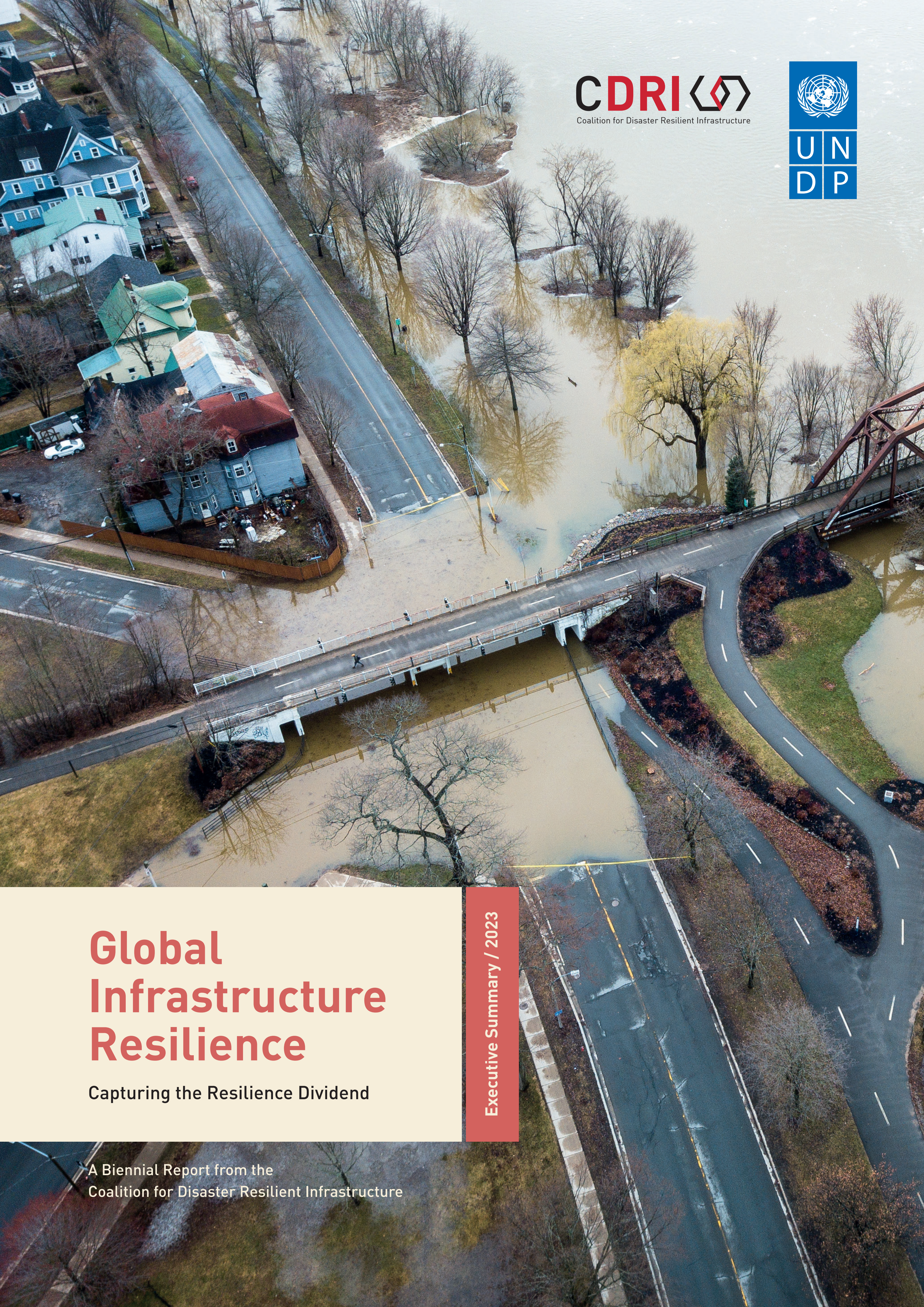

Coalition for Disaster Resilient Infrastructure

Global Infrastructure Resilience

Capturing the Resilience Dividend

Executive Summary / 2023

A Biennial Report from the
Coalition for Disaster Resilient Infrastructure

This Work is a product of the Coalition for Disaster Resilient Infrastructure (CDRI) along with external contributions from multiple organizations. The full Report and versions of the Executive Summary in Arabic, Chinese, English, French, Hindi, Russian and Spanish, may be accessed at: https://www.cdri.world/biennial-report. All background and contributing papers prepared for the Report can be consulted and downloaded from the Biennial Report microsite, accessible on the same web link as above.

An online data platform enabling visualization, analysis and downloading provisions for the results of the Global Infrastructure Risk Model and Resilience Index (GIRI), is available at https://cdri.world/giri

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Executive Summary

CDRI's Biennial Report – Global Infrastructure Resilience – lays out the political and economic imperative for investing in infrastructure resilience based on a large body of evidence and analysis. The aim of the report is to make visible the resilience dividend: the full range of benefits that can accrue from investing in infrastructure resilience. These include avoided asset loss, reduced service disruption, better quality and reliable public services, accelerated economic growth and social development, reduced carbon emissions, enhanced biodiversity, improved air and water quality, and more efficient land use, among others.

The report's theses argue that a more complete estimation and visualization of the resilience dividend can provide a solid economic imperative for investing in infrastructure resilience. Furthermore, realising the resilience dividend in a way that benefits governments, investors, and other stakeholders may provide the missing financial imperative to mobilize the capital required.

This report is the result of co-production of knowledge with a large number of collaborating partners including virtual workshops and discussions over a year-long period. The report has been peer-reviewed by panels comprising external experts and is supported by a high-level International Advisory Board (IAB).

1

The Resilience Challenge

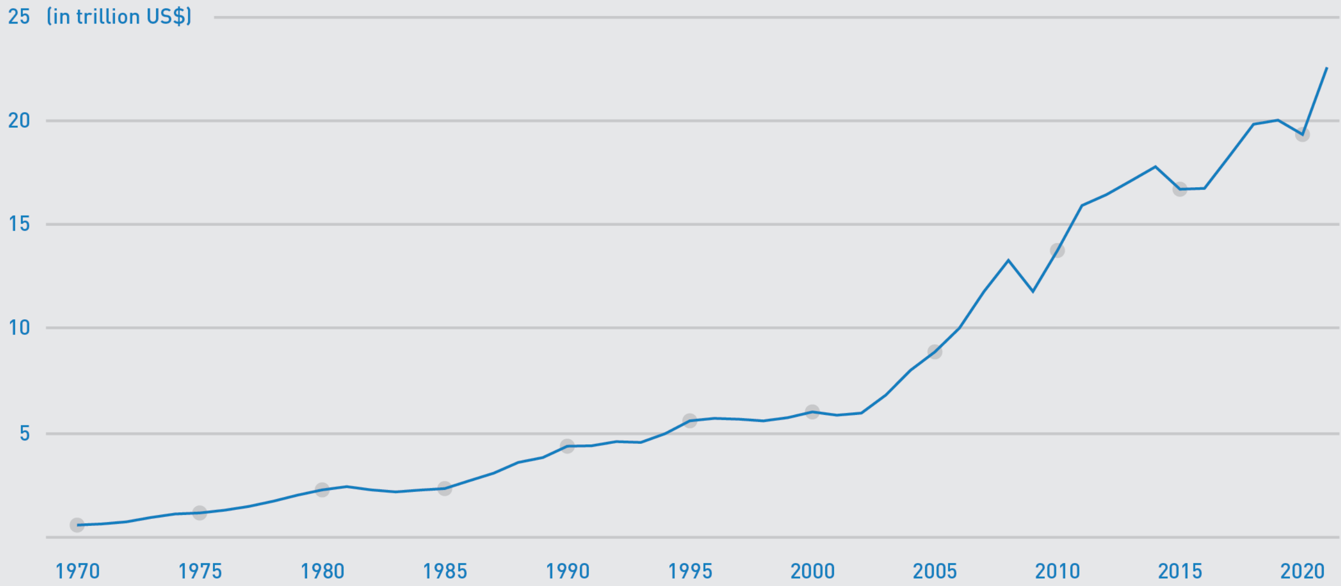
Rising asset loss and service disruption associated with disaster and climate risk erodes a significant proportion of the new capital investment countries need to address their infrastructure deficit. An estimated global Average Annual Loss (AAL)[1] of over US$ 700 billion in infrastructure and buildings (Cardona et al., 2023a), represents around one-seventh of GDP growth. New infrastructure investments without strengthened resilience are analogous to pouring water into a bamboo basket.

Strengthening infrastructure resilience is a major contemporary global challenge. Although an international agreement on the need to reduce emissions and mitigate climate change is mandating a rapid transition from carbon-locked-in infrastructure to low, zero, or negative emission infrastructure (Seto et al., 2016), social and economic development in many Low- and Middle-Income Countries (LMICs) is constrained by a large infrastructure deficit, further aggravated by weak infrastructure governance.

Worryingly, most of the infrastructure that will be required by 2050 has yet to be built. Recent estimates of the annual investment required to address the infrastructure deficit, achieve the SDGs, achieve net zero, and strengthen resilience by 2050 amount to $9.2 trillion of which $2.84 - $2.90 trillion must be invested in LMICs (Chavarot, 2023). Presently, investments are at least an order of magnitude lower than projected needs.

Therefore, the world is currently at a crossroads. In one direction, investing to strengthen infrastructure resilience can set countries on a development trajectory characterized by quality and dependable essential services, reduced damage to infrastructure assets, lowered systemic risk and sustainable social and economic development. In another direction, however, countries' growth trajectory may be characterized by stagnant social and economic development, stranded infrastructure assets, increasing contingent liabilities, unreliable and inferior services, and growing existential risk.

[1] Estimates of average losses that can be expected over a long term



1.1. Infrastructure for Sustainable Development

Massive investments in infrastructure since 1970 have underpinned the total urbanization of society (Lefebvre, 1970), with more than 90 percent of modern-day infrastructure being built in the last 50 years. The net value of the world's capital formation has seen a dramatic increase as well, growing from just over $742 billion in 1970 to more than $25 trillion today (Figure 1.1) (World Bank, 2021).

Not only is infrastructure fundamental to the achievement of the Sustainable Development Goal (SDG) on industry, innovation, and infrastructure (SDG 9), but also to good health and well-being (SDG 3), quality education (SDG 4), clean water and sanitation (SDG 6), and affordable clean energy (SDG 7). Besides, dependable essential services are closely linked to multiple welfare benefits such as sustained employment (SDG 8), poverty reduction (SDG 1) and gender equality (SDG 5) (UN, 2015).

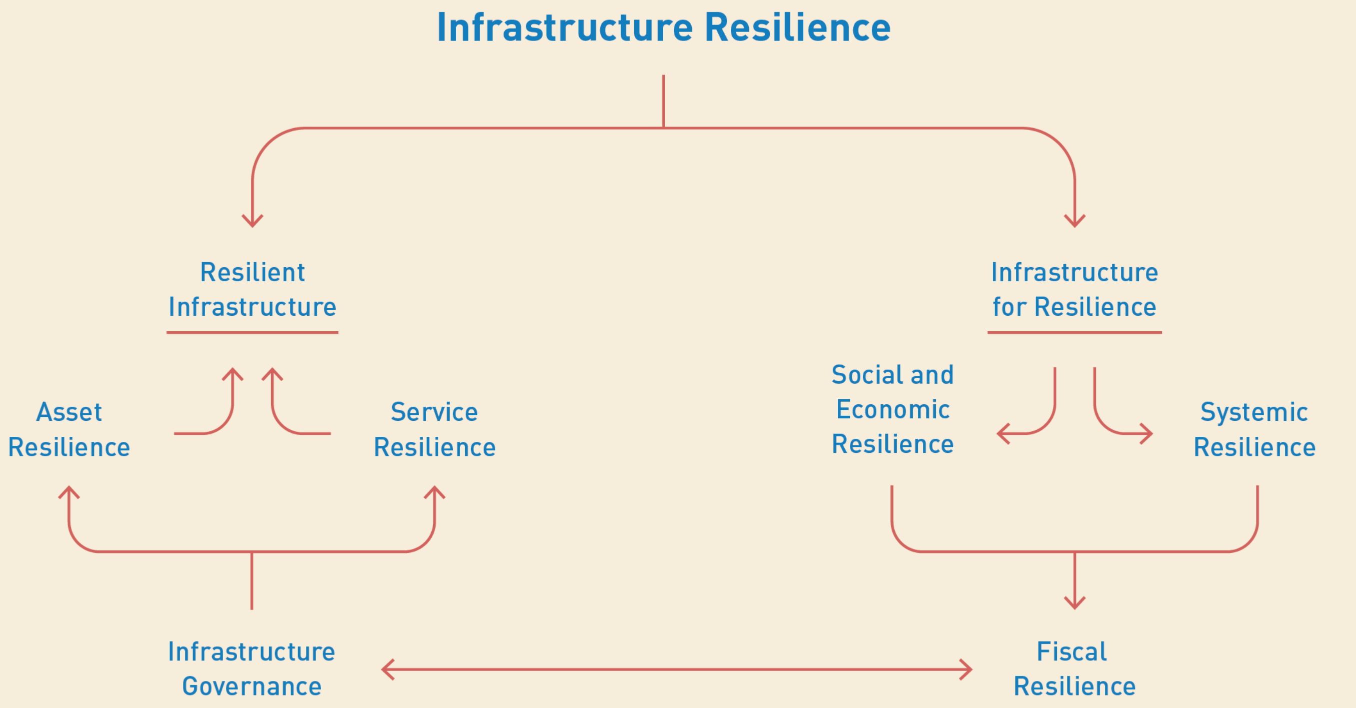
Investment in strategic economic infrastructure strengthens competitiveness and productivity as well as facilitating the territorial integration of countries and broader regions. Similarly, investments in local infrastructure systems such as piped water and sewer systems, local power and road networks, primary healthcare, and education facilities are critical to social development and the SDGs.

Large deficits of both strategic economic and local infrastructure systems constrain development in many LMICs. Weak infrastructure governance leads to precarious and low-quality infrastructure assets that undermine the provision of dependable essential services. In regions exposed to floods, earthquakes, landslides and/or tropical cyclones, infrastructure often internalizes high and growing levels of disaster risk. Loss and damage to infrastructure assets then aggravate service disruption. Much of supposedly "new" public infrastructure investment is then reoriented to patch up post-disaster damage and repair, and rehabilitate damaged infrastructure.

↑ **FIGURE 1.1**

Global gross fixed capital formation,1970 - 2020 (current $)

Source: World Bank



↑ **FIGURE 1.2**

Dimensions of infrastructure resilience

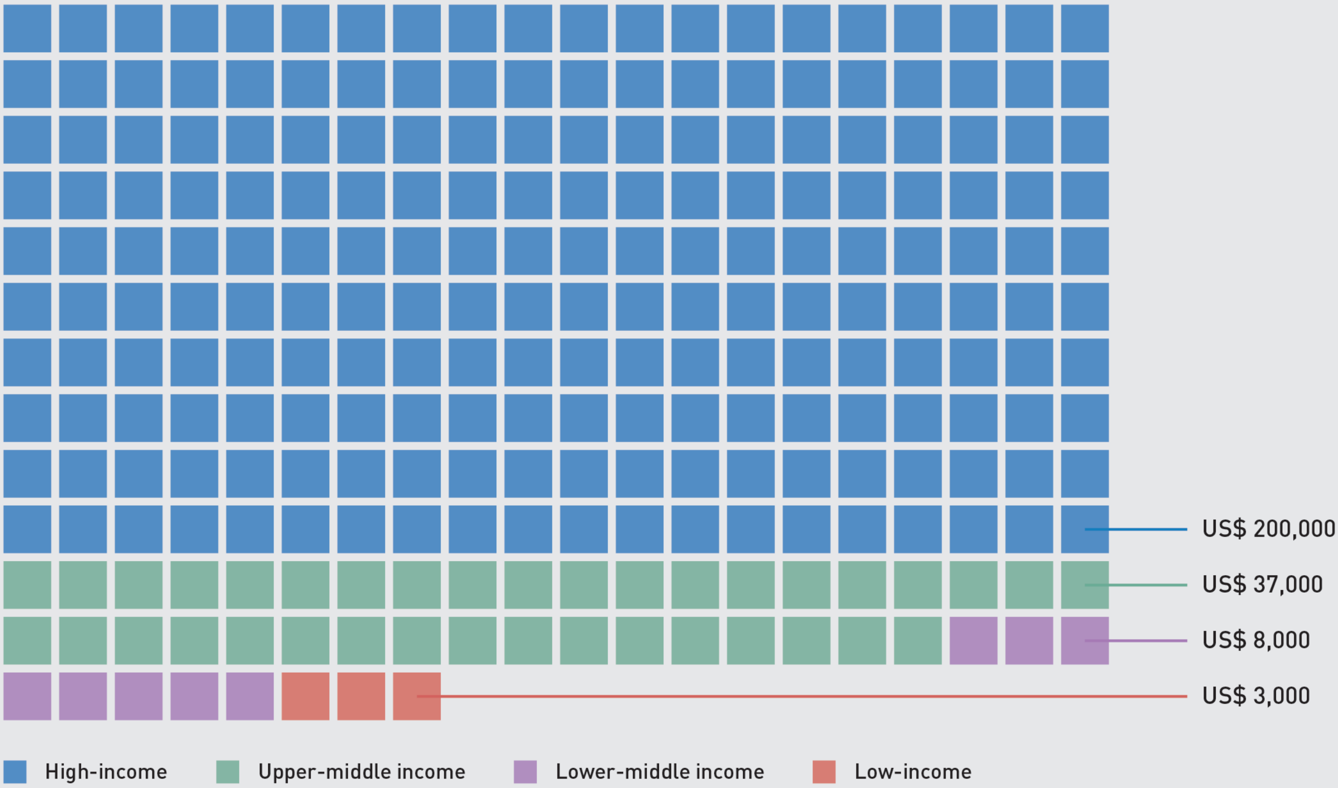
Source: CDRI

Extreme climate hazards magnify disaster risk, asset loss, and service disruption, while existing infrastructure may lose its functionality. Although growing momentum in climate change mitigation is changing the way infrastructure systems are developed and used with a transition to carbon-neutral and carbon-negative development gaining pace in sectors such as energy and transport, the climate change-conditioned global AAL in infrastructure currently lies between \$301 - \$330 billion. The inclusion of health and education infrastructure, and building stock, increases that range to \$732 - \$845 billion with nearly half of this contingent liability held by LMICs (Cardona et al., 2023).

LMICs, therefore, face a multi-dimensional challenge; a large infrastructure deficit that constrains social and economic development; precarious and poor quality infrastructure due to deficiencies in infrastructure governance; disaster-related asset loss and damage and service disruption; and a stock of legacy infrastructure increasingly ill-suited to address the challenges posed by climate change and rapid technological change

1.2. Dimensions of Infrastructure Resilience

Infrastructure resilience can be understood as both resilient infrastructure and infrastructure for resilience. Resilient infrastructure refers to infrastructure that can absorb, rebound, and adapt to hazard events and shocks. Infrastructure for resilience, on the other hand, refers to infrastructure that supports broader social and economic or systemic resilience. Both are underpinned by core enablers such as infrastructure governance and fiscal resilience



1.3. Social and Economic Resilience

Massive investments in infrastructure over the last 50 years have not been equally distributed. In high-income countries, the per capita value of capital stock is $200,000 compared to $37,000 in upper middle-income countries, $8,000 in LMICs, and $3,000 in low-income countries. For example, while Switzerland's per capita value of infrastructure assets is over $375,000, Senegal's is only $4,600, highlighting a difference of almost two orders of magnitude (Piller, Benvenuti & De Bono, 2023).

Public and private investment in low-income countries has consistently lagged behind middle- and/or high-income countries. Consequently, gaps in infrastructure investment are widening, constraining social and economic development in lower-income countries while increasing global inequities (UNCTAD, 2023). Further, the COVID-19 pandemic either stalled or reversed progress toward many of the SDGs, as Figure 1.4 highlights.

↑ **FIGURE 1.3**

Total capital stock per capita

Source: Piller, T., Benvenuti, A. & De Bono, A. (2023)

1.4. Infrastructure Governance

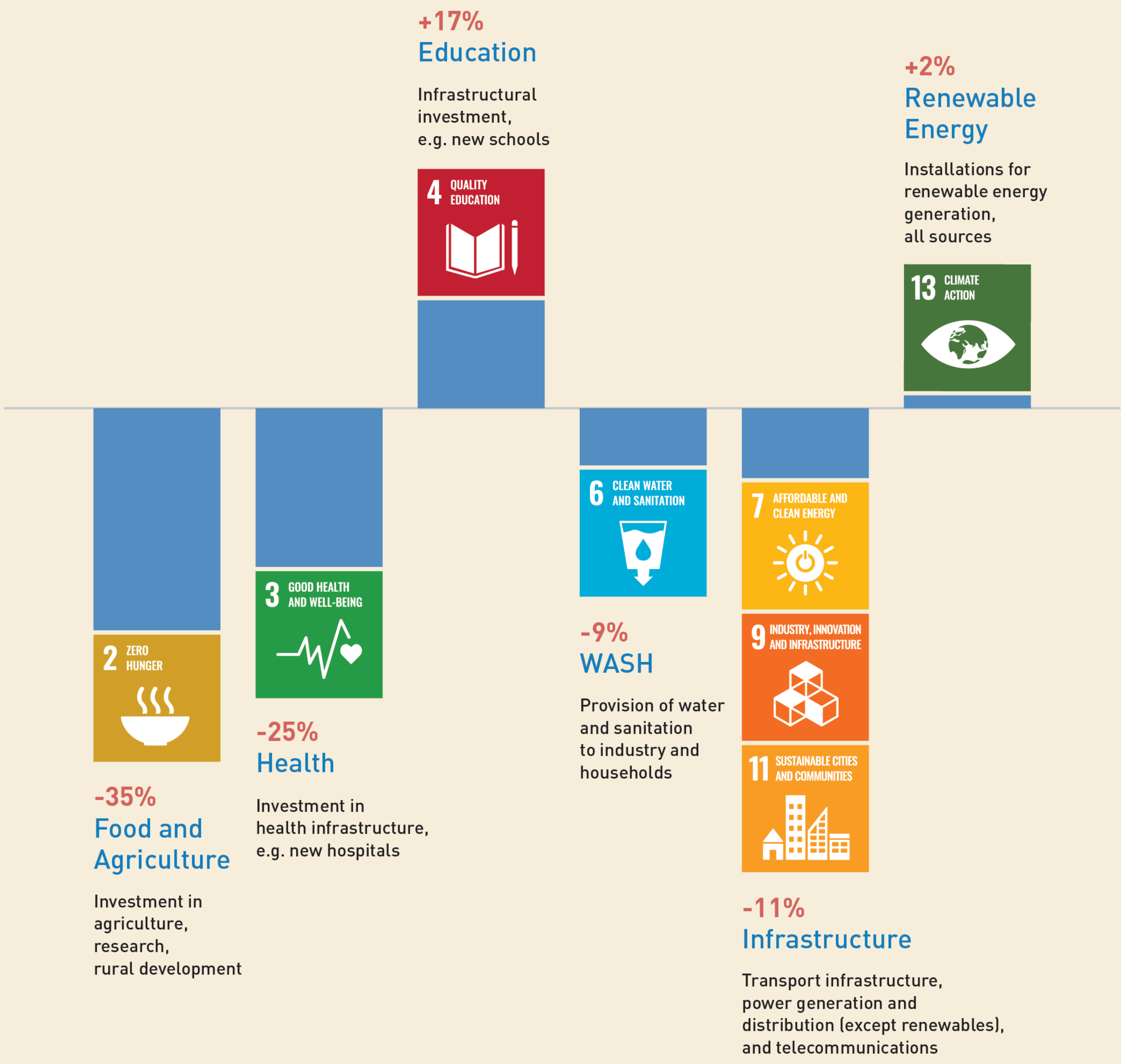
Sound infrastructure governance is a core enabler of infrastructure resilience. It can broadly be defined as the capacity to plan, finance, design, implement, manage, operate, and maintain infrastructure systems. Weak infrastructure governance, characterized by deficient planning and design, inadequate standards, ineffective systems for regulation and compliance, and low levels of investment in maintenance and operation is a barrier to resilience, aggravating the infrastructure deficit and reducing infrastructure quality (Hallegatte et al., 2019).

↓ FIGURE 1.4

International private investment across the SDGs, 2020-21 (percentage reduction compared to 2019)

Source: UNCTAD (2023)

Particularly, operations and maintenance (O&M) expenditures are often insufficient, leading to poor quality infrastructure and services, premature obsolescence, and the need to divert capital expenditure towards rehabilitation and reconstruction. Capital investment in an infrastructure asset only accounts for 15 - 30 percent of overall expenditure over its design lifecycle while 70 - 85 percent of the expenditure is attributable to O&M (UN, 2021). Patching up assets with provisional repairs further reduces resilience, contributing to increasingly frequent service interruptions.



1.5. Asset Resilience

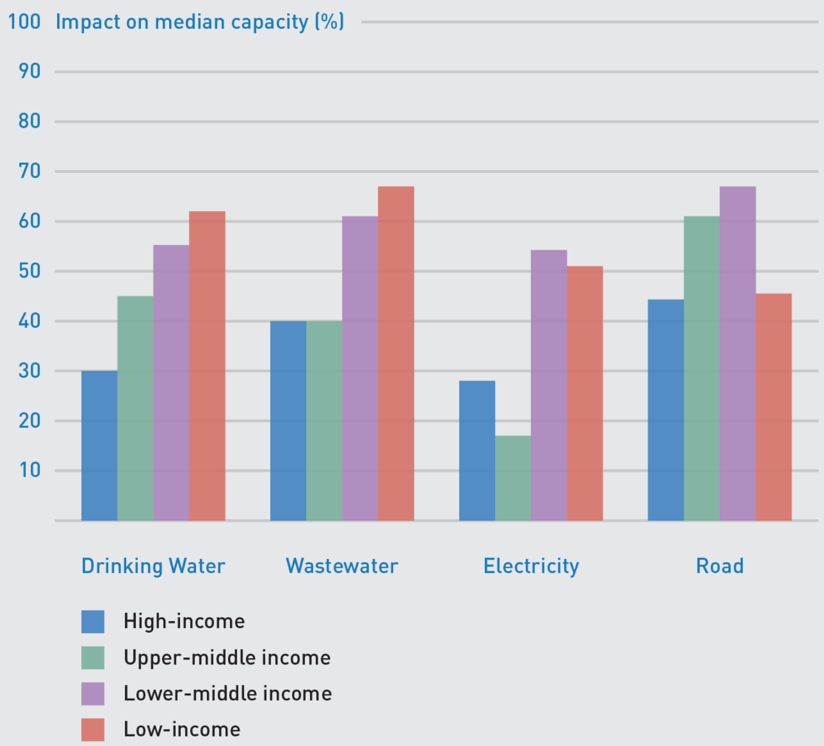
LMICs account for only 32.7 percent of exposed value, but factor 54 percent of the risk to infrastructure assets (Cardona et al., 2023a). Disaster and climate risk across many LMICs are rarely considered systematically in the conceptualization, planning, design, regulation, and management of infrastructure systems. Consequently, many infrastructure investments in hazard-exposed areas internalise and accumulate high levels of disaster and climate risk, which further increases asset loss, damage, and service disruption.

The accumulation of risk in infrastructure assets reflects socially constructed drivers such as weak infrastructure governance, badly planned and managed urban development, environmental degradation, and climate change that over time configure patterns of hazard, exposure, and vulnerability. A combination of market forces and weak planning and regulation continue to facilitate infrastructure investments in hazard-prone areas, increasing exposure without measures to reduce vulnerability and strengthen resilience. Poverty drives low-income households to occupy areas without risk-reducing infrastructure such as drainage. Additionally, the loss of regulatory ecosystem services such as mangroves, wetlands, and forests threaten to aggravate hazards such as flood or drought. Climate change can magnify the severity and frequency of storms, floods, and drought •

1.6. Service and Supply Chain Resilience

Infrastructure assets provide services like water, sanitation, energy, and transport for households, businesses, and communities. Service resilience, referring to the capacity to buffer asset loss or damage in a way that allows continued service provision, rapid recovery, or adaptation or to be "safe to fail", is, therefore, as important as that of the assets themselves.

With AALs across infrastructure sectors lying between $301 - $330 billion (Cardona et al., 2023a), the real cost of disrupted services could be as high as $700 billion per year, along with unquantified impacts on well-being, health, productivity, and competitiveness. As Figure 1.5 illustrates, the capacity loss of assets to provide essential services is highest in LMICs across different infrastructure sectors.
Climate change further challenges service resilience. Heat waves, for example, may require additional power generation and distribution capacity to cope with increasing demands for cooling. Preventing surface water flooding due to extreme rainfall may require better stormwater drainage assets. Extreme drought may disrupt water supplies, triggering displacement and migration from rural areas due to water scarcity, further straining essential services in urban areas. At the same time, rapid changes in the way services are provided or used, for example, the transition to electric mobility, require new infrastructure while at the same time leaving behind stranded assets •



← **FIGURE 1.5**

Median capacity loss due to significantly impacting hazards across sectors and income classes

Source: Chow & Hall (2023)

1.7. Systemic Resilience

→ **FIGURE 1.6**

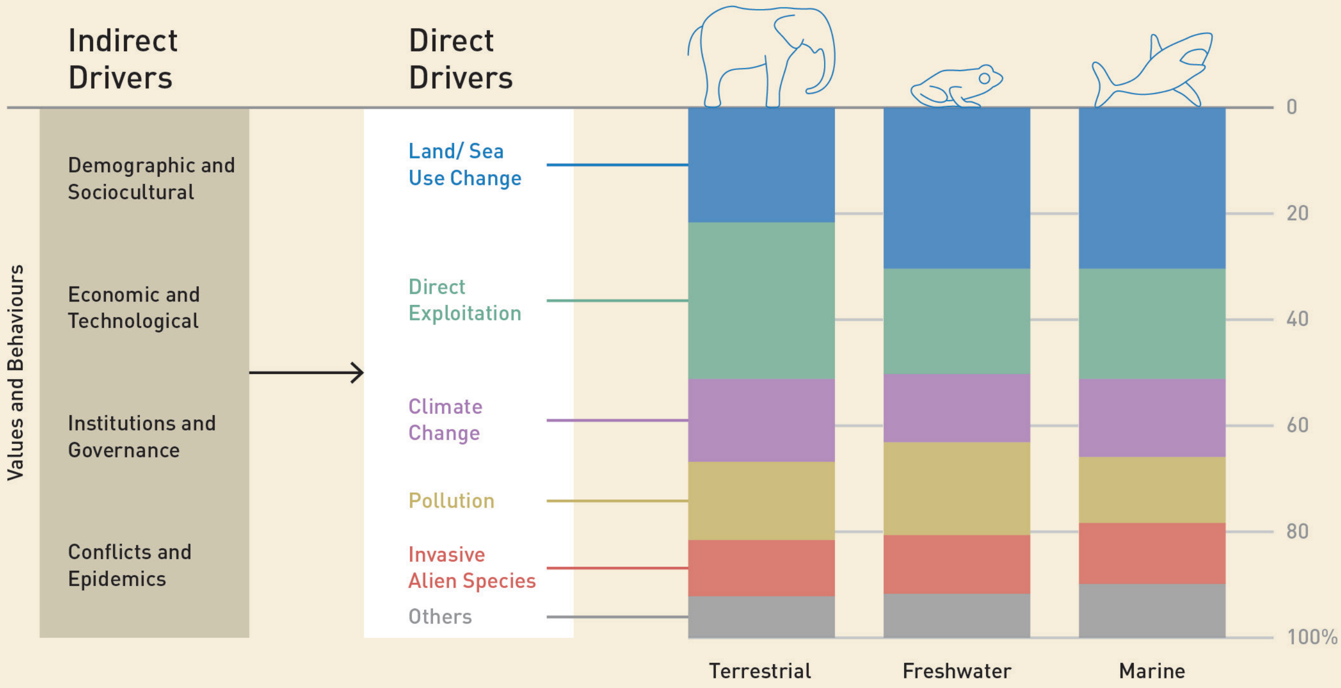
Direct and indirect drivers of biodiversity decline

Source: Adapted from Diaz et al. (2019)

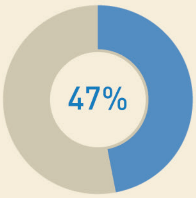
Systemic risks such as climate change and biodiversity loss are existential, as illustrated in Figure 1.6, showing how climate change, together with drivers such as urbanization, habitat loss, and pollution aggravate biodiversity loss.

Systemic risks are characterized by concatenated, non-linear, and cascading impacts (Maskrey et al., 2023). For example, cities sink due to uncontrolled groundwater extraction at the same time as they are threatened with rising sea levels and increased flooding caused by the degradation of catchments and the asphalting of green areas. Similarly, heat islands in urban areas result from urban expansion and reduced vegetation while causing an increasing demand for energy for cooling and carbon emissions, further increasing the risk of extreme heat. Dispersed urban layouts make for highly inefficient land use further amplified by the additional distances that vehicles have to cover, magnifying infrastructure costs by up to six times and increasing carbon emissions in the process (Vermeiren et al., 2022). Any new infrastructure project has the potential to either increase or reduce systemic risk. Contemporary urban processes underpinned by infrastructure investments, for example, have systemically generated new risks over the last 50 years which have fed back into increasing infrastructure loss and damage. New investments that reduce the infrastructure deficit but increase systemic risk are ultimately self-defeating. Strengthening systemic resilience, therefore, mandates designing infrastructure investments in a way that do not generate new systemic risks •

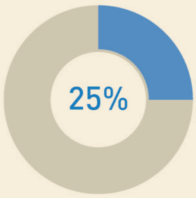
Biodiversity Decline



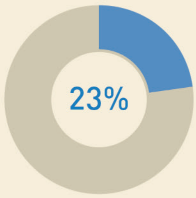
Examples of Declines in Nature



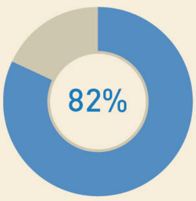
Ecosystem Extent and Condition: Natural ecosystems have declined by 47 percent on average, relative to their earliest estimated states.



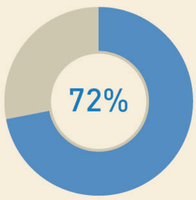
Species Extinction Risk: Approximately 25 percent of species are already threatened with extinction in most animal and plant groups studied.



Ecological Communities: Biotic integrity – the abundance of naturally-present species – has declined by 23 percent on average in terrestrial communities.*

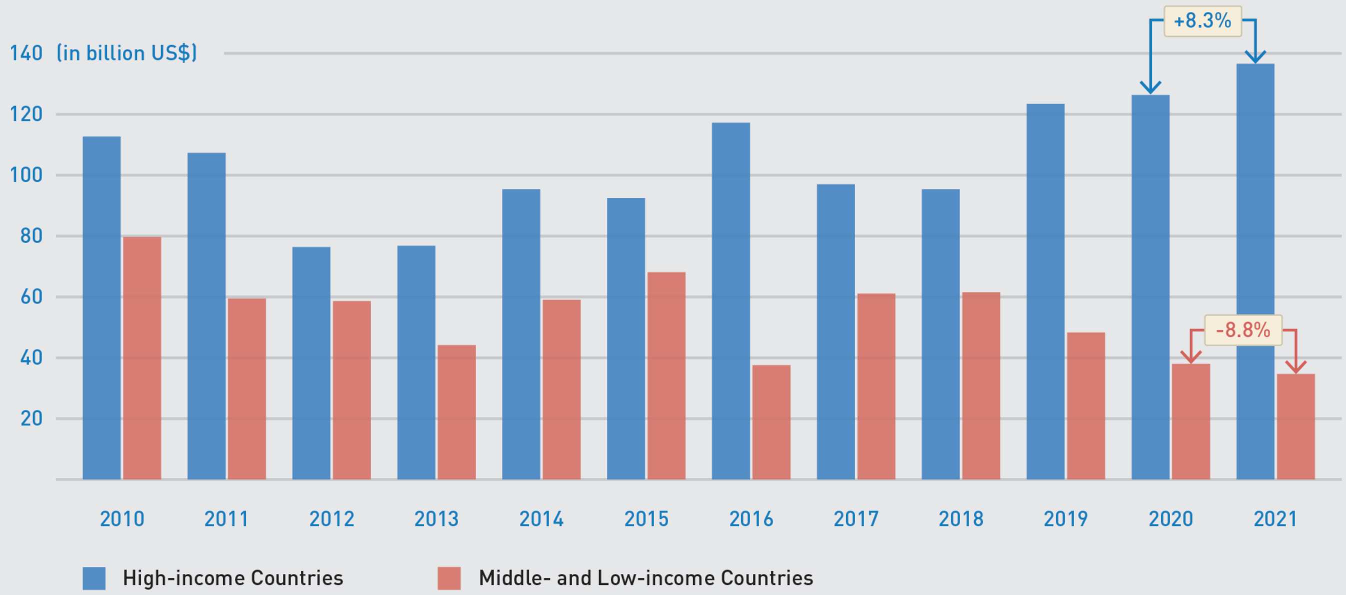


Biomass and Species Abundance: The global biomass of wild mammals has fallen by 82 percent.* Indicators of vertebrate abundance have declined rapidly since 1970.



Nature for Indigenous Peoples and Local Communities: 72 percent of indicators developed by indigenous peoples and local communities show ongoing deterioration of elements of nature important to them.

*Since prehistory



1.8. Fiscal Resilience

↑ **FIGURE 1.7**

Private investment in infrastructure in high-income versus low- and middle-income countries (2010-2021)

Source: Global Infrastructure Hub (2022)

Few low-income countries have the financial capacity to scale their public capital investment to address the infrastructure deficit, allocate sufficient budget to maintain existing infrastructure, and transition to net zero while strengthening asset and service resilience.

They also face difficulties in mobilizing private investment as gaps between high-income countries and LMICs continue to widen. In 2021, for example, 80 percent of private infrastructure investments were directed towards high-income countries. Half of these investments flowed into renewable energy generation (Global Infrastructure Hub, 2021). Further, investments per capita across North America and Europe was 57 and 41 times, respectively, greater than in Sub-Saharan Africa. As Figure 1.7 denotes, investments in high-income countries grew by 8.3 percent in 2021 but fell by 8.8 percent across LMICs. Even among LMICs, most of the available capital flowed into middle-income countries. In 2022, low-income countries received only around 2 percent of global foreign direct investment.

2.

The Global Landscape of Infrastructure Risk

2.1. Global Risk

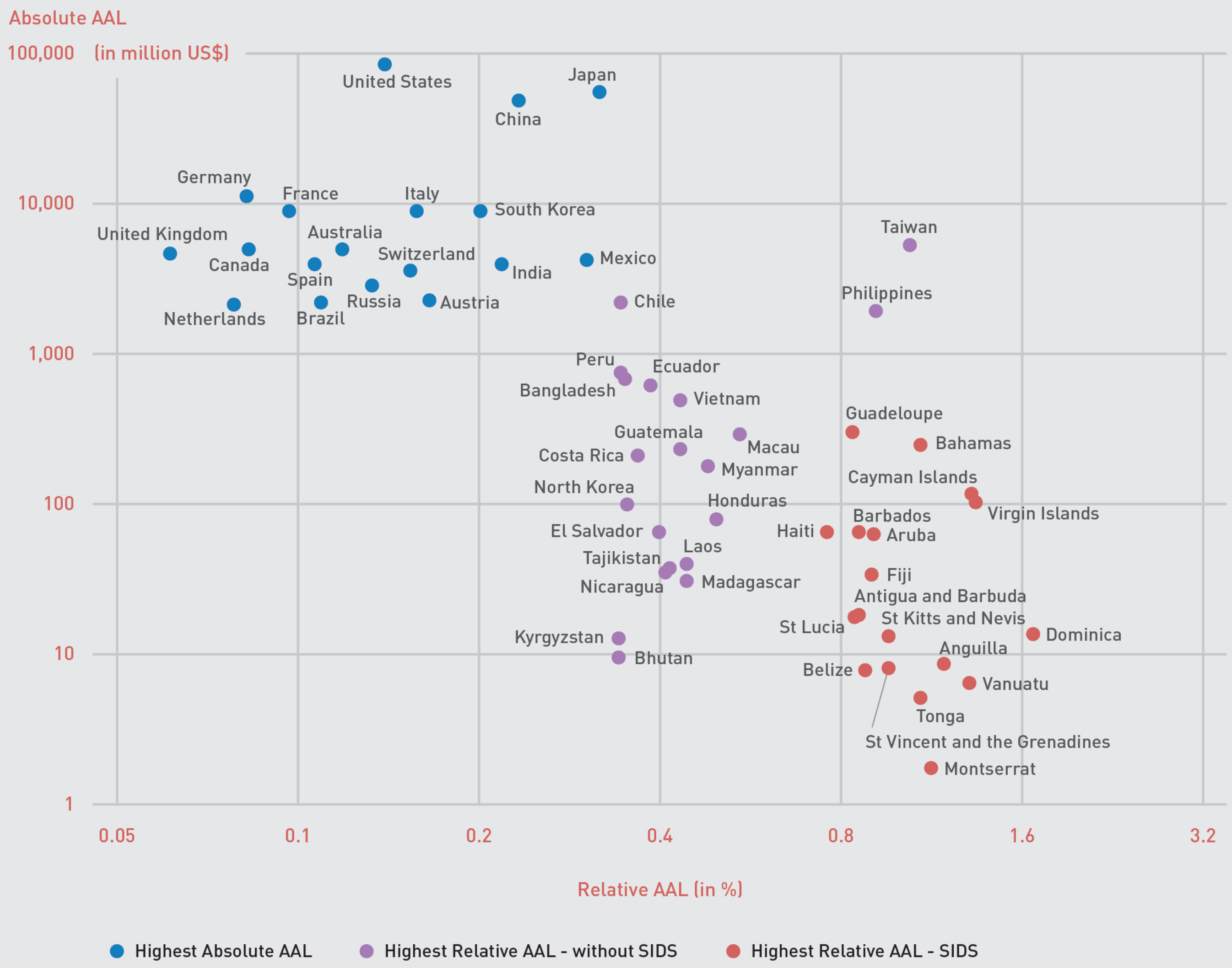
Assessing disaster and climate risk in infrastructure allows governments and other infrastructure owners to identify and estimate the contingent liabilities they are responsible for in each sector and territory. Financial risk metrics can then be used to make the economic case for investing in resilience and to design the most appropriate strategies to do so.

Considering the effects of climate change, the global AAL in the principal infrastructure sectors currently stands between $301 and $330 billion, representing 0.16 - 0.18 percent of the total value of infrastructure assets. The total infrastructure risk, including buildings and the health and education sectors, is estimated to be between $732 and $845 billion, around one-seventh of global GDP growth in FY 2021-2022. These are conservative estimates given that the AAL does not include agricultural or natural capital losses nor the contribution of frequent small-scale extensive risk (Cardona et al, 2023a)

2.2. Risk in Income and Geographical Regions

Sixty seven percent of the global value of infrastructure assets is concentrated in high-income countries. Upper and lower middle-income countries account for 24.8 and 7.0 percent, respectively, and low-income countries for 0.6 percent of the total value. However, LMICs carry the highest relative risk with a relative AAL of between 0.31 and 0.41 percent of the value of their infrastructure, compared to 0.14 percent in high-income countries. In other words, the countries with the largest infrastructure deficit also carry the highest risk.

Geographical regions with the greatest relative risk are Latin America and the Caribbean, South Asia and East Asia, and the Pacific with a total infrastructure AAL of 0.29, 0.45, and 0.26 percent, respectively.



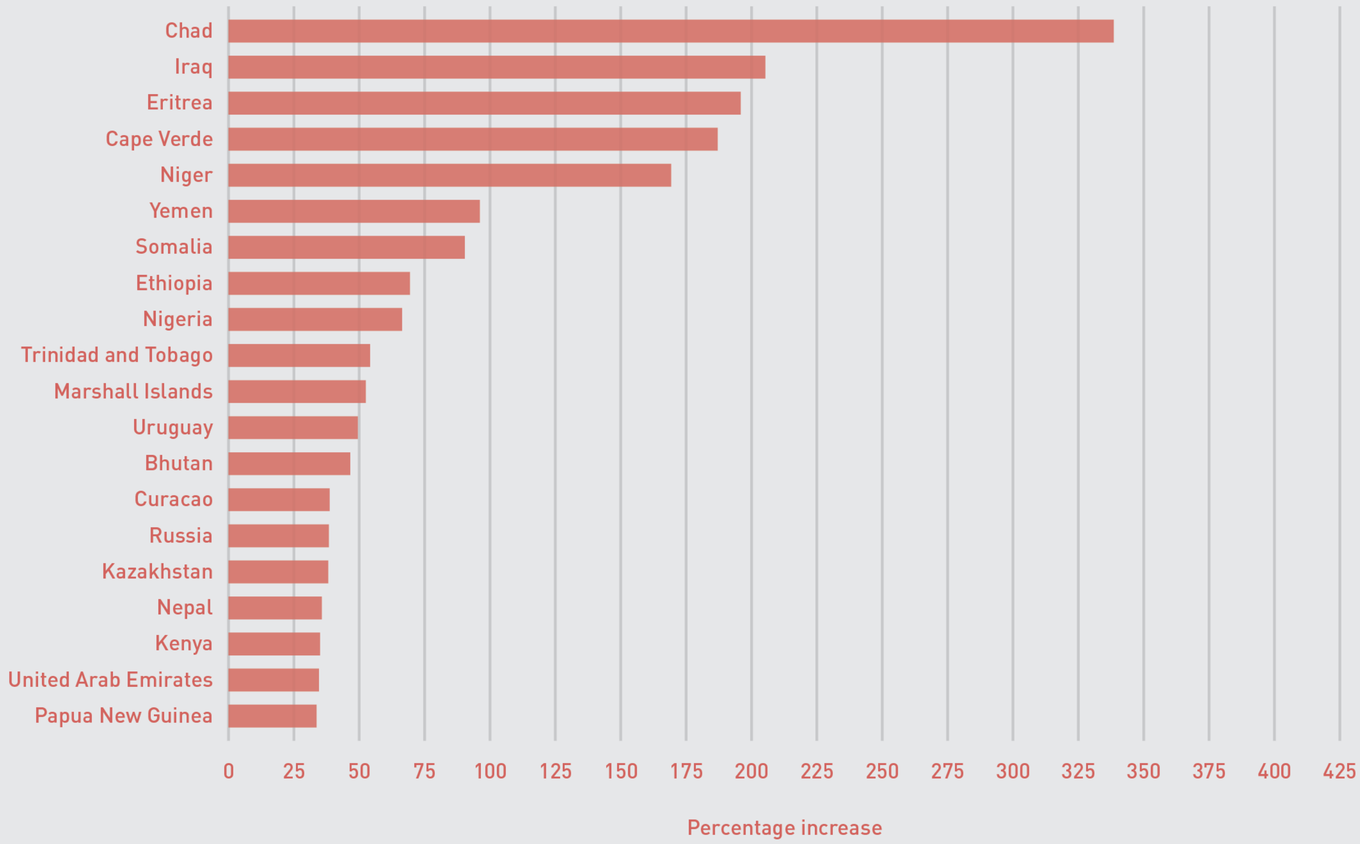
↑ **FIGURE 2.1**

Absolute and relative AAL for infrastructure sectors

Source: Cardona et al. (2023a)

Figure 2.1 shows the distribution of the absolute and relative AAL for infrastructure sectors. Most high-income countries and territories, as well as middle-income countries with large economies such as India, Mexico, and China (highlighted in blue) have high levels of absolute risk but low levels of relative risk. Their high absolute risk only represents a small proportion of their capital stock and does not threaten their resilience. Countries highlighted in purple such as the Philippines, Bangladesh, Vietnam, Myanmar, Peru, Honduras, and Ecuador have high levels of both absolute and relative risk. They can experience large-scale losses that also challenge their resilience. In contrast, most Small Island Developing States (SIDS), (highlighted in red), have low levels of absolute risk due to the small size of their territories and economies but very high levels of relative risk. These are countries that may experience major difficulties absorbing and recovering from loss and damage to infrastructure assets.

On a positive note, the amount of investment required to strengthen resilience in such countries may be relatively small. Strengthening the resilience of high-risk countries with small economies (such as SIDS) may not require globally significant investments but can make a critical difference to their sustainable social and economic development.



2.3. Climate Change

Globally, 30 percent of the total AAL is associated with geological hazards and 70 percent with climatic hazards. Across all regions, however, the relative AAL associated with climate-related hazards is higher than geological hazards. In other words, climate change can significantly increase the AAL.

While high-income countries could witness an increase in their total infrastructure AAL by 11 percent, the figure could increase by 12 to 22 percent in middle-income and 33 percent in low-income countries. As such, climate change will have a significantly greater impact in those countries with large infrastructure deficits, weak infrastructure governance, low fiscal capacity, and limited private investment.

As Figure 2.2 highlights, many of the countries faced with the greatest increase in risk due to climate change are situated in Sub-Saharan Africa and the Middle East.

Climate change could significantly modify AAL of hydropower generation in countries where it represents the primary energy source. At the upper bound of climate change, the relative AAL of hydropower production could increase from 12.8 to 34.8 percent in Lesotho and from 6.8 to 32.4 percent in Costa Rica. In contrast, Paraguay could see a reduction from 4.0 to 1.5 percent and Norway from 1.7 to 0.4 percent

↑ **FIGURE 2.2**

Countries expected to face increase in AAL

Source: Cardona et al. (2023a)

2.4. Resilience Challenges in Infrastructure Sectors

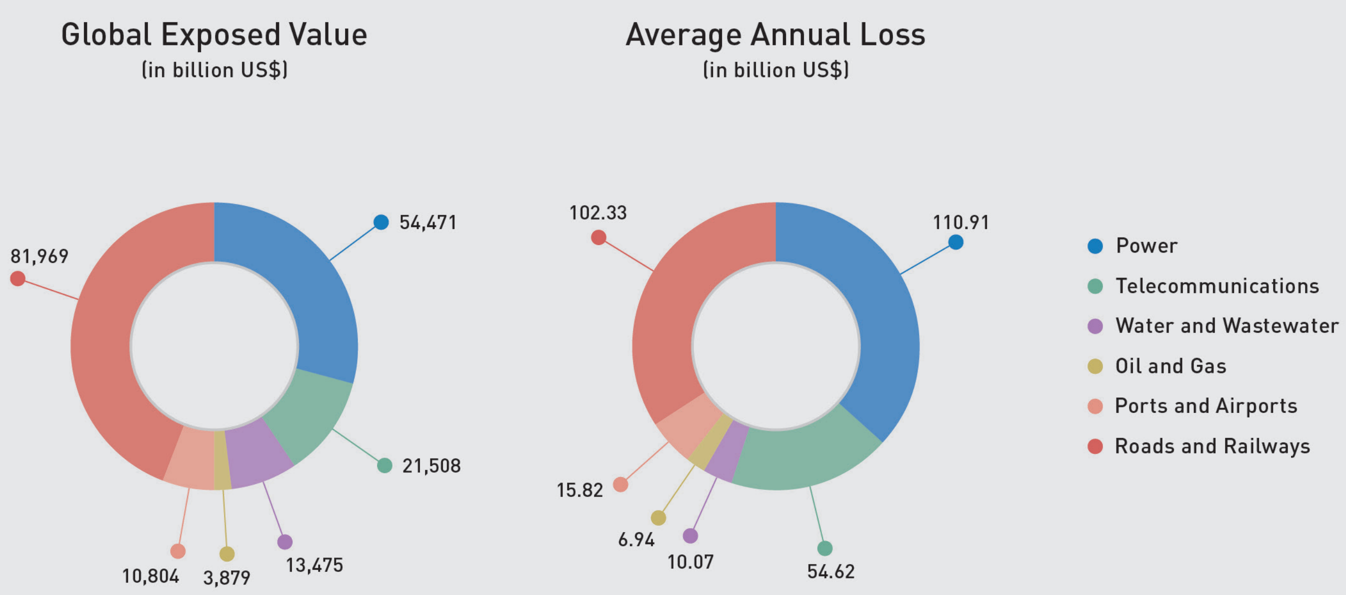
According to Figure 2.3, infrastructure risk are concentrated in power, roads, and telecommunications sectors, thus, posing significant challenges to resilience across most countries. Some country-specific resilience challenges include the power sector in Bangladesh, roads in mountainous countries such as Peru and Ecuador, telecommunications in Hong Kong and the Philippines, railways in Serbia, water and wastewater in the Philippines and Myanmar, oil and gas in the United Arab Emirates, and ports and airports in Hong Kong and Macau, all of which internalise high levels of absolute and relative risk.

Risk in each sector is associated with specific hazards. Flood and wind, for example, are associated with roughly two-thirds of the power sector AAL. Similarly, wind is associated with about two-thirds of AAL in the telecommunications sector and over half the AAL across oil and gas, ports, and airports; landslides and earthquakes are associated with over three quarters of the road and rail AAL; and earthquakes with around two-thirds of water and wastewater AAL.

Relative risk internalised in education and health infrastructure in low-income countries is currently at 0.42 percent of the exposed assets, more than three times than in high-income countries (0.12 percent). Low-income countries, therefore, face significantly higher resilience challenges, affecting progress towards the SDGs. South Asia, for example, has the highest relative AAL in the education (0.50 percent) and health (0.47 percent) sectors, with the region under threat of losing around 5 percent of the value of its total social infrastructure over a ten-year period

↓ FIGURE 2.3

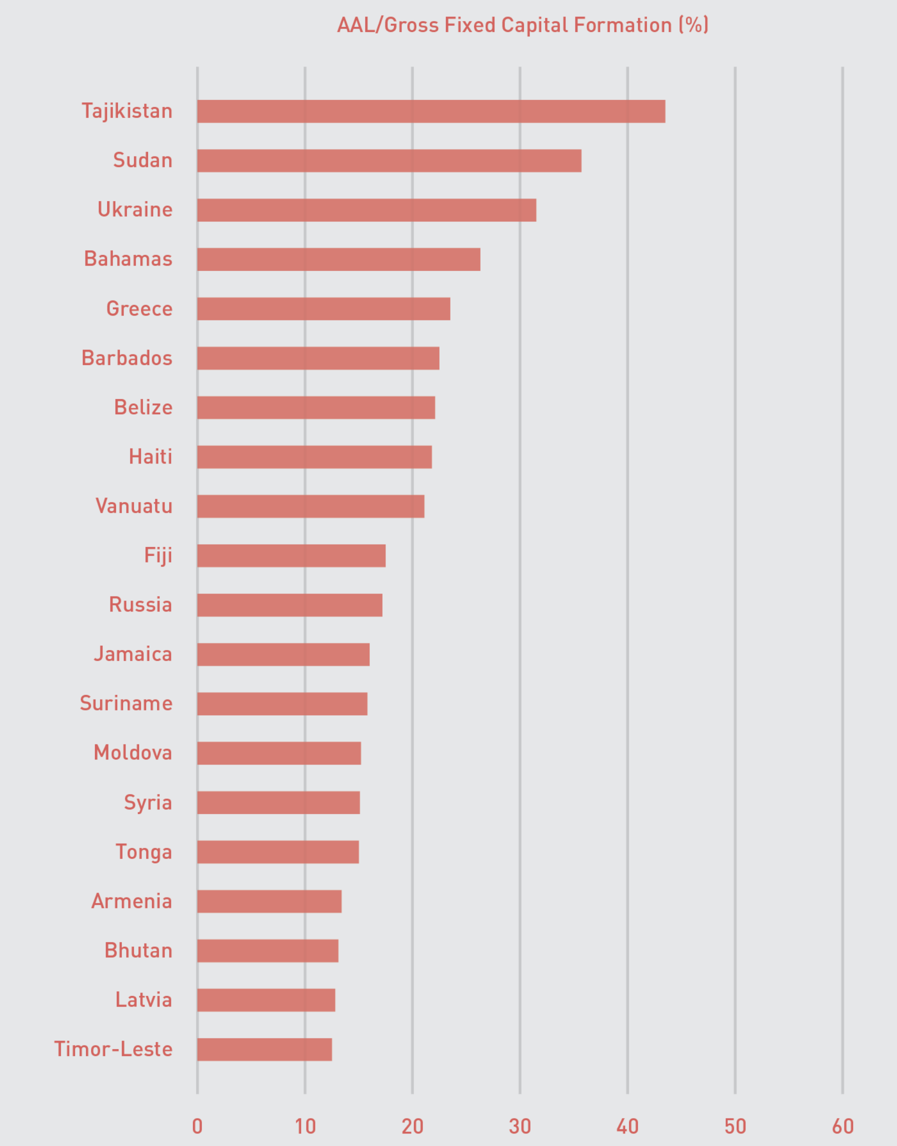
Exposed value and AAL by sector
Source: Cardona et al. (2023a)



2.5. The Implications for Resilience

A country's capacity to make new investments is reduced when the AAL represents a high proportion of capital investment[2] as resources have to be diverted to cover the repair and rehabilitation costs of damaged infrastructure. This further reduces the capacity of a country to reduce its infrastructure deficit. Similarly, countries with low levels of domestic savings and weak reserves are unlikely to be able to cover their AAL without negatively affecting future investment and fiscal stability. When the AAL represents a high proportion of social expenditure, progress towards the SDGs may be unsustainable.

Compared to high-income countries, AAL generally represents a higher proportion of key macroeconomic indicators such as capital investments, savings, reserves, and social expenditures in LMICs[3], thereby posing serious challenges. As illustrated in Figure 2.4, these include countries with large infrastructure deficits such as Tajikistan and others struggling with conflict such as Sudan, Haiti, and Syria. In several SIDS such as Barbados and the Bahamas, risk also represents over 25 percent of annual capital investment. In the case of certain high-income countries such as Greece, risk may also threaten low levels of capital investment. In such contexts, recovery of infrastructure assets may take years if a significant proportion of the capital stock is damaged.



↑ **FIGURE 2.4**

Countries with a high ratio of AAL to capital investment

Source: Cardona et al. (2023a)

[2] Measured by Gross Fixed Capital Formation (GFCF)

[3] Figure 2.4 lists the countries where risk represents a high proportion of capital investment

3.

Strengthening Systemic Resilience: Upscaling Nature-based Infrastructure Solutions (NbIS)

Given the long lifecycles of most infrastructure assets, choices made today on the types, features, and locations of infrastructure will heavily influence the ability of countries to shift to lower carbon trajectories and strengthened systemic resilience. This is why transitioning to infrastructure systems that generate fewer carbon emissions is critical to limit potentially catastrophic increases in disaster risk. Countries that are unable to proactively move on to a more resilient and sustainable trajectory of infrastructure development will accumulate a growing portfolio of stranded infrastructure assets in sectors like energy and transportation, and face even greater fiscal constraints.

3.1. The Potential for NbIS

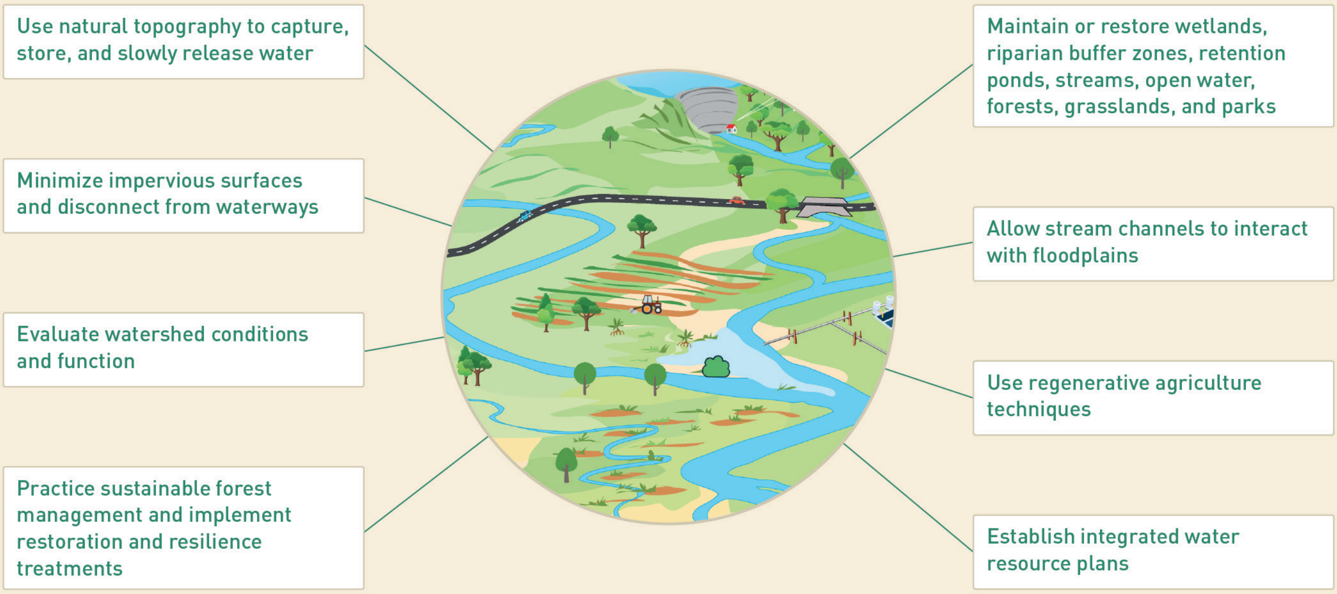
Nature-based Infrastructure Solutions (NbIS) in sectors such as water and hazard mitigation have the potential to strengthen systemic resilience. NbIS not only have a low carbon footprint but also generate a range of other co-benefits. For example, the use of deep-root systems for slope stabilisation have been estimated to produce savings of 85-90 percent compared to concrete-driven grey infrastructure. Similarly, mangrove conservation and restoration protect coastal areas against storm surges with co-benefits including improved water quality, replenished fish stocks, and ocean health. Green roofs, permeable surfaces, and vertical gardens are urban NbIS that address urban flooding and heat islands while reducing energy consumption.

NbIS can be used to complement, substitute for, or safeguard traditional grey infrastructure. In the first case, the protection or restoration of watersheds (ecological infrastructure) that feed water supply reservoirs are key to regulating hydrologic processes and protecting water quality. In the second case, deep-rooted vegetation providing

Riverine Flooding

Driven by: ● Extreme precipitation ● Hardened surfaces, compacted soils ● Increased runoff ● Rapid snowmelt, glacial retreat ● Water-repellent soils from fires ● Encroachment of infrastructure into floodplains ● Loss of wetlands and open water ● Constricted floodplains and river channels ● Channelization of deltaic rivers

Nature-based Infrastructure Solutions



Outcomes: ● Social ● Reduced mortality ● Protected vulnerable populations ● Enhanced liveability ● Economic ● Reduced flood damage to infrastructure ● Decreased damage costs ● Environmental ● Increased infiltration throughout watershed ● Increased interaction of streams with floodplains ● Reduced flood flows ● Increased carbon storage ● Enhanced wildlife and pollinator populations ● Decreased water pollution ● Enhanced spring system flows

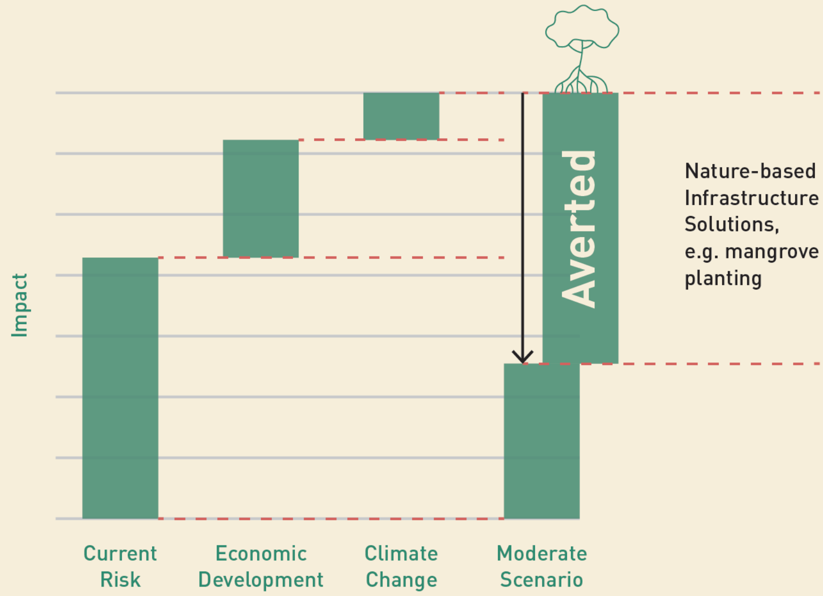
↑ **FIGURE 3.1**

Potential applications of NbIS
Source: USFS (2023)

→ FIGURE 3.2

Assessing the net value of NbIS

Source: Adapted from Bresch and Aznar-Siguan (2021)



slope stability could help substitute the need for retaining walls. In the third case, mangrove forests could protect shorelines from erosion, thus safeguarding nearby roads, buildings, and utilities from wave damage during storms (INFC, 2022).

According to estimates, the average cost of NbIS are only 51 percent of grey infrastructure projects. Further, 11 percent of all grey infrastructure could be replaced by NbIS (Bassi et al., 2021), with the greatest potential in the water sector due to the importance of functional ecosystems for water capture, storage, filtration, transmission, and in the protection of grey infrastructure (UNEP, 2023). Notably, the effectiveness of grey infrastructure and NbIS are inversely proportional. For example, and as Figure 3.2 illustrates, as sea walls depreciate in quality and resilience over time, well-protected mangroves become stronger and more widespread as they grow older, increasing their protective function. NbIS, therefore, may offer not only reduced capital and operating expenditures but also the potential for increased net present value

3.2. Pathways to Upscale the Application of NbIS

While there are a wide range of projects that demonstrate its benefits, NbIS currently represent only 0.3 percent of overall infrastructure investment, with formidable obstacles remaining to their widespread adoption. For starters, the ecosystems that provide the foundation for NbIS are still in decline. There is a lack of sufficient knowledge and capacity necessary to design and implement NbIS across LMICs. Financing of NbIS projects is challenging in the absence of mainstream standards, best practices, and methods to identify, estimate, and realize the benefits and co-benefits that these solutions provide.

Innovative pathways, therefore, need to be adopted to identify opportunities that address each of these challenges and help in realising the potential of NbIS.

Pathways	Challenges	Opportunities
Knowledge and capacity	Core knowledge that informs the design and implementation of NbIS is lacking in many countries. Few professionals are experienced in planning, design, implementation, maintenance, and monitoring of NbIS. Outdated and entrenched university curricula are siloed between different professional competencies.	It is critical to fully integrate NbIS concepts in curricula which span engineering, urban planning, and architecture as well as introducing capacity building programmes for planners and managers in infrastructure-related functions. Countries may also consider building national centres of excellence in NbIS to document and research best practices, disseminate knowledge, provide outreach to practitioners, and share information with other countries.
Mapping ecosystems and hazards	High-quality mapping at the appropriate scale of ecosystems and their services, potential hazards, exposed assets and vulnerability are often missing or only available for a fee. This limits the ability of designers to recognize the need and value of nature-based solutions in infrastructure projects.	Mapping ecosystems and their services, geological and climate-related hazards, exposed infrastructure, buildings and agriculture at an appropriate scale and obtaining data on vulnerability and economic values is critical to identifying and estimating risk.

Identifying and Estimating Risk and Resilience	Visualizing the resilience dividend accrued by adopting and implementing NbIS is difficult without credible, robust, and appropriately scaled risk identification and estimation.	Robust risk assessments are essential to determine the priority and scale of actions required and the economic, social, and environmental benefits and co-benefits of including NbIS. Risk identification and estimation should be integrated into the budgets and feasibility studies of all infrastructure projects, in order to estimate the resilience dividend that could accrue from NbIS.
Policy and Regulations	Ecosystem degradation and depletion, encouraged by economic drivers including government subsidies and measures of prosperity, undermine systemic resilience. Across LMICs in particular, environmental policy and regulation is often poorly enforced, leading to the degradation of the ecosystem services on which NbIS are based.	Effective legislation to protect and enhance ecosystems and their services is necessary to affirm a longer-term commitment and provide infrastructure investors with greater confidence and reduced risks. Working within established environmental policy could help governments achieve resilience targets set by legislation. The use of Environmental Impact Assessments (EIA) can also become a vehicle for mainstreaming NbIS to ensure compliance with national environmental policies.
Best Practices and Performance Standards	The lack of systematic codification of best practices in NbIS hinders the development of clear policy, regulations, codes and standards, slowing down and complicating the approval process for new projects. This makes it difficult, if not impossible, for engineers or other professionals to sign off on NbIS projects.	Nationally developed and adopted performance-based standards for NbIS based on best practices may provide a more flexible route that allows engineers and others to approve project designs without facing potential issues of professional liability. This may require third-party certifications to ensure that NbIS are based on standards or professionally sanctioned best practices in their absence.

Integrating NbIS into National and Local Planning	Many countries face issues with the entanglement of development, land use, environment, adaptation, and disaster risk management planning processes. Even when strong national normative capacities exist, they may be undermined by weak local capacities. The planning and adoption of NbIS is particularly challenging in LMICs where a substantial proportion of development is unregulated and informal.	National infrastructure development policies, strategies, and plans could provide a supportive environment for the introduction of NbIS at the national level and safeguard biodiversity and vulnerable ecosystems at the local level. Locally, planning can recognize the capacity of regional and/or national ecosystems such as rivers, lakes, wetlands, forests, grasslands, savannahs, agricultural lands, and coastal zones to provide the ecosystem services needed for infrastructure supply and protection.
Post-Disaster Reconstruction	Post-disaster reconstruction could be an opportunity to introduce NbIS. However, the urgency of restoring essential services often leads to replacing like-with-like and reconstructing pre-existing risk, precluding the possibility of introducing innovations such as NbIS that could reduce future risk and strengthen resilience.	The application of methods such as FORIN[4], which identify the cause of infrastructure failure in disasters, can lay the ground for changes in policy and practice in favour of NbIS. Effective progress is not possible without robust failure detection, analysis, and adaptation using knowledge gained from such methods.
NbIS Governance	Obstacles to the adoption of NbIS often reflect weak infrastructure governance. For example, the fragmentation of planning, design, and implementation of infrastructure projects across different ministries and departments does not allow a holistic approach to complex problems such as urban heat islands.	The engagement in and co-ownership of NbIS projects by households and communities that provide or benefit from ecosystem services is fundamental to their sustainability. Participatory planning builds community ownership and long-term engagement in the operation, maintenance, and monitoring of NbIS projects and increases accountability and public visibility that would further encourage governments to consider NbIS.
The Political and Economic Imperative for NbIS	Short-term economic gains are often prioritized over environmental integrity, transferring systemic risks to other social groups or territories. Being largely a common resource, NbIS may be politically unattractive as they promote social gain and reduce profit-making opportunities.	Adopting a national resilience strategy, policy, and plan, often following a catastrophic event that galvanizes political will, may provide a political imperative to consider NbIS and a long-term vision that provides a framework for infrastructure planning across sectors and territories. To be effective, this would require political support at the highest level of government.

[4] See https://www.irdrinternational.org/what_we_do/working_groups/12

Building a Business Case for NbIS	Conventional methods of accounting for costs and benefits and rates of return often fail to include the systemic risks posed by infrastructure investments. The long-term benefits of protecting, supporting, or supplementing infrastructure with NbIS are not accounted for or monetised to encourage investment. Net present value calculations do not account for the potential appreciation of the performance of NbIS over time compared to the depreciation of traditional infrastructure.	Highlighting the positive social, economic, and environmental benefits that can accrue from NbIS are critical to strengthening their political attractiveness. Therefore, it is fundamental to calculate and monetise the environmental, social, health, and economic benefits of land for uses such as cooling, aesthetics, and livelihood enrichment. Valuation thereafter builds a more comprehensive and balanced picture of the natural assets that support social and environmental well-being, and the resilience dividend provided by NbIS.
Developing Markets for NbIS	Different conservation finance instruments such as PES (Payment for Ecosystem Services) secure the protection and management of land in ways that protect ecosystem services. Local institutions are key to ensuring the viability of any conservation finance programme.	Cities or downstream communities could make payments to landowners to maintain or restore wetland and riparian areas to increase stormwater storage and attenuate storm flows to minimise flooding and improve water quality downstream. Similarly, a water company may fund landowners whose property drains directly into a water supply reservoir above their water intake system, based on the capacity of their land to reduce erosion and increase water infiltration to replenish groundwater.
Achieving Scale	The lack of scale and of demonstrable short-term returns on NbIS projects may make them unattractive to private investors. Markets for NbIS remain small and undeveloped. Even when an investor wishes to include NbIS in a project, it may be difficult to access the necessary technology and expertise.	Although pilot projects appear expensive in the initial stages, costs are reduced as best practices are curated, norms and standards codified, and investors and project designers gain confidence. Bundling NbIS projects into investment packages that mutualise risk across sectors can combine bottom-up and locally anchored knowledge and processes in project design and implementation with top-down investment opportunities.

4.

Financing for Disaster and Climate-Resilient Infrastructure

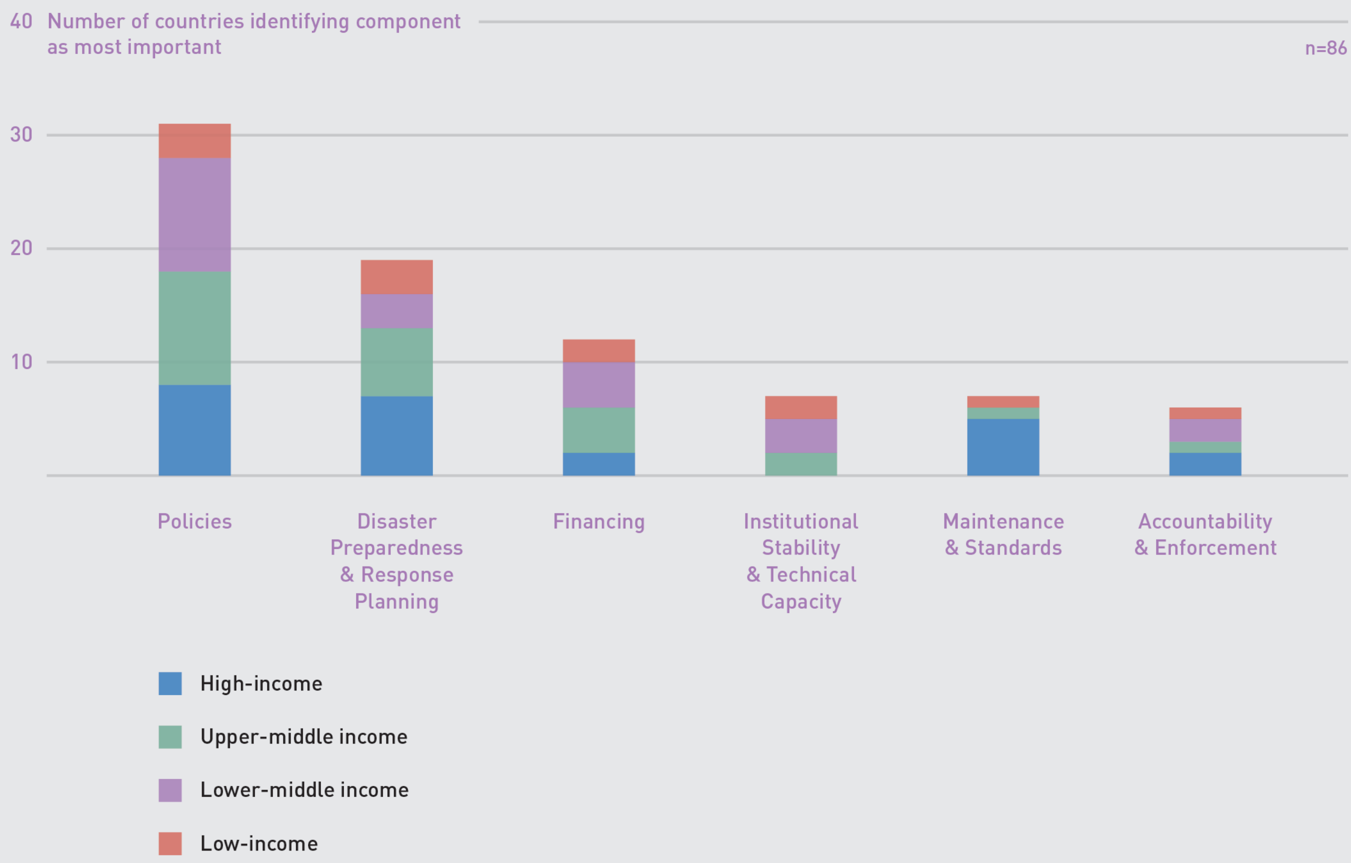
It is a huge challenge to mobilize the volume of finance required to strengthen infrastructure resilience in LMICs. Weak infrastructure governance contributes to a low rate of return on investment, project delays, complex approval mechanisms, and political uncertainty, all of which discourage private investment. Many LMICs lack clear policy frameworks that provide incentives to invest in infrastructure resilience (Figure 4.1), further exacerbated by the inability of domestic financial markets to channel capital in that direction. Identifying incentives and mobilizing finance for a new infrastructure resilience asset class, therefore, becomes imperative.

4.1. The Infrastructure Resilience Finance Gap

This gap is defined as the difference between existing and projected public and private finance, including climate finance, and the investment needed to strengthen the resilience of existing and future infrastructure, achieve the SDGs, and transit to net zero. To close this gap, LMICs will require approximately 30 percent of the required global investment in infrastructure assets and land use, through to 2050. Assuming a year-on-year increase of 3-5 percent to strengthen resilience, the investment required in LMICs would be in the range of $2.84-$2.90 trillion (Chavarot, 2023).

The sum of current public and private investment and climate finance in LMICs is at least one order of magnitude less than the estimated requirements. To illustrate, private infrastructure investment and climate financing in LMICs was approximately $40 and $50.7 billion, respectively, in 2021 (GIH, 2022).

Given that only part of adaptation funding is allocated to infrastructure, climate finance alone is clearly insufficient to strengthen infrastructure resilience. Mobilizing capital would, therefore, require a new approach,



combining public sector resources to identify and monetise the resilience dividend and de-risk investments, and private sources of capital to fund aggregated pipelines of infrastructure projects, complemented by climate and risk financing where appropriate. Resilience finance, in other words, ought to be seen as a new area of financing, complementary to and supplemented by climate finance

↑ **FIGURE 4.1**

The importance of policy frameworks for infrastructure resilience

Source: Chow & Hall (2023)

4.2. Pathways to Upscale Financing for Infrastructure Resilience

Pathways	Challenges	Opportunities
National Resilience Policies, Strategies, and Plans	Few countries have national resilience policies, strategies, and plans based on robust financial risk metrics, information on the quality of O&M and services, and data on asset loss and service interruption. These details can be vital in identifying the most appropriate strategies to facilitate the integration of resilience into infrastructure.	National resilience policies, strategies, and plans are essential to determine country-specific resilience objectives and the different levers of change that can be used in policy.
Financial Risk Metrics and the Economic Case for Resilience	Private capital investment in infrastructure does not adequately account for sustainability-related risks or opportunities. Metrics that account for disaster and climate risks need to be included in financial models and asset balance sheets for investors to fully understand their portfolio risks and shift investment towards strengthened resilience.	Financial risk metrics allow risk and resilience to be layered, helping national strategies identify the most cost-effective approaches to ensuring resilience. They also make an economic case for resilience by enabling governments to understand contingent liabilities and identifying particular sectors or territories of concern.
Identifying the Resilience Dividend	Investments in resilience are still perceived by many infrastructure developers and financiers to be incremental costs with no immediate benefits, imposed by regulators to meet standards. There is little incentive to optimize lifecycle costs given the time, value of money, and the way discount rates tend to skew asset valuations towards short- and medium-term with little consideration for an asset's residual value.	It is vital to consider the social rate of return on investment, including avoided loss and damage and service disruption, wider social, economic, and environmental co-benefits, and reduced systemic risk. Identifying and estimating the resilience dividend is essential to change the perception of resilience from a cost to an opportunity; to increase the economic and financial value of projects; and demonstrate that the risk-adjusted returns of resilient investments can be attractive to capital providers.

Public Investment Planning and Evaluation	Local infrastructure investments yield significant social and economic returns, bolstered by the role played by local governments. It is, however, much more difficult to mobilize finance for local infrastructure systems in smaller cities with limited governance capacities to manage and finance infrastructure projects.	Governments can use financial risk metrics to integrate resilience into their public investment planning and evaluation systems within the context of national resilience policies or strategies. The contingent liabilities of local governments across LMICs are associated principally with extensive risk (very frequent low-severity events). As such, a retrospective analysis of disaster loss and damage data can often be an important first step in identifying and estimating risk to local infrastructure.
Pipelines of Bankable Infrastructure Resilience Projects	Multiple small projects do not have the scale to attract investment and increase risk for private investors. Pipeline development, for example, is an essential step for governments in planning infrastructure which complements their infrastructure plans and project preparation practices.	Project pipelines can enable government, industry, and communities to better plan and raise funds for investing in resilience. Pipelines facilitate the bundling and aggregation of smaller projects in a way that optimizes the allocation of funding sources across projects and mutualizes risk across a range of projects.
Towards an Infrastructure Resilience Asset Class	Given the existing multitude of frameworks, principles, and standards, there is no universally recognizable and comprehensive set of criteria for infrastructure resilience, limiting the usefulness of current standards. Further, systematically lower Environmental, Social, and Governance (ESG) scores for companies in LMICs discourage investment.	Standards and certifications provide a common language to identify resilient infrastructure, facilitating the scaling of projects, and help in lowering perceived risks for private investors. They are critical to unlock additional finance streams. A combination of resilience standards and credible third-party certification processes can pave the way for the creation of an infrastructure resilience asset class, providing investors with greater transparency and increased opportunities.

Allocating the Resilience Dividend	The resilience dividend over the design lifecycle of infrastructure normally benefits a broad set of stakeholders. However, the dividend is rarely accounted for, allocated or monetised.	Allocating this dividend appropriately may provide an incentive to additional private investment in infrastructure resilience. Once the resilience dividend has been estimated and the stakeholders clearly identified, monetisation mechanisms will be required to enable investors to partake in the profits.
National Resilience Funds	Many governments across LMICs lack adequate vehicles to attract capital for investment in infrastructure resilience, to enable the implementation of national infrastructure resilience policies, strategies, plans, and to provide a framework for the development of pipelines of bundled projects.	National resilience funds could allow the blending of public resources, climate finance, loans from multilateral development banks, private capital, risk financing, and other sources in ways that allow governments to de-risk infrastructure investment for private capital while optimizing the use of different resources.

5.

Capturing the Resilience Dividend

LMICs, particularly low-income countries, need to increase both public and private investment to reduce their infrastructure deficit, achieve the SDGs, transition to net zero, and strengthen resilience. All new infrastructure investment needs to be disaster- and climate-resilient to avoid accumulating new contingent liabilities, increasing asset loss and damage, and service disruption.

Unfortunately, there is no one-size-fits-all solution to address such a challenge. However, there are a number of pathways that may unlock opportunities to strengthen infrastructure resilience across different income and regional geographies.

5.1. Knowledge and Capacities

- Accessing up-to-date information on ways of strengthening resilience such as NbIS via knowledge systems that enable policy-makers, planners, designers, contractors, regulators, and financiers is a core requirement.
- Financial risk metrics are required for each infrastructure sector and for geological- and climate-related hazards at global, national, and sub-national levels.
- Developing and adopting standardized methodologies that enable the integration of financial risk metrics into the calculations of costs and benefits and risk-adjusted rates of return are essential to identifying and estimating the dividends that can be obtained from investing in strengthened resilience.
- The development and adoption of performance-based resilience standards, informed by enhanced financial risk metrics and estimations of the resilience dividend, can support the emergence of a resilient infrastructure asset class helping investors, regulators, planners, and policy-makers to identify infrastructure projects that contribute to strengthened resilience.

5.2. Infrastructure Governance

- The formulation of infrastructure resilience policies, strategies, and plans, integrated with existing development policies by national governments is critical to strengthen infrastructure governance.
- The integration of resilience considerations into national systems for public investment planning and evaluation is critical to the implementation of national-level infrastructure resilience policies, strategies, and plans.
- National resilience funds can serve as a new mechanism to finance project pipelines and implement national resilience strategies and plans.

5.3. Markets for Infrastructure Resilience

- Combining the adoption of national resilience policies, strategies, and plans, the development of project pipelines, and the establishment of national resilience funds and mechanisms to monetise and distribute the resilience dividend would provide clear signals to capital markets, mobilizing additional private capital for infrastructure resilience.
- Developing project pipelines can increase the offer of bankable projects, offering greater predictability and lower risk for investors. At the same time, large numbers of identified small infrastructure projects can be aggregated or bundled, territorially or by sector, to achieve the economies of scale necessary to reduce transaction costs and increase viability.
- It is likely that markets will respond with the development of innovative financial mechanisms such as infrastructure resilience investment funds and bonds. Existing mechanisms such as catastrophe bonds can also be adapted and expanded to take advantage of the reduced risk associated with resilient infrastructure.

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An online data platform enabling visualization, analysis and downloading provisions for the results of the Global Infrastructure Risk Model and Resilience Index (GIRI), is available at https://cdri.world/giri

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