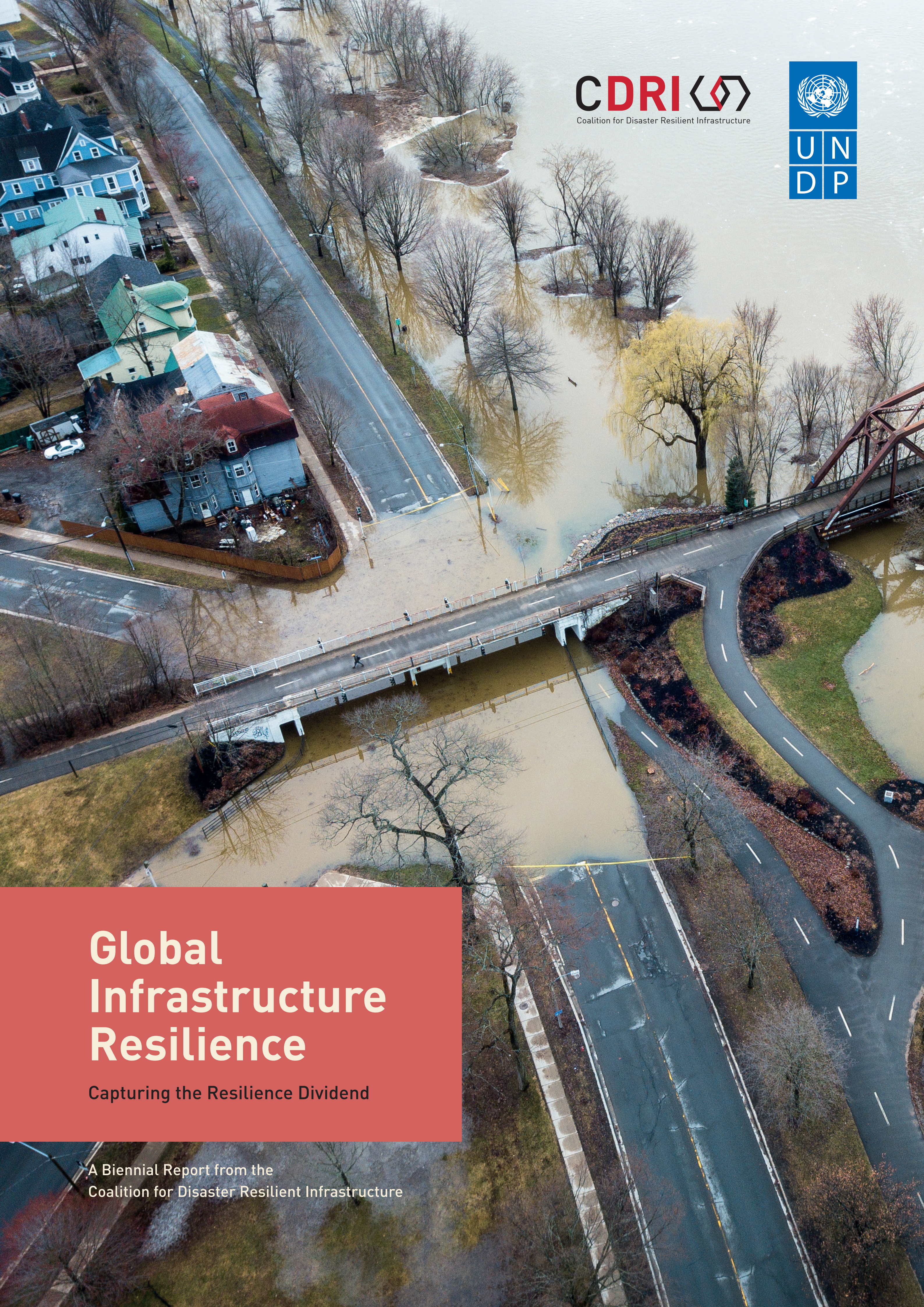

CDRI
Coalition for Disaster Resilient Infrastructure

UNDP

Global Infrastructure Resilience

Capturing the Resilience Dividend

A Biennial Report from the
Coalition for Disaster Resilient Infrastructure


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A Biennial Report from the Coalition for Disaster Resilient Infrastructure

Global Infrastructure Resilience

Capturing the Resilience Dividend

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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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Suman Bery

NITI Aayog

India's G20 presidency has rightly emphasized the importance of disaster resilient infrastructure. This first Biennial Report on Global Infrastructure is a path-breaking initiative in structuring the debate on thinking systematically or building in resilience at the very beginning, together with the associated challenges of ensuring compliance with established standards and norms. With contributions from leading experts, governments, and industry pioneers, the report sheds light on innovative strategies, transformative projects, and cutting-edge technologies that are revolutionizing the world's infrastructure landscape. Emphasizing the significance of resilient, inclusive, and environmentally conscious solutions, this report serves as a pivotal resource for policymakers, investors, and visionaries, inspiring collective action for a brighter, interconnected future.

Rosa Galvez

Independent Senators Group, Senate of Canada

It is with immense pleasure that I endorse the forthcoming Biennial Report on Global Infrastructure Resilience. This comprehensive report, crafted with collaboration from distinguished experts including CDRI, stands as a testament to our collective pursuit of a resilient future. Reflecting on our recent discussions and the insights within, I am convinced that this document will serve as a crucial roadmap, guiding policymakers, stakeholders, and communities towards enhanced infrastructure resilience across the globe. The efforts put forth in this report not only signal our commitment but also shine a light on the actionable strategies that can bring about transformative change. I eagerly anticipate the positive impacts that will undoubtedly follow.

Ngozi Okonjo-Iweala

World Trade Organization

This is an impressive piece of work solidly anchored in evidence and analysis. It promises to transform the way we think about investing in resilient infrastructure as well as infrastructure for resilience. It underscores the opportunities and incentives to invest and perhaps even create a new asset class.

Jeffrey Sachs

Columbia University

The new report on Global Infrastructure Resilience by the Coalition for Disaster Resilient Infrastructure (CDRI) is a landmark study. Every government should read it carefully, absorb its crucial messages, and utilize it in the design of long-term infrastructure strategies. The report's underlying four messages are clear: most of the infrastructure needed for the year 2050 is yet to be built; governments need to scale up massively the investments in infrastructure; infrastructure will be under dire risks of major climatological and geological hazards; governments need to invest in the resilience of the infrastructure and in societal resilience more generally. All of this requires a massive scaling up of public and private financing, as well as the deployment of new methodologies, described in the report, to embed resilience into the planning and design of infrastructure programs.

Foreword

The UNDP-CDRI Biennial Report on Global Infrastructure Resilience plugs a critical gap in the ongoing discourse around infrastructure resilience. Countries around the world, including the members of CDRI, will make unprecedented investments in infrastructure in the coming decades. The first edition of this Biennial Report is borne out of our collective consciousness and insight, and provides the analytical foundation that substantiates the case for investing in infrastructure resilience.

The Report presents a compelling economic, financial and political imperative for investing in resilience, based on a new cutting-edge Global Infrastructure Risk Model and Resilience Index (GIRI), the first-ever fully probabilistic global risk assessment of infrastructure assets in all sectors. The GIRI estimates the growing risks to infrastructure from major hazards such as earthquakes, tsunamis, floods, tropical cyclones and landslides and generates financial risk metrics, which can enable governments, financial institutions, and investors to better understand and appreciate the contingent liabilities for which they are responsible.

Furthermore, financial risk metrics enable the estimation of the resilience dividend, understood as the full range of benefits that 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. Over the lifecycle of most infrastructure assets, the resilience dividend is normally several times greater than the additional investment required.

Investing in infrastructure resilience is essential to drive progress across the Sustainable Development Goals. The Report, therefore, will be of immense use for policy-makers and financial institutions to better understand and appreciate the need to provide an enhanced level of financial support to developing countries across the world to pursue investment in this critical area. Failing to invest in resilient infrastructure and societies in this era of climate change is perhaps the biggest risk of all.

Kamal Kishore
Member and Secretary,
National Disaster Management
Authority (NDMA)

India Co-Chair, Executive Committee,
Coalition for Disaster Resilient
Infrastructure (CDRI)

Achim Steiner
Administrator,
United Nations Development
Programme (UNDP)

Preface

Infrastructure resilience is a critical global challenge. In lower income countries, a huge and widening infrastructure deficit conspires against social and economic development and the achievement of the Sustainable Development Goals (SDGs). Weak infrastructure governance leads to premature obsolescence of much of the infrastructure that exists, and poor quality and unreliable essential services, such as related to water, power, transport, health, and education. Disaster loss and damage, associated with both geological and climate related hazards is increasing, meaning that vital capital investments are diverted to repair, rehabilitate, and reconstruct existing infrastructure assets. At the same time, the transition to net-zero economies is gaining momentum in sectors such as energy and transport, mandating radical changes in the way infrastructure is developed and used. Unfortunately, the resources required in Low- and Middle-Income Countries (LMICs) to close the infrastructure deficit, achieve the SDGs, transition to net-zero and strengthen resilience are at least one order of magnitude greater than current investment.

Making the case for infrastructure resilience has, up to now, relied as much on rhetoric and aspiration as on data-driven evidence. The risk to infrastructure assets in specific sectors and territories is estimated by the insurance industry, in order to calibrate premiums. However, this vital information is rarely made publicly available. Without clear and explicit financial risk metrics, it is impossible for governments or investors to estimate the contingent liabilities they hold in existing or new infrastructure, or to calculate the dividend that could be captured through investing in resilience.

This first *Biennial Report on Global Infrastructure Resilience: Capturing the Resilience Dividend* from the Coalition for Disaster Resilient Infrastructure (CDRI) now begins to fill that information vacuum, bringing together for the first time a unique body of evidence to make a compelling economic, political, and financial case to radically upscale investment in infrastructure resilience. The brand new Global Infrastructure Risk Model and Resilience Index (GIRI) developed by a consortium of scientific and technical organizations for CDRI, has generated, for the first time ever, a suite of publicly available financial risk metrics for each country and territory in the world, for all major infrastructure sectors (power and energy, transport, telecommunications, water and wastewater, ports and airports, oil and gas, health and education) and for most major hazards (earthquakes, tsunamis, landslides, floods, cyclonic wind, storm surge and hydrological drought).

We believe making these metrics available through the Biennial Report and via an interactive on-line platform that allows for visualisation, query and analysis by governments and investors will be a game changer. The rhetoric that has characterised the call for infrastructure resilience up to now can now be validated with globally comparable metrics. As is so often said, what cannot be measured cannot be managed.

In CDRI, therefore, we expect that this Biennial Report will, give a much-needed impulse to infrastructure resilience. The resilience dividend refers to the full range of benefits that can accrue from investing in infrastructure resilience. Estimating this dividend provides economic and financial incentives to increase investment in infrastructure resilience.

However, the challenge is not only to increase investment but to radically change the way we develop our infrastructure systems. To address this challenge, CDRI convened a process of co-production of knowledge involving dozens of institutions and experts from around the world to provide essential material for policymakers, investors, and infrastructure developers to facilitate an upscaling of approaches to infrastructure resilience, such as Nature-based Infrastructure Solutions (NbIS), that not only contribute to asset and service resilience, but which can address systemic risks such as anthropic climate change and the loss of biodiversity.

CDRI is a new international organization, headquartered in India, with an ambition to become a leading global voice advocating for resilient infrastructure. This first edition of our Biennial Report is placed at the service of governments, investors and others around the world with an intention to further the dialogue on how to implement key recommendations in the Report. The Report is also aimed at broadening and deepening our collaboration with all our partners towards the goal of strengthening infrastructure resilience.

Amit Prothi
Director General, CDRI
New Delhi, India, September 2023

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Glossary

All definitions are adapted from Disaster Resilient Infrastructure Lexicon (https://lexicon.cdri.world/) and the Sendai Framework Terminology on Disaster Risk Reduction (https://www.undrr.org/terminology/)[3] unless stated otherwise.

Average Annual Loss (AAL)

A measure of annualized future losses over the long term, derived from probabilistic risk models (UNISDR, 2013).

Basic infrastructure

Infrastructure that provides services considered fundamental for human development, growth, safety, and security.

Climate adaptation

Adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects. It refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change (UNFCCC, n.d. a).

Climate change

A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (UNFCCC, 1992).

Climate finance

Local, national or transnational financing, drawn from public, private and alternative sources of financing, that seeks to support mitigation and adaptation actions that will address climate change (UNFCCC, n.d. b).

Contingent liability

Potential liability that may occur in the future depending on the disaster-related outcome of a hazard impact. In disaster risk evaluations, contingent liability refers to future projected damage and loss that must be paid for by the government, individuals, private sector, or others.

Critical infrastructure

The physical structures, facilities, networks, and other assets, which provide services that are indispensable to the social and economic functioning of society, and which are necessary for managing disaster risk.

[3] United Nations General Assembly, Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction, which was adopted by the General Assembly on February 2nd, 2017.

Disaster risk management

The application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses. Disaster risk management actions can be distinguished between prospective disaster risk management, corrective disaster risk management and compensatory disaster risk management, also called residual risk management.

- Prospective disaster risk management activities address and seek to avoid the development of new or increased disaster risks. They focus on addressing disaster risks that may develop in future if disaster risk reduction policies are not put in place. Examples are better land use planning or disaster-resistant water supply systems.
- Corrective disaster risk management activities address and seek to remove or reduce disaster risks which are already present, and which need to be managed and reduced now. Examples are the retrofitting of critical infrastructure or the relocation of exposed populations or assets.
- Compensatory disaster risk management activities strengthen the social and economic resilience of individuals and societies in the face of residual risk that cannot be effectively reduced. They include preparedness, response, and recovery activities, but also a mix of different financing instruments, such as national contingency funds, contingent credit, insurance and reinsurance and social safety nets.

Disaster risk

The potential loss of life, injury, and/or destroyed and damaged assets, which could occur in a system, society, or community in a specific period, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.

- Extensive risk, the risk of low-severity, high-frequency hazardous events and disasters, mainly but not exclusively associated with highly localized hazards.
- Intensive risk, the risk of high-severity, mid- to low-frequency disasters, mainly associated with major hazards.

Essential services

The services provided by infrastructure, such as water and wastewater, power and energy, transport, telecommunications, health, and education that are essential for social and economic development. (Definition adopted in this Report)

Grey infrastructure

Engineered physical structures that underpin energy, transport, communications (including wireless and digital), built form, water and sanitation, and solid waste management systems and that protect human lives and livelihood.

Infrastructure

Individual assets, networks and systems that provide specific services to support the functioning of a community or society.

Infrastructure lifecycle

The series of stages during the lifetime of an infrastructure asset, starting from planning, prioritization and funding to the design, procurement, construction, operation, maintenance, and decommissioning.

Infrastructure governance

The capacity to plan, finance, design, implement, manage, operate, and maintain infrastructure systems (Hertie School of Governance, 2016).

Infrastructure maintenance

Maintenance is a cycle of activities designed and undertaken to preserve the optimal functioning of infrastructure, including in adverse conditions. It is a necessary precondition for the preservation of its operational capability, and to guarantee service continuity.

Infrastructure systems

Arrangements of infrastructure components and linkages that provide a service or services.

Local infrastructure systems

Facilities at the local level, including water, drainage and sanitation networks, road, river and rail networks, bridges, health, and education facilities, as well as other local facilities services to individuals, households, communities, and businesses in their current locations.

Nature-based (Infrastructure) solutions (NbS/ NbIS)

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, and resilience and biodiversity benefits (UNEP, 2023). NbIS is used in this report to refer to the application of nature-based solutions to address infrastructure requirements, in other words, directly connecting the natural environment with the built environment.

Project pipelines

A set of infrastructure projects and assets (accounting for the existing stock of assets), and future assets in early development and construction stages prior to project commissioning, typically presented as a sequence of proposed investment opportunities over time that align with and are supportive of long-term climate and development objectives (OECD, 2018).

Redundancy

Alternative or back-up means created within an infrastructure system to accommodate disruption, extreme pressures, or surges in demand. It includes diversity, i.e., the presence of multiple ways to achieve a given need or fulfil a particular function.

Reliability

Ability of an infrastructure asset or system to perform the desired function based on specified requirements over time without interruption or degradation.

Resilience

The ability of individuals, households, communities, cities, institutions, systems, and society to prevent, resist, absorb, adapt, respond, and recover positively, efficiently and effectively when faced with a wide range of risks, while maintaining an acceptable level of functioning and without compromising long term prospects for sustainable development, peace and security, human rights and well-being for all. (UN, 2020).

Resilience dividend

The value of reduced future asset loss and damage avoided service disruption, wider social, economic, and environmental co-benefits, and reduced systemic risk, that accrue over the lifecycle of an infrastructure system. (Definition adopted in this Report)

Resilient infrastructure

Infrastructure systems and networks, the components, and assets thereof, and the services they provide, that can resist and absorb disaster impacts, maintain adequate levels of service continuity during crises, and swiftly recover in such a manner that future risks are reduced or prevented.

Systemic resilience

The resilience of social, economic, territorial, and environmental systems at all scales, that conditions the ability of infrastructure assets and the services they provide to resist and absorb disaster impacts. (Definition adopted in this Report)

Systemic risk

In the context of infrastructure, systemic risk is a cumulative risk to a system as an outcome of physical, biological, social, environmental, or technological shocks and stresses. These may be internal or external to the system. Impact on individual components of the system (assets, networks, and subsystems) becomes systemic due to interdependence and interactions between them.

Acronyms and Abbreviations

AAL	Average Annual Loss
CoP	Community of Practice
ESG	Environmental, Social and Governance
ESV	Ecosystem Service Valuation
GFCF	Gross Fixed Capital Formation
GDP	Gross Domestic Product
GIRI	Global Infrastructure Risk Model and Resilience Index
GIRS	Global Infrastructure Resilience Survey
LMIC	Low- or Middle-Income Country
MDB	Multilateral Development Bank
NAP	National Adaptation Plan
NbIS	Nature-based Infrastructure Solutions
NDC	Nationally Determined Contributions
O&M	Operations and Maintenance
PCRAM	Physical Climate Risk Assessment Methodology
PPP	Public-Private Partnership
RCP	Representative Concentration Pathway
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States

Introduction

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 deficits. Given an estimated Average Annual Loss (AAL) of over US$ 700 billion[4] in infrastructure and buildings, new infrastructure investments without strengthened resilience are analogous to pouring water into a bamboo basket.

Strengthening infrastructure resilience is a major contemporary global challenge. Many high-income countries, particularly those that industrialized prior to the second World War, need to replace obsolete infrastructure assets to strengthen resilience to new and existing hazards. Meanwhile, social and economic development in lower income countries is constrained by large infrastructure deficits that are aggravated by weak infrastructure governance.

International agreements on the need to reduce emissions and mitigate climate change mandate a rapid transition from carbon-locked-in infrastructure to low, zero, or negative emission infrastructure. However, a significant proportion of new capital investments is eroded by asset loss and service disruptions associated with disaster and climate risk. In other words, new infrastructure investment without strengthened resilience is analogous to pouring water into a bamboo basket.

Most of the infrastructure that will be required by 2050 is yet to be built. Recent estimates of the annual investment required to address infrastructure deficits, achieve the SDGs, and achieve net zero by 2050, amount to $9.2 trillion of which $2.76 trillion must be invested in low- and middle-income countries (LMICs). While investments in high- and many middle-income countries are increasing at a

[4] Global Infrastructure Risk Model and Index (GIRI). See Chapter 2.

slow but steady pace, infrastructure investment in low-income countries continues to be an order of magnitude lower than the projected investment needs.

The long design lifecycles of many infrastructure assets will be key to making investments resilient and configure development trajectories in the decades to come. At the same time, strengthening infrastructure resilience is critical to address existential risks associated with catastrophic climate change and biodiversity loss.

Globally, we are at a fork in the road. Investing to strengthen infrastructure resilience could 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. On the flipside, ignoring resilience could mean stagnant social and economic development, stranded infrastructure assets, increasing contingent liabilities, unreliable and inferior services, and growing existential risk.

Strengthening infrastructure resilience is particularly critical for low-income communities as risk distribution within countries is conditioned by factors such as social status, gender, power, access and control of resources, poverty, and vulnerability. Consequently, the disproportionate impact of climate change on women necessitates having them contribute towards strengthening resilience (Nellemann et al., 2011).

This first edition of 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 Report's aim is to highlight the resilience dividend or the full range of benefits possible from investing in infrastructure resilience. These include avoided asset loss, reduced service disruption, improved quality, and reliability of public services, accelerated economic growth and social development, reduced carbon emissions, enhanced biodiversity, improved air and water quality, more efficient land use, among others.

This Report examines the risk to infrastructure from both geological and climate-related hazards. The thesis of the Report is that a more complete estimation and visualization of the risk as well as the resilience dividend can provide a solid economic imperative for investing in infrastructure resilience. Further, realizing the resilience dividend in a way that benefits governments, investors, and other stakeholders may provide the missing financial incentive to mobilize the required capital.

The economic and financial imperatives for investing in resilience will only be effective if a political imperative is also identified. Infrastructure resilience faces challenges from short-term economic and social demands, aggravated by shocks and crises such as the COVID-19 pandemic and the war in Ukraine that consume political capital and distract attention. Although, elections have never been won on issues of avoided loss and damage or reduced contingent liabilities, improving coverage, quality, and reliability of essential services in most countries are increasingly political demands. Therefore, improving the delivery of essential services may provide the much-needed political incentive to invest in resilience.

This report is divided into five chapters and several annexures.

Chapter 1 explores the dual nature of infrastructure resilience as investing in resilient infrastructure on the one hand, and infrastructure for resilience on the other. It also discusses the scale of infrastructure deficits in relation to the SDGs; the need to consider asset, service, and supply chain resilience; the role of infrastructure governance in configuring resilience; and reducing systemic risk.

Chapter 2 provides a new and unique body of quantitative evidence on infrastructure risk and resilience. The Global Infrastructure Risk Model and Resilience Index (GIRI), as commissioned by CDRI, provides a globally comparable set of financial risk metrics for infrastructure assets. GIRI is the first-ever fully probabilistic model to identify and estimate the risks associated with major hazards (earthquakes, tsunamis, tropical cyclone winds and storm surges, landslides, floods, and hydrological drought) across principal infrastructure sectors (power, oil and gas, telecommunications, ports and airports, roads and railways, water and wastewater, health, education, and commercial, industrial and residential buildings) in all countries and territories, accounting for existing climatic conditions and two other climate change scenarios. Additionally, risk metrics such as Average Annual Loss (AAL) enable governments to identify and understand contingent liabilities internalized in their infrastructure systems and to inform resilience-related investments.

Chapter 3 examines the role of investments in infrastructure resilience in strengthening systemic resilience with a particular focus on Nature-based Infrastructure Solutions (NbIS) in complementing, substituting for or safeguarding traditional “grey” infrastructure. The chapter proposes enabling activities such as strengthening knowledge and capacities, documenting practices, and the formulation of appropriate standards necessary to transform NbIS from what is currently an exotic, into a quotidian approach to address infrastructure, particularly in sectors such as water and hazard mitigation.

Chapter 4 addresses the financing of infrastructure resilience. Between now and 2050, the gap between existing annual infrastructure investment (understood as the total of public and private infrastructure investment and climate finance) and that required to address the infrastructure deficit, reduce systemic risk, and strengthen resilience is immense. This is particularly the case in low-income countries. While there is sufficient unassigned private capital to fill this gap, investing in resilience is still generally perceived as an additional cost imposed by regulators rather than being seen as an investment opportunity. Therefore, identifying and estimating the full resilience dividend in all infrastructure projects is necessary to make a strong economic case for investing in resilience. Mechanisms to realize and distribute the identified resilience dividend could provide a solid financial case for mobilising private capital.

Chapter 5 summarizes the principal recommendations of the report, particularly highlighting the need for enabling activities that can collectively serve to strengthen infrastructure governance at national levels by sending positive market signals to unlock private capital and public investment. It concludes with a discussion on the mobilization of political capital for better quality and more dependable essential services.

Lastly, **Annexure 1** presents a proposal to monitor progress in infrastructure resilience including through the Global Infrastructure Resilience Survey that captured information on infrastructure governance and management across several countries in this iteration.

The risk and resilience metrics produced by the report cover all countries and territories across all geographic and income regions. Clearly, each country and each income and geographical region face their own specific infrastructure challenges. While high-income countries have huge capacities for public investment and are attractive destinations for private capital, many LMICs face serious challenges for mobilizing the capital needed for strengthening resilience.

LMICs include a wide range of economies, including low-income developing countries, emerging economies, Small Island Developing States (SIDS), and landlocked developing nations, each of which face different challenges. *Global Infrastructure Resilience* is unique in that it examines this challenge from an international organisation based in India, instead of a high-income European, North American, or East Asian country.

This edition of Global Infrastructure Resilience lays out the economic, financial, and political imperative for investing in infrastructure resilience and presents pathways to do so. Future editions of the Report will need to highlight the instruments that diverse LMIC can apply to transform their resilience objectives into actionable policies, strategies and plans, with greater granularity.

For example, it would be important to further specify the codes, standards, and regulations that could be applied in the planning of infrastructure resilience in each sector and for different categories, including strategic economic infrastructure and local infrastructure systems. Similarly, further work is required to define which are the most appropriate institutional architecture and governance arrangements to enable an effective application of such resilience-based codes, standards, and regulations. Other critical areas that require detailed instruments are the integration of infrastructure with land-use planning, with post-disaster recovery and the development of additional incentives for risk transfer and insurance.

Global Infrastructure Resilience is the result of collaborative research and analysis developed by many collaborating partners listed in the Acknowledgements, in a process of knowledge co-production that included online workshops and discussions over a one-year period. Each of the chapters and drafts of the report were peer reviewed by panels of external experts. The development of the report has also benefited from a high-level International Advisory Board (IAB).

Global Infrastructure Resilience is published in digital and print versions. All the Position and Contributing Papers that support the analysis presented here are listed in Annexure II and may be viewed and freely downloaded online. The GIRI Data Platform, developed by the United Nations Environment Programme (UNEP) for CDRI, enables users to access and download the full range of risk metrics and perform on-screen visualization and analysis of the results.

Chapter 1

The Resilience Challenge

1.5. Asset Resilience
1.6. Service and Supply Chain Resilience
1.7. Systemic Resilience
1.8. Fiscal Resilience

1.

The Resilience Challenge

1.1. Infrastructure for Sustainable Development

60 percent of the infrastructure needed by 2050 is yet to be built

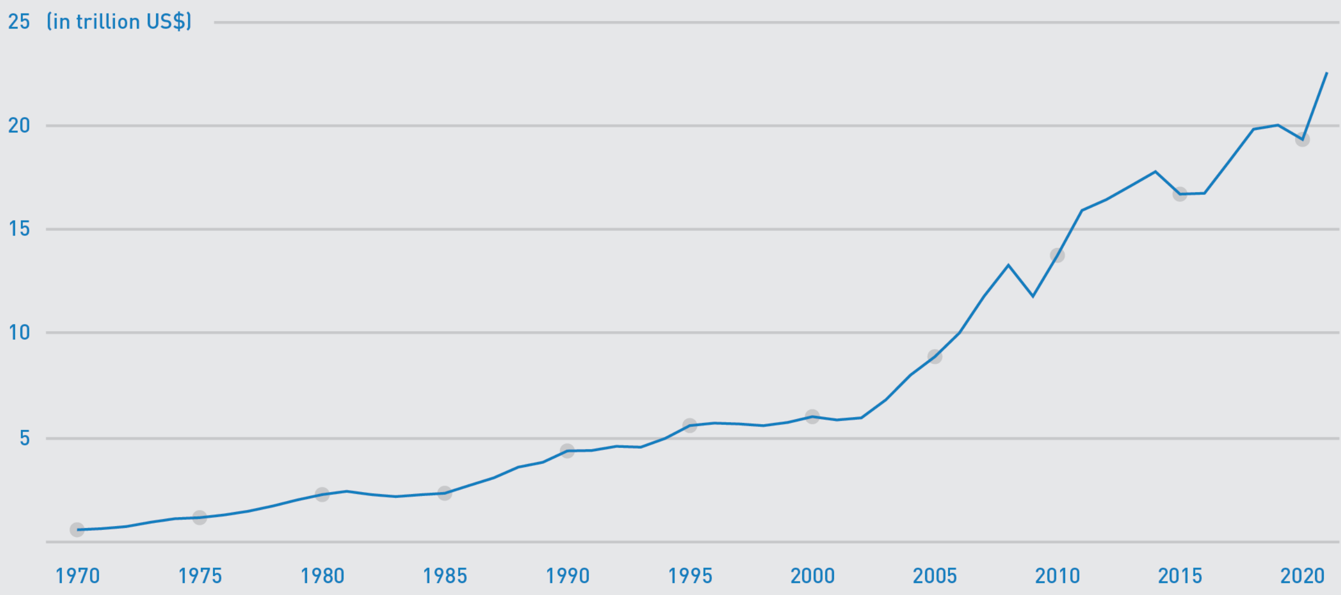
Infrastructure is the engine of economic growth and social development.

History flows through urban channels, and since the dawn of time, urbanization has been underpinned by infrastructure systems. The development of water and road networks, defensive fortifications and ports has accompanied the development of regional economies and their urban centres for centuries.

In 1970, French sociologist and philosopher Henri Lefebvre put forward a hypothesis: *the total urbanization of society* (Lefebvre, 1970). Fifty years later, his hypothesis has been largely fulfilled. Whether examined through a territorial, economic, social, cultural, or political lens, society has become essentially urbanized (UNDESA, 2019). Contemporary urban lifestyles and their associated patterns of production, distribution, and consumption now predominate in all regional and income geographies, shaping and moulding a global demand for land, water, food, energy, and other resources. The rural–urban dichotomy has gradually lost much of its interpretative value in analyzing development challenges and problems through a constantly expanding and increasingly tight web of relationships between cities, peri-urban areas, and villages.

Ongoing urbanization across Africa serves as a striking example of Lefebvre's vision. In 1950, only 13 percent of the continent's population lived in cities, but this had risen to almost 27 percent by 1980 and nearly 50 percent by 2015. The total number of towns and cities across Africa more than doubled from 3,319 in 1990 to 7,721 in 2015 too. Approximately 50 percent of rural Africans today live within 14 kilometres of a city (Kisumu, 2023).

Massive and ongoing investments in infrastructure across all sectors and territories has facilitated urbanization. Gross Fixed Capital Formation (GFCF), has steadily increased since 1970 from just over $742 billion to more than $25 trillion today (Figure 1.1). In other words, more than 90 percent of infrastructure around the world has been built in the last 50 years alone.



Infrastructure systems such as roads and railways, water, sewerage, electric and gas networks, and telecommunications have facilitated the emergence, expansion, and consolidation of modern towns and cities (Box 1.1). Other infrastructure systems such as hydroelectric dams, reservoirs, and high-tension power lines provide power, energy, and water to cities. Trunk roads, railways, ports, and airports interconnect urban areas within as well as between countries. Infrastructure systems are also closely interdependent. The capacity of infrastructure to provide essential services in one sector, such as telecommunications, depends on the resilience of infrastructure in other sectors, such as energy. Power cuts often have cascading effects on other systems, including water and sanitation, health, transport, and telecommunications.

The 2030 Agenda for Sustainable Development, endorsed by 193 countries and all G20 nations, recognized the fundamental role of infrastructure (Thacker et al., 2019). **Infrastructure is not only critical to the achievement of SDG 9 (industry, innovation, and infrastructure) but also to SDG 3 (good health and well-being), SDG 4 (quality education), SDG 6 (clean water and sanitation), SDG 7 (affordable clean energy) and SDG 11 (cities' resilience to disasters)** (UN, 2015). 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).

Reducing constraints on access to employment and risk of violence also helps facilitate greater independence and opportunity for women. Economic growth and social mobility are highly dependent on investment in inclusive and gender-responsive infrastructure even though they are mostly designed by men. Therefore, the role of women in the design and provision of infrastructure and their perspectives in building infrastructure resilience is critical. This is clearly illustrated in Colombia and India.

The Colombian Presidential Council for Gender Equality (CPEM), the National Planning Department (DNP),

↑ **FIGURE 1.1**

Global Gross Fixed Capital Formation,1970 - 2020 (current US$)
Source: World Bank (2021)

↓ **BOX 1.1**

Infrastructure Definitions and Classification

Infrastructure has Latin origins, meaning "underneath or below the structure." It was first used in France during the late 1800s to refer to the substructure or foundation of a building, road, or railroad bed and did not become a part of English vocabulary until after World War II.

CDRI defines infrastructure as "*individual assets, networks, and systems that provide specific services to support the functioning of a community or society*" (CDRI, 2023). This is similar to the definition of infrastructure adopted by the United Nations, as "*the physical structures, facilities, networks and other assets which provide services that are essential to the social and economic functioning of a community or society*" (UNDRR, 2017).

Based on their scale, purpose, and topology, infrastructure systems can also be grouped into two broad categories; strategic economic (or critical) infrastructure refers to infrastructure that supports strategic sectors, regional and global trade, and economic integration, including power stations, ports and airports, large dams, refineries, logistic hubs and major highways, railways, and high-tension transmission lines; local (or basic) infrastructure systems refer to infrastructure that provide essential services to individuals, households, communities, and businesses[5], including water, drainage, sanitation networks, local roads, rivers, rail networks, health and education facilities, and post-harvest processing and storage facilities, among others. Local infrastructure systems nest within national, regional, and global networks of strategic economic infrastructure in topological terms.

→ **FIGURE 1.2**

Growth Rates in Capital Stock and Productivity Across Economies (1960-2019)

Source: IMF (2019)

and the Ministry of Finance adopted a methodology in 2019 to identify, track, and monitor public investments that had a gender equality component (*Trazadores Presupuestales para la Equidad de la Mujer*). Their methodology also included tools for public practitioners to mainstream gender considerations throughout the investment lifecycle, particularly strategic planning.

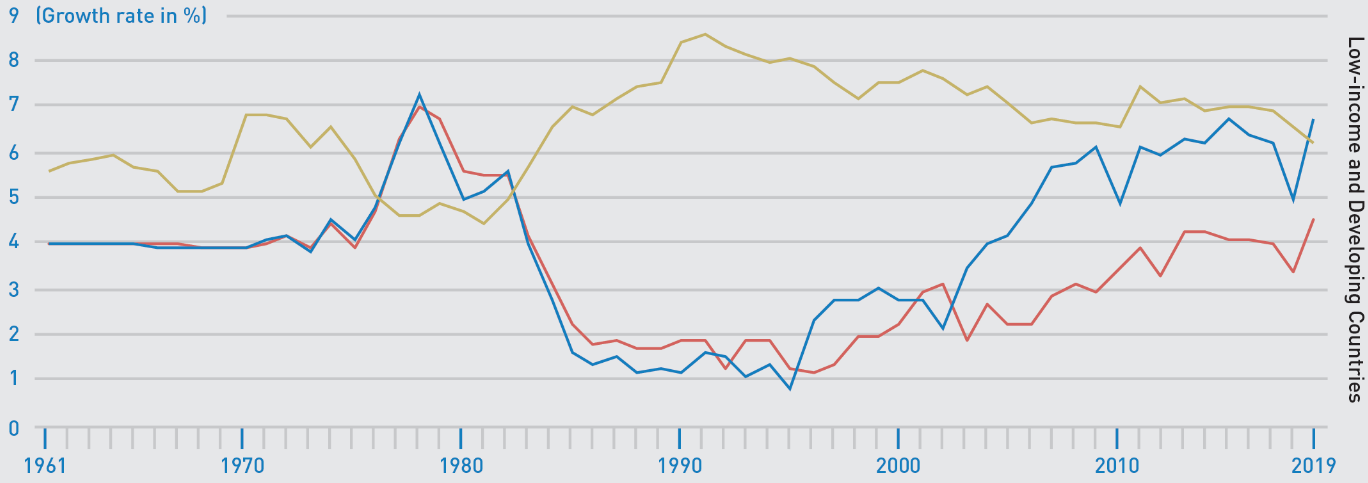
In India, national and state plans are gender-sensitive, the Department of Commerce identifies gender implications of special economic zones, and the Ministry of Urban Development introduced measures for clean and safe public toilets and adequate street lighting (OECD, 2021). It has been estimated that the application of a gender lens to infrastructure development alone would increase the total GDP of the OECD's member states by 2.5 percent until 2050 (UNEP et al., n.d.).

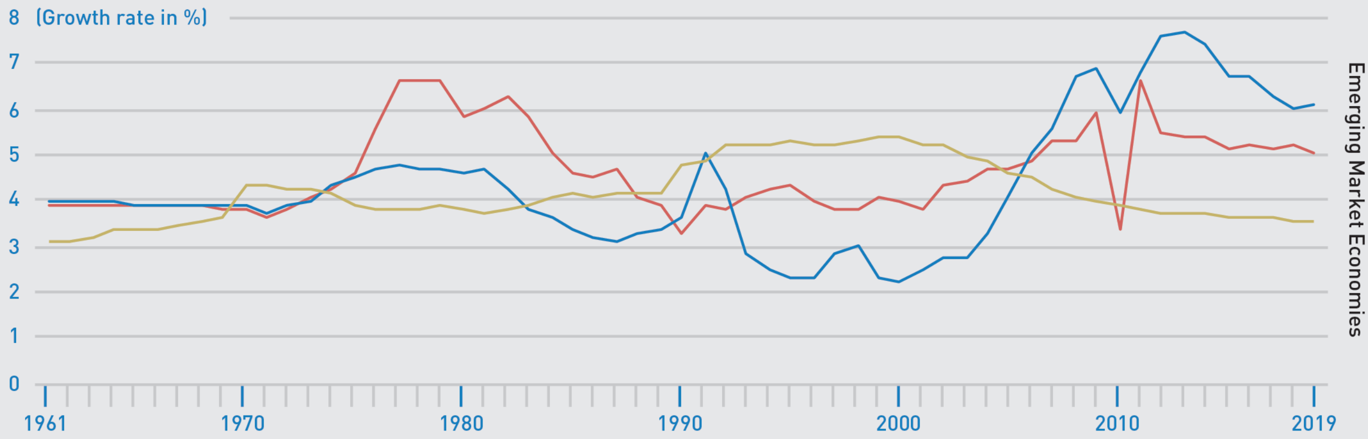
The growth of a country's infrastructure stock is closely correlated to other economic variables such as Gross Domestic Product (GDP) and labour productivity (Figure 1.2). Investing in strategic economic infrastructure, therefore, is critical to strengthening competitiveness and productivity as well as facilitating the territorial integration of countries and broader regions.

Investing in local infrastructure systems is also critical to social development and achieving the SDGs. For example, safe, reliable, and affordable rural transport would ensure that agricultural communities have access to markets, health and education facilities, employment opportunities, and are able to develop modern supply chains to prevent food loss and secure reliable income flows (Cook et al., 2017). Social infrastructure such as health centres, clinics, and schools would ensure that essential services are accessible to all (Cook et al., 2017). Seen from the perspective of the 2030 Agenda for Sustainable Development, local infrastructure systems would be better considered as the first mile rather than the last mile of development.

Conversely, development in many LMICs and low-income countries is constrained by large deficits of strategic economic and local infrastructure systems. In these countries, weak infrastructure governance leads to precarious, low quality, infrastructure assets that undermine the provision of dependable essential services.

[5] In the context of local infrastructure systems, the term 'business' is used to refer to the small and medium enterprises that provide most employment in regional economies and their urban centres.


(Growth rate in %)
9
8
7
6
5
4
3
2
1
0
1961
1970
1980
1990
2000
2010
2019
Low-income and Developing Countries


(Growth rate in %)
8
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1961
1970
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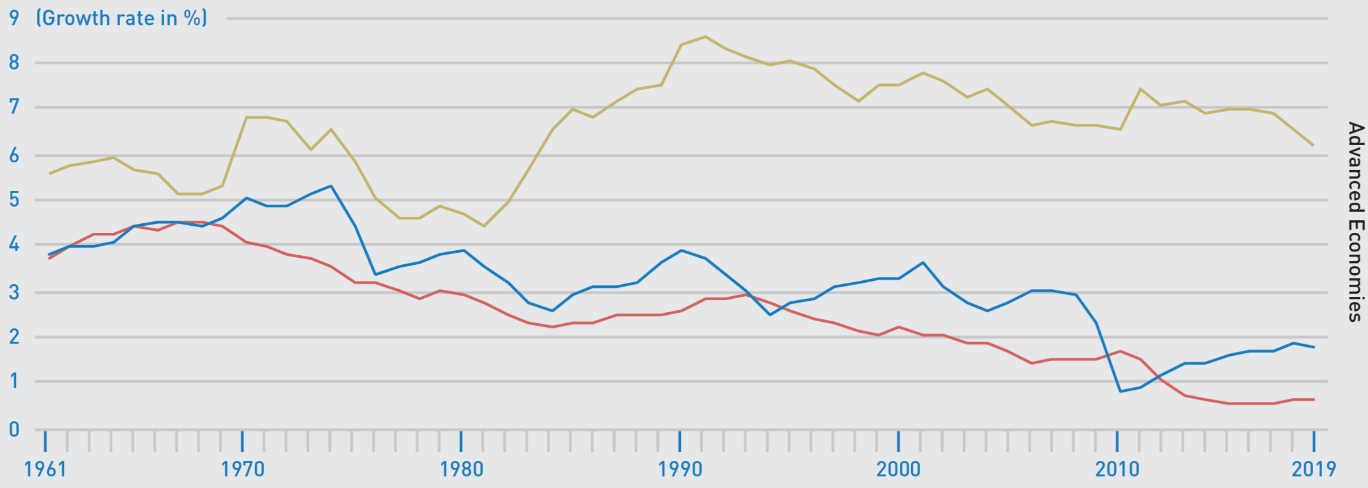
Emerging Market Economies


(Growth rate in %)
9
8
7
6
5
4
3
2
1
0
1961
1970
1980
1990
2000
2010
2019
Advanced Economies
Public Capital Stock
Private Capital Stock
GDP Relative to Total Public and Private Capital Investment

Furthermore, in regions exposed to physical hazards, such as floods, earthquakes or tropical cyclones, infrastructure often internalizes high and growing levels of disaster risk. Disaster damage leads to increasing damage to infrastructure assets and aggravated service disruption. Capital investment budgets then have to be reoriented to repair, rehabilitate, and rebuild damaged infrastructure. Much "new" public infrastructure investment is, in reality, used to patch up post-disaster damage.

Taking climate change into account, the global Average Annual Loss (AAL)[6] for infrastructure, including buildings, currently lies between $732 – $845 billion, representing about 14 percent of 2021-2022 global GDP growth. LMICs hold roughly half of this contingent liability.

Accelerating anthropic climate change challenges infrastructure in several different ways. Risk to infrastructure assets increases due to more frequent or intense hazard events, also magnifying service disruption. At the same time, changing climatic conditions may make existing infrastructure inadequate or obsolete in ways that are not reflected in the AAL. For example, power generation may be insufficient to meet additional cooling needs required to cope with urban heat waves, leading to increased heat related morbidity. Storm drainage may be unable to cope with extreme rainfall, leading to increased urban flooding. Agriculture may become unviable in areas experiencing hotter and drier conditions, forcing migration to cities, and putting further strain on urban infrastructure. Worryingly, the impact of such events is likely to disproportionately impact women, older populations, and children, and/or those with informal employment, increasing existing inequities in the process.

The growth of urban civilizations over several millennia has been enabled by infrastructure such as defensive city walls and forts that were later abandoned or demolished while infrastructure such as modern power and transport networks were introduced, ushering in new patterns and modes of urbanization. Radical changes are taking place today in the way infrastructure systems are developed and used as the transition to carbon-neutral and carbon-negative development gains pace in sectors such as energy and transport. As pipelines and refineries are replaced by wind and solar farms and new transmission lines and petrol stations are replaced with vehicle charging points, many infrastructure assets in these sectors will become stranded, stressing economies in LMICs that fall behind in the transition.

To summarize, many LMICs now face a multidimensional challenge. A large infrastructure deficit which constrains social and economic development; precarious and poor-quality infrastructure due to deficiencies in infrastructure governance; rising asset loss and damage, associated with disaster risk, leading to more frequent service disruption; and a stock of existing infrastructure increasingly ill-suited to address the challenges posed by climate change and rapid technological change.

All new infrastructure investment has the potential to either undermine or reinforce resilience. However, most of the new infrastructure required is yet to be built, so decisions taken now could lock countries in a development trajectory that may or may not be sustainable and resilient (Pols & Romijn, 2017; Seto et al., 2016). **It is unquestionable that massive new infrastructure investment is required to accelerate development. But large volumes of investment will not be effective in supporting social and economic development unless the infrastructure is resilient.**

[6] The Average Annual Loss or AAL is a measure of annualized future losses over the long term, derived from probabilistic risk models.

1.2. Dimensions of Infrastructure Resilience

Resilience derives from the present participle of the Latin verb *resilire*, meaning "to jump back" or "to recoil". In recent years, resilience has become something of a cliché in development circles. The more the term is used, the less precise its definition becomes. Box 1.2 presents the definitions of resilience used in this report.

↓ **BOX 1.2**

Resilience
Source: CDRI (2023)

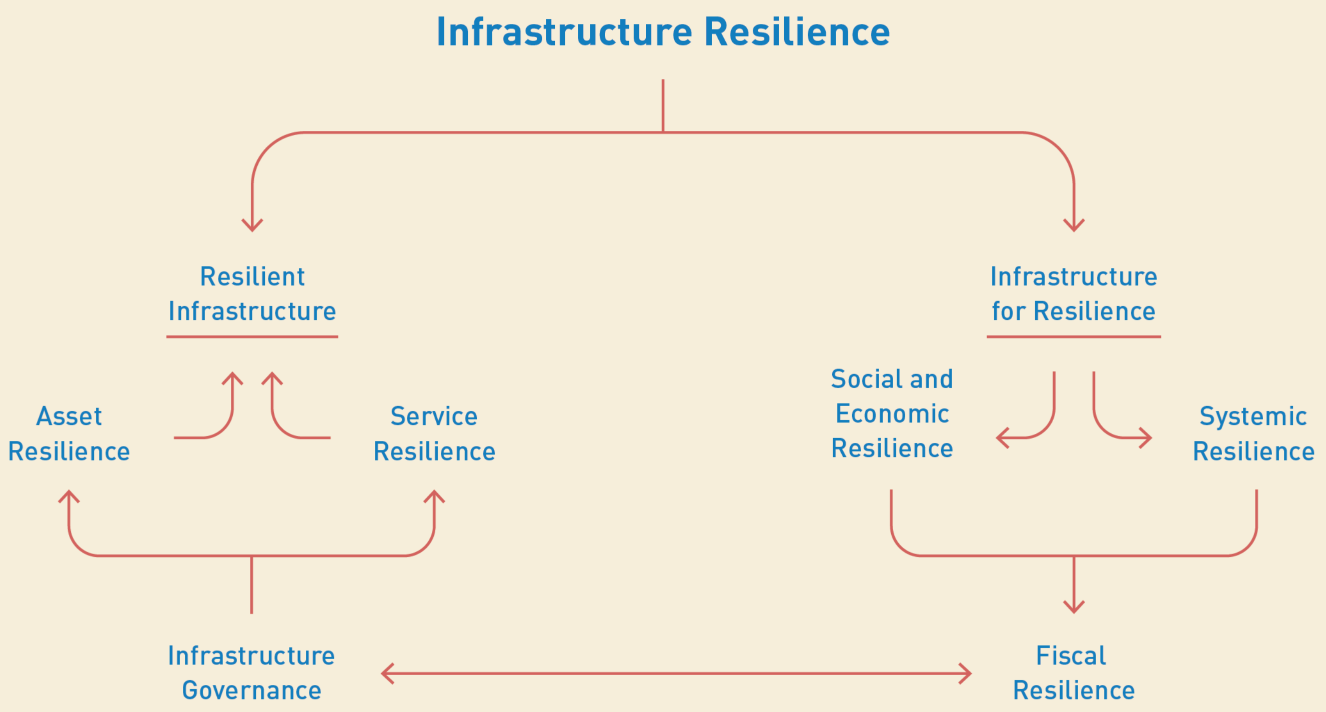
Resilience is defined by the United Nations Chief Executive Board (CEB) as "*the ability of individuals, households, communities, cities, institutions, systems and society to prevent, resist, absorb, adapt, respond and recover positively, efficiently and effectively when faced with a wide range of risks, while maintaining an acceptable level of functioning and without compromising long term prospects for sustainable development, peace and security, human rights and well-being for all*" (United Nations, 2020).

For its part, CDRI defines disaster resilient infrastructure as "*infrastructure systems and networks, the components, and assets thereof, and the services they provide, that are able to resist and absorb disaster impacts, maintain adequate levels of service continuity during crises, and swiftly recover in such a manner that future risks are reduced or prevented*".

Conventionally, infrastructure resilience has been considered to be primarily an engineering issue: strengthening the capacity of infrastructure assets and services to resist and absorb the impact of extreme geological or climatic hazards, considered as external or exogenous threats to infrastructure systems (Rogers et al., 2012). According to this perspective, improved design standards and norms, new materials, technologies, and enhanced system management and operations all help enhance resilience.

This interpretation, however, only captures some dimensions of the issue. Infrastructure resilience can be conceptualized as resilient infrastructure but also as infrastructure for resilience. In the first case, **resilient infrastructure** refers to infrastructure that can absorb, respond to, and recover from hazard events and shocks.

Infrastructure for resilience refers to infrastructure that supports broader social and economic or systemic resilience without generating or accumulating new systemic risk. Climate change, biodiversity loss, growing social and economic inequality, and unplanned urban development are ultimately endogenous attributes of the urbanization process and of the way infrastructure has been developed (Lavell & Maskrey, 2014; Maskrey et al., 2023). **As such, infrastructure investments over the last 60 years have themselves been a major driver of systemic risk.**



↑ **FIGURE 1.3**

Dimensions of Infrastructure Resilience

Source: CDRI (2023)

Infrastructure resilience is conditioned by core enablers such as infrastructure governance and financing. Figure 1.3 shows the concatenation of the different dimensions of infrastructure resilience.

Despite the close links between disaster resilience and resilience to climate change, they are different. Around 33 percent of the disaster risk internalized in infrastructure and buildings is associated with geological hazards such as earthquakes or tsunamis that are not climate conditioned. Similarly, many infrastructure assets are not resilient to hazards such as floods or tropical cyclones under existing climate conditions. However, as discussed above, climate change will increase disaster risk challenging the resilience of infrastructure assets and essential services. Climate change is expected to increase risk in infrastructure sectors between 5 and 14 percent and total infrastructure risk between 11 and 21 percent.

Climate change simultaneously affects the capacity of infrastructure to provide essential services even when assets remain intact during disasters. Existing infrastructure, for example, may no longer be functional in a changing climate or may experience premature obsolescence due to technological change. To illustrate, increased hydrological drought reduces the capacity of hydroelectric power plants to generate energy while water levels in major river systems may be too low to support barge traffic even though no infrastructure assets are damaged.

1.3. Social and Economic Resilience

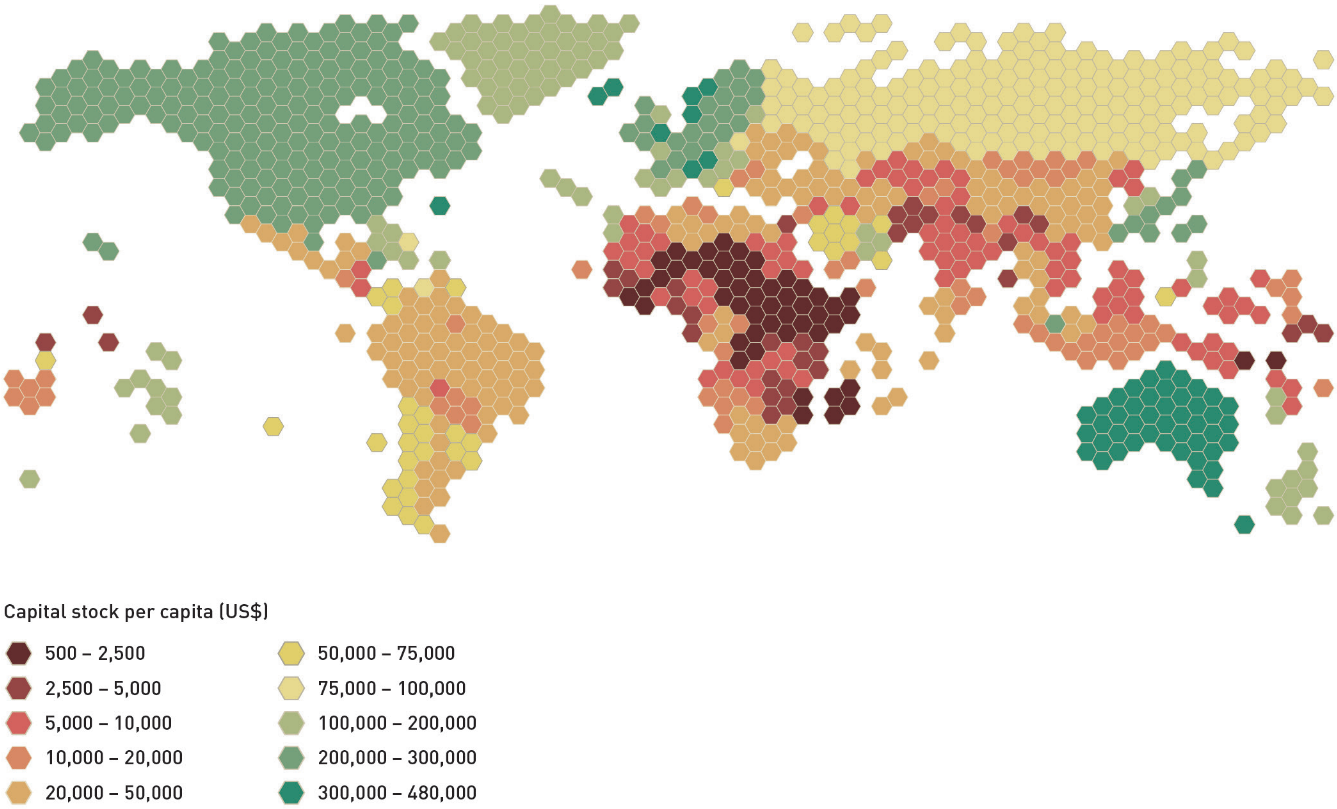
The gap in infrastructure investment between lower and higher income countries is widening, constraining social and economic development in the former while increasing global inequities.

Access to services provided by infrastructure strengthens social and economic resilience. Before the Industrial Revolution, for example, climate variability led to frequent famines across rural areas in France due to stressed or collapse of local food

↓ FIGURE 1.4

Total Capital Stock Per Capita

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



→ **FIGURE 1.5**

Average Absence of Basic Services by Regency in Jawa Barat and Gorontolo Provinces, Indonesia

Source: UNDP (2021)

production systems (Le Roy Ladurie, 1993). They became increasingly rare as new transport infrastructure connected rural areas to national, regional, and global food markets during the 19th century.

While access to essential services is largely taken for granted in high-income countries, in many LMICs, in particular in low-income countries, service provision is still constrained by a large infrastructure deficit. Inexistent or unreliable essential services undermine broad social and economic resilience. This infrastructure deficit is especially critical for women and girls. Women and girls across the world spend over 200 million hours every day collecting water (i.e., an equivalent of 8.3-million-person days or 22,800 person years) (UNICEF, 2016), increasing their exposure to physical and sexual violence. Roughly 40 billion hours per year are spent to collect water – equivalent to a whole year of labour by France's entire workforce – in Sub-Saharan Africa alone. Similarly, around 66 percent of households in Sub-Saharan Africa, 55 percent in South and South-east Asia, and 31 percent in Latin America still rely on firewood for cooking (FAO, 2018).

While the real value of the global public capital stock per capita has nearly tripled since 1960, its distribution is highly unequal, closely mirroring the global distribution of GDP per capita (Figure 1.4). Currently, the per capita value in high-income countries is $200,000 compared to $37,000 in upper-middle-income countries, $8,000 in LMICs, and $3,000 in low-income countries. In Switzerland, for example, the per capita value of infrastructure assets is over $375,000 while it is only $4,600 in Senegal, a low-income country (Cardona et al, 2023a). Such a difference in value is conditioned by factors such as the value of infrastructure, population, and territorial size.

A lack of infrastructure has drastic implications for social and economic well-being. As of 2020, roughly 300 million people in the Asia-Pacific region have no access to safely managed or basic water services such as drinking water. Further, 1.2 billion lacked adequate sanitation (ADB, 2020).

There are similar variations in the quantity and quality of infrastructure within LMICs, reflecting unequal territorial distribution and development. For example, access to essential services in some regencies in Jawa Barat and Gorontolo provinces is less than 50 percent even in an upper-middle-income country like Indonesia (Figure 1.5).

Public and private capital investment in low-income countries as a proportion of GDP has consistently lagged behind middle or higher-income countries. For example, annual capital investment in Africa has historically averaged around 13 – 14 percent of GDP. In Asia, it averages 26 – 31 percent of GDP, nearly double that rate. As a consequence, the gap in infrastructure investment between lower and higher income countries is actually widening,

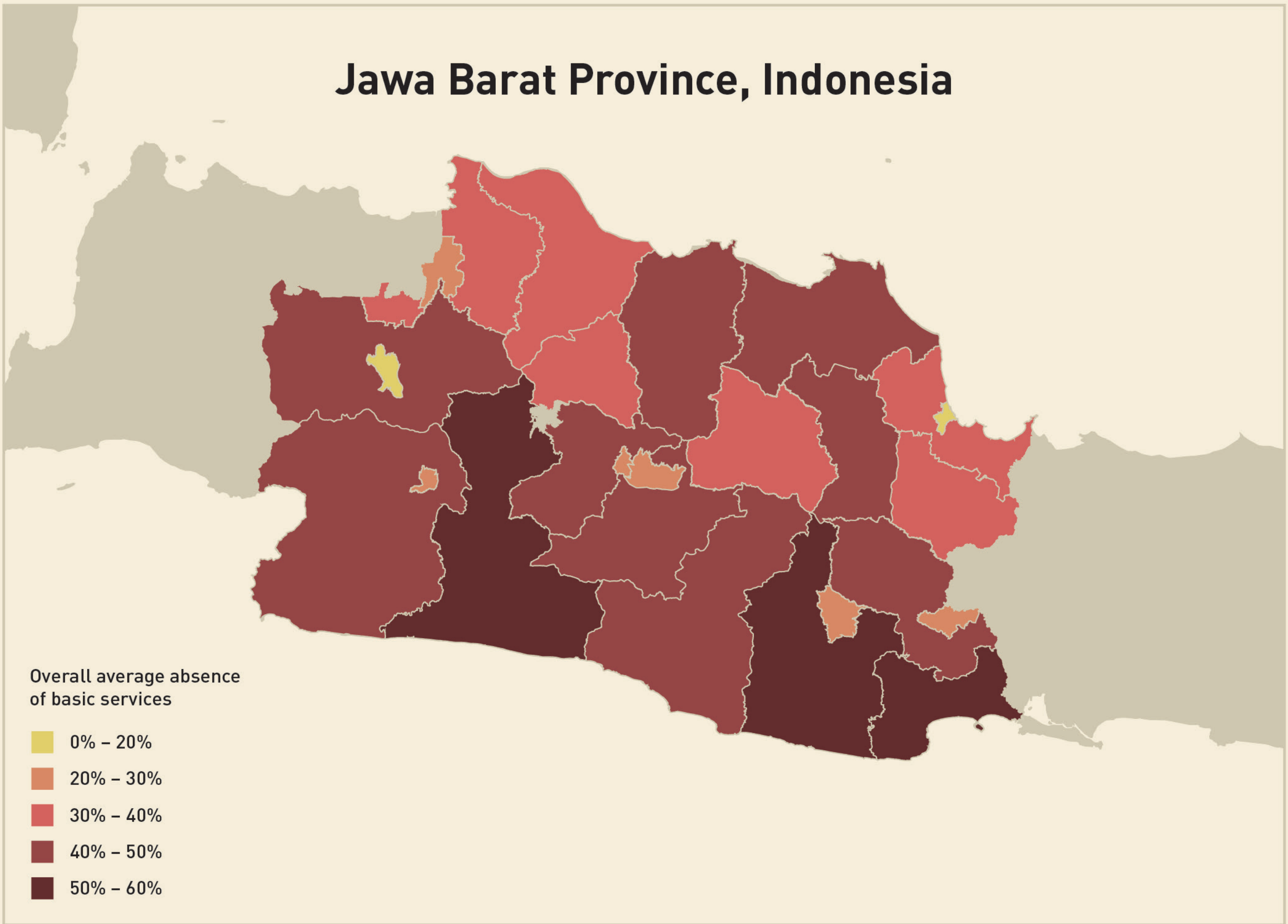
↓ **BOX 1.3**

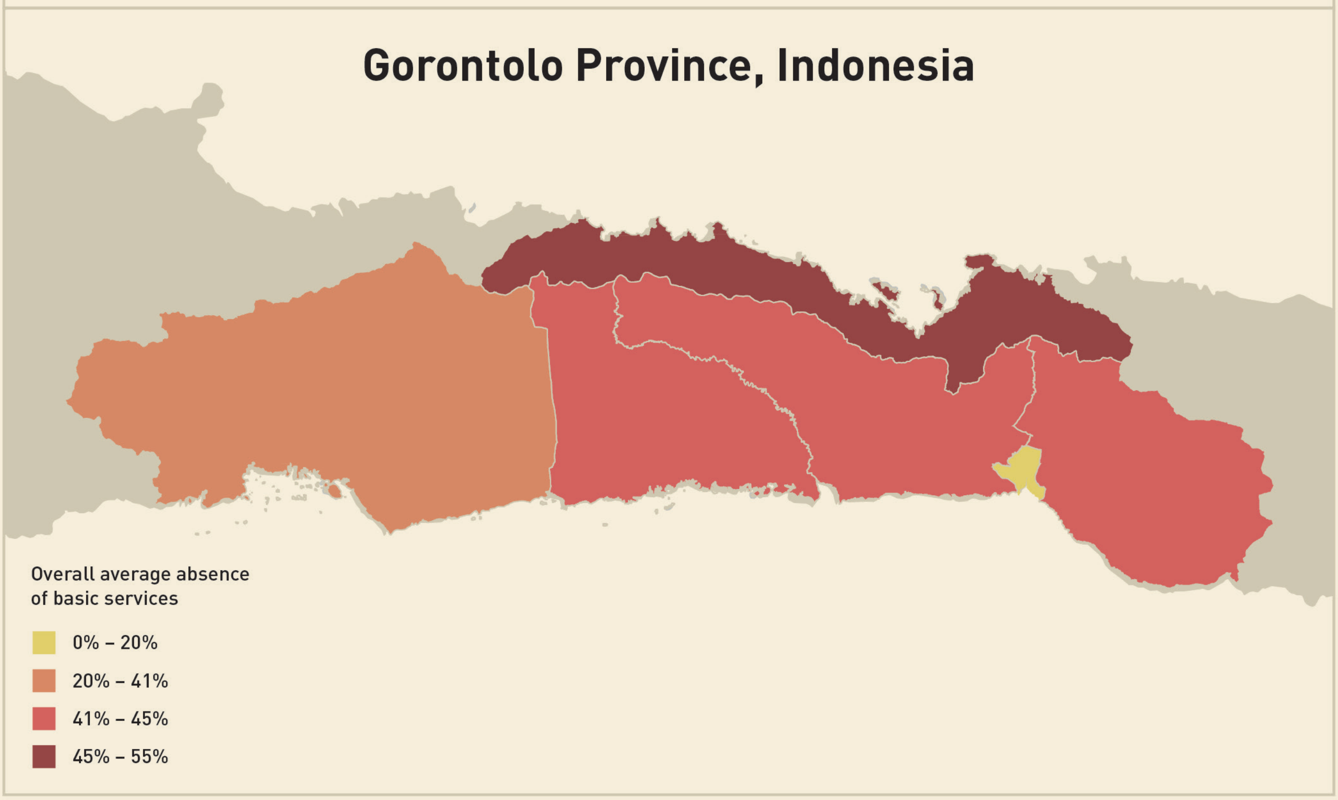
Progress Towards SDG 6 in 2022

Source: UN (2022)

Goal 6: WATER

Universal access to drinking water, sanitation, and hygiene is critical to global health. Managing to reach universal coverage by 2030, would save 829,000 lives each year only by increasing our current rate of progress by four times. Over 800,000 people die each year from diseases directly attributable to unsafe water, inadequate sanitation, and poor hygiene practices. Worryingly, 2 billion people as of this moment lack access to such services, basic or otherwise. Eight out of 10 people who lack even basic drinking water live in rural areas around the world with roughly half of them living in least developed countries (LDCs). At the current rate of progress, the world would leave 1.6 billion people without safely managed drinking water supplies and 2.8 million people without access to safely managed sanitation services of which a disproportionate burden is likely to fall on women and girls.


Jawa Barat Province, Indonesia
Overall average absence
of basic services
0% – 20%
20% – 30%
30% – 40%
40% – 50%
50% – 60%


Gorontolo Province, Indonesia
Overall average absence
of basic services
0% – 20%
20% – 41%
41% – 45%
45% – 55%

↓ FIGURE 1.6

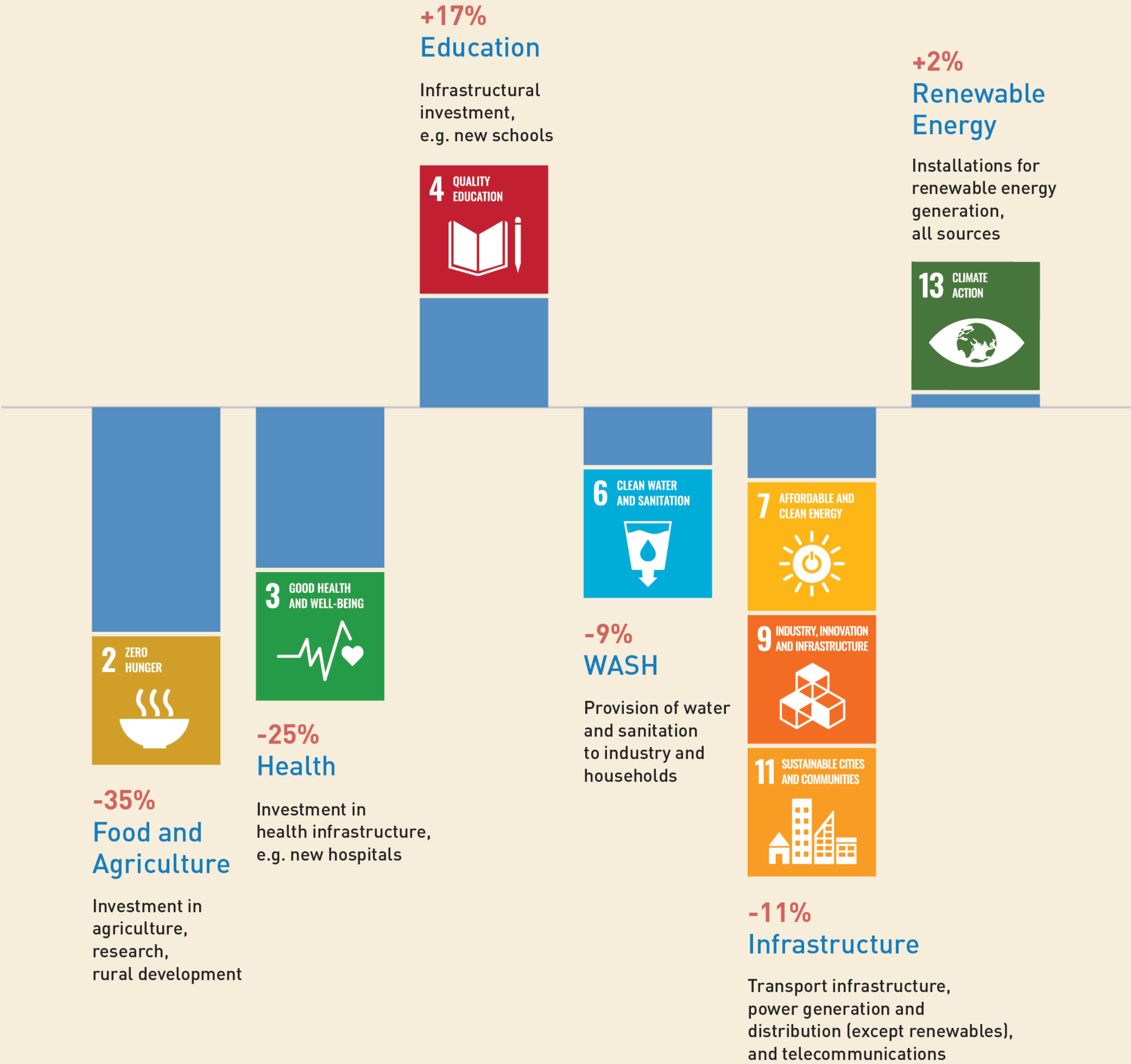
International Private Investment across the SDGs, 2020-21 (percentage reduction compared to 2019)

Source: UNCTAD (2023)

constraining social and economic development in the former while increasing global inequities.

Furthermore, most public and private infrastructure investment flows into strategic economic infrastructure such as major transportation, energy production, and distribution (Bond et al., 2012). Conversely, local infrastructure systems receive far less, impeding local economic development, exacerbating poverty, and undermining progress towards the SDGs.

It is worth noting that private investment in SDG-relevant infrastructure marked a decrease during and after the COVID-19 pandemic (Figure 1.6). Since the pandemic, progress against some SDGs such as clean water and sanitation seems to have stalled and reversed in some countries. Populations without electricity throughout Sub-Saharan Africa, for example, rose from 74 percent before the pandemic to 77 percent (IEA, 2022).



1.4. Infrastructure Governance

Deficient planning and design, inadequate standards, ineffective systems for regulation and compliance and low levels of investment in maintenance and operation characterize weak infrastructure governance, all of which aggravate the infrastructure deficit across LMICs.

Sound infrastructure governance can broadly be defined as the capacity to plan, finance, design, implement, manage, operate, and maintain infrastructure systems as a core enabler of infrastructure resilience (Hertie School of Governance, 2016).

In contrast, weak infrastructure governance is a barrier to resilience, eroding economic growth, competitiveness, and social development (World Bank, 2020). The design standards adopted in infrastructure projects may not be appropriate to cope with increased risk due to climate change, environmental degradation, overutilization, unplanned urban development, and other drivers This locks risk into infrastructure systems as many assets are designed to last decades or more (Seto et al., 2016). Bridges and sewerage systems, for example, often have design lifespans of up to 100 years (Wright et al., 2018). Unfortunately, a lack of supervision, low compliance with standards, and corruption distort and degrade what may have been resilient designs. Designs, therefore, may not necessarily be reflected in what is built or sustainable over time.

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 (UNESCAP, 2018). Capital investment in an infrastructure asset may only account for 15 to 30 percent of overall expenditure over its design lifecycle, while 70 to 85 percent of the expenditure is attributable to operations and maintenance (UN, 2021). Patching up assets with provisional repairs contributes to further service interruptions, reducing resilience in the process.

Weak infrastructure governance also means that increases in spending do not automatically result in improved quality of infrastructure or better outcomes. In France or the Netherlands, for example, infrastructure outcomes such as employment and economic growth increased between 2010 and 2015 despite reduced investment. Contrastingly, increased investments in countries such as Indonesia, South Africa, or Nigeria have not led to better outcomes (Hertie School of Governance, 2016).

Governance standards are clearly correlated with the quality of infrastructure. The higher the level of corruption in a country, the lower the overall quality of infrastructure (Hallegatte et al., 2019).

The institutional and administrative arrangements for infrastructure governance vary widely between countries. However, normative responsibilities are often vested in sector ministries or departments, responsibility for operations and maintenance in public sector organizations or private sector operators under different models of concessions and public-private partnerships, responsibilities for territorial planning and for local infrastructure in local governments, and responsibility for evaluating and approving public investment projects vested in finance and planning ministries. Multilateral development banks and private investors also play important roles. It is paramount for all these stakeholders across the whole infrastructure lifecycle to be involved and aligned if infrastructure governance is to enable strengthened resilience.[7]

Weak infrastructure governance undermines the capacity of LMICs to formulate and finance infrastructure projects. Its consequences are particularly felt in peri-urban areas and small and intermediate urban centres. Poor quality infrastructure and unreliable service delivery in informal settlements, for example, contribute towards inequality and multidimensional poverty (Pandey et al., 2022; Zhou et al., 2022). Rapidly developing second- and third-tier cities rarely have sufficient capacity to plan and manage infrastructure development, the provision of essential services, or land use (World Bank, 2016). This can further exacerbate gender inequality by, for example, limiting women's and girls' mobility and access to basic services (Morgan et al., 2020). In summary, weak or non-existent local planning conspires against infrastructure resilience, communities that depend on local infrastructure, and the most vulnerable.

It is also an obstacle to planning and managing a transition to carbon-neutral or -negative infrastructure systems. Entrenched bureaucracies with low awareness of and exposure to new technologies and with weak capacities to manage structural change are poorly placed to formulate the policies, strategies, plans, and projects needed to support such a transition or to attract requisite finance.

[7] Infrastructure lifecycle is an asset's estimated life before the next replacement.

1.5. Asset Resilience

High levels of disaster-related asset loss and damage erode the capacity to make new capital investments as budgets are diverted to repair, rehabilitate, and reconstruct damaged infrastructure and to sustain budgets for operations and maintenance.

A specific attribute of weak infrastructure governance is that disaster and climate risks are rarely considered systematically in the conceptualization, planning, design, regulation, and management of infrastructure (ADB, 2019). Consequently, many infrastructure assets in hazard-exposed areas internalize high levels of disaster and climate risk, leading to asset loss and damage and service disruption.

As mentioned above, the total global infrastructure AAL including buildings lies within $732 and $845 billion. **LMICs account for only 32.7 percent of the exposed value but 54 percent of the risk with a total infrastructure AAL of $397 billion.** Similarly, low-income countries account for only 0.6 percent of the exposed value but 1.1 percent of the risk. Given very low levels of investment in low-income countries, high levels of asset risk further deepen and widen infrastructure deficits.

Ensuring that all new infrastructure investment is resilient, such that assets can absorb, and resist hazard impacts is, therefore, essential, if infrastructure is to be a motor for social and economic development, rather than a source of increasing contingent liability and future disaster. Unless asset resilience is strengthened, the massive new investments required to reduce the infrastructure deficit will contribute to the generation of new and unsustainable contingent liabilities for governments.

Market forces combined with weak planning and regulation lead to continued infrastructure investments in hazard-prone areas, increasing exposure without the necessary measures to reduce vulnerability and strengthen resilience. Poverty drives low-income households to occupy areas exposed to floods and other hazards. Many informal settlements do not have risk-reducing infrastructure such as drainage that further magnify hazard. Environmental degradation increases hazards such as flood or drought through the loss of regulatory ecosystem services such as mangroves, wetlands, and forests, further undermining asset resilience. Climate change magnifies the severity and alters the frequency and predictability of many weather-related hazards such as storms, floods, and drought. In other words, assets that were once resilient are no longer able to resist extreme hazard events.

Asset resilience is associated with the adoption and implementation of

↓ BOX 1.4

Internalizing Risk in Infrastructure Assets

Disaster risk refers to the probability of disasters of a given intensity occurring in a given period of time. It is not an independent variable but is a function of three other variables: hazard, exposure, and vulnerability. **Hazard** refers to the probability and intensity of occurrence of a damaging event, such as an earthquake, tsunami, flood, or tropical cyclone, and is expressed in terms of frequency and severity. **Exposure** refers to the number, kinds, and value of assets located in areas exposed to the hazard. **Vulnerability** refers to the susceptibility of those assets to suffer loss or damage (United Nations, 2017).

Earthquakes and tropical cyclones are naturally occurring phenomena. However, the hazard posed by these events and the exposure and vulnerability of infrastructure assets are socially constructed (Wisner et al., 2003). The location of infrastructure (exposure) and how they are built (vulnerability) depend on planning and investment decisions which may internalize and accumulate risk in infrastructure assets.

Asset risk and resilience can only be measured in relation to hazard intensity and frequency and the exposure and vulnerability of assets. The internalization and accumulation of disaster and climate risk in infrastructure assets reflects, therefore, socially constructed drivers such as weak infrastructure governance, badly planned and managed urban development, environmental degradation, and climate change (UNISDR, 2009). Through the operation of such risk drivers, patterns of hazard, exposure and vulnerability are configured over time and disaster risk internalized and accumulated in infrastructure systems. As such, risk and resilience are **endogenous** rather than **exogenous** characteristics of infrastructure assets (UNISDR, 2015).

appropriate design standards that consider risk levels. Such standards may not exist in many LMICs or are not translated into practice. While national governments are responsible for standard setting and developing normative frameworks, implementing those norms and standards may often fall to local governments that may not have the necessary technical capacity or resources while public works contracts may be characterized by weak supervision and compliance and undermined by corruption. Resilience standards may furthermore be deliberately lowered during construction to compensate for reduced project budgets where funds have been diverted for other purposes. Consequently, there may be significant differences between designs and final outputs.

Data and information supportive of adopting appropriate resilience standards are often missing, particularly robust financial risk metrics that enable the estimation of the probable loss the asset would experience over its design lifecycle along with the costs and effectiveness of different measures to strengthen resilience. Even in the case of infrastructure projects funded by multilateral development banks (MDBs), the application of design standards supported by robust risk metrics is still uncommon (World Bank, 2022). Few countries invest in the data and systems required to generate the risk information required (UNISDR, 2015).

1.6. Service and Supply Chain Resilience

Indirect losses associated with service disruption are often greater than the value of asset loss and damage.

Providing services like water, sanitation, energy, transport, and telecommunications for households, businesses, and communities is the ultimate function of infrastructure assets, so ensuring the resilience of those services is as important as the assets. Service resilience refers to the capacity to buffer asset loss or damage in ways that allow continued service provision, rapid recovery, or adaptation or to be "safe to fail" (Ahern, 2011; Haraguchi & Kim, 2016; Kim et al., 2019).

Most service disruption is associated with asset damage or dysfunction. Sub-standard and poorly maintained infrastructure assets such as unreliable electricity grids, inadequate water and sanitation systems, and overstrained transport networks aggravated by disaster and climate risk leads to the disruption of essential services. The direct financial cost of disrupted infrastructure services on businesses and households in LMICs where data was available for gauging quantifiable impacts ranges from $391 billion to $647 billion per year along with unquantified impacts on well-being, health, productivity, and competitiveness (Hallegatte et al., 2019). Service resilience at local levels is, hence, critical to enhancing the capacity of communities and households to cope with and recover from different risks and shocks.

Indirect losses associated with service disruption are often greater than the value of asset loss and damage. A study of multiple post-disaster assessments (UN, 2015) indicated that the indirect economic losses associated with service disruption average roughly double the value of asset loss. Given a $301 - $329 billion AAL range in infrastructure sectors, the real cost of disrupted services could be as high as $700 billion per year without considering the broader impacts, as discussed above. As Box 1.5 describes, the implications of asset loss in critical infrastructure nodes such as ports are greater still.

Infrastructure systems characterized by variety and redundancy and with greater capacity to buffer losses, organically evolve, adjust and adapt to changing contexts are more resilient than rigid or brittle systems, that are dependent on single nodes or pathways for their functionality (da Silva et al., 2012).

For example, an agricultural area connected to urban markets through a variety of alternative transport routes would have greater redundancy and transport resilience compared to urban markets that are connected by a single bridge. Similarly, many Small Island Developing States (SIDS) depend on a single airport and port for the totality of

↓ **BOX 1.5**

Implications of Port and Maritime Disruptions on Global Supply Chains

Source: Verschuur et al. (2022)

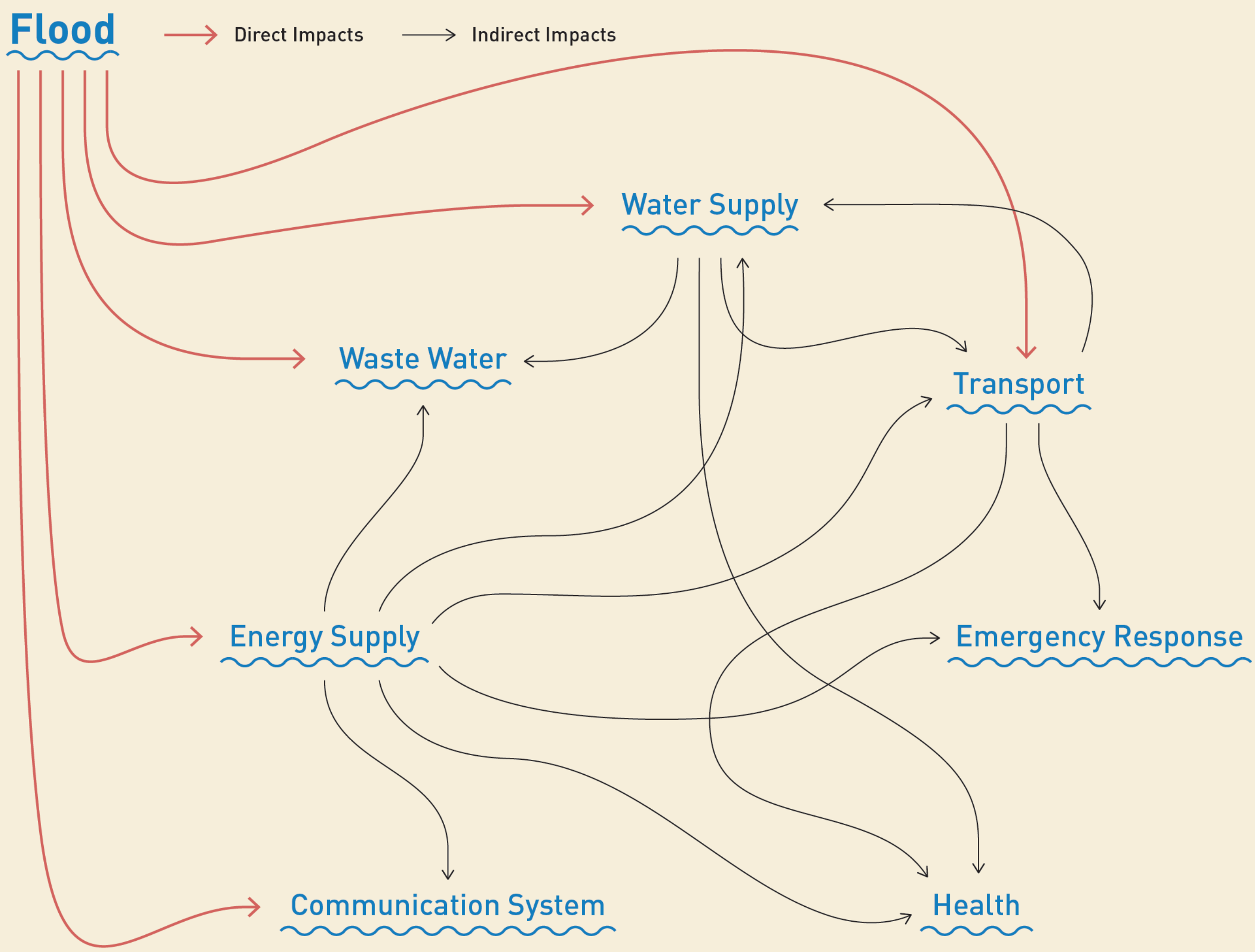
Ports are important for the local and regional economies, providing large employment opportunities, industrial clustering, and other value-added services. More importantly, they facilitate global trade flows by connecting supply chains across borders. But disasters affecting port areas leading to downtime can lead to large physical damages to port infrastructure, given the high density of valuable assets and revenue losses to terminal operators. Beyond these locally confined damages and losses, delays or disruptions of trade flows can affect domestic supply chains as well as supply chains in trade-dependent countries. Extreme winds associated with Typhoon Maemi (2003), for example, damaged multiple ship-to-shore cranes in the Port of Busan, disrupting exports for almost three months and affecting global supply chains dependent on South Korean products.

Based on a detailed analysis of climate risks to port infrastructure and trade flows (Verschuur et al., 2022) and the dependencies between port-level trade flows and global supply chains (Verschuur et al., 2022), the exposure of global economic activity to climate-related disruptions can be quantified and compared to physical infrastructure damages. For instance, current physical asset damages were estimated at $6.5 billion per year. Downtime associated with operational disruptions and asset reconstruction can further lead to an additional $1.93 billion per year in revenue losses to port operators at 1,320 ports worldwide.

More importantly, a total of $108.2 billion worth of maritime trade value is at risk every year. As every dollar of global maritime trade through ports contributes – directly or indirectly – $4.3 to the global economy (forward and backward supply-chain dependencies), disruptions could put economic activity worth over $400 billion at risk. In relative terms, SIDS face the highest risk in terms of macroeconomic multipliers. Although physical damages are often relatively small, given ageing infrastructure and small port areas, ports in many SIDS supply goods that contribute to over 10 percent of domestic economies. As such, disruptions to these ports could diminish the economic growth potential of SIDS' economies.

their imports and exports, implying far lower redundancy or resilience than a larger country with multiple ports and airports. The ability of a hospital to divert its patients to other facilities and continue to provide services, for example, in the event of a collapse would imply greater redundancy or resilience than being dependent on a single facility.

Redundancy levels are closely related to the density of infrastructure assets servicing a given territory or population. As discussed in Section 1.4., low-income countries have far lower redundancy and thus, service resilience based on their difference in the per capita value of infrastructure assets with high-income countries. Service resilience is also conditioned by the treatment of interdependence in system design



and operation, given that asset loss or damage in one system may generate non-linear service disruptions in other systems (Figure 1.7). As system complexity and interdependence increase, the channels through which direct impacts are translated into indirect impacts and their wider effects are increasingly characterized by non-linearity and multiple feedback loops (Renn et al., 2020).

According to preliminary findings from the pilot Global Infrastructure Resilience Survey (GIRS),[8] low and lower-middle income countries are particularly challenged by low service resilience in the water, wastewater, electricity, and road sectors (Figure 1.8).

The economic impact of service disruption is aggravated by weak supply chain resilience. For example, the 2011 earthquake and tsunami in east Japan followed by the failure of the Fukushima nuclear power plant's cooling systems led to the collapse of the electricity grid in east Japan after 11 nuclear reactors were taken offline, paralyzing the manufacture of critical components for automobile and information technology industries. Component shortages

↑ FIGURE 1.7

Direct and Indirect Impact of a Hazard on Different Infrastructure Assets and Services

Source: Arrighi et al. (2021)

[8] For further details on Global Infrastructure Resilience Survey (GIRS), refer to Annex II.

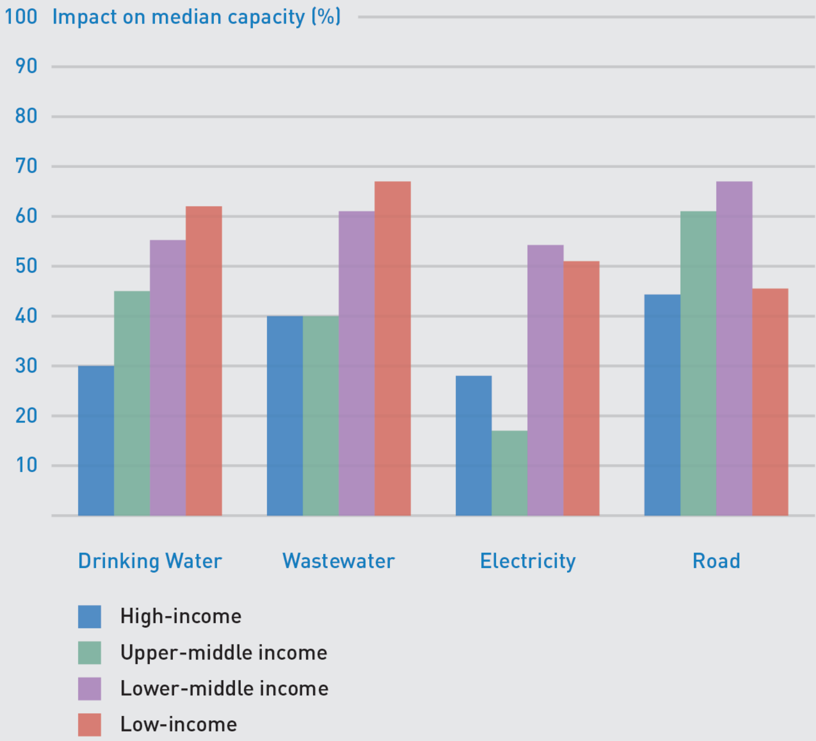


FIGURE 1.8

Median Capacity Loss Due to Significantly Impacting Hazards Across Sectors and Income Classes

Source: Chow & Hall (2023)

BOX 1.6

Impact-based Forecasts Strengthening the Resilience of Water and Power Sectors

Source: UNESCAP (2018)

Impact-based early warning systems use hazard data and forecasts to assess their likely impact on various sectors (water, for example). Based on these forecasts, decision-makers can then rule on water storage and use in ways that minimize risk.

In Sri Lanka, for example, forecasts for less-than-average annual rainfall between November 2017 and January 2018 allowed water management measures to take anticipatory measures that ensured provisions of 100 percent potable water requirement, 85 percent of irrigation water, and enough for the environment, wildlife, and inland agriculture across most districts. It also took a decision to boost thermal power generation in this period to compensate for declining hydropower. Impact-based forecasting, therefore, helps reduce service disruption and avoid negative impact on productivity and welfare.

were then transmitted along global supply chains, slowing down or halting production altogether throughout Europe and North America (Maskrey et al., 2023; Todo et al., 2014).

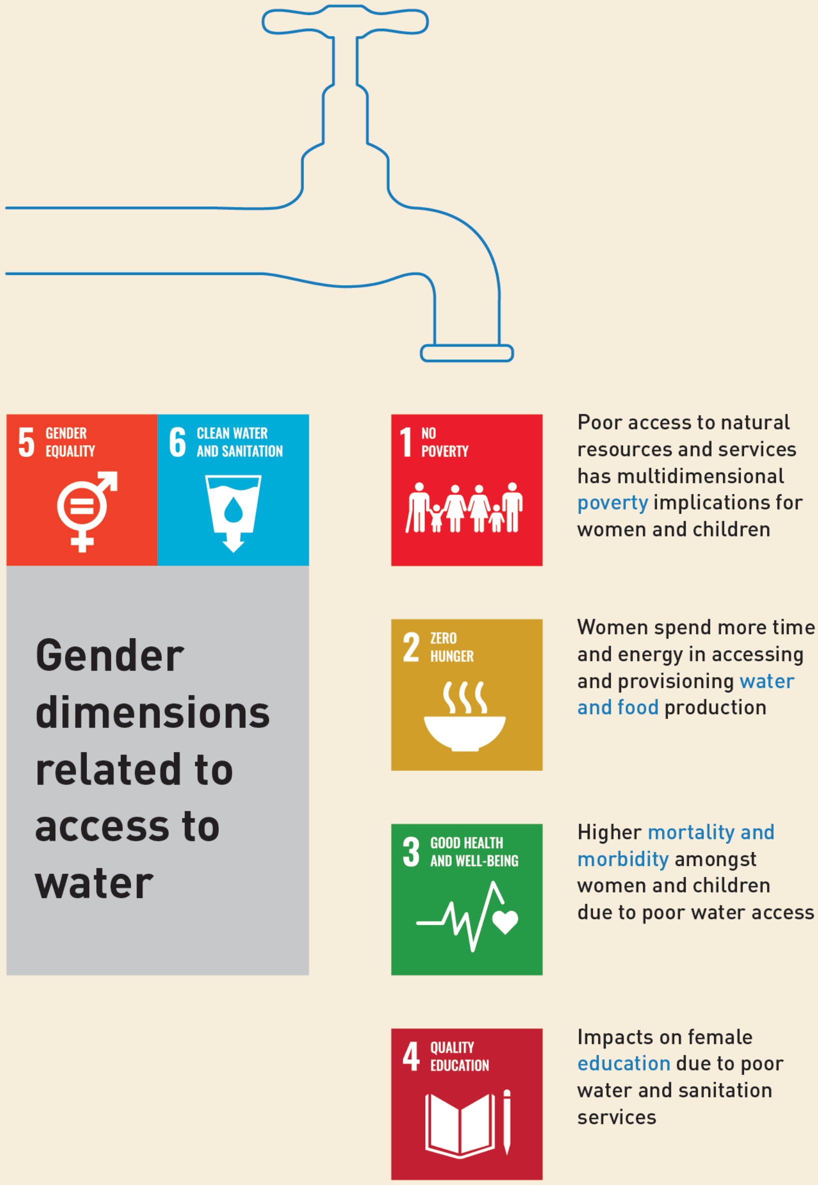
Service resilience, however, can be enhanced by effective early warning systems that can allow service providers to take account of an impending hazard and activate contingency arrangements that allow for the rapid service restoration. Cases where such an approach would be applicable would include the restoration of power following the loss of transmission infrastructure or the repair or replacement of bridges following floods.

Impact-based early warning systems can enable water and power utilities to take decisions regarding service resilience based on seasonal forecasts of expected rainfall, as Box 1.6 illustrates.

→ **FIGURE 1.9**

Water Supply Deficits Disproportionately Impacting Women and Children

Source: CDRI (2023)



As discussed above, climate change challenges service resilience even when infrastructure assets are not affected. For example, stormwater drainage provides the service of mitigating surface water flooding in urban areas. Due to climate change, even though the stormwater drainage assets are not damaged, more extreme rainfall events may increase service disruption. Similarly, extreme droughts do not damage water retention infrastructure such as reservoirs or bore wells but may disrupt the service provided, in this case, water supply. Importantly, water supply deficits affect marginalized groups of people more than others, as illustrated in Figure 1.9. Adopting policies and programmes that overcome and challenge issues of exclusion, vulnerability, and underrepresentation, therefore, will enhance resilience of the most marginalized.

1.7. Systemic Resilience

Systemic risks such as climate change and biodiversity loss, can be considered existential, given that they lead not only to escalating risks to infrastructure assets but threaten the habitability of the planet as a whole.

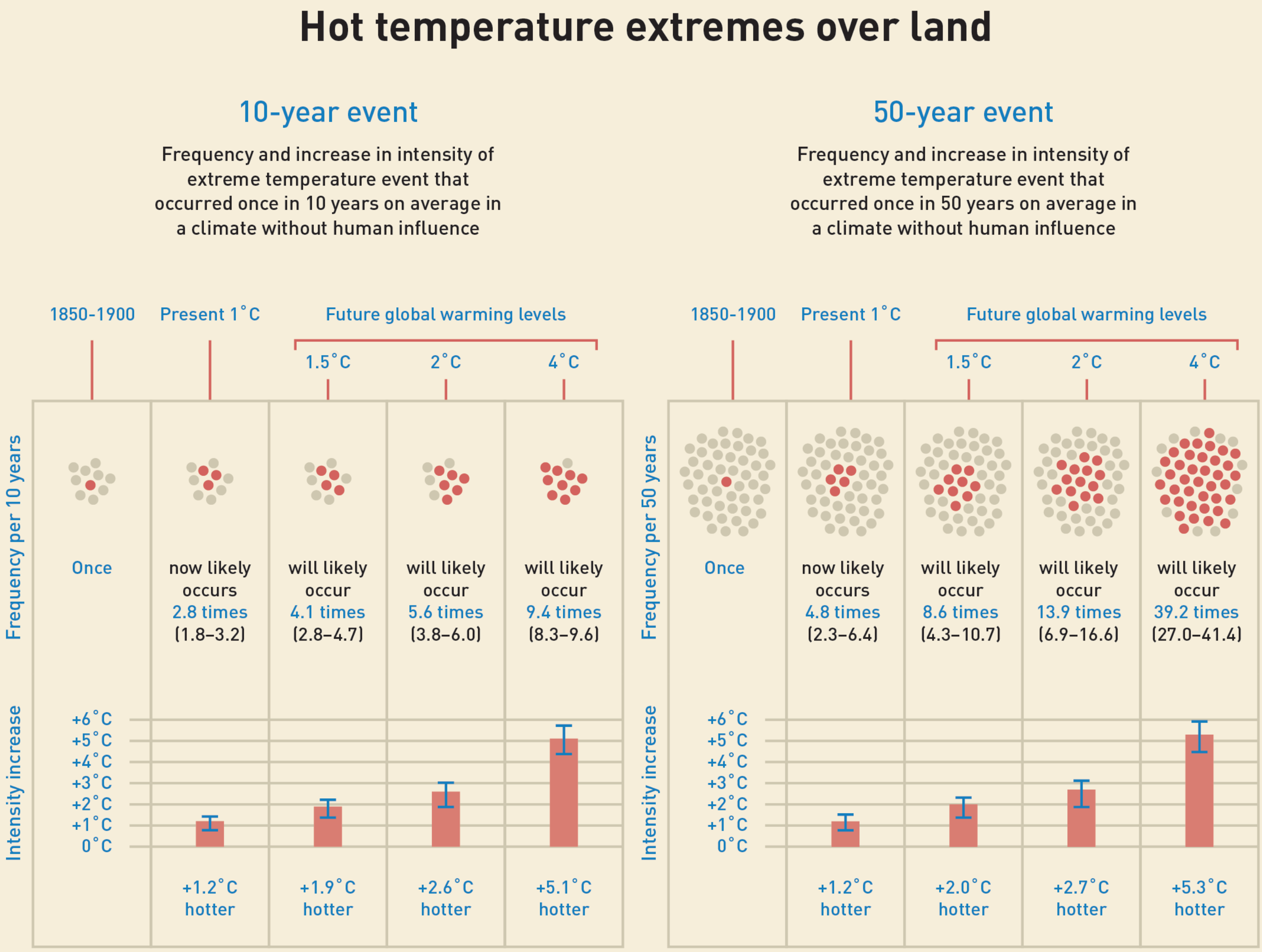
Any new infrastructure project has the potential to either increase or reduce systemic risk. Infrastructure developed to support modern day society is based on a growth paradigm that requires the global overexploitation of natural resources. Global demand for concrete and steel for building and for energy for transport, heating, and cooling, for example, are endogenous attributes of the dominant pathways of urbanization and infrastructure development in recent decades.

As such, the contemporary urban process, underpinned by a massive expansion in infrastructure investment, systemically generates risk. This systemic risk then feeds back into increasing infrastructure loss and damage. **New investment that closes the infrastructure deficit but leads to increased systemic risk is ultimately self-defeating. Systemic resilience, therefore, is contingent on designing infrastructure investments in a way that does not generate new systemic risk.**

Systemic risk is characterized by concatenated, non-linear, and cascading impacts. Cities such as Venice, Tokyo, Bangkok, and Jakarta, for example, sink due to a combination of uncontrolled groundwater extraction and rising sea levels (Hayashi et al., 2009; Phien-wej et al., 2006). Similarly, urban expansion and the replacement of green areas with asphalt, creates heat islands and increases the demand for energy for cooling, as well as carbon emissions. Finally, dispersed urban layouts, in contrast to concentrated layouts, make for highly inefficient land use but also magnify infrastructure costs by up to six times. At the same time, asphalting formerly green areas increases peak run-off and flood hazard while additional distances for vehicles to travel multiply carbon emissions.[9]

Systemic risks such as catastrophic climate change and the collapse of biodiversity on a planetary scale are existential threats (Maskrey et al., 2023). As described in a recent IPCC report *"[Climate change has caused] substantial damages and increasingly irreversible losses in terrestrial, freshwater and coastal, and open ocean marine ecosystems"* (IPCC, 2021, p. 9). Approximately 3.3 to 3.6 billion people *"live in contexts that are highly vulnerable*

[9] A study that compared the implications for land use and infrastructure costs for dispersed and concentrated urban layouts in Puerto Rico found dispersed layouts required between 3 and 6 times more infrastructure assets for power, water, and wastewater services. Road length was 2.4 times longer, while twice as much land was required to accommodate the same area of private housing. (Caminos & Caminos, 1980).



to climate change". Climate change is also "*contributing to humanitarian crises*" and "*increasingly driving displacement in all regions, with small island states disproportionately affected*". Lastly, increasing weather and climate extreme events "*have exposed millions of people to acute food insecurity and reduced water security*", with the most significant impact seen in parts of Africa, Asia, Central and South America, SIDS, and the Arctic.

Approximately 50 to 75 percent of the global population could be exposed to periods of "*life-threatening climatic conditions*" due to extreme heat and humidity by 2100. Climate change "*will increasingly put pressure on food production and access, especially in vulnerable regions, undermining food security and nutrition*" while extreme weather events "*will significantly increase ill health and premature deaths from the near- to long-term*". If global warming passes 1.5°C, "*human and natural systems will face additional severe risks*" including some that are "*irreversible*" (IPCC, 2021). Figure 1.10 shows how extreme weather events grow in frequency and intensity with every degree increment.

↑ **FIGURE 1.10**

Climate Change and Extreme Events

Source: Adapted from IPCC (2021)

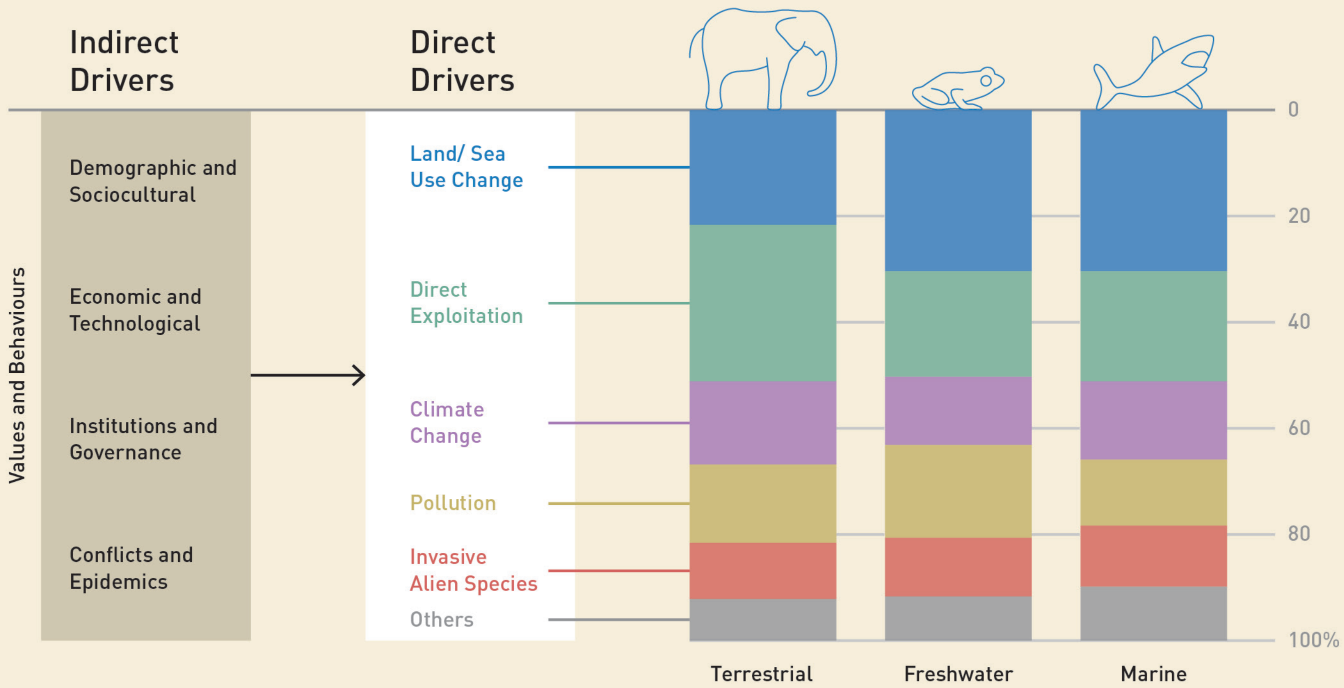
↓ **FIGURE 1.11**

Direct and Indirect Drivers of Biodiversity Decline

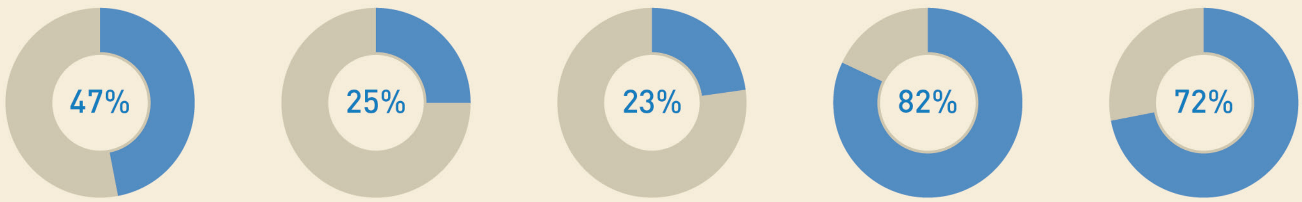
Source: Diaz et al. (2019)

Biodiversity is declining in parallel with anthropic climate change. Climate change aggravates biodiversity loss, together with urbanization, habitat loss, pollution, and others. Figure 1.11 highlights major declines in biodiversity across a wide range of indicators.

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

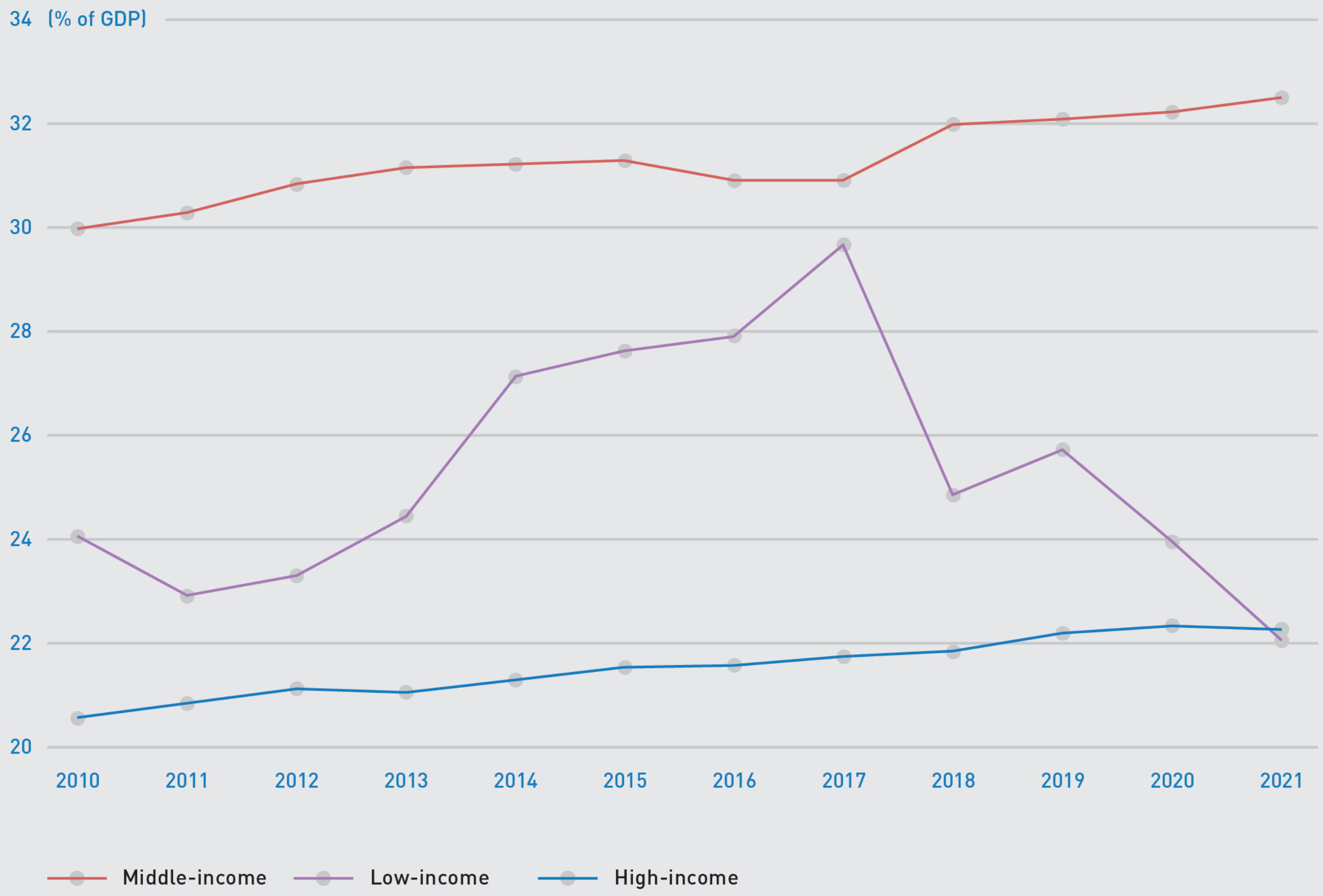
Presently, few low-income countries have the financial capacity to address infrastructure deficits; allocate sufficient budget to maintain existing infrastructure; and invest in the transition to net zero, strengthened assets, and service resilience. They also face difficulties in mobilizing significant private investment.

Domestic resource mobilization in LMICs, particularly low-income countries, is currently insufficient to address infrastructure deficits due to factors such as low national revenue, high debt repayments, weak growth, governance failures, and political crises. Over the past decade, infrastructure investment in low-income countries has followed a different path compared to other income geographies (Figure 1.12).

The COVID-19 pandemic further affected capacities for public capital investment. Despite the global economy rebounding in 2021, many LMICs and low-income countries are battling inflation, rising interest rates, and looming debt burdens. Competing priorities, low domestic resource mobilization, rising debt, an increasing cost of capital, and constrained fiscal space are further challenging increased public investment despite record levels of Official Development Assistance (ODA), a strong rebound in global Foreign Direct Investment (FDI), and remittance flows.

Many LMICs now also face unsustainable levels of debt, undermining their ability to invest in resilience. Even before the COVID-19 pandemic, around half of low-income countries as categorized by the International Monetary Fund (IMF), and many emerging market economies were found to be either in debt distress or at a high risk (IMF, 2022). The pandemic has pushed debt levels to new heights as new spending needs were added while revenues were falling due to lower growth and trade, raising debt burdens of several LMICs and resulting in 60 percent of low-income countries at high risk of debt distress (Figure 1.13). In 2020 itself, the total external debt stocks of LMICs had risen by 5.3 percent to $8.7 trillion. Meanwhile, the total public and publicly guaranteed debt service to export ratio had risen from an average of 3.1 percent in 2011 to 8.8 percent among low-income countries.

As far as private investment is concerned, the volume of capital raised by funds had quadrupled from about $34 billion in 2010 to $129 billion in 2021 (GIH, 2022). The longer-term story of private investment, however, depicts a widening gap between high-income and lower-income countries. **Over the past decade, about three-quarters of private infrastructure investment in infrastructure has been concentrated in high-income countries, half of which**



↑ **FIGURE 1.12**

Infrastructure Investment Trends in Low-, Middle- and High-Income Countries (2010-2021) (expressed as a percentage of GDP)

Source: World Bank (2023)

has flown into renewable energy generation. LMICs only attracted a quarter of global private infrastructure investment mainly in non-renewable energy and transport sectors. In relative terms, investments in 2021 grew by 8.3 percent in high-income countries but fell by 8.8 percent across LMICs (Figure 1.14). Even among LMICs, however, most capital flows into middle-income countries. Low-income countries received only around 2 percent of global foreign direct investment in 2022 (UNCTAD, 2023).

Such a pattern is unsurprising given that private capital tends to flow into sectors and territories that offer the highest rates of return with lowest risk and the greatest potential for growth. Consequently, social infrastructure remains the smallest beneficiary of private investment growth in infrastructure (Figure 1.15).

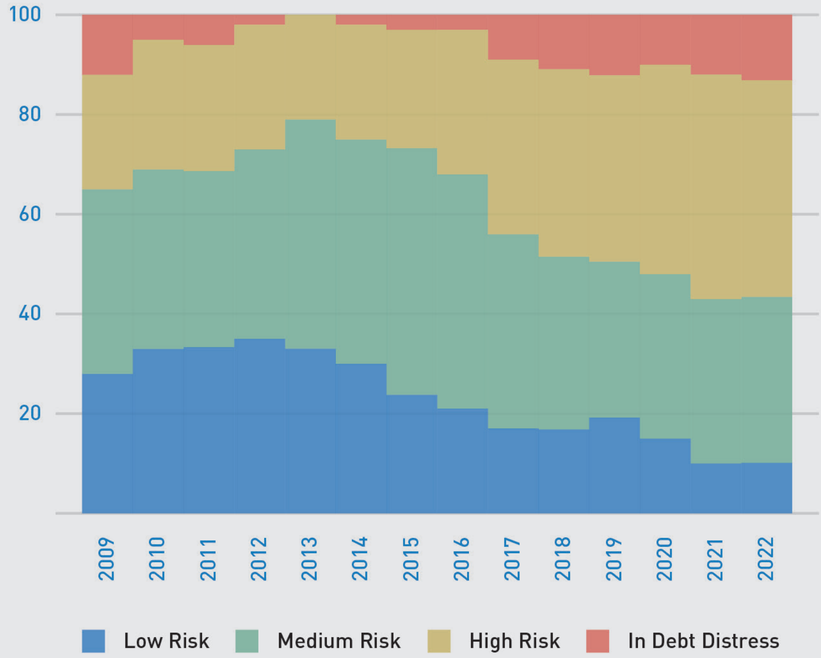
The cost of capital offers a critical benchmark to assess the risks and return preferences of investors and the pricing of money in different geographies. For example, the cost of capital for utility-scale solar photovoltaics and onshore wind ranges from 3 to 6 percent, depending on the region. For other sectors, the regional variation is much higher with 5 to 25 percent for buildings and 4 to 15 percent for transport percent (IEA, 2022a).

The capital committed by investors and available to fund managers but not yet invested or allocated to infrastructure projects has quadrupled from $72 billion in 2010, to $298 billion in 2021

→ **FIGURE 1.13**

Percent of Low-Income Countries (IMF Classification) with Low, Medium and High Risk of Debt Distress (as of March 2022)

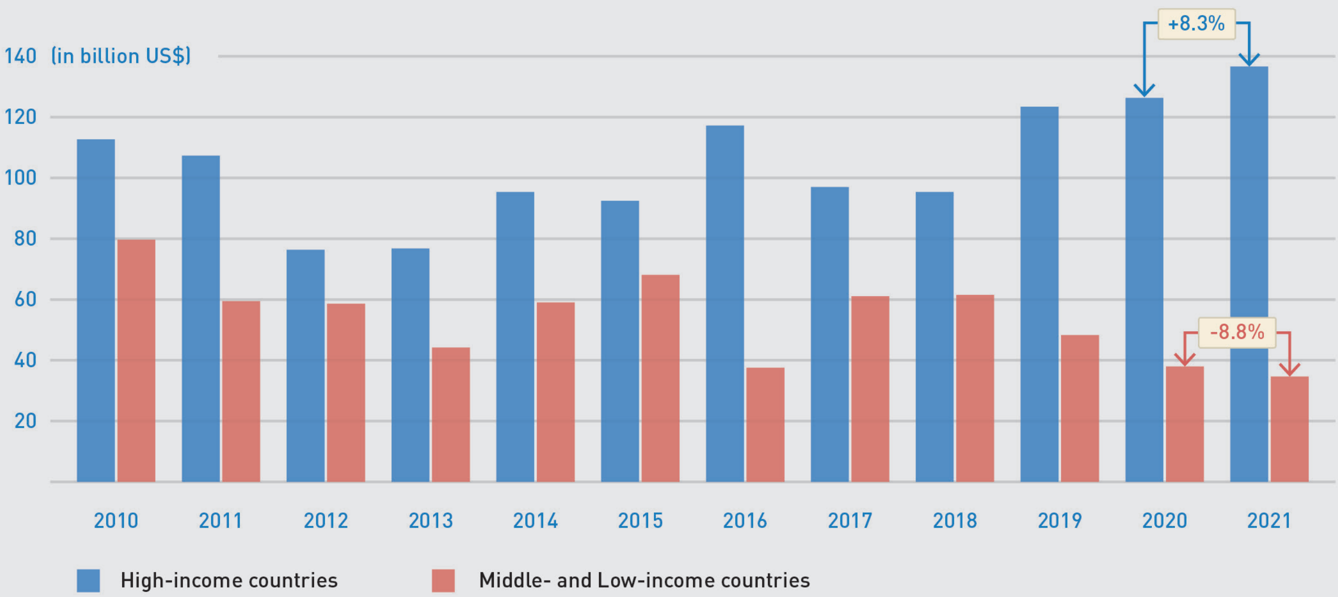
Source: IMF (2022)

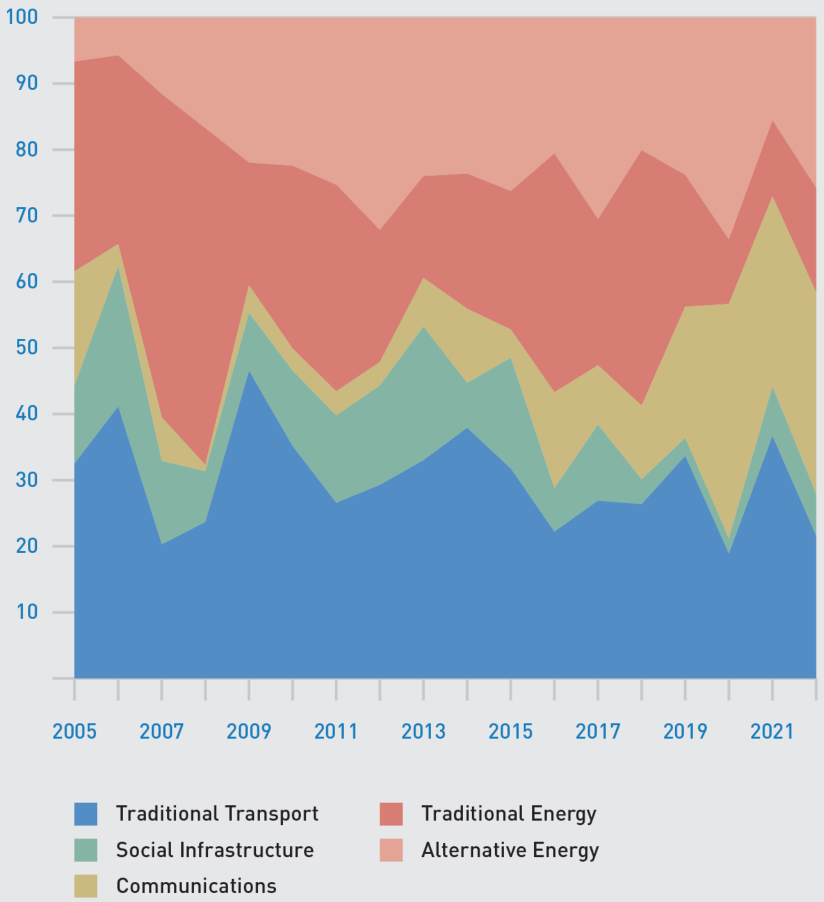


↓ **FIGURE 1.14**

Private Investment in Infrastructure in High-income versus Low- and Middle-income Countries (2010-2021)

Source: Global Infrastructure Hub (2022)





← **FIGURE 1.15**

Private Investments Across Infrastructure Sectors, 2005-2022 (by Share of Deal, in percentage)

Source: Averstad et al. (2023)

(Global Infrastructure Hub, 2021). This translates into a greater capacity to deploy capital in the short to medium term as new infrastructure investment opportunities arise, especially in a post-pandemic era with rising interest rates.

However, while the Global Infrastructure Facility, a G20 initiative, advocates for increasing gender-balanced and inclusive private investment in sustainable infrastructure to improve services and implementation of poverty reduction strategies enshrined in the SDGs across developing economies (G20, 2020), more private capital does not automatically translate into greater investments in LMICs. Apart from higher risks for investors, a shortage of bankable infrastructure projects is indicative of available capital greatly exceeding investment opportunities.

Climate finance, totalling $632 billion in 2019 (Buchner et al., 2021), is another potential source of capital to close infrastructure deficits, strengthen asset and service resilience, and reduce systemic risk (Buchner et al., 2021). Over 90 percent of this funding was invested in climate mitigation, however, particularly in renewable energy, while adaptation finance (which can potentially be used to strengthen resilience) represented only 7 percent of the total funding. Moreover, almost all adaptation finance is public investment while mitigation finance is mostly covered by the private sector. As Box 1.7 highlights, even in countries like India, which are investing heavily in renewable energy, there is still a significant finance gap, in which the requirements are estimated to be three times greater than existing investment.

Identifying a political and economic imperative to capture the resilience dividend is a critical challenge of our time. If that imperative is not recognized, decisions made now can lock cities, countries and the world into development trajectories that are neither sustainable or resilient. Investing in resilience today is critical to a sustainable future.

BOX 1.7

India's Clean Energy Investments
Source: (Birol & Kant, 2022)

India aims to meet 50 percent of its electricity requirements from renewable sources by 2030, equalling about 450 GW capacity, in its path to reach net-zero emissions by 2070. India has been consistently investing in renewable energy over the last decade and most significantly in the past few years; $8 billion in 2019, $6 billion in 2020, and $14.5 billion in 2022, recently pledging $4.3 billion more in the FY 2023-24 budget. These allocations are set to attract more private capital amounting between $80 and $125 billion by 2030. The International Energy Agency, however, estimates that India would need annual investments to the tune of $160 billion between now and 2030 to realize its goals.

Infrastructure resilience is, therefore, a multifaceted challenge. First, high-income countries need to invest massively to replace obsolete and decaying infrastructure to remain competitive and maintain public service provisions. Middle-income countries, secondly, need investments to enhance, modernize, and complete existing infrastructure and ensure full access to essential services for their societies. Third, low-income countries need investments in new strategic economic as well as local infrastructure systems to accelerate social and economic development and poverty reduction. Lastly and perhaps most importantly, countries across all income geographies need to transition towards net-zero economies while strengthening asset and service resilience.

Most high and some large middle-income countries are already increasing their infrastructure investment levels. The USA, for example, allocated $550 billion in new spending via the Infrastructure Investment and Jobs Act of November 2021 to rebuild roads, bridges and rails, airports, provide high-speed internet access, and address climate concerns with spending spread over five years beginning in 2022. While India spent less than 0.4 percent of its GDP until 2014 on rail and road infrastructure, capital investments in this sector is expected to reach 1.6 percent of GDP in 2023, quadrupling over a 10-year period (Box 1.8). Similarly, it is estimated that China has invested $892 billion in its "One Belt One Road" initiative since 2013 to develop port, road, and rail infrastructure to integrate regional markets with its economy. **In the coming years, it is expected that just four countries (China, India, Japan, and USA) will account for 50 percent of total global infrastructure investment and 80 percent within the G20 alone** (Global Infrastructure Hub, 2021).

As has been highlighted, much of the infrastructure needed to support social and economic development is yet to be built in most LMICs (Thacker et al., 2019). In India, for example, capital investments of $840 billion are estimated to be required. Over half of this, about $450 billion, will be needed for basic municipal services, such as water supply, sewerage, municipal solid waste management, stormwater drainage, urban roads, and street lighting, to house the 40 percent of the country's population that are expected to be living in cities by 2036 (Hallegatte et al., 2019).

Achieving the SDGs and net-zero economies in ways that also strengthen resilience for LMICs would require a significant increase in financial flows for infrastructure investments,

estimated at approximately $2.94 trillion per year (McKinsey Sustainability, 2022). Current levels of public investment and climate finance represent only a fraction of these estimates. While there is more than enough private capital available, very little currently flows to LMICs, particularly low-income countries. In India, for example, central and state governments currently finance over 75 percent of urban infrastructure while just 5 percent are financed through the private sector (World Bank, 2023).

In such a context, an estimated total infrastructure AAL of over $500 billion across LMICs is unsustainable. Many countries can ill-afford to divert a substantial proportion of their capital to repair and rehabilitate disaster damaged infrastructure with their fiscal capacity further stressed if they are also left with a growing legacy of stranded assets amid an accelerated transition to net-zero. Many LMICs may be left behind as private investment flows into sectors such as renewable energy in high-income countries.

Changing trajectory to address the infrastructure deficit, transition to net zero, and strengthen resilience is far from straightforward. Countries with a constrained fiscal space are challenged to significantly increase public investment. High levels of disaster and climate risk mean that much of this limited public investment is diverted to repair and rehabilitate damaged

↓ BOX 1.8

India's Eastern Dedicated Freight Corridor
Source: World Bank Communication

India's Eastern Dedicated Freight Corridor (EDFC) is a freight-only railway line financed by the World Bank through three investment loans totalling up to $1.7 billion in IBRD financing. The modal shift of cargo from road to rail would help the EDFC reduce greenhouse gas emissions on freight by nearly 50 percent by 2052 through electrification of rail lines and fuel consumption reduction.

The Dedicated Freight Corridor Corporation of India Limited (DFCCIL), responsible for the EDFC, embeds the five pillars of resilience in railway design and operation, namely System Planning, Design and Engineering, Operations and Maintenance, Contingency Programming, and Institutional Capacity Coordination.

DFCCIL identifies climate and disaster risks during planning by referring to a database of historical events/hazards. They include design features in bridges and embankments to address climate and disaster risks arising from floods, earthquakes, and other events. DFCCIL plans assets for collective redundancy, such as building connecting lines at locations vulnerable to floods, to support transport needs during an emergency.

EDFC incorporates specific climate and disaster-resilient engineering measures during design and construction, such as resilient track design, mechanized track laying, and climate-resilient signalling systems.

infrastructure assets and restore essential services. Weak infrastructure governance translates to high risk and unattractive environments for private investors. Lack of access to knowledge and weak technical capacities further challenge adopting innovative solutions such as NbIS. Consequently, the infrastructure deficit and the *resilience deficit* are widening together between higher- and lower-income countries.

The economic case for investing in resilience is clear. First, strengthened asset resilience helps avoid asset loss and damage, reduce expenses for repair and rehabilitation over each asset's design lifecycle, and reduces service disruption. Second, strengthened service resilience improves productivity and economic growth and enhances social development indicators through better quality health and education services. Third, strengthened systemic resilience contributes to enhanced biodiversity, cleaner water and air, reduced carbon emissions, and cooler cities, among other benefits. Lastly, strengthened fiscal resilience can contribute to more predictable and enhanced cash flow forecasts that can lead to higher asset values. Quantifying these economic benefits would help the outlines of a resilience dividend begin to take shape, where the full benefits of investing in resilience outweigh additional costs.

Capturing this resilience dividend, however, remains challenging. Weak infrastructure governance, a constrained fiscal capacity, and broader social and political challenges make it difficult to change trajectories across many LMICs. Resilience dividends may not be politically attractive even if they are identified as many of their benefits and co-benefits only materialize over long periods of time. Investing in resilience does not yet offer a compelling political or economic imperative for many governments or private investors.

Identifying a political and economic imperative to capture the resilience dividend is a critical challenge of our time. If such an imperative is not recognized, decisions could lock cities, countries, and the world into development trajectories that are neither sustainable nor resilient (Pols & Romijn, 2017; Seto et al., 2016; USFS, 2023). Investing in resilience today is, therefore, critical to a sustainable future.

Chapter 2

The Global Landscape of Infrastructure Risk

2.

The Global Landscape of Infrastructure Risk

2.1. The Importance of Risk Estimation

Financial risk metrics clarify the economic case for investing in resilience.

Assessing disaster and climate risk in infrastructure enables governments and other infrastructure owners to identify and estimate the contingent liabilities they are responsible for in each sector and territory.

Strengthening asset resilience is fundamental if new infrastructure investments are to be a motor for social and economic development, rather than a source of increasing contingent liability and future disasters. Identifying and estimating risk internalized in infrastructure assets (Box 1.4) are, therefore, a first and essential step towards infrastructure resilience, enabling governments and other infrastructure owners to identify and estimate the contingent liabilities they are responsible for in each sector and territory. **Financial risk metrics clarify the economic case for investing in resilience and help identify the most effective strategies.**

Infrastructure asset risk reflects the concatenation of geological and climate related hazards, the exposure of infrastructure assets, and their vulnerability or susceptibility to loss and damage.

Hazard patterns are controlled by geographic features such as tectonic faults, cyclone tracks, and floodplains. Asset risk can be higher in countries that are subject to multiple hazard events of higher frequency and intensity than in others with benign hazard landscapes. Climate change and drivers such as environmental degradation and changes in land use modify hazards such as floods, landslides, cyclonic wind and storm surges, and droughts. Identifying and mapping of hazards at an appropriate scale including flood-prone areas and those susceptible to earthquake- and rainfall-triggered landslides, tsunami inundation zones, high earthquake intensities, and others (USFS, 2023) is normally the first step towards estimating asset risk.

Risk is configured not only by hazard but also by the density of the exposed population and assets. Estimating infrastructure exposure requires identifying the location and assigning an appropriate economic value to each asset (USFS, 2023). High-income countries have an infrastructure density[10] that may be orders of magnitude greater than most low-income countries. The value of infrastructure assets in a medium-sized city in the USA, for example, may be greater than entire low-income countries in Sub-Saharan Africa (USFS, 2023).

Vulnerability, on the other hand, is associated with the quality of infrastructure governance and the capacity to ensure that infrastructure assets are built to appropriate resilience standards. If standards are higher, risk may be lower even in countries with high levels of hazard exposure. Conversely, countries with weak infrastructure governance may have higher asset risk than those with stronger governance, even if hazard levels and the value of exposed assets are lower.

Vulnerability functions are applied to each kind of exposed infrastructure asset and for hazards of different frequency and intensity to estimate probable levels of loss and damage. These functions are generated from the statistical analysis of loss values over a range of hazard severities, derived from field observations, analytical studies or expert judgement.

[10] Public capital stock per capita

2.2. The Global Infrastructure Risk Model and Resilience Index (GIRI)

2.2.1. Probabilistic Risk Assessment

Traditionally based on the frequency and severity of historical events, earlier approaches to risk assessment failed to account for low-frequency yet intense hazard events and drivers such as climate change.

The insurance industry in 1990s adopted probabilistic risk modelling as the best approach to estimate the full spectrum of risk and generate financial risk metrics to calibrate insurance premiums and risk financing mechanisms such as catastrophe bonds. Probabilistic models simulate future disasters which could possibly occur based on scientific evidence, reproducing the physics of the phenomena, and recreating the intensity of a large number of synthetic hazard events. In doing so, they provide a more complete picture of risk than is possible using historical data alone.

Insurance industry catastrophe models normally estimate risk for specific insurance markets or bundles of assets and are rarely available to governments or infrastructure investors. Open-source global risk assessments such as the Global Risk Model have partially addressed this gap (UNDRR, 2017).

Open risk modelling platforms and initiatives such as the OASIS Loss Modelling Framework and the Global Risk Modelling Alliance (GRMA) have also emerged (Oasis Loss Modelling Framework Ltd., 2023; V20 Members, 2023).

2.2.2. The Global Infrastructure Risk Model and Resilience Index (GIRI)

The Global Infrastructure Risk Model and Resilience Index (GIRI) is the first publicly available and fully probabilistic risk model to estimate risk for infrastructure assets with respect to most major geological and climate-related hazards.

Figure 2.1 illustrates the flow of the GIRI model:

1. Hazard input data was obtained by developing comprehensive sets of simulated events accounting for all the possible manifestations of each hazard and providing information about the geographical distribution of the hazard intensities and their frequency of occurrence.
2. The intensities and frequency of the hydrometeorological hazards were modified to account for two

future scenarios, reflecting a lower and upper bound of climate change[11]. As such, climate change was integrated into the GIRI model from its conceptual design.

3. The exposure database was assembled by geolocalizing exposed assets and networks in each infrastructure sector from available public data sources. Public and private buildings were also included in addition to the infrastructure sectors listed in Figure 2.1.

4. Economic values were assigned to each exposed asset using a bottom-up procedure (Marulanda, 2023). The total value of the infrastructure assets in each country was then scaled to reflect the value of the capital stock relative to other countries.

5. Vulnerability functions, relating the hazard intensities to expected asset losses in a continuous, qualitative, and probabilistic manner, for all hazards, were developed for over 50 infrastructure archetypes. These archetypes, for example a power station or an airport, are assemblies of different infrastructure elements, each of which has a specific vulnerability signature.

6. The associated damage and loss for each asset included in the exposure database was then calculated for each stochastic hazard event. The distribution of probable future losses was generated from the exceedance rates for each loss value and presented for each sector as a loss exceedance curve (LEC) and derived financial risk metrics such as the AAL.

The AAL estimates the contingent liabilities for each infrastructure sector in each country or territory. It is a compact metric with a low sensitivity to uncertainty, corresponding to the expected or average loss that may be experienced in the long run rather than historical loss or losses that will be experienced every year. This is known as the pure risk premium in the insurance industry when normalized by the exposed values. The AAL for any given infrastructure sector and country measures the resources that governments would need to set aside each year to be able to cover asset loss and damage over a long term.

2.2.3. Scale and Application

GIRI's purpose is to improve understanding and make the global landscape of infrastructure risk and resilience visible.

GIRI can assist in the identification of the contingent liabilities internalized in each infrastructure sector and the implications for social and economic development in a context of climate change. It can, thus, provide the basis for developing national resilience policies, strategies and plans, and resilience standards.

Models with a global level of observation and a national level of resolution are too coarse to quantify risk in specific infrastructure assets or in the design of new infrastructure projects. However, assessments can be developed for specific portfolios of infrastructure assets at the sub-national, urban, or local scales, with the same methodology using more detailed input data on hazard, exposure, and vulnerability (USFS, 2023).

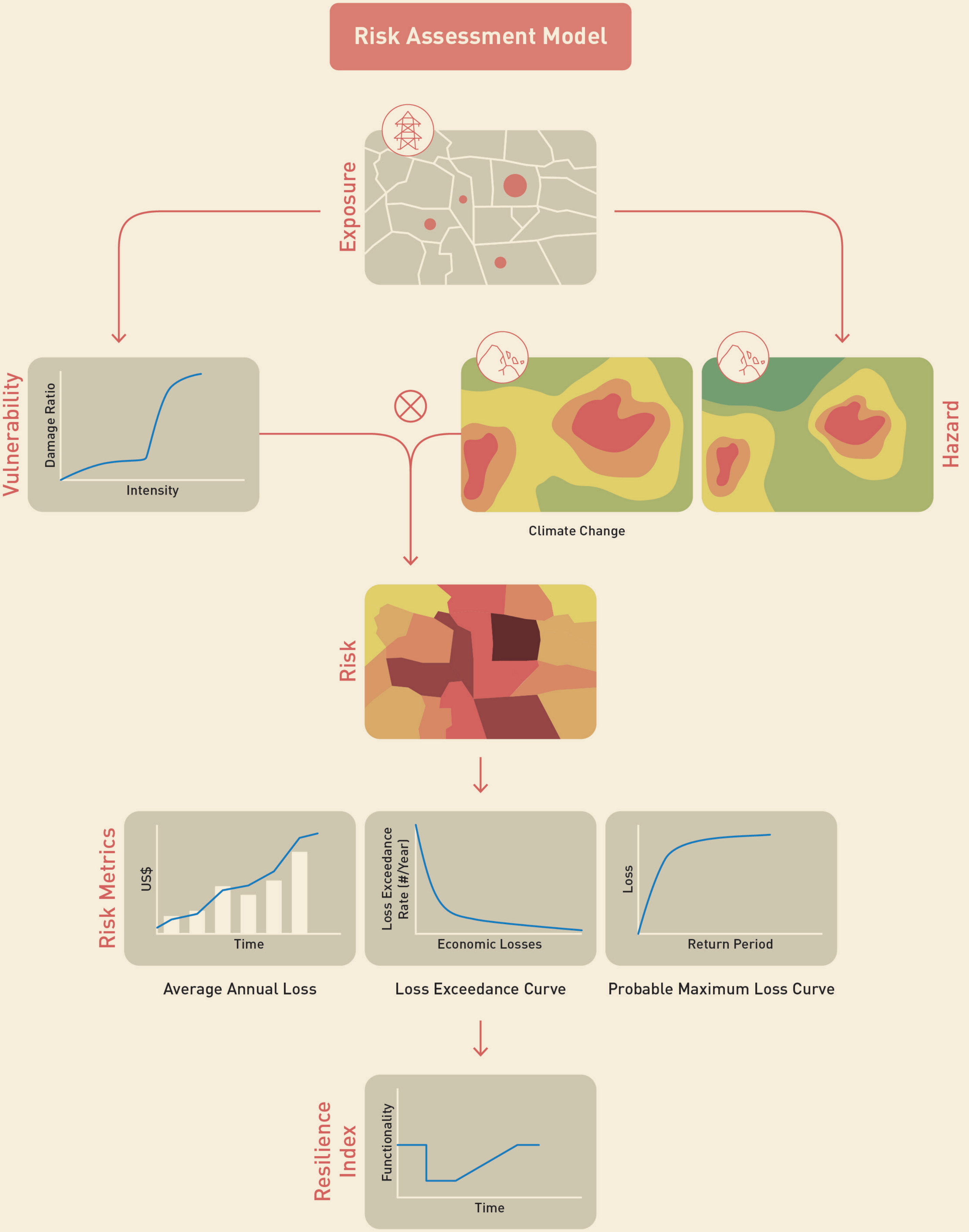
→ FIGURE 2.1

Components of the Global Infrastructure Risk Model and Resilience Index (GIRI)

Source: Cardona et al. (2023a)

[11] The methodology paper referenced in Annexure 1 explains how the lower and upper limits of climate change were calculated, with respect to Representative Concentration Pathways (RCP).

Global Infrastructure Risk Model and Resilience Index – GIRI


Risk Assessment Model
Exposure
Vulnerability
Damage Ratio
Intensity
Hazard
Climate Change
Risk
Risk Metrics
US$
Time
Loss Exceedance Rate [#/Year]
Economic Losses
Loss
Return Period
Average Annual Loss
Loss Exceedance Curve
Probable Maximum Loss Curve
Resilience Index
Functionality
Time

2.2.4. GIRI's Limitations

Although based on well-established risk modelling methodologies, GIRI presents a novel approach to model infrastructure risk and resilience. While the financial risk metrics presented here are in the correct order of magnitude, the AAL values are likely to evolve as the model is further calibrated and developed.

GIRI's quality will improve as new hazard and exposure data becomes available. As climate change models become more robust, downscaling to local levels becomes more advanced, and the attribution science progresses, more precise data on hydro-meteorological hazards will also become available. Vulnerability functions are also likely to improve over time as they are used and tested in different applications.

Estimating asset risk is critical, given that service disruption and broader systemic impact are normally associated with asset loss and damage. While GIRI improves the understanding and estimation of global infrastructure asset risk and resilience, the costs of service disruption have not been measured and identified even though they are often greater than the cost of asset loss. Similarly, the model does not estimate the cost of the wider impact of asset loss and service disruption on productivity, employment, health, education, and poverty.

Likewise, this iteration of the GIRI does not model other important hazards including heatwaves, wildfires, permafrost melting, sea-level rise, or risk to ecosystems, natural capital, agriculture, or food production. These may be addressed in future iterations.

2.3. Global Infrastructure Risk

Decades of infrastructure investment without adequately considering disaster and climate resilience means that approximately a seventh of the economic benefits generated by those same assets, as measured by GDP growth, is now being lost.

Under the present climate, the value of the global AAL in the principal infrastructure sectors is $301 billion. When buildings[12], including health and education infrastructure, are included, the total infrastructure AAL of $732 billion represents approximately 14 percent of the global 2021 -2022 GDP growth. This estimate is conservative given that it does not include losses in agriculture or natural capital, or some small-scale extensive risks.

As discussed in Chapter 1, LMICs have a widening infrastructure deficit, low capacities for public investment, and difficulties in mobilizing private capital. According to GIRI, such countries have accumulated higher asset risk compared to high-income countries. In other words, countries that cannot afford to lose their existing infrastructure have the highest risk.

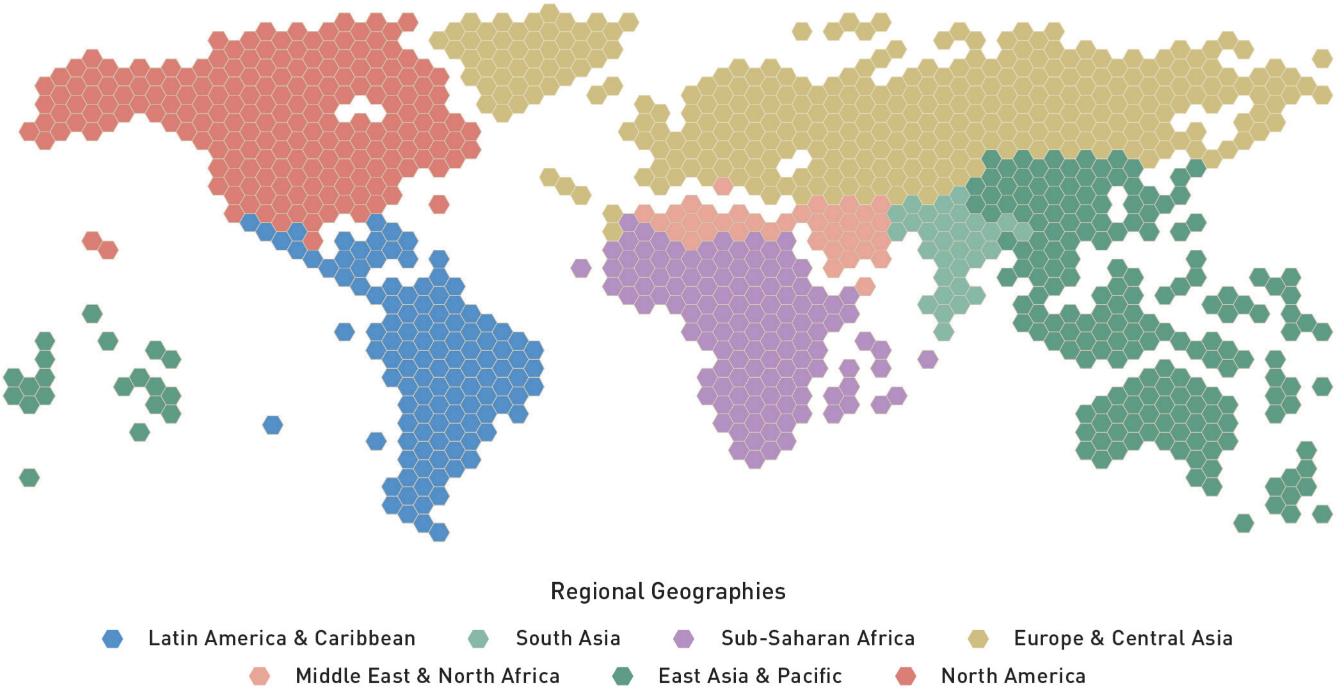
As Figure 2.4 shows, high-income countries concentrate 67.3 percent of the global exposed value of infrastructure assets. **While LMICs account for only 32.7 percent of the exposed value, they account for 54 percent of the risk, with a total infrastructure AAL of $397 billion.** While low-income countries account for only 0.6 percent of the exposed value, highlighting the infrastructure deficit in those countries, they hold 1.1 percent of the risk.

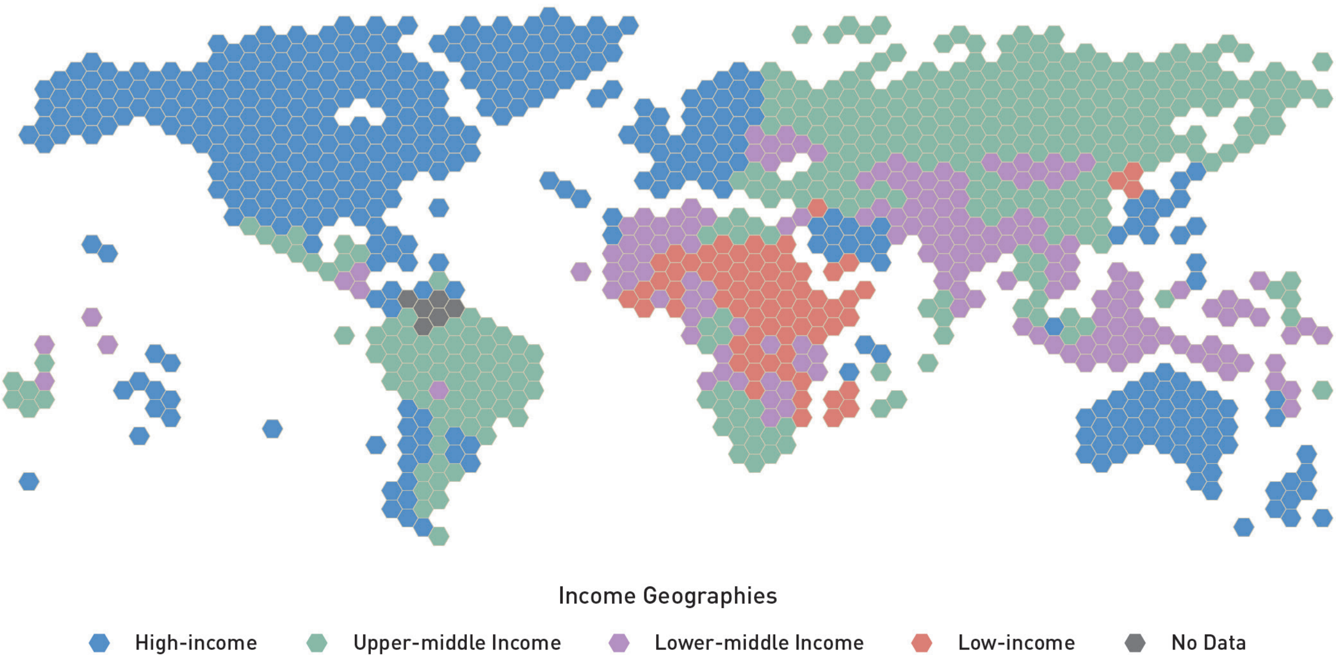
The AAL in high-income countries represents only 0.14 percent of the exposed value. In contrast, this figure stands at 0.38 percent in low-income countries, 0.41 percent in lower-middle income, and 0.31 percent in upper-middle-income countries. LMICs, therefore, have less infrastructure, lower investment, and higher risk compared to high-income countries.

[12] There are strong arguments for and against including the building stock within an overall definition of infrastructure. It has been included in this analysis for three reasons. Firstly, risk in social infrastructure, such as health and education facilities are included within the building stock and therefore, needs to be estimated as with other infrastructure sectors. Secondly, in LMICs most of the building stock is uninsured. Given that governments then become the insurers of last resort, in principle, loss and damage to the building stock form part of the contingent liabilities that governments hold, with critical fiscal implications. Thirdly, Gross Fixed Capital Formation (GFCF), which is a core economic indicator against which the AAL can be compared, includes buildings as well as infrastructure sectors.

↓ FIGURE 2.2

Map of Regional Geographies





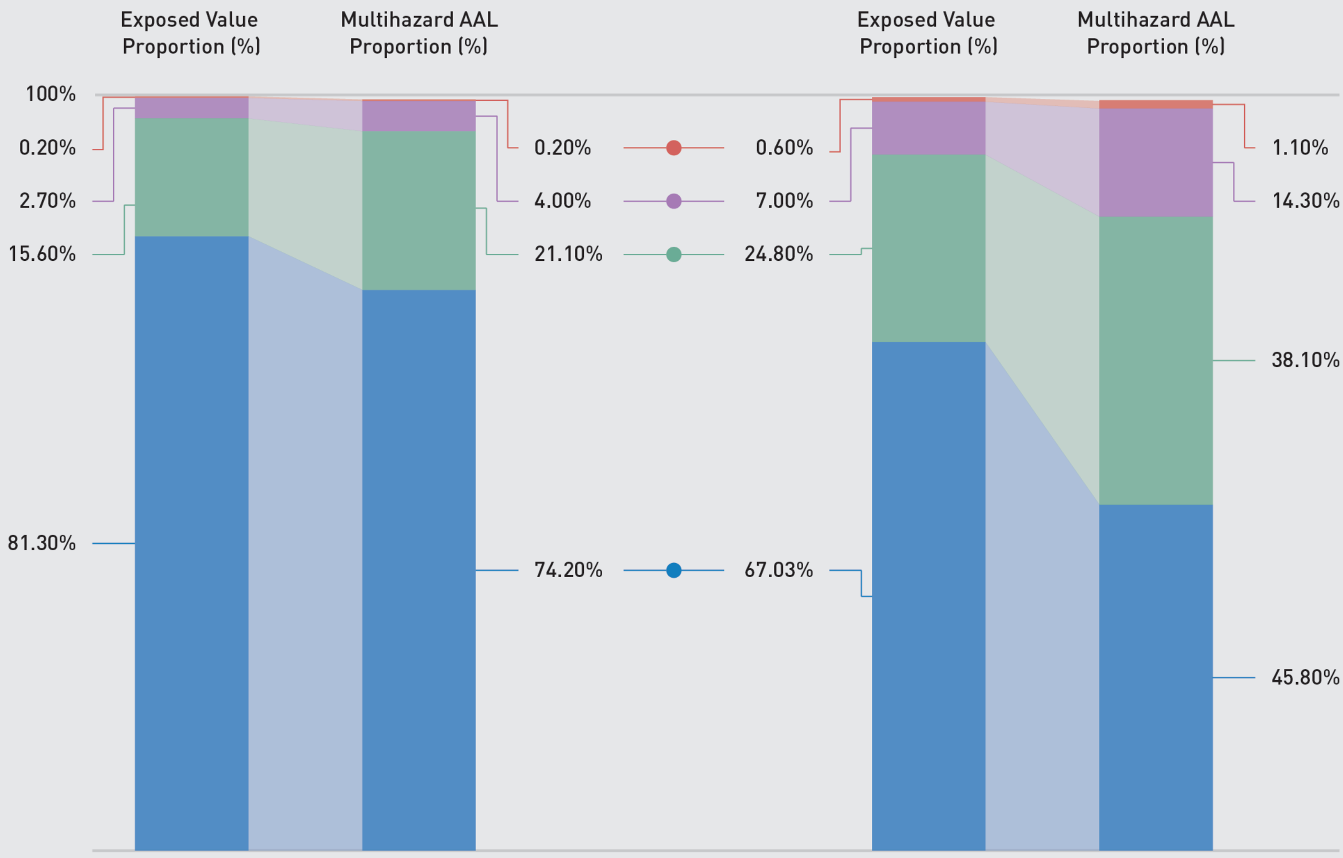
↑ FIGURE 2.3

Map of Income Geographies

↓ FIGURE 2.4

Value of Buildings and Infrastructure Assets and AAL by Income Region

Source: Cardona et al. (2023a)



Infrastructure Sectors

Exposed Value (billion US$)	Multihazard AAL (billion US$)	Relative AAL (%)
287	0.51	0.18
4,976	12.06	0.24
28,955	63.44	0.22
151,369	222.99	0.15

Total Infrastructure

Exposed Value (billion US$)	Multihazard AAL (billion US$)	Relative AAL (%)
2,131	8.06	0.38
25,766	104.88	0.41
91,121	278.57	0.31
247,251	335.11	0.14

Income Group: High-income, Upper-middle Income, Lower-middle Income, Low-income

Infrastructure Sectors = Power; Roads and Railways; Ports and Airports; Water and Wastewater; Telecommunications; Oil and Gas.
Total Infrastructure = Infrastructure Sectors plus buildings, including Health and Education infrastructure.

Figure 2.5 shows the distribution of the absolute and relative AAL for countries with the highest risk. A group of mainly high-income countries and some middle-income countries with large economies having high absolute but low relative risk such as India, China, and Mexico, are highlighted in blue. These countries are normally able to absorb major losses, which represent only a small proportion of their capital stock, given the size of their economies. Countries highlighted in red are mainly SIDS that have low levels of absolute risk due to the small size of their territories and economies but very high levels of relative risk. Infrastructure loss and damage and the resources required to repair and rehabilitate damaged infrastructure often exceed the capacity of their small economies.

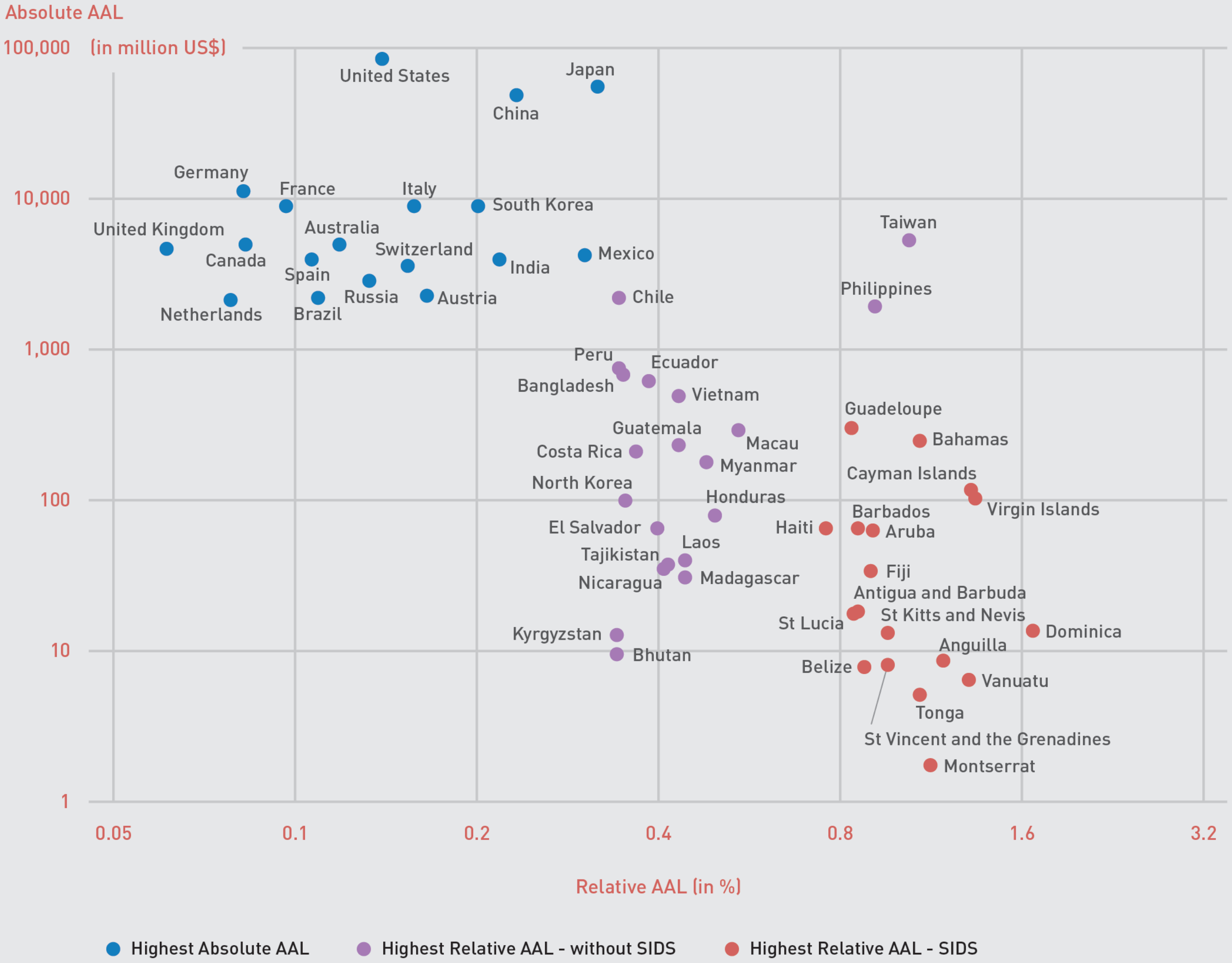
A group of mainly LMICs (highlighted in purple), have high levels of both absolute and relative risk which means they will experience large-scale losses that would also be economically challenging.

Figure 2.6 complements these observations. Eighty nine percent of the exposed value is concentrated in North America, Europe and Central Asia, East Asia, and the Pacific, regional geographies that include most high-income countries. Conversely, Sub-Saharan Africa accounts for only 1.4 percent of that value due to lower hazard exposure, but has a relative risk of 0.20 percent. **Latin America and the Caribbean, and South Asia (with many LMICs), are the regions faced with the greatest resilience challenge. Loss and damage would annually account for 0.29 percent and 0.45 percent, respectively, of the exposed value.**

Countries with high absolute but low relative risk experience losses that do not necessarily challenge their fiscal resilience. It is, however, severely challenged in countries with low absolute but very high relative risk. On the flipside, the investments required to strengthen resilience may be relatively small in these countries. **Strengthening resilience in high-risk countries with small economies such as SIDS may not require globally significant investments but could make a critical difference to their sustainable social and economic development.**

↓ FIGURE 2.5

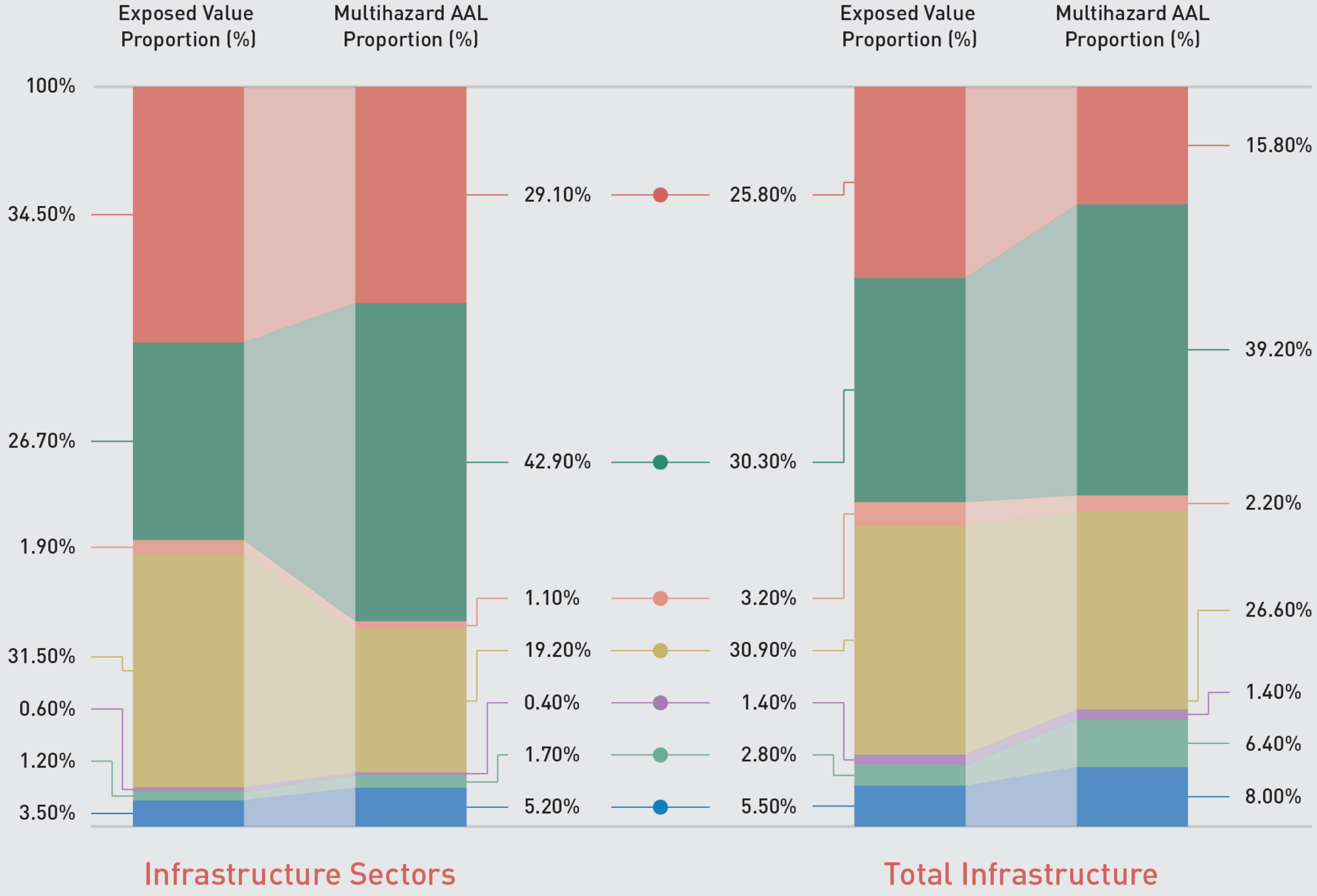
Absolute and Relative AAL for Infrastructure Sectors
Source: Cardona et al. (2023a)



↓ **FIGURE 2.6**

Value of Infrastructure Assets and AAL by Geographical Region

Source: Cardona et al. (2023a)



Region	Infrastructure Sectors: Exposed Value (billion US$)	Infrastructure Sectors: Multihazard AAL (billion US$)	Infrastructure Sectors: Relative AAL (%)	Total Infrastructure: Exposed Value (billion US$)	Total Infrastructure: Multihazard AAL (billion US$)	Total Infrastructure: Relative AAL (%)
North America	64,240	87.53	0.14	94,961	115.49	0.12
East Asia & Pacific	49,679	129.05	0.26	111,209	286.77	0.26
Middle East & North Africa	3,561	3.42	0.10	11,608	16.46	0.14
Europe & Central Asia	58,554	57.72	0.10	113,412	194.84	0.17
Sub-Saharan Africa	1,117	1.28	0.11	5,142	10.4	0.20
South Asia	2,162	5.17	0.24	10,340	46.65	0.45
Latin America & Caribbean	6,572	15.52	0.24	20,366	58.41	0.29

● Latin America & Caribbean ● South Asia ● Sub-Saharan Africa ● Europe & Central Asia
● Middle East & North Africa ● East Asia & Pacific ● North America

Infrastructure Sectors = Power; Roads and Railways; Ports and Airports; Water and Wastewater; Telecommunications; Oil and Gas.
Total Infrastructure = Infrastructure Sectors plus buildings, including Health and Education infrastructure.

2.4. Geological and Climate-Related Risk and the Impact of Climate Change

Globally, 30 percent of the AAL is associated with geological hazards such as earthquakes, tsunamis, and earthquake-induced landslides and 70 percent with climatic hazards such as cyclonic wind, storm surge, flood, and rainfall-induced landslides. While climate change is an increasing threat, in many countries, geological risk cannot be ignored.

Across all regions, the relative AAL associated with climate-related hazards is higher than that associated with geological hazards. The two regions with the highest climate-related AAL are South Asia with 0.43 percent and Latin America and the Caribbean with 0.22 percent.

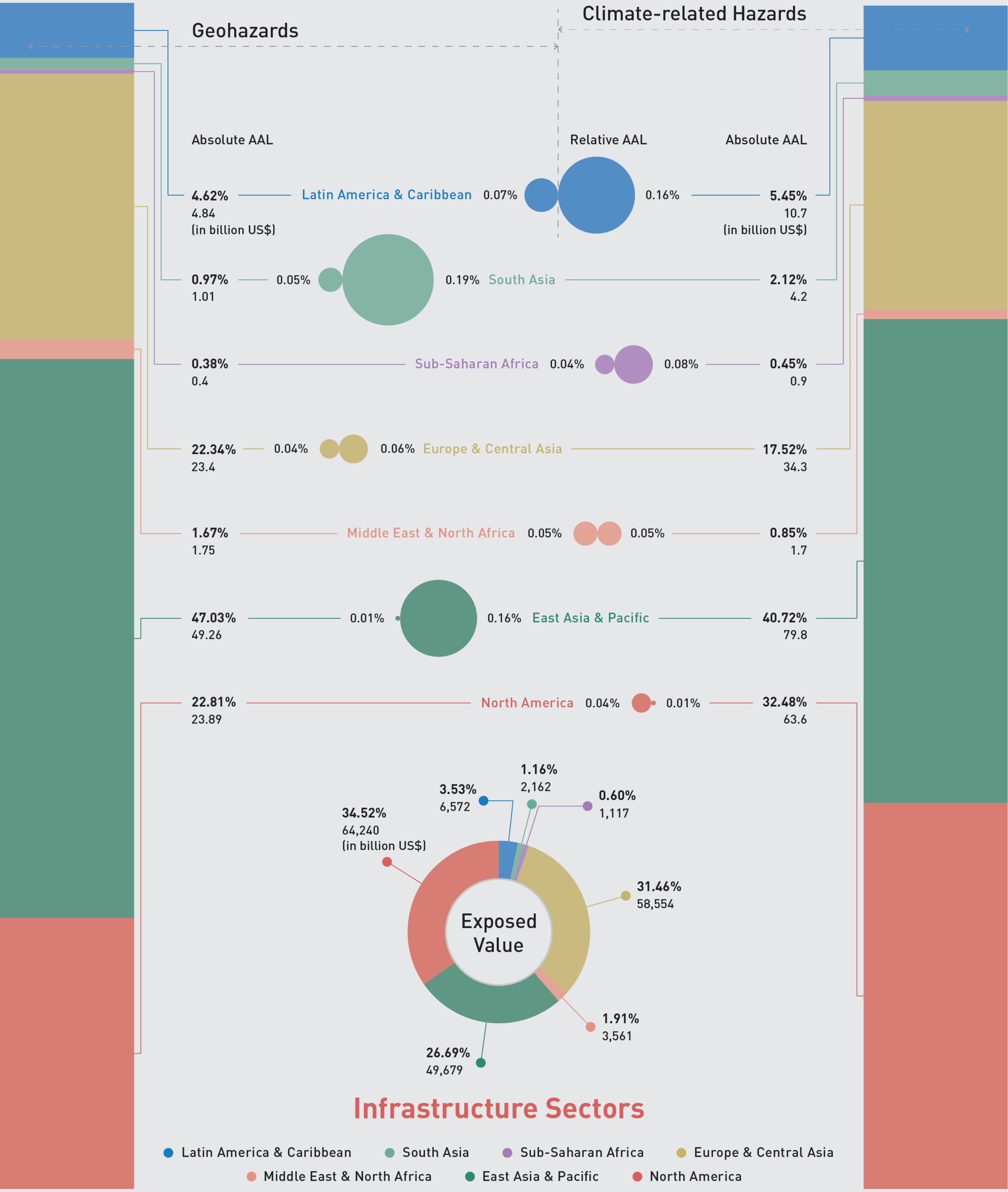
Risk was modelled using two future climate scenarios for 2100, one based on a lower bound of climate change and the other on a more carbon-intensive pathway. At the lower bound, the global AAL for infrastructure sectors rose to $304 billion and to $329 billion at the upper bound, representing 0.16 to 0.18 percent of the exposed value. **Taking into account climate change, the total infrastructure AAL, including buildings and the health and education sectors, would be in a range of $732 - $845 billion.**

Climate change will have the greatest impact on the AAL throughout South Asia and Sub-Saharan Africa where risk to infrastructure assets from floods, cyclonic winds, storm surge, and rainfall-triggered landslides at the upper limit may increase by around 24 percent. In other regions, such as North America and Latin America and the Caribbean, high levels of risk, associated with other risk drivers, such as weak governance, poverty and inequality, and environmental degradation, are already locked in with the existing climate. **Therefore, while climate change mitigation and adaptation are crucially important, strengthening infrastructure resilience will require a holistic approach that addresses the full range of risk drivers.**

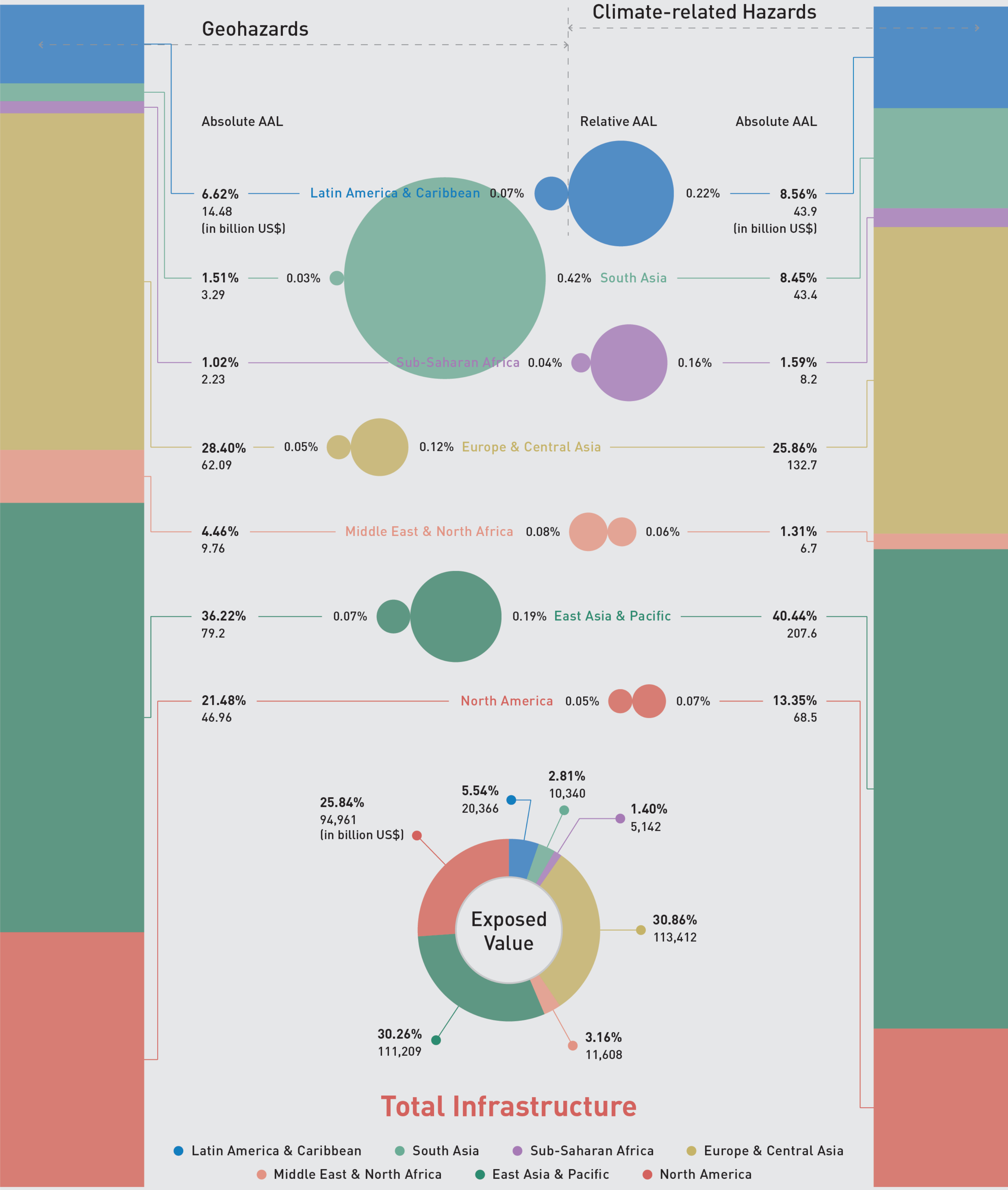
→ **FIGURE 2.7**

Risk in Geographic Regions Associated with Geological and Climate-Related Hazards

Source: Cardona et al. (2023a)



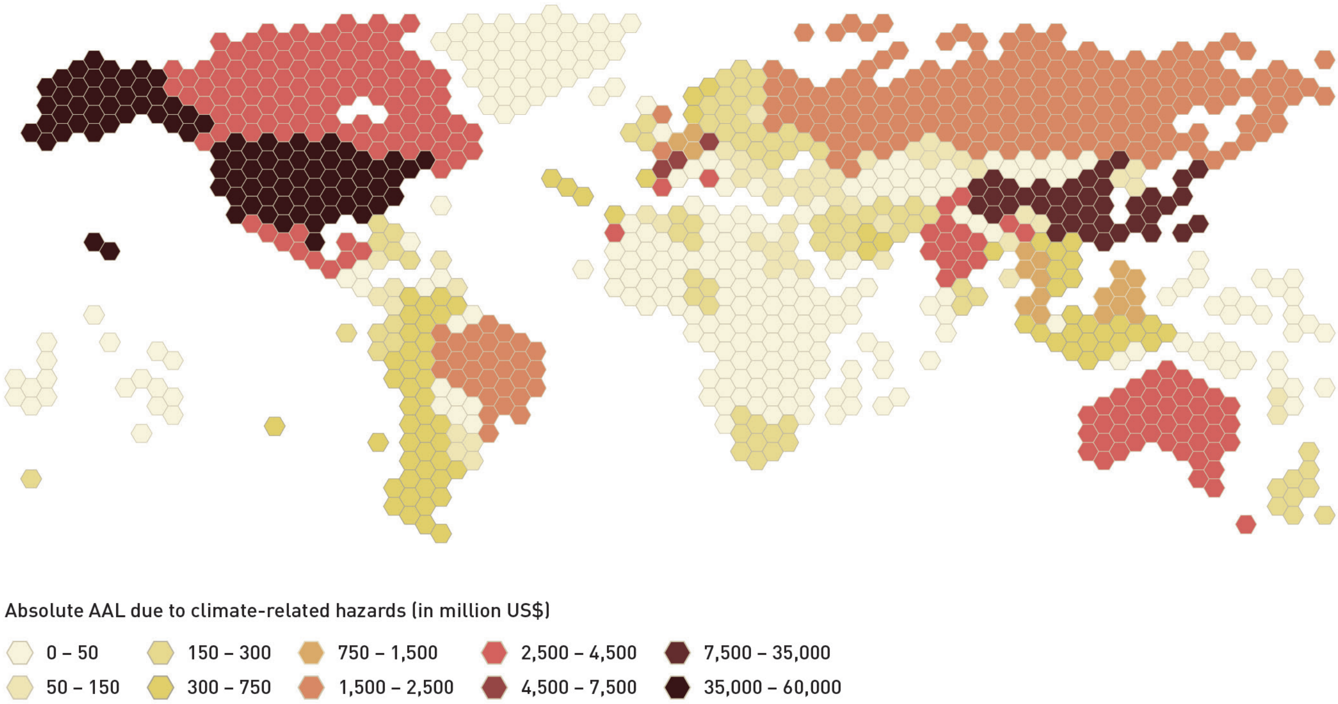
The stacked bars on the opposite edges of each page represent the proportion of Absolute AAL for geohazards (left) and climate-related hazards (right). Follow the lines emerging from these bars for additional data on Relative AAL for each geographic region, shown through circles.

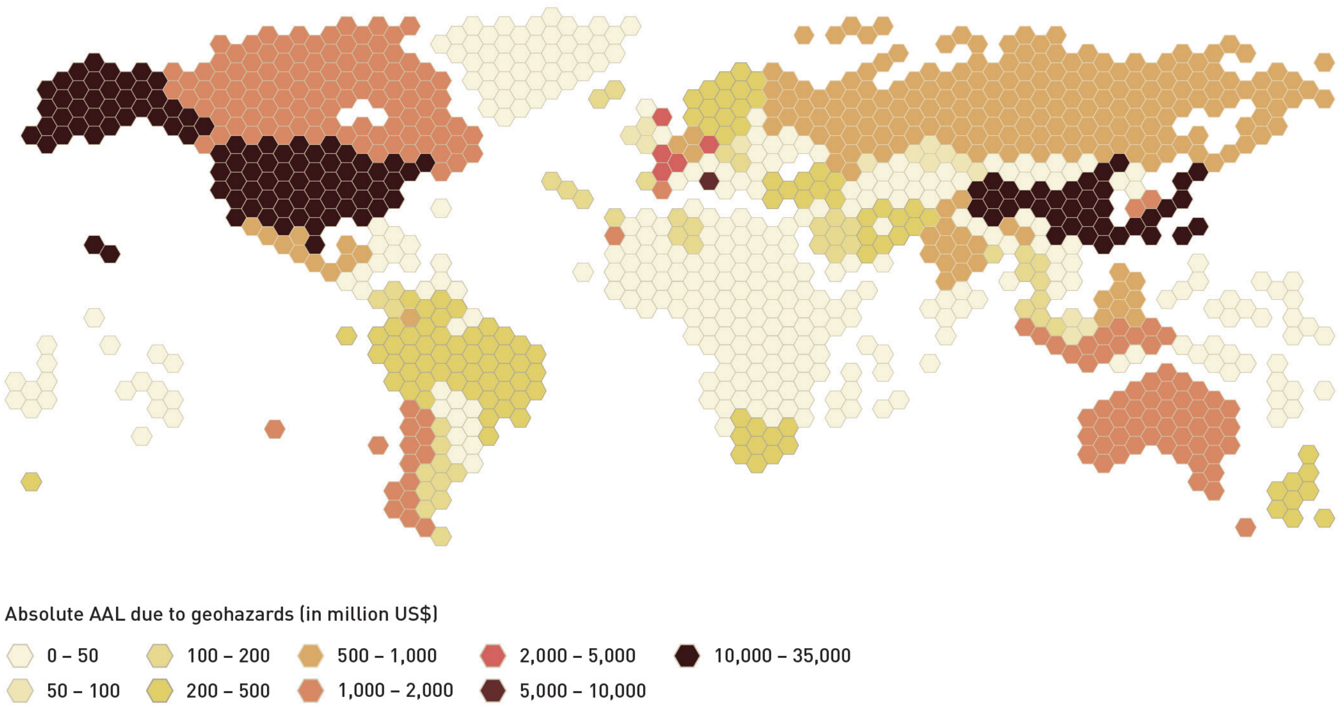


Infrastructure Sectors = Power; Roads and Railways; Ports and Airports; Water and Wastewater; Telecommunications; Oil and Gas.
Total Infrastructure = Infrastructure Sectors plus buildings, including Health and Education infrastructure.

↓ FIGURE 2.8

Absolute AAL Due to Climate-related Hazards (in million US$)
Source: Cardona et al. (2023a)



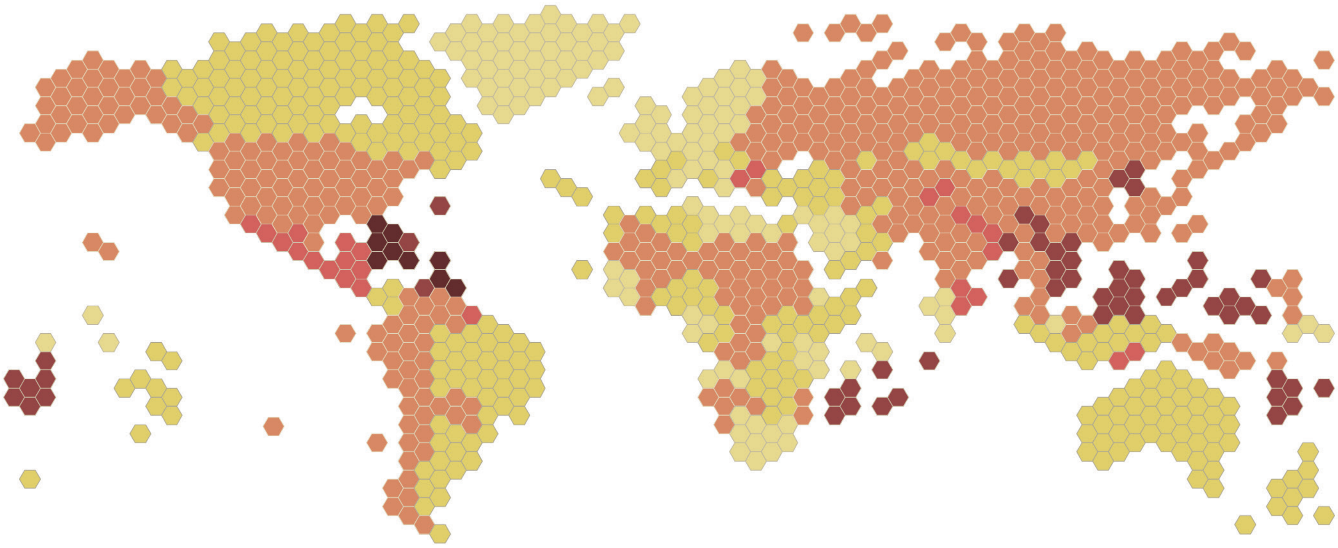


↑ FIGURE 2.9

Absolute AAL Due to Geohazards (in million US$)
Source: Cardona et al. (2023a)

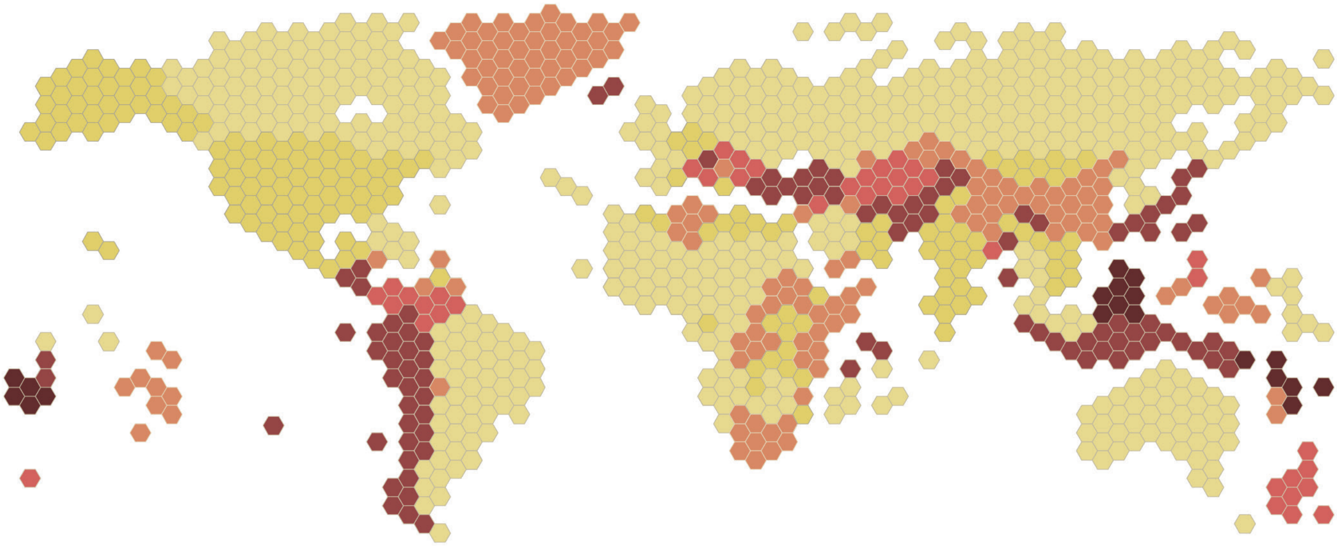
↓ FIGURE 2.10

Relative AAL Due to Climate-related Hazards (x1,000 US$)
Source: Cardona et al. (2023a)



Relative AAL due to climate-related hazards (x 1,000 US$)

0 – 0.5
0.5 – 1
1 – 2
2 – 3
3 – 8
8 – 16



Relative AAL due to geohazards (x 1,000 US$)

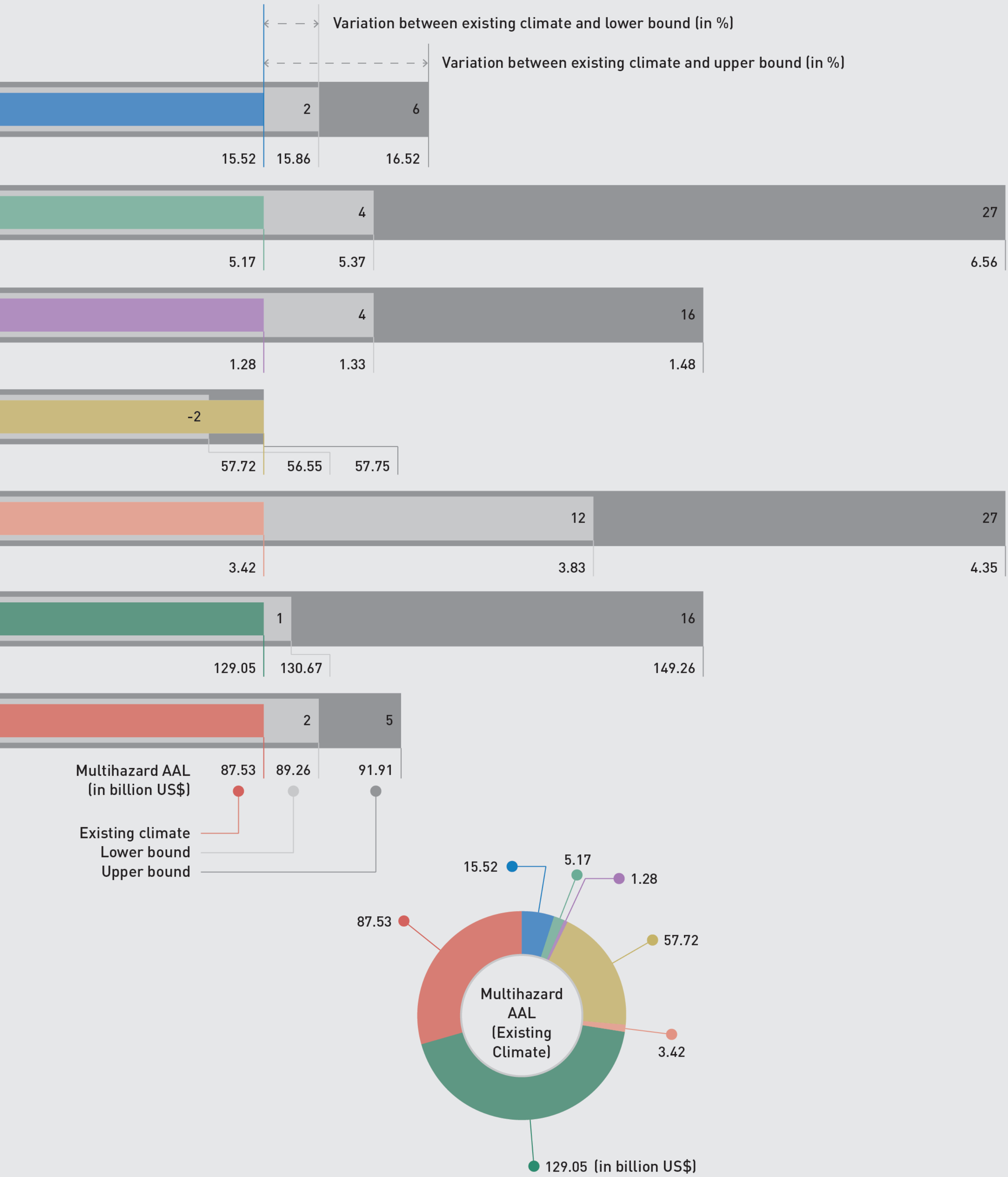
0 – 0.3
0.3 – 0.5
0.5 – 0.8
0.8 – 1.25
1.25 – 2.5
2.5 – 7.5

↑ FIGURE 2.11

Relative AAL Due to Geohazards (x1,000 US$)
Source: Cardona et al. (2023a)

↓→ FIGURE 2.12

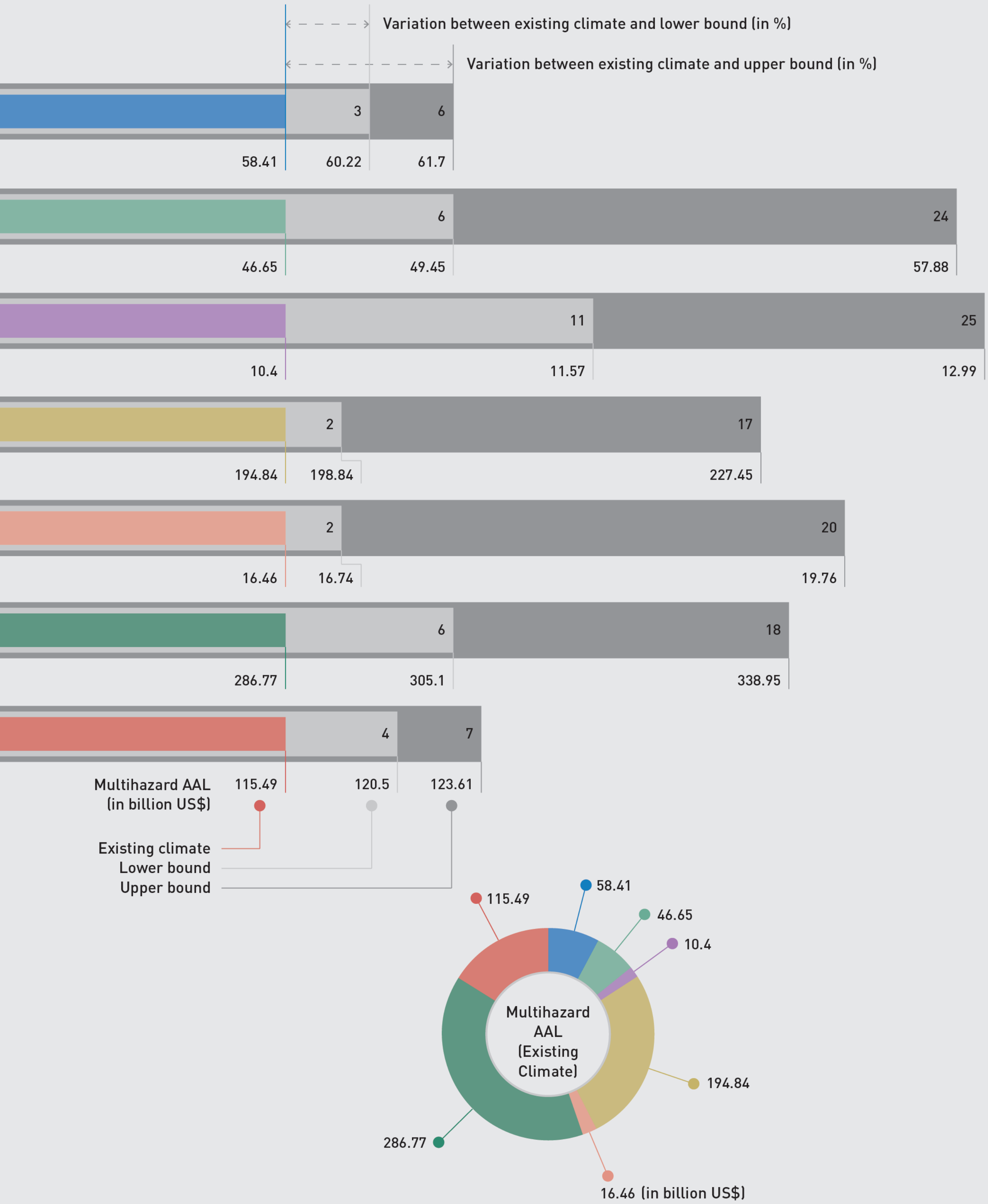
The Impact of Climate Change on Buildings and Infrastructure
Source: Cardona, et al. (2023a)



Infrastructure Sectors

● Latin America & Caribbean ● South Asia ● Sub-Saharan Africa ● Europe & Central Asia
● Middle East & North Africa ● East Asia & Pacific ● North America

Infrastructure Sectors = Power; Roads and Railways; Ports and Airports; Water and Wastewater; Telecommunications; Oil and Gas.
Total Infrastructure = Infrastructure Sectors plus buildings, including Health and Education infrastructure.

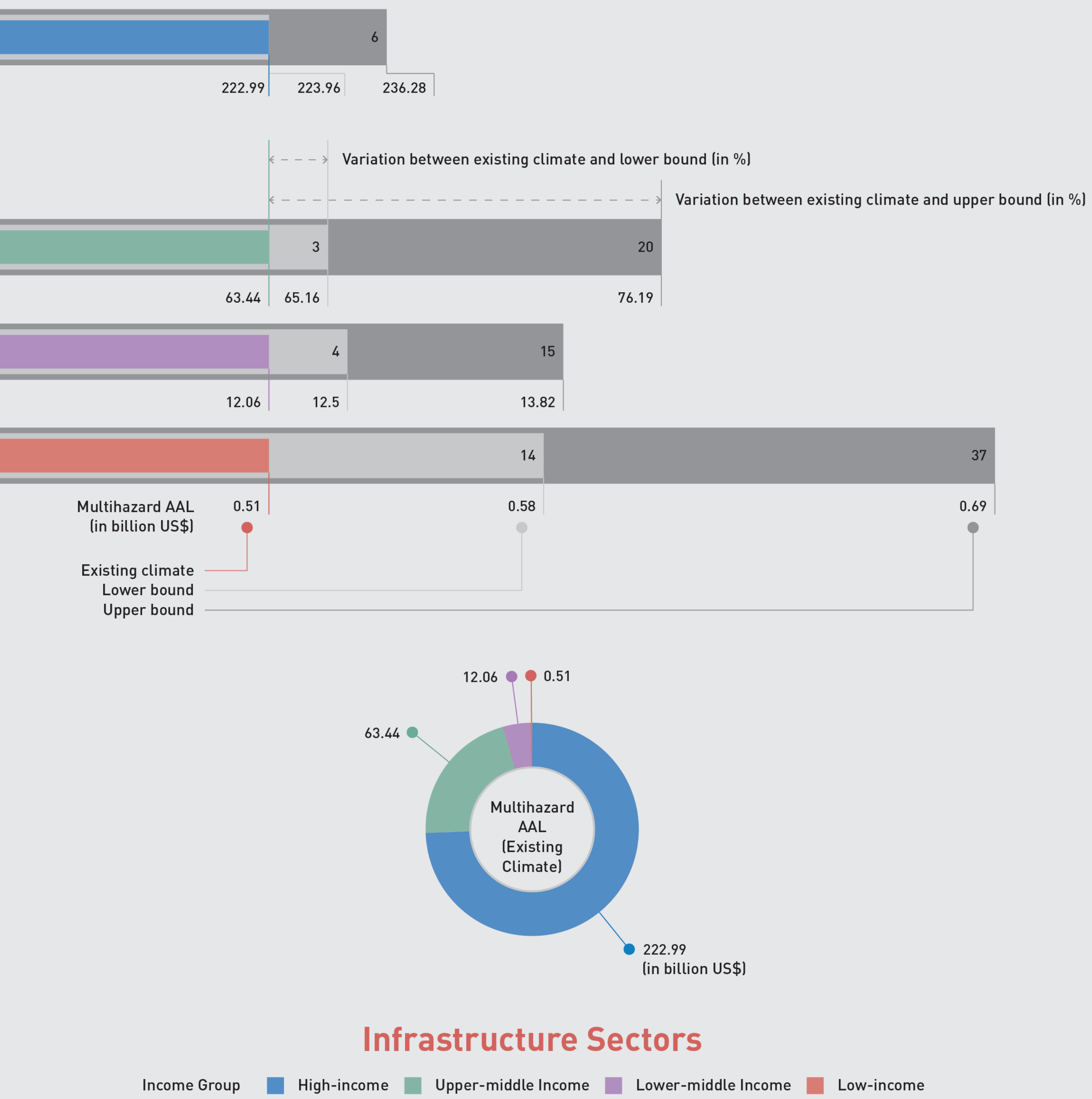


Total Infrastructure

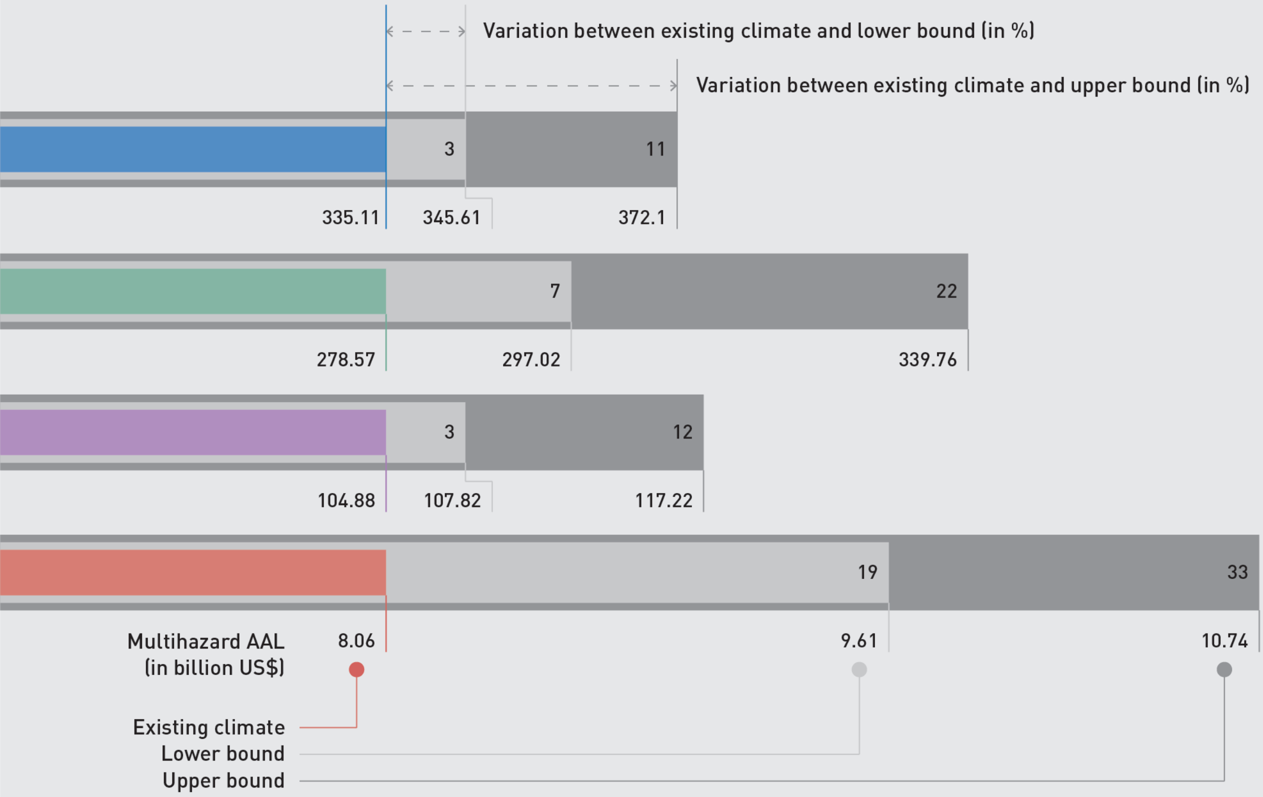
Latin America & Caribbean · South Asia · Sub-Saharan Africa · Europe & Central Asia · Middle East & North Africa · East Asia & Pacific · North America

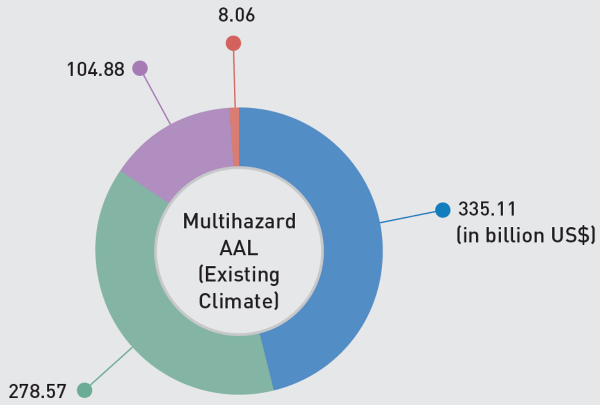
↓→ FIGURE 2.13

The Impact of Climate Change on Infrastructure and Buildings by Income Geography
Source: Cardona, et al. (2023a)



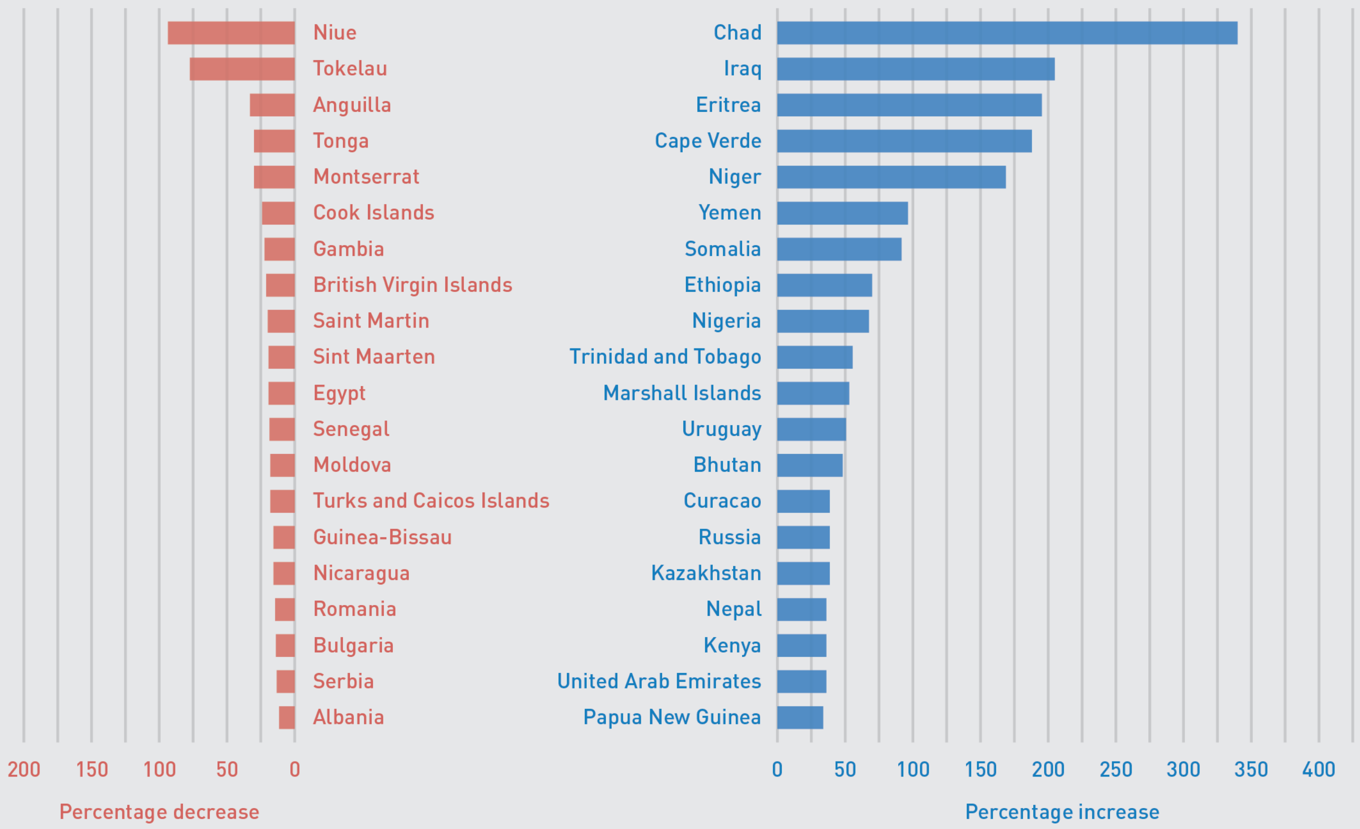
Infrastructure Sectors = Power; Roads and Railways; Ports and Airports; Water and Wastewater; Telecommunications; Oil and Gas.
Total Infrastructure = Infrastructure Sectors plus buildings, including Health and Education infrastructure.





Total Infrastructure

Income Group High-income Upper-middle Income Lower-middle Income Low-income



↑ **FIGURE 2.14**

Countries Expected to Face Decrease (Left) and Increase (Right) in AAL

Source: Cardona et al. (2023a)

Figure 2.13 shows the impact of climate change by income geography. The total AAL may increase by 9 percent within high-income countries at the upper bound of climate change, 12 percent within lower-middle income countries, and 22 percent within upper-middle income countries. It may increase by 33 percent within low-income countries, implying that climate change will have a significantly greater impact in those countries with the largest infrastructure deficit, weak infrastructure governance, low fiscal capacity, and low levels of private investment.

Figure 2.14 depicts countries that would experience the greatest increase and decrease in their AAL due to climate change. **Countries and territories in the Sahel, Middle East, the Horn of Africa, and several SIDS are all likely to see major increases in their risk. Chad, Cape Verde, Eritrea, and Iraq, for example, could see over 200 percent increase to their AAL by 2100.**

In contrast, other countries, particularly in Europe, may see declines in their AAL where hotter and drier conditions reduce flood risk to infrastructure assets.

↓ BOX 2.1

Hydrological Drought and Power Generation
Source: Camalleri et al. (2023)

Hydrological drought occurs when reduced rainfall leads to shortfalls of surface or ground water availability. It can stress the availability of water for domestic, industrial, agricultural, transport and power generation, disrupting essential services and generating major economic losses. As hydropower plants require a consistent supply of water to generate electricity, water stress may reduce output leading to power shortages and increased reliance on other energy sources such as fossil fuels.

Climate change may significantly modify the AAL of hydropower generation[13] in countries where it represents a primary source of energy under a lower and upper climate change scenario. Estimates indicate that AAL may increase dramatically under the upper climate change scenario in countries like Afghanistan, Lesotho, and Costa Rica. In Lesotho, for example, the relative AAL would increase from 12.8 to 34.8 percent of the annual hydropower production and 6.8 to 32.4 percent in Costa Rica. Paraguay, in contrast, would see a reduction from 4.0 to 1.5 percent and Norway from 1.7 to 0.4 percent.

However, these countries may experience higher non-asset related loss due to agricultural drought or heat waves in cities.

Production and welfare losses due to climate change are only partially associated with infrastructure loss and damage. Climate change can stress agriculture, food systems, urban areas, and ecosystems without necessarily damaging or destroying infrastructure assets. **New ways of delivering infrastructure will be required, including through NbIS, that adapt infrastructure systems to a changing climate beyond asset resilience.**

Box 2.1 examines how increased water stress from climate change will modify hydropower generation in countries where this is a major source of energy.

[13] Countries where 75 percent of the total energy between 2011 and 2020 was generated by hydropower, with a total annual production greater than 0.5 TWh. The energy production data used in this study were obtained from the BP Statistical Review of World Energy and Ember.

2.5. Risk in Infrastructure Sectors

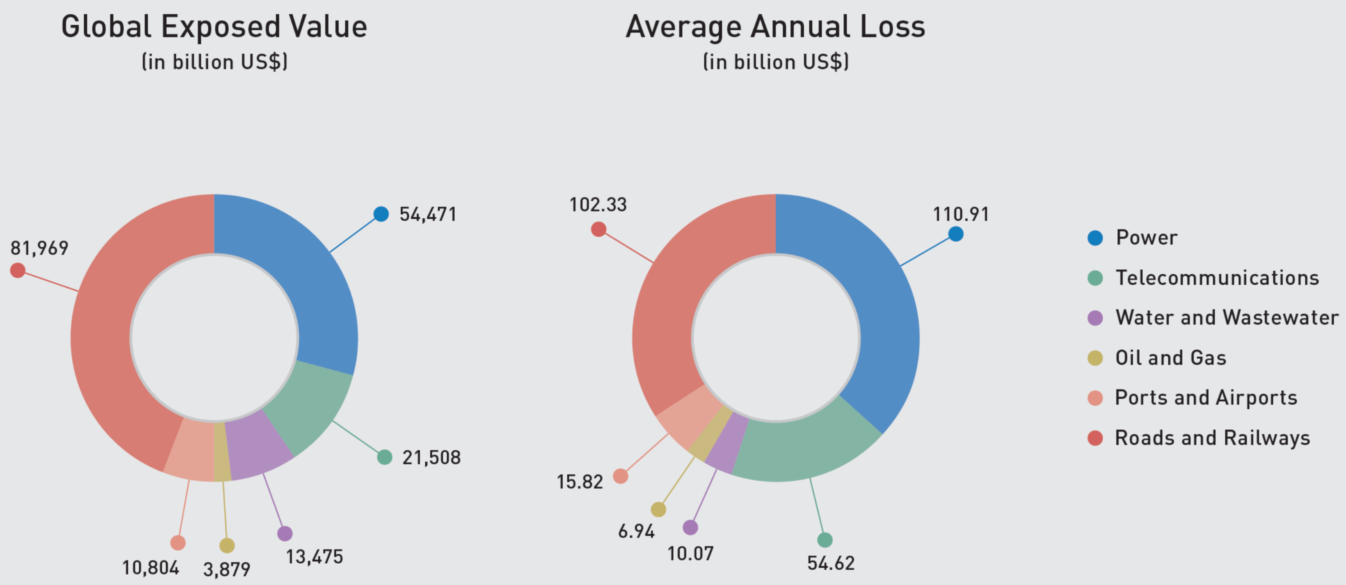
↓ FIGURE 2.15

Exposed Value and AAL by Sector
Source: Cardona et al. (2023a)

The power, roads and railways, and telecommunications sectors present major resilience challenges across most national economies.

Figure 2.15 shows how the exposed value and AAL are distributed across infrastructure sectors. **Roads and railways, telecommunications, and power and energy account for around 80 percent of the total AAL of infrastructure sectors, so strengthening resilience in these sectors will generate an important dividend in most countries.**

The following sections illustrate absolute and relative AALs for each sector. SIDS continue to have the highest relative risk and high-income countries the highest absolute risk across almost all sectors. However, countries with the highest absolute and relative risk vary considerably from sector to sector. Power in Bangladesh, roads in Peru and Ecuador, telecommunications in Hong



Kong and the Philippines, water and wastewater in Myanmar, oil and gas in the United Arab Emirates, and ports and airports in Hong Kong and Macau are all examples of country-specific resilience challenges.

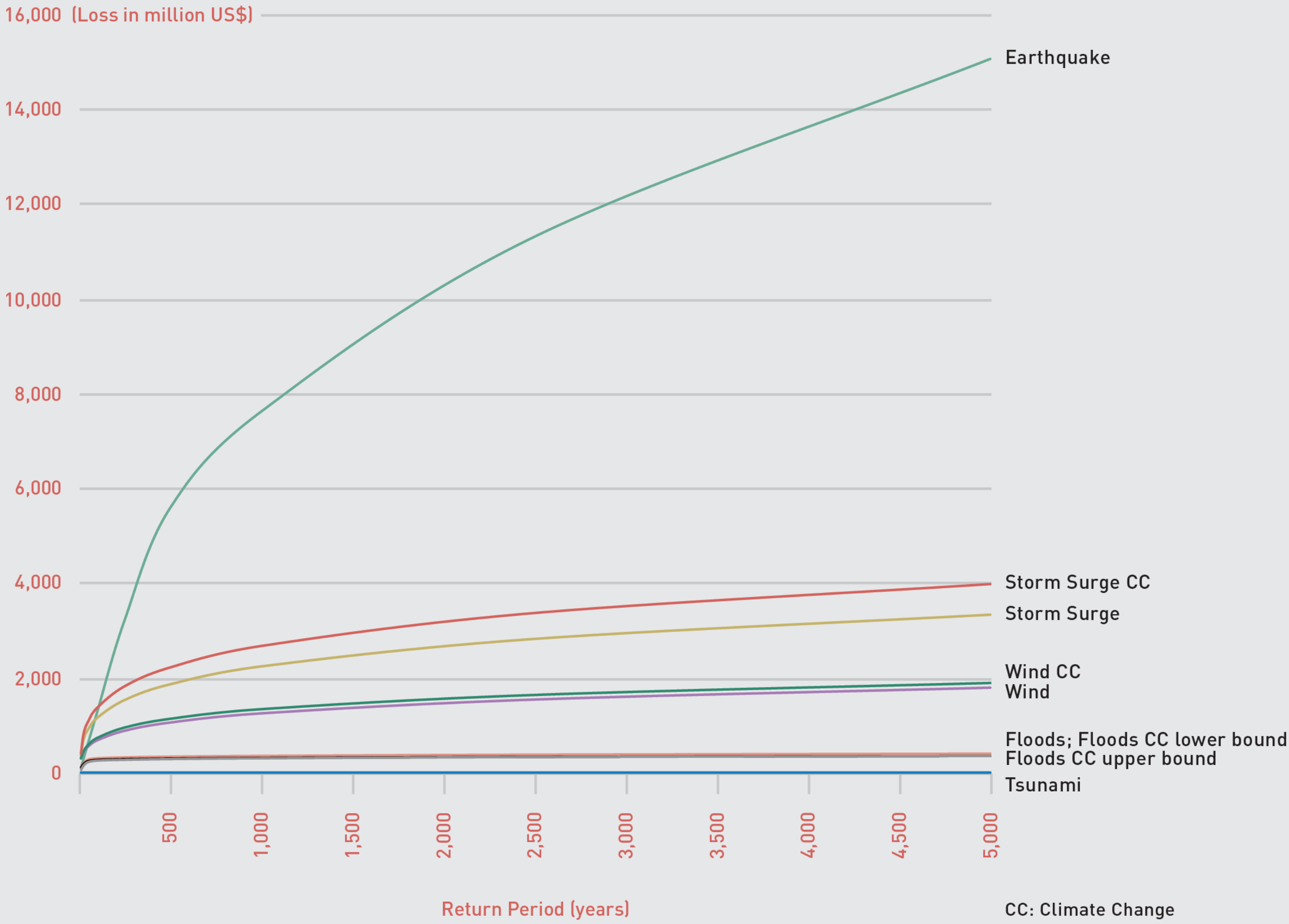
Each hazard also has an impact on infrastructure sectors in different ways. **Flood and wind are associated with around two-thirds of the power sector's AAL. Wind is associated with about two-thirds of the telecommunications sector's AAL, and over half the oil and gas and ports and airports' AAL. In contrast, landslides and earthquakes are associated with over three-quarters of the road and rail AAL and earthquakes with around two-thirds of the water and wastewater AAL.**

Resilience challenges in each sector are associated with specific hazards that have different periods of recurrence. As Figure 2.16 highlights, earthquake risk in the case of Jamaica is associated with longer periods of recurrence compared to wind and flood. **Countries, therefore, need to adopt hazard and sector-specific resilience policies, tailored to maximize the resilience dividend.**

↓ FIGURE 2.16

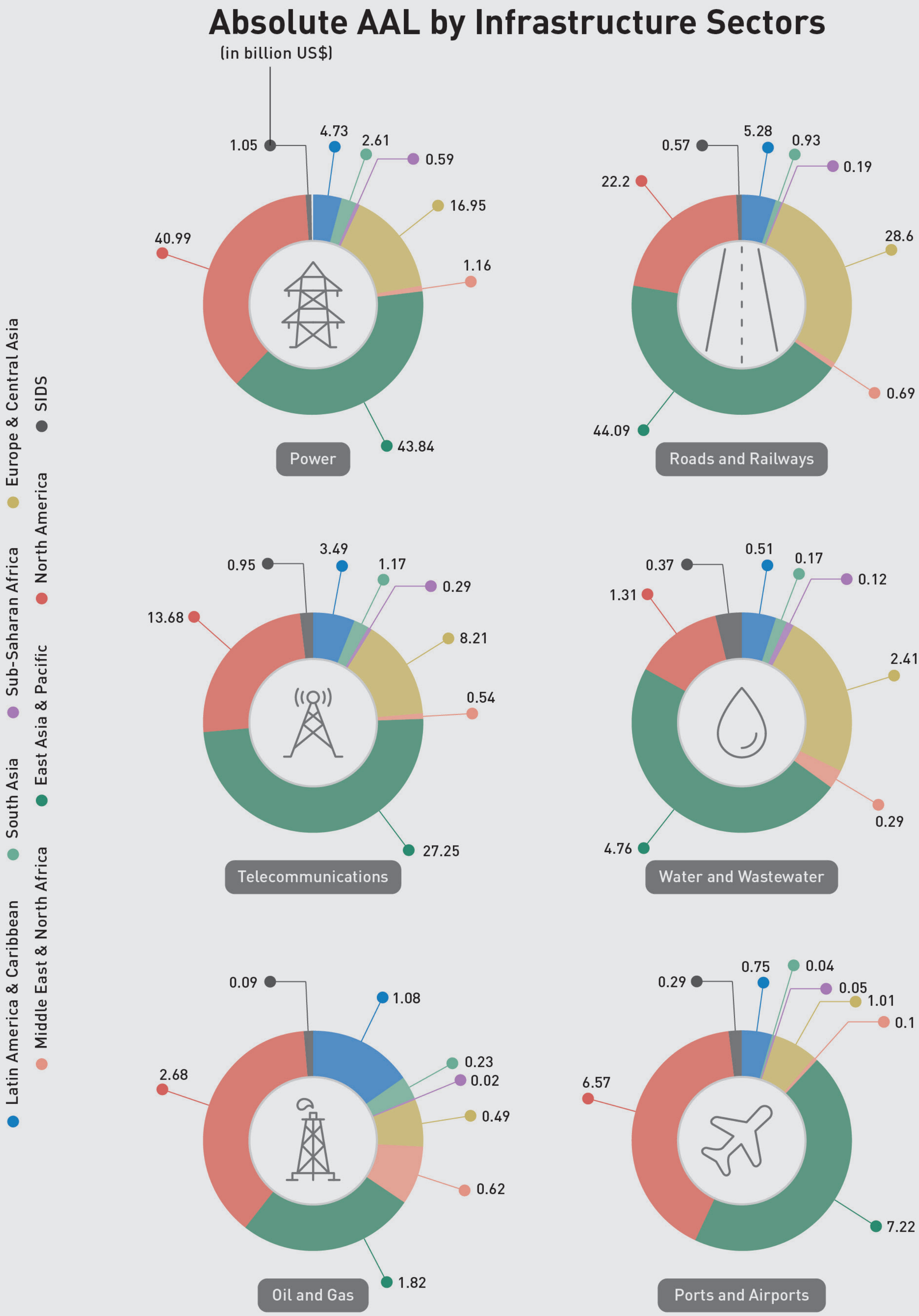
Expected Probable Maximum Loss (in US$) by Return Period (in Years) in Jamaica

Source: Cardona, et al. (2023a)



↓→ FIGURE 2.17

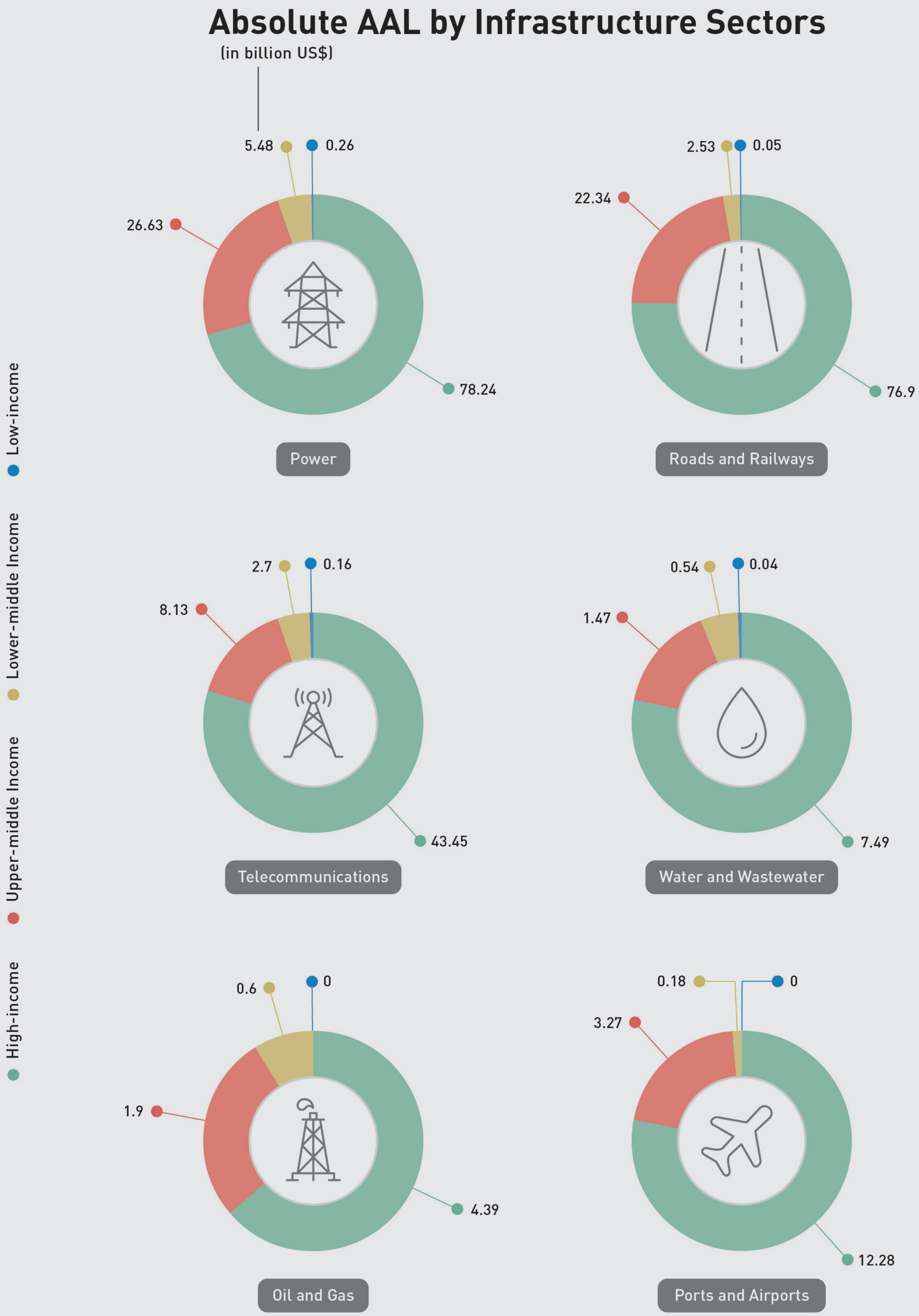
Absolute and Relative AAL in Geographical Regions
Source: Cardona, et al. (2023a)



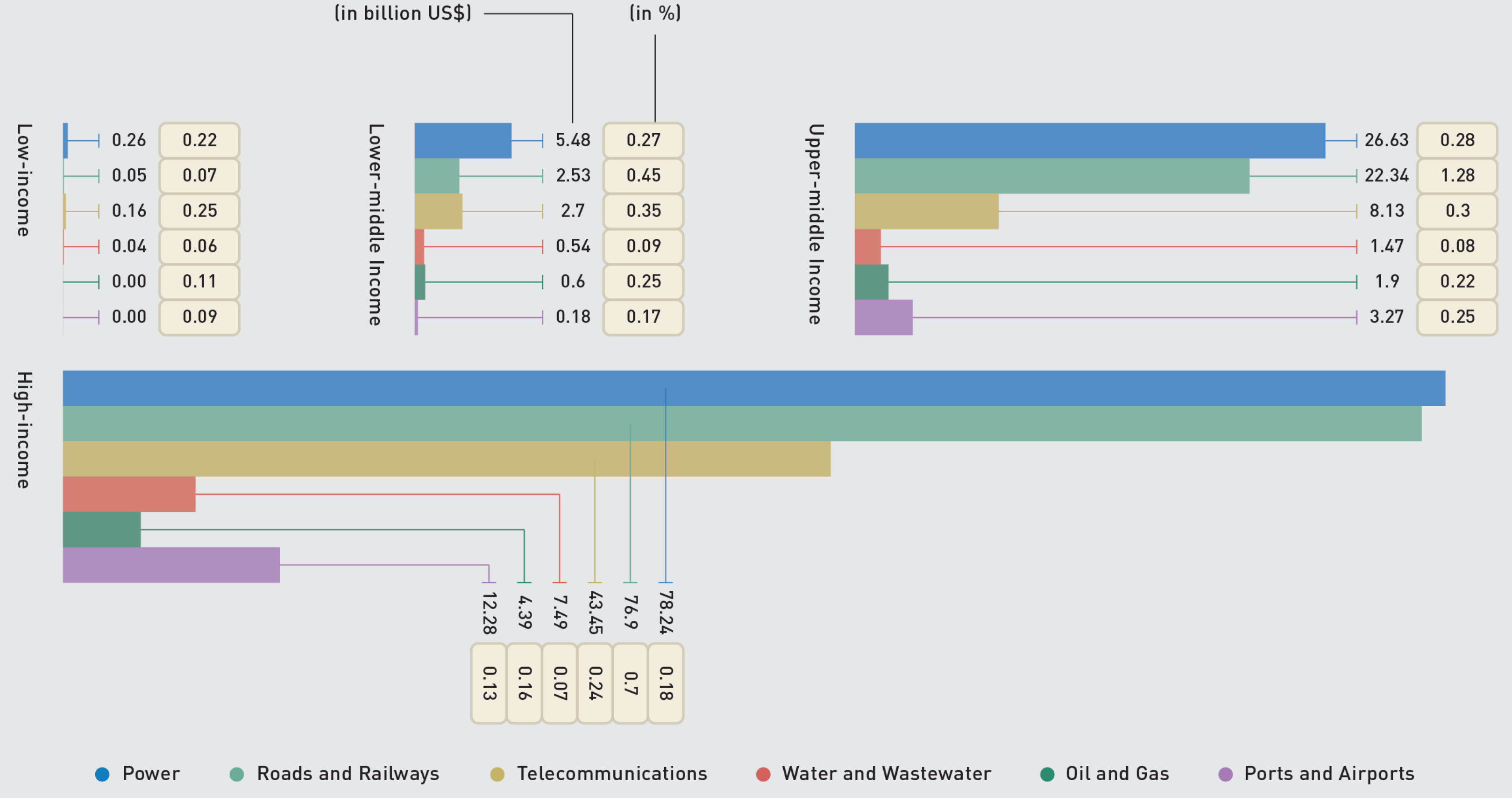
Absolute and Relative AAL by Geographical Regions

↓→ FIGURE 2.18

Absolute and Relative AAL in Income Regions
Source: Cardona, et al. (2023a)



Absolute and Relative AAL by Income Regions

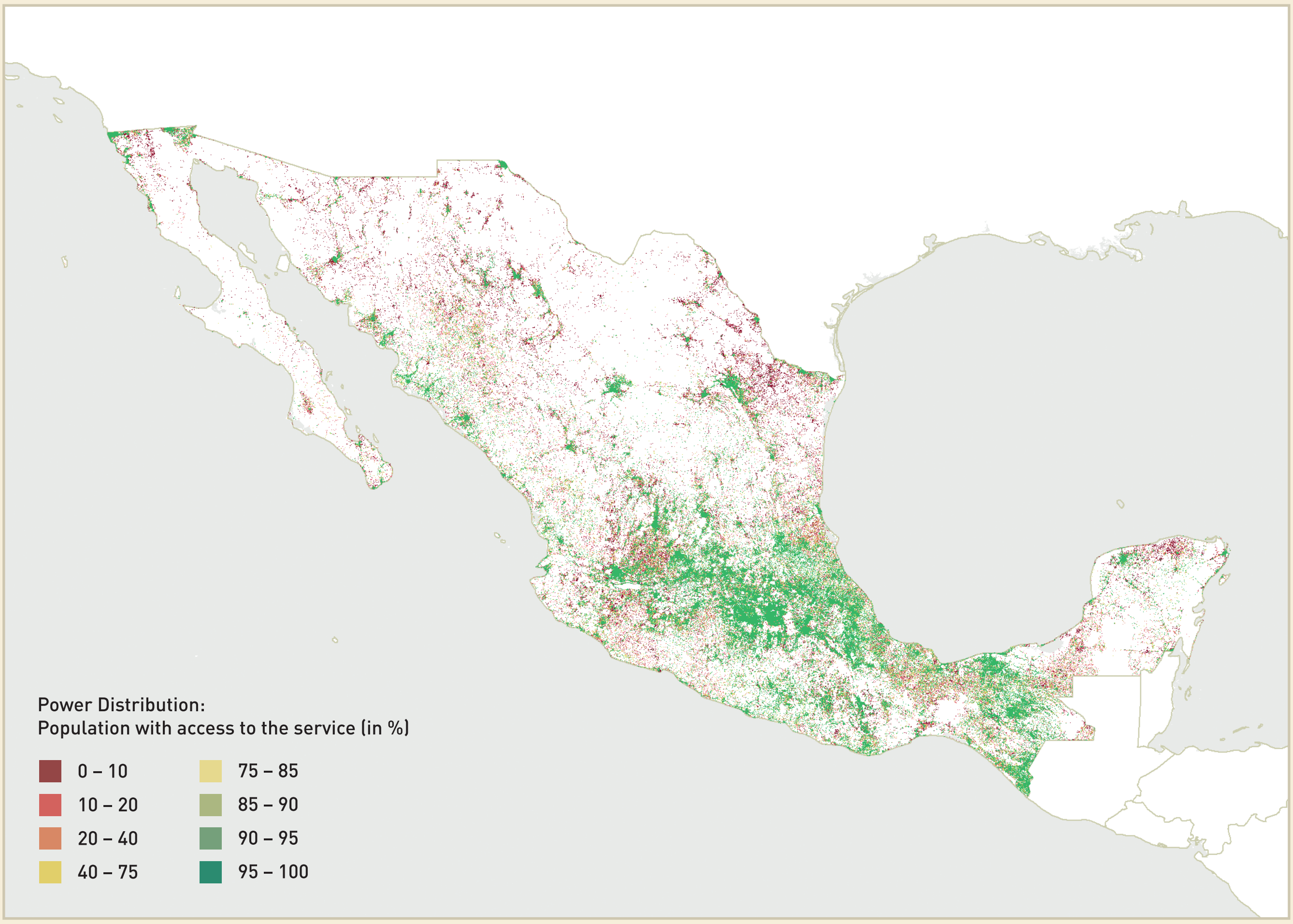


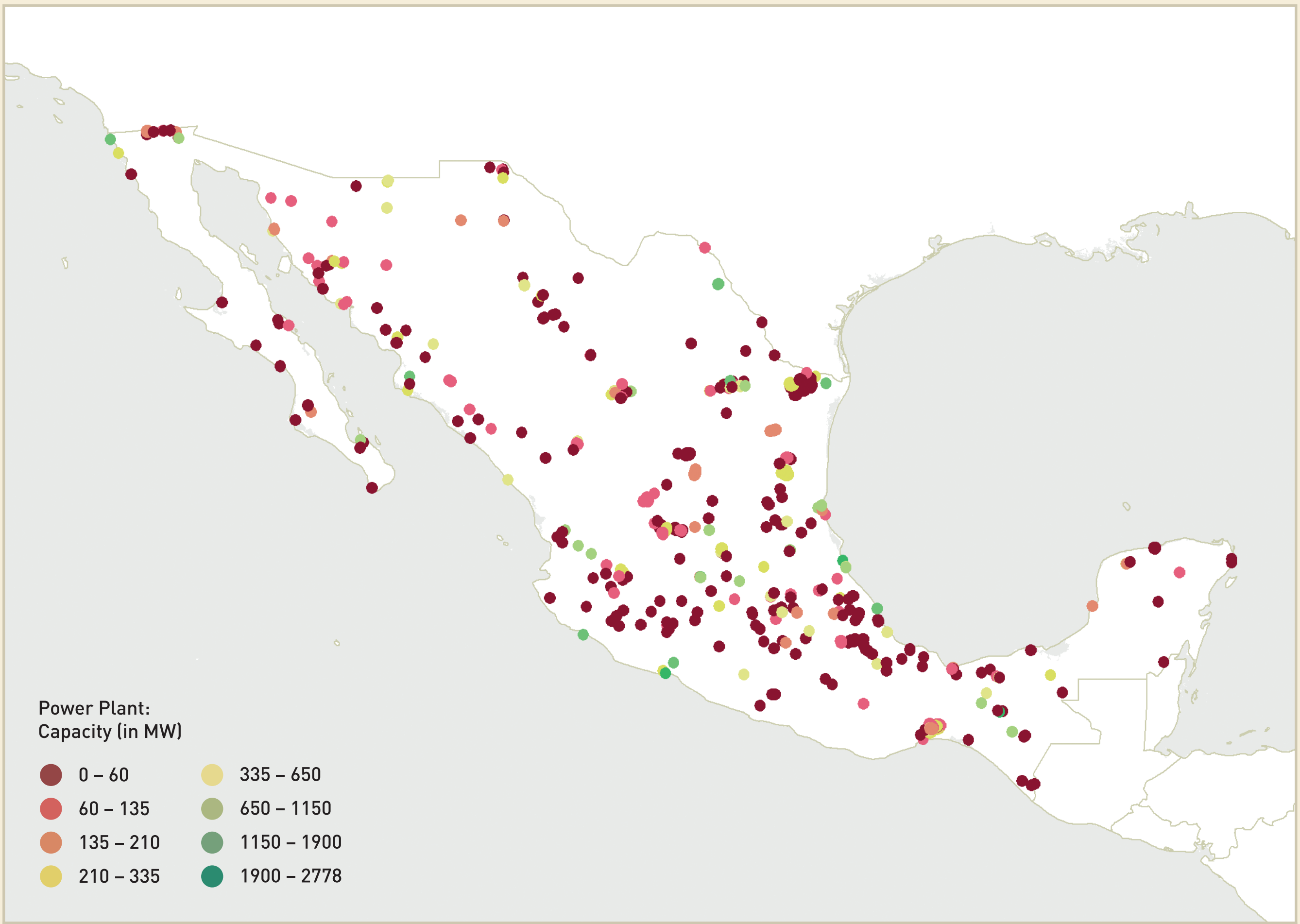
2.5.1. Power

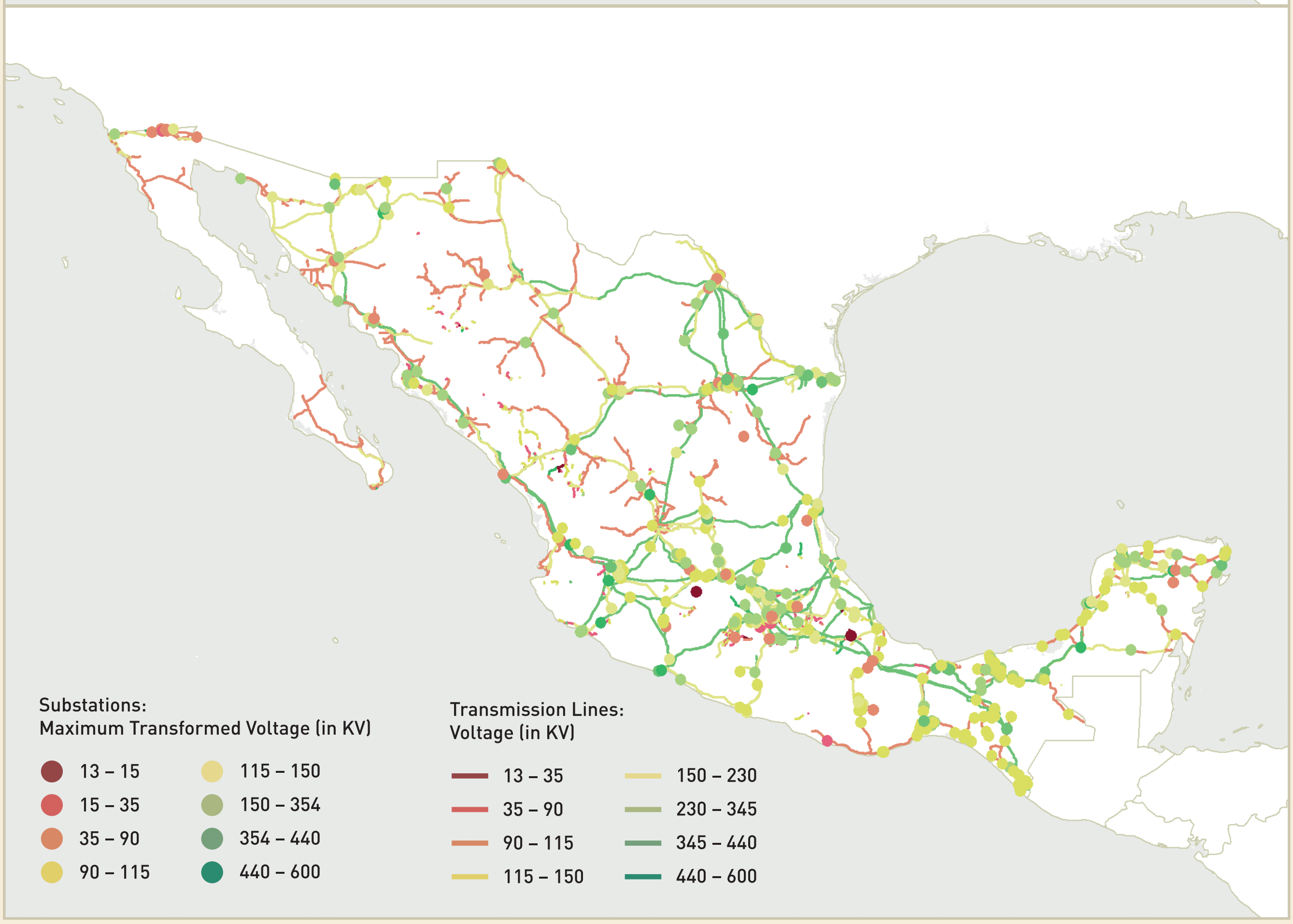
↓→ FIGURE 2.19

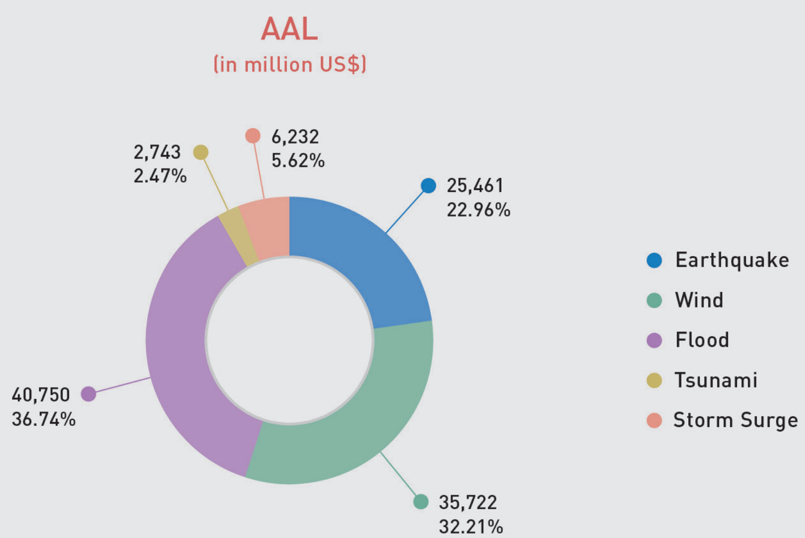
Power Sector Infrastructure in Mexico

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




Power Plant:
Capacity (in MW)
0 – 60
60 – 135
135 – 210
210 – 335
335 – 650
650 – 1150
1150 – 1900
1900 – 2778


Substations:
Maximum Transformed Voltage (in KV)
13 – 15
15 – 35
35 – 90
90 – 115
115 – 150
150 – 354
354 – 440
440 – 600
Transmission Lines:
Voltage (in KV)
13 – 35
35 – 90
90 – 115
115 – 150
150 – 230
230 – 345
345 – 440
440 – 600



↑ FIGURE 2.20

Relative and Absolute AAL in Power Sector

Source: Cardona, et al. (2023a)

→ FIGURE 2.21

Proportion of AAL by Hazard for Power Sector

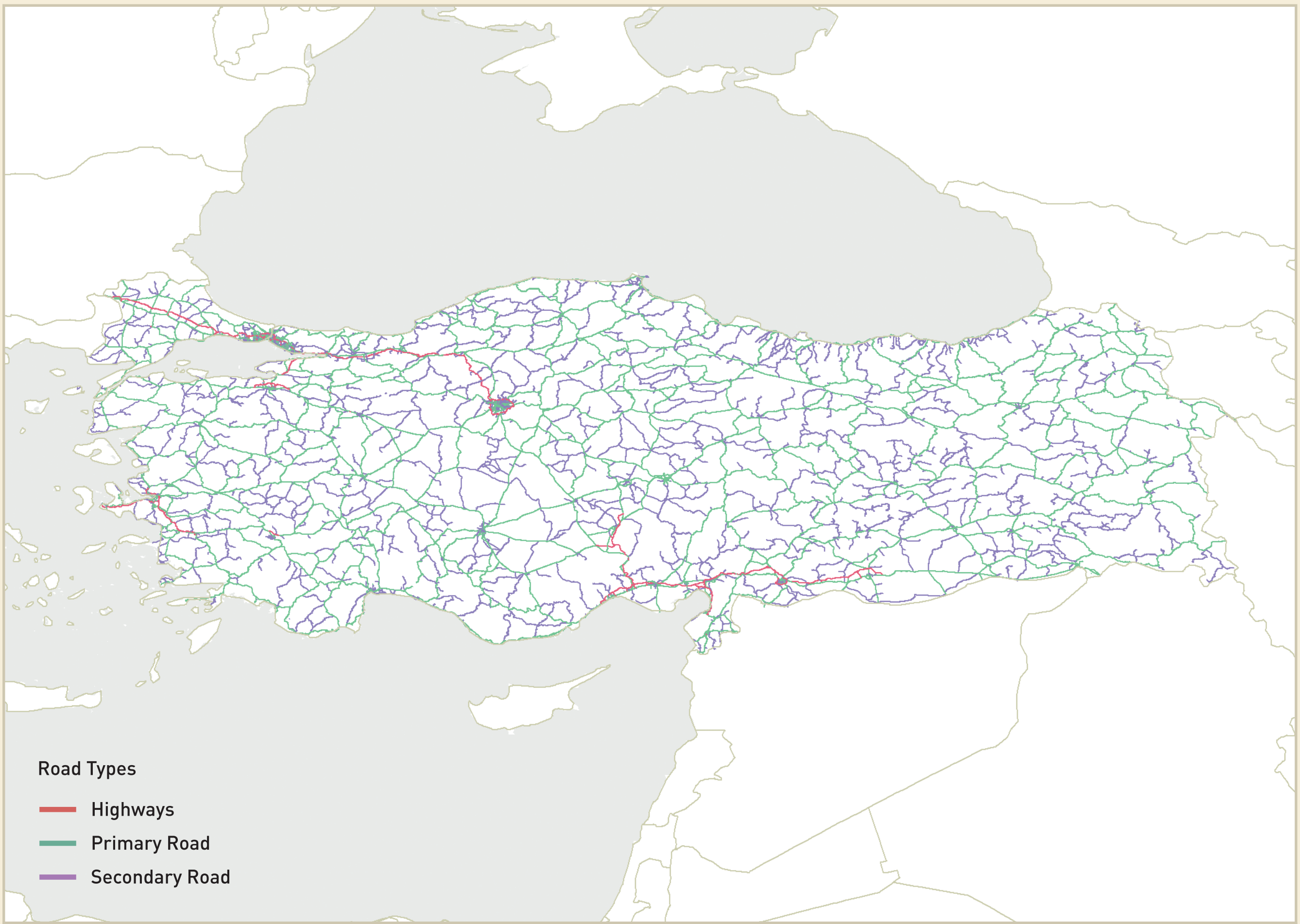
Source: Cardona, et al. (2023a)

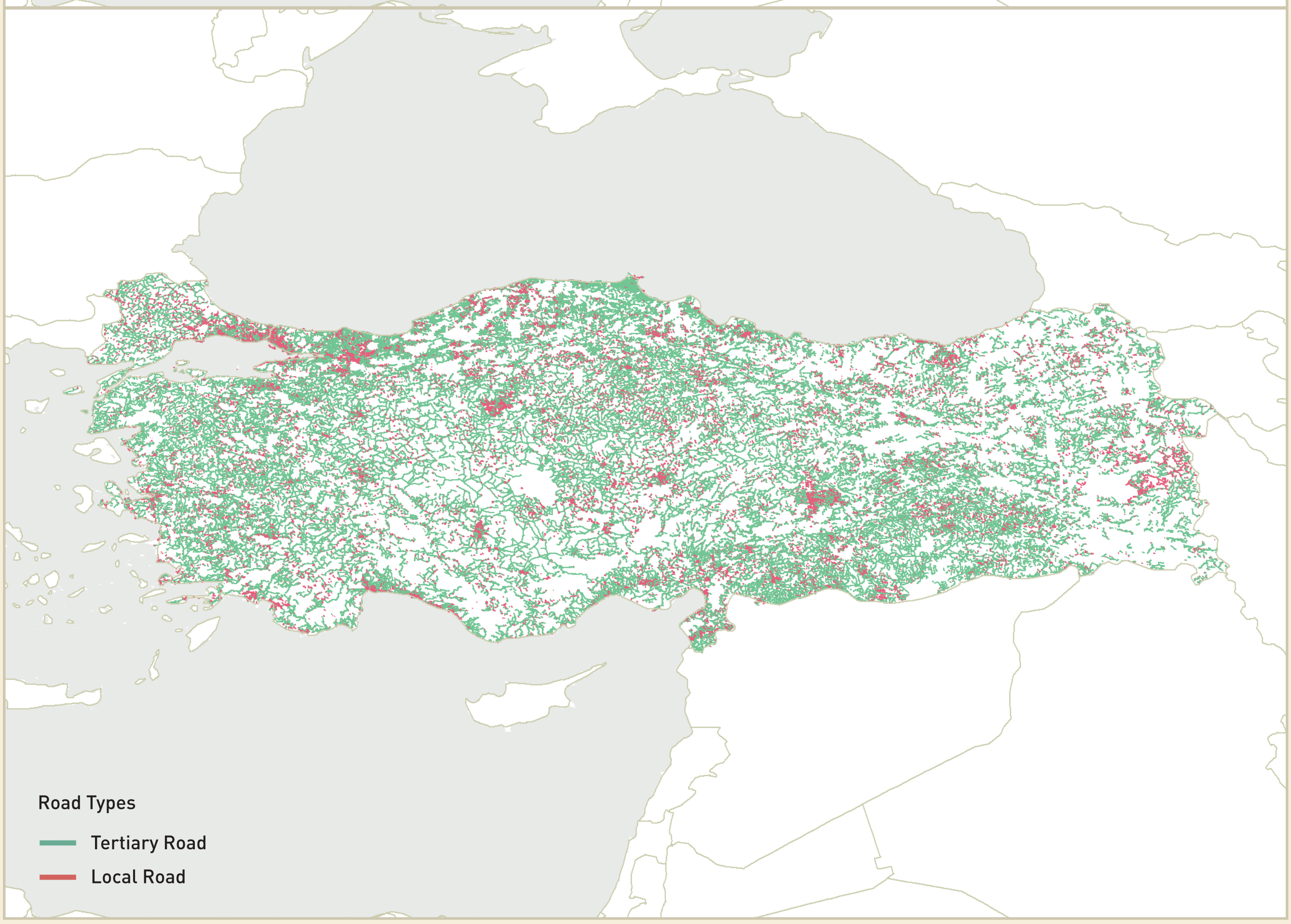
→→ FIGURE 2.22

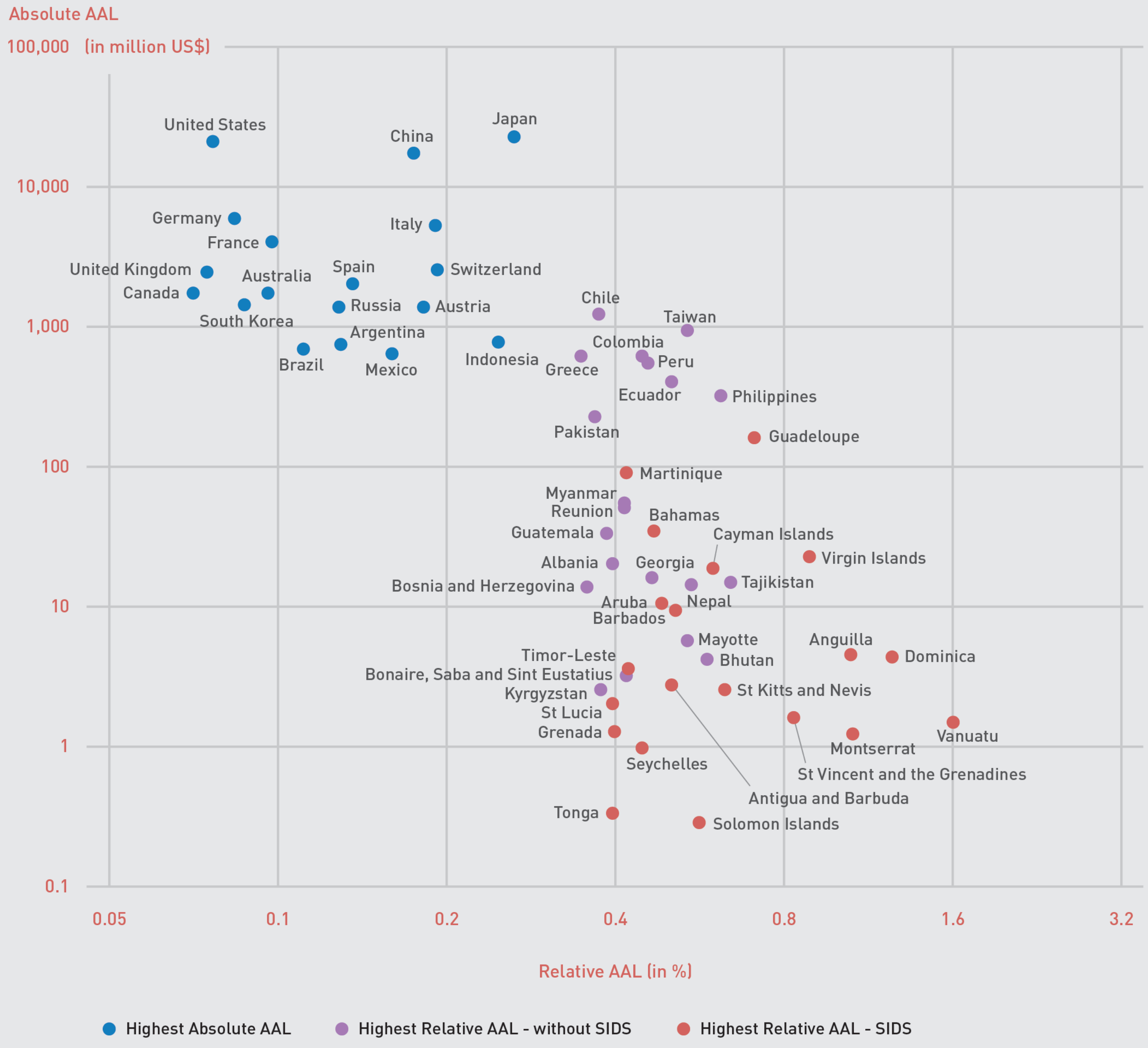
The Road Network in Turkey

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

2.5.2. Roads and Railways







↑ **FIGURE 2.24**

Relative and Absolute AAL for Road and Railways Sector

Source: Cardona, et al. (2023a)

→ **FIGURE 2.23**

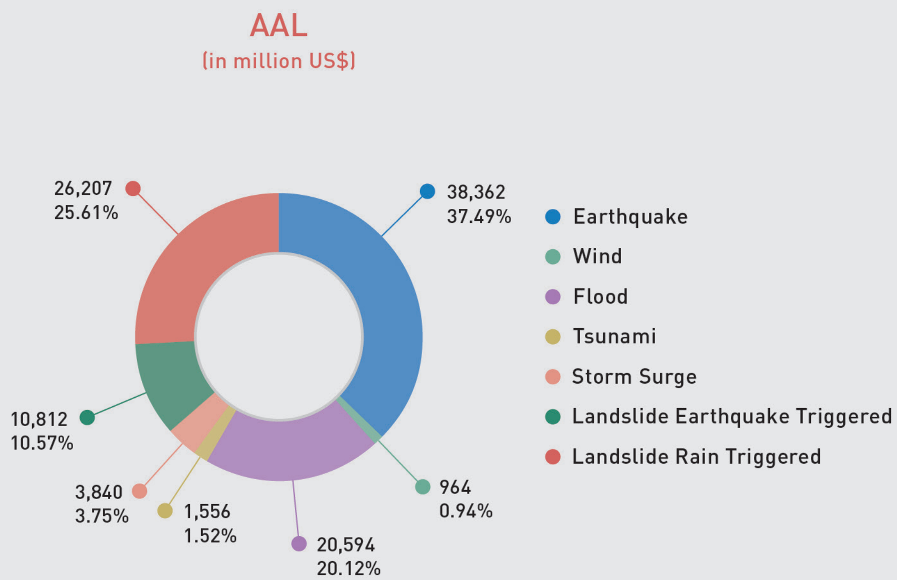
Proportion of AAL by Hazard for Roads and Railways Sector

Source: Cardona, et al. (2023a)

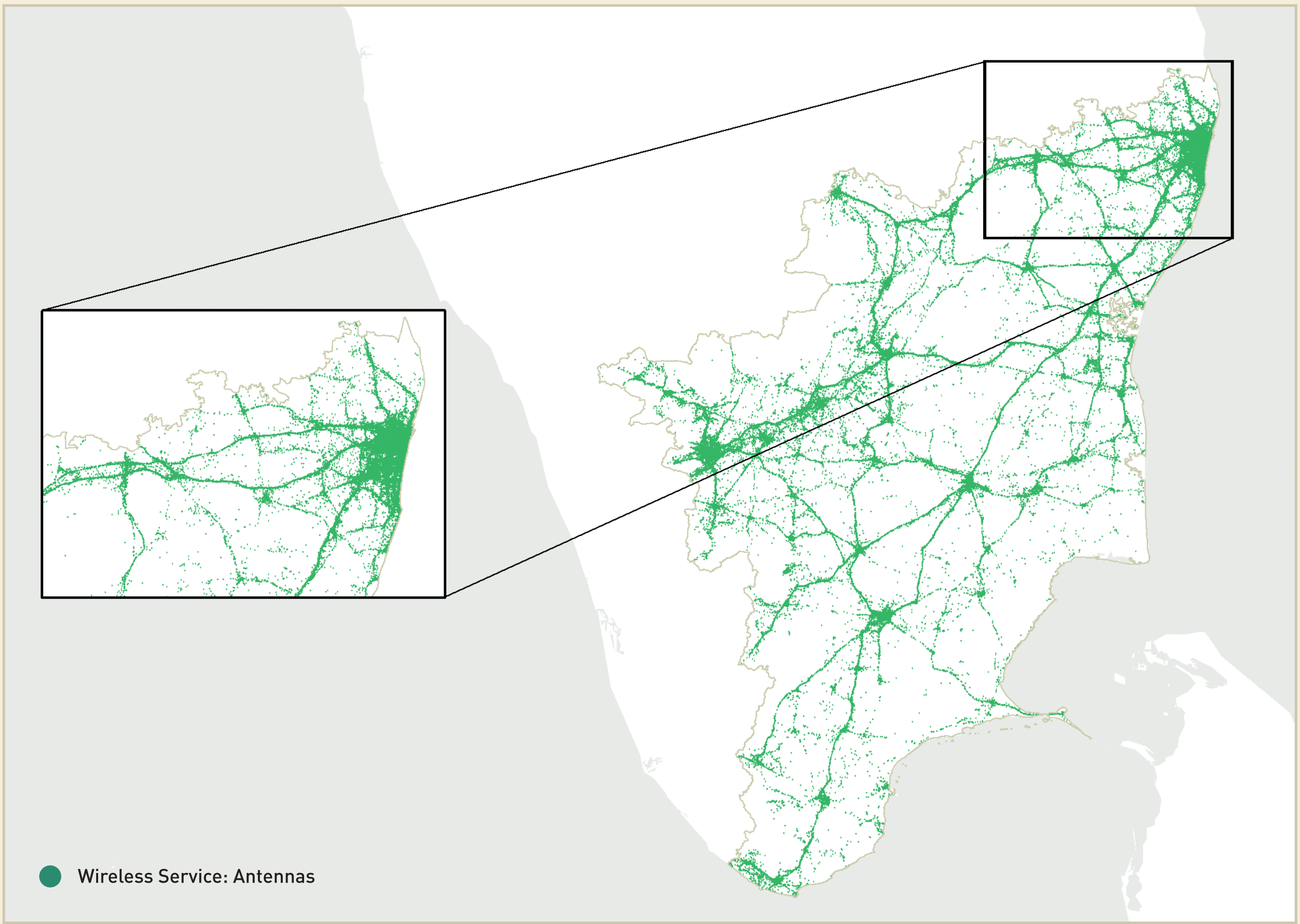
→→ **FIGURE 2.25**

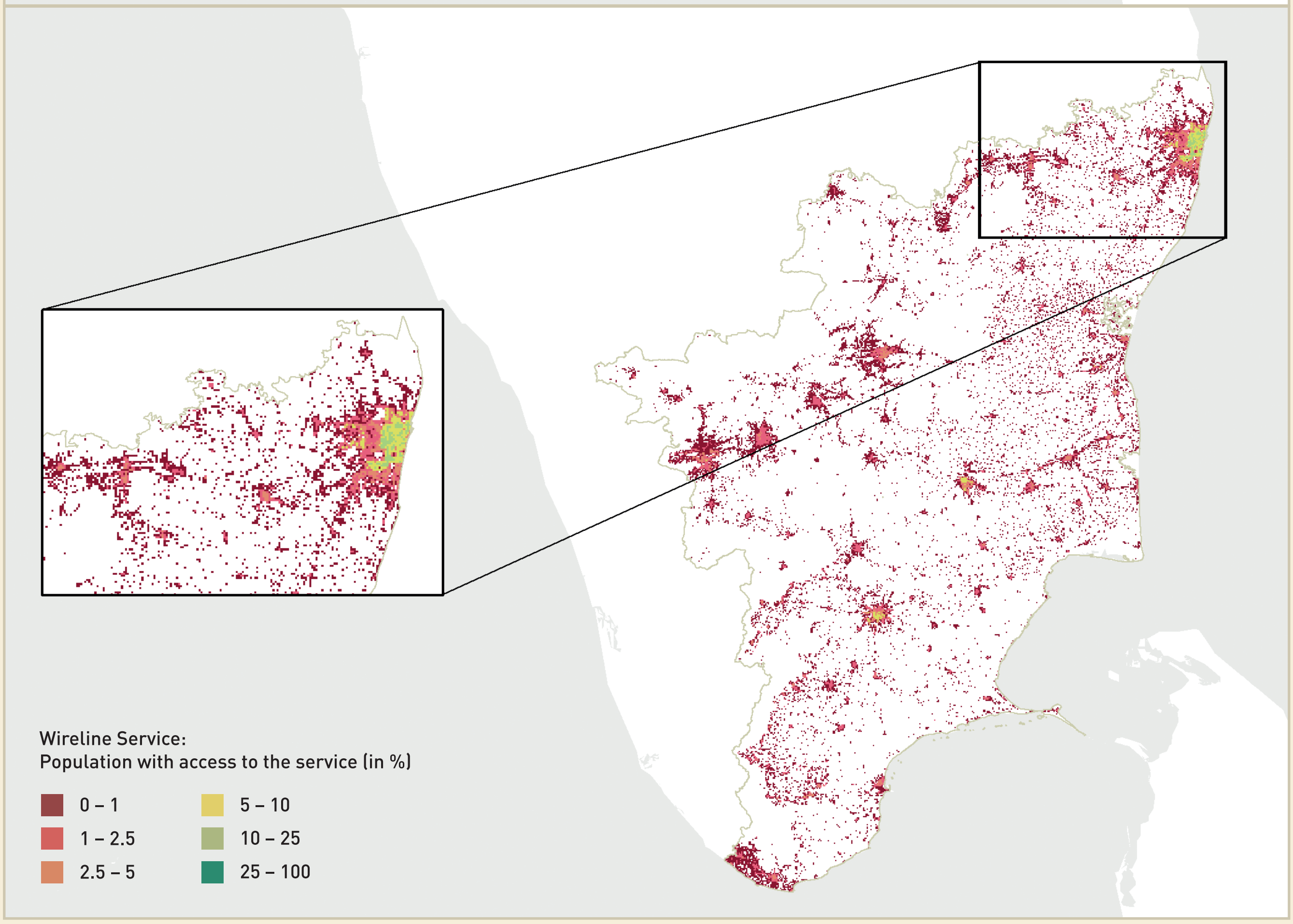
Telecommunications Infrastructure in India

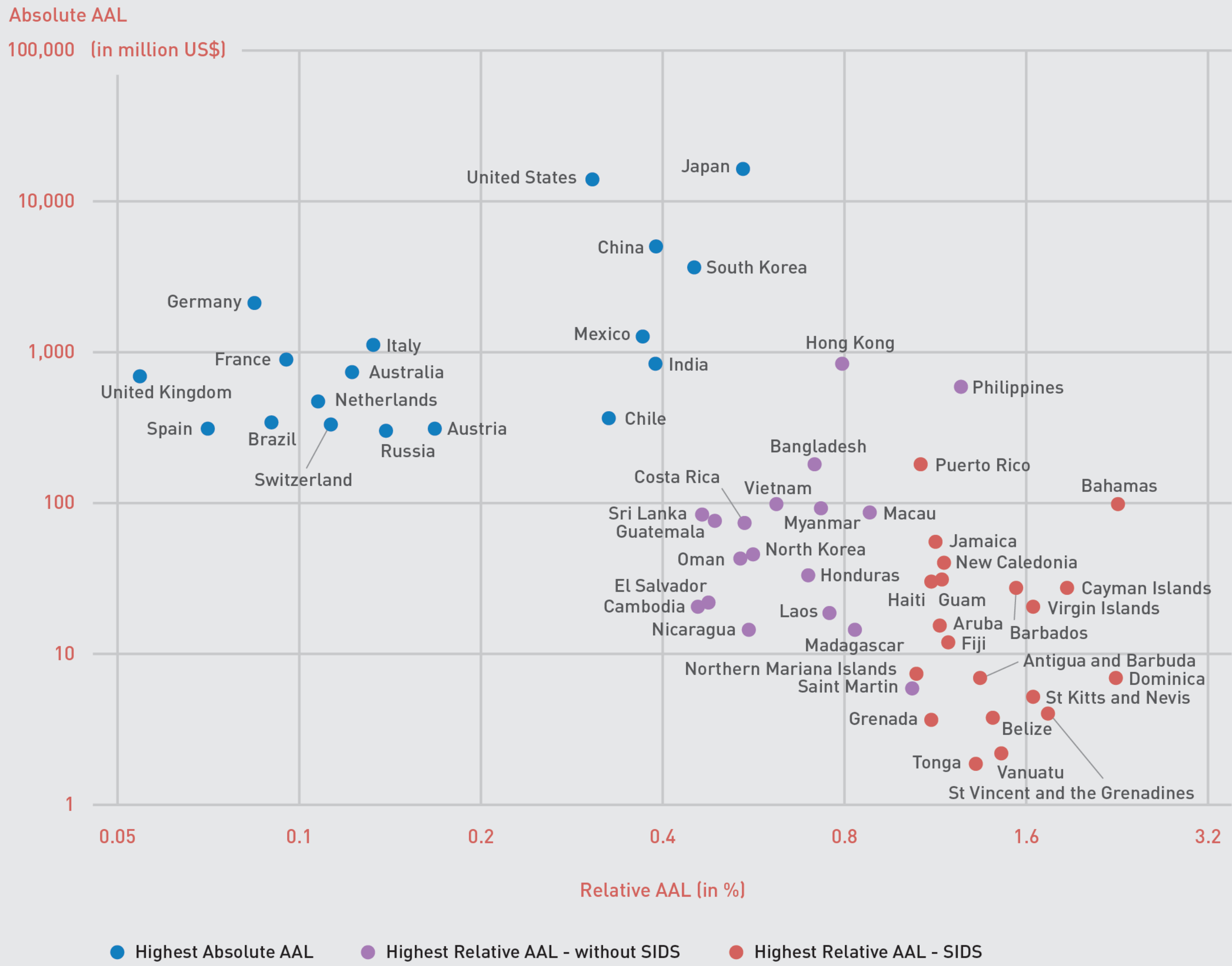
Source: Piller, T., Benvenuti, A. & De Bono, A. (2023)



2.5.3. Telecommunications







↑ FIGURE 2.26

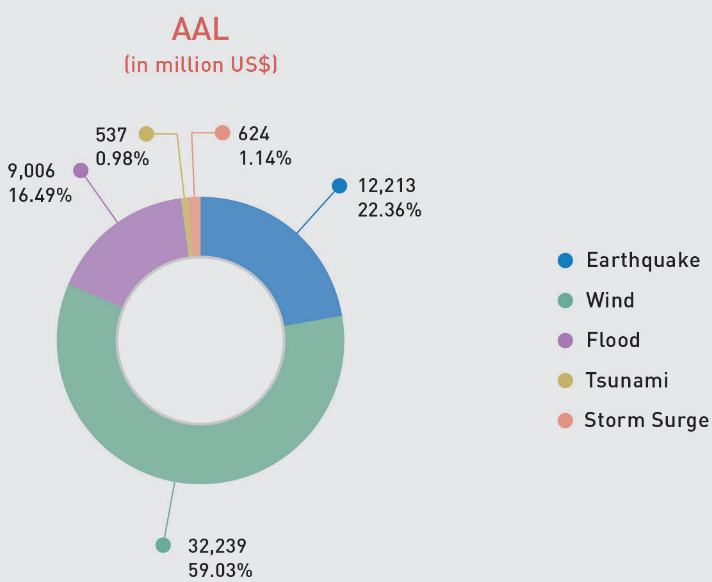
Relative and Absolute AAL for Telecommunications Sector

Source: Cardona, et al. (2023a)

→ FIGURE 2.27

Proportion of AAL by Hazard for Telecommunications Sector

Source: Cardona, et al. (2023a)

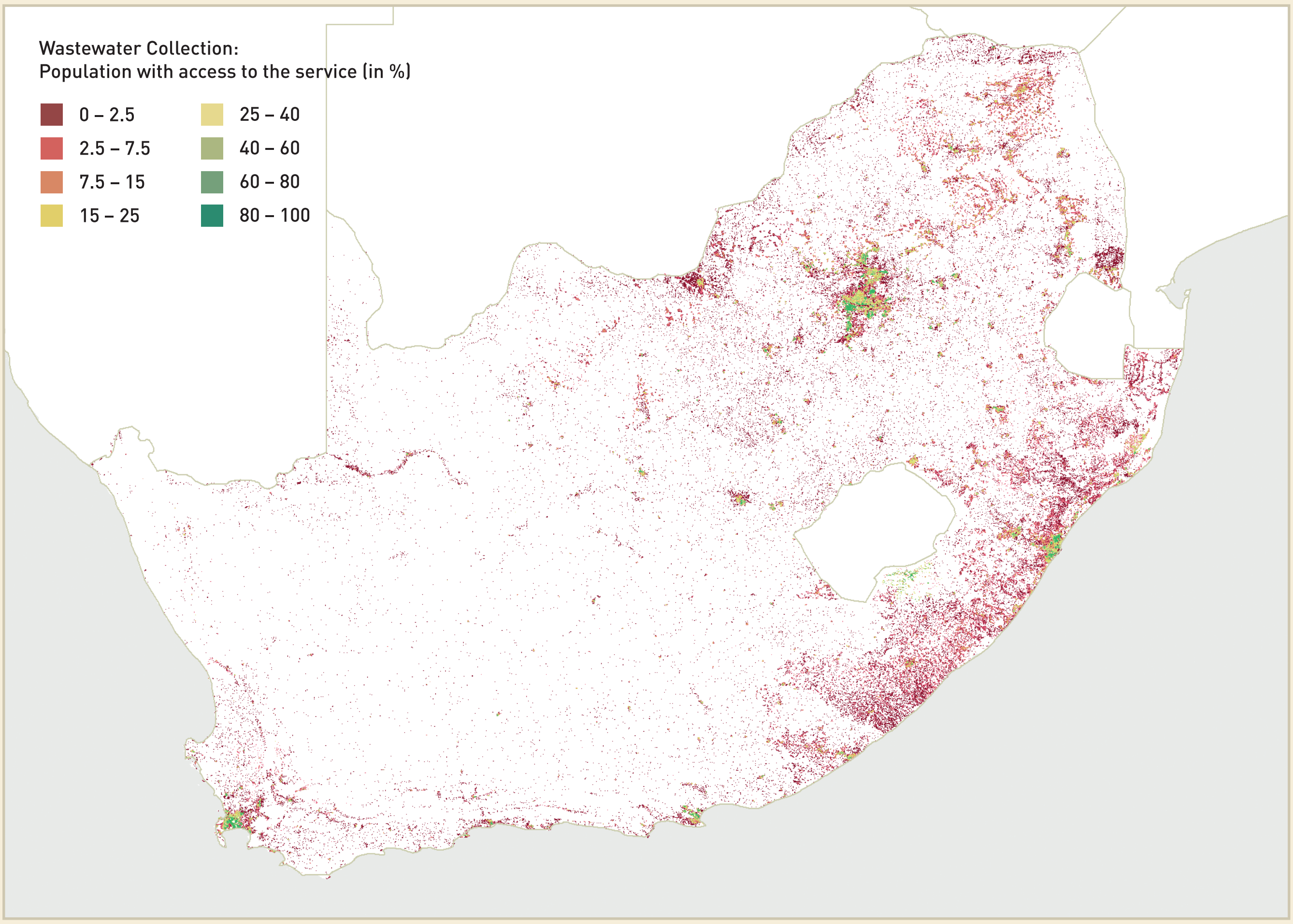


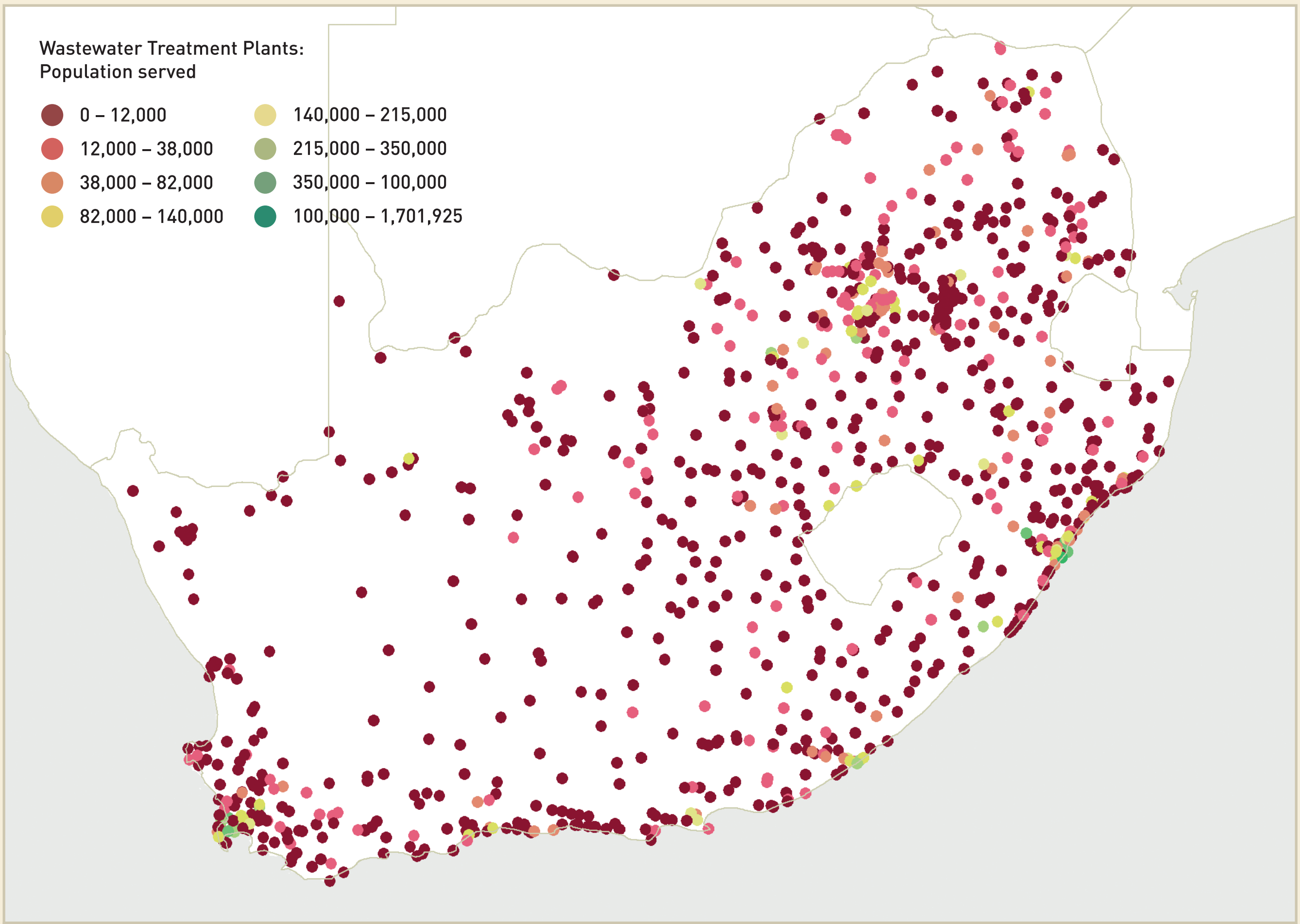
2.5.4. Water and Wastewater

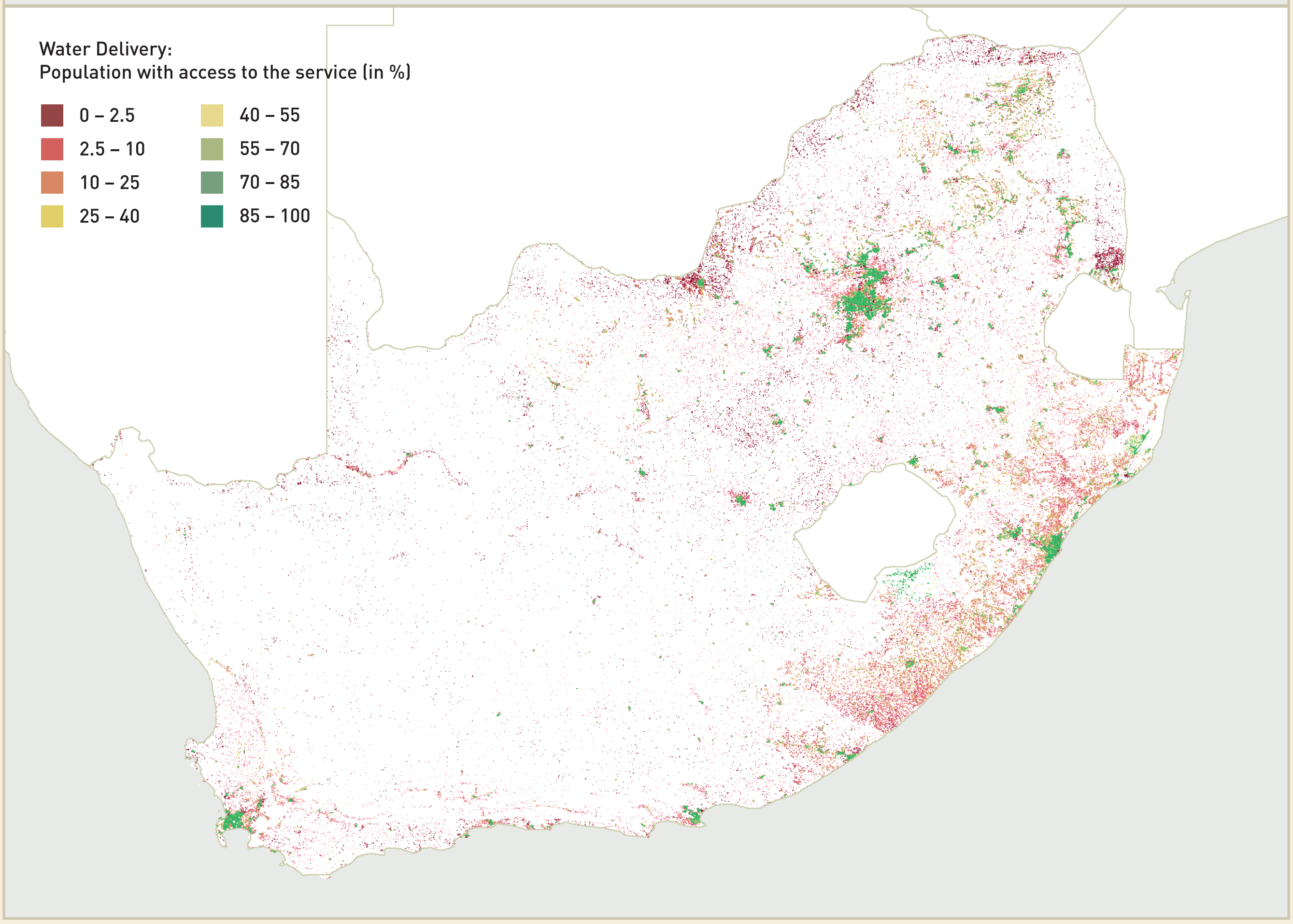
↓ FIGURE 2.28

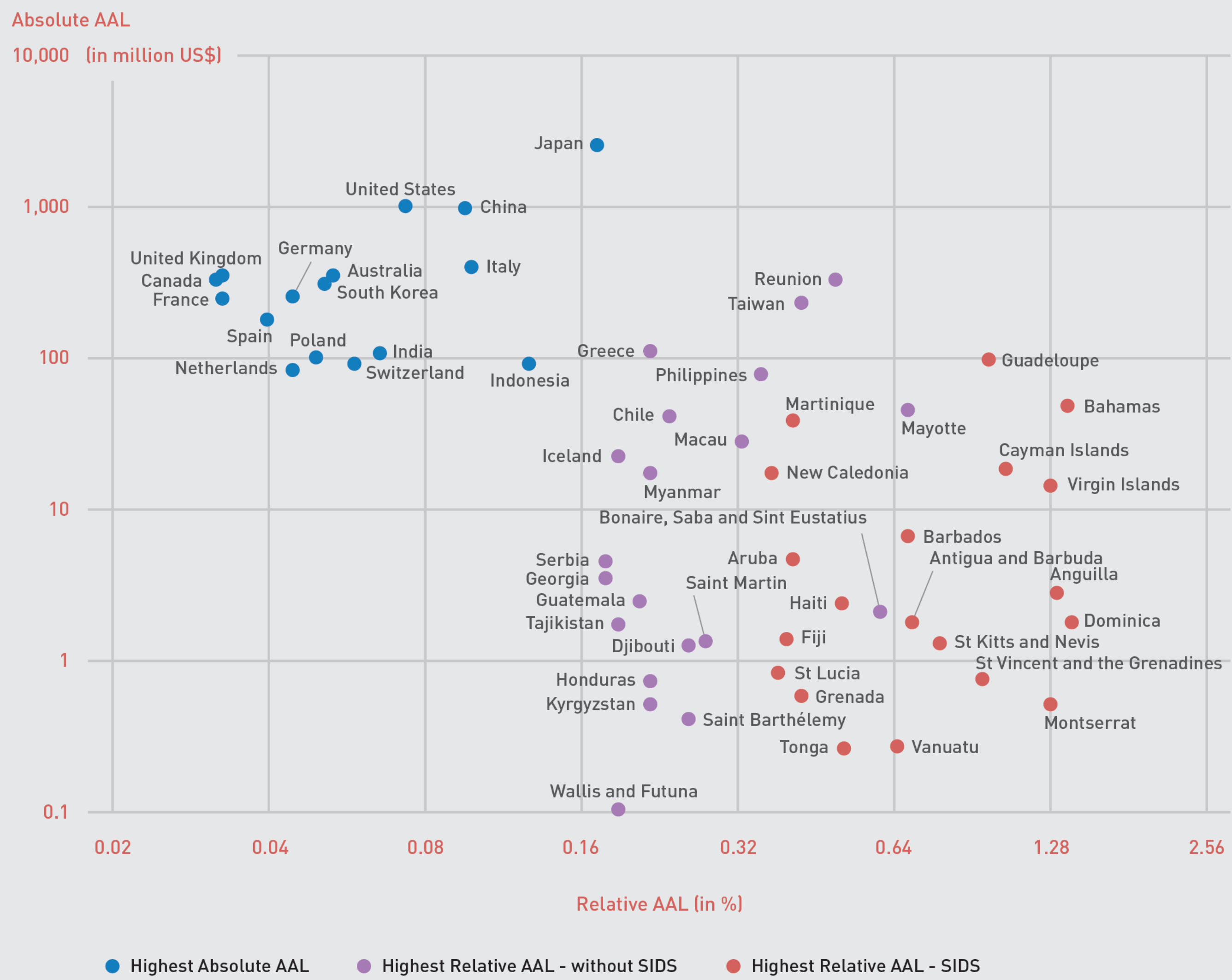
Water and Wastewater Infrastructure in South Africa

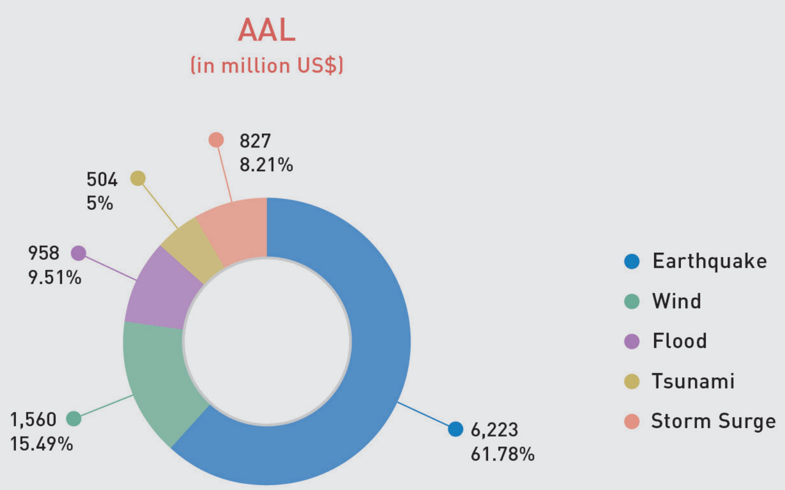
Source: Piller, T., Benvenuti, A. & De Bono, A. (2023)




Wastewater Treatment Plants:
Population served
0 – 12,000
12,000 – 38,000
38,000 – 82,000
82,000 – 140,000
140,000 – 215,000
215,000 – 350,000
350,000 – 100,000
100,000 – 1,701,925


Water Delivery:
Population with access to the service (in %)
0 – 2.5
2.5 – 10
10 – 25
25 – 40
40 – 55
55 – 70
70 – 85
85 – 100





↑ **FIGURE 2.29**

Relative and Absolute AAL for Water and Wastewater Sector

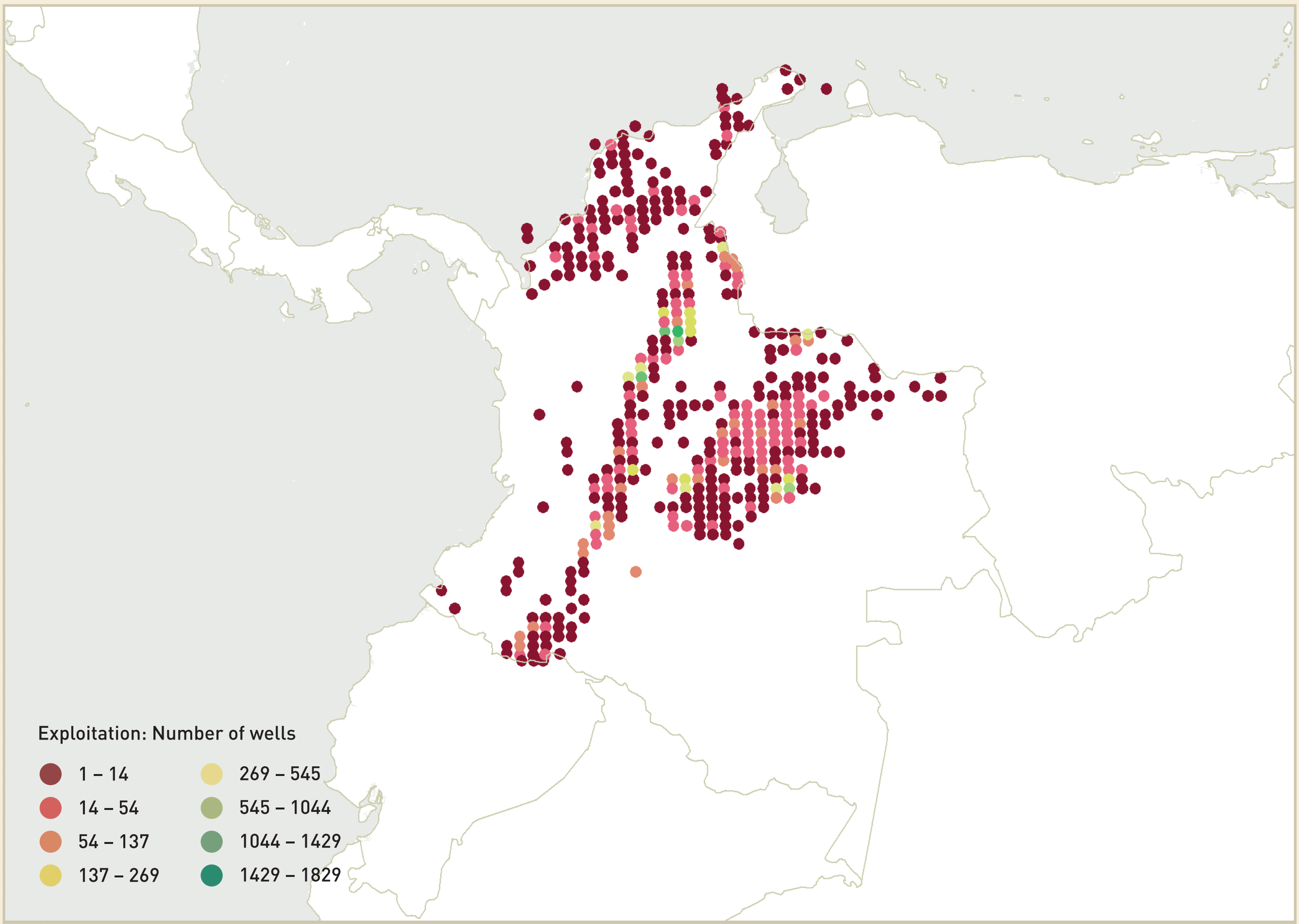
Source: Cardona, et al. (2023a)

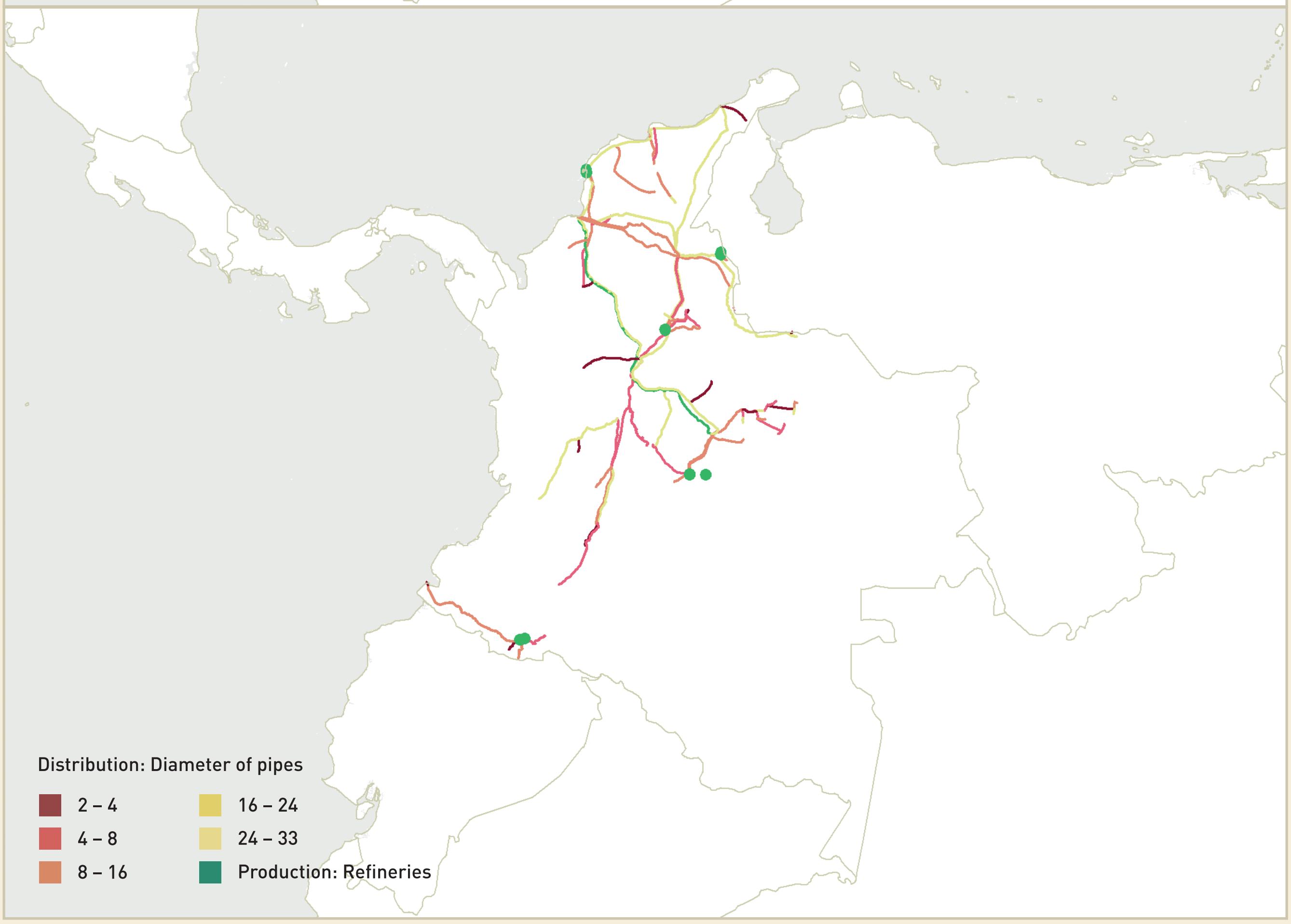
← **FIGURE 2.30**

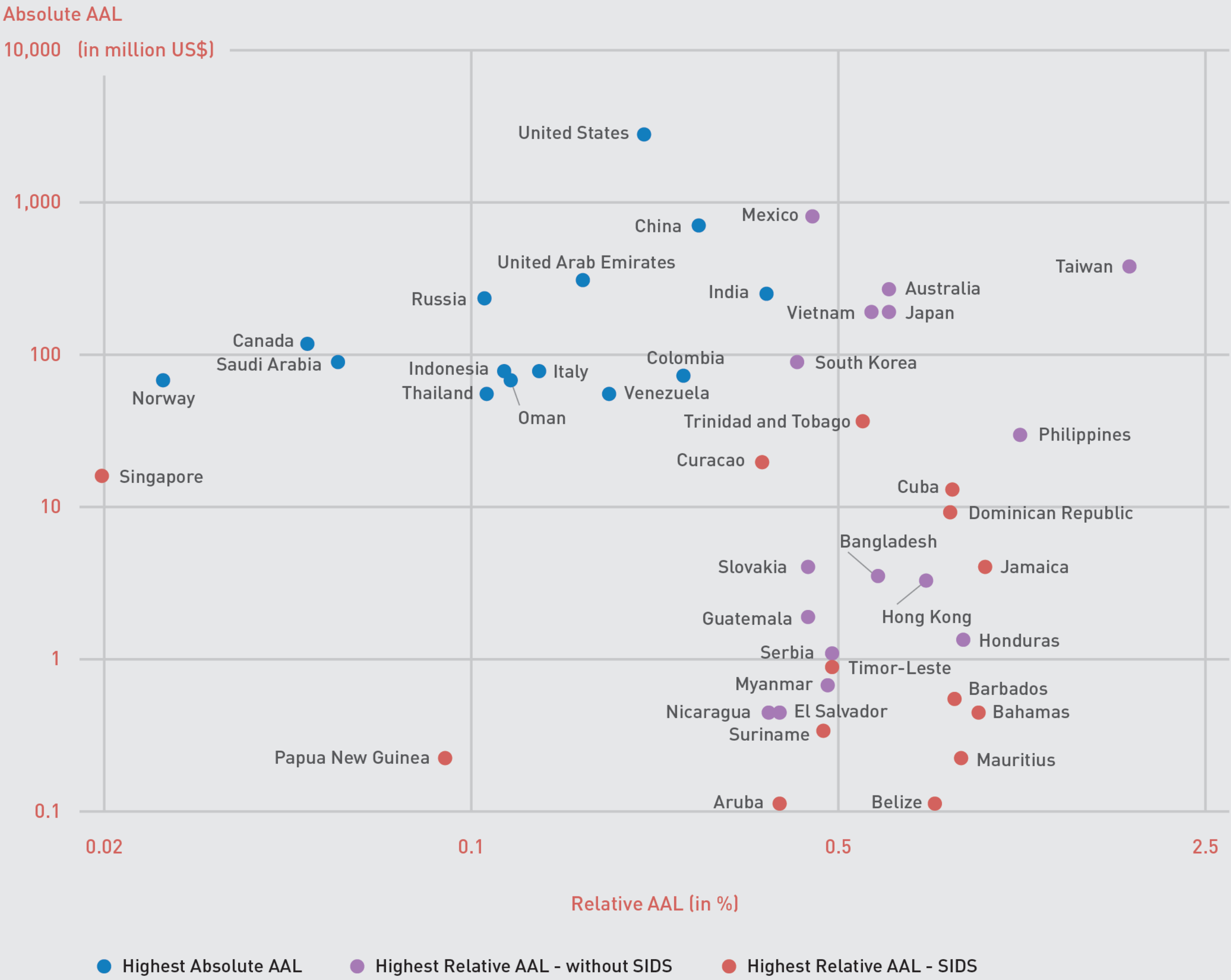
Proportion of AAL by Hazard for Water and Wastewater Sector

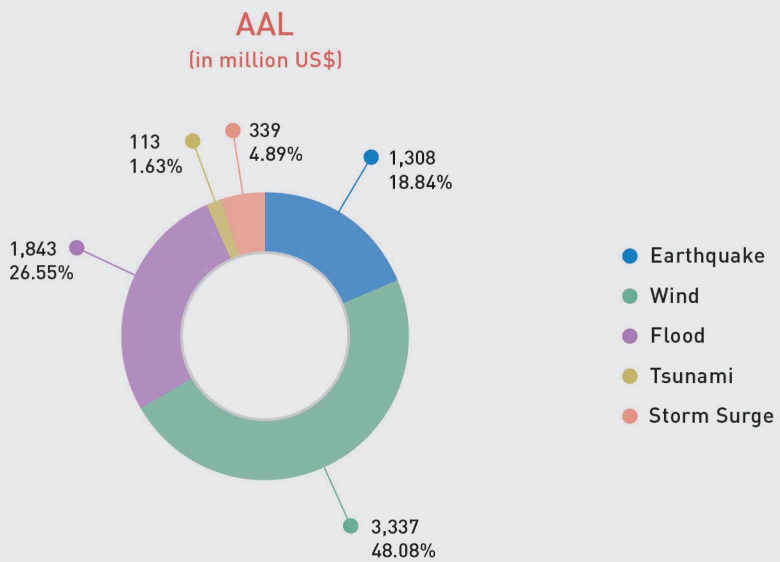
Source: Cardona, et al. (2023a)

2.5.5. Oil and Gas









↑ FIGURE 2.33

Relative and Absolute AAL for Oil and Gas Sector

Source: Cardona, et al. (2023a)

← FIGURE 2.32

Proportion of AAL by Hazard for Oil and Gas Sector

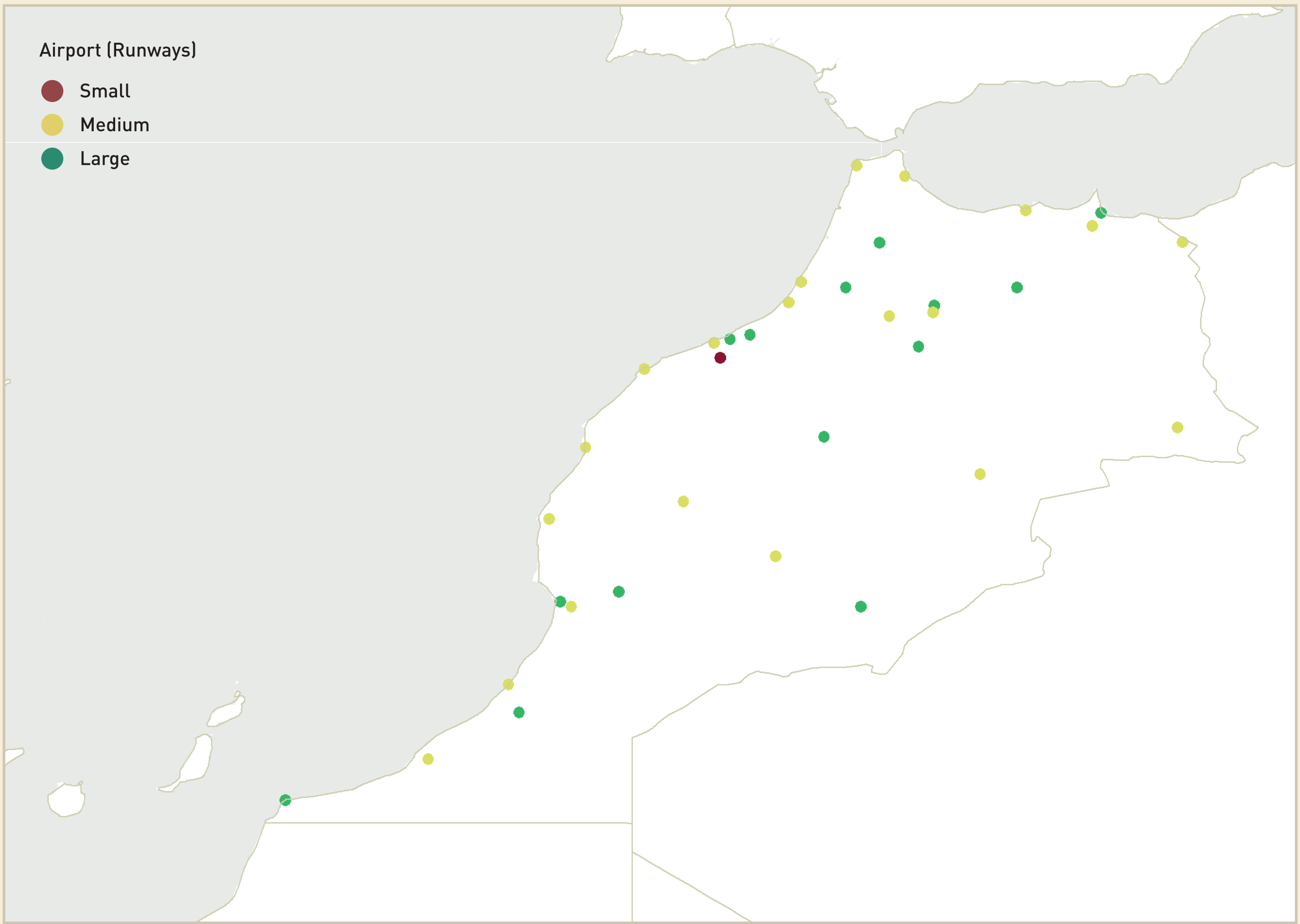
Source: Cardona, et al. (2023a)

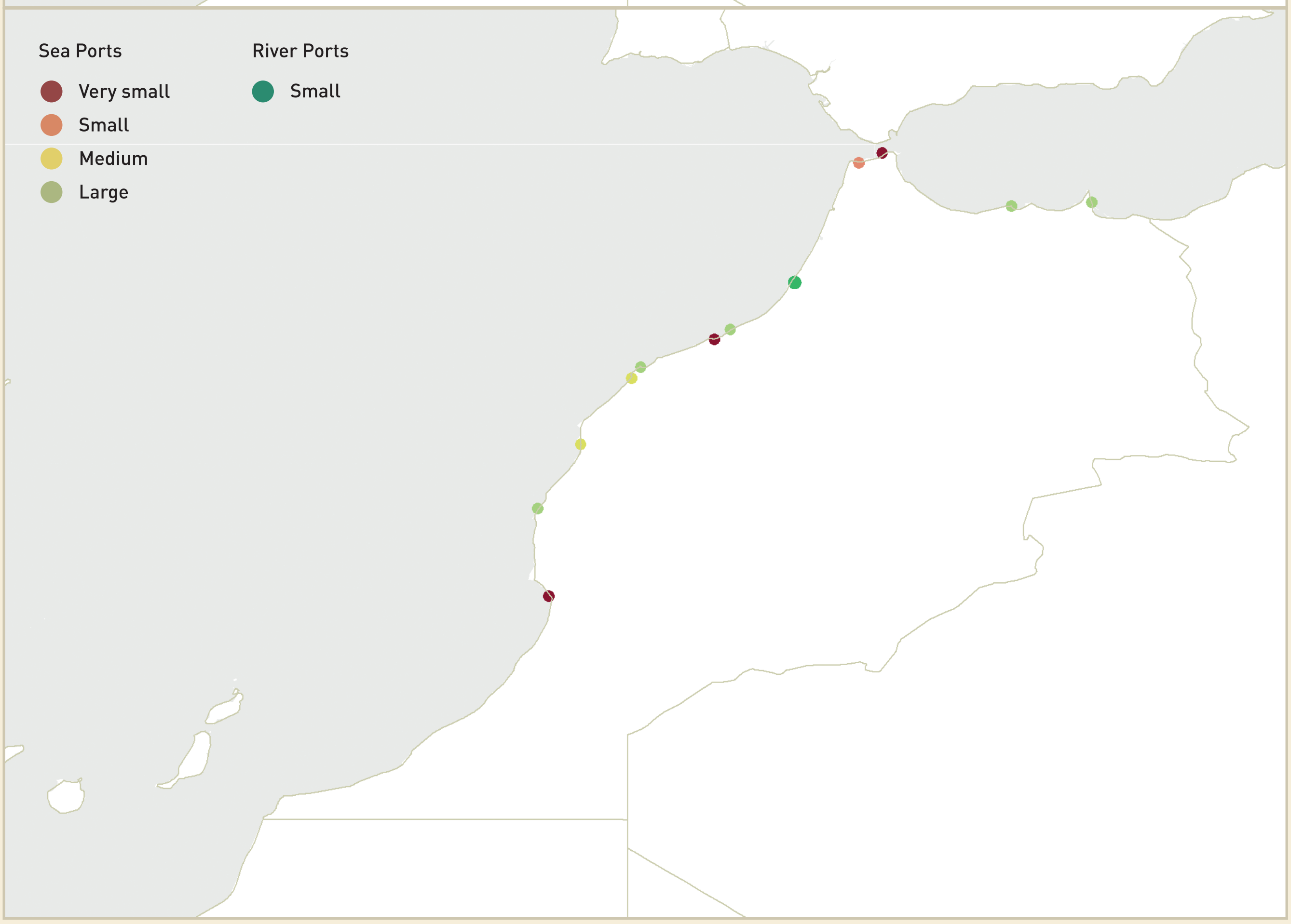
←← FIGURE 2.31

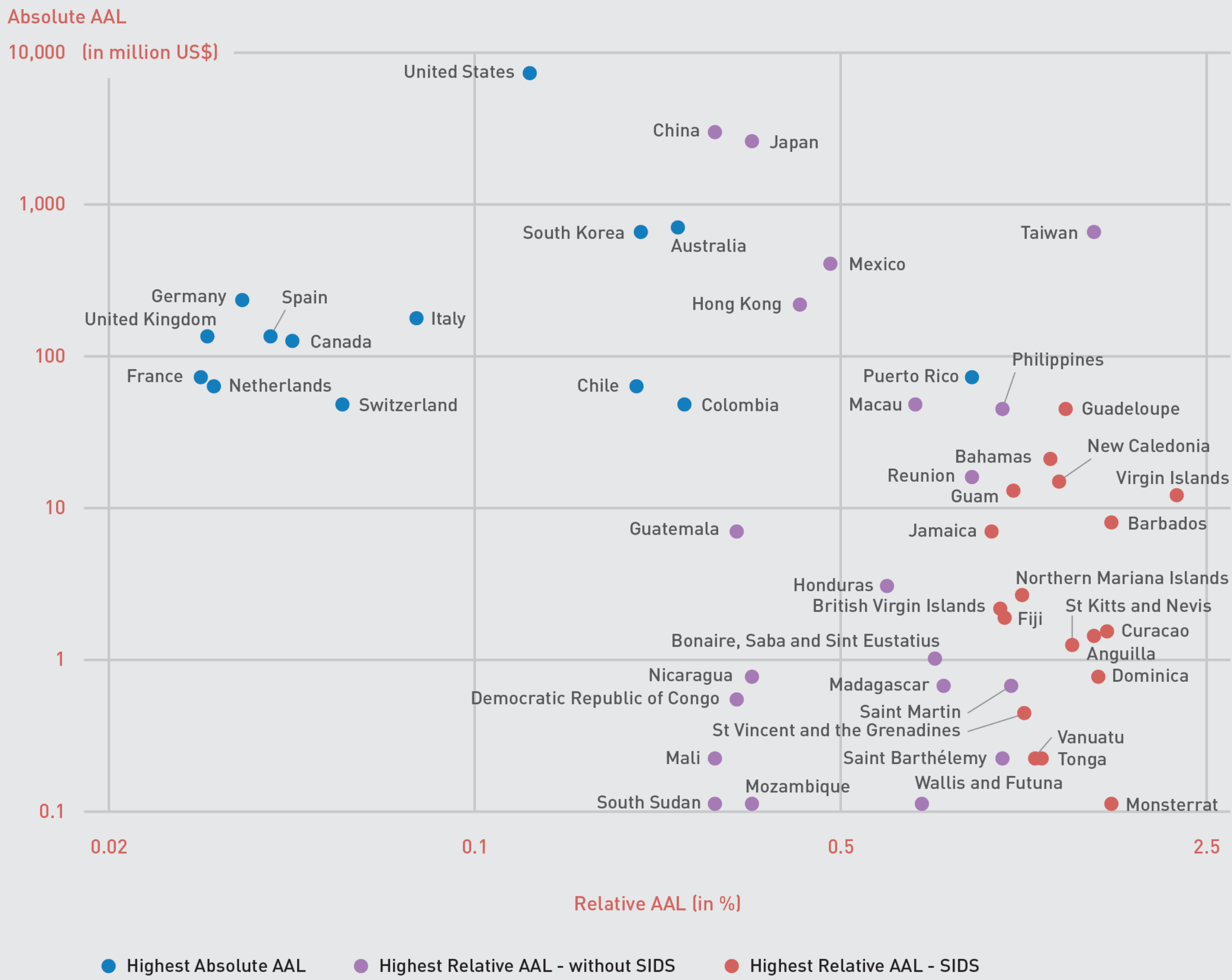
Oil and Gas Infrastructure in Colombia

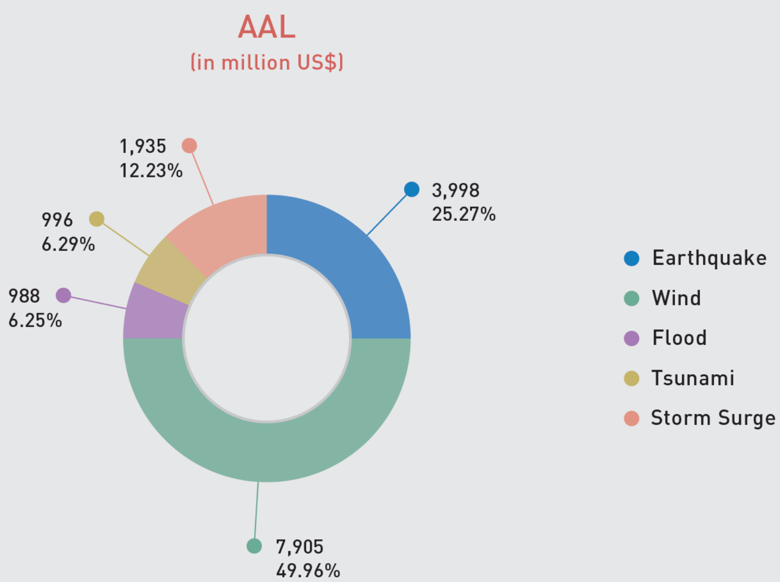
Source: Piller, T., Benvenuti, A. & De Bono, A. (2023)

2.5.6. Ports and Airports









↑ FIGURE 2.35

Relative and Absolute AAL for Ports and Airports

Source: Cardona, et al. (2023a)

← FIGURE 2.36

Proportion of AAL by Hazard for Ports and Airports

Source: Cardona, et al. (2023a)

←← FIGURE 2.34

Ports and Airports in Morocco

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

2.6. Social Infrastructure

→ FIGURE 2.37

Exposed Value, Absolute AAL and Relative AAL of Education and Health Sectors across Income Regions

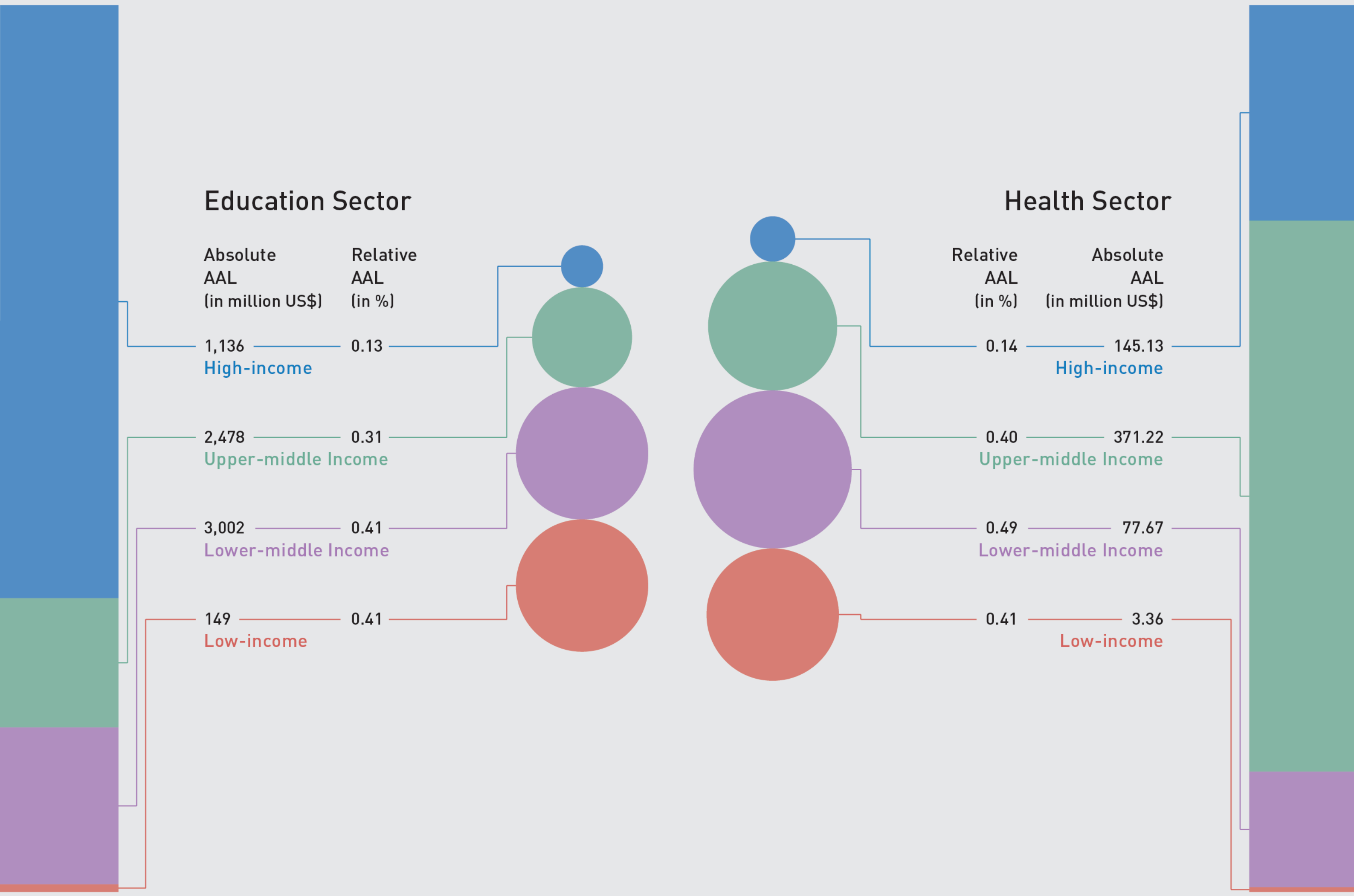
Source: Cardona, et al. (2023a)

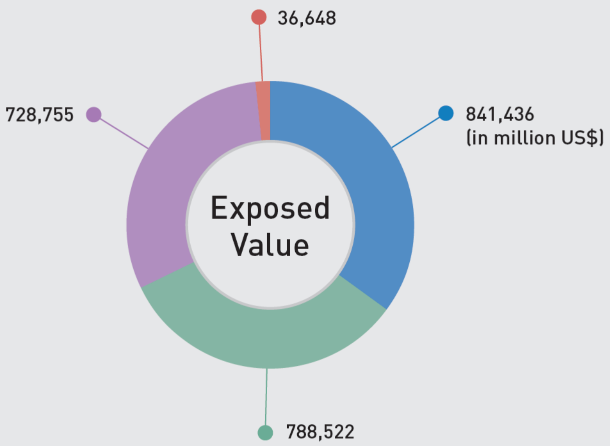
The distribution of risk across different income and regional geographies is more skewed for social infrastructure compared to other sectors.

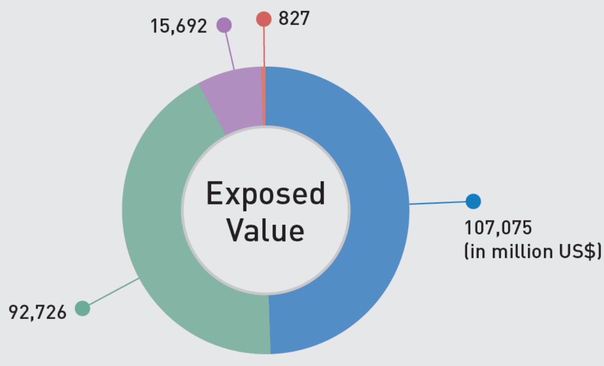
Health and education infrastructure in the form of schools, universities, hospitals, and care centres is a core pillar of a country's social and economic development. If these assets are insufficient and lack resilience, asset loss and damage will be further aggravated by the social implications of interrupted education and healthcare. This can further exacerbate gender inequality as women are likely to have severely constrained access to social infrastructure, including that which enables access to the employment market and safe childbirth.[14]

As Figure 2.37 illustrates, relative risk in low-income countries across the education and health (0.41 percent) sectors is over three times greater than high-income countries (0.13 and 0.14 percent, respectively). These figures stand at 0.41 and 0.49 percent across low-middle income countries and 0.31 and 0.4 percent for upper-middle income countries, respectively. The lack of resilience in health and education infrastructure, therefore, presents a serious challenge for LMICs, to achieve the SDGs, particularly in South Asia where relative AAL for the education and health sectors stand at 0.51 and 0.47 percent, respectively, followed by Latin America and the Caribbean with 0.35 and 0.31 percent in education and health sectors, respectively.

[14] For example, in South Korea, reliance on unpaid care labour of women poses a serious demographic and social sustainability challenge (Hong, 2019). Meanwhile, studies suggest that the impact of spending on social infrastructure in South Korea can result in a significant increase in the total non-agricultural output and employment in the short to medium term, and raises both male and female employment in the medium to long term due to increasing output (Oyvat & Onaran, 2022).







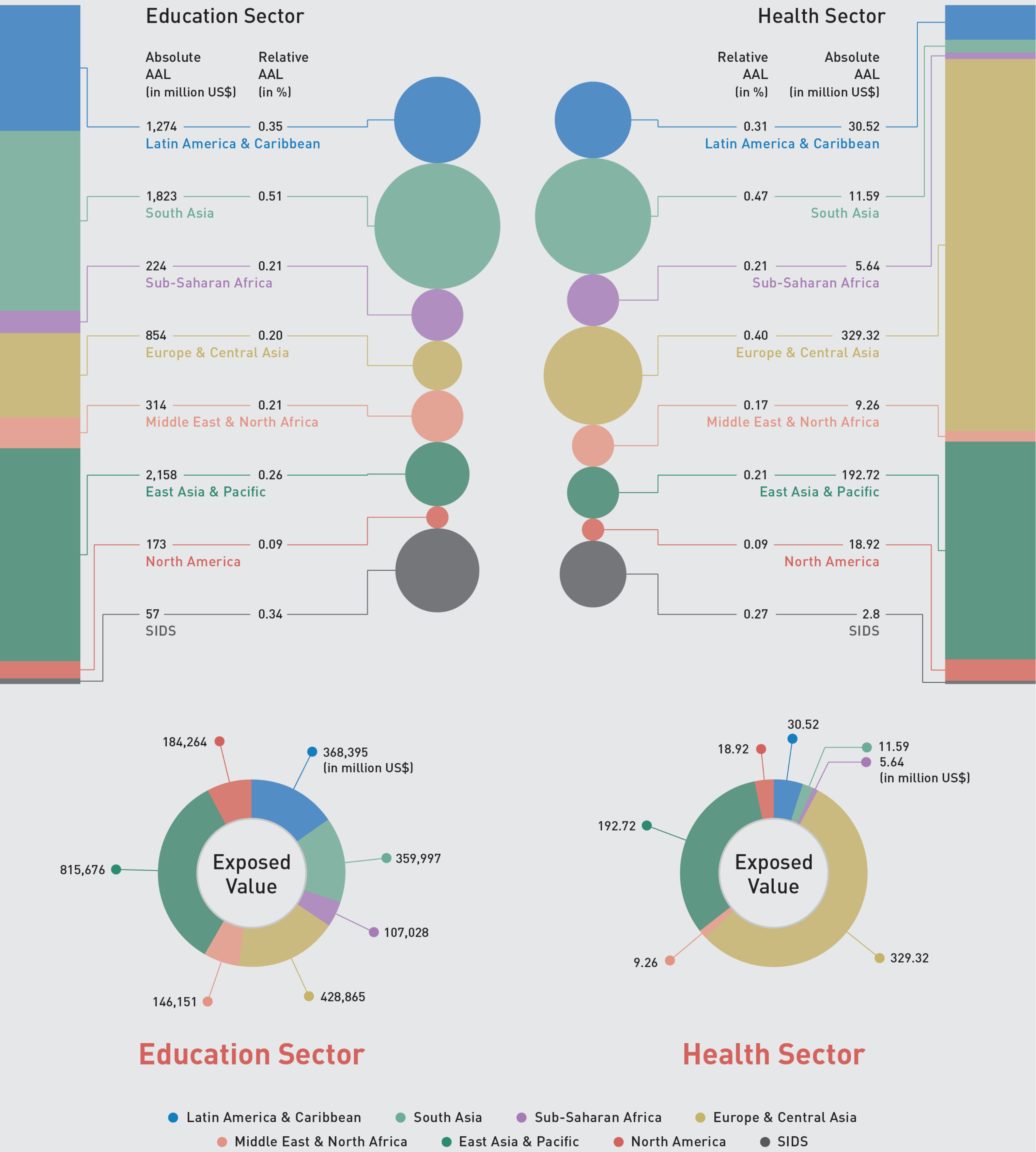
Education Sector **Health Sector**

Income Group ■ High-income ■ Upper-middle Income ■ Lower-middle Income ■ Low-income

↓ FIGURE 2.38

Exposed Value, Absolute AAL and Relative AAL for Education and Health Sectors across Geographic Regions

Source: Cardona, et al. (2023a)

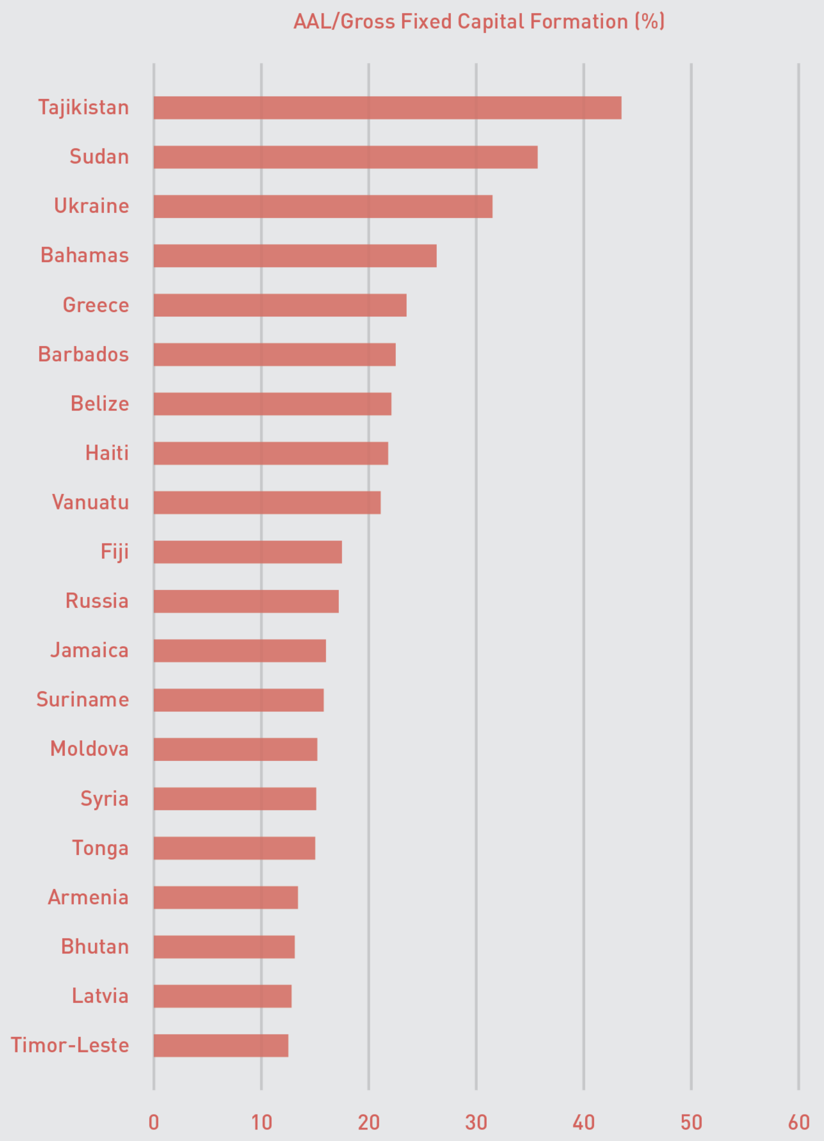


2.7. The Economic and Social Implications of Infrastructure Risk

The AAL should also be understood as an opportunity cost as fiscal resources required to cover for loss and damage could be used for new capital investment.

Infrastructure risk also has implications for fiscal resilience and social and economic development. This is particularly important for many LMICs where only a small proportion of infrastructure assets are protected by insurance or other risk financing mechanisms (Miyamoto International, 2022).

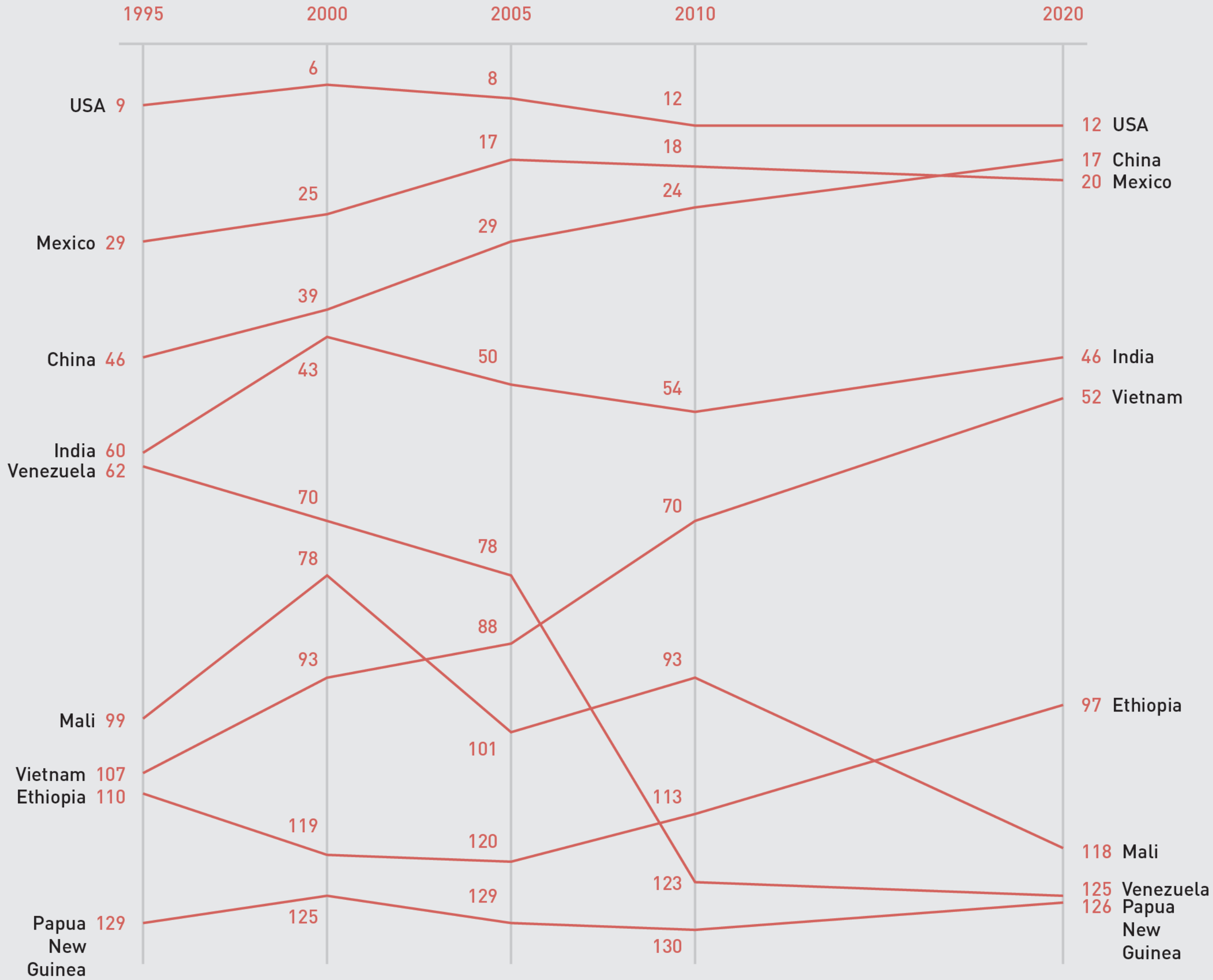
The relative AAL reflects the proportion of a country's capital stock at risk and provides an initial indicator of its economic implications. The higher the relative AAL, the greater the likelihood that resources for capital investment will have to be diverted to repairing and rehabilitating lost and damaged infrastructure. Similarly, the relative AAL is an indicator of low asset resilience, indicating a need to strengthen resilience standards.



→ **FIGURE 2.39**

Countries with a High Ratio of AAL to Capital Investment

Source: Cardona et al. (2023a)



↑ **FIGURE 2.40**

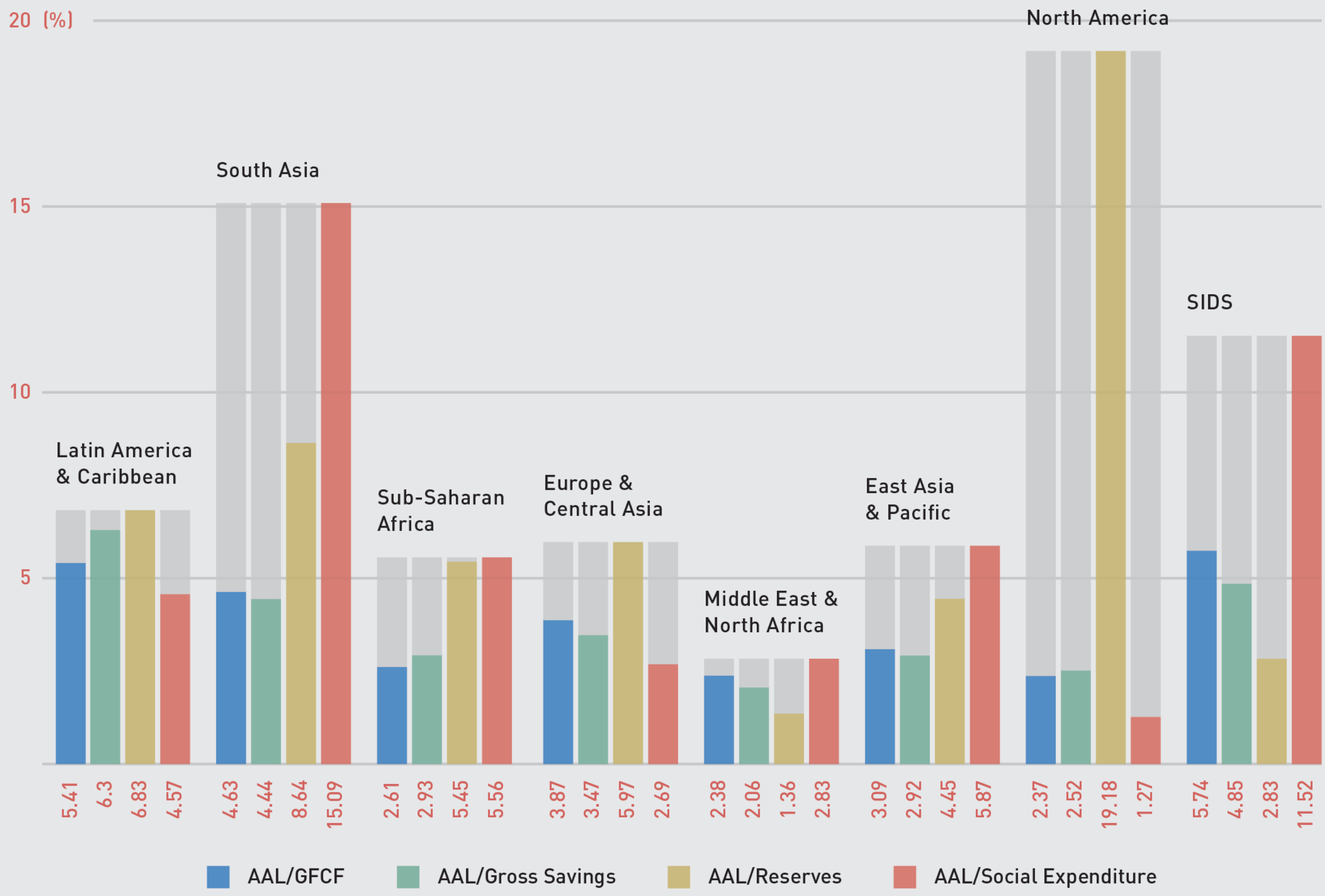
Measuring Economic Complexity and Diversity over Time for Selected Countries

Source: Economic Complexity Index, Harvard University, Growth Lab, 2023

Gross Fixed Capital Formation (GFCF) is a reasonable proxy value for capital investment in infrastructure and buildings. The higher the AAL/GFCF ratio, the lower will be the sustainability of future capital investment. High AAL/GFCF ratios are, therefore, a major handicap in countries that need to attract significant new investment to reduce their infrastructure deficit. Figures 2.39 and 2.41, respectively, compare AAL with GFCF in each income and geographical region.

Countries with very high ratios of risk to capital investment include those struggling with conflict or post-conflict fragility such as Sudan, Haiti, Syria, Ukraine, several SIDS, and countries like Bangladesh, the Philippines, and Honduras that have high absolute and relative AAL.

The relationship between AAL and savings and reserves is also key. Countries with high levels of domestic savings may be able to cover for AAL



without negatively affecting their capacity to make new investments. Fiscal stability may be threatened when the AAL represents a high proportion of reserves. Similarly, when the AAL represents a high proportion of social expenditure, countries may be challenged to increase that figure to the levels required to achieve the SDGs.

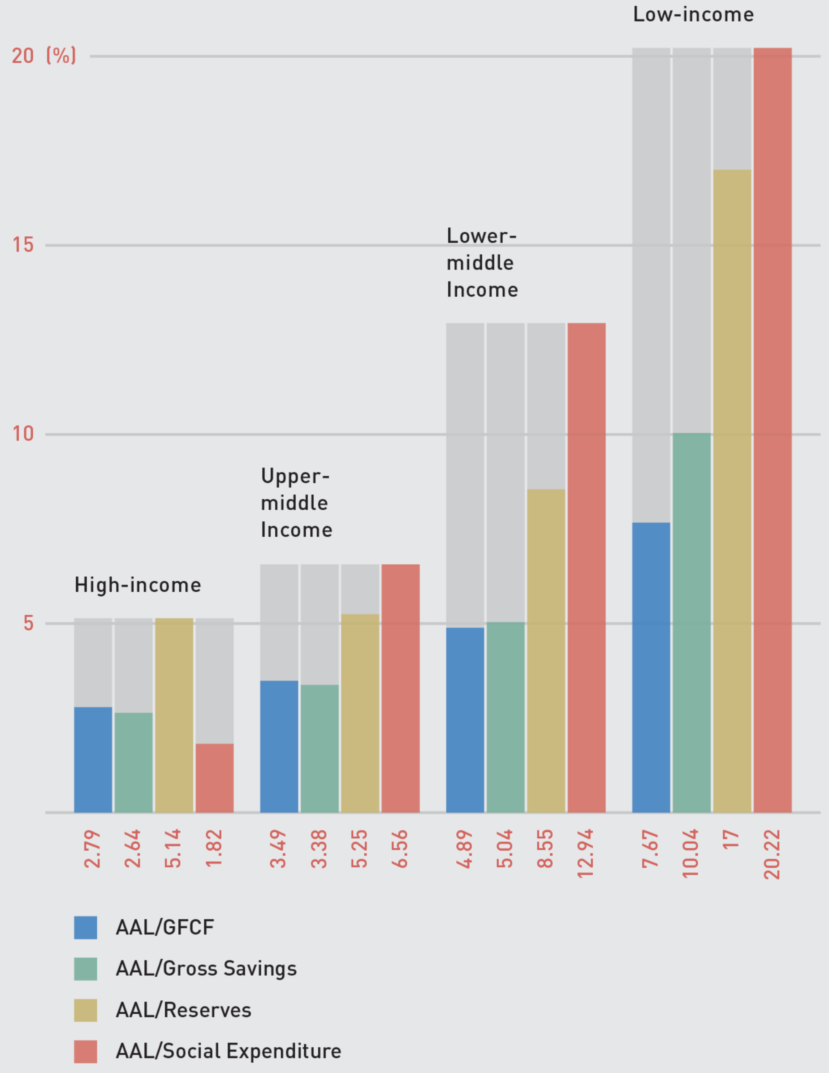
Figure 2.41 shows that each region faces different challenges with respect to their GFCF, gross savings, reserves, and social expenditure. In Latin America and the Caribbean, for example, the AAL represents a very significant proportion of GFCF, savings, and reserves. In South Asia it represents a very high proportion of social expenditure.

In countries with low levels of capital investment, even low to medium levels of risk can threaten development. In Greece, for example, the AAL /GFCF ratio is 32 percent, implying that the recovery of infrastructure assets may take years if a significant proportion of the capital stock is damaged. The size and diversity of a country's economy is also an important factor. Greater economic complexity and diversity offers a means for redundancy and flexibility useful at the time of shocks to some sectors. Figure 2.40 compares the economic diversity of some countries, where economies such as China, Mexico, and India are seen to be much more diverse as compared to smaller economies such as Papua New Guinea,

↑ **FIGURE 2.41**

AAL Relative to GFCF, Gross Savings, Reserves and Social Expenditure by Region

Source: Cardona, et al. (2023a)



↑ **FIGURE 2.42**

AAL Relative to GFCF, Gross Savings, Reserves and Social Expenditure in Income Geographies

Source: Cardona, et al. (2023a)

Mali, and Peru. **Countries with small and vulnerable economies, especially the SIDS, face far greater challenges to cover their AALs than large and diversified economies** (Fig. 2.41).

As Figure 2.42 highlights, the development implications across LMICs are generally greater than in high-income countries. Low-income countries face particularly extreme challenges as the AAL represents a high proportion of GFCF, savings, reserves, and social expenditure.

The AAL represents almost a fifth of social expenditure across low-income countries and more than 12 percent in lower middle-income countries. Constrained social budgets may be further reduced, given the need to cover for asset loss and damage, generating a downward spiral of reduced investment and increasingly precarious social services. The AAL also represents more than 15 percent of the reserves of low-income countries, compromising fiscal resilience.

2.8. Using Financial Risk Metrics to Estimate the Resilience Dividend

Financial risk metrics make the economic case for resilience as they enable governments to understand their contingent liabilities and identify sectors or territories of concern. Understanding contingent liability is an essential step towards measuring the fiscal risk internalized in infrastructure systems, generating a political and economic incentive for strengthening resilience and reducing uncertainty for potential investors. In Barbados, for example, the GIRI highlights that contingent liabilities from all hazards represent around 34 percent of the country's GFCF. Unless resilience is strengthened, as stated in Chapter 1, new infrastructure investment would be analogous to pouring water into a bamboo basket.

Risk identification can also guide land use planning, determining hazard-exposed areas, where either no new infrastructure should be located, or where the costs of ensuring adequate asset resilience would be too high to justify the services provided by the infrastructure. By estimating the costs of achieving different levels of resilience, and the benefits associated with the resilience dividend, risk estimation can stimulate a transparent debate on the level of resilience that is most cost-effective and feasible.

The GIRI, when replicated at a higher resolution, can be used to test different strategies to strengthen resilience. Any strategy has the possibility to increase or decrease the AAL with a given level of capital and operating expenditure. This can help estimate the value of the full range of other resilience benefits, for example, improvements in water supply or quality, enhanced local economic development and others, and aid in the selection of an appropriate strategy.

In the case of Colombia, Boxes 2.2 and 2.3 illustrate how financial risk metrics were used to assist governments in understanding their contingent liabilities, estimate the resilience dividend, and select the most appropriate strategies.

Financial risk metrics were used to quantify the resilience dividend accruing not only from reduced asset loss and damage but also reduced service disruptions. Box 2.4 examines the resilience dividend that could be captured by strengthening the resilience of East Africa's roads and railways.

→ **BOX 2.2**

E2050 Strategy Colombia – Adaptation Measures for a More Resilient Main Road Network

Source: Cardona et al., (2020); Eslamian & Eslamian, (2022)

Colombia's E2050 Strategy aims to establish a carbon-neutral and climate-resilient economy. Guided by principles of mitigation, adaptation, and climate risk, the national policy prioritizes meeting goals for 2022, 2030, and SDG compliance. Efficient measures within limited resources are sought to achieve these objectives, considering risk reduction and implementation costs. Assessing the impact of climate change is crucial, starting with identifying risk in various territories and sectors. As part of E2050, a probabilistic analysis evaluated landslide disaster risk on the main road network, including risk exacerbated by climate change (Table 2.1).

The upper and lower climate bounds are associated with scenarios of GHG emissions by 2050. The upper bound represents a high emissions scenario, under which far less rainfall is expected. As such, the risk associated with rainfall-triggered landslides will also be lower, exemplifying what is sometimes a non-linear relationship between emissions and risk.

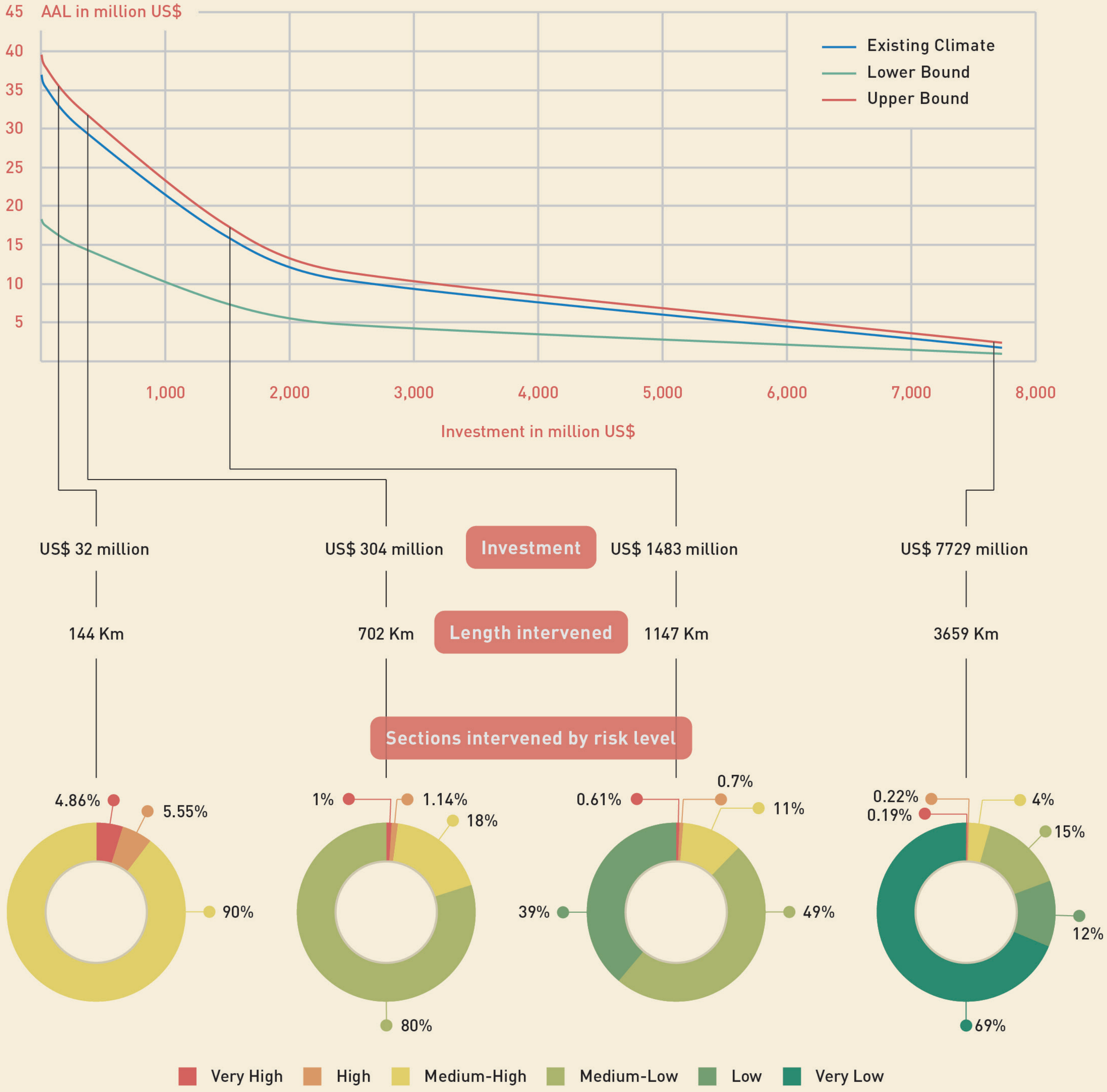
The Risk Control Engineering methodology identifies adaptation strategies for mitigating landslide risk in the main road network. As Figure 2.43 illustrates, these strategies are implemented gradually with intervention levels established to assess their effectiveness in reducing risk, measured by the AAL. Interventions can vary from small-scale to larger and costlier approaches. Evaluating the costs of each strategy helps determine the practical limit of adaptation where further investments yield diminishing risk reductions. Reaching the maximum feasible adaptation level makes the impact of climate change less visible. The remaining loss represents residual risk that cannot be mitigated by the considered measures.

In general, it is not possible to affirm that one measure is more appropriate than another without incorporating the context, technical and political feasibility, and institutional execution capacity, among other factors. The costs of implementing different adaptation measures are average yet indicative estimates of the real values that are used to establish an order of magnitude of the investment required in adaptation.

Risk results due to landslides			Exposed value (million US$): 37,615					
Climate	Average Annual Loss		Probable Maximum Loss 250 years		Probable Maximum Loss 500 years		Probable Maximum Loss 1000 years	
	Million US$	%	Million US$	%	Million US$	%	Million US$	%
Existing climate	36.9	0.98	609.22	1.62	698.57	1.86	744.6	1.98
Lower bound of climate change	39.54	1.05	647.12	1.72	720.23	1.91	809.58	2.15
Upper bound of climate change	18.27	0.49	360.11	0.96	546.94	1.45	663.37	1.76

↑ **TABLE 2.1**

Landslide Risk Results for Colombia's Main Road Network



↑ **FIGURE 2.43**

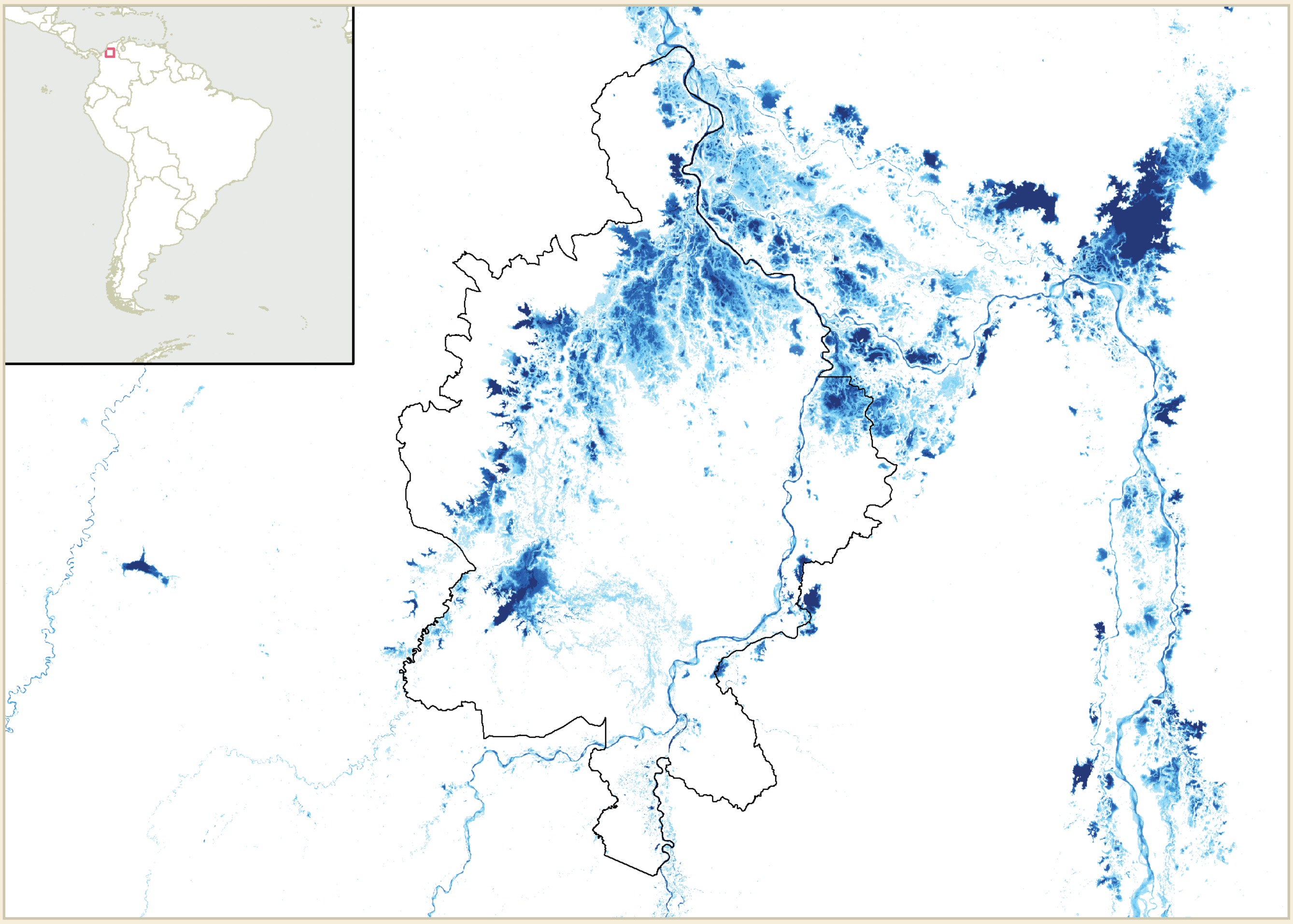
Variation of the AAL as a Function of the Amount of Adaptation Investment for the Main Road Network

Source: Cardona, O.D., et al. (2020)

↓ **BOX 2.3**

Ecosystem-Based Adaptation and Flood Risk Reduction in La Mojana Region: Recommendations Based on Probabilistic and Holistic Risk Assessment

Source: Cardona et al., (2017); CONPES, (2022)



↑ **FIGURE 2.44**

La Mojana Region Flood Risk Map

Source: Sarmiento (2021)

La Mojana region, with a population of 400,000 in the northwest of Colombia, covers a vast alluvial delta of approximately 1,089,200 hectares, formed by the convergence of three major rivers. The wetlands are vital in regulating river flow, mitigating flood hazard, and maintaining the ecological balance. Poverty affects 83.3 percent of the population.

The region faces increasing risk due to the construction of inappropriate drainage and protective infrastructure that provides the population with a false sense of security. Physical risks associated with flood hazard in La Mojana was estimated using a probabilistic methodology.[15] Similarly, the costs and benefits of a range of strategies were assessed to reduce the risk, ranging from no intervention at all (No. 1), reinforcing the existing dyke (No. 2), reinforcing and extending other dykes (No. 3), reinforcing the existing dyke but with bypass structures that allowed water to flow from one water body to another (No. 4), and constructing a parallel dyke with floodgates (No. 5).

[15] Developed by INGENIAR for the Colombian Adaptation Fund (Fondo Adaptación)

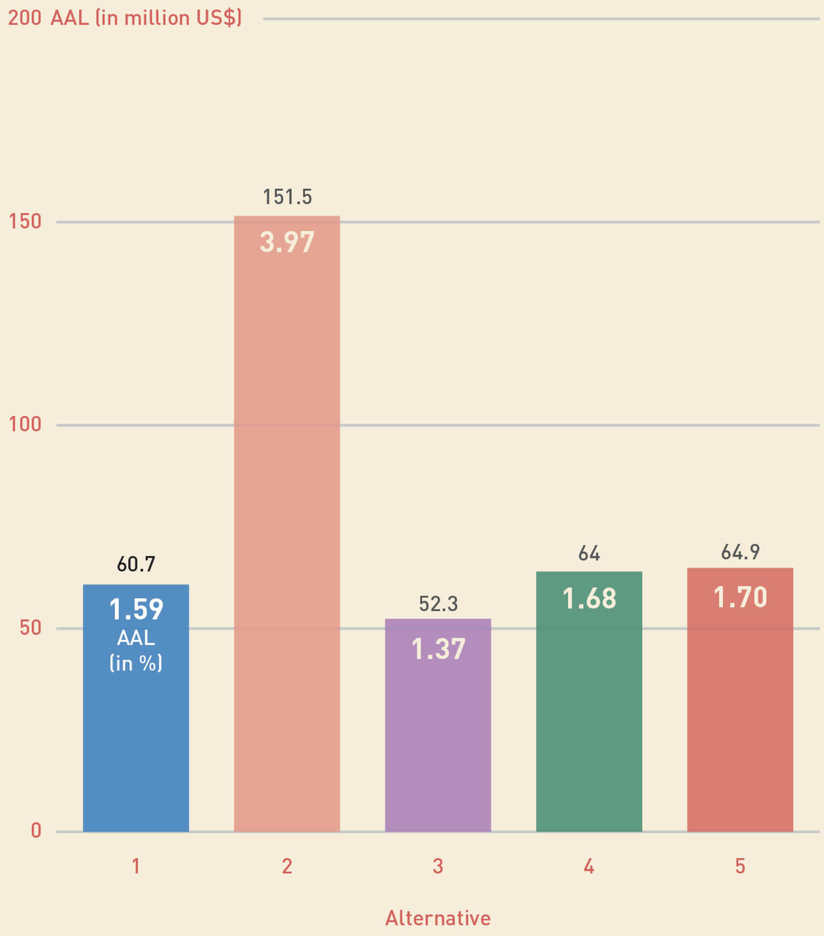


FIGURE 2.45

Cost of Strategy

Source: Cardona, O.D., et al (2017)

Figure 2.45 shows the cost of each strategy and how they would modify the AAL. No. 2 was the most expensive strategy with the highest resulting AAL while strategies 3, 4, or 5 did not offer any significant advantages.

Strategies were also examined to reduce exposure and vulnerability by (1) constructing protective walls around the towns, building health centres, and schools, and promoting productive and environmental projects, and (2) raising rural houses on stilts and improving natural drainage channels. Each intervention had a different cost and considered different sets of municipalities and adaptation combinations.

These strategies were compared with respect to their benefit/cost ratios with 10 of the best and most effective selected and compared in terms of risk, social, and ecosystem benefits, and the net resilience dividend with the full community's involvement. Ultimately, a series of non-structural measures, including NbIS, were chosen to address the underlying drivers of vulnerability and risk with a total investment of $580 million.

→ **BOX 2.4**

Flood Risks and Adaptation of Long-Distance Transport Links in East Africa

Source: Pant, Jaramillo & Hall (2023), Hickford et al. (2023)

Long-distance road and rail networks across Kenya, Tanzania, Uganda, and Zambia are vital for underpinning trade flows that sustain economic growth. Major transport infrastructure investments in recent years have reinforced the role of these countries as gateways to growing domestic markets in Africa (Horvat et al., 2020).

However, extreme floods repeatedly cause infrastructure damage and disruption. About three-quarters of all counties in Kenya experienced flooding in 2020 (Makena et al., 2021) whereas climate hazards in Tanzania have cost the country about one percent of their GDP (Erman et al., 2019). Rising water levels of Lake Victoria in Uganda have destroyed roads and flooded homes and businesses (Brown, 2020), while flooding in Zambia in 2023 disrupted transport access for several communities (Davies, 2023).

Social and economic development in East Africa is contingent on resilient long-distance transport networks. It is vital, therefore, to estimate climate risk and propose resilience outcomes. A recent study estimated extreme riverine flood risks and climate adaptation options spatially across long-distance road and rail links across the four countries, looking at the exposure of rail and road networks to flooding in the present with futuristic projections; the extent of direct physical flood-induced damage to the transport network; losses and the wider economic impact of infrastructure failures; identifying quantifiable climate resilience adaptation options for infrastructure assets; and proposing priority network locations for intervention (Hickford et al., 2023).

According to the study, asset risk for road and rail assets in the four countries would grow from an AAL of $41 million per year to about $82 to $131 million per year by 2080 with climate change due to an increasing frequency of more extreme floods. Further, road and railway assets designed for historical flooding would not be resilient to future extremes, increasing indirect risk to trade flows due to disruptions of key transport linkages from $0.16 million to about $4.2 million per day by 2080.

The study put forward a compelling case for investing in strengthening asset resilience, showing that the benefits far outweighed investments required until 2080. Strengthening resilience of the 20 roads and railway lines in the region with the highest flood risk would cost $9 million and $92 million, respectively, but would avoid losses as high as $875 million and $234 million across future climate scenarios.[16]

The visual in Figure 2.46 shows growing risks from the baseline (2010) to the future (2080) to direct damages and indirect economic losses for a road link exposed to river flooding modelled under future RCP 4.5 and RCP 8.5 climate scenarios.

[16] The outputs of the study have been made available through an open-access web-portal accessible at: https://east-africa.infrastructureresilience.org/. Results of this study are being used to inform stakeholders in Kenya about the risks to new road highway projects being planned in the country.

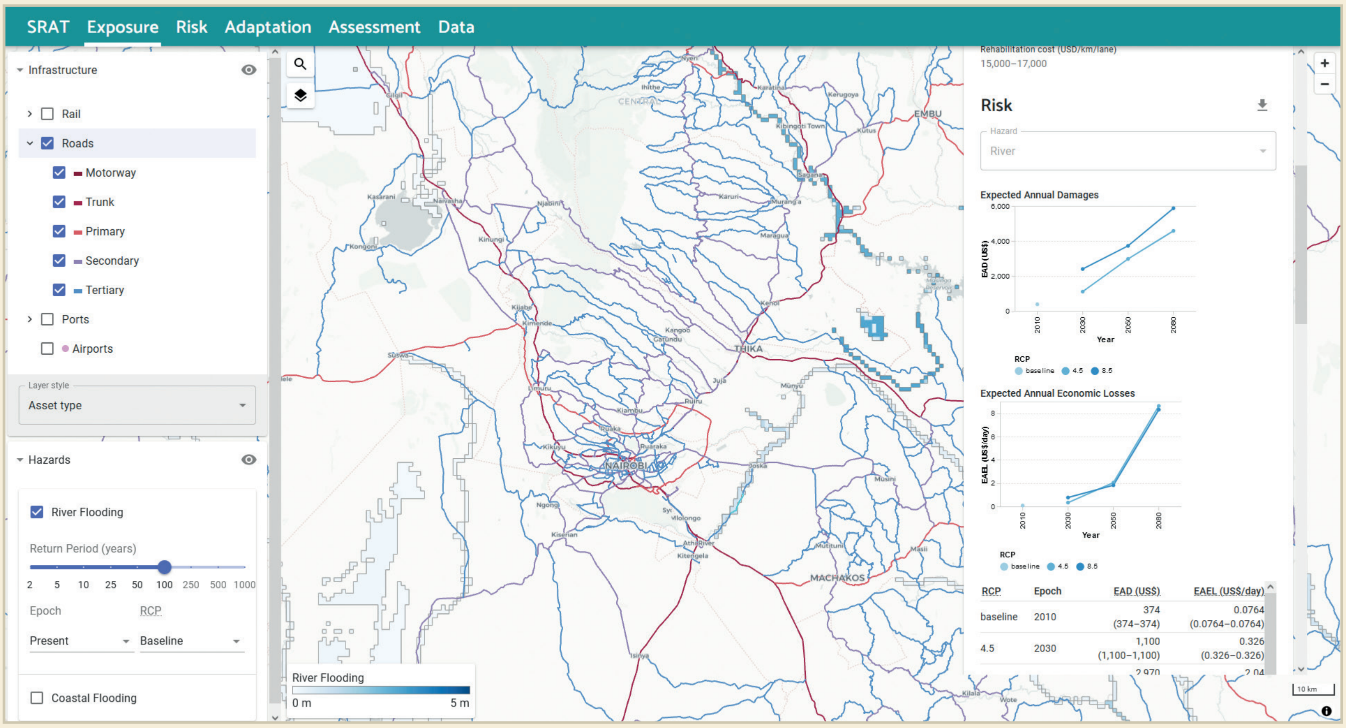


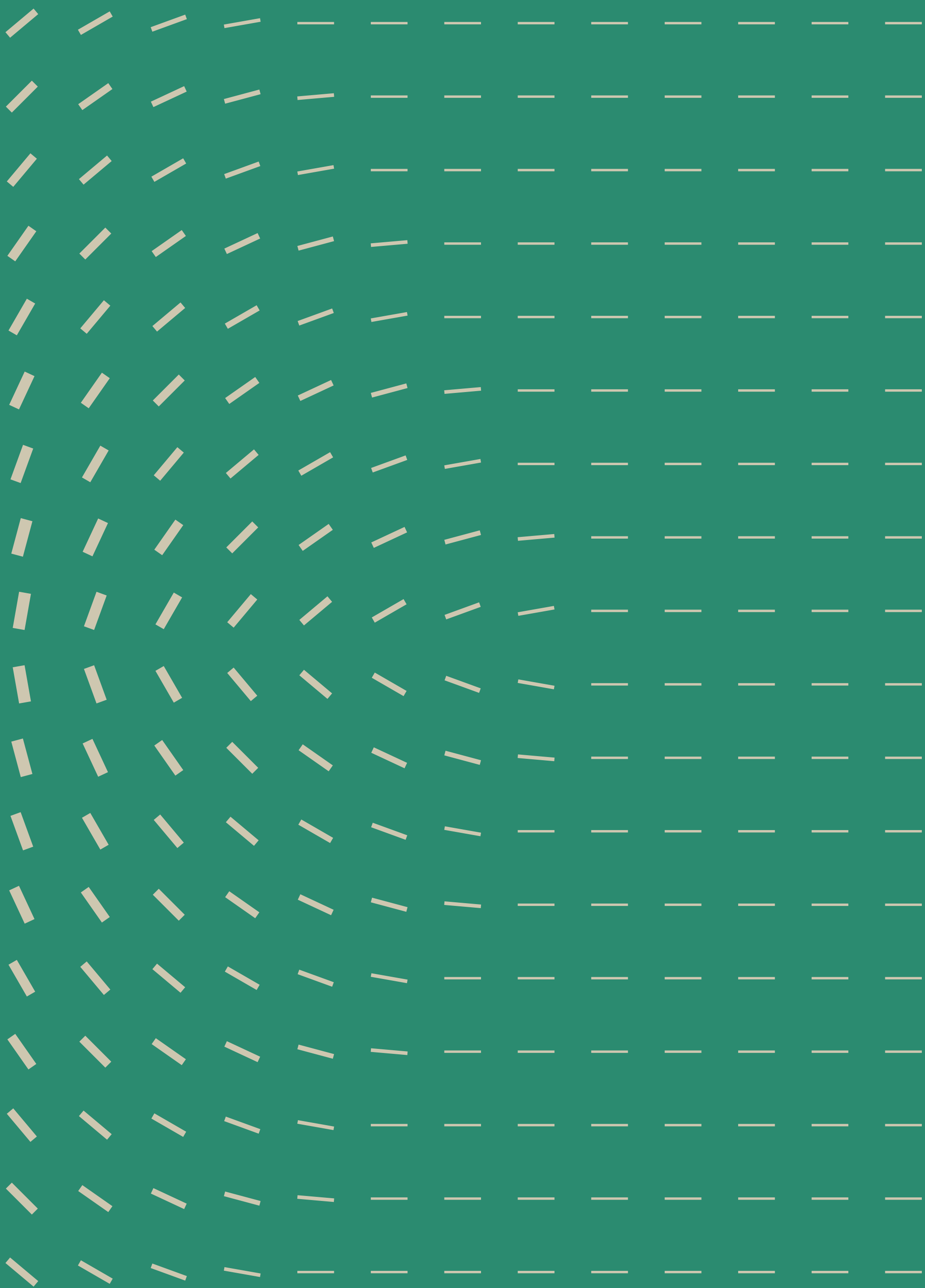
FIGURE 2.46

Web-Based Visualization Output of the Flood Exposure and Risks Analysis of Roads in East Africa

Source: Pant, Jaramillo & Hall (2023), Hickford et al. (2023)

Chapter 3

Strengthening Systemic Resilience: Mainstreaming Nature-based Infrastructure Solutions



3.

Strengthening Systemic Resilience: Mainstreaming Nature-based Infrastructure Solutions

3.1. Introduction

The application of nature-based solutions has far-reaching potential to support the transition to low-carbon-resilient infrastructure

Owing to the long lifecycles of most infrastructure assets, choices made today on the types, features, and locations of infrastructure will heavily influence the world's ability to shift to lower carbon trajectories and strengthen systemic resilience.

Efforts to limit global warming to 1.5°C above pre-industrial levels[17] now require rapid and far-reaching transitions in energy, land, urban and industrial systems, and infrastructure. Ninety percent of today's infrastructure has been built over the last 50 years (IPCC, 2018). Meanwhile, 60 percent of the infrastructure needed by 2050 is yet to be built. This increases the need to immediately transition from a 'business-as-usual' to a low-carbon-resilient infrastructure.

The application of nature-based infrastructure solutions (NbIS) in sectors such as water and hazard mitigation has a far-reaching potential to support this transition (Box 3.1). NbIS not only have a low carbon footprint and address climate mitigation objectives but also offer a wide range of other co-benefits. For example, the use of deep-root systems for slope stabilization has been estimated to produce 85–90 percent savings compared to traditional engineered solutions (Truong, n.d.) Likewise, mangrove conservation and restoration not only protect coastal areas against storm surges but also improve water quality, replenish fish stocks, safeguard ocean health, and reduce coastal erosion (INFC, 2022).[18] In urban areas, green roofs, permeable surfaces, and vertical gardens address urban flooding and heat islands while at the same time reducing energy consumption.

Infrastructure design and use affect both climate change mitigation and adaptation (Rydge et al., 2015). As a result of the long lifecycles of most infrastructure assets, choices made today will heavily influence the ability

[17] Included as an aim, but not a binding commitment, under the Paris Agreement

[18] For example: https://www.iucn.org/regions/asia/our-work/regional-projects/mangroves-future-mff and https://cicloud.s3.amazonaws.com/docs/default-source/s3-library/publication-pdfs/guyana-green-gray-infrastructure-engineering-guidelines-inclexecsumm-final-updatedfront.pdf?sfvrsn=fa704d98_2

↓ **BOX 3.1**

Nature-based Infrastructure Solutions

Nature-based infrastructure solutions (NbIS) refer to practices that concurrently protect and provide infrastructure, adapt to climate change, promote environmental integrity and biodiversity, and provide social well-being. If widely adopted, they can play a crucial role in strengthening resilience.

The concept of ecosystem services (what nature provides for people) has evolved into the broader concept of nature-based solutions, based on the insight that while nature provides services for people, people also need to protect nature and safeguard environmental integrity and biodiversity to continue to receive societal benefits (Cohen-Shacham et al., 2016; WB, 2006). Nature-based solutions encompass the idea that humans should work with nature, not against it (Sowińska-Świerkosz and García, 2022).

Nature-based solutions are defined 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, and resilience and biodiversity benefits*' (UNEA-5, 2022).

Nature-based solutions can be considered an umbrella concept encompassing practices such as ecosystem-based management, forest landscape restoration, ecological restoration, bioengineering, protected area management, watershed health, and ecosystem-based adaptation (Wadhawan and Bajpai, 2023). The term 'NbIS' is used in this report to refer to the application of nature-based solutions to address infrastructure requirements. In other words, it means directly connecting the natural environment with the built environment (FEMA, 2021).

IUCN (International Union for Conservation of Nature) offers the following eight criteria to assess what NbS is, to avoid misuse of the term "nature-based" for green-washing traditional grey projects (IUCN, 2020):

1. Nature-based solutions effectively address the societal challenges of climate change mitigation and adaptation, disaster risk reduction, economic and social development, human health, food and water security, and environmental degradation and biodiversity loss.
2. The design of nature-based solutions is informed by scale.
3. Nature-based solutions result in a net gain in biodiversity and ecosystem integrity.
4. Nature-based solutions are economically viable.
5. Nature-based solutions are based on inclusive, transparent, and empowering governance processes.
6. Nature-based solutions equitably balance trade-offs between achieving their primary goal(s) and providing multiple benefits.
7. Nature-based solutions are managed adaptively, based on evidence.
8. Nature-based solutions are sustainable and mainstreamed with an appropriate jurisdictional context.

Different terms are used for nature-based solutions in different geographical contexts. For example, *Green Infrastructure* (European Union), *Green Growth* (Vietnam), *Low-impact development* (USA), *Water-sensitive urban design* (Australia), *Natural Infrastructure* (Peru), *Ecosystem-based Adaptation* (India), and so on (Millennium Ecosystem Assessment, 2005). Ultimately, the terminology itself is less important than the concept behind the term.

of countries to shift to lower carbon trajectories (OECD et al., 2018) and strengthen systemic resilience, in LMICs where most infrastructure investment will occur in the coming decades.

If investments in fossil fuel-based infrastructure continue, countries will be locked into higher emissions, making it impossible to limit warming to 1.5°C or 2°C. It will also lead to leaving behind stranded assets in the energy, building, and transportation sectors and increasing fiscal constraints, thus reducing options for future responses (IPCC, 2018). Avoiding this lock-in requires a radical change in infrastructure governance and how infrastructure is designed and used (Seto et al., 2016).

Countries will have to transition towards low-carbon infrastructure systems to establish low-carbon and climate-resilient pathways that align with the Paris Agreement and meet their commitments under their Nationally Determined Contributions (NDCs). This is critical for limiting climate change and potentially catastrophic increase in disaster risks (Saha, 2018). Given the magnitude of already accumulated risk in LMICs, not taking aggressive action now means reducing future options for strengthening systemic resilience, as increasing loss and damage will further widen an already massive infrastructure deficit (Denton et al., 2014).

Chapter 1 discussed how the contemporary urban process, underpinned by investment in high-carbon infrastructure, *systemically* generates risk, which then feeds back into increasing infrastructure loss and damage. *Systemic* resilience, therefore, is contingent on designing infrastructure investments in a way that does not generate new systemic risk. Climate change mitigation and adaptation are the principal paradigms through which systemic risk is currently being addressed. However, progress in climate change adaptation is still 'unevenly distributed, fragmented, small in scale [and] incremental'. As a result, 'gaps exist between current levels of adaptation and levels needed to respond to impacts and reduce climate risks'. These gaps are 'partially driven by widening disparities between the estimated costs of adaptation and documented finance allocated to adaptation', meaning that the 'overwhelming majority' of global climate finance has so far been targeted at climate change mitigation (IPCC, 2023).

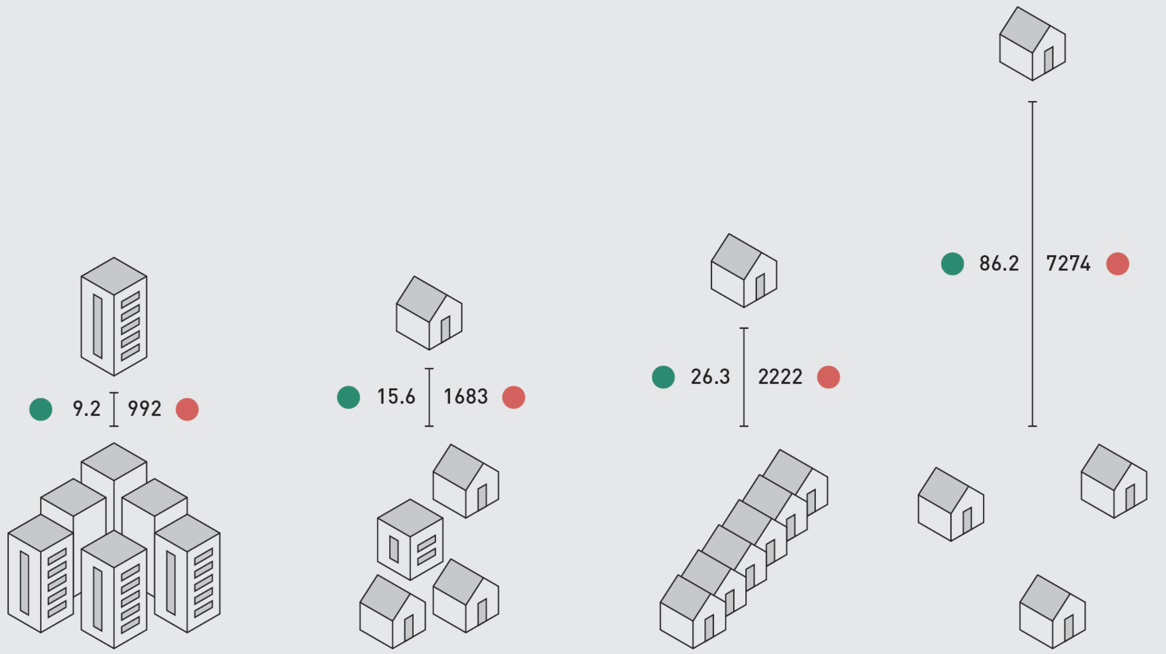
Systemic risk is associated not only with climate change but also with a range of concatenated drivers, including loss of biodiversity, poorly managed and planned urban development, growing social inequality, and weak governance. Strengthening systemic resilience, therefore, is not limited to climate change mitigation and adaptation but addresses a broader agenda. As Chapter 2 highlights, while climate change will increase the risk to infrastructure assets, particularly in LMICs, most of the infrastructure risk is already locked in or associated with geological hazards, such as earthquakes, tsunamis, and earthquake-induced landslides.

Fortunately, how infrastructure is developed and used is undergoing a rapid transformation. **Disruptive technologies in the energy, transportation, and construction sectors are now achieving the economies of scale necessary to be economically competitive. Fossil fuel-generated electricity costs 5–17 cents per kilowatt-hour, while solar energy-generated electricity costs only 3–6 cents per kilowatt hour and is trending down** (IRENA, 2021). In high-income countries, new building technologies, electric vehicles, and more efficient appliances are enabling a reduction in energy consumption.

↓ FIGURE 3.1

Comparing Costs of Infrastructure and Utilization across Different Urban Configurations

Source: Adapted from Vermeiren et al. (2022)



	(Dense) Urban Areas	Villages & Urban Fringes	Ribbon Development	Dispersed Buildings
Car	21	27.8	32.6	34.1
Bus	2	1.7	1.4	2
Train	3.7	2.6	2.8	2.2
Bike	1.2	1.7	1.9	1.9
Walking	0.8	0.5	0.5	0.3
Motorcycle	0.2	0.3	0.4	0.5
Other	0.9	0.9	2	2.6
Total	29.8	35.5	41.6	43.7

- Average running meter of infrastructure network per building
- Average annual infrastructure cost per building (€)
- Average passenger-km per day per transport mode
- Average daily transportation cost per person per urban sprawl type (€)

Moreover, smart energy systems, such as microgrids, are enabling renewable energy to feed more efficiently into national grids.

These technological changes are already reconfiguring investment flows. As highlighted in Chapter 1, about three-quarters of private infrastructure investment is concentrated in high-income countries, half of which has flowed into renewable energy generation, storage, and transmission. Unfortunately, LMICs have attracted only a quarter of this investment which is still flowing into sectors such as non-renewable energy and transport, which will further lock in systemic risk.

Other required transformations, for example, in urban layout and design, are lacking. Figure 3.1 highlights how more efficient urban layouts and design can dramatically reduce infrastructure costs, make more efficient use of land, reduce transportation costs and associated carbon emissions, and mitigate urban flood hazards.

In the case of NbIS, the potential benefits have been demonstrated in different country contexts through a wide range of applications. However, formidable obstacles to their widespread adoption remain. Many of the ecosystems that were the foundation for NbIS are in decline. Furthermore, the knowledge and capacities necessary for designing and implementing NbIS are insufficiently developed. Methods for identifying, estimating, and realizing the benefits and co-benefits of NbIS can provide are yet to become mainstream. Therefore, the absence of standards and documented best practices hinders the adoption and financing of NbIS. This chapter examines how these challenges can be addressed and how the broad potential of NbIS to strengthen systemic resilience can be fully leveraged.

3.2. Ecosystems are Declining

Ecosystem degradation, compounded by anthropic climate change, is limiting the earth's ability to provide the ecosystem services people value and depend on. It is also increasing the risk to infrastructure. Ecosystem degradation is a major risk driver; therefore, protecting and restoring ecosystems is critical to risk reduction and resilience building.

Healthy ecosystems sustain life on the planet and provide ecological integrity, biodiversity, economic systems, and human well-being through four categories of ecosystem services: *Supporting services*, such as nutrient cycling, soil formation, and primary production; *Provisioning services*, such as food, water, wood, fibre, and fuel; *Regulating services*, such as flood control, climate regulation, disease control, and water purification; and *Cultural services*, such as education, recreation, aesthetics, and spiritual values (Millennium Ecosystem Assessment, 2005).

The degradation of ecosystems means these services cannot be provided. As of 2021, over a million species are under threat of extinction. Since the 1870s, over half of the world's corals have disappeared, and 75 percent of the land surface has been significantly altered. In the last 50 years alone, 85 percent of wetlands have been lost (Díaz et al., 2019). Ecosystem degradation, compounded by anthropic climate change, is a core risk driver. Thus, protecting ecosystems from degradation is critical to strengthening systemic resilience. Protection has greater potential to supply ecosystem services than trying to restore ecosystem functions on degraded landscapes. Therefore, without protecting the ecosystems on which living beings depend, NbIS cannot prosper (Box 3.2).

↓ **BOX 3.2**

The Feedback Relationships between Ecosystem Decline and Infrastructure Risk

Building sea walls has become an increasingly common climate adaptation strategy to address sea-level rise and storm surge. However, sea walls can negatively affect the self-regulating functions of coastal ecosystems, such as mangroves (Gilman et al., 2008). Mangrove loss, in turn, can increase the risk to sea walls during tidal changes and storm surges, reducing their protective capacity over time. Thus, NbIS in the form of replanting or protecting mangroves not only provides coastal protection *per se* but also may reduce the risk for other *hard* coastal infrastructure, such as sea walls.

↓ **BOX 3.3**

Five Functional Categories of NbIS
Source: UNEP (2022)

Deliver infrastructure services directly

NbIS can directly deliver infrastructure services like flood protection, water filtration, and temperature regulation. These services can reduce or avoid the need for engineered infrastructure assets. NbIS, such as wetlands, constructed wetlands, reeds, and ponds, can filter pollutants and assimilate wastes, providing water treatment services and reducing requirements for built wastewater treatment facilities.

Enhance engineered infrastructure function

NbIS can enhance the functioning of engineered infrastructure assets and systems. In addition to increasing the efficiency of service provision, NbIS also reduces the need for operation and maintenance. Riparian vegetation can stabilize soils and reduce sedimentation and turbidity of reservoirs, thus reducing the need for flocculants and mechanized maintenance such as dredging that can require service downtime.

Protect engineered assets

Some NbIS can protect engineered infrastructure assets from climate impacts such as flooding, high winds, and coastal inundation. Agroforestry, especially deep-rooted trees on slopes, can help in stabilizing soils and reducing the occurrence of shallow, rapidly moving landslides onto road networks (Forbes et al., 2012).

Benefit the workforce

Implementation of NbIS can boost the health of infrastructure sector workers, create employment and decent work, and improve the productivity and sustainability of existing employment in various sectors (ILO et al., 2022).

Deliver multiple additional social, environmental, and economic benefits

NbIS can deliver societal benefits that advance progress towards global targets, such as SDGs and the Paris Agreement (Cohen-Shacham et al., 2016). For example, NbIS promotes opportunities for women's involvement in decision-making and governance, particularly in rural areas (IISD, 2021). This can benefit labour force participation and lead to better social outcomes.

As Box 3.3 highlights, NbIS can be used to *complement, substitute for, or safeguard* traditional 'grey' infrastructure, particularly in the water and hazard mitigation sectors, thus representing a paradigm shift towards designing and building with nature (McHarg, 1969). NbIS also increases opportunities for women's involvement in decision-making and governance, particularly in rural areas (IISD, 2021), offering a win-win for both the environment and the society (Bassi et al., 2021).

Figure 3.2 illustrates potential applications of NbIS to address riverine flooding, urban heat islands, water scarcity, and coastal erosion and flooding.[19]

It is estimated that NbIS cost, on average, only 51 percent of grey infrastructure projects and that 11 percent of all grey infrastructure could be replaced by NbIS (Bassi et al., 2021). The greatest potential for NbIS is in the water sector due to the importance of functional ecosystems for water capture, storage, filtration, and transmission and in protecting grey infrastructure (UNEP, 2023). Over time, the effectiveness of grey infrastructure degrades while that of NbIS increases. For example, as sea walls depreciate in quality, well-protected mangroves become stronger and more widespread as they grow older, thus strengthening resilience.

[19] Additional hazards and potential solutions can be found in position paper 3.1 (USFS, 2023).

As NbIS provide social, environmental, and economic co-benefits, their widespread adoption would influence the achievement of 115 of the 169 targets across all 17 SDGs. In specific infrastructure sectors, adopting NbIS would influence up to 25 to 44 percent more SDG targets compared to using *grey* infrastructure alone (UNEP, 2023). NbIS also reduce carbon emissions across infrastructure lifecycles, which will enable avoiding land use change and extending infrastructure lifespans. Transitioning to NbIS has the potential to create an estimated 59 million jobs by 2030, including livelihood-enhancing jobs that are directly related to ecosystem protection and restoration (WEF, 2022). By providing essential services and strengthening assets, service, and systemic resilience, NbIS thus positively contribute to restoring environmental integrity, biodiversity, and societal well-being.

Unfortunately, despite this potential, the current investment in NbIS represents only 0.3 percent of overall infrastructure investment (WEF, 2022). In LMICs, substantial barriers exist to the widespread acceptance and implementation of NbIS, including those related to education, policy, governance, and finance (Ghosh & Soundarajan, 2023; Håkanson, 2021; S. Sarabi et al., 2020; S. E. Sarabi et al., 2019). To address each of these barriers and realize the potential of NbIS, innovative solutions need to be adopted.

→ **FIGURE 3.2**

Potential Applications of NbIS
Source: USFS (2023)

Coastal Erosion and Flooding

Driven by: • Sea level rise • Storm surge, high tides, high surf, freshwater flooding • Loss of mangroves, coral reefs, sea grass, dunes, deltas, and beach vegetation • Alteration of coastal sediment regimes • Infrastructure close to shoreline • Higher global average temperatures • Continental ice sheet melting and collapse • Glacial melting • Warmer oceans, thermal expansion • Coastal land subsidence: due to seismic, changes, sediment starvation, groundwater extraction, weight of infrastructure

Nature-based Infrastructure Solutions

- Move infrastructure out of sea level rise and tsunami zone and prevent future development
- Restrict development close to coast and on barrier islands
- Maintain or restore coastal wetlands in estuaries, mud flats, salt marshes
- Develop integrated management plans for: water resources; coastal zone management; coastal zone adaptation

- Maintain or restore mangroves, coral reefs, sea grass, dunes, and beach vegetation
- Maintain or restore natural sediment fluxes along shorelines
- Use forestry best practices
- Combine green and gray solutions
- Allow saltwater inundation where possible and beneficial

Outcomes: • Social • Enhanced liveability, coastal protection • Potential to increase food security • Reduced mortality • Reduced number of disaster refugees • Economic • Reduced damage costs associated with storms and flooding • Environmental • Increased carbon storage • Decreased storm damage to ecosystems • Protected critical coastal aquatic species habitat • Enhanced biodiversity • Captured sediments may keep pace with sea level rise • Maintained natural sediment fluxes • Reduced pollution

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Extreme Heat & Urban Heat Islands

Driven by: • Climate warming • Asphalt and concrete • Dark surfaces • Lack of tree cover • Lack of vegetation • Tall buildings, narrow streets, limited airflow • Fuel combustion • Heating, ventilation, and air conditioning exhaust

Nature-based Infrastructure Solutions

- Establish and maintain urban forests on streets and in parks
- Maintain and restore shade trees in riparian areas
- Establish vertical forests on buildings, green roofs, grassed sidewalks
- Maintain or restore bodies of water and aquatic ecosystems

- Use topographic shading and building orientation to reduce solar radiation
- Create community gardens and other green spaces
- Implement agro-forestry to increase tree cover and shading on farms and homes

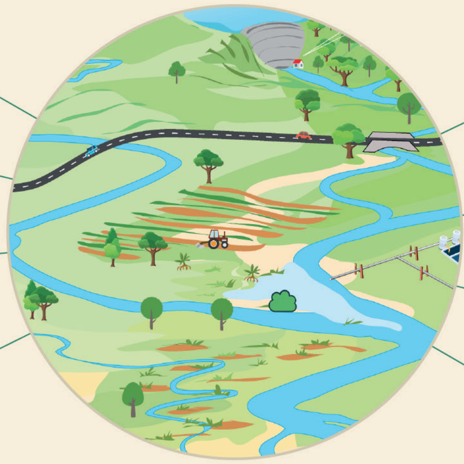
Outcomes: • Social • Reduced mortality • Decreased temperatures inside and out • Enhanced liveability • Potential to increase food security • Improved mental and physical health • Economic • Lowered utility bills • Reduced energy needs • Environmental • Increased carbon storage • Enhanced wildlife and pollinator populations • Improved air and water quality

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

- Use natural topography to capture, store, and slowly release water
- Minimize impervious surfaces and disconnect from waterways
- Evaluate watershed conditions and function
- Practice sustainable forest management and implement restoration and resilience treatments



- Maintain or restore wetlands, riparian buffer zones, retention ponds, streams, open water, forests, grasslands, and parks
- Allow stream channels to interact with floodplains
- Use regenerative agriculture techniques
- Establish integrated water resource plans

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

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Water Scarcity

Driven by: • Climate disruption • Increased evapotranspiration • Low rainfall, prolonged drought • Cross-basin water transfer • Water pollution • Overuse of water, groundwater depletion • Water-intensive crops • Inefficient or excessive irrigation practices • Accelerated runoff

Nature-based Infrastructure Solutions

- Maintain or restore stream systems, riparian buffers, wetlands, forests, with native vegetation species
- Maintain depth, infiltration capacity, permeability and cover of watershed soils
- Minimize impervious surfaces
- Regulate groundwater withdrawal

- Convert irrigation systems for water-use efficiency
- Grow drought-resistant crops in drought-prone areas
- Regulate and limit irrigation on highly porous soils
- Install permeable pavements, green roofs, and rainwater collection systems that can store runoff for reuse

Outcomes: • Social • Efficient use of water leads to increased availability • Reduced need for irrigation • Improved livelihoods • Improved health • Increased food security • Economic • Jobs are created • Reduced need for large-scale irrigation • Environmental • Increased organic matter and water content of soil • Increased carbon storage • Reduced runoff • Increased infiltration stores water on landscape for slow release during droughts and aquifer recharge • Increased water levels in springs, creeks, rivers • Reduced pollution • Increased biodiversity

3.3. Challenges and Opportunities for Integrating NbIS into Infrastructure Delivery

3.3.1. Knowledge and Capacity

Improved access to knowledge increases awareness and understanding of the capacity of NbIS to complement, substitute, or safeguard historically grey infrastructure.

Many LMICs also lack core knowledge of ways to introduce NbIS. Few professionals have experience in the planning, designing, implementing, maintaining, and monitoring of NbIS. Local government officials, civil engineers, households, investors, insurers, and MDBs, among others, may not have managed or previously imagined how NbIS can strengthen infrastructure resilience.

While grey infrastructure projects are generally planned and designed solely by engineers, NbIS require new interdisciplinary knowledge and skill sets that engineers and architects do not necessarily possess. For example, incorporating rain gardens or wetland features into urban infrastructure requires a holistic analysis rather than a linear calculation of surface runoff in a storm drainage system. Knowledge about the sustainability of ecosystems is required to avoid further degradation that would undermine the potential for NbIS.

University curricula are often outdated, slow to change, professionally siloed, and unfit to address interdisciplinary challenges such as NbIS. Rarely can one find research that quantifies ecosystem services, integrates nature-based values into modelling and cost-benefit accounting, and facilitates the design of NbIS. Even if such research exists, it is often not translated into practice. Moreover, it is difficult to access literature on NbIS which has been peer-reviewed for veracity, relevance, or trustworthiness. Finding literature on NbIS in languages other than English is rarer still.

As a result, a new approach is required to build capacities and share knowledge. Integrating NbIS concepts in engineering, urban planning, and architecture curricula is critical, as is introducing capacity-building programmes for infrastructure planners and managers in national and local governments, regulators, and utilities. Carefully reviewed, curated, up-to-date, and publicly available research, libraries, guides, design standards, and case studies, tagged by topic, are essential, including in different languages and multimedia formats such as mobile apps, webinars, and podcasts. All countries, particularly LMICs, will need national centres of excellence in NbIS, with the capacity to document and research good practices, disseminate knowledge, provide outreach to practitioners, and network information with other countries. Box 3.4 illustrates UNDP's efforts to integrate NbIS to strengthen storm and flood protection along the 3260-km coastline in Vietnam.

Curating literature on NbIS will encourage the emergence of *Communities of Practice* (CoPs). Bringing together land use planners, civil engineers, coastal specialists, foresters, infrastructure policymakers, hazard and risk modellers, financing experts, and others[20] in CoPs will be critical to moving NbIS into the mainstream. CoPs can help bind together and provide mutual support between local initiatives, increasing the confidence of households, communities, businesses, and local governments and sharing good practices to assist other communities facing similar issues.

Mature CoPs will also stimulate the national markets for professional services and technology necessary to implement NbIS projects through the creation and spin-off of small- and medium-sized NbIS businesses. *Exotic* locally championed and isolated projects may become *quotidian* normative practices, supported by mature markets for technology and professional services and readily available finance.

Box 3.5 illustrates how a not-for-profit organization can adopt an innovative initiative, utilize diverse funding sources, and support the contextual application of NbS through training and education for local government staff, developers, community members, and other relevant stakeholders (INFC, 2022). Monitoring project performance is critical to providing evidence-based proof of concept; it supports the adaptation of designs and adoption of additional and more expansive projects and helps to prioritize and focus on NbIS to enhance beneficial outcomes. Standardized quantitative metrics on data types, costs, benefits, and performance over the long term are required to develop benchmarks for success and effectiveness that can be compared across different interventions, sectors, contexts, NbIS, and engineered solutions (UNEP, 2022).

↓ BOX 3.4

Vietnam Coastal Communities Adapt to Climate Change

Source: USFS (2023)

In collaboration with the Vietnamese government and the Green Climate Fund, UNDP is strengthening storm and flood protection for coastal communities along the 3260-km coastline in Vietnam. The project is based on nationwide climate risk assessments, innovative architectural solutions, and NbIS. By planting and rehabilitating mangrove and nipa palm forests, the project is enhancing biodiversity and restoring coastal ecosystems and, in turn, benefiting the livelihoods of coastal communities.

To create storm surge buffers, 4000 hectares of mangroves will be planted, creating local jobs, and enhancing fisheries that support coastal livelihoods and ecotourism opportunities. Local community members are engaged in the design, implementation, and maintenance of storm- and flood-resilient housing benefiting up to 20,000 people and in the project's decision-making processes. By enhancing their understanding of the importance of sustainably managing mangroves and nipa palm forests, the project has helped coastal residents to strengthen their livelihoods through involvement in ecological and environmental protection.

[20] As an example, the Global Green-Grey Infrastructure Community of Practice is a forum for collaboration across the conservation, engineering, finance, and construction sectors to generate and scale-up green–grey climate adaptation solutions. The multidisciplinary CoP has grown to a global membership exceeding 140 organizations in the NGO, academic, government, and private sectors working to share ideas and facilitate collaboration; innovate and pilot new approaches; expand science, engineering, and policy activities; and implement and learn from projects in varied geographies and settings.

Linking NbIS monitoring to the achievement of the SDG and the goals of the Paris Agreement, the Bonn Challenge, the New York Declaration on Forests, the UN Decade on Ecosystem Restoration, and regional commitments, such as the 20x20 Initiative in Latin America, may also facilitate greater uptake of NbIS (Buckingham et al., 2019).

BOX 3.5

Integrating Local and Indigenous Knowledge into Planning and Design: Stewardship Centre for British Columbia, Green Shores Program

Source: INFC (2022)

In 2005, the Stewardship Centre for British Columbia (SCBC) adopted the Green Shores Program and mobilized and refined it to accelerate ecological restoration approaches. The program provides technical NbIS guidance at three scales: local government, shoreline development, and homes. The programme builds awareness and capacity for local governments through workshops, one-on-one coaching, and milestone-based certification. The Green Shores Credits and Rating Guide helps homeowners, builders, and developers identify the benefits of NbIS through a rating system that rewards participants.

It is an inclusive process that brings developers, community members, local governments, and First Nations together in planning and design. One of the RC4S project sites, on K'omoks First Nation territory, facilitates collaborative NbIS design activities and the sharing of local and traditional knowledge, involving stakeholders from K'ómoks First Nation, Project Watershed, Northwest Hydraulic Consultants, Hapa Collaborative, Paul de Greef Landscape Architect, Pacific Salmon Foundation, and SCBC.

The programme provides technical support to assess the trade-offs between options and realize the social, economic, and environmental benefits. The report, *Green Shores 2020: Impact, Value and Lessons Learned*, shows the social impacts and extended cost-benefits of the projects in British Columbia (Eyzaguirre et al., 2020).

3.3.2. Identifying, Mapping, and Estimating Risk and Resilience

Without a credible and robust risk identification and estimation process at an appropriate scale, it is impossible to identify the resilience dividends that can accrue through adopting NbIS, compared with conventional grey infrastructure, thus blocking potential opportunities.

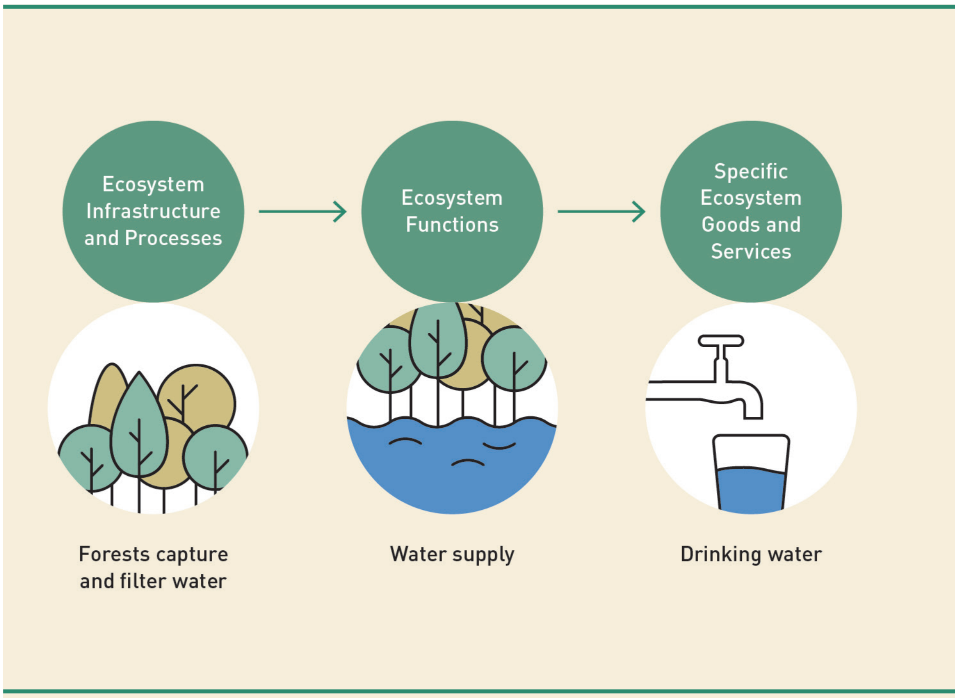
Ecosystems must be fully integrated into infrastructure planning and development at multiple scales to strengthen resilience. This requires recognition that resilience is contingent on healthy ecosystem function and an understanding of the impact environmental hazards has on infrastructure assets and of the way infrastructure can be a driver of increased systemic risk. For different scales of assessments, mapping and updating key elements at regular frequency is critical. For instance, at the national level, mapping and tracking river systems or the coastline alongside developmental changes can help build an understanding of their causal relationships with risk. At the project level, refinement of this mapping with community input can enable ecosystem fragility to be considered in project design to avoid damage or access to sensitive ecosystems that contribute to systemic resilience.

Figure 3.3 illustrates the connection between a healthy ecosystem, its functions, and its services. NbIS often harness the protective functions of ecosystems such as stormwater retention, wildfire resilience, slope stabilization, and infiltration.

The GIRI does not currently estimate the risk to ecosystems, though it should in the future. However, the necessary information on global biodiversity

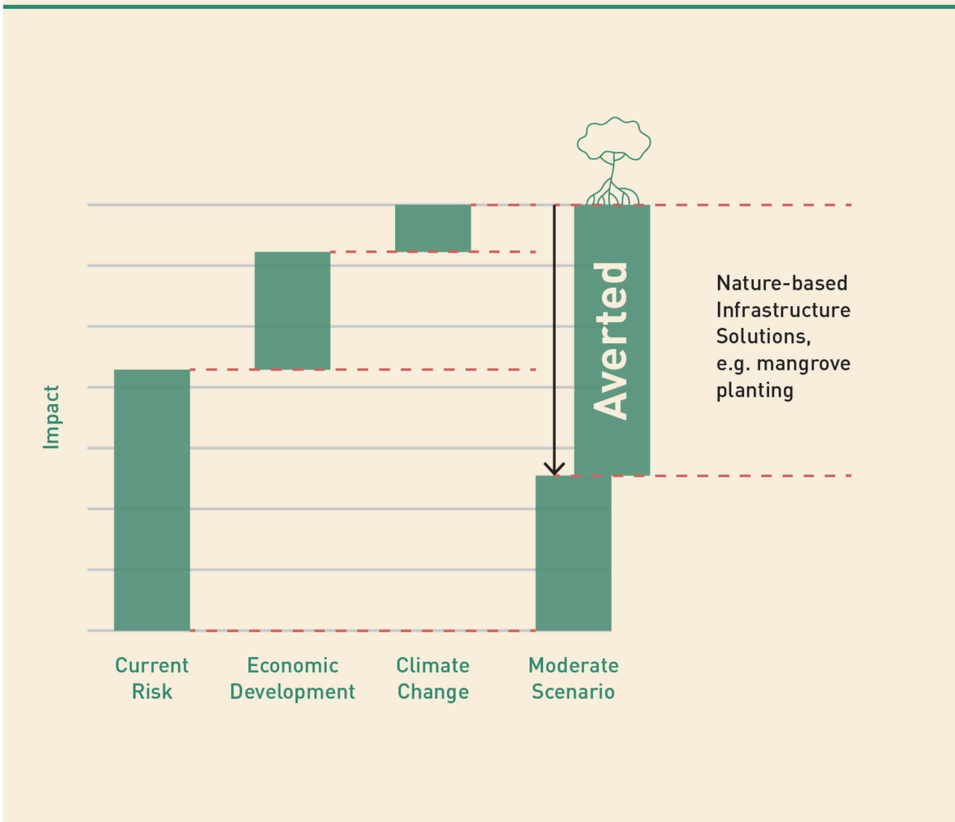
→ **FIGURE 3.3**

Mapping and Understanding Ecosystems
Source: USFS (2023)



hotspots and vulnerable ecosystems is already available (Chaplin-Kramer et al., 2022). As highlighted in Chapter 2, probabilistic risk identification and estimation, including modelling the underlying climate-related and geological hazards, the existing or potential future infrastructure assets exposed to those hazards and their vulnerability, and the modification of all the above through climate change and other risk drivers are the factors that need to be considered when estimating the contingent liability in infrastructure. A credible and robust risk identification and estimation process, at an appropriate scale, can help clearly identify the resilience dividends that can accrue through adopting NbIS.

This kind of analysis is critical to strengthening the case for NbIS but is rarely included in project design. Financial risk metrics, such as AAL, when integrated into the budgets and feasibility studies developed to finance infrastructure projects, enable the assessment of the benefits and costs of alternative strategies to strengthen resilience, including NbIS. For example, in assessing different climate adaptation options in Vietnam, a combination of mangrove planting and conservation, in combination with dykes and seawall construction and insurance, generated a net value, thus reducing the expected damages more than the cost under different climate scenarios (Figure 3.4).



↑ **FIGURE 3.4**

Assessing the Net Value of NbIS
Source: Bresch and Aznar-Siguan (2021)

3.3.3. Policy and Regulations

Effective legislation to protect and enhance ecosystems and their services is necessary to affirm a longer-term commitment, providing investors with greater confidence and reduced risks and encouraging greater investment in NbIS.

As NbIS are rolled out to strengthen infrastructure resilience, ongoing ecosystem degradation needs to be stopped. When environmental policy and regulations are weak and poorly enforced, it will lead to the degradation of the very ecosystem services on which NbIS are based. Economic drivers in many countries encourage moral hazard that leads to degradation and depletion of natural resources at a rate far faster than their regeneration.

Effective legislation to protect and enhance ecosystems and their services is necessary to affirm a longer-term commitment. It will provide investors with greater confidence and reduced risks, thus encouraging greater investment in NbIS. For example, in June 2022, the EU Commission proposed the EU Nature Restoration Law that, if enacted, will establish legally binding targets to protect and restore rivers, wetlands, forests, peatlands, marine, and urban areas to benefit biodiversity, climate, and people (European Commission, 2019). The Paris Agreement provides a framework to initiate similar actions across the globe. Similarly, the UN System of Environmental and Economic Accounting promotes a broader framework that includes social capital and environmental-economic accounting measures (UN System of Environmental and Economic Accounting, 2021), which, if adopted, could create a positive enabling environment for NbIS. Such legislation should integrate with existing environmental policies that protect air, soil, water, floral, and faunal resources. Working within an established environmental policy can help government sectors achieve resilience targets set by legislation (TARU Leading Edge, 2022). As all infrastructure development projects and operations should comply with national environmental policies, the use of environmental impact assessments can also become a vehicle for mainstreaming NbIS.

By 2020, the submitted NDCs under the Paris Agreement were found to be insufficient to keep the global temperature rise below 2ºC (Seddon et al., 2019). However, NDCs do provide a policy umbrella for the adoption of NbIS. In comparison to high-income countries, LMICs NDCs often give greater emphasis to NbIS with a particular focus on forest protection and restoration. As NDCs expand to include other NbIS, such as protecting and restoring rivers, wetlands, coastal and marine ecosystems, and improving soil and forest health in wildlands, agriculture, and urban areas, this can create further momentum (UNDP, 2019).

Some countries are considering the transition to net zero in the energy, transportation, and other sectors to be a critical issue of national security. For example, a massive reallocation of public and private capital in the USA is already occurring to catalyze the transition (Box 3.6).

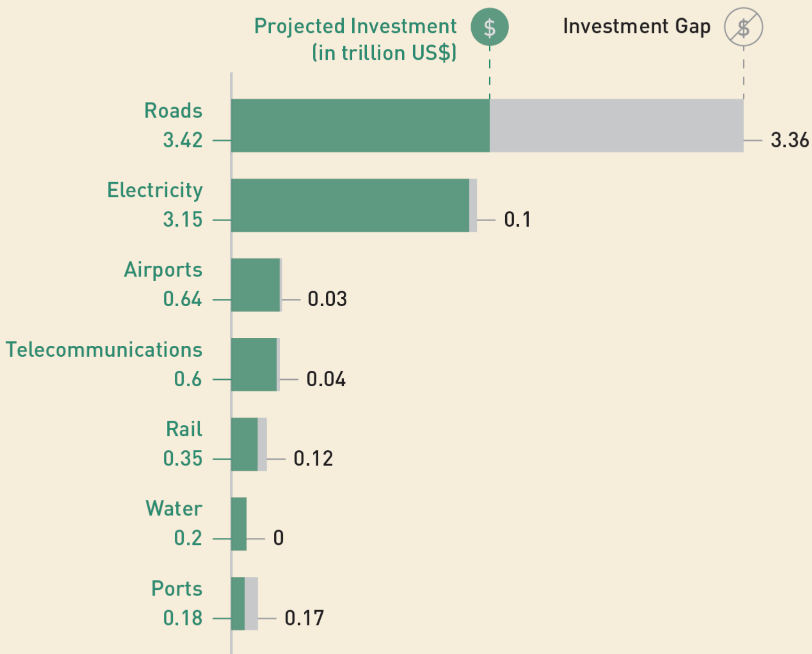
↓ **BOX 3.6**

US Federal Infrastructure Investment of
$1 Trillion for Growth and Resilience

Most infrastructure in the USA was built decades ago. Rising maintenance costs and unreliable services have eroded economic performance (Petroski, 2016). During the COVID-19 pandemic, poor infrastructure was recognized as a threat to human safety and a source of lost economic productivity.

Recognizing that the country was lagging behind other high-income countries, in November 2021, the US Congress approved a $1 trillion plan to upgrade roads, bridges, and water systems, modernize the electrical grid, and expand the adoption of electric vehicles and broadband internet access (Figure 3.5). It is also proposed to include social infrastructure for child and elder-care programmes.

On Earth Day 2022, President Biden announced protecting and restoring nature and using NbS as a core tenet of national policy. Executive Order 14072, Strengthening the Nation's Forests, Communities, and Local Economies, called for the accelerated deployment of NbS to tackle climate change and adapt (White House Council on Environmental Quality et al., 2022). Apart from existing modalities, such as municipal bonds, Public-Private Partnerships (PPPs), and increased corporate taxes, there is an increasing bipartisan support for a national infrastructure bank (Mallett, 2016), with an initial appropriation of $25–$50 billion that could help finance these investments.



↑ **FIGURE 3.5**

Projected US Infrastructure Investment Gaps by 2040
Source: McBride & and Siripurapu (2021)

↓ **BOX 3.7**

Incentive Design and the Impact of Rating Systems: Lessons from the Domain of Green Buildings in India

The stated benefits of NbIS for infrastructure resilience and sustainability will gain credibility when a third party audits a project using rating systems. Rating tools can serve as a market signal for resilience or sustainability and provide verified examples of good practice. Governments can guide markets by endorsing well-proven systems and incentivizing positively rated developments (Berrang-Ford et al., 2021).

The role of green building rating systems in promoting innovation in the construction sector and the design of incentives around it hold potential lessons for turbocharging the adoption of NbIS.

Rating systems need to be adapted to the local context. In India, GRIHA (Green Rating for Integrated Habitat Assessment) was developed by The Energy and Resources Institute (TERI) as a building rating system to address and assess non-air-conditioned and partially air-conditioned buildings at a time when international systems focused solely on rating air-conditioned buildings. GRIHA was adapted to each climatic zone in India and awarded points for unique vernacular building practices, such as rat-trap bonds and filler slabs, that reduce stored energy in a building. GRIHA was adopted nationally by the Ministry of New and Renewable Energy in November 2007 (Ministry of New and Renewable Energy & and TERI, 2010, p 18).

Incentives at the national, regional, and urban levels have now translated into high adoption rates of green building rating systems in India's private and public sectors. For example, the Ministry of Environment, Forest, and Climate Change provides fast-track environmental clearance for buildings certified by GRIHA, IGBC (Indian Green Building Council), LEED (Leadership in Energy and Environmental Design), EDGE (Excellence in Design for Greater Efficiencies), and IMF (International Monetary Fund). The Ministry of Housing and Urban Affairs approves an increased Floor Area Ratio (FAR) of 1 – 5 percent on plots of more than 3000 square metres in size on buildings certified by GRIHA.

GRIHA-certified 4- and 5-star projects are also eligible for financial incentives under SUNREF (Sustainable Use of Natural Resources and Energy Finance) India, an initiative of the French Development Agency (AFD) that supports green investments through environmental credit lines extended to local financial institutions. Many states in India have also adopted policies and incentives [for example, the Karnataka Green Building Incentive Policy, in draft version since 2018; Punjab Municipal Green Building Incentive Policy, 2016; Kerala State Housing Policy, 2011; Odisha Development Authorities (Planning and Building Standards) Rules, 2020; Haryana Building Code, 2017; Tamil Nadu Industrial Policy, 2021].

3.3.4. Good Practices and Performance Standards

Based on best practice, nationally developed and adopted performance-based standards for NbIS may provide a more flexible route that allows engineers and others to approve project designs without facing potential professional liability issues.

Design and performance standards that include and codify NbIS are uncommon. NbIS good practices are rarely systematically codified. This hinders the development of clear policies, regulations, codes, and standards. The lack of appropriate norms and standards for NbIS may slow down or complicate the approval process for new projects. It can also make it difficult or impossible for engineers or other professionals to sign off on NbIS projects, as it may invalidate their professional liability insurance.

Resilience standards are often scattered across different laws, regulations, guidelines, decrees, environmental assessments, and manuals, and are dispersed in multiple locations and formats. In many contexts, it is difficult, if not impossible, to identify what is appropriate for NbIS.

Prescriptive global standards for NbIS could provide a pathway for greater project financing. However, their application can be counterproductive unless standards are nationally and context-appropriate (TARU Leading Edge, 2022). Nationally developed and adopted performance-based standards for NbIS, based on good practices, may provide a more flexible route.

'Best or Good Practice' is a professional procedure that is accepted or prescribed as being correct or most effective in particular contexts. The term conveys a sense of acceptability, respect, and professional endorsement. Developing a framework of 'good practices' within a body of curated literature would encourage convergence around what could be the most appropriate performance-based standards in each context.

Developing and refining good practices may be a 'bottom-up' process to arrive at nationally or context-appropriate performance standards. For example, a 'Nature-based Infrastructure Design Hub' could leverage modern computing and information collection technology using an online, open-source structure, thus allowing users to input knowledge and data to crowdsource information about NbIS technology, performance, and cost to inform performance standards (Conservation International, 2022). Such a voluntary, collaborative effort would contribute to improving NbIS design, selection, implementation, cost-effectiveness, and performance.

It is particularly important to monitor if NbIS are constructed as planned, and maintained and enhanced over time (Furniss, 2014). Third-party certification may be needed to ensure that NbIS are based on standards when they exist and professionally sanctioned good practices when they do not. In other sectors, such as in building, third-party certification has played an important role in enabling change, as Box 3.7 shows. However, until a significant hazard event tests the functionality of an NbIS, it may not be practical to certify that it delivers as expected. The concept of 'Pay for Performance', which is often a requirement in investments, may not be appropriate for NbIS until performance monitoring improves and is fully codified (Blue Forest Conservation, n.d.).

Ultimately, if *exotic* isolated projects are to mature into *quotidian* normative actions, the implicit knowledge existing throughout societies and across professional disciplines needs to be unveiled. As such, building local and user involvement and co-ownership of NbIS projects is fundamental to social acceptance, economic success, and sustainability (Centola, 2021).

3.3.5. Integrating NbIS into National and Local Planning

National infrastructure development policies, strategies, and plans can provide a supportive environment to introduce NbIS at the national level and safeguard biodiversity and vulnerable ecosystems at the local level.

National-level plans may provide a planning scale larger than the site itself and consider the conditions of the surrounding landscapes at the regional or even national scale.This higher-level analysis can highlight both the potential risks to the planned infrastructure and the potential of the infrastructure to strengthen systemic resilience. Transboundary partnerships at sub-regional, regional, and national levels are often needed. For example, transboundary cooperation in the Himalaya and Terai regions of Nepal and northern India is required to address community resilience and flooding impacts on infrastructure.

Locally, planning can recognize the capacity of providing goods and services needed for infrastructure supply and protection, of regional or national ecosystems such as rivers, lakes, wetlands, forests, grasslands, savannahs, agricultural lands, and coastal zones.

Assessing ecosystems and the services they provide and of the risks, costs, and benefits of different alternatives for providing resilience can provide a sound basis for the development of such policies, strategies, and plans, both at the national and at the local levels and include sector-based planning by integrating territorial plans at the local level.

However, a profusion of complementary but often overlapping planning processes, including development plans, land use plans, environment plans, adaptation plans, and disaster risk management plans (Berke et al., 2015), does not necessarily make for good planning. Strong national normative capacities may be undermined by weak capacities for formulating and implementing plans at the local level. Land use planning is often not integrated with sector-based planning and evaluation of public investment, meaning that the resources needed to implement local plans may not be available. In LMICs, much development is unregulated and informal, invalidating the benefits of planning.

In LMICs, instruments such as National Adaptation Plans (NAPs) can be used to integrate NbIS into the planning process with sectors such as urban and infrastructure (Box 3.8). For local planning, in countries such as India, integration of NbIS can be targeted through the State Action Plan for Climate Change (SAPCC).

↓ BOX 3.8

Gender-inclusive NbIS and Ecosystem-based Adaptation: Lessons from Fiji and Dominica

Source: Bechauf (2021)

Fiji and Dominica, both highly vulnerable to climate change owing to their geographical contexts, depend on nature for their economic development.

Fiji adopted a national action plan (NAP) to scale up ecosystem-based adaptations by promoting gender and human rights approaches. This has generated social and economic returns and provided multiple benefits, including improved health, food security, and alternative livelihood opportunities, all aimed at building ground-up resilience to climate change. With one of the NAP's guiding principles *'the role of ecosystems in vulnerability reduction for people, their livelihoods, and socioeconomic development'* (Government of Fiji, 2018), Fiji aims to fulfil the bill of rights framed within its constitution. The NAP also embraces participatory and inclusive processes by engaging sub-national and local governments in the design and implementation of NbIS.

Meanwhile, Dominica created the Climate Change Trust Fund's legal establishment to support vulnerable segments of society. This was in pursuit of the national climate resilience building priority: *'Create the supportive enabling framework whereby communities and vulnerable segments of society (women, youth, elderly, people with disabilities) can manage their climate change risks, thereby addressing climate change impacts on vulnerable sectors... and threats to food security, human health, poverty alleviation, sustainable livelihoods and economic growth.'* Dominica pursues the Gender Equality and Social Inclusion (GESI) approach throughout the development process.

3.3.6. Reconstruction Following a Disaster

Unless NbIS is already mainstream in the country, the necessary support for well-established good practices, standards, trained professionals, and technology will likely not exist in post-disaster contexts.

Introducing new ways of implementing infrastructure resilience in post-disaster contexts remains challenging. In theory, post-disaster reconstruction could be an excellent 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 strengthen resilience. Repairs usually occur as rapidly as possible, often replacing damaged assets in the same location without analyzing the causes of failure and considering other more effective alternatives.

For example, upper watershed degradation, inappropriate land use, loss of wetlands, and poor or inappropriate levee construction may have been the cause of flood damage to infrastructure in the lower watershed. A rapid bridge repair provides a provisional patch, responding to immediate social demand. At the same time, a NbIS project that could address the risk drivers may take years to design, approve, and finance (Box 3.9).

The application of methods such as FORIN (Alcántara-Ayala et al., 2016), through detailed analysis, can identify the cause of infrastructure failure in disasters and lay the ground for changes in policy and practice in favour of NbIS (Bella, 1997). As effective progress is not possible without robust failure detection, analysis, and adaptation, the knowledge gained from methods such as FORIN could help NbIS practitioners implement solutions that offer better outcomes.

3.3.7. Governance for NbIS

The engagement in and co-ownership of NbIS projects by the households and communities that provide or benefit from the ecosystem services generated is fundamental to their success and, above all, their sustainability.

Weak infrastructure governance is a major obstacle to the adoption of NbIS. Infrastructure projects' planning, designing, and implementation are often fragmented and siloed across different ministries and departments, discouraging a holistic approach to complex problems, such as urban heat islands. As Box 3.10 highlights, NbIS normally require interdisciplinary and cross-departmental coordination, with the extensive engagement of and ownership by communities and other stakeholders (Green et al., 2016), and processes that challenge entrenched bureaucratic structures and procedures. For example, implementing a successful stormwater upgrade with NbIS would require civil engineers, community organizations, government regulators, landscape architects, natural resource professionals, horticulturalists,

↓ **BOX 3.9**

Strategically Returning the Land to Nature:
The Town of High River, Alberta
Source: INFC (2022)

The managed retreat strategy in High River, Alberta, is a good example of the opportunities and challenges that post-disaster recovery offers when NbIS are introduced. After a devastating flood, the High River Council initiated a managed retreat strategy for the neighbourhood of Wallaceville and asked the province to initiate a Floodway Relocation Program (FRP). With the high risk of recurring floods, residents living in the floodplain were provided with a buyout option for their properties. The town's council initiated the floodplain buyout programme with provincial funding, providing incentives to remove exposed assets and people from high-risk areas to transit towards a naturalized floodplain.

The demolition of human-made structures provides space for nature to thrive again, yet restoration can expedite improvements in biodiversity. However, unlike other floodplain buyout programmes, the FRP did not include ecological restoration projects. It was voluntary and the limited one-way communication did not create shared responsibility for collective action.

The province owns the reclaimed land, and the town recommended transforming the area into an ecological park. However, some homeowners chose to rebuild despite being disqualified for disaster relief assistance in the event of another flood. Poorly executed knowledge sharing and communication about the risks and consequences were considered reasons for some people choosing to stay. As of 2015, the Wallaceville neighbourhood returned to an 'undeveloped' state. The town of High River integrated the buyout area into a park's master plan.

Global experiences, especially from LMICs, have also shown that resettlement in the context of risk reduction is complex, given that socio-economic and hazard risks compete for attention from communities and risk professionals and are rarely addressed holistically (Johnson et al., 2021). In these processes, often new environmental risks may emerge (Jain, Singh, et al., 2017). The overall relocation costs are significant and must be avoided, and other alternatives must be assessed in close partnership with affected communities (Jain, Johnson, et al., 2017).

financiers, and others to build a common vision and reach a consensus. Centralized and short-term budget cycles further hinder the adoption of NbIS.

Participatory planning and co-ownership of NbIS projects by the households and communities that provide or benefit from the ecosystem services generated are fundamental to their success and sustainability. Participatory engagement increases accountability and creates greater public visibility and resources to address public needs (Carothers & and Brechenmacher, 2014).

↓ **BOX 3.10**

Green Infrastructure for Stormwater Management
Source: USFS (2023)

The city of Portland, Oregon, used innovative green infrastructure design to address challenges such as urban flooding, water quality, biodiversity, heat islands, liveability, and climate change. The design addressed the risks posed by runoff in the existing combined sewer and stormwater systems across the city. It included both green and grey infrastructure, such as underground piping, eco-roofs, green streets, bioswales, rain gardens, sumps, and disconnected downspouts.

In addition, the city planted 59,000 trees, increasing the tree canopy by 9.3 percent in industrial, commercial, and residential areas, and installed over 550 eco-roofs covering more than 38 acres. Detailed modelling of the combined sewer system showed that green technology is more cost-effective than upsizing existing pipes in some city areas. The city's regulations, including a Stormwater Management Manual, require green roofs in some parts of the city and have a 'Green Street Stewards Programme' that partners with community members.

Portland funds construction projects through borrowed revenue bonds that are paid off with revenues from the city's sewer and stormwater rates. It has a strong commitment to inclusive governance, using outreach and communication, public/private partnerships, grant funding programmes, and collaborative planning and implementation with communities. It continues to adapt and modify its programmes based on feedback and monitoring and evaluation reports to ensure effective implementation.

3.3.8. In Search of a Political and Economic Imperative for NbIS

NbIS is often a slow solution in a context where many infrastructure requirements require quick action.

The prioritization of short-term economic gains over environmental integrity is an example of a moral hazard (Maskrey et al., 2023). Economic gains are *privatized*, while any resulting systemic risks are *shared* and *transferred* to other social groups or territories. NbIS may sometimes be unattractive politically precisely because it shares social and environmental gains and reduces opportunities for *privatized* profits.

NbIS is often a *slow* solution in a context where many infrastructure requirements need quick action. For example, grey infrastructure, such as a seawall, can be constructed in a relatively short time frame to deflect storm surges. At the same time, mangrove establishment or restoration is a longer-term venture. Even though effective, NbIS are often slower to mature and provide tangible benefits than grey infrastructure. The lengthy time frames required for planning and achieving measurable results may not mesh well with electoral cycles, thus undermining the political imperative for their adoption. Politicians normally favour highly visible projects with immediate results.

Similarly, investors prefer infrastructure projects that provide clear, tangible, and immediate benefits. The resilience dividends from NbIS may be slow to develop and require additional costs, while the social and environmental benefits do not accrue to the investor. At the same time, in many LMICs, powerful economic interests advocating grey infrastructure undermine the case for NbIS. Economic imperatives, such as the need to attract foreign direct investment, may override proposals to introduce NbIS if these are seen to hinder investment.

Additionally, NbIS often require more land than traditional infrastructure. High-priority areas for protecting or restoring ecosystems may not be publicly owned or may require negotiations with landowners to proceed, particularly in cities with limited green space, creating increased resistance.

Box 3.11 highlights how extractive activities, such as mining or timber, often fail to value the benefits provided by ecosystem services (such as wetland flood attenuation) to enhance infrastructure function (such as sediment and erosion control), and protect engineered assets (for example, mangroves protecting coast telecommunication networks) and co-benefits, including potential for increased ecotourism, food security, and employment opportunities.

There is no single recipe for improving political will in a way that would facilitate the uptake of NbIS. In many countries, adopting a national resilience strategy, policy, and plan following a catastrophic event that galvanizes political will may provide a vehicle for adopting NbIS. To be effective, a national resilience strategy would require political support at the highest level of government and developed with a long term vision. It would need to provide a framework for infrastructure planning across different sectors and at the territorial level. This would also require an interdisciplinary approach bringing together the skill sets currently siloed in different sectors, such as environment and public works, with the technical capacity to value the ecosystem services provided. Ultimately, and as discussed in Chapter 4, adopting a strong resilience policy and strategy may positively change the risk perception of the country in question, increasing investor confidence and analyst ratings and reducing the cost of capital. If a strong economic, financial, and social imperative emerges for nature-based infrastructure, it may generate a stronger political imperative.

↓ BOX 3.11

In Defence of Biodiversity in Intag, Ecuador
Source: USFS (2023)

The Intag community in Ecuador faces the dilemma of extracting significant copper reserves or valuing the ecosystem services of the area for their future growth. The cloud forest area measures 150,000 hectares and includes two globally significant biodiversity hot spots. The Ecosystem Service Valuation (ESV) found that 17 out of 23 ecosystem services across the landcover types in Intag provide regional and national communities with an average of $447 million in yearly benefits and ecosystem services, including carbon storage, water provision, erosion control, and pollination. On the other hand, economic feasibility studies estimated the areas had 318 million tonne of copper ore in the ground valued at $85 billion in 2011.

Ecuador's innovative constitution gives rights to nature, stating that 'nature has the right to exist, persist, maintain, and regenerate its vital cycles, structure, functions, and processes in evolution'. Ecuador's mining law also states that 'all mining investors must respect the right to the communities' information, participation, and consultation regarding environmental management of all mining activities.

For over two decades, the Intag community has worked to develop and implement an alternative and prosperous vision of the region's economy, which does not include mining. In 2022, Intag community leaders used the 2011 ESV report to support a lawsuit against the Ecuadorian government over mining concessions. This case is headed to Ecuador's Supreme Court, where it is likely to establish a key precedent for the fate of other cloud forests in the country.

A key recommendation of the report is that economic development within the Intag region is best achieved by tapping the vast value that ecosystem goods and services provide. This study allows decision-makers to develop a sustainable economy in which natural capital is an integral part of investments that maintain or rise in value over time. It is a first step towards understanding the significant economic and social risks of mining operations in Intag while accounting for the significant economic contributions that ecosystems make to the regional and national economies.

3.3.9. Building the Business Case for NbIS

Conventional methods for accounting costs and benefits and rates of return used in infrastructure financing often fail to include the systemic risks posed by infrastructure investments on the environment.

Many businesses and public services have good reasons for investing in NbIS. To stay viable, they depend on ecosystem services, including clean and abundant water, fertile soils, healthy forests, and biodiversity. Business leaders often state that investing in nature helps to achieve sustainability goals, strengthen their market brand, manage regulatory requirements, promote employee well-being, and reduce disaster risks (The Nature Conservancy, n.d.). Highlighting the positive social, economic, and environmental benefits that can accrue from NbIS is critical to its political attractiveness and viability. While reduced loss and damage should be accounted for in calculating the costs and benefits and rates of return on investment of NbIS projects, it should be noted that local politicians rarely win elections on promises of avoided future losses but rather on tangible present benefits (Lavell & Maskrey, 2014).

However, providing 'proof of concept' that NbIS can provide these benefits, by itself or in concert with grey infrastructure, continues to be a challenge. Much of the existing evidence is not widely available nor easily accessible. Rather than generating *more* proof, the challenge is to disseminate and market existing proof.

The conventional methods used in infrastructure financing to account costs and benefits and rates of return often fail to include the systemic risks posed by infrastructure investments on the environment. The net present value calculations do not account for the potential appreciation of the performance of NbIS over time, compared with the depreciation of traditional infrastructure, thus largely undervaluing NbIS. Notably, the long term benefits of protecting, supporting, or supplementing infrastructure with NbIS are not accounted for or monetized in a way that encourages investment.

In contrast, environmental cost-benefit (OECD, UN Environment, et al., 2018) may show how including NbIS in a project would have a greater cost-benefit ratio than grey infrastructure alone. **In the USA, it was found that for every 10 percent increase in forest cover above a water source, there was a 20 percent decrease in water treatment costs. Costs were 211 percent higher for a watershed with 10 percent forest cover than one with more than 60 percent** (Ernst et al., 2004). The USA has now begun to protect watersheds by limiting human intervention above municipal water supply points.

Unfortunately, environmental accounting methodologies and their use in cost-benefit analyses are still not standardized. At the same time, they require interdisciplinary input from natural scientists, engineers, and economists to minimize uncertainty and accurately account for all costs and benefits to societies and the environment (Center for Neighborhood Technology, 2011; The Water Research Foundation, 2021).

The 'valuation of ecosystem services is often confused with commodifying or privatizing nature' (Costanza et al., 2014). However, calculating and monetizing the environmental, social, health, and economic benefits of applying NbIS is fundamental. Valuation builds a more comprehensive, balanced picture of the resilience dividend accrued using land and ecosystems to support social and environmental well-being. Its importance, therefore, cannot be underestimated (Costanza et al., 2014).

Several methods (e.g., replacement costs, market pricing, hedonic pricing, avoided costs) exist that can monetize the economic value of ecosystem services. Due to the time required to gather the raw data for most of these valuation methods, the simpler benefit transfer method is often used. This method accumulates information from studies done in similar ecosystems to provide a low- and high-value range of ecosystem types and service values (Plummer, 2009). Improvement in the confidence of the benefit transfer methodology can be accomplished through in-depth studies shared by NbIS practitioners.

For the valuation of ecosystem services to become common practice in environmental policy and infrastructure investment decisions, three shifts need to happen: the realization that ecosystem services have a value, understanding and knowledge of how to monetize ecosystem service value, and a requirement to undertake valuation exercises to decide future land use.

3.3.10. Developing Markets for NbIS

When developing programmes that pay for ecosystem services, it is important that payments prioritize the land that offers the most significant level of ecosystem services or risk reduction.

Various conservation finance instruments have been used to protect and enhance the ecosystem services provided by given areas of land (Box 3.12). Conservation finance programmes require underpinning by strong community-based, local institutions. The engagement of local institutions plays an important role in the viability and sustainability of any conservation finance programme (Thuy et al., 2013). Therefore, it is critical that communities be engaged upfront in project design and CoPs be established to accompany them in the future.

When developing programmes that pay for ecosystem services, it is important that payments prioritize the land that offers the most significant level of ecosystem services or risk reduction. For example, a water company may fund landowners whose property drains directly into a water supply reservoir or stream system above its water intake system. The landowners would be funded based on the capacity of their land to reduce erosion and increase water infiltration to replenish groundwater. Similarly, cities or downstream communities could make payments to landowners to maintain or restore wetland and riparian areas to increase stormwater storage and attenuate peak flows to minimize flooding and improve the water quality downstream.

Potential threats, such as deforestation, mining, rainforest conversion for palm oil, soy, cattle grazing, and so on, to these ecosystem services should be identified and payment rates and schedules established to compensate landowners for not pursuing these other, often lucrative, land uses.

A known user base is also required to identify ecosystem service buyers (Box 3.12). For example, users of electricity from a hydropower plant, building owners or renters who benefit from reduced energy costs from green roofs, transport users benefiting from resilient roads, communities or powerline companies protected from wildfire, and so on. Ecosystem service providers can also be identified by identifying, estimating, and geolocating risks. For example, owners of land that affects adjacent and downstream infrastructure resilience. Infrastructure developers can then pay for the management of that land so that it provides the required ecosystem services. Payment rates could vary based on the ecosystem condition.

↓ **BOX 3.12**

Valuation of Ecosystems

Source: Eugene Water and Electric Board (2017)

Valuations of ecosystems vary by locality and ecosystem types. Figure 3.6 shows the values of ecosystem services obtained from the protection of riparian forests for developing a water quality protection programme by the Eugene Water and Electric Board (EWEB), USA. Other ecosystem services, such as habitat values, disaster risk reduction, recreation and tourism values, water temperature benefits, and cultural values, should have been added to the total ecosystem value but were not assessed in this study.

Even without considering the full range of benefits, EWEB's future costs for protecting riparian forests under the watershed protection programme were estimated at $1980 per acre, while the net present value of the benefits was $7131 per acre. This represents a return of approximately $2.60 for every $1 invested, over a 20-year period, due to reduced water quality treatment operation costs from implementing NbIS to protect the environment above the water treatment plant. When adequately valued, the ecosystem services can often justify the implementation of NbIS (Figure 3.6).

→ **FIGURE 3.6**

Examples of benefits and values of ecosystem services

3.3.11. Achieving Scale

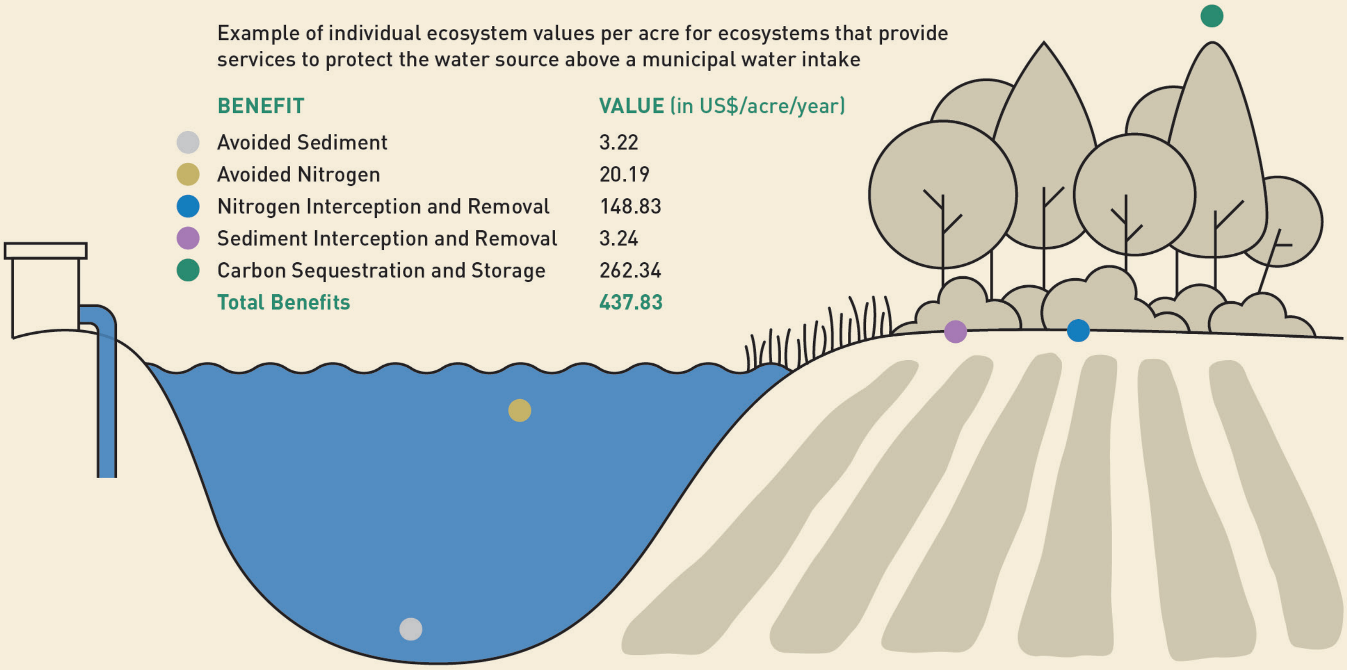
While pilot projects are often initially expensive, costs can be reduced as good practices are curated, norms and standards codified, and investors and project designers gain confidence.

According to a 2016 Forest Trends and JP Morgan report, over $3.1 billion in sustainable investment capital remained idle due to a lack of investment opportunities in conservation finance, and only 51 percent of government climate funds had been deployed due to a lack of projects in the pipeline or projects that were too small for private finance (Buchner et al., 2021). As a result, conservation-focused investors have not had sufficient opportunities to support NbIS projects (Hamrick, 2016).

Many NbIS projects are too small scale, and the expected returns on investment are too far into the future to be attractive to private investors. The challenges described above conspire to limit the development of self-sustaining national markets for NbIS. These markets 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.

Example of individual ecosystem values per acre for ecosystems that provide services to protect the water source above a municipal water intake

BENEFIT	VALUE (in US$/acre/year)
Avoided Sediment	3.22
Avoided Nitrogen	20.19
Nitrogen Interception and Removal	148.83
Sediment Interception and Removal	3.24
Carbon Sequestration and Storage	262.34
Total Benefits	**437.83**



Example of the types of ecosystem services and their values per acre based on avoided costs at the water treatment plant resulting from the protection of riparian forests

NATURAL ASSET	VALUE (in US$/acre/year)
Wetlands	34,888
Lakes and Rivers	3,041
Riparian Forests	6,717
Forests	3,677
Shrub and Scrub	2,710
Grassland	695
Agriculture	644

However, while pilot projects are often initially expensive, costs can be reduced as good practices are curated, norms and standards codified (Blue Forest Conservation, n.d.), and investors and project designers gain confidence. In particular, the identification of financial incentives and innovations unlocks solutions to some of the systemic challenges. Bundling NbIS projects into investment pipelines that mutualize risk across sectors may draw private investors' interest and enable a centralized funding source for local NbIS practitioners to access. This structure combines bottom-up locally anchored knowledge and processes in project design and implementation with top-down investment opportunities and is further discussed in Chapter 4. Integrating NbIS into existing pipelines of grey infrastructure delivery systems can be a way to achieve scale, reduce loss and damage to infrastructure assets, and prevent loss of biodiversity. For instance, Jamaica Systemic Resilience Assessment Tool (J-SRAT) was developed to identify the co-benefits derived from NbIS (Box 3.13).

→ BOX 3.13

Jamaica Systemic Resilience Assessment Tool (J-SRAT) and Hybrid Projects Pipeline Structuring Methodology with the Deployment of Nature-based Solution (NBS)

Source: GCF (2023)

Societal Challenge Addressed: Water, energy, and transport infrastructure are resilience priorities for Jamaica. The J-SRAT integrates climate risk analytics into decision-making and planning for these critical infrastructure sectors (Figure 3.7). It shows how integrating NbIS can reduce loss and damage to infrastructure assets and loss of life and biodiversity from development pressures and extreme weather events. It also provides mitigation co-benefits when carbon-intensive hard infrastructure is replaced by NbIS, and existing carbon sinks are protected.

Scale of Design: A nationwide assessment was done of existing terrestrial and marine ecosystems and relevant existing and potential ecosystem services to reduce flooding, increase water quality, reduce droughts, and protect infrastructure from extreme wind events. Development and climate threats were identified and mapped, as well as potential NbIS to address those threats. A cost-benefit analysis of implementation and maintenance costs and factoring of the time required for NbIS to become effective was used to prioritize projects across the country.

Economic Feasibility: A comparison of high-level estimated capital expense (CAPEX) and operational expense (OPEX) was conducted for high-priority projects, as well as a broader analysis of the feasibility of mobilizing climate finance.

Inclusive Governance: Led by the Jamaican Government, the design included an inclusive multi-stakeholder structure involving financing, development, and project implementers.

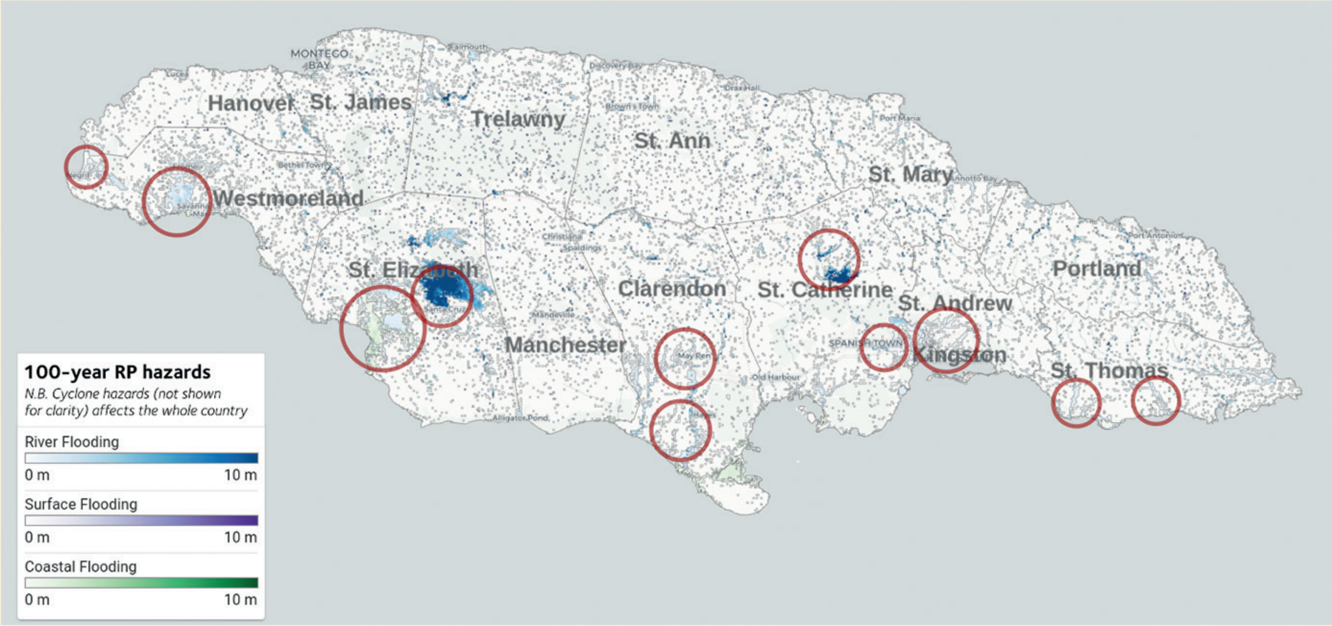
Adaptive Management: The inclusive governance set-up was based on consultations allowing refinement of the approach-based ground truthing.

Mainstreaming and Stability: This step-by-step methodology facilitated upscaling in Jamaica or replication in other contexts.

↓ FIGURE 3.7

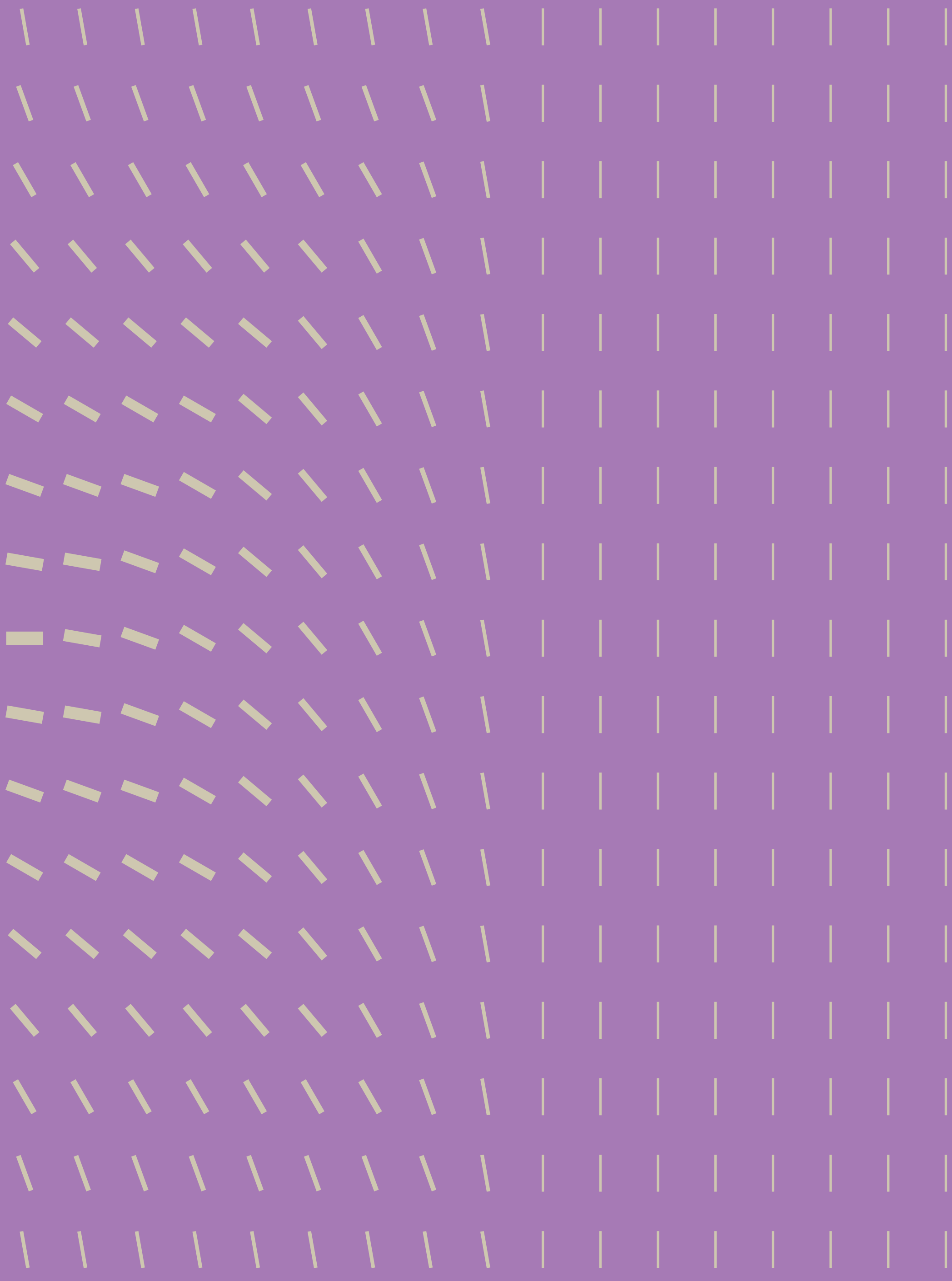
J-SRAT Tool Showing Sub-national Hazard Hotspots

Source: Oxford University



Chapter 4

Financing for Disaster- and Climate-Resilient Infrastructure



4.

Financing for Disaster- and Climate-Resilient Infrastructure

4.1. Introduction

The bulk of new infrastructure investment over the next 30 years needs to take place in LMICs

Financing infrastructure resilience requires mobilizing investment from geographies and sectors with surplus capital to those where major new funding is required.

Mobilizing new investment at large scale can only be facilitated by significant changes in the financial system and by building on the capacities of existing institutions (G20, 2018). Underinvestment in infrastructure is fundamentally one of the fault lines of the world economy and a key risk driver of stagnation in global economic growth (Blanchard, 2019; Krugman, 2014; Rachel and Summers, 2019).

As announcements of major new infrastructure investments by the USA and EU have shown, high-income countries have sufficient capacity for public investment to scale up their infrastructure investments (Chapter 1). They are also attractive markets for private capital. High-income countries are upgrading and replacing obsolete infrastructure that has outlived its design life and making major investments in renewable energy to accelerate the transition to net-zero emission. However, even these countries struggle with the increasing cost of capital, governance issues, and inadequate return on investments in infrastructure assets.

The bulk of new infrastructure investment over the next 30 years needs to take place in LMICs. As previously argued, given the design lifecycles of new infrastructure, planning and investment decisions made today will determine whether countries follow one of the two alternative future trajectories: sustainable social and economic development or constrained development and increasing contingent liabilities and higher systemic risk (IIHS, 2023). It is not just new investment that is required; it is investment in infrastructure resilience.

Mobilizing the finance required to strengthen infrastructure resilience in LMICs is a huge challenge. Weak infrastructure governance is consistent with a low rate of return on investment, project delays, complex approval mechanisms, and political uncertainty, all of which discourage private investment. At the same time, domestic financial markets generally lack capacities to channel capital towards infrastructure resilience. Therefore, identifying incentives and mobilizing finance for a new 'resilient infrastructure asset class' becomes imperative (IIHS, 2023).

Most infrastructure in LMICs is currently financed through public investment, with significant participation from MDBs. However, the infrastructure resilience deficit cannot be addressed without a drastic increase in private investment. Unfortunately, governments and private investors are yet to fully recognize the significance of investing in resilience.

In the public sector, only a weak political and economic imperative exists for investing in resilience. As discussed earlier, resilience benefits typically accrue over long periods, while electoral cycles demand short-term and visible results. Private investors are yet to be convinced of the relevance or commercial benefits of investing in resilience. As highlighted in Chapter 3, traditional cost-benefit analysis rarely captures the broader benefits of resilience, such as avoided loss, damage, and service disruption, or the environmental, societal, or economic co-benefits over the entire lifecycle of infrastructure assets. Furthermore, even if the resilience dividend is identified and measured, it is unclear how it can benefit investors. Identifying a compelling political and economic imperative for investment in resilience is, therefore, critical, along with mechanisms and incentives developed to integrate that imperative into investment decisions.

4.1.1. The Infrastructure Resilience Finance Gap

The infrastructure resilience finance gap can be defined as the difference between the sum of the investment needed to strengthen the resilience of existing infrastructure and build future resilient infrastructure and existing and projected public and private finance, including climate finance.

Estimates of the size of this gap vary widely and depend on the type of transformation envisaged,[21] the assumptions made, and the way income geographies are classified.[22] Most estimates include the requirements to achieve the SDGs or net-zero economies or both, but do not explicitly contemplate strengthening resilience. The World Bank estimated that developing countries need to invest around 4.5 percent of GDP to achieve infrastructure-related SDGs (Rozenberg and Fay, 2019). Other studies showed an annual shortfall of $2.5 to $3 trillion between required and available resources (OECD, UNEP et al., 2018).

The assumptions that underpinned these earlier estimates now need to be reappraised. Recent assessments have found that investment in physical assets, energy, and land use amounting to $9.2 trillion per year would be required between 2021 and 2050 to achieve net zero; this is an increase of $3.5 trillion or the equivalent to one-quarter of global total tax revenue in 2020 (McKinsey Sustainability, 2022).

LMICs, particularly those with low GDP per capita and a high dependency on fossil fuels, require more investments relative to GDP to undertake this transition (Averstad et al., 2023).

[21] For example: to achieve the SDG or to transit to net-zero economies.

[22] The definition of developing countries by the United Nations is different from that of LMICs by the World Bank or low-income developing countries and emerging economies by the IMF. However, there is a significant overlap between all three classifications.

They are also more vulnerable to the downsides, such as stranded infrastructure assets and employment shocks. **LMICs will thus have to spend approximately 30 percent of the global investment in infrastructure assets and land use to achieve net zero, which amounts to $2.76 trillion annually (South Pole Carbon, 2022). If it were assumed that the cost of strengthening infrastructure resilience represents an additional 3-5 percent, the total annual requirement would be in the range of $2.84-$2.90 trillion.**

The infrastructure investment of LMICs is far behind of what is actually required (African Development Bank et al., 2021). Private investment in LMICs was approximately $40 billion in 2021, with additional climate financing of around $50.7 billion channelled through MDBs (GIH, 2022). Estimates of public investment vary, but it seems likely that the sum of public and private investment and climate finance may be around one order of magnitude lower than the requirements in these countries.

Furthermore, even this estimate is probably overstated as much of the *new* investment is, in reality, used for repairing and rehabilitating damaged infrastructure. As highlighted in Chapter 2, **the proportion of GFCF at risk of disaster, climate loss, and damage in LMICs ranges from 4.7 percent in upper-middle income countries to 9.1 percent in low-income countries (GIRI, 2023). In 2021, total GFCF in low-income countries was $124 billion. This implies that around $11.3 billion would have to be set aside annually to cover the costs of repair and rehabilitation.** Owing to accumulated disaster and climate risk, less investment is available for new infrastructure in LMICs.

4.2. Climate Financing

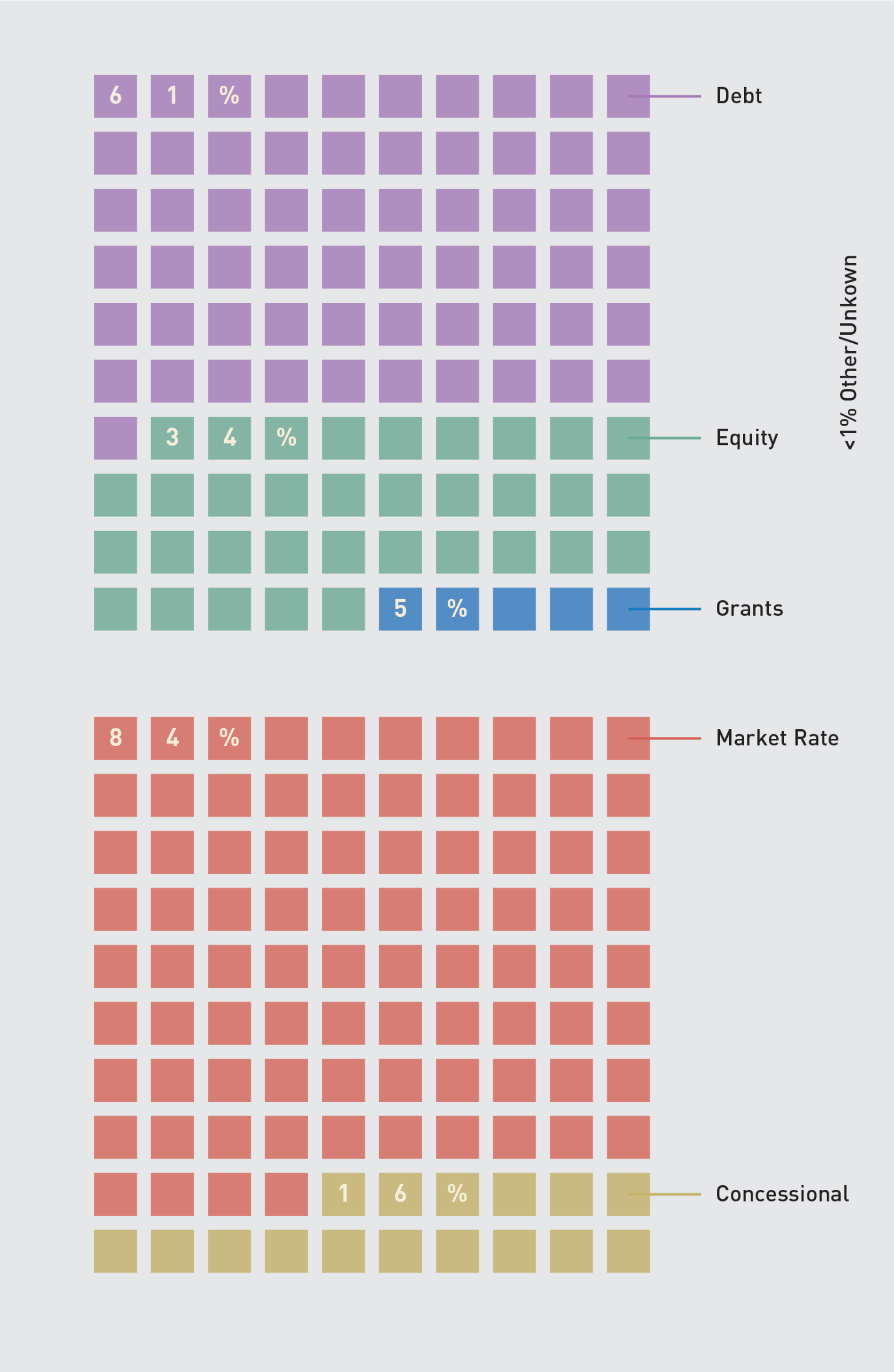
Climate adaptation finance is one of the few new sources of funding that LMICs can access to strengthen infrastructure resilience, primarily through MDBs. **In 2021, MDBs provided $19 billion in total adaptation financing, of which 92 percent went to LMICs, with South Asian and Sub-Saharan African countries accounting for 41 percent of committed funds** (African Development Bank et al., 2021). An additional $3 billion was mobilized from the private sector by MDBs. However, only a part of these funds has been dedicated to strengthening infrastructure resilience.

Dedicated multilateral funds, such as the Green Climate Fund (GCF), are also key sources of adaptation finance to LMICs, particularly in least-developed countries and SIDS. GCF has made an overall commitment of $11.3 billion since its inception in 2010, with $8.8 billion currently under implementation. The crucial feature of GCF is that it can tap into and catalyze both public and private finance flows, offering a range of financing instruments, from loans, equity, guarantees, and grants to specifically adapted solutions in investment-scarce environments. Its ability to partner with the private sector means it can help countries to de-risk large infrastructure investments and raise additional funding for climate action.

Over the past decade, only 16 percent of climate finance was concessional finance while 5 percent was grants (Figure 4.1). Concessions and grants are crucial in de-risking investment in the new technologies required to achieve net zero and in markets such as LMICs (Buchner et al., 2021). Instead, **debt remains the dominant instrument for climate finance**, increasing the risk for countries already struggling with high debt levels. As discussed, climate finance may not be appropriate for all resilience requirements. A significant proportion of infrastructure risk is associated with high-severity, long-return period events such as major earthquakes and tsunamis and is already internalized in existing infrastructure. Climate adaptation funding is not appropriate for addressing these risks.

In large emerging economies, such as India and South Africa, domestic budgets are an important source of adaptation finance, far exceeding international finance. In line with Article 2.1(c) of the Paris Agreement, there is a growing recognition that domestic budgeting should fully account for revenues and expenditures that enhance resilience in order to make finance flows consistent with low-carbon and climate-resilient development pathways.

Debt remains the dominant instrument for climate finance



↑ FIGURE 4.1

Climate Finance by Instrument, 2011-20 (in bn US$)

Source: Buchner et al. (2021)

If climate finance is insufficient to strengthen infrastructure resilience, a new approach to mobilizing capital is required. This would combine public sector support to de-risk investments and identify, estimate, and monetize the resilience dividend with private sources of capital to fund aggregated pipelines of infrastructure projects. In other words, resilience finance should become a mainstream channel for developing infrastructure, supplemented by climate finance.

4.3. Investing in Resilience

Investing in resilience can provide a dividend that outweighs the additional costs.

Some estimates claim that including resilience measures in infrastructure projects produces an average dividend of $4 for every $1 spent (Hallegatte et al., 2019). However, in reality, the costs and benefits vary enormously, asset by asset and sector by sector.

For example, the global power sector would require annual capital spending of around $2 trillion to decarbonize; it could create employment benefits of up to 43 million additional jobs by 2050. Meanwhile, the mobility sector would require annual spending of $3.5 trillion for road transportation transformation alone, but with net losses in employment of up to 3 million jobs lost by 2050 due to productivity gains in low-emission vehicle manufacturing (McKinsey Sustainability, 2022).

The Ministry of Economy and Finance in Peru was a pioneer in introducing resilience considerations into public investment planning and evaluation. Table 4.1 shows how the resilience dividend varies widely across public investment projects in Peru for hazard events of different return periods, considering only the value of avoided loss and damage. Achieving high levels of structural resilience of infrastructure may not always be economically viable, and normally some of the risks must be retained (ICSI, 2022). Strengthening resilience always involves trade-offs that must be identified and negotiated politically in each sector or territory. However, as the case studies summarized in Section 2.8 show, a resilience dividend exists even when considering only avoided loss and damage.

There is an estimated $106 trillion of untapped private institutional capital worldwide

↓ TABLE 4.1

Cost-benefit Relationship in Public Investment Projects in Peru

Source: UNISDR (2009)

Public Investment Project	Additional cost of disaster risk reduction(US$)	ESTIMATED VALUE OF AVOIDED LOSSES AND RECONSTRUCTION COSTS			
		25% probability of disaster in 10 years	50% probability of disaster in 10 years	75% probability of disaster in 10 years	100% probability of disaster in 10 years
Reconstruction of housing and water infrastructure following the 23 June, 2001 earthquake in Castilla Province	382,788	132,601	265,202	397,802	530,403
				Benefit / cost ratio = 1	
Prevention and preparedness for mudslides and floods in the upper Rimac Valley	95,616	330,986	661,971	992,957	1,323,942
				Benefit / cost ratio = 10	
Extension of the Pampacolca health centre (module to attend pregnant women)	15,570	6,789	13,579	20,368	27,158
				Benefit / cost ratio = 1.3	
Rehabilitation and construction of dykes in the Cansas Valley	95,616	330,986	661,971	992,957	1,323,942
				Benefit / cost ratio = 37.5	
Rehabilitation of the Machu Picchu hydroelectric plant	95,616	330,986	661,971	992,957	1,323,942
				Benefit / cost ratio = 19	

Note

Shaded cells indicate that value of avoided losses exceeds additional costs of disaster risk reduction investment

4.4. Challenges to Mobilizing Finance for Resilient Infrastructure

There is an estimated $106 trillion of untapped private institutional capital worldwide, which would be more than sufficient to close the current infrastructure resilience investment gap (World Bank Group, 2016). **However, only 1.6 percent of it is currently invested in infrastructure, mainly in high-income countries and renewables.[23] How to attract this capital to geographies with the greatest need, therefore, is the crux of the financing challenge.**

The ability of countries to mobilize private capital for infrastructure resilience is highly dependent on their capacity to develop and implement projects in the context of their overall quality of infrastructure governance (South Pole Carbon, 2022).

Challenges and barriers to accessing private capital include misperceptions of the costs and benefits of investing in resilience, governance issues, weak institutional capacities, and the limited buoyancy of public domestic capital markets (Table 4.2).

↓ TABLE 4.2

Challenges and Barriers to Investing in Resilience

Source: South Pole Carbon (2022)

Key Challenges	Barriers
Unquantified risk and misperception of investment in climate resilience	
Perception of additional cost, uncertain benefits	Building resilience often requires higher upfront costs while bringing potentially uncertain, heavily discounted long term economic benefits. Given the deferred benefits, investment in resilience is perceived to be more expensive.
Externalities – the broader resilience dividends	Typical cost-benefit analysis underestimates the broader benefits of resilience, making such investments appear unattractive. Cost-benefit analysis may focus only on avoided physical asset damages, not other benefits.
Information asymmetries	There is no common agreed way to measure resilience or its wide-reaching benefits. Infrastructure owners rarely share information on risk due to security concerns. Many infrastructure managers have little experience with disasters.

[23] Another assessment by the IMF estimates that low-income countries and small state countries would require additional investment to the tune of 1 to 2% of their GDP annually in resilient infrastructure and ecosystems, the majority of which are targeted towards coastal protection.

Key Challenges	Barriers
Infrastructure governance, policy, and institutional capacity	
Commitment and ownership of risk	Identifying key stakeholders in resilient infrastructure is difficult. Often, the infrastructure is owned and managed by multiple stakeholders and requires a clearly defined institutional mechanism to aggregate or take ownership of the associated risks.
Institutional, technical and enforcement capacity	Resilience requires additional technical capacity and an enabling environment to ensure compliance. However, basic infrastructure management may be lacking in many LMICs, particularly at the local level. Many countries do not have a resilience policy or strategy for infrastructure.
Maintenance	To be sustainable, resilience requires ongoing operations and maintenance, which can further misalign the incentives to invest.
Institutional capacity to develop 'bankable' projects	LMICs often lack the institutional capacity to develop 'bankable' projects that clearly quantify the risks and the broader benefits of investing in resilience.
Public finance and capacity to innovate	
Limited public capital	Many LMICs, particularly small economies, have limited public capital to invest and to balance social and economic development requirements, climate mitigation ambitions, and strengthening resilience. Often due to limited upfront capital, 'additional' resilience financing is not available.
Public investment planning	Most LMICs lack capacities for risk estimation to inform public investment planning and evaluation, and incorporate financial resilience metrics in project formulation.
Credit rating of public agencies and vibrancy of local capital market	Low credit rating of public agencies, coupled with a limited revenue base that can be escrowed to mobilize financing from upfront investments, limits access to local and international debt capital markets. Additionally, local debt capital markets may be at the inception phase of development. Financial markets in LMICs often lack depth, access, efficiency, and stability,[24] limiting the possibility of using capital markets to access financing for resilience.
Knowledge and flexibility to access funding from innovative tools	Most LMICs have limited knowledge of innovative financing tools, such as carbon offsets, event-based insurance and reinsurance, catastrophe bonds, and their potential. Often accessing funding from these tools requires flexibility in policies and regulations as a prerequisite.
High cost of capital	The current macroeconomic context of high inflation, increasing interest rates, a higher debt burden, and supply chain constraints exacerbate the costs of project capital.

[24] Market depth reflects the sufficient size of the financial institutions and financial markets. Market access represents the degree to which economic agents can use financial services. Market efficiency reflects the ability of financial institutions to successfully intermediate and facilitate financial resources and transactions. Market stability represents the low volatility and institutional fragility of the market.

4.5. Pathways to Upscaling Financing for Infrastructure Resilience

4.5.1. Strengthening Infrastructure Governance: National Resilience Policies, Strategies and Plans

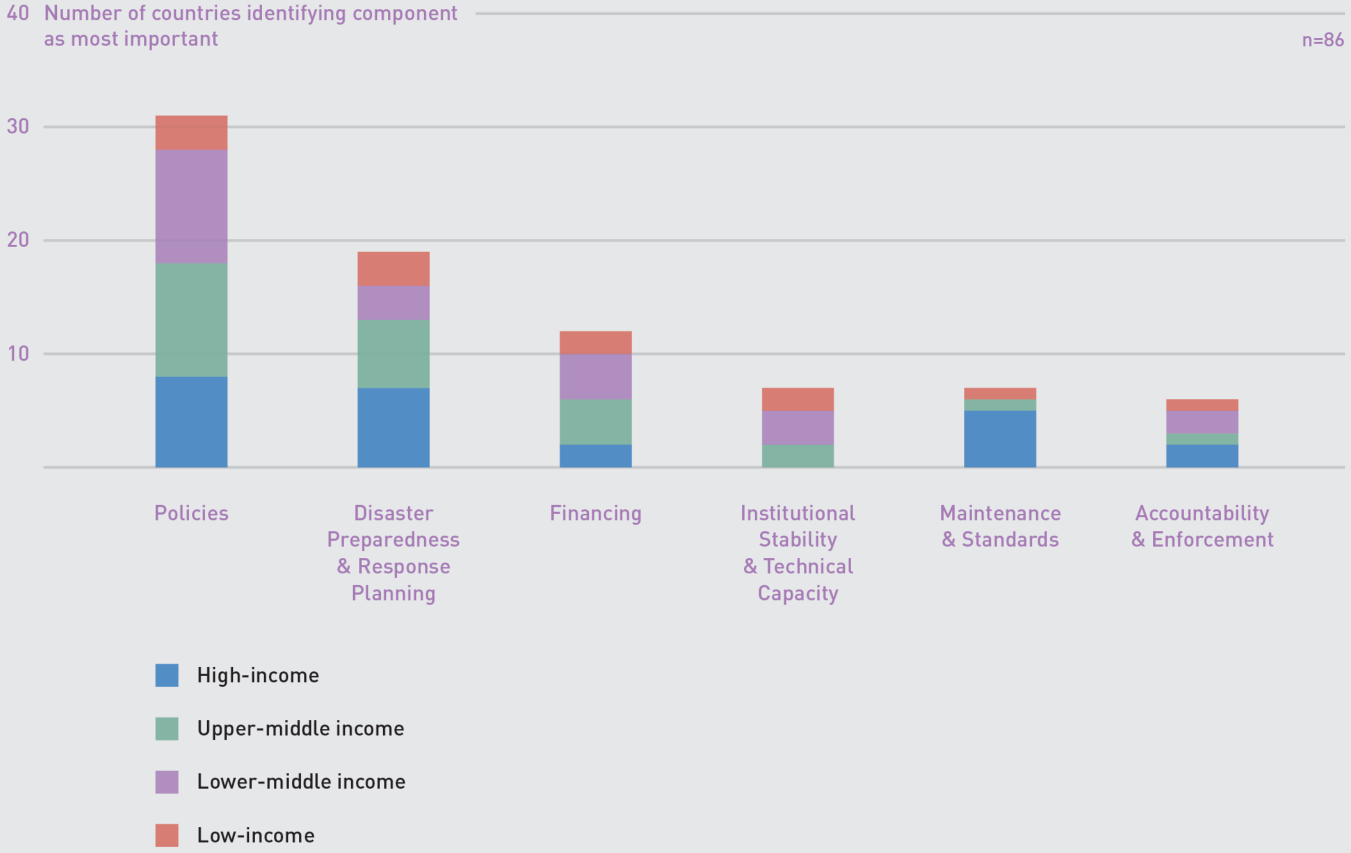
Infrastructure governance should encompass not only asset resilience but also service and systemic resilience. Infrastructure characteristics that require specific attention include long-duration assets, natural monopoly, social returns that exceed private returns, and the role of government as a shareholder.

Infrastructure governance may be strengthened by developing national resilience policies, strategies, and plans that identify which levers of change can facilitate the integration of resilience into infrastructure as part of a systemic approach (ICSI, 2022) with inclusiveness practised throughout the design cycle of procurement, delivery, management, and risk assessment. The integration of levers of change can enable identifying infrastructure projects with the greatest potential for a net positive impact in terms of reduced risk and strengthened resilience.

An essential first step in most countries is to ensure the development and maintenance of a national audit of all infrastructure asset classes and service nodes, including spatial information, data on the authorities involved in building, the quality of O&M and services, and asset loss and service interruption. Such audits can identify per capita access to local and strategic infrastructure and ascertain the basic infrastructure deficit. The service delivery levels and updates can give greater insight into the level of resilience and the establishment of priorities for investment.

The application of financial risk metrics, such as those produced by the GIRI, can then allow risk and resilience to be layered in each sector and territory. The layering of risk is critical as some assets may be resilient to high-frequency, low-severity events such as floods or storms but not to low-frequency, high-severity events such as high-magnitude earthquakes or tsunamis. By layering risk, national resilience strategies can then identify the most cost-effective approach to ensuring resilience, including prospective risk management (higher infrastructure standards, environmental protection, etc.), corrective risk management (retrofitting, reinforcing, and remedial measures), compensatory risk management (risk financing and transfer), and reactive risk management (early warning systems and effective response and recovery).

National resilience policies are essential for determining country-specific resilience objectives and the different levers of change that can be



↑ FIGURE 4.2

The Importance of Policy Frameworks for Infrastructure Resilience (GIRS)

Source: Chow and Hall (2023)

used in the policy mix; for example, to ensure that procurement policies adhere to internationally agreed resilience standards and encourage the development of Model Concession Agreements (MCAs) forPPPs aligned with resilience targets (IIHS, 2023). Japan, for example, introduced the PPP model on a large scale by enacting and promoting the Private Finance Initiative (PFI) Act. The Cabinet Office has established a PPP/PFI Promotion Office, which plays an advisory role to the Prime Minister and other relevant public agencies and has developed several guidelines that help local governments understand the process of PPP projects and contracting. The same office coordinates PPP promotion with the public and across central government agencies (Chavarot, 2023).

As Figure 4.2 shows, the GIRS confirmed the importance of national policies: 'In most nations, having stronger policies are seen as the most important infrastructure management development to ensure long term resilience'.

The development of national resilience policies, strategies, and plans can already send positive signals to capital markets that a country is serious about strengthening resilience, improving potential returns, and reducing risks for investors. If reflected in the reports of rating agencies and risk indexes,[25] risk perceptions may then be improved and the cost of capital reduced. Box 4.1, in the case of Dominica, shows how aspirational national policies can create a centre of gravity to attract a range of resilience actions.

[25] For example, the WEF Global Competitiveness Index or the EIU Country Risk Profiles.

4.5.2. Financial Risk Metrics and the Economic Case for Resilience

Private capital investment in infrastructure does not adequately account for sustainability-related risks, but the sector is changing rapidly. For investors to fully understand their portfolio risks and shift investments towards more strengthened resilience, metrics that account for disaster and climate risks need to be included in financial models and asset balance sheets.

Disaster and climate risk translate into financial risk (Figure 4.3) (WWF India, 2023). This includes risk associated with hazards that impact the asset and systemic risk that the asset itself may generate (Maskrey et al., 2023). For example, the Delhi Metro was designed considering earthquake risk. Still the surrounding development facilitated by the Metro increased the overall systemic risk, including local impacts on the surrounding environment and communities and global impacts, such as carbon emissions (Jain, 2015). Both kinds of risk affect an asset's financial performance via feedback loops, referred to as 'double materiality' (WWF India, 2023).

Unfortunately, in most LMICs, robust, comparable, and credible disaster and climate risk metrics are not available in a form that can be easily used to measure the financial risk in projects. Consequently, the resilience dividend cannot be properly quantified. This remains a key hurdle in attracting private capital as it adds additional uncertainty to projects and implies hidden contingent liabilities for potential investors.

The lack of accessible risk data is now recognized as a critical barrier by financial institutions (Willis Towers Watson, 2021). In many LMICs, the required input data on hazard, exposure or vulnerability, disaster loss and damage, or ecosystem services may not exist or be heavily constrained due to institutional silos and national security issues. However, the growing availability of high-resolution, publicly accessible global data enables the development of global risk models such as GIRI that begin to close the gap, even in countries where official data is difficult to access. As explained in Section 2.8, downscaling these models to the national or sub-national level can make a clear

↓ **BOX 4.1**

Dominica's Vision to be the World's First Climate-resilient Country

Source: Maskrey et al. (2023)

Before Hurricane Erika and Hurricane Maria devastated this Small Island Developing State in 2015 and 2017, respectively, Dominica pursued a more traditional approach of corrective risk management with a dominant focus on preparedness and response. The increasing concern for climate change opened a window of opportunity to drive a significant shift in the national policy towards prospective action and a commitment to transforming the island into the first climate-resilient country in the world.

The Prime Minister, in his address at the CARICOM (Caribbean Community)-UNDP Conference in New York in November 2017, soon after Hurricane Maria, stated, 'The unprecedented challenge we face has led us to take the unprecedented decision to build an executive agency outside of our standard public service systems. We are calling it CREAD – Climate Resilient Execution Agency of Dominica. The mission of the agency will be to coordinate all reconstruction work to avoid duplication, maximize economies of scale, spot and fill critical gaps, avoid bureaucratic infighting, and ensure all reconstruction activities are focused on a single climate-resilient recovery plan developed by Dominica and its partners.'

CREAD was accompanied by the 2018 National Resilient Development Strategy (NRDS), Dominica Climate Resilience and Recovery Plan 2020-30, and a new environmental law. These plans and strategies are built on its existing 2012 National Climate Change Adaptation Policy and the Low Carbon Climate Resilience Development Strategy. Collectively, these integrated climate resilience and disaster risk management into the national growth and development planning framework.

Systemic risk being socially constructed was also well articulated within the NRDS, which states that 'government is aware that climate change will affect many different economic sectors both directly and indirectly, and the characteristics of our social and economic systems will play an important role in determining their resilience amidst other development challenges. Therefore, addressing climate impacts in isolation is unlikely to achieve the desired equitable, efficient or effective outcomes of small island developing states such as Dominica.'

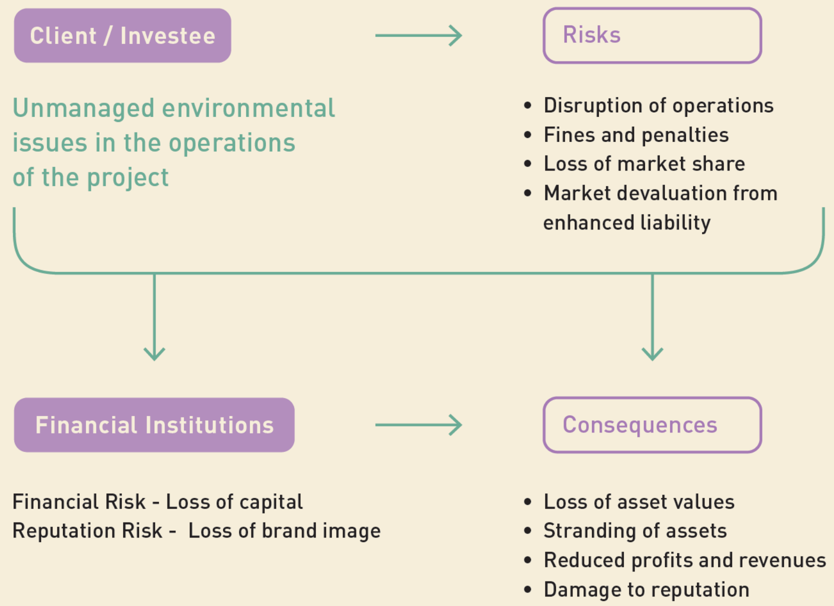


FIGURE 4.3

How Environmental Risks Translate to Financial Risks

Source: WWF India (2023)

economic case for investing in resilience and estimating the resilience dividend, including through NbIS.

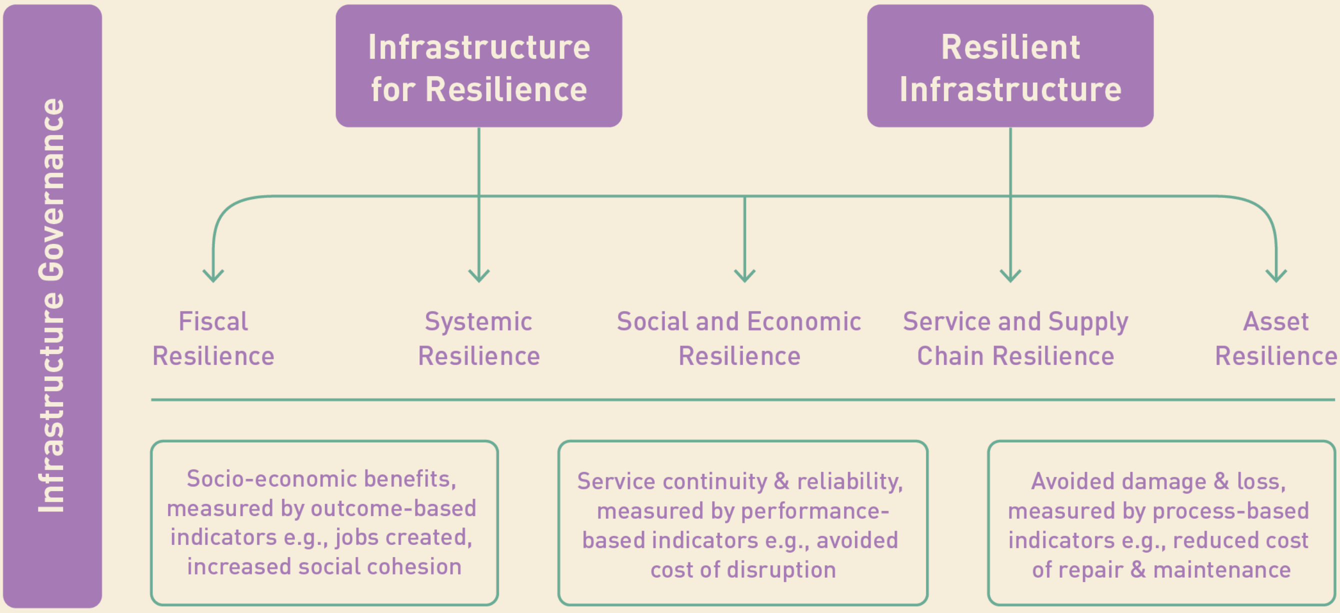
Financial risk metrics are also used to price risks and underpin insurance markets. Risk transfer mechanisms such as insurance (Miyamoto International, 2022)[26] can and should form an integral part of a national infrastructure resilience policy, strategy, and infrastructure financing. With a major loss of infrastructure assets in a large disaster, governments without an adequate level of savings and reserves cannot access contingency loans. They will have difficulties paying for the rehabilitation and reconstruction of uninsured assets (Mechler et al., 2016). Due to interrupted economic activity, fiscal shocks further reduce the capacity to finance recovery. If infrastructure assets are insured, recovery and reconstruction can be accelerated, avoiding fiscal downsides.

Unfortunately, in most LMICs, public infrastructure is protected neither by asset insurance nor by other instruments such as risk pools or insurance-linked securities (IIHS, 2022). The sovereign catastrophe risk pools that do exist in the Caribbean, Pacific, and Africa have required many years of sustained technical assistance from partner organizations[27] to facilitate the political and policy dialogue and coordination between participating governments (Miyamoto International, 2022).

While it is desirable that all infrastructure assets are insured, the pricing of premiums is generally insensitive to investments in resilience. Insurance premiums are usually calibrated with respect to the AAL of large pools of assets with differing levels of resilience (OECD, 2015). Thus, the cost of risk financing is rarely an effective incentive to encourage investments in resilience.

[26] Risk transfer is defined as the formal or informal transfer of the financial consequences of specific risks from one party to another (a household, community, organization, or state authority), obtaining resources from a different party after a disaster happens in return for ongoing or compensatory social or economic benefits given to that other party.

[27] For example, the World Bank Group has assisted the development of the Caribbean Catastrophe Risk Insurance Facility (CCRIF), Pacific Catastrophe Risk Assessment Finance Initiative (PCRAFI), Southeast Asia Disaster Risk Insurance Facility (SEADRIF), and the World Food Programme has assisted African Risk Capacity (ARC).



↑ FIGURE 4.4

Framework for Infrastructure Resilience: Dimensions, Enabling Conditions, and Outcome Monitoring

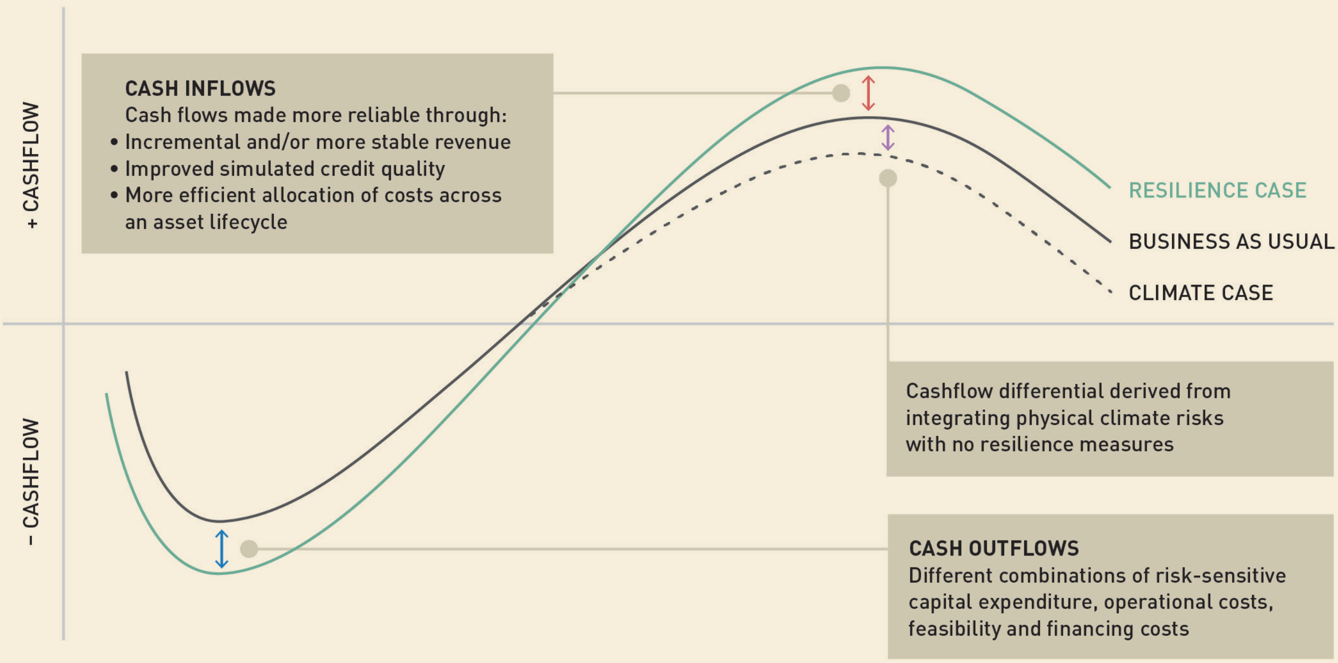
4.5.3. Identifying the Resilience Dividend

Investments in resilience are still considered by many infrastructure developers and financiers as incremental costs with no immediate benefits and sometimes imposed by regulators to meet safety standards.

Similarly, 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 the short and medium terms, with little consideration for an asset's residual value. There is still insufficient awareness that investment in resilience can lead to value creation through a combination of reduced future loss and damage, optimized lifecycle costs, and improved certainty of operating cash-flows, combined with positive development outcomes, such as increased well-being and economic growth (Figure 4.4).

As already highlighted in Section 3.3.7, if investment in resilience is to become more attractive, the social rate of return on investment, including avoided loss and damage and service disruption; broader social, economic, and environmental co-benefits; and reduced systemic risk, needs to be considered (GCF, 2022; IIHS, 2023). Identifying and estimating the *resilience dividend* clearly is essential to change the perception of investments in resilience from a cost to an opportunity.

To be resilient, infrastructure assets need to be robust and well-maintained, with adequate O&M standards and targets (European Commission, 2019). As mentioned earlier, the capital cost of an infrastructure asset often only accounts for 15–30 percent of the overall expenditure over the design lifecycle, while 70–85 percent represent O&M expenses (UN, 2021). This requires a steady flow of resources, and hence, well-planned and soundly estimated



↑ **FIGURE 4.5**

Changes in Cashflow under Business-as-usual and Resilience Scenarios

Source: Chavarot et al. (2021)

investments. For example, in countries such as Austria, Denmark, Italy, Moldova, New Zealand, and Slovenia, over 50 percent of the total budget for road transport is spent on maintenance (OECD International Transport Forum, 2022).

If appropriate resilience standards are integrated at the project planning and design stage, then both capital expenditure (CAPEX) and operating expenditure (OPEX) can be optimized to convert resilience from a cost to a vehicle to generate additional, stable revenue over the asset lifecycle. Integrating financial risk metrics into asset design enables more predictable cash flows, improved credit quality simulations, and a more efficient allocation of costs across the whole asset lifecycle (Figure 4.5).

A critical challenge is determining who bears the contingent liability. For example, if a flood damages a major transportation hub, there is often no procedure for distributing losses amongst different stakeholders. The actual fiscal liability for investors, operators and users, as well as the public sector, is unclear. Furthermore, in most low-income countries, most of these losses are currently uninsured. Consequently, the burden of risk may lie entirely with the public sector (Jain, 2015), though this challenge can be addressed by explicitly defining shares in contingent liability.

If resilience is to be fully factored into the planning, design, financing, operations, and maintenance costs of infrastructure projects, the benefits and costs of resilience need to be correctly priced.

As discussed in Section 3.3.9, conventional cost-benefit analysis for infrastructure projects often fails to identify the total resilience dividend that can accrue over the lifecycle of a project. To identify the resilience dividend, this approach should be broadened to include avoided asset loss and damage and service disruption; the value of protected ecosystem services; co-benefits for households, communities, and businesses; and avoided systemic risk, including climate change and loss in biodiversity.

These broader benefits should be identified early in a project's development. Some are more easily quantifiable and measurable, such as the creation of new jobs. While others, such as loss avoidance associated with low-return period hazards, can be quantified but may seem less tangible to owners and users of the infrastructure. As Box 4.2 shows, investing in the planning of infrastructure development, for example, through pre-development technical assistance, plays a crucial role in allowing quantification of such benefits.

Realizing these benefits requires a shift in terms of how projects are planned, executed, and monitored. For instance, transport infrastructure would have to be planned from a broader perspective that includes the benefits of asset resilience, as well as reduced emissions and protected biodiversity, rather than only considering time and distance optimization (WWF India, 2023).

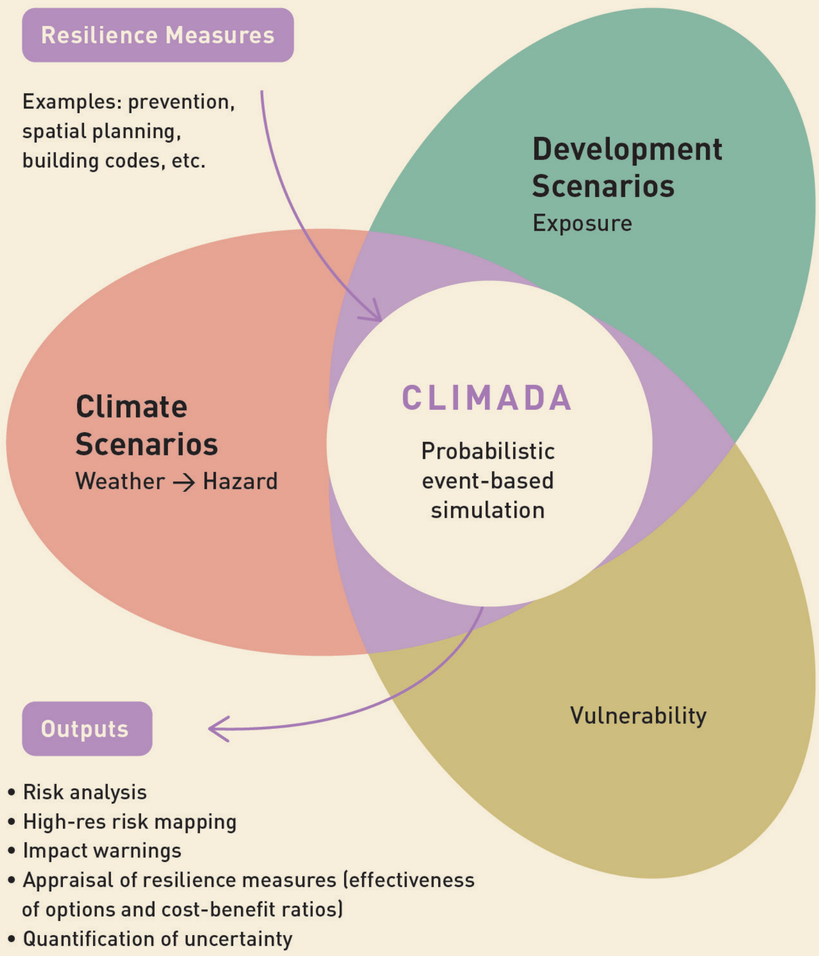
↓ BOX 4.2

The City Climate Finance Gap Fund
Source: ICSI (2022))

Investing in planning and risk-informed policymaking is key to resilient infrastructure development and yet is often overlooked and underfunded. The Gap Fund seeks to address this. It is a unique collaboration between implementing agencies (the World Bank and the European Investment Bank), donors, and city networks (Global Covenant of Mayors for Climate and Energy (GcOM), C40, International Council for Local Environmental Initiatives (ICLEI), and Cities Climate Finance Leadership Alliance (CCFLA) that supports planning for resilient infrastructure assets and urban systems. Since its inception, the Gap Fund has supported 80+ cities worldwide by mobilizing more than Euro 7 million in early-stage project preparation. The Gap Fund's work in Pristina enabled the city to develop policies that encourage resilient infrastructure, which will have an impact on all projects in the future.

Identifying the resilience dividend can increase the economic and financial value of projects, thus demonstrating that the risk-adjusted returns of resilient investments can be attractive. There are a number of tools that facilitate the identification of the resilience dividend. For example, the CCRI Physical Climate Risks Assessment Methodology (PCRAM) determines the baseline climate resilience level of an asset and undertakes a cost-benefit analysis of potential resilience options (Chavarot et al., 2021). The Economics of Climate Adaptation studies present another useful framework and a modelling platform, CLIMADA, to assess not just the risks related to climate change but also the costs and benefits of different adaptation options (Figure 4.6).

The integration of resilience features in project design and operations should address bankability issues, improve the ability to raise project debt, and lower the cost of capital. Therefore, methodologies and frameworks, such as PCRAM or CLIMADA, should form part of standard lender due diligence processes. Discount rates can then be adjusted to reflect the Net Present Value of an asset once resilience features are factored into cash-flow projections. For example, in a renewable energy power plant in Asia, resilience was embedded into the design of the project from the outset. Implementing this resilience option increased the initial CAPEX by approximately 2 percent and decreased the internal rate of return by 0.1 percent. However, accounting for avoided future potential losses increased the internal rate of return by 2 percent, which highlighted an important resilience dividend (Chavarot et al., 2021).



↑ FIGURE 4.6

The CLIMADA Platform for Assessing Climate Change Impacts and Cost-benefit Ratios of Adaptation Options

Source: Adapted from ETH Zürich (2023)

4.5.4. Public Investment Planning and Evaluation

Within the context of a national resilience policy or strategy, governments can use financial risk metrics to integrate resilience into their public investment planning and evaluation systems.

In most LMICs, local infrastructure systems, such as health and educational facilities, water and power systems, and rural roads, are financed almost exclusively through public investment. Local infrastructure investments yield significant social and economic returns. While local governments play a key role (McIntosh et al., 2018), it is difficult to mobilize finance for local infrastructure systems in smaller cities with limited governance capacities (UNDESA, 2012).

The capacity of local government varies across the globe: in Europe, municipalities account for around 45 percent of all public investment in infrastructure, but in LMIC, it is often just a fraction of this (EIB, 2021). The contingent liabilities of local governments in lower-income countries are often associated with extensive risk (frequent low-severity events). A retrospective analysis of disaster loss and damage data[28] can often be an important first step in identifying and estimating risks to local infrastructure.[29] However, as Box 4.3 highlights, data availability is still a challenge.

[28] Despite several decades of efforts to strengthen data collection and reporting, disaster loss and damage data continues to be inconsistently documented in many countries.

[29] Probabilistic risk estimation rarely accounts adequately for the extensive risk layer of highly idiosyncratic, localized, frequent events, in which case a retrospective approach, using disaster loss and damage data, may be the most appropriate.

Several governments in Latin America and Asia have adopted methodologies for incorporating risk and resilience into their prioritization of capital investment (ICAP & GIZ, n.d.). These efforts have produced mixed results to date, mainly due to limited local capacities to formulate infrastructure projects based on financial risk metrics and resilience standards. The DX4 Resilience initiative of UNDP and the Government of Japan developed a composite methodology to provide analysis and findings that are actionable by local governments to make their urban infrastructure disaster- and climate-resilient and achieve relevant SDGs. The composite methodology comprises five components that together enable local governments to assess the local infrastructure deficit, estimate the risk to existing and future local infrastructure, and generate the order of magnitude estimates for the costs of reducing the deficit and strengthening resilience.

↓ BOX 4.3

Disaster Databases in India

In India, the National Remote Sensing Centre has established a National Database for Emergency Management (NDEM) that brings together geo-referenced data on historical climatic and non-climatic disasters at multiple scales with the participation of multiple institutions.

A global database, EM-DAT (International Disaster Database of the Centre for Research on the Epidemiology of Disasters, i.e. CRED), documents major disasters; however, it neither captures extensive events, such as urban droughts, heat or local floods, or storm events, nor data on infrastructure damage [EM-DAT, 2009]. At the same time, it is not geo-referenced to the local level, which is necessary to identify infrastructure-relate risk. Initiatives, such as NDEM have the potential to close this gap.

NDEM attempts to bring together hazard-specific data that is spread over multiple sources. For example, the Cyclone eAtlas has historical tracks [Ministry of Earth Science et al.' 1891]. The India Meteorological Department [IMD] recently launched a Climate Hazard and Vulnerability Atlas. All states and most districts have Disaster Management and Climate Change Action Plans that document much of the disaster losses and expenditure made by the state and non-state actors. Post-Disaster Needs Assessments [PDNAs] are a potentially useful resource too but split into multiple documents [ECHO et al., 2018]. NDEM can integrate historical data from multiple sources on all hazards and their impacts.

On the basis of IMD's more than 100-year records of temperature, rainfall, and cyclone tracks, state and district plans and national atlases, and satellite image processing, a useful Atlas of Disaster Loss and Damage could be established as an open access portal that documents and freely disseminates information on the spatial extents and attributes of infrastructure loss and damage and recovery costs (India Water Portal & Tyndall Centre for Climate Change Research, 2005). Such an atlas could be invaluable for estimating risk and calculating the investment required to strengthen resilience.

↓ **FIGURE 4.7**

Steps towards Developing Integrated Projects Pipelines to Mitigate Risk

Source: GCF (2022)

1. Infrastructure systems approach to climate risk assessment/ climate data use

2a. Climate risk and vulnerability assessment of infrastructure

2b. Development of overarching hydrological and geological studies

2c. Preliminary structuring of project concepts

3. Integration of climate mitigation options (emissions reduction)

4. Developmental needs identification

5. Technology needs assessment

6. Market situation, identification of market failures

7. Assessment of financial needs

8. Projects sequencing and bundling

9. Further analyses leading to full programmes or project proposals

4.5.5. Pipelines of Bankable Resilience Projects

National resilience plans can include developing project pipelines consisting of a series of projects developed in connection with each other.

Project pipelines can enable government, industry, and communities to plan better and finance investment in resilience (GIH, 2022). For governments, pipeline development is an essential step in planning infrastructure. The industry needs pipelines to plan and prepare its resources both on a micro level (in pursuit of specific programmes and projects) and on a macro level (by using pipelines to identify market trends). Pipelines are an important signal for attracting new entrants to infrastructure markets and for industry and academia to prioritize workforce education and upskilling programmes. Moreover, pipelines can be an effective tool to demonstrate transparency so that communities can see what is being built and when.

Project pipelines also allow the bundling and aggregation of smaller projects in a way that optimizes the allocation of funding sources across projects. Small projects do not have the scale to attract private investment and increase risk for investors. But if they are aggregated and bundled together in a project pipeline, they become more attractive to investors as the risk is distributed across the range of projects.

Project and portfolio risk valuation needs to cover a range of risks, from construction to market risks and O&M to regulatory and political risks (GCF, 2022). By accounting for the full range of risks, project pipelines can help to *de-risk* private infrastructure investment. This allows governments to then select the most appropriate mix of financial instruments for the pipeline rather than bundling projects to match specific financing mechanisms, which can increase the portfolio risk (Figure 4.7).

A well-bundled project pipeline presented in an investment road map for climate-resilient investment can attract private-sector institutional investors alongside public-sector funding (Box 4.4) (GCF, 2022).

4.5.6. Towards a Resilient Infrastructure Asset Class

Standards and certifications provide a common language to understand and compare different infrastructure projects, which could aid in scaling projects and prioritizing project benefits.

In particular, standards and certifications can help lower perceived risks for private investors by providing additional clarity, therefore unlocking additional financing and funding streams (ICSI, 2022). Environmental, social and governance (ESG) performance indicators can also potentially inform infrastructure investors. Figure 4.8 provides an example of how to map the most relevant ESG criteria for the selected asset, outlining which ESG criteria should be measured and reported, and quantifying and assigning monetary value to ESG metrics (WWF India, 2023).

However, no single comprehensive set of criteria for ESG in infrastructure is universally recognized, limiting the usefulness of current multiple ESG frameworks for infrastructure resilience. At the same time, there is insufficient evidence that confirms how positive ESG scores increase investment in resilience. ESG scores for LMICs companies tend to be systematically lower than those in high-income countries, meaning ESG-focused funds allocate only limited resources to LMICs (Ehlers et al., 2022).

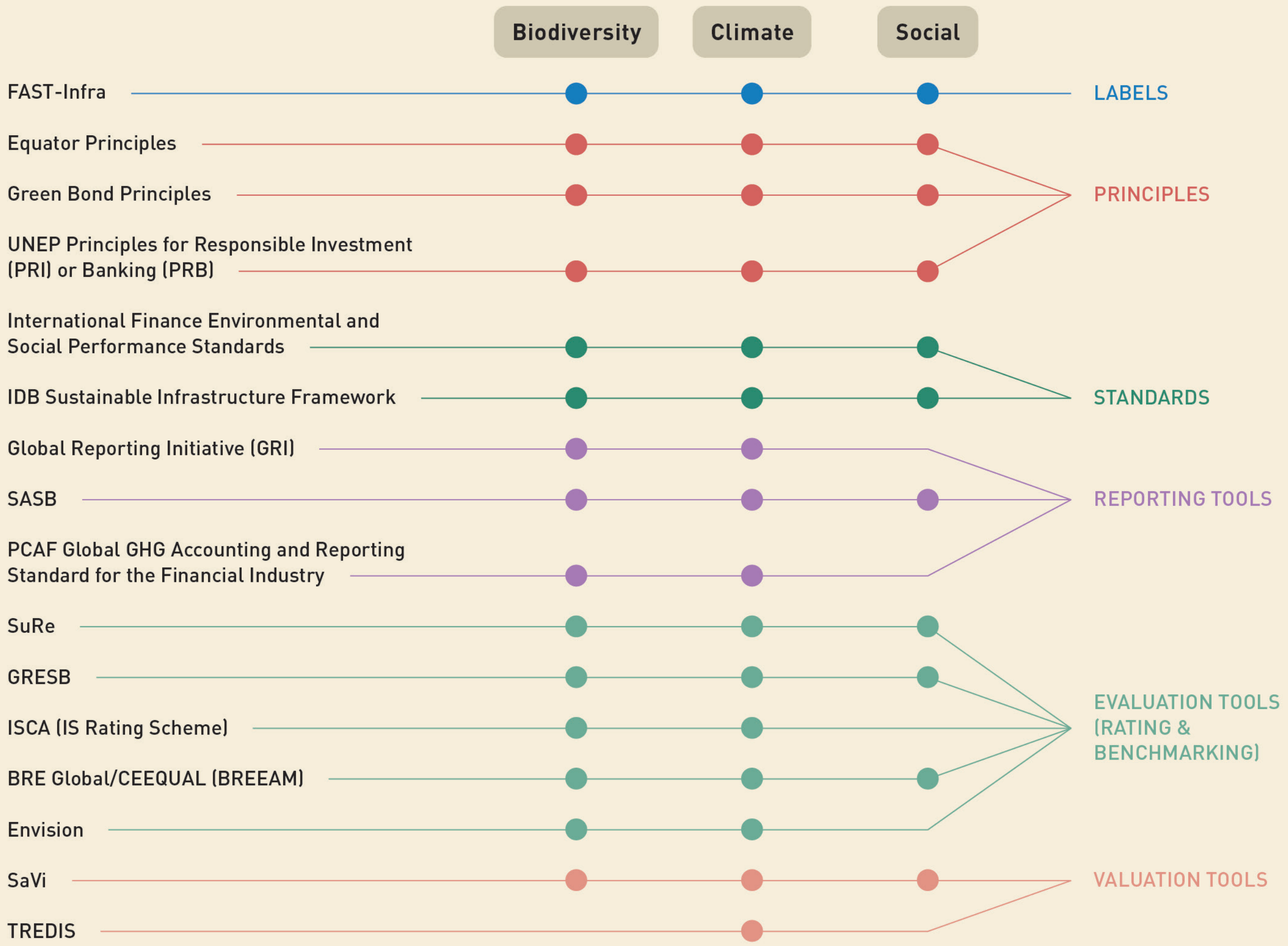
Initiatives that promote a common approach to identifying sustainable, quality, and/or green infrastructure projects include several 'meta-standards', such as FAST-Infra (Finance to Accelerate the Sustainable Transition-Infrastructure) label, the SuRe (Standard for Sustainable and Resilient Infrastructure) standard, and the Blue Dot Network (BDN). FAST-Infra (presented in Box 4.5), led primarily by finance-sector institutions, launched the Sustainable Infrastructure Label to identify sustainable infrastructure projects. SuRe is a third-party verified global voluntary standard developed by Global Infrastructure Basel (GIB). It provides certificates in line with insurance standards (Global Infrastructure Basel Foundation, n.d.). The American, Australian and Japanese governments introduced the Blue Dot Network framework to certify quality infrastructure projects (US Department of State, 2019).

↓ BOX 4.4

Ghana's Investment Roadmap for Climate-resilient Infrastructure

Source: GCF (2022)

The Ministry of Environment, Science, Technology and Innovation of Ghana (MESTI) and GCF developed Ghana's first investment roadmap for climate-resilient infrastructure in collaboration with UNOPS (United Nations Office for Project Services), University of Oxford, and UNEP. The roadmap quantified the direct and indirect impacts of exposure of infrastructure to climate risks and prioritized an evidence-based pipeline of 35 adaptation investment options. GCF is working with the Government of Ghana and other partners to finance these projects, which requires the support of public and private partners.



↑ FIGURE 4.8

Principles, Standards, Frameworks and Tools in the Context of Infrastructure Investments

Source: WWF India (2023)

Going forward, it is essential that these meta-standards are fully aligned and address the user needs across all infrastructure sub-sectors, especially in emerging geographies where the majority of new infrastructure is expected to be built (WWF India, 2023). A combination of resilience standards and credible *third-party* certification processes can pave the way for creating an infrastructure resilience asset class, providing investors with a transparent identification of opportunities for investment in resilience.

↓ BOX 4.5

FAST-Infra
Source: Losos and Fetter (2022)

FAST-Infra (Finance to Accelerate Sustainable Transition-Infrastructure) is a PPP aimed at closing the current investment gap in sustainable infrastructure. Initially launched as a collaboration between Hongkong and Shanghai Banking Corporation Limited, the Organization for Economic Co-operation and Development, the International Finance Corporation, the Global Infrastructure Facility, and the Climate Policy Initiative under the auspices of the One Planet Summit, it has become a broad partnership supported by more than 80 public and private institutions.

The main objective of FAST-Infra is to accelerate the deployment of sustainable infrastructure globally by promoting the development and improvement of sustainable, affordable, and inclusive infrastructure services. To achieve this, FAST-Infra has developed a three-pronged strategy consisting of:

1. Sustainable Infrastructure Label: Certifying the sustainability of infrastructure projects
2. FAST-Infra Platform: Increasing the volume of bankable/financeable projects
3. FAST-Infra Beyond: Accelerating innovation in the field of sustainable infrastructure

The Sustainable Infrastructure Label is based on five dimensions (Figure 4.9) of sustainability: environmental, social, governance, adaptation, and resilience, and is intended to define and measure sustainability contribution and credentials, increase market trust and confidence around the sustainability of infrastructure assets, inform investment decision-making and attract private investment into infrastructure, and encourage new financial product development. The FAST-Infra platform supports stakeholders in preparing, developing, financing, and deploying large-scale sustainable infrastructure programmes, particularly in developing countries. The platform is designed to enhance cooperation around project data and mobilize third-party technologies, as well as lower transaction costs, accelerate lead time, and enhance project quality and bankability. FAST-Infra Beyond is a sustainable infrastructure innovation hub that incubates and accelerates digital, tech, financial, legal, regulatory, and governance innovations. The hub aims to help institutions de-risk, aggregate, and automate projects across the sustainable infrastructure value chain.

↓ FIGURE 4.9

FAST Mechanism
Source: Losos and Fetter (2022)

4.5.7. Allocating the Resilience Dividend

One of the major barriers to increasing private investment in resilient infrastructure is that the resilience dividend over the design lifecycle usually benefits a broad set of stakeholders. Allocating the costs and benefits of risk and resilience amongst these stakeholders is the key to providing incentives for the proper integration of resilience in infrastructure systems.

Resilience is important to everyone involved in the value chain of infrastructure but is valued differently by different stakeholders, including national and local governments, private asset owners, landowners, and users (ICSI, 2022). Governments may benefit from reduced asset loss and damage and a reduction in the costs of rehabilitation and reconstruction. Households, communities, and businesses may benefit from reduced service disruption and, thus, enhanced social and economic development. Other benefits, such as protected biodiversity of reduced carbon emissions, may be shared more broadly, including with other countries or the global commons.

Once the resilience dividend and stakeholders have been clearly identified, it is necessary to develop policies that monetize the socio-economic benefits of investing in resilience and enable investors to capture a part. The value of the resilience dividend needs to be estimated first, combining project and economic evaluation (e.g., through the Resilience Dividend Valuation Model).[30] In this approach, the resilience dividend is calculated as the sum of benefits, over time, from a project investment integrating resilience, compared to one that does not.

↓ **BOX 4.6**

Implementing NbIS at Scale
Source: USFS (2023)

Blue Forest (BF) is a mission-driven non-profit organization dedicated to leveraging financial innovation to develop sustainable solutions to pressing environmental challenges. In 2017, the United States Forest Service and Blue Forest signed a memorandum of understanding (MOU) to develop and implement the Forest Resilience Bond (FRB)[31], and in 2018, launched Yuba I, the first FRB pilot project to fund forest restoration across 15,000 acres of the Tahoe National Forest in California.

The FRB is based on the idea that the value of the ecosystem services that restored healthy forests provide, such as decreasing the severity of wildfires, exceeds the restoration cost. The FRB allowed public agencies to increase the pace and scale of forest landscape restoration with a cost-benefit analysis that showed the programme to be more effective than current models of forest landscape restoration.

Yuba I provided $4 million in upfront private capital from four investors to fund ecological restoration treatments to reduce wildfire risk. Three beneficiaries-the US Forest Service, Yuba Water Agency, and the State of California-provided in-kind support and funding at contracted rates to reimburse investors for restoration work. Restoration activities were carried out by the National Forest Foundation, the project's primary implementation partner and its contractors (Figure 4.10).

[30] Developed by the Rand Corporation with support from the Rockefeller Foundation (Bond et al., 2017).

[31] https://www.blueforest.org/forest-resilience-bond

The $4 million pilot project attracted $25 million in private investment, paving the way for larger projects. There was a net gain in biodiversity from maintaining existing wildlife habitats and increasing habitats for species that require less dense forest structures. Restoring aspen and meadow ecosystems and removing invasive weeds also enhanced plant and animal biodiversity in these habitats.

The economic feasibility was ensured by grants from private foundations that agreed to a 1 percent return on investment. Other private investors agreed to a 4 percent return on investment. Infrastructure entities paid for the investments with proceeds generated from monetized benefits, including avoided wildfire costs and improved water quality and quantity. The funds generated from thinning activities were used to pay contracts and for additional ecosystem restoration work. Ecosystem valuation cost-benefit accounting convinced the beneficiaries and investors that the value of benefits outweighed their contribution to the project.

The pilot project laid the foundation for the future use of this instrument for NbIS to restore landscapes. Private finance capital and blended finance mechanisms can influence the public sector to participate in new forms of financing to benefit its goals and objectives.

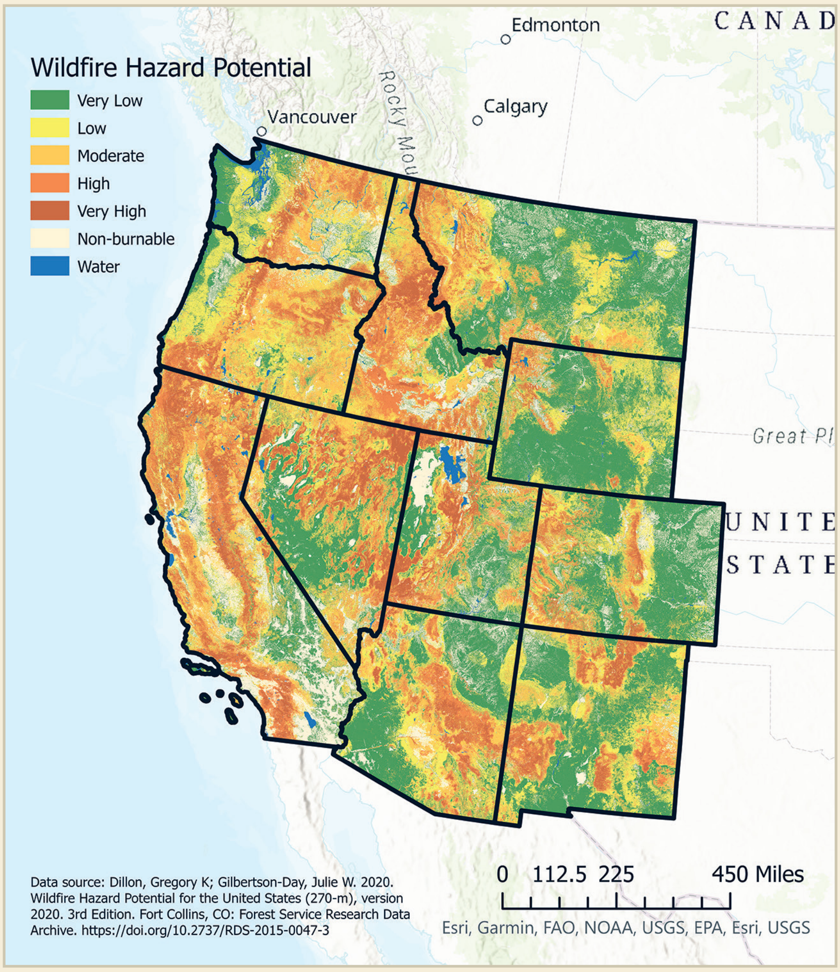
Initiative 20x20 is a regional fiscal intermediary group launched in 2014 to change the dynamics of land degradation in Latin America and the Caribbean. Currently, 18 countries and 3 regional programmes have committed to improving more than 52 million hectares of land by protecting and restoring forests, farms, pastures, and other landscapes by 2030. Over 85 technical organizations, institutions, impact investors, and funds have contributed $3.09 billion in private investment to Initiative 20X20 (Initiative 20x20, 2014).

Both Blue Forest Conservation and Initiative 20x20 have now developed long term PPPs, built a collective of investors, and supplied a robust pipeline of NbIS projects ready for funding (Gartner et al., 2022). Private funds supplement government funding for NbIS projects and greatly increase the pace and scale of strengthening infrastructure resilience (Blue Forest Conservation, n.d.).

↓ FIGURE 4.10

Yuba Project Completed Treatments (2019)

Source: Tahoe National Forest & Blue Forest Conservation (2018)



↓ **BOX 4.7**

Blending Public and Private Capital to de-risk Investments: Climate Investor Two

Source: ICSI (2022)

Climate Investor Two (CI2) is an infrastructure fund established in 2019 by Climate Fund Managers (CFM). It uses a blended finance approach that invests in private equity water, water-based energy, and ocean infrastructure projects in emerging markets. CI2 has developed an innovative project finance structure that works across three stages: (i) a development fund (DF), (ii) a construction equity fund (CEF), and (iii) a climate credit fund. The DF is a wholly concessional capital pool funded by donor contributions, which aims for capital preservation and mobilizes private capital into the CEF. The DF offers up to 50 percent of the planning and development costs of the projects along with technical assistance. Equity financing of up to 75 percent of construction costs is available under the CEF.

Blended finance was an enabler to accelerate the development of, and subsequent investment in, resilient infrastructure projects such as solar-powered desalination units in Kenya and two waste-to-energy facilities in Thailand. CI2 closed its first round at $675 million in November 2021. CI2's success is owed to its flexible and modular governance structure that attracts institutional investors at scale while delivering projects locally. Aligning investment instruments to focus on distinct risk periods in the project lifecycle lowers the cost of capital and accelerates timelines. Flexibility and adaptability in transaction design can also prove critical for successful fundraising.

In other words, the additional value generated by investing in resilience in comparison to 'business as usual' (Bridgett-Jones, 2017).

Monetizing the resilience dividend can be seen through the dual lenses of tangible vs. intangible benefits and internal vs. external benefits. Tangible benefits relate to potential streams of cash flows that can be quantified relatively easily, such as reduced maintenance costs, avoided asset losses, improved infrastructure services and other benefits including biodiversity preservation that can be quantified (and monetized) through a voluntary carbon market mechanism. Intangible benefits are more diffuse and benefit broader society. Quantification is less obvious, meaning they are more difficult to monetize. They may only be measurable nationally (e.g., health, environmental, or other societal benefits).

Internal benefits are those that accrue at the asset level to the users, managers, or owners of the asset. Their allocation is generally governed by the regulations and legal framework under which the asset operates. For example, a public highway with no toll fees is an infrastructure asset where the internal tangible benefits are allocated entirely to its users. In contrast, if the same highway is operated by a concessionaire with the right to charge tolls, the benefits are normally allocated between the concessionaire, the users, and the authority that granted the concession. External benefits are typically not attributes of the infrastructure asset *per se*. While the asset owner may benefit directly or indirectly, these benefits are normally not quantified (e.g., economic growth from new or improved infrastructure or the increased resilience of a national economy to economic-, financial-, and hazard-related shocks).

Tangible, internal benefits are the easiest to monetize (for example, through the identification and quantification of costs and benefits of different resilience strategies). In contrast, intangible and external benefits are the most difficult to monetize, as demonstrated through decades of negotiations on the costs of climate change. Benefits that are tangible and external can be monetized by mechanisms such as fiscal incentives provided that the beneficiaries, and their propensity to be taxed, can be clearly identified, with proceeds redistributed to asset owners.

On the other hand, internal and intangible benefits can be monetized through existing mechanisms, such as payment for ecosystem services and other conservation 'banking' tools developed to support NbIS, distinguishing between benefits that communities and local businesses should pay and the benefits that governments should pay. Box 4.6 highlights a case where investors can monetize part of the resilience benefits accrued from an NbIS programme.

For the monetization of the resilience dividend to become a quotidian practice, 'Voluntary Resilience Benefit Certificates', modelled along the lines of the Voluntary Carbon Market, could be introduced (Chavarot, 2023). The certificates could identify and monetize the resilience dividend based on predefined standards. Finance ministries could then issue the certificates and implement or regulate a trading scheme. They could also be potentially structured as a pre-payment of future resilience dividends and used for finance investments in resilience through national resilience funds. MDBs could be asked to co-fund such pre-payments through investment in national resilience funds.

It could also be possible to develop and structure a parametric insurance product that links pay-outs with a reduction in losses as a result of embedded resilience features in an asset. This could then be replicated at a portfolio or even national level with insurance-linked resilience securities issued in capital markets.

4.5.8. Innovative Financing Instruments for Infrastructure Resilience

New financial instruments and mechanisms are required to mobilize capital for infrastructure resilience, thus unlocking new economic opportunities.

First, there is a need for financial structures that adequately blend public and private sources of capital through de-risking mechanisms (Box 4.7).

↓ **BOX 4.8**

Financial Instruments to Mobilize Untapped Financial Resources: Philippines Energy Development Corporation (EDC)

Source: ICSI (2022)

Following the major earthquake in Leyte in July 2017 and a series of severe weather events throughout the year, the renewable energy company Philippines Energy Development Corporation (EDC) and its partners developed an approach to prioritize the implementation of risk reduction measures to protect key assets. In June 2018, the International Finance Corporation (IFC) issued the first AAA peso-denominated green bond for approximately $90 million with a 15-year maturity. The bond was intended to support EDC with restoration and resilience efforts at the Malitbog plant. The bond quickly attracted investment from several major players within the Philippines. These efforts reduced the risk to EDC Philippines's assets, allowing EDC to expand its generation capacity and offerings to other clients.

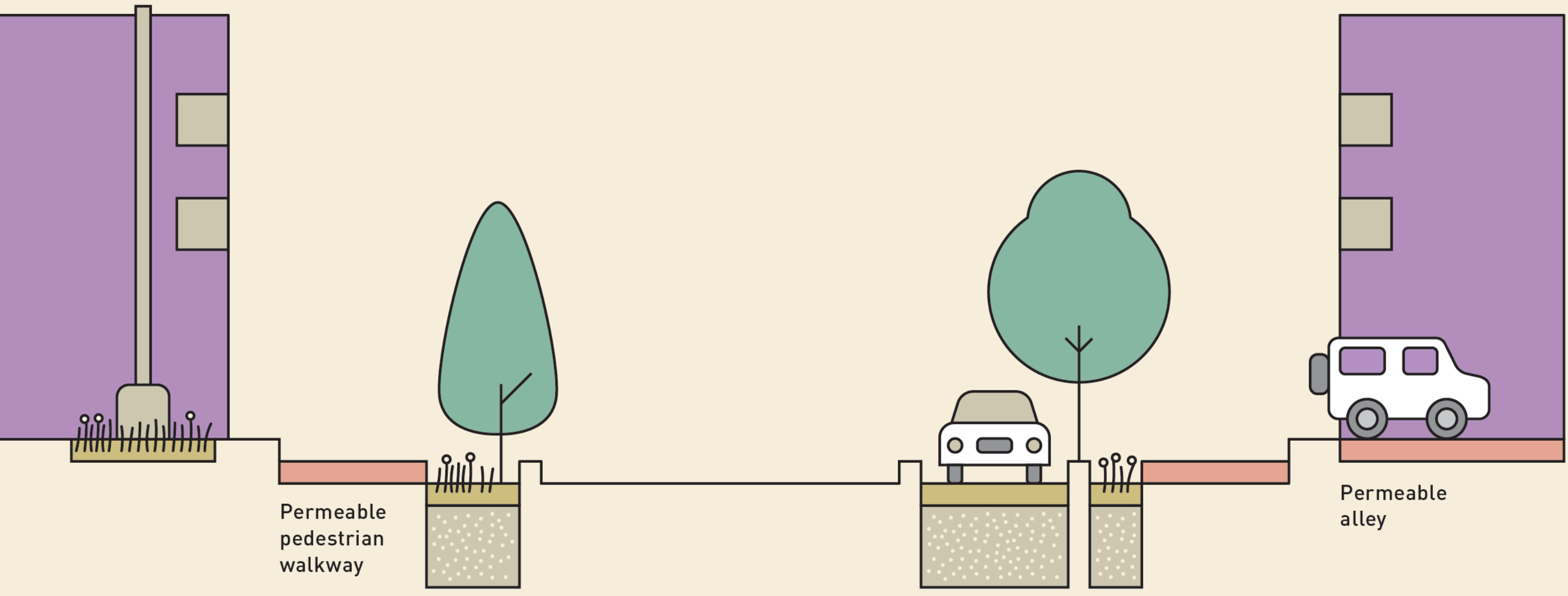
In addition to increasing resilience to physical assets, IFC's green bond paved the way for EDC Philippines to issue its own green bonds. IFC and other investors anticipated that the first green bond issued for the Philippines could create a market for local green bond investments in the country. EDC Philippines established a similar procedural model for green bond issuance as the IFC, with clearly defined guidelines for projects and a second reviewer. It issued its first bonds in 2021 for several small projects across its portfolio, benefitting from a regulatory environment that was amenable to green finance and resilience projects. Pre-established governance structures related to risk and capacity in disaster risk reduction allowed EDC Philippines to engage with different departments and incorporate new assessment tools.

→ **BOX 4.9**

Integration of Green Financial Instruments Linked to Nature-based Solutions into the Funding of Infrastructure Assets: District of Columbia Water and Sewer Authority (DC Water)

Source: ICSI (2022)

The combined stormwater/sewer system in the District of Columbia (DC) could no longer handle capacity, especially during flooding events, thus increasing sewage levels in the District's rivers and exceeding existing water quality standards. DC Water and its partners financed an integrated green-grey infrastructure solution with the first-ever Environmental Impact Bond (EIB) to remediate stormwater and sewer pollution. Alongside retrofitting sewage tunnels, the project integrated green infrastructure measures (e.g., rain gardens, rain barrels, green roofs, street-side bio-retention planters, tree cover, permeable pavement, and green verges) to reduce stormwater runoff and volumes and frequencies of overflows into the rivers (Figure 4.12).



↑ **FIGURE 4.11**

Interventions to Reduce Stormwater Runoff

Source: Adapted from USFS (2023)

Traditional financial products could not adequately incorporate project uncertainty or capture the longer-term benefits of DC Water's green-grey solution. The EIB adapted performance mechanisms from a social impact bond to meet these needs. The bond used performance-based metrics to hedge project performance uncertainties for DC Water and yet remained attractive to investors. The $25 million EIB was structured as a tax-exempt municipal bond with a 30-year maturity. The bond functioned much like a standard bond except for a one-time mandatory tender date at the bond's five-year mark. The DC Water case study demonstrates that innovative financing often does not necessitate the creation of completely new instruments but rather the creative application of existing ones.

With the help of such mechanisms, public funds can provide the basis for and stimulate private investment in resilient infrastructure while simultaneously accelerating development goals.

The creation of national resilience funds, to fund project pipelines, could provide a vehicle that blends public capital, private investment, and, where appropriate, climate finance in a way that de-risks projects for investors, maximizes rate-of-return, and appropriately distributes the resulting resilience dividend amongst the range of stakeholders. They can also potentially provide a vehicle for integrating insurance and other risk financing mechanisms, such as catastrophe bonds, as an integral part of infrastructure financing.

Second, new financial instruments can allow the mobilization of untapped financial resources. As Box 4.8 illustrates, the issue of *green bonds* has helped strengthening resilience in the Philippines.

Third, as Box 4.9 shows, green financial instruments can also promote the integration of NbIS (ICSI, 2022).Debt relief programmes or new debt swap mechanisms are another mechanism that can significantly increase the fiscal space of heavily indebted LMICs, generating new resources for resilience building and energy transition (Box 4.10) (Elston, 2021).

Figure 4.12 summarizes some of the sources and innovative instruments that LMICs may use to mobilize resilience financing (South Pole Carbon, 2022). Sources of financing range from local to international and public to private and include instruments that can be used for resilient infrastructure development and those linked to post-disaster risk financing.

↓ **BOX 4.10**

Debt for Climate Swaps as New Ways to Align Increased Fiscal Spaces with Globally Shared Climate and Development Goals

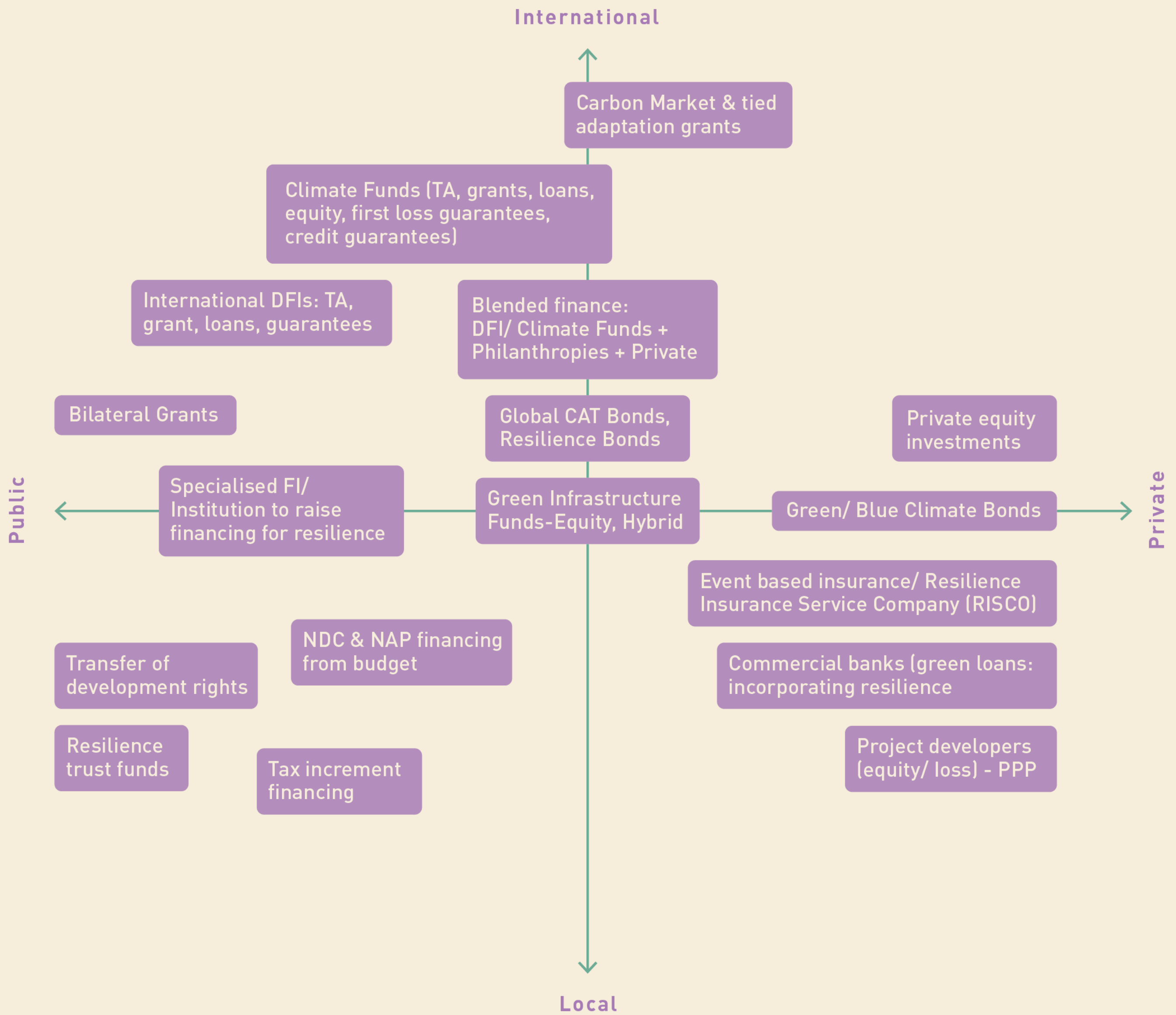
Source: Arlington (2022); IMF (2022)

Debt for climate swaps and debt for nature swaps are new mechanisms that can free up fiscal resources currently bound up in servicing unsustainable debts to improve resilience without triggering financial crises or sacrificing spending on existing development priorities. The principle is relatively simple: creditors provide debt relief conditional on a country's commitment to invest in resilient infrastructure, protect forests or marine ecosystems, or decarbonize the economy.

While such debt swaps cannot provide a universal solution to countries struggling with debt, they can be developed in a manner that complements existing instruments and helps strengthen resilience building in countries already affected by climate change or biodiversity loss. Despite having existed in various forms for decades, debt swaps are still a niche product and can now be scaled up by structuring deals around broad environmental and adaptation goals and linking swaps to clear and measurable metrics.

One country that has developed an innovative debt swap tool is Barbados, supported by The Nature Conservancy (TNC) and the Inter-American Development Bank. The financial deal will enable the Government of Barbados to redirect a portion of its sovereign debt service into marine conservation funding. Under this debt swap agreement, Barbados has committed to conserve 30 percent of its ocean and develop a sustainable marine economy. Barbados' high debt burden severely limited its efforts to invest in climate change adaptation and conservation. Under the new initiative, it completed a $150 million debt conversion that is expected to free up approximately $50 million to be invested in environmental and sustainable development over the next 15 years, building the resilience of the country and the livelihoods of its people.

Barbados is a good example of where climate action at this scale could not have been taken without a swap. In the mid to long term, debt reduction that translates into resilience investment in this manner can not only just give a country fiscal relief through budget savings but also result in the upgrade of a country's credit rating, making future government borrowing cheaper.



NDC: Nationally Detemined Contributions; **NAP**: National Adaptation Plans; **FI**: Financial Institutions;
DFI: Development Finance Intitutions; **TA**: Technical Assistance; **ITMI**: Internationally Traded Mitigation Outcomes;
PPP: Public Private Partnership

FIGURE 4.12

Innovative Sources to Finance/
Fund Resilient Infrastructure

Source: South Pole Carbon (2022)

Chapter 5

Capturing the Resilience Dividend

5.

Capturing the Resilience Dividend

5.1. Introduction

All new investments need to be disaster- and climate-resilient to avoid accumulating new contingent liabilities, increasing asset loss and damage, and service disruption

The analysis presented in this Biennial Report highlights the depth and breadth of the multifaceted challenge to strengthen infrastructure resilience in LMICs, particularly in low-income countries. These countries need to increase both public and private investment to reduce their infrastructure deficit and achieve the SDGs. They also need to ensure that this major new infrastructure investment enables them to transition to net-zero economies and reduce systemic risk. Above all, all new investments need to be disaster- and climate-resilient to avoid accumulating new contingent liabilities, increasing asset loss and damage, and service disruption.

There is no 'one size fits all' solution to address these challenges. Countries with large economies, such as India and China, have the capacity to increase public investment and are attractive markets for private capital. In contrast, in smaller developing economies, the fiscal space to increase public investment may be heavily constrained and there is little to attract private capital. Moreover, the capacity to address the multifaceted resilience challenges described above is mediated by broader macroeconomic factors, such as indebtedness, political stability, and the strength and quality of governance. How much countries want or can invest in strategic economic infrastructure to boost productivity, competitiveness, and growth or in local infrastructure systems to strengthen social development and welfare, and in the resilience of both, is a question that pertains to national development and political priorities.

However, while recognizing the specificity of the governance challenges in each country, there are several pathways that, if followed, may unlock opportunities to strengthen infrastructure resilience. These opportunities can be grouped into three categories:

1. **Knowledge and capacities:** how to identify and estimate the resilience dividend.
2. **Infrastructure governance:** how to create an enabling environment to capture the resilience dividend and attract additional investment.
3. **Markets for resilience:** how to mobilize untapped private capital for investment in infrastructure resilience.

5.2. Knowledge and Capacities

5.2.1. Knowledge Systems

Knowledge systems that enable policymakers, planners, designers, contractors, regulators, and financiers to access up-to-date information on ways of strengthening infrastructure resilience, including through NbIS, are a core requirement.

What are currently incipient CoPs at the national, regional, and global levels and for specific infrastructure applications need to be nurtured to encourage the systematization and production of knowledge on resilience and ensure that this knowledge is widely accessible through information systems in different languages.

A critical knowledge component is the creation of accurate and updated national infrastructure registries or audits, which provide ministries and investors alike with a baseline to assess the risk and resilience of infrastructure and the services provided. A systematic overview of infrastructure assets and services is essential for planning and programming capital investment and operating expenses.

Another core knowledge component is a national risk information system (for example, a digital national risk atlas). This should include information on the risk internalized in each infrastructure sector, associated with all major hazards, based on probabilistic risk identification and estimation, a georeferenced database on loss and damage to infrastructure assets and service disruption, spending on repair and rehabilitation, as well as input data, such as exposure databases, vulnerability functions, and hazard maps.

Taking advantage of new investments being made in smart city infrastructure in many parts of the world, national risk information systems could be integrated with existing data collection and monitoring systems at the local, sub-national, and national levels. Technologies such as remote sensing and smart sensors can be leveraged to get regularly updated and automated information processes, thus enabling regular monitoring of the status of infrastructure systems.

Strengthening knowledge systems on infrastructure resilience is critical to introducing resilience concepts in professional education (for example, for engineers, planners, and architects) and public policy (for example, public investment planning and evaluation systems). South–South and North–South knowledge exchange can also contribute to raising awareness and understanding of infrastructure resilience and strengthening capacities.

5.2.2. Economic and Financial Risk Metrics

Financial risk metrics are required for each infrastructure sector and geological- and climate-related hazards at the global, national, and sub-national levels.

Such metrics provide an evidence-based framework to identify and estimate the contingent liabilities internalized in each infrastructure system. They can help to reveal the resilience dividend that is latent in all infrastructure investments and contribute to informed infrastructure planning and project formulation.

Risk models and indices such as the GIRI provide a first-level global estimation of infrastructure risk and, thus, help to articulate a clear economic and financial rationale for investing in resilience. Without such evidence-based risk estimates, policies and strategies to strengthen infrastructure resilience will likely be unfocused, rhetorical, and ultimately hollow.

The GIRI, however, is only a starting point. Hazards such as wildfires and heatwaves, and systems such as ecosystems and food systems, need to be integrated into the risk analysis. It is also important to model asset risk and the risks posed by service disruption and climate change to identify the resilience dividend that can drive increased investment. Higher resolution models are needed to inform national resilience policies, strategies, and plans and develop pipelines of bankable projects.

At the same time, it is important to strengthen detailed loss and damage accounting to estimate the impacts associated with high-frequency, low-severity extensive risks. This risk layer may not be adequately captured in prospective risk models but is highly relevant for the local infrastructure systems that provide essential public services. Improving the quality and reliability of public services is an imperative that may generate important political momentum in favour of infrastructure resilience.

5.2.3. Estimating the Resilience Dividend

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 is essential for identifying and estimating the dividends that can be obtained from investing in strengthened resilience.

As a first step, this would require assessments of the additional costs and resulting benefits for different strategies to strengthen infrastructure resilience. Estimating the resilience dividend means considering the avoided asset loss and damage and avoided service disruption over the lifecycle of an infrastructure system. It also means quantifying the broader economic, social, and environmental benefits and co-benefits, including cleaner water and air, enhanced biodiversity, and reduced carbon emissions. This is particularly important in the case of NbIS.

Estimations of the resilience dividend in infrastructure projects must also account for changes in the net present values over different time horizons. NbIS, for example, may take longer to provide returns on investments but may appreciate over time. Grey infrastructure options, in contrast, may depreciate. The role of MDBs in developing and applying such methodologies in their lending operations is critical to introducing such concepts and ensuring that they become standard features of infrastructure project formulation.

5.2.4. Resilience Standards and Certification

The development and adoption of performance-based resilience standards, informed by enhanced financial risk metrics and enhanced estimations of the resilience dividend, is essential to enable investors, regulators, planners, and policymakers to differentiate between infrastructure projects that contribute to strengthening resilience and those that do not.

In evolving infrastructure areas, such as NbIS, compendiums of good practices provide a vehicle through which appropriate standards can gradually evolve. Meanwhile, unifying and enhancing the existing global resilience standards and facilitating their adaptation to national contexts and adoption in formalized codes, norms, and standards is also essential. Resilience standards reduce uncertainty and help to de-risk projects for potential investors. They also enable the technical certification of infrastructure resilience. Without explicit standards, professional liability insurance may be invalid, particularly in the case of new approaches such as NbIS.

One way to encourage the adoption of resilience standards in infrastructure projects could be to strengthen the professional norms and rules that regulate the conduct of planners, engineers, architects, and contractors. In many LMICs, professional regulations are often weak or insufficient, leading to a loss of accountability.

The widespread adoption of resilience standards would facilitate third-party certification of infrastructure resilience. Credible international certification is a step towards the creation of an infrastructure resilience asset class, as proposed in Section 5.4.1.

5.3. Infrastructure Governance

5.3.1. National Infrastructure Resilience Policies, Strategies, and Plans

Formulating infrastructure resilience policies, strategies, and plans integrated with existing development policies by national governments is critical for strengthening infrastructure governance.

When countries develop national resilience policies and plans, they send a strong political signal to potential investors that they are taking resilience seriously and have found a political and economic imperative to do so. These instruments need to be aspirational, highlighting a resilience pathway in infrastructure development. They also need to connect to broader development objectives. At the same time, they should be evidence-based, building on financial risk metrics and retrospective information from national loss and damage databases.

National infrastructure resilience policies could include recommendations to introduce NbIS in sectors such as water, where the benefits and co-benefits of designing with nature can be maximized. Similarly, policies may include the adoption of resilience standards in national legislation, and the introduction of performance standards for urban planning and design, in ways that dramatically reduce infrastructure costs and maximize the resilience dividend.

National infrastructure resilience strategies and plans could provide a national framework for all infrastructure investment directly linked to national development plans and targets, public investment planning, and budgeting. In this way, the strategies can link infrastructure investment to the broader social and environmental resilience dividends that could be generated in other sectors. National strategies can then be used to guide specific resilience strategies in each sector and territory.

Strategies should include clearly defined goals, targets, and indicators (for example, to reduce the AAL in each infrastructure sector by a given percentage over a determined period). Such targets could provide guidance for each sector, while indicators can allow the monitoring of whether the target is being achieved or not.

To highlight the political imperative for resilience, these policies, strategies, and plans must be endorsed as a priority at the highest level of government and used as '*all of government*' instruments rather than being owned by a specific sector. Sectors such as environment or disaster risk management are often politically weak and have limited influence over investment decisions.

Demonstrating a strong political and economic imperative for resilience will help improve a country's risk perception by risk analysts, rating agencies, and markets. If a government is seen as serious about reducing risk and strengthening resilience, the country will become more attractive for potential investors, its sovereign risk may be lowered, and capital costs reduced.

5.3.2. Public Investment Planning and Evaluation Systems

Integrating resilience considerations into national systems for public investment planning and evaluation is critical to implementing national-level infrastructure resilience policies, strategies, and plans.

Ensuring that resilience is factored into all new public investment in infrastructure is critical to reducing risk, avoiding the disruption of public services, and achieving the targets defined in a national resilience strategy.

In Latin America and some countries in Asia, significant progress has been made in the development and adoption of normative standards and methodological guidelines. However, implementation at the sub-national and local levels has often been undermined by weak local government capacities to formulate and evaluate projects. Integrating resilience into public investment planning and evaluation requires the adoption of methodologies, as discussed in Section 5.3.1. It requires the integration of financial risk metrics to identify the broader resilience dividend into project evaluation over the entire lifecycle of the project. This is critical for ensuring that the budgeting processes make adequate provision for future operating and maintenance requirements.

Public investment planning and evaluation is ultimately both a political and technical process, given that it reflects a trade-off between strengthening resilience and increased capital investment. Clearly identifying the resilience dividend over the design life of a project can create an imperative for investments in strengthening resilience, even in contexts characterized by a constrained fiscal space.

5.3.3. National Resilience Funds

National resilience funds can provide a new mechanism to finance project pipelines and implement national resilience strategies and plans. A national resilience fund could allow the blending of public resources, climate finance, loans from MDBs, private capital, risk financing, and other sources in a way that allows governments to de-risk infrastructure investment for private capital while at the same time optimizing the use of different resources.

National resilience funds would also provide a vehicle for applying standardized agreements for concessions and PPPs, further increasing predictability in implementation and streamlining the project design and evaluation process.

National resilience funds could feature mechanisms to monetize the resilience dividend. As described in Section 4.5.7, monetization mechanisms for infrastructure resilience would need to be multifaceted, considering, as far as possible, the internal and external and tangible and intangible benefits that could accrue over the lifecycle of the asset, a clear identification of all the relevant stakeholders and transparent and efficient procedures to distribute the monetized resilience dividend. At present, experience in this area is still incipient and emerging. However, it has the potential to attract currently untapped private capital for investment in infrastructure resilience.

5.4. Markets for Infrastructure Resilience

5.4.1. A Resilient Infrastructure Asset Class

Adopting national resilience policies, strategies, and plans; developing project pipelines; establishing national resilience funds and mechanisms to monetize and distribute the resilience dividend, if combined, would send signals to capital markets that could increase the mobilization of private capital in infrastructure resilience.

If resilience standards and certification mechanisms, as described in Section 5.2.4, are adopted, conditions would then exist for the emergence of a resilient infrastructure asset class. Such an asset class could demonstrate attractive rates of return, which would mean financial markets may respond by creating resilient infrastructure investment funds and other vehicles to attract private capital interested in capturing the resilience dividend.

A first step towards such a process, however, would be developing a common set of standards in order to reduce the risk associated with investing in resilient infrastructure, thereby, bringing down the cost of capital for developers.

5.4.2. Project Pipelines and Project Aggregation

Many countries at present are not attractive for private capital due to real or perceived risks, weak infrastructure governance, and a high cost of capital. At the same time, there may be too few bankable projects of a sufficient scale to interest private investors.

Financing small-scale projects increases transaction costs and risk, while investing in *one-off* projects is less attractive than a predictable stream of investment opportunities. Attracting private investment depends on generating confidence and building relationships between governments and private capital, which take time to establish.

In the context of national infrastructure plans, developing a project pipeline can increase the offer of bankable projects in a way that offers greater predictability and lower risk for investors. At the same time, many 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 become attractive for private investment.

For example, several hundred small water projects can be bundled as a single aggregated project or a combination of road, water, and energy projects in each province or department. Project aggregation lowers risk, given that a project bundle will include a mix of higher- and lower-risk projects. The overall risk to potential investors of the project bundle will be lower than if any specific project was chosen.

Project bundles can form a part of the project pipeline, along with major infrastructure projects, providing potential investors with a medium-term horizon to build relations and generate confidence in working in the country, further de-risking the investment process. From the perspective of national governments, project pipelines can increase certainty regarding the achievement of targets and indicators in national resilience strategies.

Project pipelines may also be a way of reducing the costs of risk transfer. Insurance premiums are often insensitive to investments in resilience as they are estimated with respect to bundles of both higher- and lower-risk assets. However, if many aggregated projects in a pipeline integrate resilience features linked to measurable targets and indicators in a national strategy, it may be possible to reduce the cost of risk finance over time in the same way that car insurance is reduced through the mechanism of a *no-claims bonus*.

5.4.3. Innovative Financial Mechanisms

Apart from vehicles such as resilient infrastructure investment funds, it is likely that markets will respond through the development of other innovative financial mechanisms.

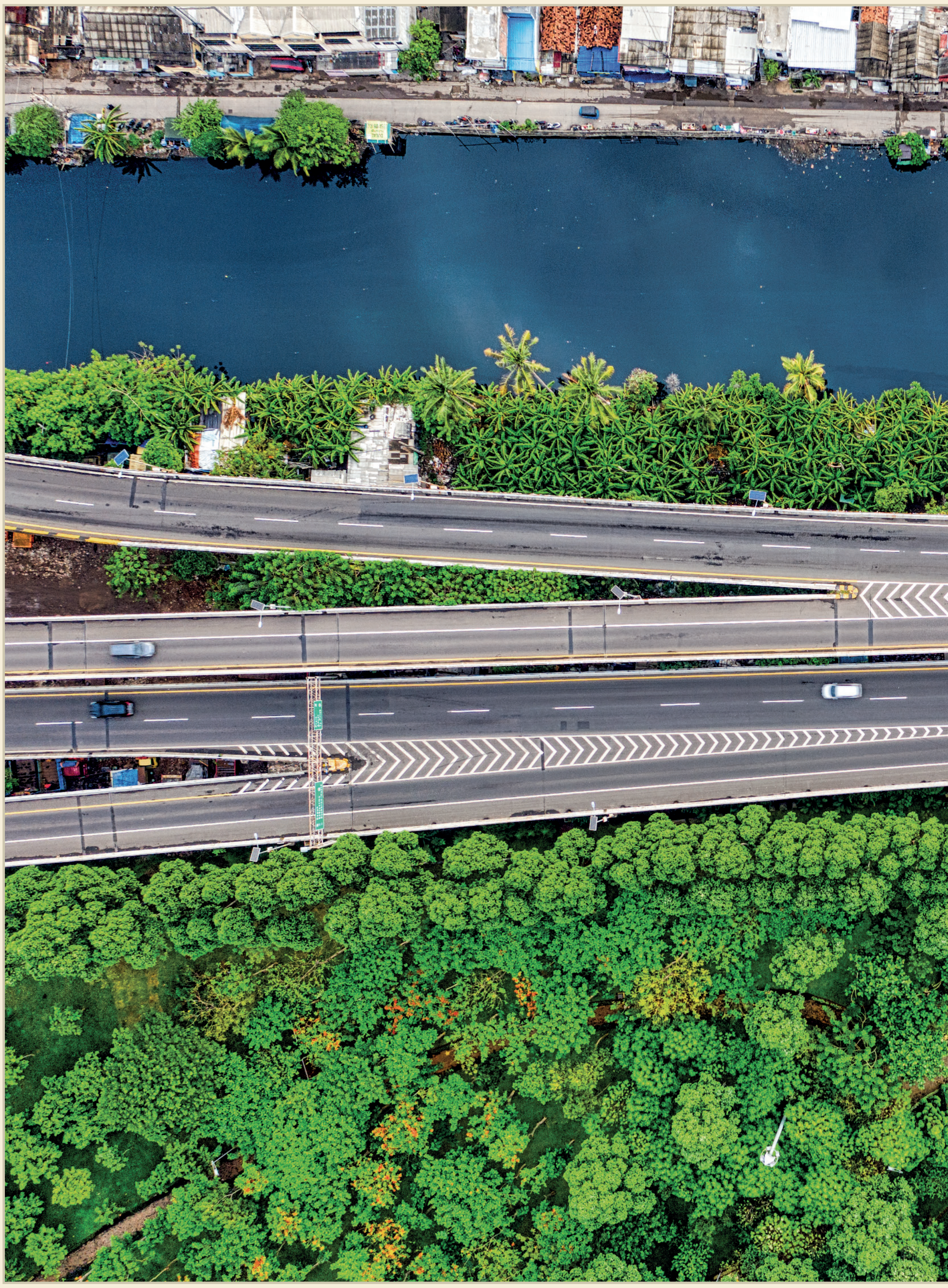
Existing instruments include resilience and catastrophe bonds, which can be adapted and expanded to take advantage of the reduced risk associated with resilient infrastructure.

Debt for climate swaps is another way to generate new funding or release finances otherwise bound up in servicing the crippling national debt. This can increase the fiscal space and room for manoeuvre for countries with limited resources to invest in resilience while meeting longer-term development and climate goals.

Carbon markets and tied adaptation grants, such as those developed under the Paris Agreement, as well as grants and loans that are accessible through existing and new climate funds, provide another source of funding. However, as discussed in Chapter 4, these funds are still not operating to their full potential and, thus, will only be able to meet a fraction of the demand in financing.

Specialized instruments of the private sector such as green or blue bonds, private equity investments for resilience, and sector-specific PPPs hold much promise for single projects and distinct portfolios, particularly for new technologies. However, they need to be scaled up significantly, particularly in LMICs, to become a relevant source of funding resilience in the future.

Finally, new domestic funding sources will become increasingly important for LMICs, especially in emerging economies. National resilience funds may become useful mechanisms if coupled with the national resilience strategies discussed above and if tied to business and insurance-relevant resilience standards. In addition, national revenues from incremental tax reforms and progressive tax regimes can generate significant additional funding in LMICs with dynamic markets and high capital levels, such as Brazil, India, and South Africa.



Annexure I

Looking Forward: How to Monitor Progress towards Infrastructure Resilience

A.1. Towards an Operational Concept of Resilient Infrastructure

All new investments need to be disaster- and climate-resilient to avoid accumulating new contingent liabilities, increasing asset loss and damage, and service disruption

As discussed in Chapter 1, resilience is a broad concept that can refer to different domains: social and economic, assets, services, sustainability, systemic, and financial or fiscal resilience. *Resilient infrastructure and infrastructure for resilience* (GCA, 2021) refer to two different, but interdependent, dimensions of infrastructure resilience.

Resilient infrastructure refers to infrastructure that, through appropriate planning, design, construction, operations, and maintenance, can absorb, adapt, and transform to changing conditions and which can, therefore, continue providing essential services to households, communities, and businesses. The asset and service resilience domains described in Chapter 1 are closely associated with resilient infrastructure. They are also supported by infrastructure governance and fiscal resilience. With respect to the latter, asset loss and damage and service disruption have negative fiscal effects, particularly in weak economies. At the same time, fiscal health influences the capacity to strengthen assets, services, and sustainable resilience.

This Annexure proposes a composite indicator, based on the GIRI, that combines the financial risk metrics presented in Chapter 2 with three different sets of social, economic, environmental, and political indicators representing the capacity of infrastructure assets and the services they provide to absorb the impact of hazard events, respond, and restore. As the Index can be disaggregated according to the range of indicators chosen, it can be used to monitor change over time and whether countries are making progress in strengthening their resilient infrastructure.

The GIRI Index is a proof of concept of a methodology to measure the evolution of infrastructure resilience over time. The testing and application of the methodology will allow further review and refinement, such that it can be validated for use as a monitoring tool in future editions of the Biennial Report.

A.2. Indicators or Surveys?

Many initiatives have proposed indicators for measuring resilience, mainly at the local and community levels,[32] including the Critical Infrastructure Resilience Index (CIRI) (Cadete et al., 2018), Technical Resilience Analysis (ITRA), Organizational Resilience Analysis (IORA) (Storesund et al., 2018), the Resilience Measurement Index (RMI)(Petit et al., 2013), the Critical Infrastructure Resilience Evaluation (CIRE)(Bertocchi et al., 2016), the Benchmark Resilience Tool (BRT) (Resilient Organizations, 2023), the Organizational Resilience Health Check (ORHC) (Department of Home Affairs, n.d.), the Resilience Analysis Grid (RAG) (Hollnagel et al., 2011), the OECD Guidelines for Resilience System Analysis (OECD, 2014), the Resilience Management and Matrix Audit Toolkit (*The RESILENS Decision Support Platform,* n.d.), the Resilience Maturity Model Tool (Hernantes et al., 2016), among many others. Reviews have also been undertaken that highlight their diversity and overlap (Curt and Tacnet, 2018; Derakhshan et al., 2022; Dianat et al., 2022; FEMA, 2022; GCA, 2021; Gillespie-Marthaler et al., 2018; Graveline and Germain, 2022; Pursiainen and Rød, 2016; Zuzak et al., 2022).

The EU SmartResilience project is another initiative that aims to compare and align efforts to measure resilience and promote standardization. The SmartResilience indicators are based on questions that respond to the expected behaviour of infrastructure if adverse events occur, how the operation of one can impact the operation of others, and how to optimize infrastructure investment (Jovanovic et al., 2018).

Indicators represent the simplification of complex systems (Vinchon et al. 2011) and, as such, are only an indicative, indirect representation of reality. Normally, sets of indicators are required to represent different aspects or domains of an issue and to identify which domains contribute more to aggravate or minimize a problem. Also, the use of multiple sub-indicators recognizes that interventions in a single area might not be enough to achieve a broad goal, such as resilient infrastructure.

Surveys can also support the understanding of infrastructure resilience (Chow and Hall, 2023; Jovanovic et al., 2018). If the sample used is statistically significant and the right stakeholders are chosen,

[32] Over 90 methodologies were identified in the report: Community Resilience Indicator Analysis (CRIA) methodologies from 2018 and 2021, most of them at the community and local levels (FEMA, 2022). These methodologies, however, are the ones included for the CRIA methodology and other methodologies at global, national, and regional levels have not been included.

they can provide in-depth information, particularly on issues for which quantitative information is not available. Examples of surveys addressing resilience include the Risk Management Index (RMI), which was developed for the InterAmerican Development Bank (IDB) in 2004 (Cardona et al., 2005). The RMI benchmarks the effectiveness and performance of disaster risk management and has been used by the IDB to support the evaluation and monitoring of programmes in that region. Another IDB survey-based index is the Index of Governance and Public Policy in Disaster Risk Management (iGOPP) (Lacambra and Guerrero, 2017). Risk auditing is another way to assess the effectiveness of disaster risk management, as, over time, it is possible to determine whether the risk is increasing or decreasing by benchmarking the same country.

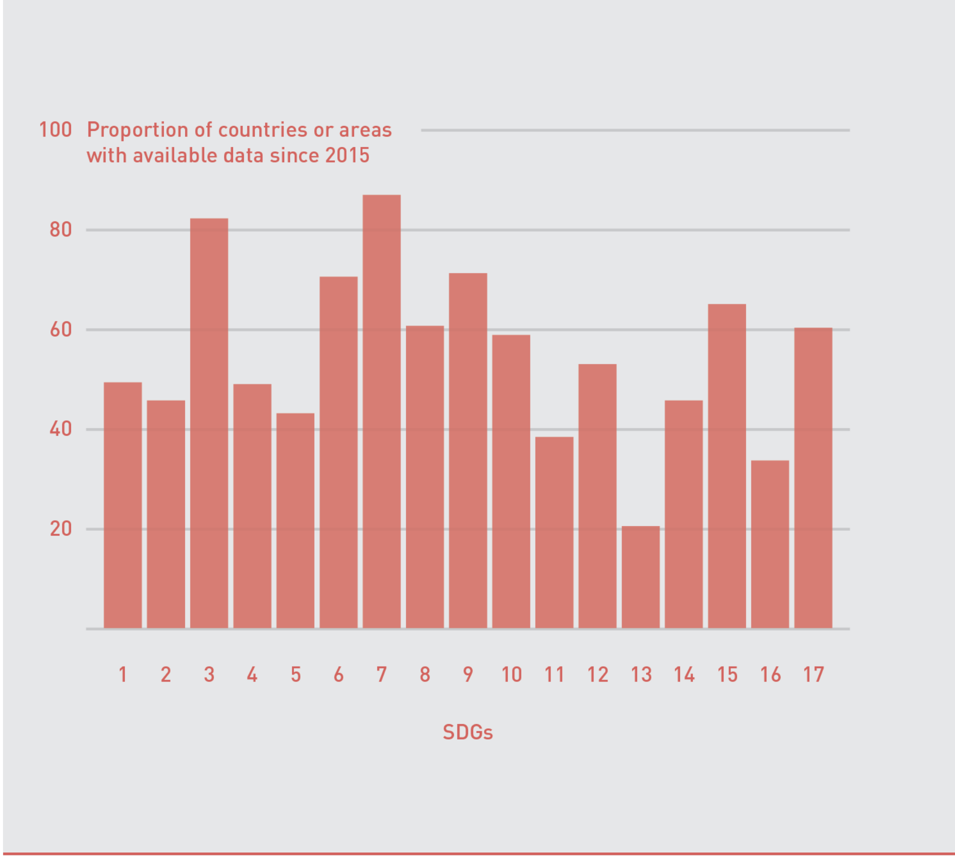
A survey of infrastructure resilience proposed by the University of Oxford and CDRI is the Global Infrastructure Resilience Survey (GIRS). This survey proposes to capture intangible aspects of infrastructure resilience, particularly qualitative aspects of infrastructure governance and management. Through the analysis of infrastructure management components: policy, accountability and enforcement, financial capacity, institutional stability, disaster response, and maintenance and standards, the GIRS captures and reflects the impediments that specialists and stakeholders may face in the management process. The first edition of GIRS has captured survey data from 686 experts in 87 countries and opens future opportunities for deepening the understanding of infrastructure governance and management beyond top-down infrastructure governance datasets, such as the World Governance Indicators (WGI) (Chow and Hall, 2023).

A.3. Global Frameworks for Monitoring Progress

Three global frameworks were agreed upon in 2015: the 2030 Agenda for Sustainable Development, structured around a set of Sustainable Development Goals (SDGs), the Paris Agreement on Climate Change, and the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030. Each of these frameworks adopted or created sets of targets and indicators to measure progress, which, in principle, could provide a basis for monitoring infrastructure resilience.

Unfortunately, the mid-term reviews of the SDGs and the Sendai Framework show that most of the indicators are not yet available in all countries. The development of the information and data infrastructure needed to fill this gap will require a greater investment of financial and human resources to support statistical development (UN, 2022).

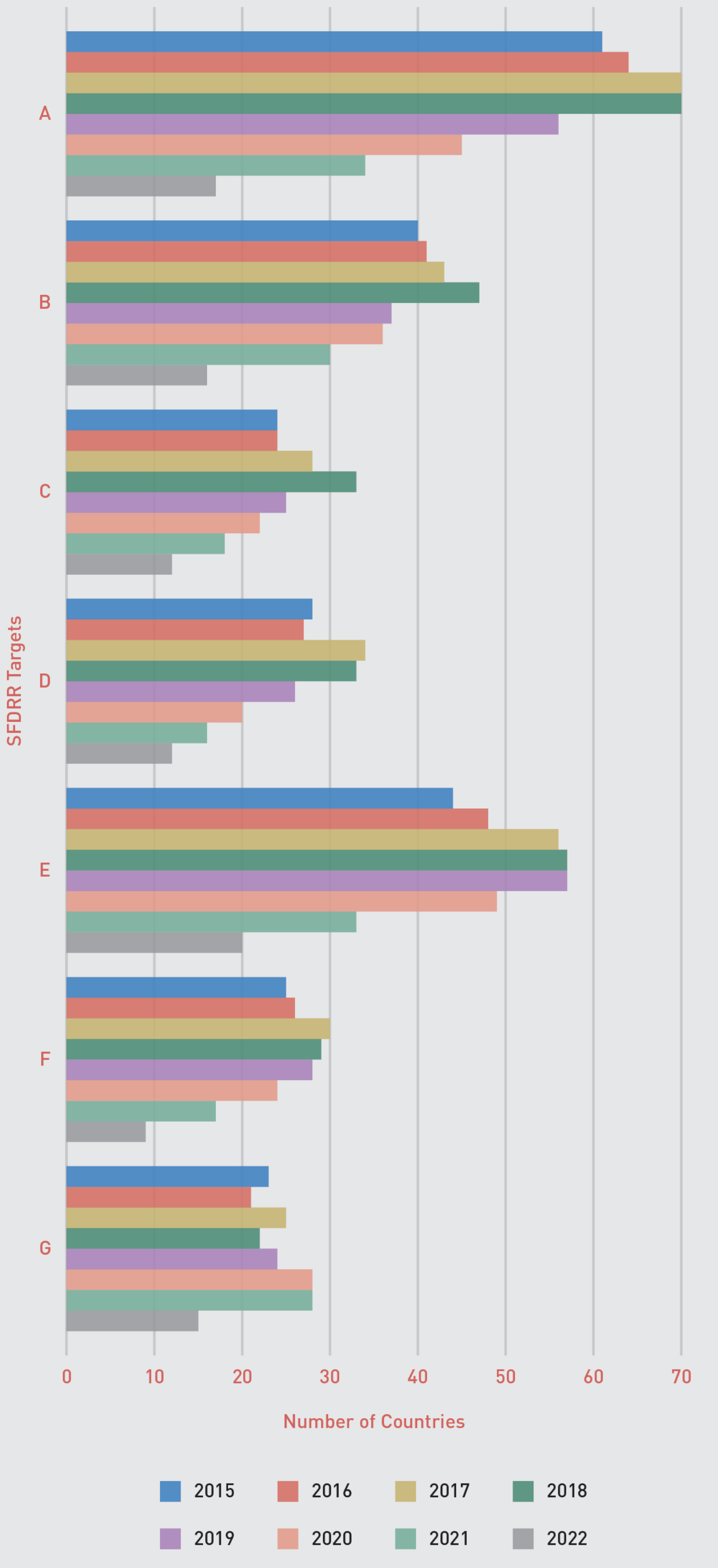
Figure A.1 shows that the number of countries with data to inform the indicators of each SDG is less than 100 across all the SDGs. Less than 60 countries have data to inform indicators of each SDG, except for SGDs 6, 7, 9 and 15. While the SDG indicators include data that could be extremely valuable for measuring and monitoring infrastructure resilience, global comparative coverage is still a future aspiration rather than a present reality.



↑ FIGURE A.1

Proportion of Countries or Areas with Available Data Since 2015, by SDGs

Source: UN (2022)



← **FIGURE A.2**

Evolution of Country Reporting by the SFDRR Target, based on the Sendai Monitor

Source: UNDRR (2022)

In the case of the Sendai Framework for Action (Figure A.2), the number of countries reporting back across Targets A–G has steadily declined since 2017. In 2021 and 2022, less than 20 countries reported on the indicators chosen to measure Target D (*Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030*). This is not a statistically significant or useful sample on which the global monitoring of progress towards infrastructure resilience can be based.

Until the coverage of data dramatically improves, the indicators proposed by the SDGs and Sendai Framework are not useful for measuring progress in resilient infrastructure. However, when better data coverage is achieved, they could make an important contribution.

A.4. The GIRI Resilient Infrastructure Composite Indicator

The risk of service disruption and interrupted social and economic development is largely a function of asset loss and damage. As such, while the financial risk metrics presented in Chapter 2 only measure the contingent liabilities associated with infrastructure assets, they do capture an important part of the resilience challenge.

This challenge can be understood in terms of the capacity of a country to design, build, and manage infrastructure assets in a way that reduces vulnerability and exposure to hazard events and to have systems in place that enable rapid response to asset loss and effective recovery of damaged assets and interrupted services after an event. Measuring this capacity can make resilience a more tangible and visible concept and may provide additional incentives for governments to invest in resilience and capture the associated dividend.

Even if the focus is limited to asset resilience, there is no single intervention that can make infrastructure resilient but a coordinated set of actions. A range of social, economic, political, environmental, and other considerations influence a country's capacity to invest in resilience. If countries are to set resilience goals and targets in the context of national resilience policies, strategies, and plans, indicators are required to measure their progress in terms of achievement of the targets.

The proposed GIRI composite indicator[33] integrates the financial risk metrics discussed in Chapter 2 with three different sets of indicators that represent the capacity to resist and absorb, respond, and restore or recover from hazard events. Additionally, the GIRI incorporates an estimated infrastructure gap[34] that accounts for the difference between the infrastructure required to meet the SDGs and the existing infrastructure.

The Index offers an operational picture of resilience based on multi-hazard physical risk in infrastructure systems, conditioned by the infrastructure gap and further impacted by various social, economic, and environmental factors. Within this holistic framework, vulnerability is considered from a physical perspective (the susceptibility

[33] The GIRI was calculated for 171 countries that have indicators available for the capacities considered in the composite indicators. Countries that have not been included in the GIRI did not have enough indicators available.

[34] The infrastructure gap is expressed as a percentage of GDP. The data has been sourced from the Global Infrastructure Hub, Asian Development Bank, and Infralatam. Due to significant variations in the information and the absence of data for certain countries, averages for geographic and income regions were calculated to assign values to countries with missing information. For African countries, the African Infrastructure Development Index provided by the African Development Bank was used to adjust the derived factor from the average.

of exposed elements or assets to damage) and contextual perspective, encompassing a range of additional attributes or variables.

The composite indicator maps the global landscape of resilient infrastructure with a national level of resolution. Nevertheless, the same 'arithmetic' can be applied by countries at higher resolutions at the sub-national and local levels.

The composite indicator illustrates how probabilistic risk metrics and social, economic, and other variables can be integrated into a methodology that identifies the levels of change available to countries to strengthen infrastructure resilience.

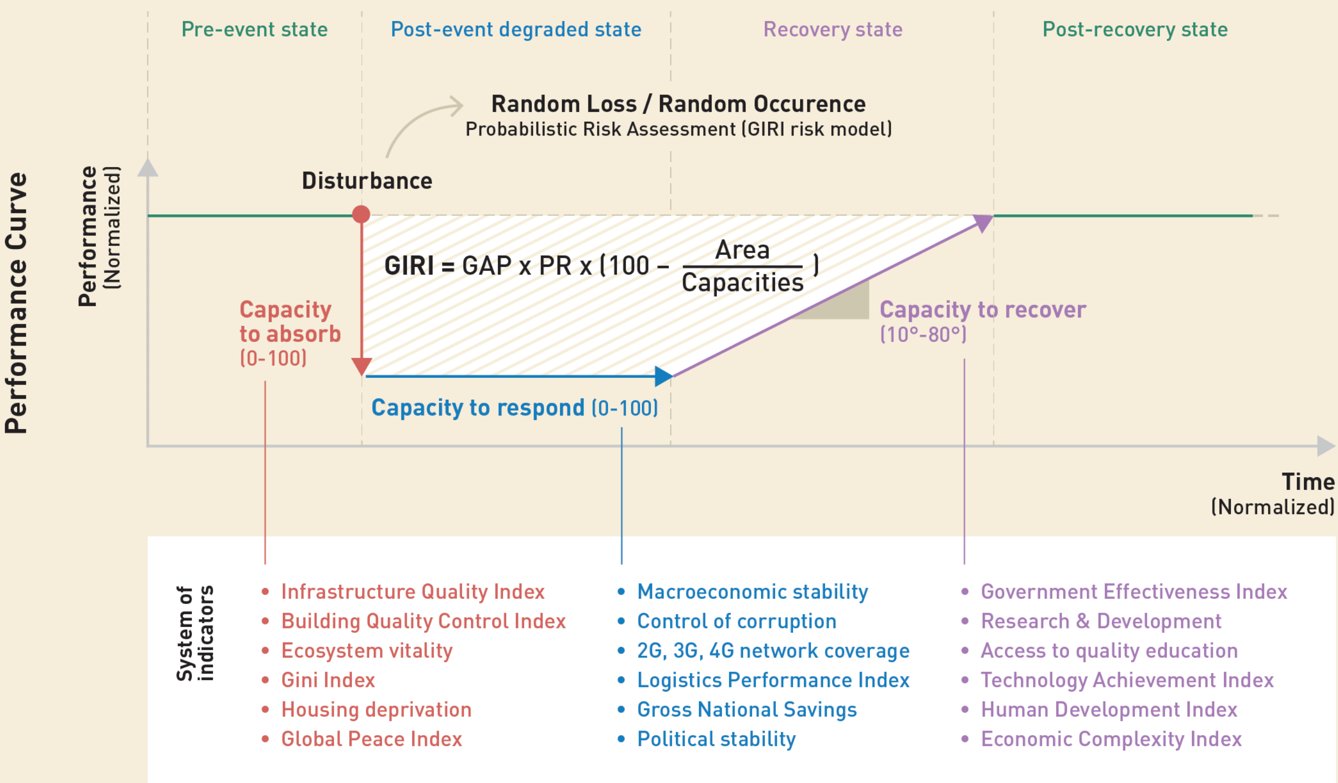
A.5. Methodology and Indicators

The GIRI composite indicator has relative values between 0 and 100. The lowest value (0) indicates that infrastructure has low resilience, and the highest value (100) means resilience is high. Figure A.3 shows how the GIRI composite indicator can be disaggregated into the three capacities, each of which, in turn, can be disaggregated into component indicators.

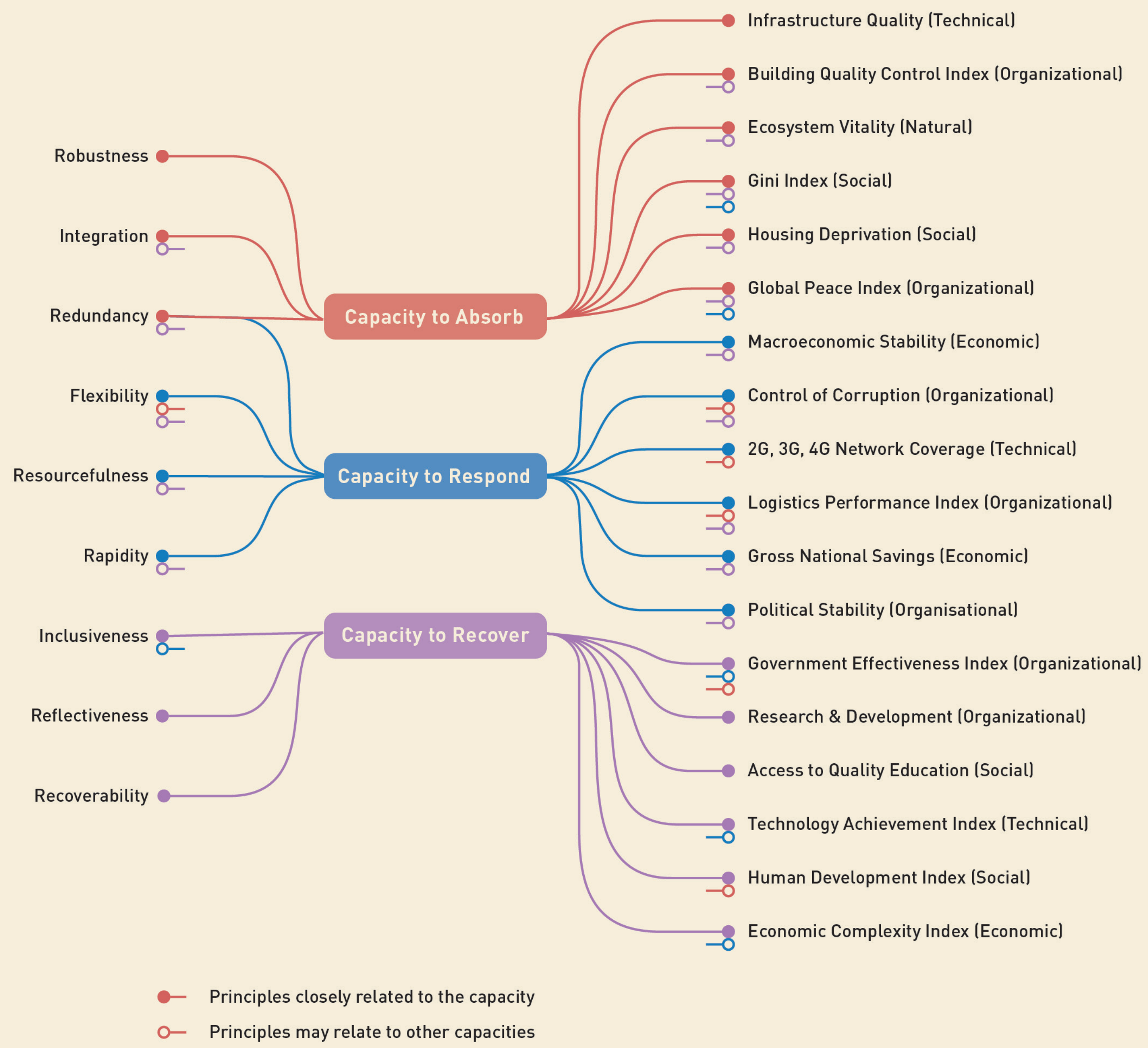
The capacity to absorb is represented as a sudden loss in the performance or capacity of infrastructure assets to provide essential services due to loss and damage associated with hazard events. It is conditioned by physical risk and social and economic variables, which may aggravate the potential impact of the hazard events, leading to larger losses in performance (Cardona,

↓ **FIGURE A.3**

Conceptual Framework of GIRI
Source: Cardona et al. (2023b)



GAP – Infrastructure Gap Factor
PR – Physical Risk



↑ **FIGURE A.4**

Interconnectedness between the Qualities of Resilient Systems and the Three Resilience Capacities and between Indicators

Source: Cardona et al. (2023b)

2001; Birkmann et al., 2013; Bruneau et al., 2003; Burton et al., 2014; Carreño et al., 2007).

The capacity to respond is represented as a horizontal line, whose length represents the ability to respond fast and efficiently. The shorter the line, the higher the capacity to respond following the event as a first phase of recovery. The recovery stage is assumed to start after the response phase and continues until the assets have been restored and services recovered. The inclination of the slope represents a strong (80°) or weak (10°) capacity to recover quickly and efficiently.

Figure A.4 shows the relationship between a set of qualities that would characterize resilient infrastructure, the three capacities described above, and the suite of indicators chosen to measure the capacities. Some indicators can be associated with all the three capacities but have been assigned to the capacity with which they seem more closely related.

For example, the quality of infrastructure indicator was assigned to the capacity to absorb because, in the case of better-quality infrastructure built to high standards, the drop in performance is likely to be less than in lower-quality infrastructure. Similarly, countries with significant investments in innovation and technology are likely to experience faster and more efficient recovery compared to countries with lower levels of investment in innovation and technology.

Six indicators were chosen for each capacity, based on their relevance and the availability of publicly accessible, reliable global data in as many countries as possible. Many other indicators were considered but not chosen because they did not meet these criteria.

The indicators that compose each capacity are normalized to allow their aggregation. All indicators were assigned the same weight. For instance, the indicators for the capacity to absorb and for the capacity to respond range from 0 to 100, where the higher values mean a slight drop in performance and rapid and efficient response, respectively, and lower values mean a high drop and poor and inefficient response, respectively. Inverted scaling was used to provide appropriate measurement.

A.5.1. Capacity to Absorb

The average annual loss (AAL) from the GIRI model presented in Chapter 2 is the base input for the GIRI composite indicator. The AAL is a robust metric that condenses in a single number the overall level of disaster and climate risk, internalized in a country's infrastructure.

The AAL provides insight into potential loss and damage to infrastructure assets. It, thus, provides a first window to examine the capacity to absorb hazard events of different intensity and frequency. However, while the AAL captures the physical resistance and robustness of an asset, the relative AAL can result in low values due to various factors. These factors include the absence of significant hazards in the country, low vulnerability of the exposed assets, or even the absence of assets themselves. To account for these situations, a factor is applied to the relative AAL, addressing the lack of infrastructure and, indirectly, obsolescence and the lack of redundancy.

The physical risk is, then, aggravated by combining six contextual indicators that condition it:

- **Infrastructure quality** (FM Global Resilience Index, 2022): Good quality infrastructure will be reflected in a better performance of the assets when a hazard event occurs.
- **The building quality control index** (World Bank, 2002): This includes variables such as the quality of regulation; of control before, during, and after construction; professional liability and insurance regulation; and certification. Good building quality should indicate better building practices inherent in infrastructure with higher resistance to hazard events.
- **Ecosystem vitality** (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network Earth Institute, 2022): Healthy ecosystems can lead to more sustainable growth of assets and income, economic development, and well-being of people. As Chapter 3 highlighted, ecosystem

preservation and restoration can contribute to resilience to climate change and climate change mitigation. In turn, environmental degradation is a major driver of disaster risk. The low quality and quantity of ecosystem services exacerbate climate change.

- **Gini Index** (World Bank, 2023): This index represents income, wealth, or consumption inequality within a nation or social group. More unequal countries are less likely to dedicate resources to strengthen the resilience of infrastructure meant to service disadvantaged social groups. More equal societies are also more resilient. Flatter hierarchies lead to higher cooperation among individuals (Germano and Demetrius, 2014).
- **Housing deprivation** (University of Oxford, n.d.): This reflects social and economic inequality and the capacity of governments to deliver safe and affordable housing (SDG11). High rates of housing deprivation are likely to be reflected in significant parts of the population living in unplanned and unregulated settlements with precarious infrastructure that has a low capacity to resist hazard events.
- **The Global Peace Index** (Vision of Humanity, n.d.): This index considers international and domestic conflict, social safety and security, and militarization. A positive value may indicate outcomes such as higher per capita growth, better environmental performance, less civil conflict, or violent political shocks, as well as infrastructure with higher resistance.

A.5.2. Capacity to Respond

The following six indicators represent a country's capacity to respond to disasters as well as how well it performs in terms of disaster response.

- **Macroeconomic stability** (The Legatum Institute Foundation, 2021): It measures how robust an economy is. A strong economy means that a government will have more resources available for an effective and timely response without having to increase indebtedness.
- **Control of corruption** (Kaufmann and Kraay, 2022): Corruption may erode the financial resources available to respond to infrastructure failures and undermine capacities for service restoration.
- **2G, 3G, and 4G network coverage** (Groupe Speciale Mobile Association, n.d.): Access to wireless communication directly influences effective and timely disaster response. Better network coverage can allow authorities to access real-time information on the distribution of asset loss and damage and service disruption, and can facilitate communication between affected households, communities, businesses, and the different stakeholders involved in the response, including utility providers, emergency services, and others.
- **Logistics and Performance Index (LPI)** (World Bank, 2023): Emergency response requires proper, structured, standardized, and organized logistics to respond efficiently and fast. Ineffective logistics can result in underperformance in emergency response and an inability to handle an event fast and efficiently. The LPI consists of both qualitative and quantitative measures that provide an understanding of how well countries do in terms of logistics

processes, logistics environment and institutions, and constraints hindering the smooth flow of logistics activities present at ports, borders, or inside the country. It, therefore, measures performance along the whole logistics supply chain within a country. LPI is considered a vital element in the economy's competitiveness (Arvis et al., 2007).

- **Gross National Savings** (World Bank, 2023): The national savings rate measures the amount of income that households, businesses, and governments save. It looks at the difference between the nation's income and consumption and is a gauge of a nation's financial health, as investments are generated through savings. Gross national savings can serve as access to resources in the case of emergencies or as a backup to borrow economic resources to respond to emergencies.
- **Political stability** (Kaufmann and Kraay, 2022): Political stability and absence of violence measure perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically motivated violence and terrorism. Political instability and violence may undermine response efforts due to the difficulty in accessing resources and the lack of strong institutions that avoid rapid and efficient interventions.

A.5.3. Capacity to Recover

The capacity to recover reflects how well a country can recover from asset damage and service disruption. The better the performance, the steeper the line. This is more closely related to the depth of the drop in the capacity to absorb than to the length of the response line. The six indicators chosen for the capacity to restore infrastructure and strengthen future resilience are as follows:

- **Government Effectiveness Index** (Kaufmann and Kraay, 2022): It captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. This index reflects the capacity of a government to plan and manage a robust recovery of infrastructure assets and essential services.
- **Research and Development** (WIPO, 2022): According to the OECD, research and development intensity is one of the several indicators used to measure progress towards achieving SDG 9. SDG 9 seeks to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.
- **Access to Quality Education** (The Legatum Centre for National Prosperity, 2023): Access to quality education leads to a country with higher productivity and, therefore, a stronger economy. Access to quality education ensures the presence of highly qualified professionals who will work towards a robust and quick recovery of infrastructure and services.
- **Technology Achievement Index** (Desai et al., 2002): It reflects the country's technological capacity, including associated human resources. Access to new or enhanced technologies

will normally speed up recovery, including the opportunity to use the recovery process to introduce innovations.

- **Human Development Index** (UNDP, 2021b): The Human Development Index (HDI) is a composite index of life expectancy, education, and per capita income indicators. It is directly relevant to local and community vulnerability, which, in turn, influences the recovery process (Raikes et al., 2021; Hallegatte et al., 2020; UNDP, 2020; Lewis, 2012; UNDP, 2004). A high HDI indicates countries with better levels of education and hence, skills and scientific knowledge, better health systems that provide a basis for sustainable recovery, and higher income levels that reflect the availability of savings, access to credits, insurance, etc., that are critical to effective recovery.
- **Economic Complexity Index** (Observatory of Economic Complexity, n.d.): It reflects the overall state of a country's economy and, therefore, its capacity to successfully recover from hazard events.

The resilience of today's infrastructure is the result of decisions and actions of the past. However, resilience can be enhanced if the underlying factors that condition its capacity to absorb, respond, and restore are modified. That is why it is important to treat resilience as an attribute of performance rather than as the state of a system. The former creates incentives for action, while the latter may lead to inertia and inaction.

Therefore, the GIRI composite indicator can be used to monitor how capacities change over time, which in turn can be disaggregated by the indicators that compose each capacity. Understanding resilience as a performance characteristic improves understanding of the dynamics of change in each country.

A.6. The GIRI Assessment

The GIRI is presented in two formats: as a single numerical value and as a curve. The numerical value represents the ratio of the area of the trapezoid formed by the three capacities to the sum of those capacities, as shown in Figure A.3. This quantitative representation enables the ranking of countries based on their resilience. However, depicting the shape of the curve provides a more comprehensive understanding of resilience. It also offers a clearer illustration of how physical risk and the infrastructure gap influence the value and shape of the GIRI curve.

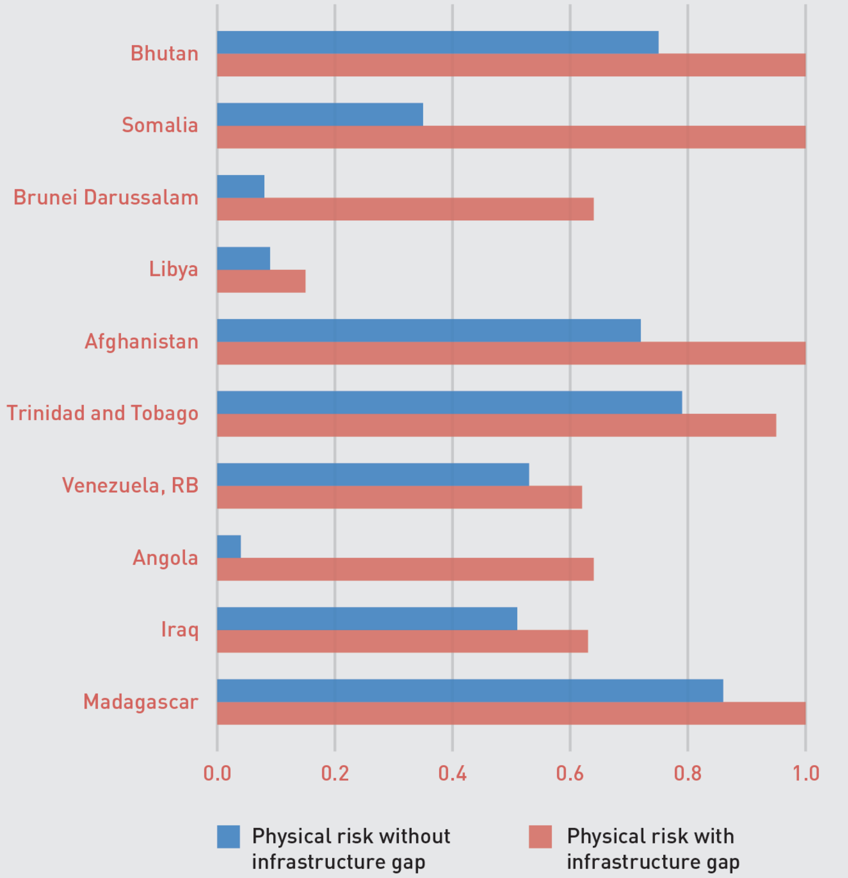
A.6.1. Infrastructure Gap

The infrastructure gap (Cardona, 2001; Carreño et al., 2007) is defined as the difference between the existing infrastructure and the infrastructure needs. The gap reflects implications that are not necessarily reflected in the risk metrics as shown in the following examples:

- **Lack of capacity:** The lack of capacity of infrastructure assets to provide services and support social and economic development creates system vulnerability and magnifies the effects of hazard impacts.
- **Infrastructure obsolescence:** Outdated or obsolete infrastructure that has outlived its design life is more prone to failures and collapses. Insufficient investment in infrastructure maintenance, modernization, and upgrading increases its fragility and reduces its resilience against threats and adverse events.
- **Limited diversification and redundancy:** A large infrastructure gap challenges system redundancy, increasing dependence on single infrastructure assets and increasing service vulnerability.
- **Longer recovery time:** A large infrastructure gap may increase the recovery time after an adverse event, reflecting a lack of resources and capabilities for recovery.

The infrastructure gap factor was used to condition the risk metrics in the GIRI resilience index. The infrastructure gap is basically the difference between the actual investment and the investment required to fill the gap, expressed as a percentage of gross domestic product (GDP). This is then used to modify the AAL. Due to significant variations in the information available in some countries, averages were calculated by geographic and income regions to assign values to those countries with missing information.[35]

[35] For African countries, the African Infrastructure Development Index provided by the African Development Bank was used to adjust the derived factor from the average.



↑ **FIGURE A.5**

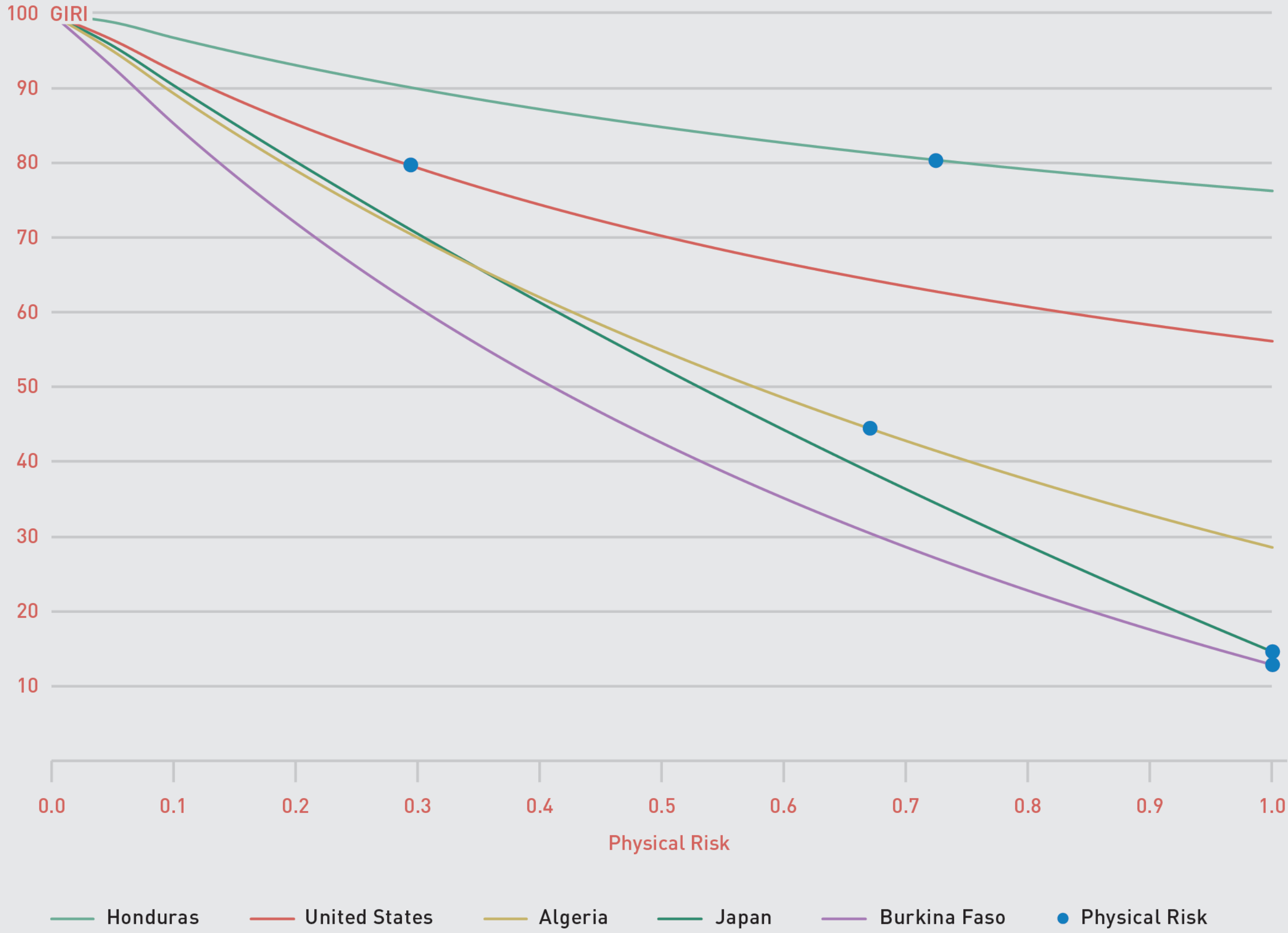
Influence of Infrastructure Gap on Physical Risk

Countries with a very low infrastructure density may appear to have very low risk. However, this often reflects a very low exposed value rather than high levels of physical resilience. Without taking the gap into account, hazard-prone countries with a low infrastructure density may appear to have high levels of resilience. Conditioning the risk by the infrastructure gap factor corrects this.

Figure A.5 highlights how the risk metrics change after processing, considering the gap factor. Countries with a greater infrastructure density exhibit less significant changes in their physical risk values than countries with a considerable infrastructure gap.

A.6.2. Inherent Resilience

Given that the GIRI is an index of resilience to disaster- and climate-related risk, using the AAL as the base of the index is crucial. To demonstrate the influence of the physical risk on the GIRI, inherent resilient curves were constructed for each country. They consist of varying the value of physical risk, from zero to one, by maintaining all the other values that compose the GIRI. By following this procedure, it is possible to obtain points of GIRI values for each assigned physical value. The curve is then the union of all the points for a country. The blue points in Figure A.6 correspond to the GIRI values obtained with the level of physical risk



the country currently faces, according to the risk model.

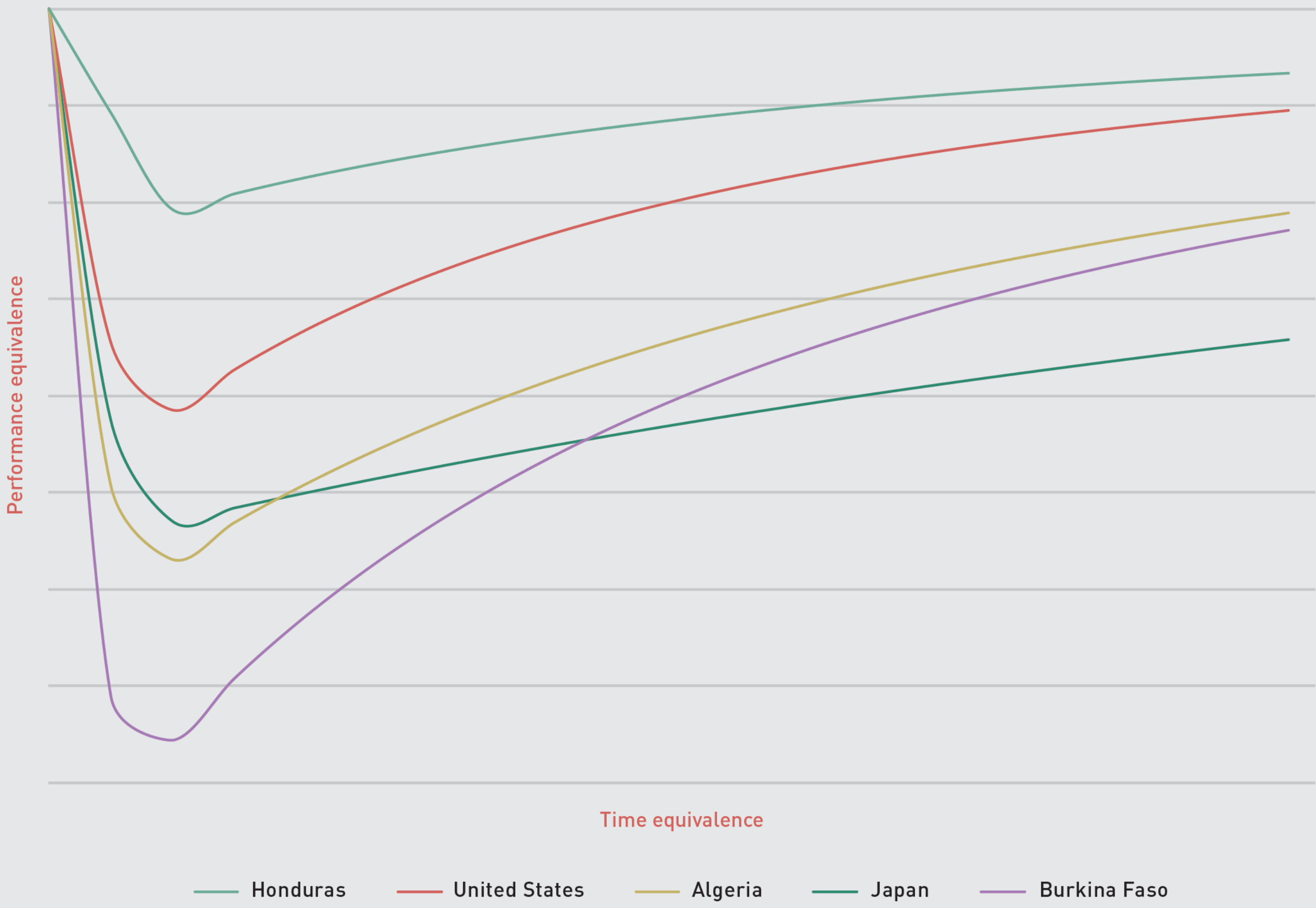
As Figure A.6 shows, countries with strong capacities to absorb, respond to, and recover from asset loss and damage have a flatter curve. This indicates a lower variation in resilience, even when there is a high degree of variation in risk. Conversely, countries with weaker capacities have a high variation in resilience, particularly in the case of significant fluctuations in physical risk. When a country faces low physical risk, the GIRI tends to have higher values, whereas higher physical risk levels result in lower GIRI values. How steep or flat the curve is depends on each country's capacity to absorb, respond, and recover. For instance, Japan exhibits stronger capacities than the United States of America, Honduras, Algeria, and Burkina Faso.

The rate of change of the inherent resilience curves results in a representative resilience curve due to the similarity with the performance and time attributes that represents a country's performance in the face of a potential disaster. Although the values resulting from the derivative of inherent resilience do not hold representative significance, the curves offer valuable insights into the speed at which a country can restore its infrastructure and services. For instance, in Figure A.7, Japan demonstrates a relatively

↑ **FIGURE A.6**

Representation of Inherent or Endogenous Resilience for Honduras, the United States, Burkina Faso, Algeria, and Japan

Source: Cardona et al. (2023b)



↑ **FIGURE A.7**

Representative Resilience Curves Reflecting the Rate of Change of the Inherent Resilience Curves for Honduras, the United States of America, Burkina Faso, Algeria, and Japan

Source: Cardona et al. (2023b)

shorter decline and achieves a faster recovery compared to the other countries presented. Although Honduras experiences a shorter decline than Burkina Faso and Algeria, their capacities enable a more favourable recovery than Honduras.

A.7. Global Infrastructure Risk Model and Resilience Index (GIRI)

The primary objective of the GIRI is to assess and rank countries based on their resilience levels, thereby identifying areas that require focused efforts. The GIRI also enables the measurement of progress over time in enhancing resilience. For instance, countries may have similar GIRI values, but their resilience curves can differ, as shown in Figure A.7. One country may exhibit shortcomings in its capacity to absorb but possess stronger capacities to respond and recover. While the area under the resilience curve and thus the overall GIRI value may be similar, each country has a different range of capacities.

The resilience of today's infrastructure is the outcome of past decisions and actions. However, resilience can be enhanced through appropriate investments in improving infrastructure robustness, flexibility, redundancy, and overall quality, including enhanced design standards and increased investment in operations and maintenance. Modifying the underlying factors that reflect the capacities to absorb, respond, and recover can strengthen resilience.

The GIRI composite indicator can be utilized to monitor changes in vulnerability and capacities over time, and it can be disaggregated into risk indicators and individual capability indicators. Viewing resilience as a performance characteristic enhances our understanding of the dynamics of change within each country. A similar approach can be implemented at the sub-national level to track infrastructure resilience using a localized GIRI, which incorporates indicators and surveys to directly capture and measure risk and the capabilities of isolated and systemic infrastructures.

A.8. Towards a Methodology for Measuring Infrastructure for Resilience

As described above, the GIRI composite indicator has been designed to monitor progress in *resilient infrastructure*. However, many of the indicators can be reconfigured to measure *infrastructure for resilience*, in other words whether infrastructure is contributing to social and economic development, systemic resilience, and fiscal health (GCA, 2021), and how a country is performing in different areas or domains [Technical, Organisational, Social, Economic and Ecological or Ecosystemic -TOSEE] (Bruneau et al., 2003).

The disaggregation of the GIRI composite indicator to its component indicators allows the exploration of aspects that can support the measurement of performance in infrastructure for resilience in TOSEE domains. For example, indicators on contextual conditions, such as ecosystem vitality or the building quality control index, could be useful for measuring whether new infrastructure investment is contributing to increased (GCA, 2021; UNDRR, 2022) systemic risk, while others, such as housing deprivation, Gini and HDI, can measure whether infrastructure investment is contributing to sustainable and equitable social and economic development.

Annexure II

List of Position and Contributing Papers

Please access all the position papers and contributing papers for CDRI's Biennial Report through the following link: https://cdri.world/biennial-report-position-and-contributing-papers.

Chapter 1

1. Revi, A., & Bazaz, A. (2023). Metanarrative: Global Report on Climate & Disaster Resilient Infrastructure (Global Infrastructure Resilience 2023 Position Paper 1.1). Indian Institute for Human Settlements, Bangalore, India.

Chapter 2

1. Alfieri, L., Campo, L., Gabellani, S., Ghizzoni, T., Herold, C., Libertino, A., Trasforini, E., & Rudari, R. (2023b). The GIRI global flood hazard model (Global Infrastructure Resilience 2023 Position Paper 2.1). CIMA Foundation, Italy.
2. Alfieri, L., Campo, L., Gabellani, S., Ghizzoni, T., Herold, C., Libertino, A., Trasforini, E., & Rudari, R. (2023a). Supplement material to the GIRI global flood hazard model (Global Infrastructure Resilience 2023 Position Paper 2.2). CIMA Foundation, Italy.
3. Camalleri, C., Naumann, G., Rossi, L., Ghizzoni, T., Isabellon, M., Campo, L., & Rudari, R. (2023). Global Drought impact on Hydropower, Water Use and Fluvial Navigation (Global Infrastructure Resilience 2023 Position Paper 2.3). CIMA Foundation, Italy.
4. Cardona, O.D., Bernal, G.A., Villegas, C.P., Molina, J.F., Herrera, S.A., Marulanda, M.C., Rincón, D.F., Grajales, S., Marulanda, P.M., Gonzalez, D., Maskrey, A. (2023). Multi-hazard Disaster Risk Model of Infrastructure and Buildings at the Global Level. (Global Infrastructure Resilience 2023 Position Paper 2.4). Background Report, INGENIAR: Risk Intelligence for the CDRI Flagship Report.

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7. Piller, T., Benvenuti, A. & De Bono, A. (2023). The GIRI global building exposure model (BEM) (Global Infrastructure Resilience 2023 Position Paper 2.7). GRID, University of Geneva, Switzerland.

Chapter 3

1. Bennett, K., Furniss, M., Weinhold, M., & Chowhan, B. S. (2023). Mainstreaming Nature-based Solutions in Infrastructure Development and Reconstruction (Global Infrastructure Resilience 2023 Position Paper 3.1). United States Forest Services, Washington DC, USA.

2. Corwin, E. (2023). Collaborate to create 21st century engineering guidelines for our 21st century challenges (Global Infrastructure Resilience 2023 Contributing Paper 3.1.1). Conservation International.

3. Wadhawan, S., & Bajpai, A. (2023). Pathways to unlock the potential of nature-based solutions in climate and disaster resilient infrastructures (Global Infrastructure Resilience 2023 Contributing Paper 3.1.2). Council on Energy, Environment and Water (CEEW), New Delhi, India.

4. Leon, S. F. M., Goedhart, Y., Tucaltan, G., & Wouterse, F. (2023). Nature-based Solutions for Adaptation in the Global South; Global Center on Adaptation (Global Infrastructure Resilience 2023 Contributing Paper 3.1.3). Global Center on Adaptation (GCA).

5. Mathew Alex, A., & Mathew, B. (2023). Pathways to Upscaling Nature-based Solutions for Disaster and Climate Resilient Infrastructure - Advocating for development of codes and standards at the local level (Global Infrastructure Resilience 2023 Contribution Paper 3.1.4). TARU Leading Edge, New Delhi, India.

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Chapter 4

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8. Mishra, A. (2023). Role of ESG Integration in Infrastructure Investments (Global Infrastructure Resilience 2023 Contributing Paper 4.1.7). World Wide Fund for Nature.

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2. Marulanda, M. (2023). Looking forward: how to monitor progress towards infrastructure resilience. (Global Infrastructure Resilience 2023 Methodology Paper 5.2).

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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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