different incentives and have different fiscal and planning capacities. Together, these can result in actions that work at cross purposes and do not harness synergistic opportunities (OECD, 2014[17]).

Vertical co-ordination can help align climate-resilient infrastructure investments by supporting policy and investment coherence, resolving conflicts and mobilising shared competencies across levels of government. Governments in OECD countries share infrastructure policy and planning competencies across levels of government. On average, subnational governments undertook 69% of all climate-significant public investment in 33 OECD and EU countries in 2019 (Figure 6.3). Credible co-ordination mechanisms with clear incentives can help maximise benefits and limit transaction costs. For example, setting up joint authorities could reduce set-up and overhead costs by sharing resources and capturing economies of scale. It is not always realistic to co-ordinate on everything, but at the very least different levels of government should work together and not against each other.

Figure 6.3. Infrastructure policy and investment competencies are shared across levels of government

Climate-significant public investment by level of government in OECD and EU countries, 2019



Note: Climate-significant public investment includes both adaptation and mitigation finance. WA = weighted averages.
Source: OECD (2022[4]), Subnational Government Climate Finance Hub, https://www.oecd.org/regional/sngclimatefinancehub.htm.

All governments are responsible for vertical co-ordination, which needs to be both bottom-up and top-down. Such co-ordination is not limited to higher-level governments overseeing lower-level governments. It also includes harnessing the full set of mutually dependent competencies that do not exist in any single layer of government (OECD, 2019[50]). To strengthen vertical co-ordination for climate resilience, governments can take the following actions:

- **Develop high-level climate policy to set policy priorities, guide policy making and align priorities across all levels of government**. National governments can publish national climate resilience policy statements to set clear directions and objectives for the development and infrastructure plans of regional and local governments. For example, Germany adopted its first nationwide climate adaptation law in December 2023. The new law defines the strategic framework for future climate adaptation at federal, state and local levels. This framework aims to co-ordinate climate adaptation at all levels and to enable progress across all fields of action. With the law, the German government also commits to pursuing a precautionary climate adaptation strategy with measurable goals (BMUV, 2023[51]). The Delta Programme in the Netherlands provides an example of both vertical and horizontal co-ordination to build resilience against flooding and secure freshwater resources (Box 6.7). In Peru, the Ministry of the Environment is working with the regional governments of Cusco and Ucayali to update instruments, standards and plans for climate adaptation (GIZ, 2023[52]).
- **Adopt intergovernmental contracts to support co-ordination across levels of government.** Vertical co-ordination can also take the form of intergovernmental contracts or deal-making between the central and subnational governments. In France, the government has developed a

new type of contract with French inter-municipal groups to align policy priorities and advance green transition goals (Box 6.8).

- **Co-develop projects to harness joint competencies across levels of government to make the most of existing capacities**. A regional and a local government might co-fund a feasibility study for a major infrastructure project. The regional government can provide technical expertise that might not be available at the local level. Meanwhile, the local government can provide the local networks and context needed for effective stakeholder engagement.
- **Consult and engage regularly to identify opportunities and bottlenecks**. National governments can launch formal consultation processes with city and regional officials and residents to better understand climate-related urban and regional issues and secure political buy-in. For example, they can establish National Climate Change Councils, comprising representatives from both central and subnational governments, as well as other key stakeholders including civil society. Such Councils can serve as a platform for discussions, policy co-ordination and collaborative decisions to address climate change challenges and implement effective climate policies. This can take the form of climate resilience task forces or dialogue forums. In Canada, the federal government collaborated with the provinces and territories to develop the Pan-Canadian Framework on Clean Growth and Climate Change. This co-operation platform, introduced in December 2016, committed the governments to address climate change, reduce greenhouse gas emissions, foster clean economic growth and build resilience to climate impacts across the country (OECD, 2023[1]). In the Dominican Republic, the National Council for Climate Change and Clean Development Mechanism provides regular stakeholder meetings across government, utilities, business associations and civil society organisations as a means of co-ordinating adaptation policy and action (OECD, 2023[44]).

Box 6.7. Netherlands Delta Programme

Much of the Netherlands sits on deltas, with around 55% of the country susceptible to flooding. Coastal and river floods could affect more than half of the population and two-thirds of economic activity (OECD, 2014[53]). Following the floods of 1953, the Dutch government introduced measures to protect the country more effectively from flooding. However, further action is needed to cope with the future impacts of climate change.

The Delta Act, adopted in 2012, established the Delta Programme, the Delta Commissioner and the Delta Fund. It advanced an adaptive governance approach to respond to the country’s current and future challenges on water safety and freshwater supply. It also aims to improve the system of flood defences with a vast programme of construction and land management – the Delta Works. The 2009 Water Act established four river basins as the basis for integrated water management. The Delta Act on Flood Risk Management and Freshwater Supplies, passed as an amendment to the Water Act, provides the backbone of the Delta Programme.

The Delta Programme is a national planning instrument with three objectives: flood risk management, freshwater availability and spatial adaptation. The Programme is a joint endeavour between the central government, provinces, municipal councils and regional water authorities, in close co-operation with social organisations and businesses. It sits alongside the National Climate Adaptation Strategy as the core component of Dutch climate adaptation policy. The Delta Programme Commissioner oversees the Programme and updates plans every year.

The Delta Programme has an estimated annual budget of EUR 1.5 billion on average between 2023 and 2036. Around half of the budget is targeted at new investment and the other half for overhead, management and maintenance.

Source: Government of the Netherlands, (n.d.[54]) Delta Programme: flood safety, freshwater and spatial adaptation, https://www.government.nl/topics/delta-programme/delta-programme-flood-safety-freshwater-and-spatial-adaptation; IMF (2023[55]), *Assessing Recent Climate Policy Initiatives in the Netherlands*, https://doi.org/10.5089/9798400235849.018; OECD (2014[53]), *Water Governance in the Netherlands: Fit for the Future?*, https://doi.org/10.1787/9789264102637-en.

6.3.2. Strengthen horizontal co-ordination across regions and cities

The impacts of, and solutions to, climate change do not always conform to administrative boundaries. Climate-resilient infrastructure cannot exist in isolation as insufficiently resilient infrastructure can have spillover effects across jurisdictions, potentially affecting areas with limited influence over said infrastructure. Local infrastructure failure could have far-reaching effects. This is especially the case in networked infrastructure, such as highways or electricity grids, where damage to a node could deteriorate performance across entire networks. Similar dependencies exist in shared water catchment areas.

The interdependence of infrastructure systems means that building climate-resilient infrastructure in one place and sector often requires actions in other places and sectors. This calls for horizontal co-ordination across governments to improve the coherence of efforts to make infrastructure more climate resilient. In the United States, for example, the 2021 power crises in the state of Texas highlight both dimensions. A winter storm in Texas caused insufficiently weatherised natural gas power plants to fail. This, in turn, shut down parts of the natural gas network, leading to further power plant failures. Although the plant failures occurred in specific places, the connectivity of the Texas Interconnection caused price spikes and demand imbalances across the power grid. The event led to blackouts with vast economic impacts and loss of lives across the state (University of Texas at Austin Energy Institute, 2021[56]).

Strengthening horizontal co-ordination across national and subnational boundaries is key to ensuring that infrastructure systems and networks are resilient. Horizontal co-ordination often occurs between neighbouring jurisdictions but is beneficial between any governments with similar climate challenges and solutions. There is no one-size-fits-all solution since different places and sectors have different contexts that call for different co-ordination approaches.

Governments can support horizontal co-ordination and reduce co-ordination costs through many mechanisms – from the simple (such as ad hoc meetings) to the complex (such as territorial reforms). Four potential actions are to:

- **Support peer learning through regular dialogue and co-operation to build local knowledge**. Local governments can convene regular forums to share experiences on building more climate-resilient infrastructure and co-ordinate future investment plans.
- **Create forums for co-ordination on specific climate hazards to seek shared solutions.** Governments sharing a catchment network can meet regularly to identify the impact of climate risks across the catchment and identify shared solutions. Depending on the hazard, these can range from informal networks to formal and structured inter-governmental agreements. The Hamburg Metropolitan Region in Germany spans four federal states, creating an important need to co-ordinate spatial planning and infrastructure investment across jurisdictional boundaries. In recognition of the need for collaboration, governments in the metropolitan region are developing an informal spatial plan for the entire region (OECD, 2024[57]).
- **Harness economies of scale by pooling planning and fiscal resources at the relevant scale**. Governments within an urban functional area could establish joint water infrastructure authorities to streamline planning, funding and delivery of stormwater networks that are more resilient to extreme rainfall. Non-neighbouring jurisdictions can also pool fiscal resources, such as for insurance. In the Philippines, the Asian Development Bank supported the Philippine City Disaster

Insurance Pool to provide rapid post-disaster access to pay-outs for local tiers of government by pooling disaster risk insurance (See Chapter 3).

- **Provide horizontal contracts to incentivise delivery and maintenance of critical infrastructure where there are local costs but regional benefits**. Maintenance costs of a flood barrier may fall entirely upon one jurisdiction though it provides benefits to multiple jurisdictions. Governments along the watershed may compensate the government maintaining the flood barrier to ensure the asset is properly maintained. In France, contracts for the Success of the Ecological Transition require horizontal co-ordination mechanisms to ensure policy actions at the relevant scale (Box 6.8).

Box 6.8. France: Contracts for the Success of the Ecological Transition (CRTEs)

The absence of an effective collaboration mechanism between different levels of government frequently undermines the successful implementation of policies and strategies. Overarching policies initiated by the central government may overlook the nuanced needs and priorities of local governments, requiring local authorities to adjust their specific actions to align with broader objectives. Uneven distribution of resources further compounds these challenges. This is because disparities in financial support, personnel and technical assistance can significantly affect the capacity of regional and local governments to design and enforce policies effectively.

In France, the Contracts for the Success of the Ecological Transition (*Contrats pour la réussite de la transition écologique* – CRTEs) provide a framework for local and municipal bodies to manage the co-ordination challenges around territorial cohesion and the ecological transition. Initiated in 2020 by the government of France, CRTEs aim to promote collaboration between the central government, subnational governments, and local public and private actors. A steering committee of stakeholder representatives develops the contracts, which outline specific projects, objectives, financing plans and monitoring indicators. These priorities are defined locally but agreed upon with central government. When the contract is in force, inter-municipal co-operation bodies can access project funding from a range of sources, including the Local Investment Support Grant, EU funds, relevant government ministries, the private sector and regional *Conference des Parties*.

CRTEs are designed to span six years, during which the steering committee monitors the annual progress of projects against pre-set objectives. An online toolbox provides guiding documents and indicative templates for each stage of the contract, enhancing transparency and awareness. CRTEs facilitate alignment of policies across different levels of governments, addressing the requirements of both national and local priorities. They promote not only vertical co-ordination between national and subnational governments but also horizontal co-operation among municipalities. Between 2021 and 2023, 847 inter-municipal or multi inter-municipal contracts were successfully implemented. In addition, CRTEs have led to innovative tools such as an ecological transitions compass (self-assessment tool) and territorial indicators that inform decision making and planning.

Source: OECD (OECD, 2022[58]), Subnational government climate expenditure and revenue tracking in OECD and EU Countries, https://doi.org/10.1787/1e8016d4-en; Agence nationale de la cohésion des territoires (n.d.[59]) Contrats pour la réussite de la transition écologique, https://agence-cohesion-territoires.gouv.fr/le-crte-un-contrat-au-service-des-territoires-et-de-la-mise-en-oeuvre-de-la-planification.

6.3.3. Scale up regional and local capacity to build climate resilience

Building climate-resilient infrastructure requires public and private sector capacity at a regional and local level. Many regions and cities already face capacity constraints (OECD, 2024[60]). Megatrends such as demographic change and globalisation threaten to further strain regions and cities' capacities, with varying impact across places (OECD, 2022[2]). Climate change, for example, could shape regions and cities' attractiveness, affecting their ability to attract public and private sector talent (OECD, 2023[24]). Capacity constraints are often most acute locally. This means that regional and local governments will have an essential role to identify, anticipate and tackle capacity gaps across both the public and private sectors.

There is room to further strengthen public sector capacity and expertise for climate-resilient infrastructure, especially in subnational governments. As the authority and responsibility of governments increase so does their need for capacity (OECD, 2014[17]). The significant role of many subnational governments in planning, regulating, consenting, funding, procuring and operating infrastructure highlights the need to reinforce subnational public sector capacity to cope with the increasing demand for climate-resilient infrastructure. Failure to do so could hurt the framework conditions needed to support climate resilience (OECD, 2014[17]) by, for example, delaying approval and consent.

Regional and local governments can face considerable barriers in building institutional capacity. Some governments operate in ageing regions with reduced labour supply and limited specialised skills. These governments might not be able to offer salaries competitive with the private sector. Smaller regions and cities in particular can find it difficult to acquire the diversity of competencies needed (OECD, 2014[17]). Boosting participation of under-represented groups, such as young people, women and minorities, remains a challenge in many places. However, it also offers opportunities to improve equity and expand the workforce needed to build climate resilience (Brookings, 2022[61]; OECD, 2023[62]).

The need for climate resilience is demanding new skills, roles and competencies. Yet these demands are neither uniform nor static. Instead, they depend both on the place-based impacts of climate change over time and the differing baselines of different places. Increasingly, regional and local governments are creating new roles, such as Chief Resilience Officers, to co-ordinate resilience-building efforts within their jurisdictions (CEB, 2022[63]). Building long-term climate resilience will require investing in skills that go beyond knowing how to build resilient infrastructure (such as environmental engineering). They will also include skills needed for individuals and communities to cope with climate hazards (such as knowledge of which climate hazards are present locally) (OECD, 2023[64]). There is also a need to better understand the impact of emerging technologies, such as artificial intelligence and modular construction, on the types and volumes of skills needed to build climate-resilient infrastructure. Regions and cities will play a central role in providing the training, education and communication that is tailored to the place-based climate vulnerabilities faced by specific communities.

Implementing the vast pipeline of resilience-building actions will require boosting capacity in the private sector. Local small and medium-sized enterprises (SMEs) and innovative green start-ups can have a key role in infrastructure delivery and climate innovation. Therefore, there is a need to harness and strengthen climate competencies and local ecosystems to support green entrepreneurship (OECD, 2023[65]).

To build the capacity of regions and cities for building climate resilience, governments can take the following actions:

- **Support subnational governments to scale up their capacity to build climate-resilient infrastructure.** National governments can provide grants to fund access of subnational governments to capacity building (such as through technical assistance from experts, experience-sharing with peers and creation of capacity-building facilities). In the United States, philanthropic organisations, such as the Local Infrastructure Hub and Accelerator for America, are helping train local government officials to deliver historic levels of investment (OECD, 2024[60]).
- **Pool and share capacity between governments to make the most of limited capacity**. Regional governments can create public sector consultancies to provide on-demand technical assistance to local governments. This is especially useful for competencies that are important to retain but not necessarily used often at the local level. In Germany, the government-owned consultancy PD provides infrastructure advisory services to public sector clients throughout the

country, including state and municipal governments. In 2021, Germany also launched the Climate Adaptation Centre to support municipalities and social institutions in designing and implementing climate adaptation measures (Box 6.9).

- **Co-ordinate with each other and with the private sector to build market capacity**. Governments can identify and share anticipated capacity gaps resulting from the planned infrastructure pipeline. This can help stakeholders identify required skills, as well as where and when they are needed, to meet the workforce demand required for climate resilience (OECD, 2024[66]).
- **Explore the role of Chief Resilience Officers to help mainstream and co-ordinate climate resilience in governments**. First created in 2013, Chief Resilience Officers (CROs) can help co-ordinate planning and implementation of resilience building actions across government (CEB, 2022[63]). The Resilient Cities Network connects more than 200 CROs, policy makers and researchers in over 100 cities to advance urban-oriented resilience solutions (Resilient Cities Network, n.d.[67]).

Box 6.9. Germany PD in-house public sector consultancy and Centre for Climate Adaptation

It is important to develop public sector capacity at the right scale. Governments, especially smaller subnational governments, can find it challenging to justify permanent staffing for large but less frequently used competencies, such as digital transformation, large-scale procurement and major project delivery. These competencies are often outsourced to higher levels of government or the private sector. However, this can result in higher costs, reduced local knowledge and long-term attrition of local expertise. These pose significant challenges for building climate resilience given the specific skillsets demanded, especially with the volume of infrastructure investment needed over the coming decades.

PD, the German in-house consultancy of the public sector

PD, a consultancy owned by the public sector, advises public sector clients in Germany on infrastructure and modernisation. PD is jointly owned by 202 stakeholders, including 14 state governments and 132 local governments. The consultancy model helps build experience at scale within PD, which might not be possible for local governments. It also encourages cross-pollination of ideas across places and sectors. Since PD is partly owned by subnational governments, it can be more responsive to their needs and priorities compared with a fully nationally owned alternative. PD has advised on a range of projects contributing to climate resilience, including Brandenburg's climate change adaptation strategy and Hamburg's urban economic strategy (including an adaptation component).

Centre for Climate Adaptation

In 2021, the German Federal Environment Ministry launched the Climate Adaptation Centre (Zentrum KlimaAnpassung) to support German municipalities and social institutions in designing and implementing climate adaptation measures. Hosted by the German Institute of Urban Affairs and Adelphi Consult, it provides needs-based support to local actors such as municipal climate adaptation managers (a priority role supported by the new climate adaptation law). It has gathered experts from national government, subnational government, academia and civil society to pool institutional knowledge, including those tailored to the local level.

Source: PD (n.d.[68]), https://www.pd-g.de/en/; Zentrum KlimaAnpassung (n.d.[69]), https://zentrum-klimaanpassung.de/.

6.4. Subnational finance for climate resilience

Subnational governments have key responsibilities linked to climate resilience and are responsible for 69% of climate-significant investment. Thus, it is important to support subnational government finances to ensure these governments can generate funding and mobilise finance for local climate resilience actions.

Regional and local governments are important investors in climate-resilient infrastructure. In 2019, they undertook 69% of all climate-significant public investment in OECD and EU countries,[2] equivalent to 0.4% of gross domestic product (Figure 6.3). They are directly responsible for setting policies and providing infrastructure and services in sectors related to climate resilience such as water, waste, housing, transportation and energy (OECD, 2022[70]). Further, regional and local governments carry out regulatory functions (such as land-use planning, project permitting and standard setting) that can influence both public and private sector efforts to build climate resilience.

Climate change could place fiscal stress on regional and local governments regarding both revenue and expenditure. Asset damage, property value loss, business disruption and community displacement from climate change could threaten revenues of subnational governments. Meanwhile, the need to recover from climate-related disasters and build resilience will require greater up-front expenditure, which is often shouldered by subnational governments (Gilmore, Kousky and St. Clair, 2022[71]). Ratings agencies view climate risk as increasingly important, with negative impacts on subnational governments' access to finance (S&P Global Ratings, 2023[72]). In the United States, officials in the city of Miami noted how climate-resilient infrastructure can strengthen credit ratings (Cox, 2021[73]). Further, there are questions around the long-term sustainability of subnational government-backed insurance schemes supporting homeowners priced out of private insurance from climate risks (Smith, Mooney and Williams, 2024[74]).

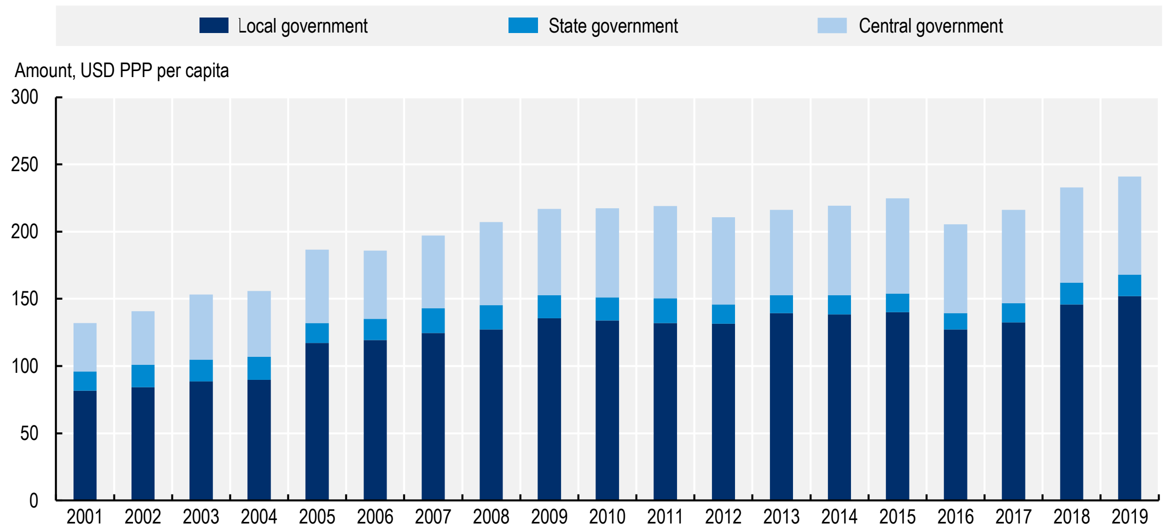
The amount of climate-significant investment has increased over the past decade but must further increase to meet climate resilience goals (Figure 6.4). In 2019, subnational governments accounted for 63% of climate-significant public expenditure and 69% of climate-significant public investment in OECD and EU countries (OECD, 2022[4]). However, subnational climate-significant investment remains relatively low compared to total subnational expenditure. In 2023, six in ten municipalities in the European Union reported their planned investment in climate-resilient infrastructure as insufficient; those in less developed regions faced greater uncertainty to increase investment (EIB, 2023[26]).

Regional and local governments have a key investment role but face more and different barriers to accessing funding and financing than national governments (OECD, 2022[13]). Investing in local climate resilience will require subnational governments to fund investment through a mix of self-funding and capital transfers, as well as by mobilising finance through borrowing (OECD, 2022[13]). Yet fiscal frameworks can sometimes limit the funding and financing capacity of subnational governments.

Subnational government debt sat at 19% of total public debt on average in OECD countries in 2021 (OECD, 2023[75]), with strong variation across countries and subnational governments. Already, many subnational governments are fiscally stretched. Indeed, one survey suggests that one in five councils in England could declare bankruptcy by 2024 due to lack of funding to maintain essential services (Local Government Association, 2023[76]). In many countries, these debt measures do not include potential contingent liabilities linked to climate change. Low fiscal capacity could limit the ability of governments to make needed investments for climate resilience, even where they are likely to have a positive economic impact in the long term. Yet the cost of inaction could be higher.

Figure 6.4. The increase in climate-significant public investment must continue to help regional and local governments improve climate resilience

Climate-significant investment by level of government in OECD countries, USD PPP per capita (real terms)



Source: (OECD, 2022[4]), Subnational Government Climate Hub, https://www.oecd.org/regional/sngclimatefinancehub.htm

Many essential local investments in climate resilience and climate-resilient infrastructure (such as flood protection, coastal protection and stormwater infrastructure) might not generate revenue. Investors are increasingly interested in climate-resilient infrastructure (The Economist, 2024[77]). However, private investment will not be sufficient to fund all resilience-building actions, particularly those that are not financially viable. Even after accounting for the savings in remedial costs of addressing climate impacts that new climate-resilient infrastructure can avoid, building climate resilience often generates net positive economic benefits (World Bank, 2019[8]). The gap between economic and financial viability means that governments can find it challenging to raise revenue to cover funding. This is especially the case because resilience benefits can be difficult to quantify or attribute to specific investments or beneficiaries (see Chapter 3).

The risk of revenue shortfall could have a strong impact on regional and local governments due to their smaller size and more limited revenue-raising powers. Many regional and local governments can increase funding through general taxation. However, this is not always appropriate (if the benefits are not broad-based) or feasible (if raising taxes is politically contentious or if fiscal frameworks do not allow for general taxation). Their smaller size, smaller asset bases, less diversified revenue streams and often more limited financial competencies compared to national governments can also increase financing costs for regional and local governments. The growing challenge of population shrinkage in many urban and rural areas in OECD and non-OECD countries is likely to put further pressure on the public revenues needed to fund climate-resilient infrastructure (OECD, 2023[78]). Meeting the scale of the local resilience tasks will require identifying appropriate funding avenues.

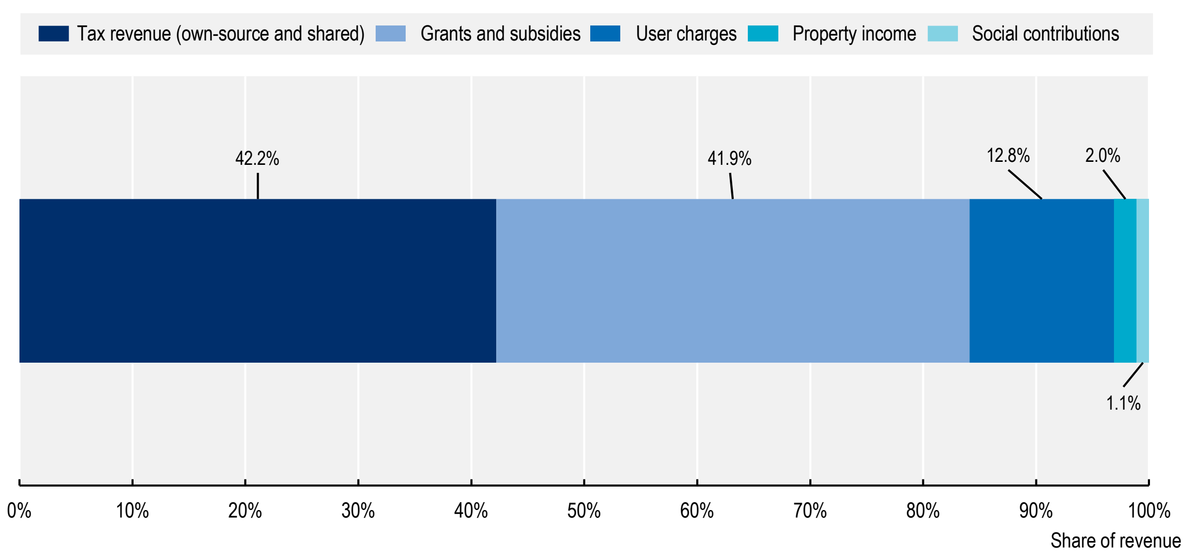
Climate-resilient infrastructure may have lower life-cycle costs (in part due to reduced risk of climate damages). However, it may also require greater up-front costs (in part due to higher initial capital expenditure) (See Chapter 3). The additional investment to make exposed infrastructure more resilient in developing countries is estimated at USD 11-65 billion per year (World Bank, 2019[79]). However, the net benefits could reach USD 4.2 trillion, with every dollar invested returning four dollars in benefits (World Bank, 2019[8]). This means that resilient infrastructure can require both greater up-front costs but also create greater long-term benefits relative to non-resilient infrastructure (see Chapter 1). As a result, subnational governments need greater funding and financing capacity to meet the greater up-front costs.

6.4.1. Seek alternative revenue sources and funding solutions for climate resilience actions

Subnational governments will need to mobilise a diverse set of funding instruments to fund investments in climate resilience. Across the OECD, most subnational government revenue comes from taxes (shared and own source), grants and subsidies from higher levels of government and, to a lesser extent, from user charges, fees and income from assets (Figure 6.5). Some governments also deploy “asset recycling” and “land value capture” to raise funding for new infrastructure (see Chapter 3).

Figure 6.5. Taxes, grants and subsidies account for over 80% of subnational government revenue in the OECD

Subnational government revenue in OECD countries by source, 2021



Source: (OECD, 2023[75]) , Subnational Governments in OECD Countries: Key Data, https://www.oecd.org/regional/multi-level-governance/NUANCIER%202023-3.pdf.

The type of instruments used and volume of revenue gathered vary substantially across and within countries, notably depending on the level of fiscal decentralisation. Regions and cities operate in different fiscal, regulatory and governance contexts, affecting their revenue-raising autonomy, decisions and potential (OECD/UCLG, 2022[3]). Diversifying revenue-raising sources can help regional and local governments build up their fiscal resilience and capacity to deliver climate-resilient infrastructure (OECD, 2022[13]).

Regions and cities will need to deploy innovative instruments to capture local revenue to boost funding and secure political buy-in for climate-resilient infrastructure. They also need to manage the fiscal impacts from demographic change, digitalisation and COVID-19, which can put pressure on the revenue-raising instruments that regional and local governments rely on. Moreover, not all regions and cities have the same revenue-raising capacity. This means that fiscal transfers may be needed to build climate-resilient infrastructure, especially in disadvantaged regions, those with lower own-sourced revenue or those more in need of climate-resilient infrastructure (see next section).

A key question, therefore, relates to equity, fairness and how governments distribute the costs of climate-resilient infrastructure between people and places. In general, there are three approaches – user pays, polluter pays and progressive redistribution – but the appropriate mix will depend on local contexts (Figure 6.3). Climate-resilient infrastructure services could be more expensive to provide in places more exposed to climate hazards, but some view entirely cost-based charges as unfair (New Zealand Infrastructure Commission, 2024[80]). In turn, these raise the potential for solidarity mechanisms and equalisation systems to mitigate potentially higher costs for vulnerable communities. The costs and benefits of climate-resilient infrastructure do not necessarily align with local administrative boundaries. Therefore, questions also arise concerning shared costs across benefiting governments, regardless of the asset's physical location.

Table 6.3. Pricing approaches to fund climate-resilient infrastructure

Approach	Main source of funding	Advantages	Disadvantages	Example instrument
User pays	Those who use or benefit from the asset	Horizontal equity, market efficiency	Unequal access, potential under-provision	Tariffs, congestion charges
Polluter pays	Those who have caused the need for the asset	Justice, deterrence	Might not be feasible, especially at global scale	Environmental taxes
Progressive redistribution	Those who can pay	Vertical equity, equality	Inefficiencies	Grants

National, regional and local governments need to work together to ensure subnational governments have access to instruments to fund essential climate investments in regions and cities. Both traditional and innovative instruments can help mobilise alternative sources of revenue that are fair, equitable and sustainable. To do so, governments can take the following actions:

- **Ensure that fiscal frameworks provide appropriate sources of self-funding**. National governments can ensure subnational governments' revenue-raising powers are sufficient to meet their investment needs for climate resilience. Among other areas, they can provide flexibility to raise taxes, set localised tariffs and set regulatory guidelines that balance the needs for increased financing (vs. maintaining strong creditworthiness to reduce fiscal risks). This helps avoid these governments from having "unfunded mandates".
- **Consider earmarked funding instruments for resilience building**. Earmarking the proceeds of new revenue sources can help build public support for new revenue mechanisms and increase government transparency (OECD, 2021[81]). For example, regional governments can apply a levy on water rates that is hypothecated to projects that make the stormwater system more resilient to climate change. There could be specific earmarking of current ongoing expenditure to fund infrastructure operations and maintenance. Different climate-resilient infrastructure needs will likely require different funding solutions that are accepted by the community (Table 6.4).
- **Design land value capture schemes that help recover the cost of climate-resilient infrastructure in a spatially targeted way** (OECD/Lincoln Institute of Land Policy, PKU-Lincoln Institute Center, 2022[82]). Municipal governments can uplift property rates near a transit corridor to help fund the delivery of the transit project, on the grounds that nearby property values are likely to increase as a direct consequence of the project. Local governments in Korea are charging developers for additional development rights, the proceeds of which are earmarked to local infrastructure improvement projects (Box 6.10).
- **Target current and capital expenditure to adaptation through green budgeting** (Box 6.11). Green budgeting can help governments ensure their expenditure and investment projects support adaptation (OECD, 2022[70]). Long-term green budgets better match the long-term nature of climate resilience and can help "price-in" potential contingencies around climate losses and damages.

Table 6.4. Meeting different climate-resilient infrastructure needs will require mobilising different funding instruments

Illustrative examples matching climate-resilient infrastructure needs with appropriate funding solutions

Example of climate-resilient infrastructure	Possible funding instrument(s)	Rationale
Climate-proofed electricity transmission connection to industrial customer	User pays	Benefits of more resilient power supply largely accrue to customer requesting connection, as they are the only user on the improved connection. Grid owners could also provide funding if they subsequently gain ownership over the asset.
New rapid transit line	General taxation, user pays and land value capture	Benefits of more resilient connectivity solutions are broad, but there are additional specific benefits to communities located near the transit corridor and users.
Flood barrier to shield critical highway link from inundation	Earmarked environmental tax, grants	Benefits of more resilient highways largely accrue to motorists, who could pay additional petrol taxes (potentially to regional and local governments). User pay (such as toll booths) is not always practical due to site constraints. Further, increased resilience of critical highway link also increases resilience of entire network, benefiting not just those who use the link but those using the entire highway system. Higher-level governments could contribute funding if the highway link is considered nationally significant.
New reservoir to increase water supply resilience to droughts	User pays	Benefits of resilient water supply are broad. Where water is metered, it is relatively straightforward to implement volumetric charges to recover funding over time. If the reservoir can bring benefits to users outside of the local water management area, there is room for horizontal transfers to the authority operating and maintaining the reservoir to boost ongoing funding.
Flood barrier to shield entire urban area from inundation	Land tax, land value capture, carbon tax and/or earmarked grant	Benefits of flood resilience are broad across the urban area. Revenue could be raised solely from the targeted area. Alternatively, a national carbon tax could raise revenue from polluters, which could fund the investment.

Box 6.10. Korea Floor-Area-Ratio (FAR) incentive system

Rapid growth and urbanisation can put stress on infrastructure systems. These systems may not be climate resilient today let alone in the future. As more people and assets become exposed, there is a need to scale-up both the amount of infrastructure to cope with increased demand and its resilience against climate hazards.

The Floor-Area-Ratio (FAR) system in Korea mobilises private funding to boost local infrastructure in anticipation of growth. In exchange for increased development rights (usually increased density), developers negotiate with local authorities to contribute to local infrastructure through cash or direct provision. The cash is earmarked for local infrastructure improvement, which can be targeted to resilience-building actions. Charges are based on project characteristics and estimated land value gains from increased density. In addition to FAR, Korea also has other local-level land value capture instruments, such as mandatory developer obligations and land readjustment processes. In principle, the revenue raised does not have to go to climate-resilient infrastructure. In practice, the revenue contributes to local climate resilience in combination with other instruments, such as planning, infrastructure standards and local investment priorities. For example, Seoul is permitting greater densities in the Yeouido financial district in exchange for eco-friendly building designs.

First introduced in Seoul Metropolitan City in 2009 for housing, FAR was expanded to the whole of Korea in 2011 for all developments. It is widely used by local governments to collect revenue. Combined with other land value capture instruments, FAR enables almost all infrastructure improvement costs to be borne by developers.

Source: OECD/Lincoln Institute of Land Policy (2022[82]), Global Compendium of Land Value Capture Policies, https://doi.org/10.1787/4f9559ee-en; BusinessKorea (2023[83]), Seoul Metropolitan Government Lays Out Yeouido Financial Center District Development Plan, https://www.businesskorea.co.kr/news/articleView.html?idxno=115434

Box 6.11. Green budgeting for regions and cities

Fiscal policy is an essential tool to build climate resilience. Green budgeting refers to a priority-based budgeting approach to align government budgets with climate and environmental goals.

Green budgeting is relatively new at the subnational level, but there is growing interest and uptake. Regions and cities face several hurdles to implementing green budgeting. Existing green budget methodologies at the national level do not always translate well to the subnational level due to differing fiscal competencies and contexts. Resource, operational and political challenges also exist in setting up new budgeting structures and relationships. As a result, green budgeting at the subnational level needs to fit local contexts – there is no one-size-fits all approach.

Aligning Regional and Local Budgets with Green Objectives: Subnational Green Budgeting Practices and Guidelines (OECD, 2022[70]) provides six guidelines to help regions and cities implement green budgeting:

1. Diagnose local environmental and climate challenges before launching green budgeting.
2. Ensure strong, high-level support from administrative and elected sides of government.
3. Have robust scientific basis to facilitate public trust and adapt to changing evidence.
4. Take a stepwise approach to implementation to learn from previous steps and reinforce the alignment of the practice with local strategic priorities.
5. Integrate green budgeting into existing procedures and tools to ensure the practice endures.
6. Include revenues within green budgeting to align the entire budget with green objectives.

In recent years, interest in subnational green budgeting has also grown steadily as has the number of subnational governments implementing green budgeting practices. France stands out for having a large number of green budgeting exercises at both regional levels (such as Brittany, Grand Est and Occitanie), and departmental and municipal levels (such as Lille, Strasbourg, Paris, Rennes and Lyon). For example, the region of Brittany launched its green budgeting practice in 2020 by assessing the climate adaptation and mitigation impact of expenditure (OECD, 2022[70]). Other interesting exercises were identified in Austria, Italy, Norway, Spain and the United Kingdom (OECD, 2022[70]).

In France, the 2024 Finance Law has generalised use of green budgeting in all regions, departments and municipalities with more than 3 500 inhabitants. In keeping with the law, financial accounts must include an annexed statement entitled “Impact of the budget for the ecological transition”. This new annex concerns investment expenditure which, within the budget, contributes negatively or positively to all or part of the ecological transition objectives of France, including mitigation and adaptation to climate change. The law also stipulates that subnational governments have the possibility of "identifying and isolating" the part of their debt devoted to financing investments contributing to environmental objectives, that is, their "green debt”.

Source: OECD Aligning Regional and Local Budgets with Green Objectives: Subnational Green Budgeting Practices and Guidelines, https://doi.org/10.1787/93b4036f-en; Caisse des Dépôts (2024[84]) Les budgets verts des finances locales : un premier pas sur lequel l’engagement local reste la clé, https://www.caissedesdepots.fr/blog/article/les-budgets-verts-des-finances-locales

6.4.2. Support subnational governments climate resilience through targeted fiscal support

As noted above, subnational governments can sometimes have high exposure to climate risks and low fiscal capacity. They may struggle to invest in climate-resilient infrastructure on their own, even if the investment could meaningfully reduce climate-related risks and costs that they may later incur. Moreover, climate resilience can create large benefits outside of local administrative boundaries. Consequently, national governments also play an important role to facilitate investments with wider benefits, including through targeted fiscal support to fill funding gaps.

Transfers can be key to addressing regional and local disparities, particularly where impacts have strong spatial variations – as is the case with climate change. However, overreliance on transfers to cover ongoing costs can expose subnational governments to possible future cuts. This could result in volatile funding for public services, and infrastructure operations and maintenance (OECD, 2023[85]). Many countries have fiscal equalisation schemes, which support regular transfers to maintain a standard level of public services across jurisdictions. Countries with such arrangements may have opportunities to redesign these schemes to better account for the different needs and capacities of regions and cities to build climate-resilient infrastructure (OECD, 2023[86]).

Upper-level governments need to work closely with lower-level counterparts to carefully design fiscal support to minimise associated risks. Funding for redistribution could come from environmental or general taxation. Earmarking can be appropriate to direct funding towards its intended purpose of climate resilience. However, excessive earmarking can infringe upon the autonomy of regional and local governments and limit their flexibility to adapt to changing circumstances (de Mello and Ter-Minassian, 2022[87]).

Upper-level governments (and international organisations) may allocate funding through formula-based grants or competitive grants. Formula-based grants allocate funding to jurisdictions based on specified criteria (such as on a per capita basis). Competitive grant funding is allocated based on the evaluation of competitive applications. Competitive grant-making can encourage innovation and help identify the most appropriate solutions. However, when poorly structured, it can also undermine collaboration among subnational governments and risk disadvantaging those with limited capacity.

National governments and international organisations (and state governments in federal countries) can take the following actions to provide targeted fiscal support for climate resilience:

- **Integrate climate-resilience considerations into the national system of intergovernmental current and capital transfers.** The system of national intergovernmental transfers (such as grants for transport, energy or business support) could be reviewed through a climate resilience lens. For example, climate resilience could be a condition for disbursement. Alternatively, the systematic climate change impacts of substantial intergovernmental transfers could be assessed. Either approach could also allow for more policy coherence across levels of government and sectors (such as energy, transportation, housing and land use) with climate resilience objectives. For example, the Climate Lens in Canada requires climate change resilience assessments for projects seeking funding through the Investing in Canada Infrastructure Program, Disaster Mitigation and Adaptation Fund, and Smart Cities Challenges (OECD, 2021[29]) (see also Chapter 2). At the international level, the European Union has considerably extended the use of conditionalities in its cohesion policy. Climate and environmental objectives are now an integral part of many EU-supported policy areas. For example, the EU Multiannual Financial Framework 2021-2027 requires that at least a quarter of the total EU budget relates to climate. In this way, it supports the mainstreaming of climate resilience across policy areas (European Parliament, 2023[88]).
- **Establish and develop capital transfers to subnational governments earmarked to climate resilience.** The international community and national and state governments can disburse capital grants to support climate-resilient projects developed by regions and municipalities that meet certain criteria. Subnational governments can benefit from some multilateral adaptation grant funding for projects that enhance resilience, such as the Green Climate Fund and the Adaptation Fund. However, it remains difficult for local governments to access these resources. Some examples of these funds are listed below:

- **International** – To help local governments in Least Developed Countries, Small Island Developing States and Africa access international adaptation funds, the United Nations Capital Development Fund has established the Climate Adaptive Living Facility. This combines performance-based climate resilience grants with technical and capacity-building support (Box 6.12).
- **Colombia** – During the 2010-11 La Niña, the government of Colombia created the National Adaptation Fund (Fondo Nacional de Adaptación). Since then, the fund has been empowered to execute comprehensive risk management and climate change adaptation projects with a multi-sectoral and regional approach (Government of Colombia, 2023[89]).
- **France** – The new French Green Fund (Fonds Vert), created in 2020, provides EUR 3.3 billion to help local authorities in mainland France and French Overseas Territories build their climate resilience (Ministere de la Transition Ecologique et de la Cohesion des Territoires, 2020[90]).
- **Germany** – The German government has established measures for adaptation to climate change under its Adaptation Strategy to Climate Change framework. The Federal Ministry for Environment provides support to municipalities for their projects related to heatwaves, floods and heavy rain events (ZUG, 2022[91]).
- **European Union** – Several funding streams and tools are accessible to subnational governments, including the Recovery and Resilience Facility, the LIFE programme and the European Climate Adaptation Platform (OECD, 2022[92]).

- **Work alongside subnational governments to develop mechanisms to reduce the impact of climate hazards on subnational finances**. For example, national governments can contribute top-up funding to help subnational governments purchase insurance that can limit climate-related fiscal risks and strengthen recovery efforts in the event of infrastructure failure. They can also encourage subnational governments to create "rainy day" funds.

Box 6.12. UNCDF Climate Adaptive Living Facility

The United Nations Capital Development Fund has introduced the Climate Adaptive Living Facility (LoCAL) to tackle the unmet mandate of local governments in addressing climate change adaptation. LoCAL is channelled through Performance-Based Climate Resilience Grants (PBCRGs) and local capacity building. PBCRGs provide a financial top-up to address the additional costs associated with building climate resilience. They have specific conditions, performance metrics and eligible investments to ensure local programming and verification. The funding of PBCRGs flows to local governments through fiscal systems. However, decision making occurs locally to support local adaptation programmes and align grant disbursements with local budgeting cycles. The flexibility of PBCRGs positions them as cross-sectoral grants for climate change adaptation. When combined with regular grants, PBCRGs can help transform investments in climate-sensitive sectors into resilient initiatives over time. National ministries regulate the system and undertake regular audits to monitor progress.

The mechanism advocates for incorporating climate change adaptation into local development planning and ensuring that local development plans and investments include the perspectives of communities and the most economically disadvantaged. This ensures that climate finance reaches those who need it the most in the most effective manner. Through a mix of financial support, technical assistance and capacity building, PBCRGs can help develop more robust and transparent government financial systems.

As of 2023, LoCAL has been tested in 20 countries and has mobilised over USD 180 million, mostly in the form of grants, to more than 350 subnational authorities, reaching over 16 million people.

Source: UNCDF (2024[93]), LoCAL Brochure 2023 (November Update), https://www.uncdf.org/article/8507/local-brochure-2023-november-update; UNCDF (n.d.[94]), Performance based grants for climate resilience, https://www.uncdf.org/local/performance-based-grants-for-climate-resilience.

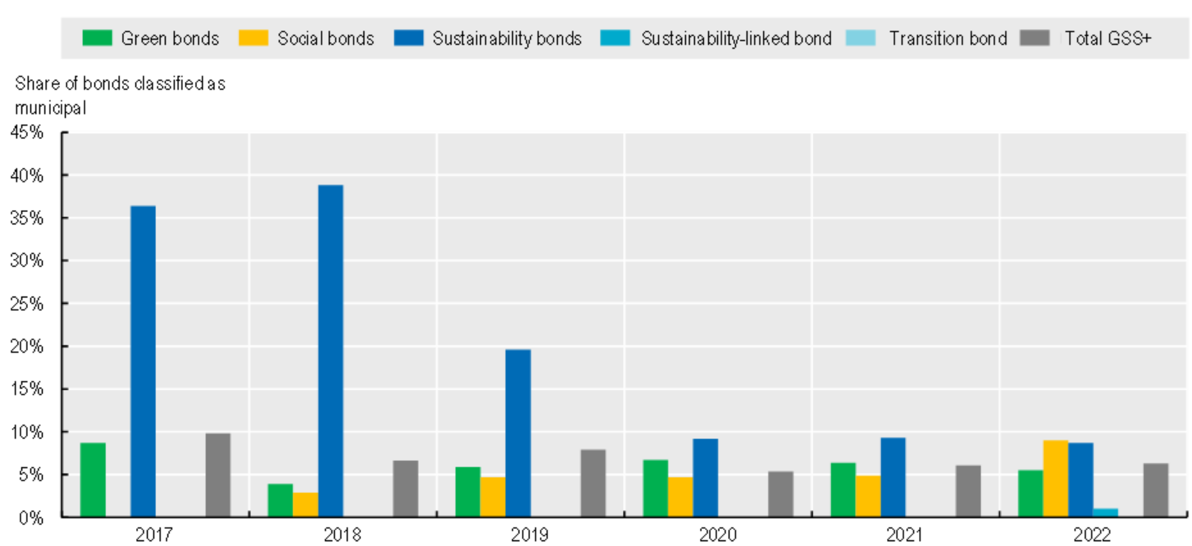
6.4.3. Unlock climate finance and private investment at a local level

Barriers to accessing international and domestic climate finance can be particularly high for regional and local governments. To reduce macroeconomic fiscal risk, national governments often establish fiscal frameworks that limit the ability of their regional and local counterparts to take on debt (OECD, 2022[13]). Beyond these frameworks, subnational governments need a high level of administrative capacity; the varying criteria for eligibility, selection and evaluation around climate finance can strain limited resources (IMF, 2023[95]). Subnational governments may also have insufficient fiscal capacity and low credit ratings, and local financial markets may be under-developed (OECD, 2022[13]). Many regional and local governments are also less familiar with the climate finance landscape, which can limit their ability to access climate finance (Rossi, Gancheva and O'Brien, 2017[96]).

While international financial institutions are one of the main sources of climate finance, direct climate finance flows to subnational governments from these institutions can be limited. Although climate finance is increasingly being mobilised internationally, it is often targeted towards national governments (see Chapter 5). This limits the ability of regions and cities to access these resources. While many regions and cities may ultimately benefit from international finance, they generally do not have direct access. This is partly because few donors (such as multilateral development banks and development finance institutions) work directly with subnational governments. Rather, donors often prefer to channel resources through national governments or financial intermediaries (OECD, 2021[9]).

Figure 6.6. Regions and cities have potential to further mobilise sustainable finance

Annual percentage of GSS+ bond issuance classified as municipal by bond category



Note: Sustainable finance refers to labelled financing instruments earmarked to support green, social and sustainable objectives and projects.
Source: (Environmental Finance, 2023[97]), *Sustainable Bonds Insight 2023*, https://www.environmental-finance.com/assets/files/research/sustainable-bonds-insight-2023.pdf

Financial markets provide another important pathway for subnational governments to access finance, especially larger and fiscally stronger governments. As the global sustainable finance market has grown, the potential to further mobilise sustainable finance instruments (Figure 6.6) has grown alongside it. Such instruments include green, social and sustainable bonds, sustainability-linked bonds and catastrophe bonds (OECD, 2023[12]). However, these instruments present two key challenges for subnational governments. First, the municipal bond markets remain limited in many countries. Second, sustainable finance instruments can create additional reporting, compliance and capacity challenges (OECD, 2023[12]). Furthermore, to date, sustainable bond issues have been more focused on mitigation than adaptation or resilience. Of the USD 755 billion in sustainable bonds issued in 2022, only 3.3% (USD 24.8 billion) went towards climate change adaptation (Environmental Finance, 2023[97]).

Mobilising public finance is important, but there can be similar barriers to attracting private finance. Regional and local governments are almost always seen as riskier than national governments, especially if they are not backed by guarantees. Indeed, many subnational governments are not creditworthy on their own and rely on credit enhancement to borrow from private financial institutions. Although credit enhancement tools, such as guarantees, can improve the access of regions and cities to finance, risks relating to the transfer of contingent liabilities must be closely managed (OECD, 2023[12]).

To unlock additional and affordable finance for climate-resilient infrastructure, governments can take the following actions:

- **Explore innovative financing tools targeted towards subnational government climate resilience investment**. National governments can set up financing facilities for local government climate resilience actions. In the United States, the federal government is providing capitalisation grants to help state governments set up revolving loan facilities. State governments can then on-lend to support the hazard mitigation projects of local governments (Box 6.13).
- **Explore the use of green, social and sustainable bonds at a subnational level.** Regional and local government provide services that align well with sustainable finance definitions. This highlights the potential for regions and cities to harness sustainable finance for climate resilience. However, the green, social and sustainable municipal bond market remains limited. It has also historically targeted mitigation rather than adaptation and climate resilience. In 2016, Mexico City (Mexico) issued the first municipal green bond in Latin America for USD 50 million directed towards water infrastructure, energy efficiency and public transport. More recently, in 2022, the State of Mexico issued a sustainable bond of MXN 2 890 million based upon the Sustainable Bond Framework developed by the state government (OECD, 2023[12]).
- **Seek to mobilise international climate finance for subnational investments.** Since subnational governments undertake a large proportion of climate-related investment, international climate finance will need to be sufficiently mobilised at the local level. Climate finance providers might support these governments through financial intermediaries with knowledge of the local context (such as by on-lending through a national development bank) or directly to subnational governments with sufficient scale and fiscal capacity.
- **Develop and share local climate-related data to inform private sector decision making**. For example, governments can publish more detailed climate-risk data to help finance providers understand the climate-resilience risk of infrastructure projects (see also Chapter 3).
- **Scale up capacity of regional and local governments to apply for finance for climate-resilient infrastructure**. For example, national governments can provide technical assistance to regions and cities to strengthen local capacity for accessing finance for climate-resilient infrastructure.

Box 6.13. Safeguarding Tomorrow Revolving Loan Fund in the United States

In the United States, the Safeguarding Tomorrow Revolving Loan Fund (STRLF) programme helps state governments1 lend to local governments to support local hazard mitigation projects that build resilience to hazards and climate change. Administered by the Federal Emergency Management Agency (FEMA), the programme provides capitalisation grants to help states set up revolving loan funds, which aim to be self-sustaining through principal and interest payments.

A key risk of relying on federal funding is volatility due to uncertainty in congressional appropriations. STRLF addresses this problem by setting up a revolving fund to mobilise state financing and generate revenue, slowly reducing the federal share of funding. Recipient governments must match at least 10% of the federal grant. The STRLF programme builds upon the structure of similar proven funds in the water sector, such as the Clean Water State Revolving Fund. However, taking advantage of STRLF requires innovative revenue-raising mechanisms – unlike water infrastructure, hazard mitigation projects do not always have clear revenue sources.

Unlike similar FEMA grant schemes, STRLF empowers states to disburse funds directly without requiring FEMA reviews. This empowers state and local governments to innovate local solutions. By bypassing FEMA reviews, funds can streamline processes and increase local government access to climate finance. STRLF also aims to support equitable investments by directing 40% of loan funds to under-served communities.

As STRLF is in the early stages of implementation, it is too soon to assess its impact. FEMA plans to learn from initial applications to further enhance the programme. Already, many states have developed plans to make use of STRLF.2 With a total approved budget of USD 500 million between FY2021 and FY2026, STRLF has released a second funding round of USD 150 million for FY 2024.

Notes:
1 As well as eligible tribes, US territories and the District of Columbia.
2 Including the District of Columbia, South Carolina and Maryland.
Source: (FEMA, n.d.[98]; 2023[99]; South Carolina Emergency Management Division, 2023[100]; Maryland Department of Emergency Management, 2023[101])

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Notes

[1] Climate-significant public investment refers to direct investment (i.e. gross fixed capital formation minus disposals of non-financial, non-produced assets) going towards activities that contribute significantly to climate change adaptation and mitigation, as identified by the EU Technical Expert Group on Sustainable Finance and matched to internationally comparable government expenditure by function (COFOG) data. It includes both adaptation and mitigation finance. However, it could be undercounted due to several COFOG functions unable to be matched against climate-significant activities. Source: OECD (2022), “Subnational government climate expenditure and revenue tracking in OECD and EU Countries”, *OECD Regional Development Papers*, No. 32, https://doi.org/10.1787/1e8016d4-en.

[2] Including both adaptation and mitigation activities.

Infrastructure for a Climate-Resilient Future

This report provides an overview of the impacts of climate change on infrastructure , and key policy areas to be considered to render infrastructure more resilient. It discusses advances and persisting gaps in planning and developing infrastructure across its lifecycle to build in climate resilience and how this can be fostered by place-based approach. The report explores how climate risk awareness and understanding can be strengthened and become a norm for all financing and investment decisions, through standards and financial instruments that integrate climate adaptation and resilience. It includes a spotlight on nature-based solutions and offers insights on how nature can be harnessed as a cost-effective measure to build climate resilience. The report also recognises the specific needs of developing countries as requiring global attention for economic development and through strengthened international partnerships and support. Key policy insights are provided and advocate for national and subnational policy-makers to adopt a multi-level governance approach to resilience, working with infrastructure owners and operators to support decision-making.

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